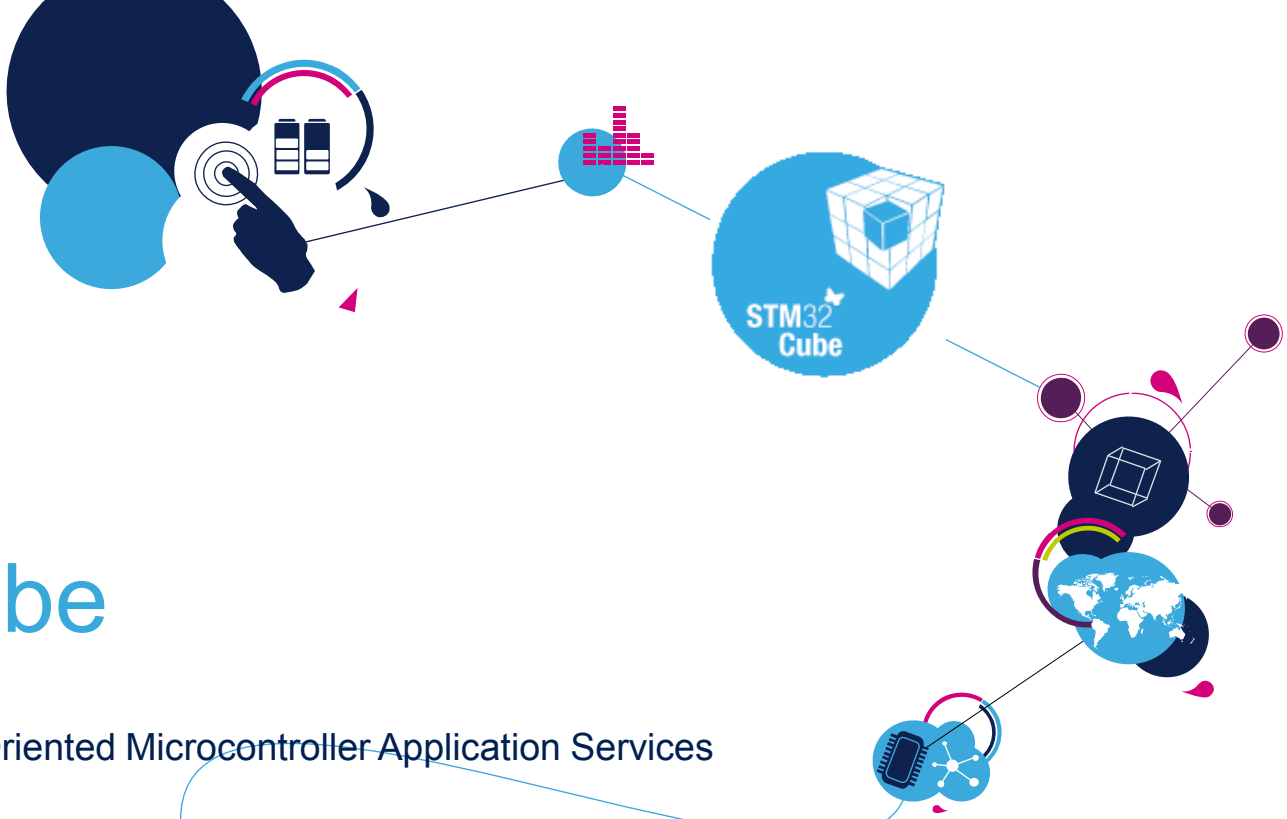

STM32Cube

T.O.M.A.S – Technically Oriented Microcontroller Application Services
v0.02

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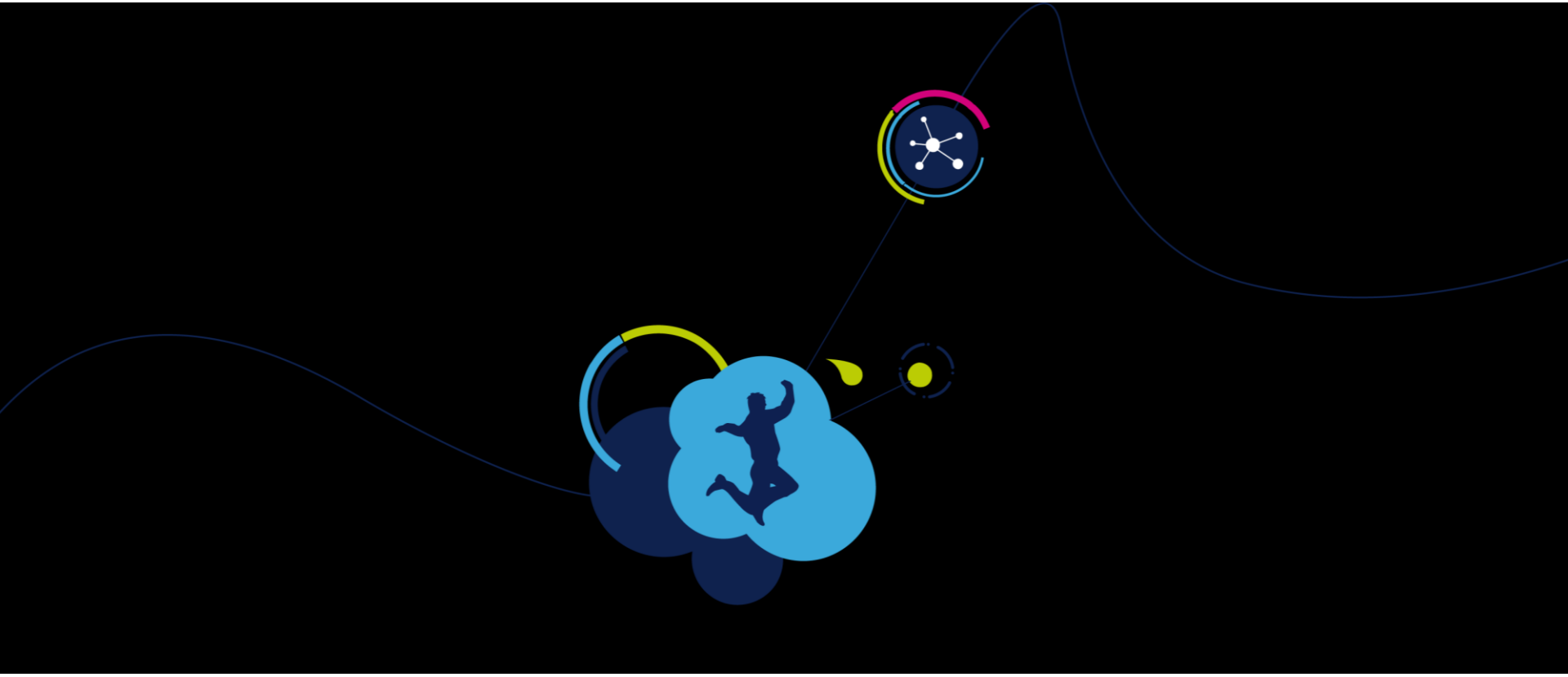
Agenda

- Installation of STM32CubeMX
- CubeMX features
- HAL overview
- CubeMX and HAL basics
  - CubeMX configuration and project generation
  - First HAL project generated by CubeMX
  - Project structure
- Interrupts in CubeMX and HAL
- DMA in CubeMX and HAL
- Communication peripheries in CubeMX and HAL
- Other peripherals ADC, TIM, …



STM32CubeMX installation

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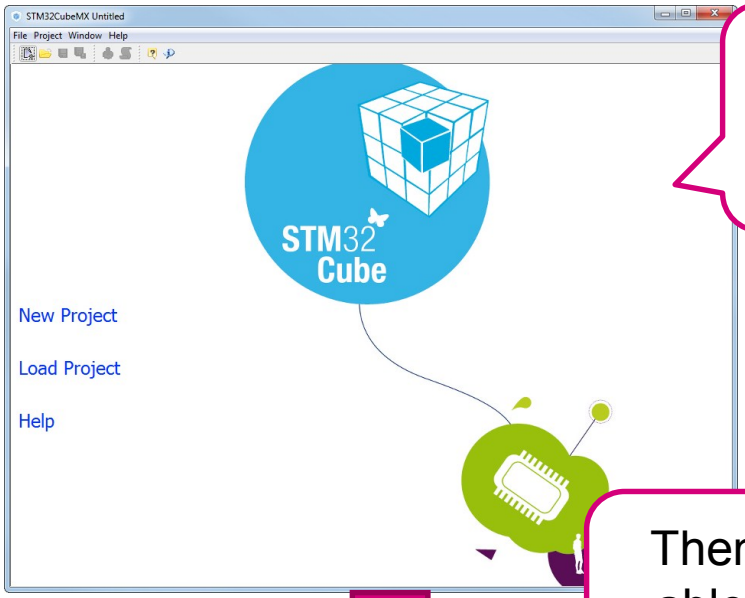
CubeMX install

- CubeMX tool
  - http://www.st.com/web/catalog/tools/FM147/CL1794/SC961/SS1533/PF259242?s_searchtype=partnumber
- The CubeMX tool need java
  - Please check if you have last java on your pc, for sure 32bit and 64bit version
- Optionally you can download the Cube packages for STM32 device if you don’t want to download them throe CubeMX
  - STM32CubeL0
  - STM32CubeL1
  - STM32CubeF0
  - STM32CubeF1
  - STM32CubeF2
  - STM32CubeF3
  - STM32CubeF4

CubeMX install

- Install the CubeMX
- Run CubeMX



The CubeMX is used for configuration

For project generation we also need configure repository

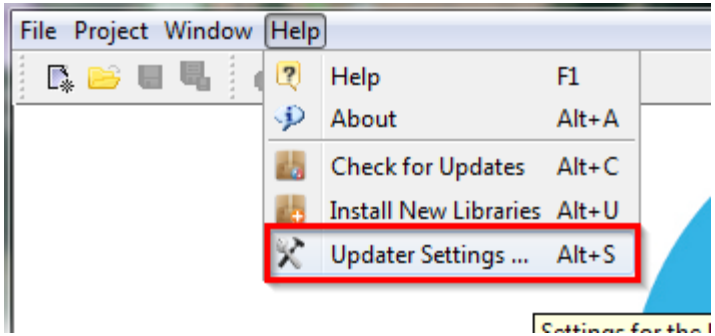
Then CubeMX is able to generate project

CubeMX repository

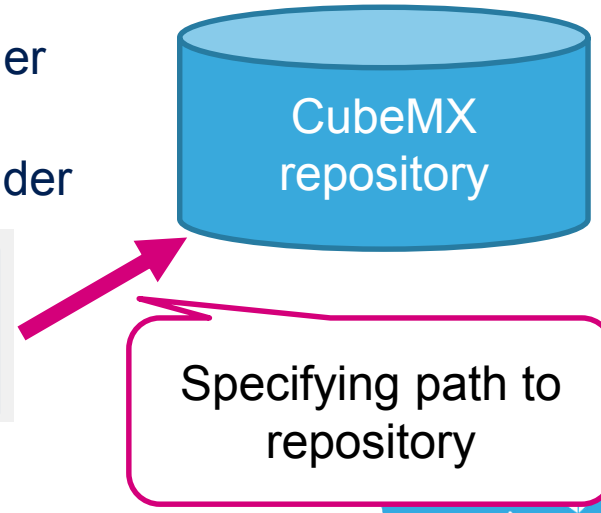
Project

CubeMX install

- In case you download the package from web we need to find the place where they need to be stored

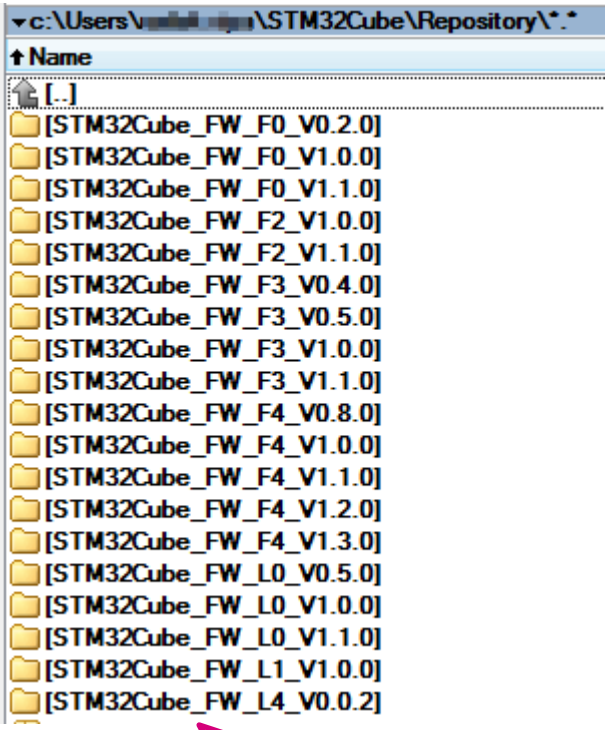


- MENU>Help>Updater Settings…
- You will see where is the repository folder
  - Default is C:/User/Acc_name/STM32Cube/Repository/
  - **In case that you have in your repository path diacritics, the CubeMX may not work properly, please change you repository path (ex: C:/Repository)**
- You need to download STM32 packages into this folder
- Or CubeMX automatically download them into this folder

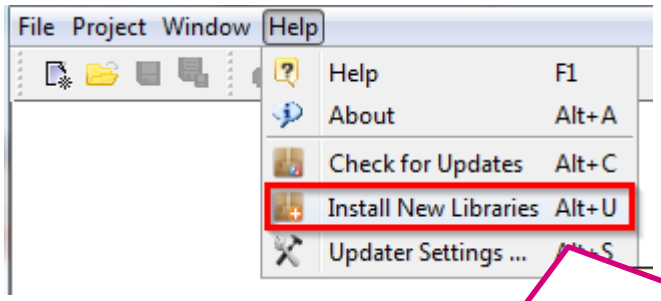


CubeMX install

- The comparison of the CubeMX repository settings and structure in this folder



- In case you want to download this files automatically use in CubeMX
  - MENU>Help>Install New Libraries
  - Select libraries which you want
  - Force download with button Install Now



CubeMX can download for you the repository packages automatically

Example how the repository structure looks like

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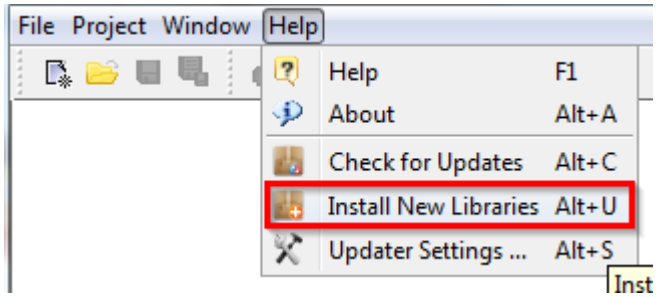
STM32 Cube

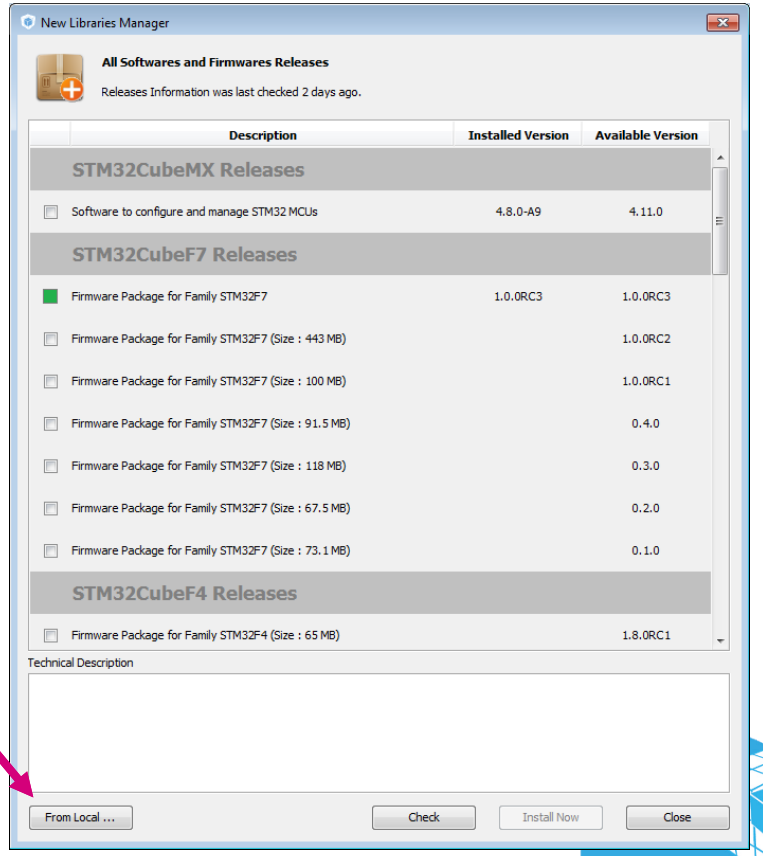
CubeMX install

- The comparison of the CubeMX repository settings and structure in this folder
- In case you want to install files manually use in CubeMX
  - MENU>Help>Install New Libraries



  - Click “From Local…” button
  - Select the file from the USB stick package

\HAL\STM32Cube_FW_F7_V1.0.0.zip



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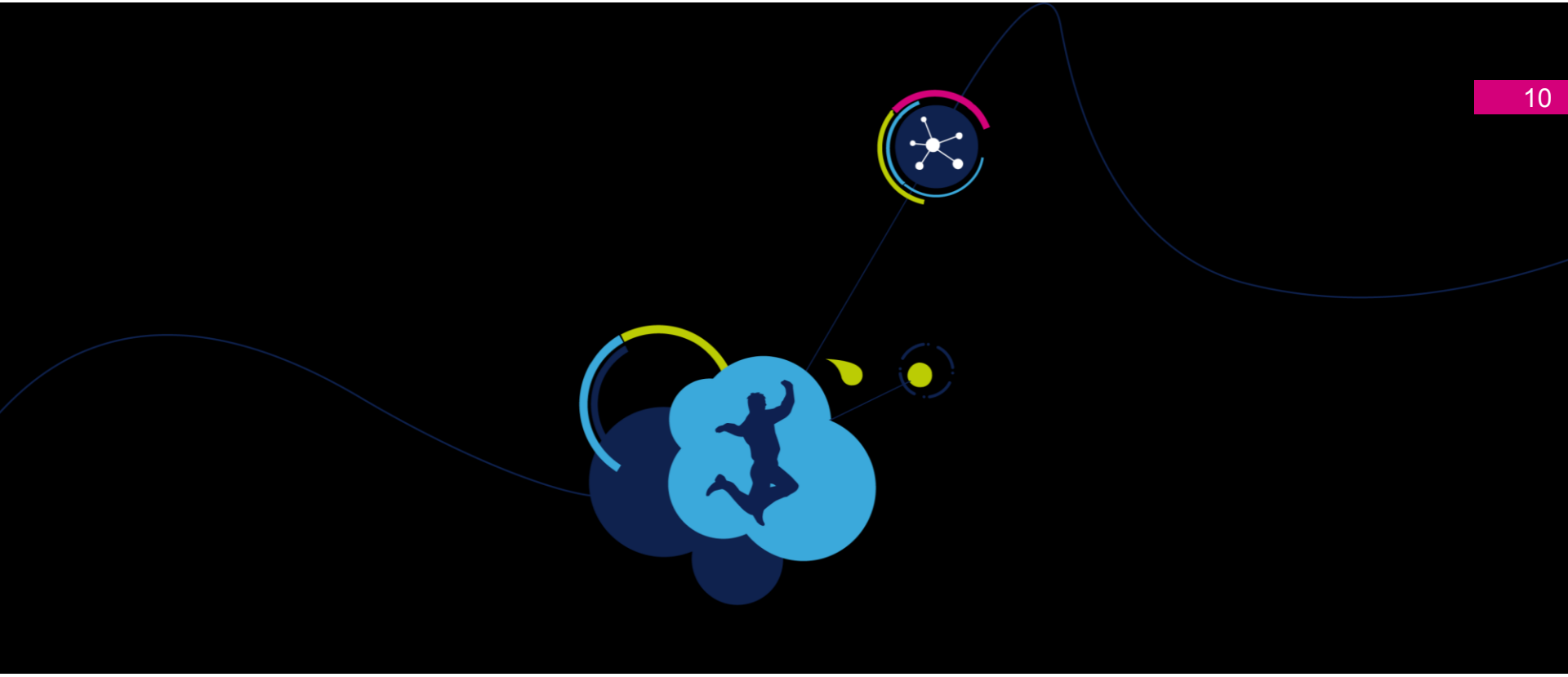
STM32 Cube

CubeMX install

- For the code generation the CubeMX use the package from the Repository folder
- The CubeMX can generate the code for some GUI
  - Keil
  - IAR
  - Atollic
  - System Workbench(Free)
- For the debugging is necessary to have the ST-Link drivers
  - STSW-LINK003 driver for Win XP/Vista/7
  - STSW-LINK006 driver for Win 8
- For driver installation you will need the **Admin rights** on your PC

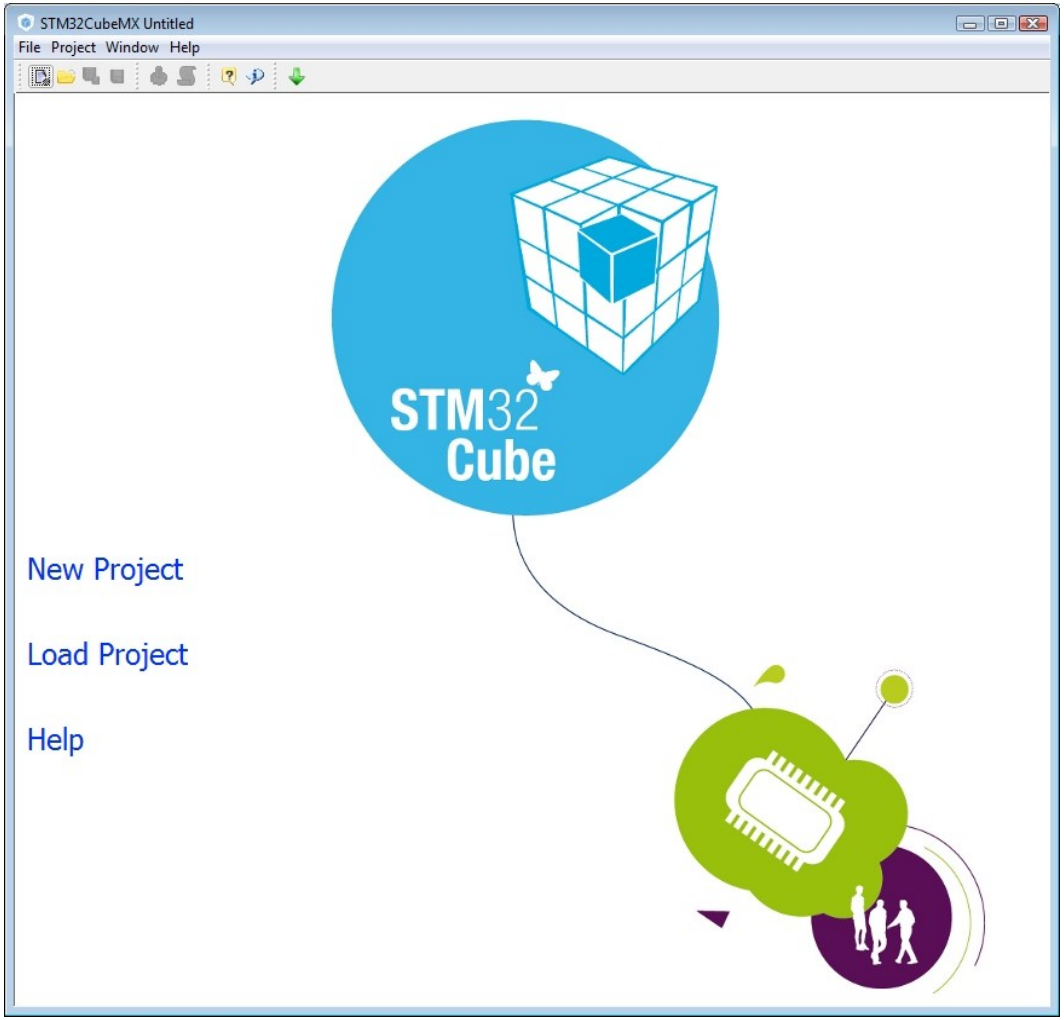


STM32CubeMX presentation

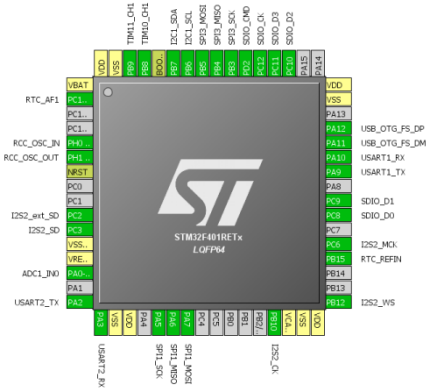
STM32Cube: STM32CubeMX

Step by step:

- MCU selector
- Pinout configuration
- Clock tree initialization
- Peripherals and middleware parameters
- Code generation
- Power consumption calculator



STM32CubeMX



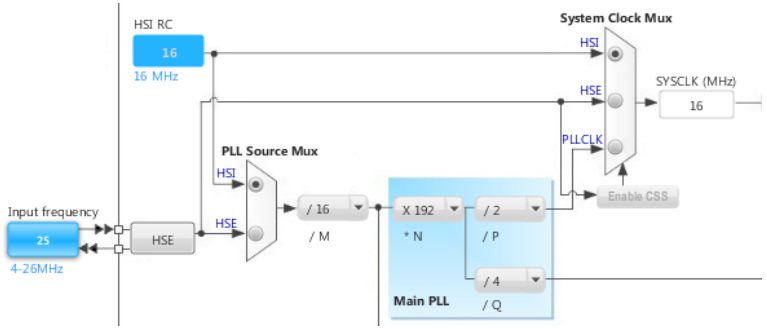
Pinout Wizard

Basic Parameters	
Baud Rate	115200 Bits/s
Word Length	8 Bits (including Parity)
Parity	None
Stop Bits	1
Advanced Parameters	
Data Direction	Receive and Transmit
Over Sampling	16 Samples

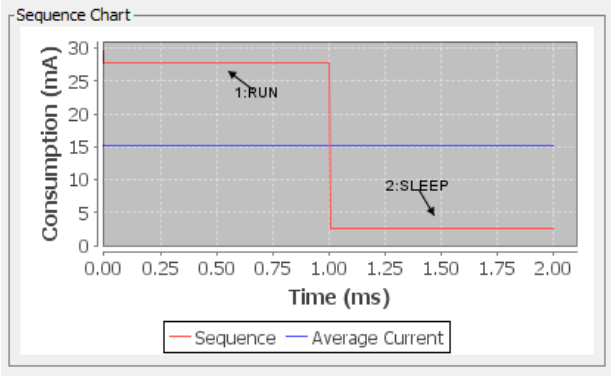
Baud Rate
BaudRate must be between **110 Bits/s** and **10.5 MBits/s**.

Peripherals & Middleware Wizard

Clock Tree wizard



Power Consumption Wizard



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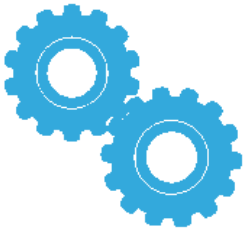
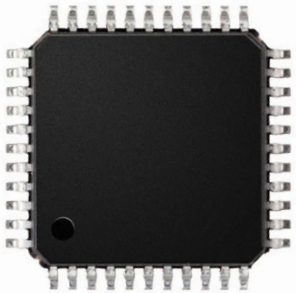
STM32CubeMX



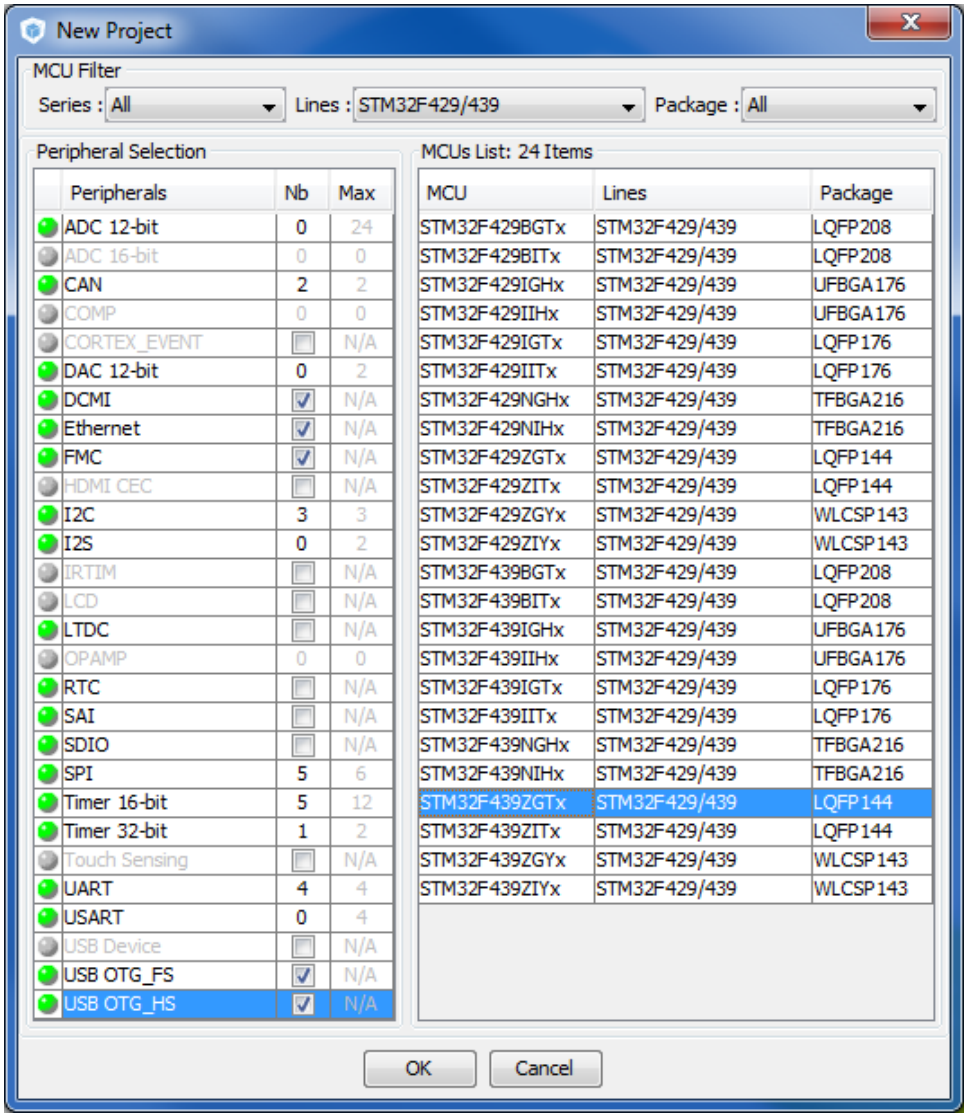
Generates Initialization C Code based on user choices !



STM32CubeMX: MCU Selector

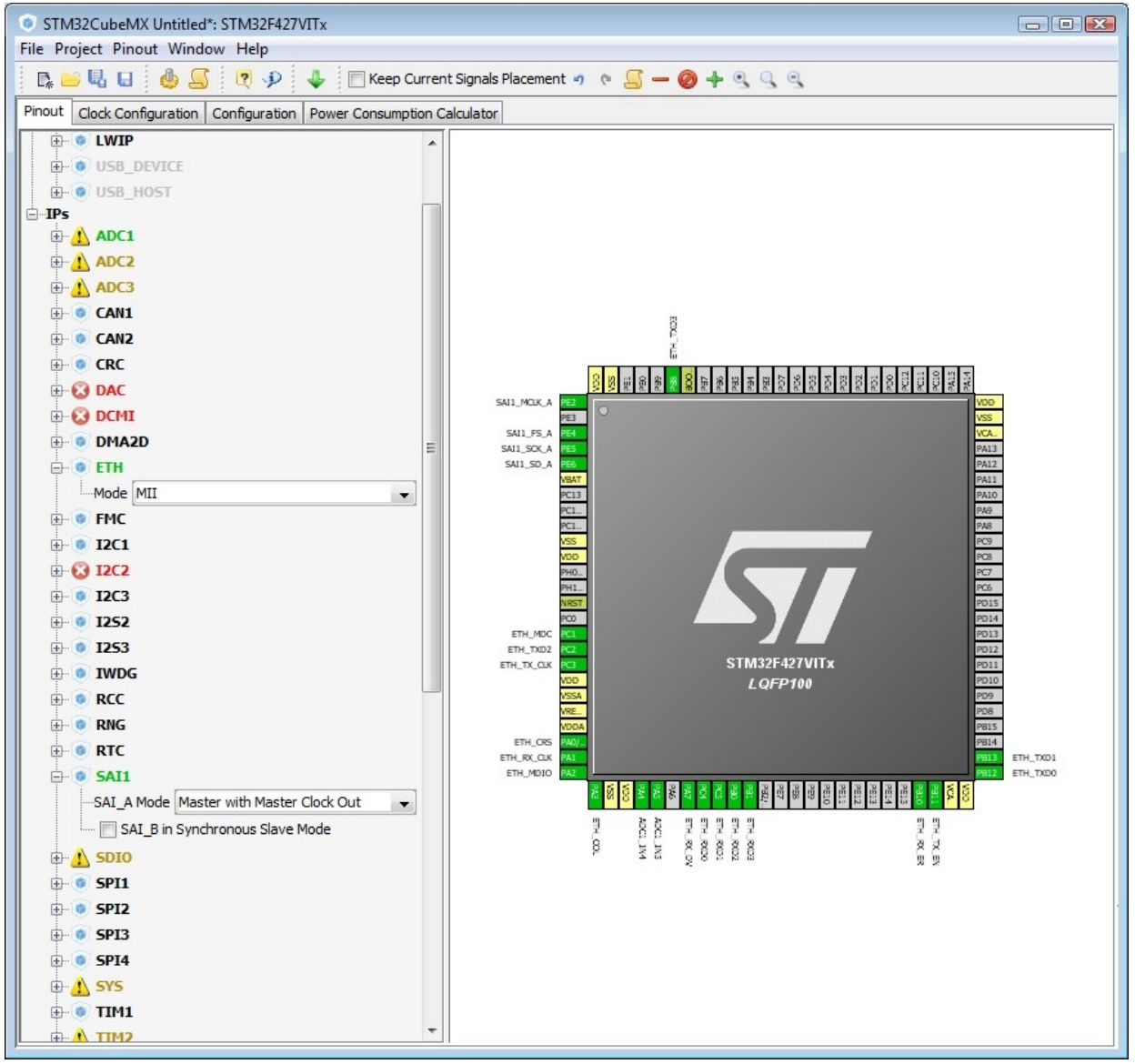
Easy Optional filtering:

- Series
- Line
- Package
- Peripherals



STM32CubeMX: Pinout configuration

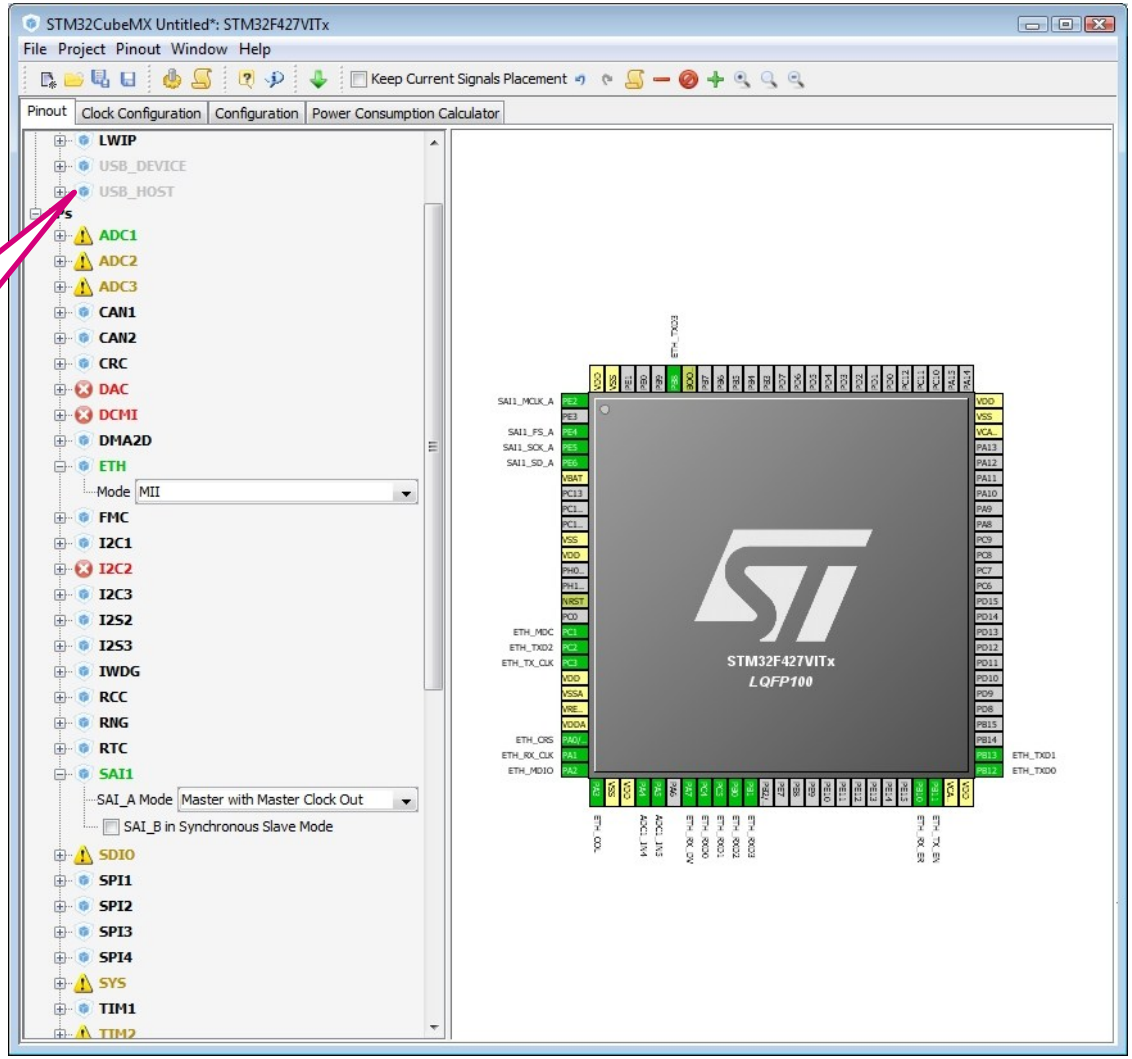
- Pinout from:
  - Peripheral tree
  - Manually
- Automatic signal remapping
- Management of dependencies between peripherals and/or middleware (FatFS, LWIP, …)



STM32CubeMX: Pinout configuration

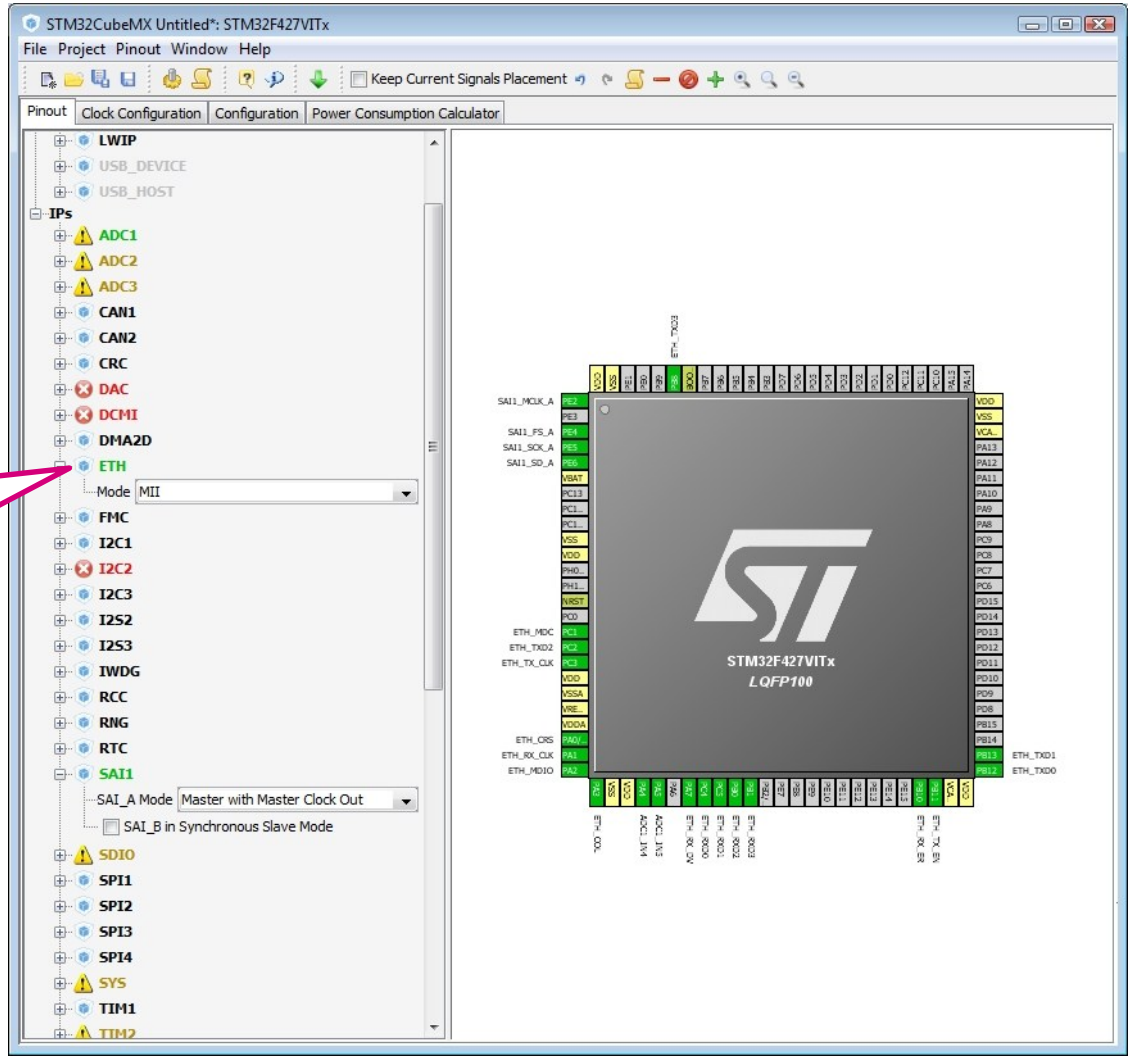
- Different possible states for a peripheral modes
  - Dimmed:
    the mode is not available because it requires another mode to be set (just put the mouse on top of the dimmed mode to see why)

Dimmed:
The additional periphery must be selected



STM32CubeMX: Pinout configuration

- Different possible states for a peripheral modes
  - Green:
    Periphery is assigned to pinout

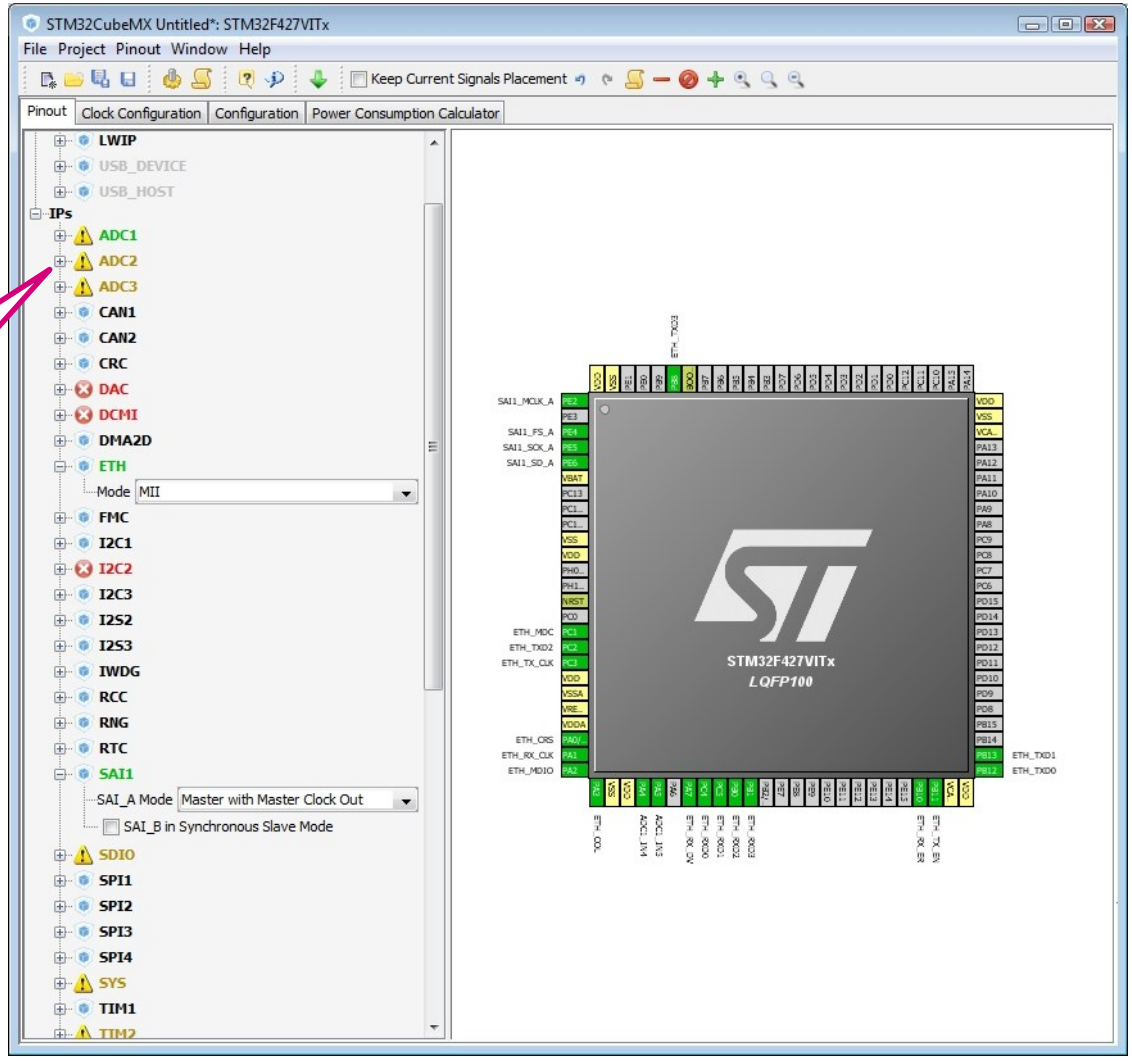


Green:
Periphery will
be functional

STM32CubeMX: Pinout configuration

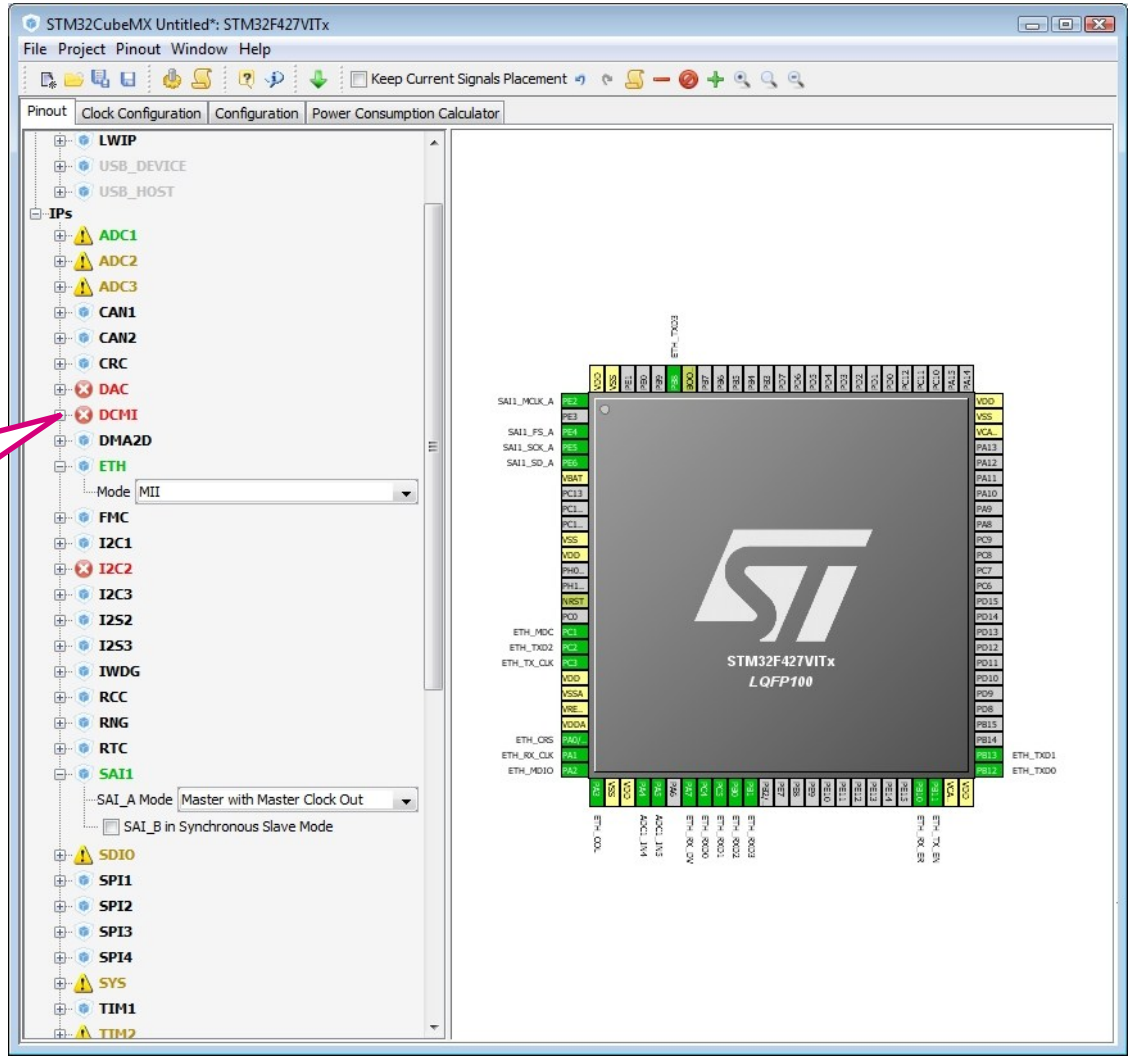
- Different possible states for a peripheral modes
  - Yellow:
    Only some functionalities of periphery can be used

Yellow:
On ADC only some channels can be used



STM32CubeMX: Pinout configuration

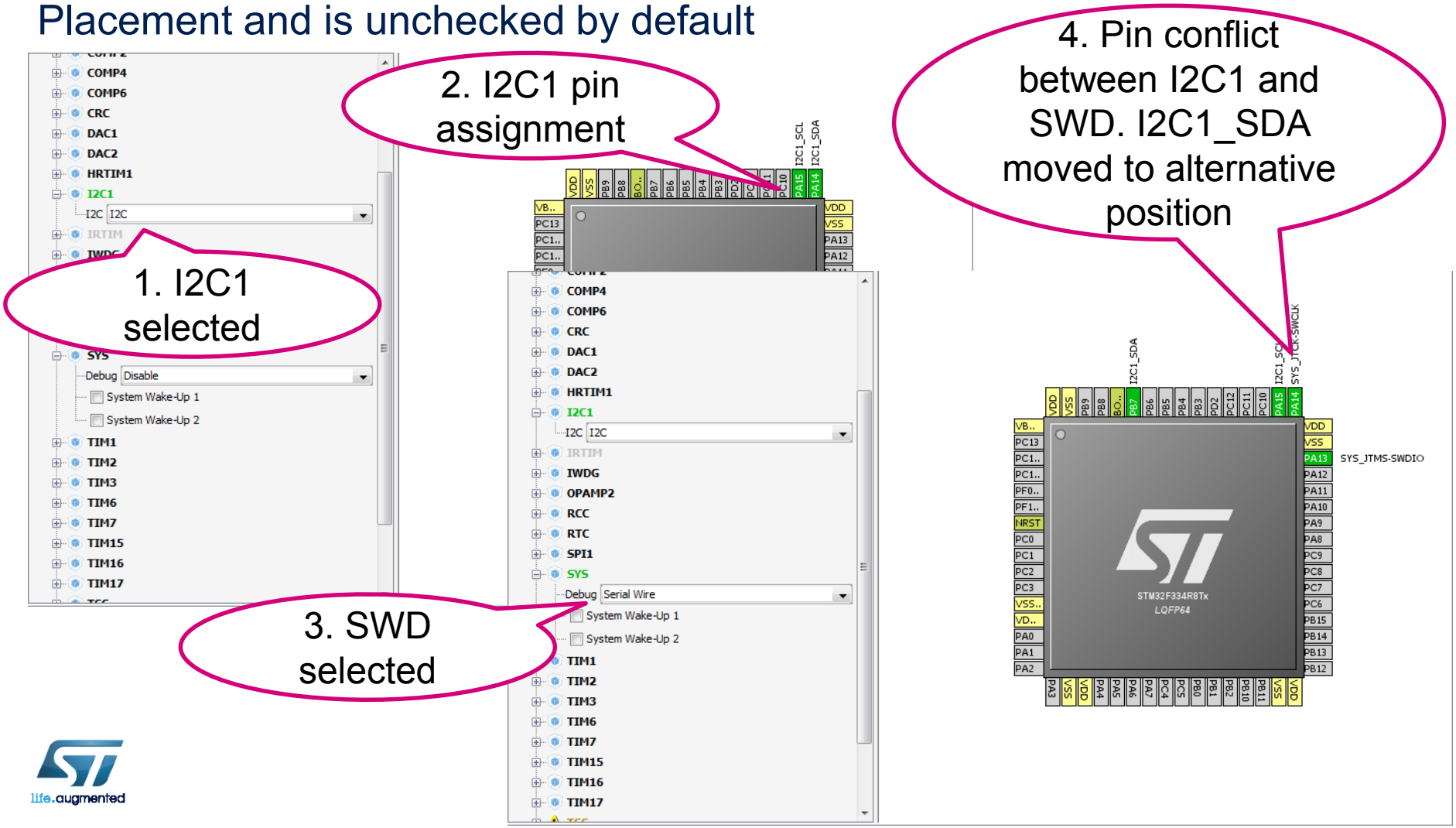
- Different possible states for a peripheral modes
  - Red:
    Signals required for this mode can't be mapped on the pinout (see tooltip to see conflicts)



Red:
Periphery cannot be used in this pinout setup

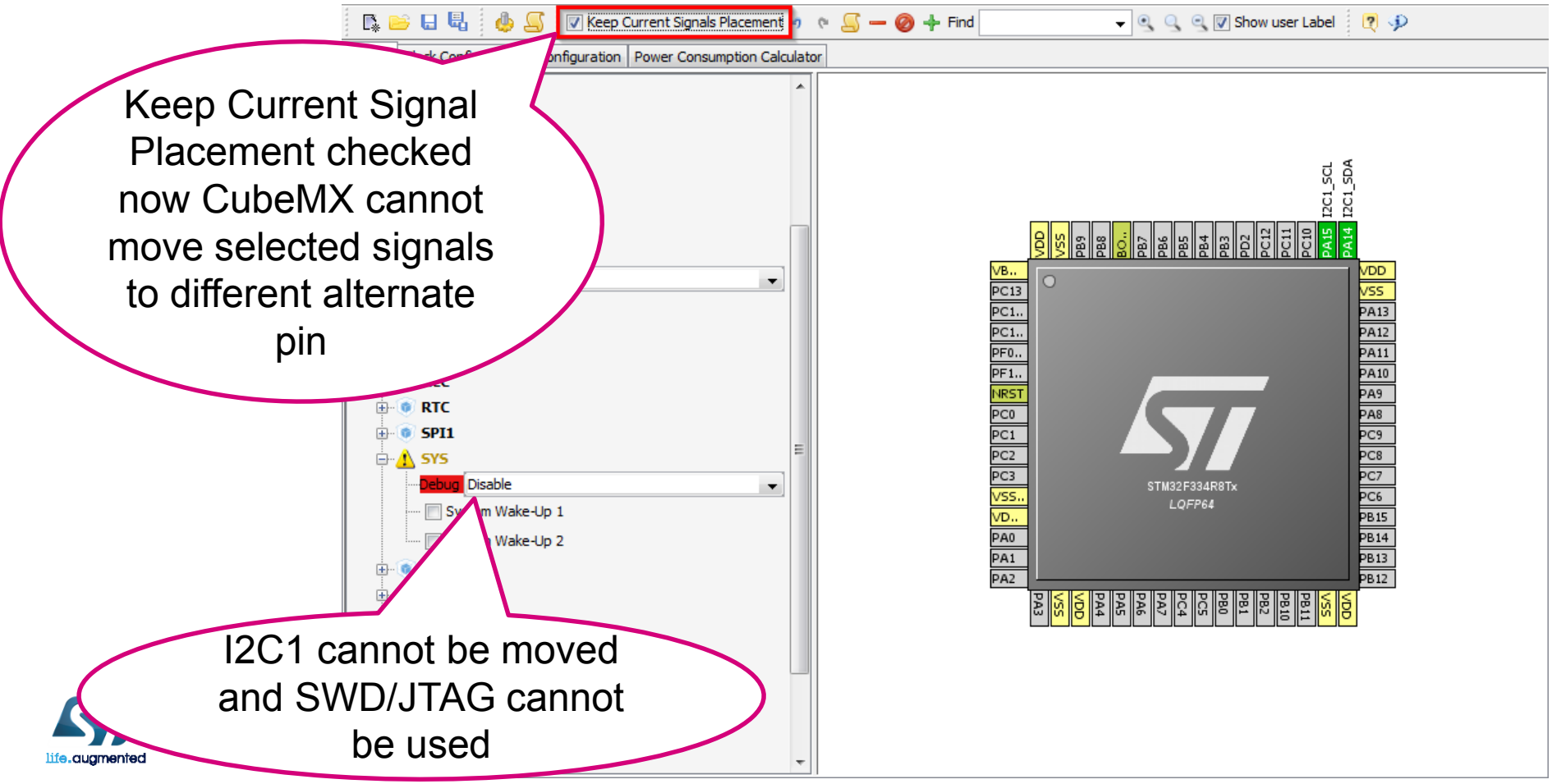
STM32CubeMX: Pinout configuration

- Keep User Placement renamed to Keep Current Signal Placement and is unchecked by default



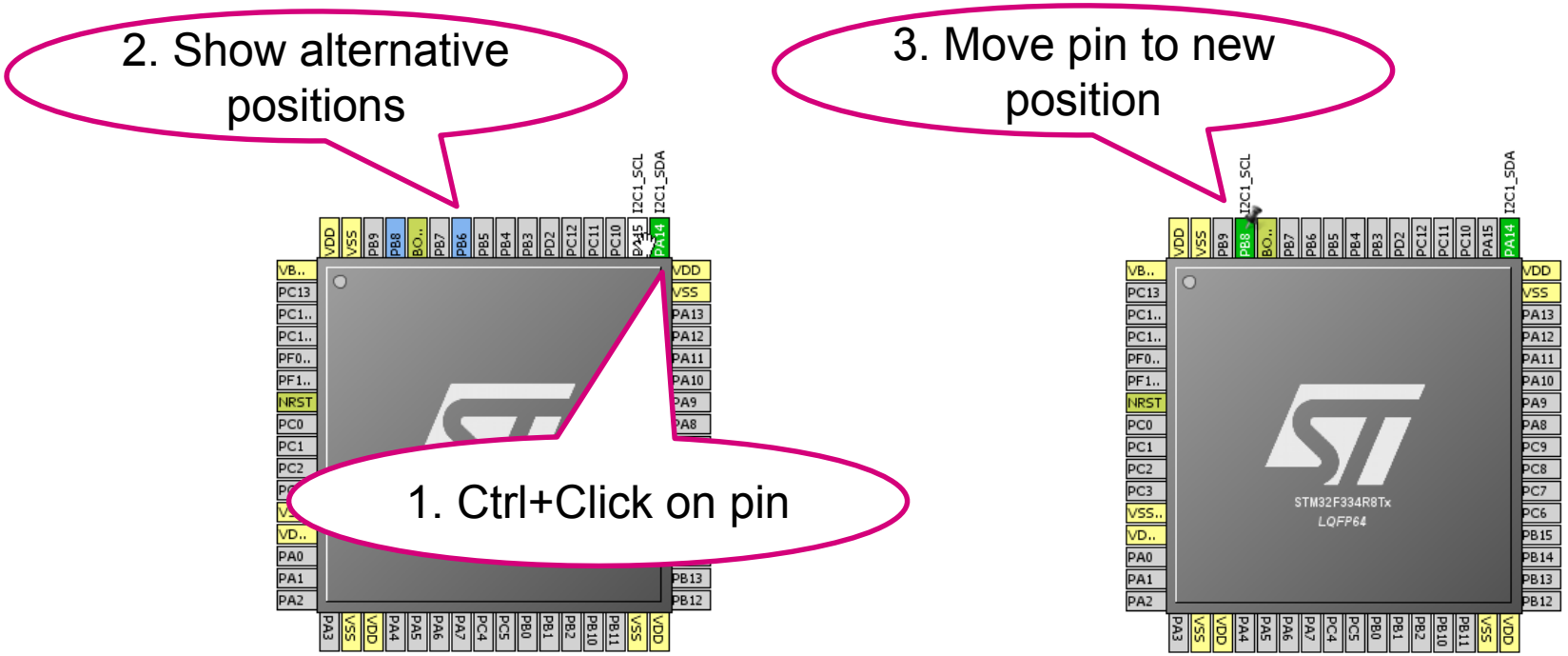
STM32CubeMX: Pinout configuration

- Keep User Placement renamed to Keep Current Signal Placement and is unchecked by default



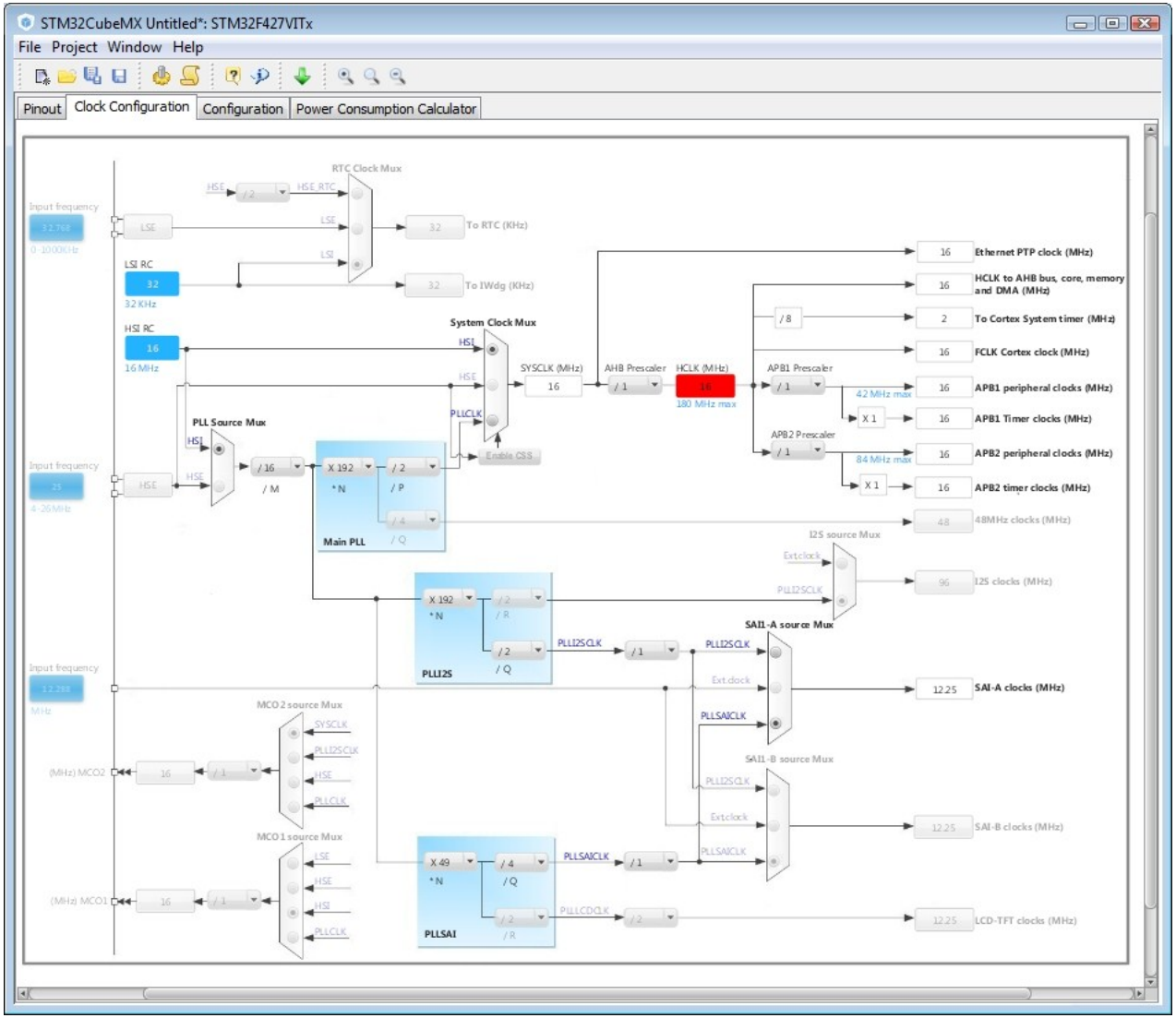
STM32CubeMX: Pinout configuration

- Signals can be set/moved directly from the pinout view
  - To see alternate pins for a signal Ctrl+Click on the signal, you can then drag and drop the signal to the new pin (keep pressing the Ctrl key)



STM32CubeMX: Clock tree

- Immediate display of all clock values
- Management of all clock constraints
- Highlight of errors



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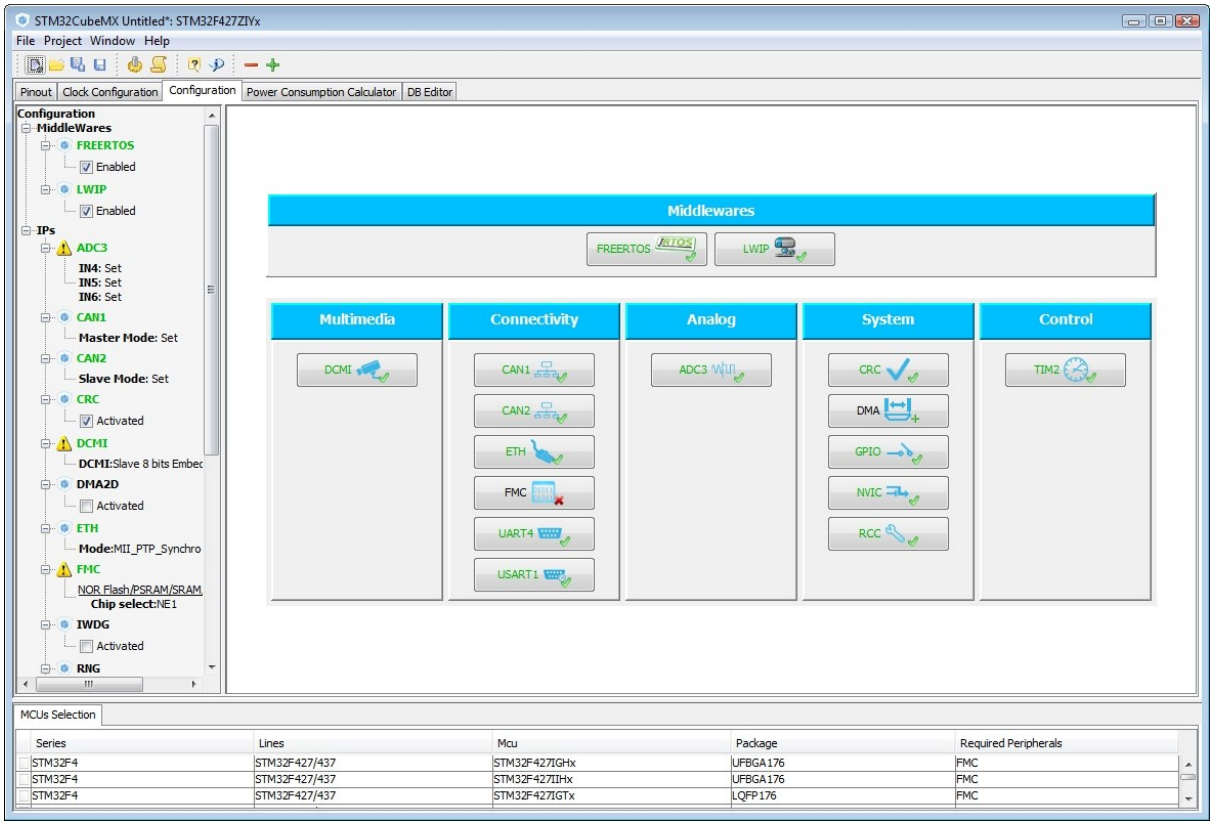
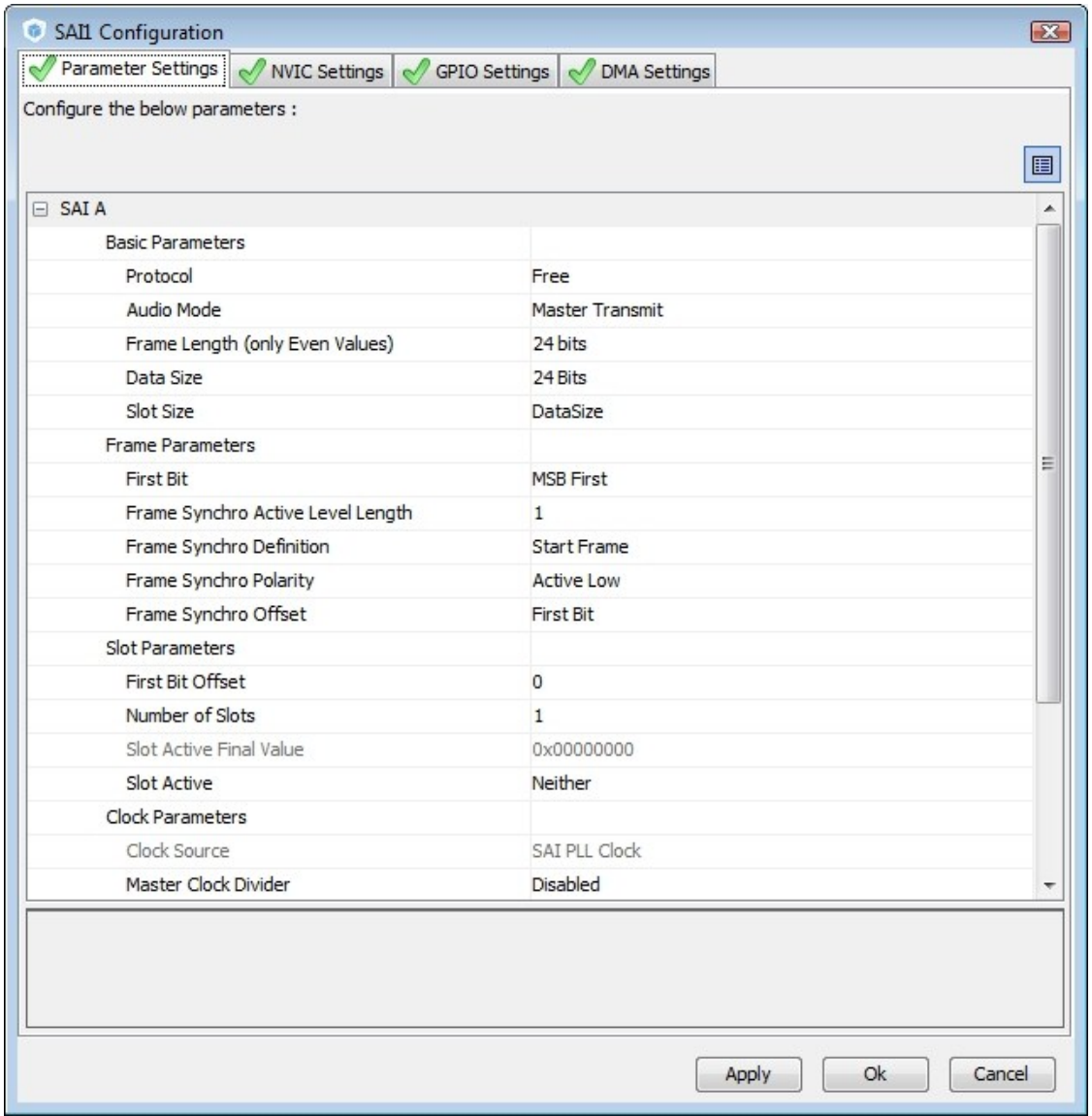
STM32CubeMX: Peripheral and middleware configuration

- Global view of used peripherals and middleware
- Highlight of configuration errors
  - + Not configured
  - v OK
  - x Error
- Read only tree view on the left with access to IPs / Middleware having no impact on the pinout



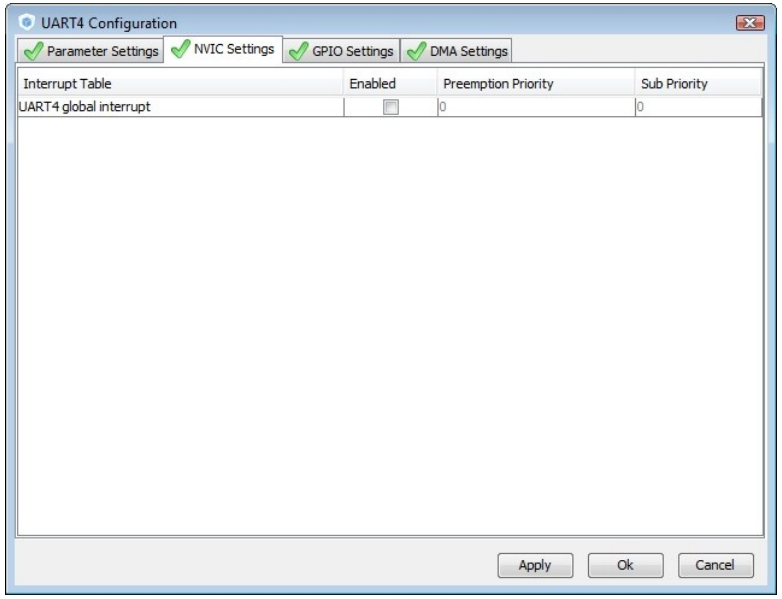
STM32CubeMX: Peripheral and middleware configuration

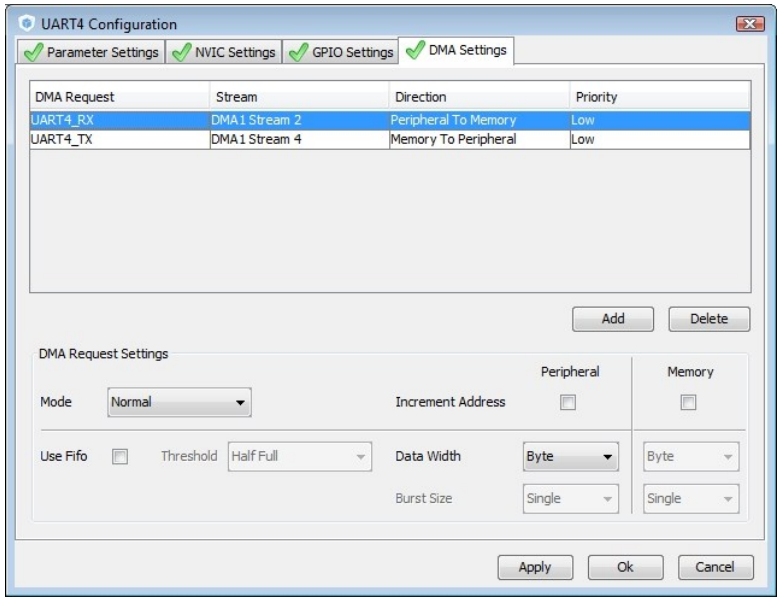
- Parameters with management of dependencies and constraints
- Interrupts
- GPIO
- DMA



STM32CubeMX: Peripheral and middleware configuration

- Manage Interruptions
  - priorities can only be set in the NVIC global view
- Manage GPIO parameters
- Manage DMA
  - Configure all the parameters of the DMA request
  - Runtime parameters (start address, …) are not managed





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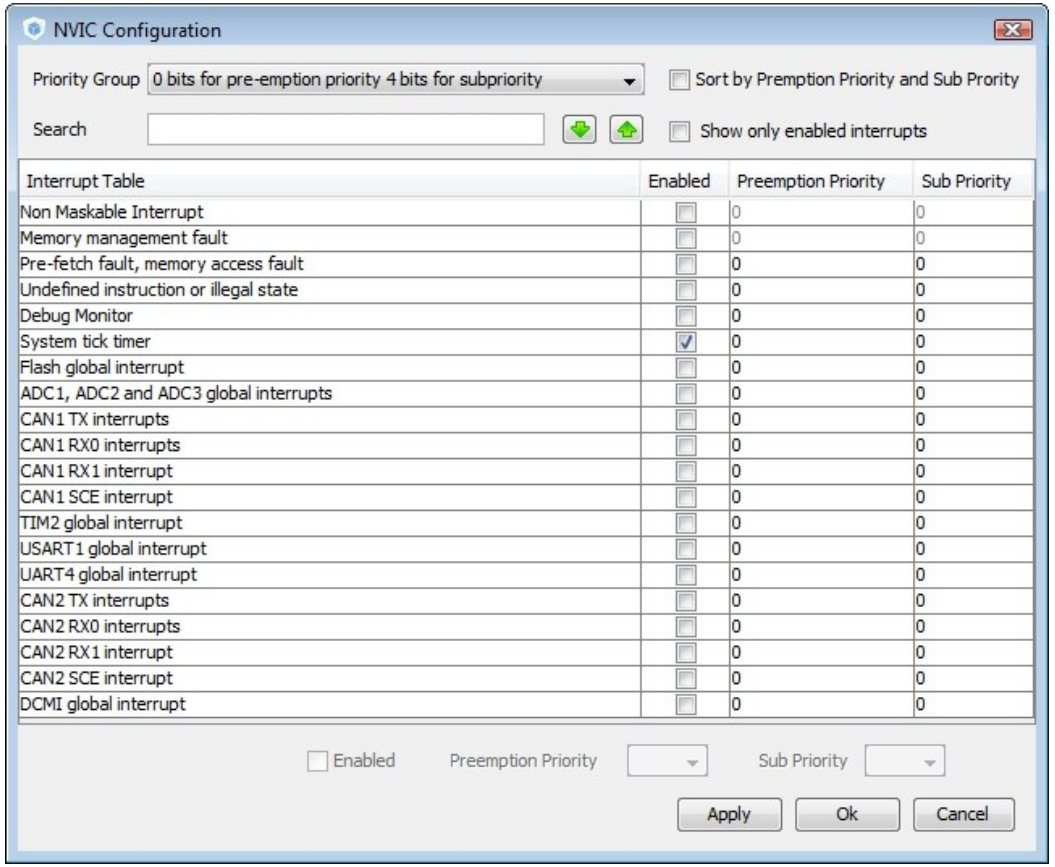
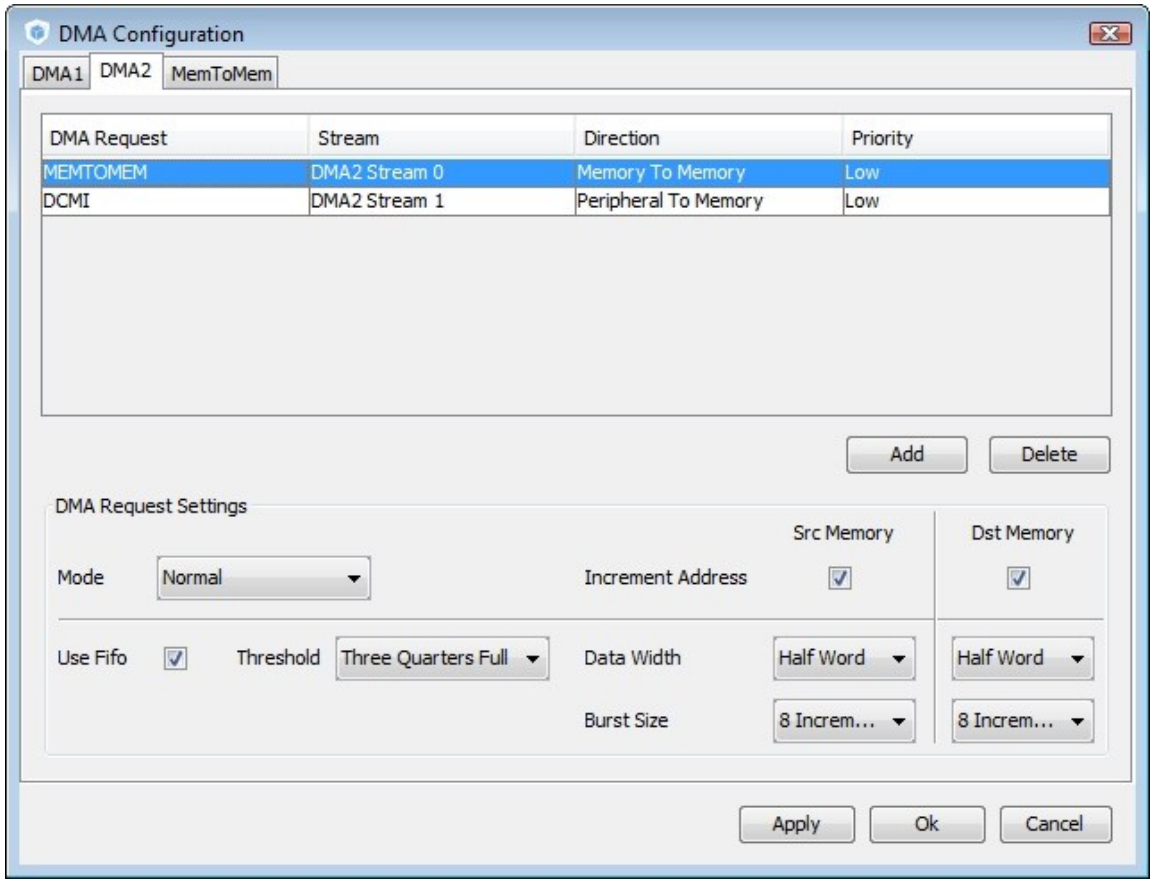
NVIC Panel

- Manage all interruptions
- Manage priorities and sort by priorities
- Search for a specific interrupt in the list



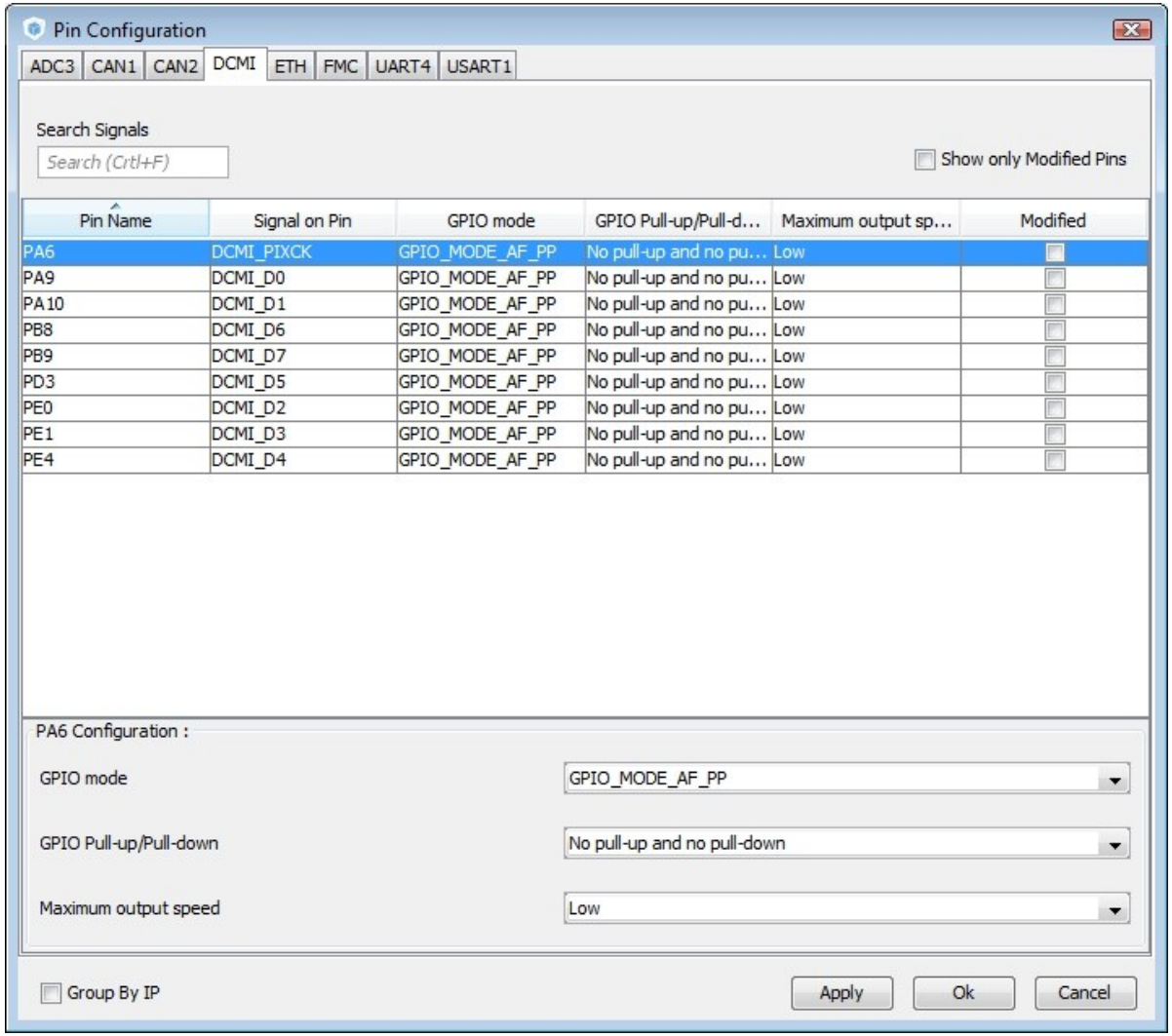
DMA Panel

- Manage All DMA requests including Memory to Memory
- Set Direction and priority
- Set specific parameters



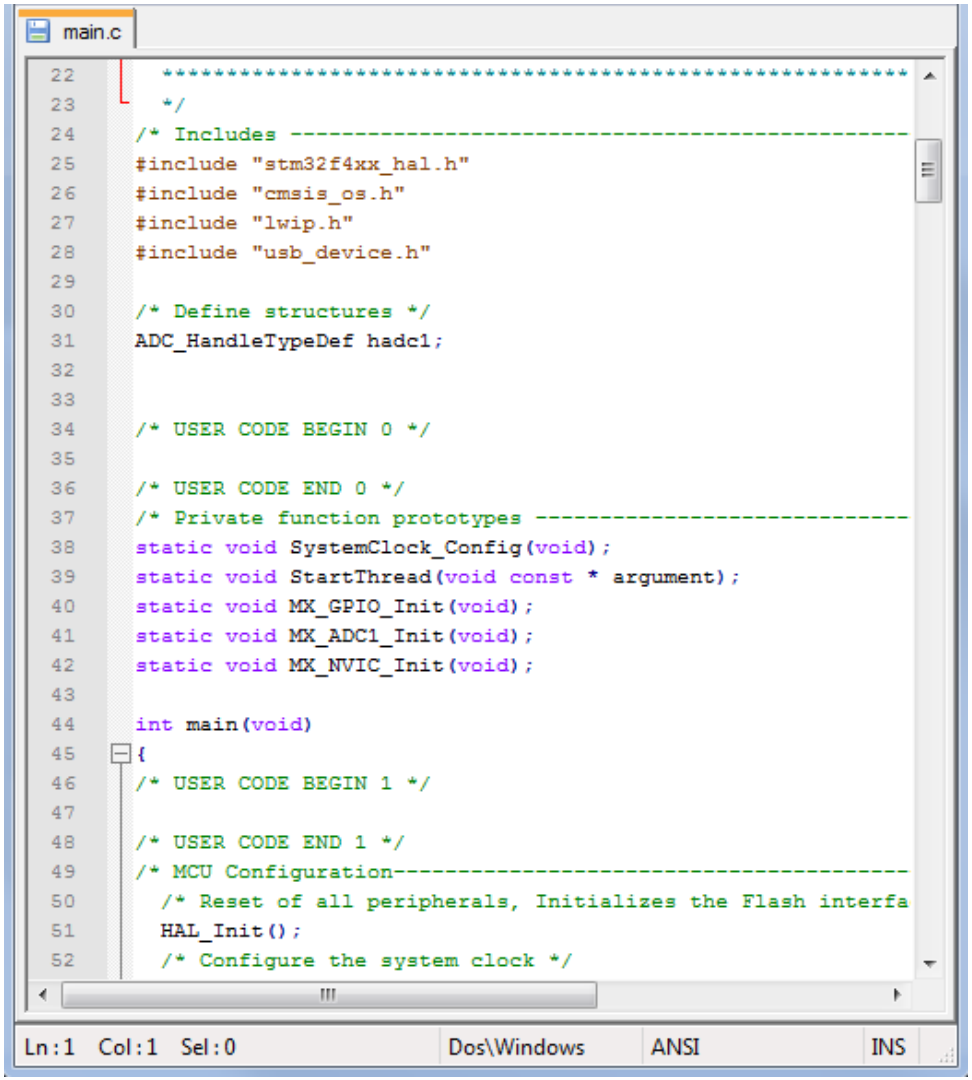
GPIO Panel

- Most of the GPIO parameters are set by default to the correct value
- You may want to change the maximum output speed
- You can select multiple pin at a time to set the same parameter



STM32CubeMX: Code generation

- Generation of all the C initialization code
- Automatic integration with partners toolchains
- User code can be added in dedicated sections and will be kept upon regeneration
- Required library code is automatically copied or referenced in the project (updater)

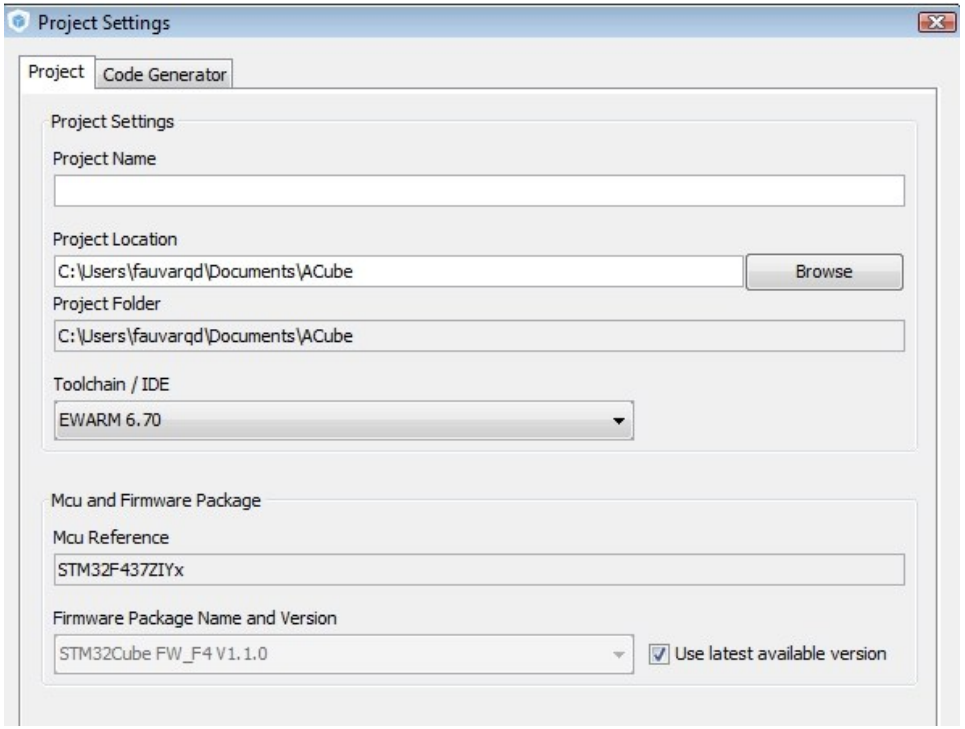


STM32CubeMX: Updater

- Help->Updater settings
  - Choose location of STM32CubeFx firmware libraries repository
  - Choose manual or automatic check
  - Set Connection proxy
    - Inside ST use lps5.sgp.st.com port 8080 with your windows login name and password
- Help->Install new libraries : Manage the content of the library repository
  - Click on the check button to see what is available
  - Select the library you want to install and click install now
    - The libraries will be automatically downloaded and unzipped

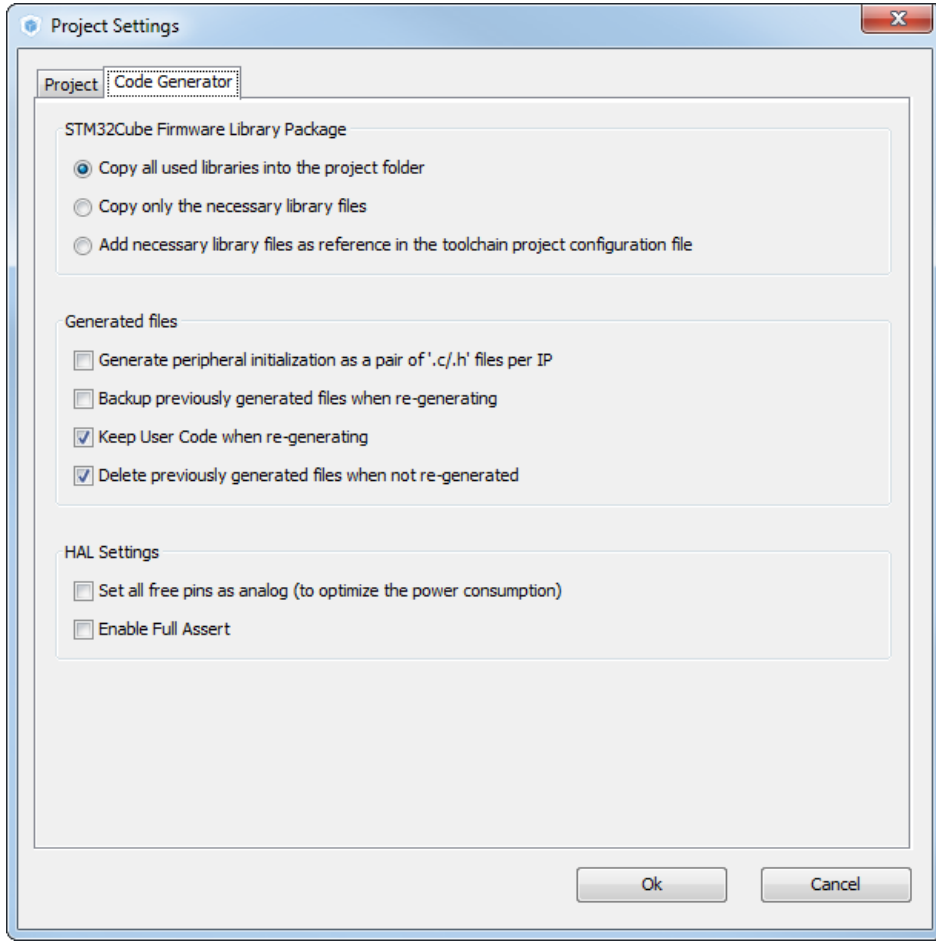
STM32CubeMX: Project settings

- Project -> Settings
  - Set project name and location
  - A full folder will be created named with the project name.
  - Inside this folder you'll find the saved configuration and all the generated code
  - Select toolchain (Keil, IAR, Atollic, SW4STM32)
  - You can choose to use the latest version of the firmware library or a specific one

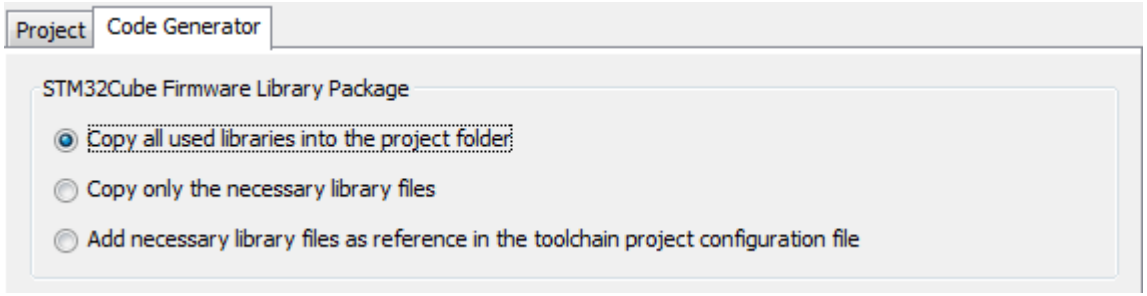


STM32CubeMX: Code Generator settings

- Code generator options
  - Either copy the full library or only the necessary files or just reference the files from the common repository
  - Generate all peripherals initialization in the stm32fYxx_hal_msp.c file or one file per peripheral
  - Keep user code or overwrite it (code between User code comment sections)
  - Delete or keep files that are not useful anymore
  - Set free pins as analog, this settings helps keep low consumption (**if SWD/JTAG is not selected in pinout, this option will disable it**)
  - Enable full assert in project, this help discover incorrect HAL function parameter used in user code



STM32Cube Firmware Library package



- Copy all used libraries into the project folder

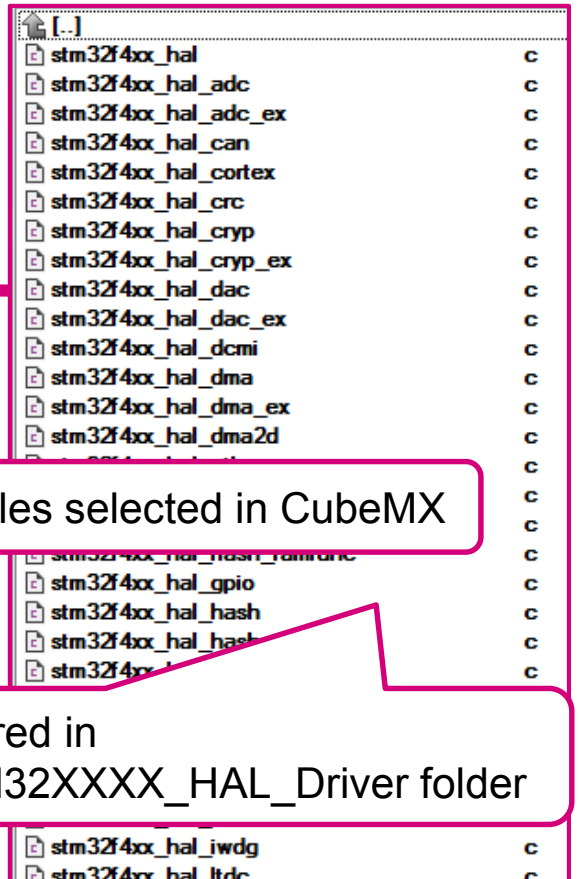
CubeMX repository

Project Driver Folder

Copy all driver files from CubeMX repository

In project are used only peripheral files selected in CubeMX

Stored in project_folder/Drivers/STM32XXXX_HAL_Driver folder



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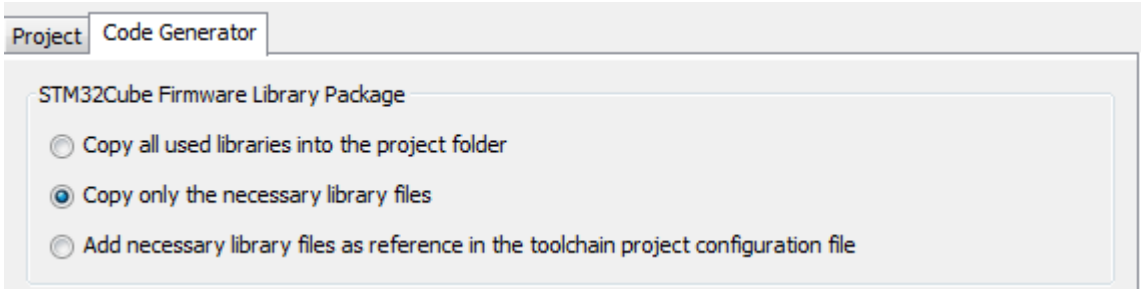
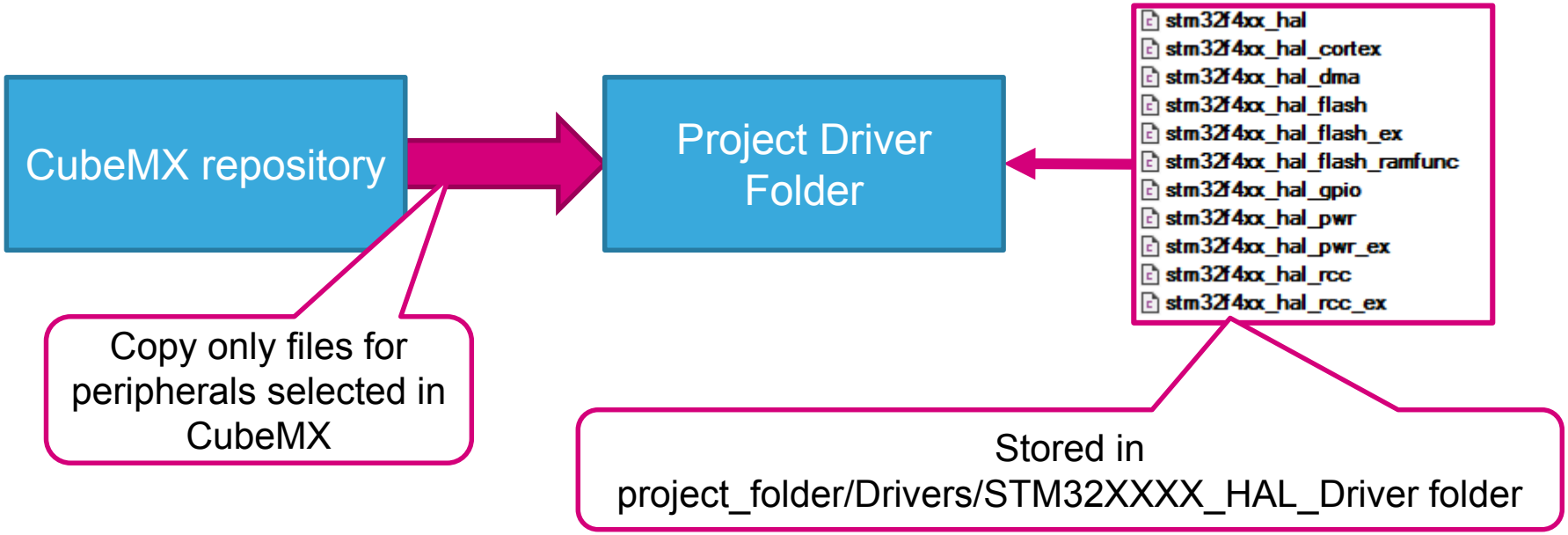
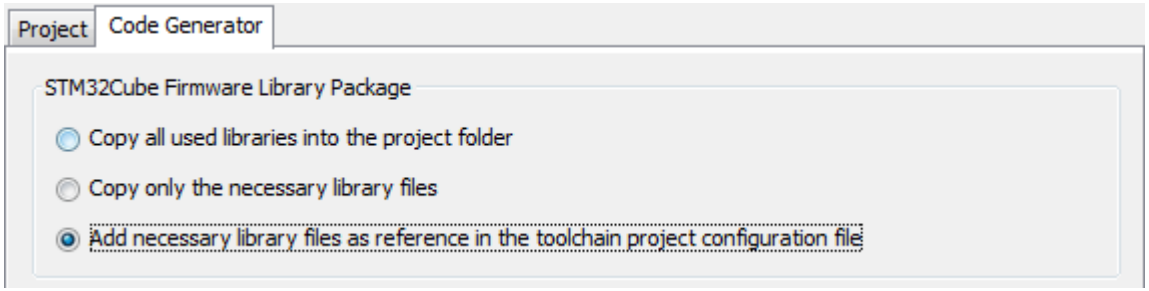
STM32Cube Firmware Library package



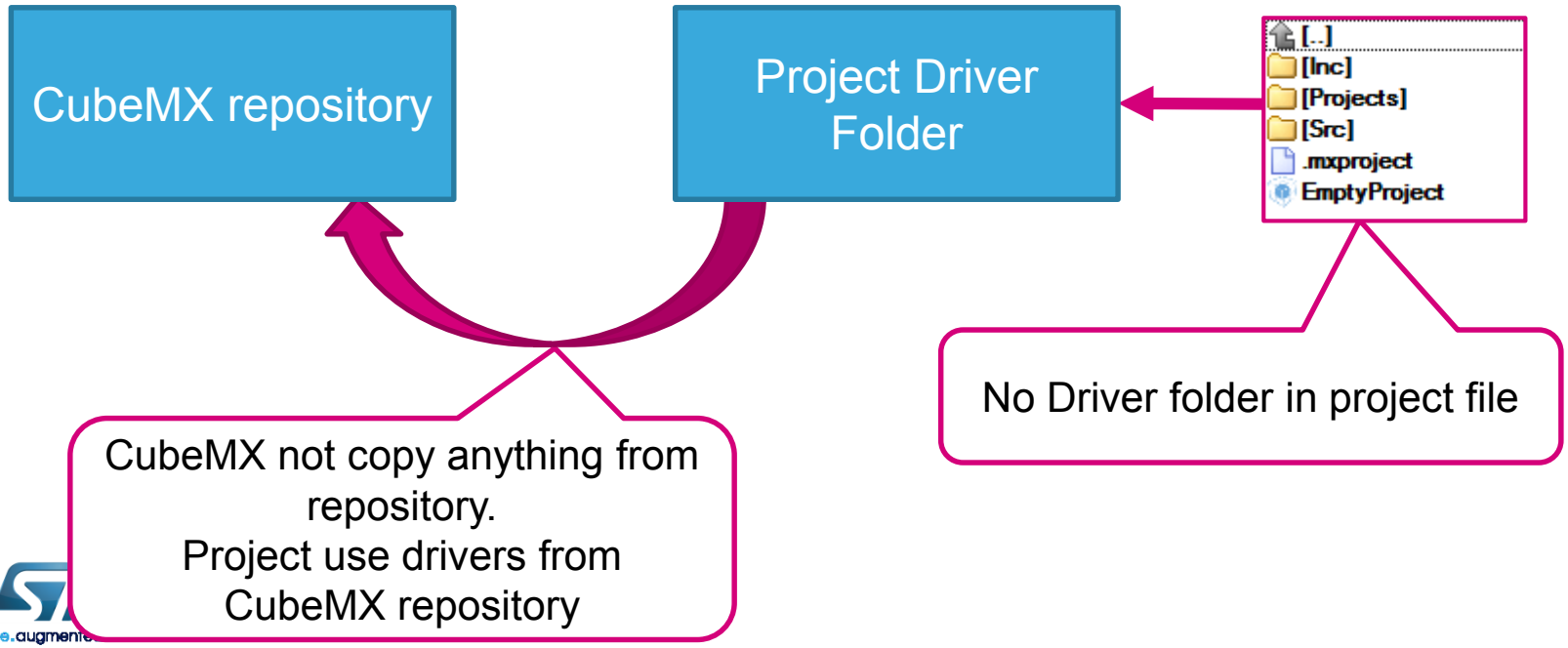
- Copy only the necessary library files



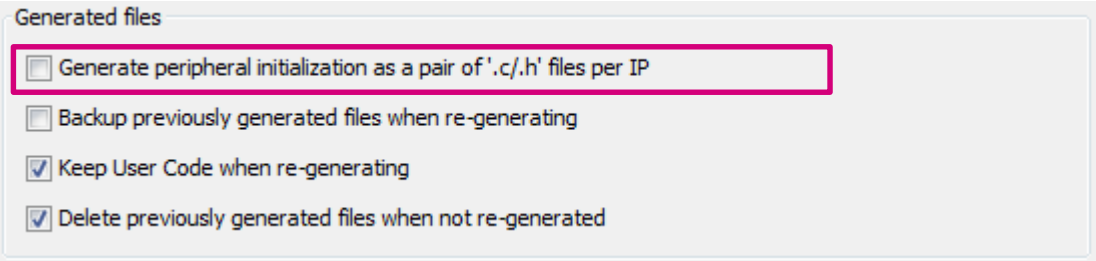
STM32Cube Firmware Library package



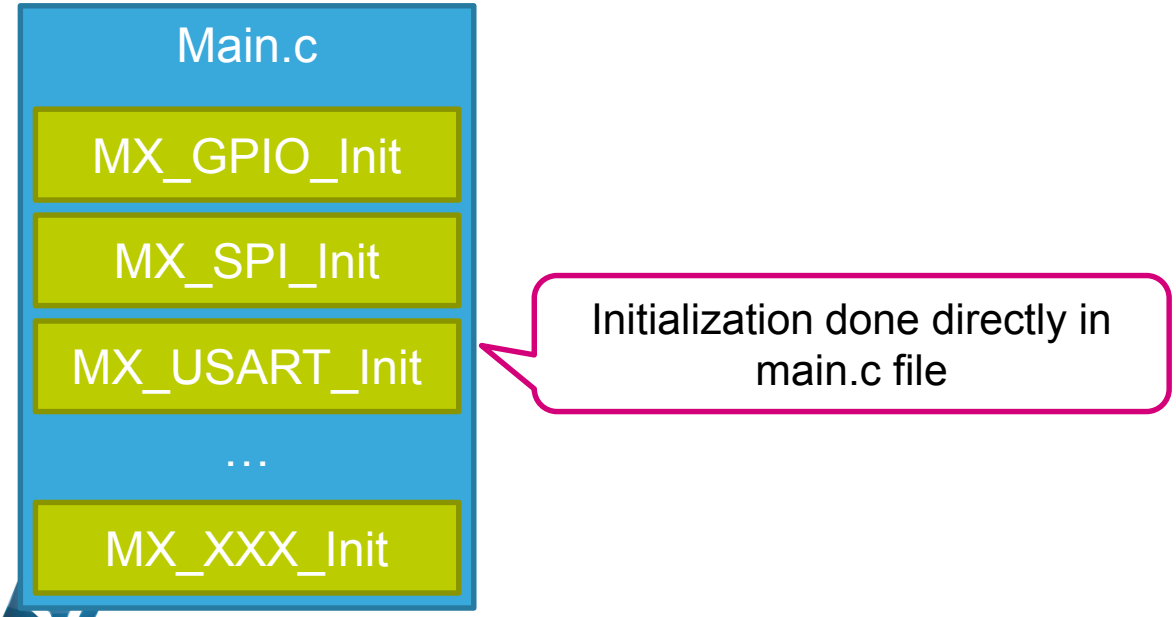
- Add necessary library files as reference in the toolchain project configuration file



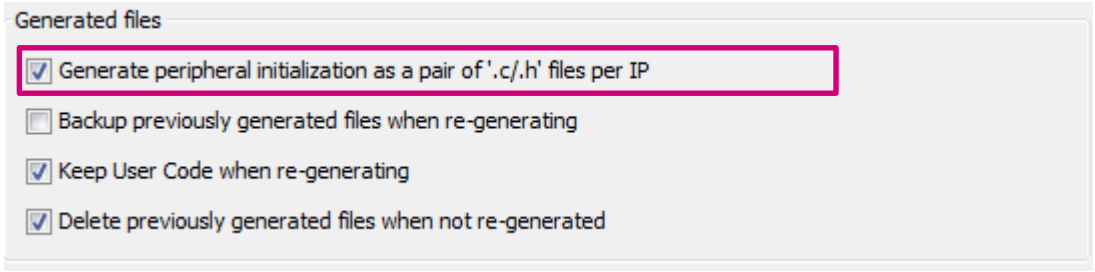
Generate peripheral initialization as a pair of '.c/.h' files per IP



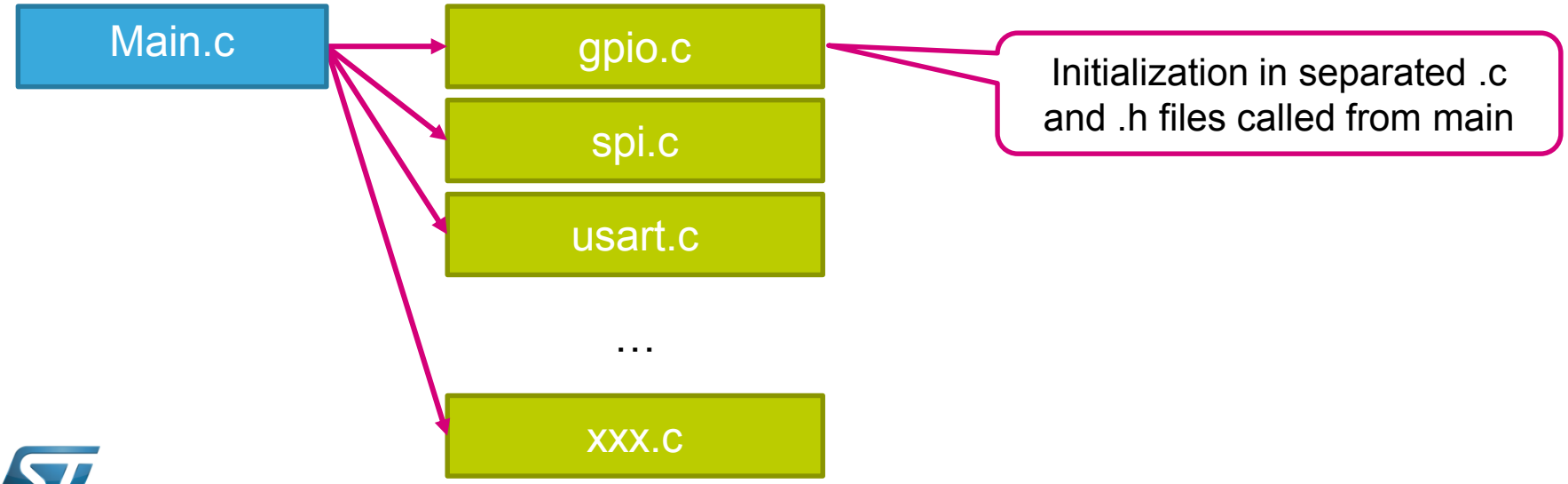
- In default not used
- Generate initialization of peripherals selected in CubeMX in main.c



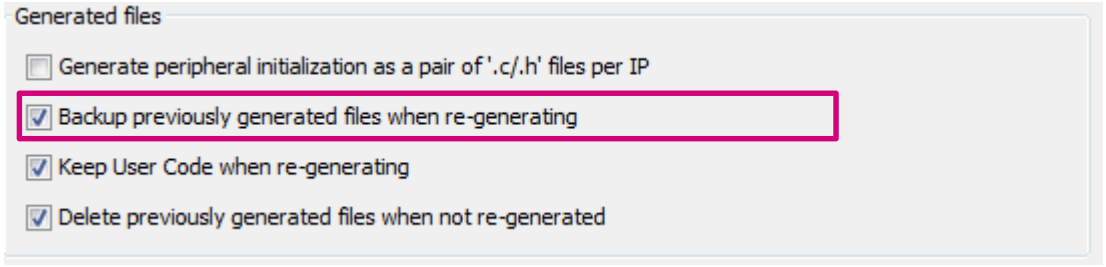
Generate peripheral initialization as a pair of '.c/.h' files per IP



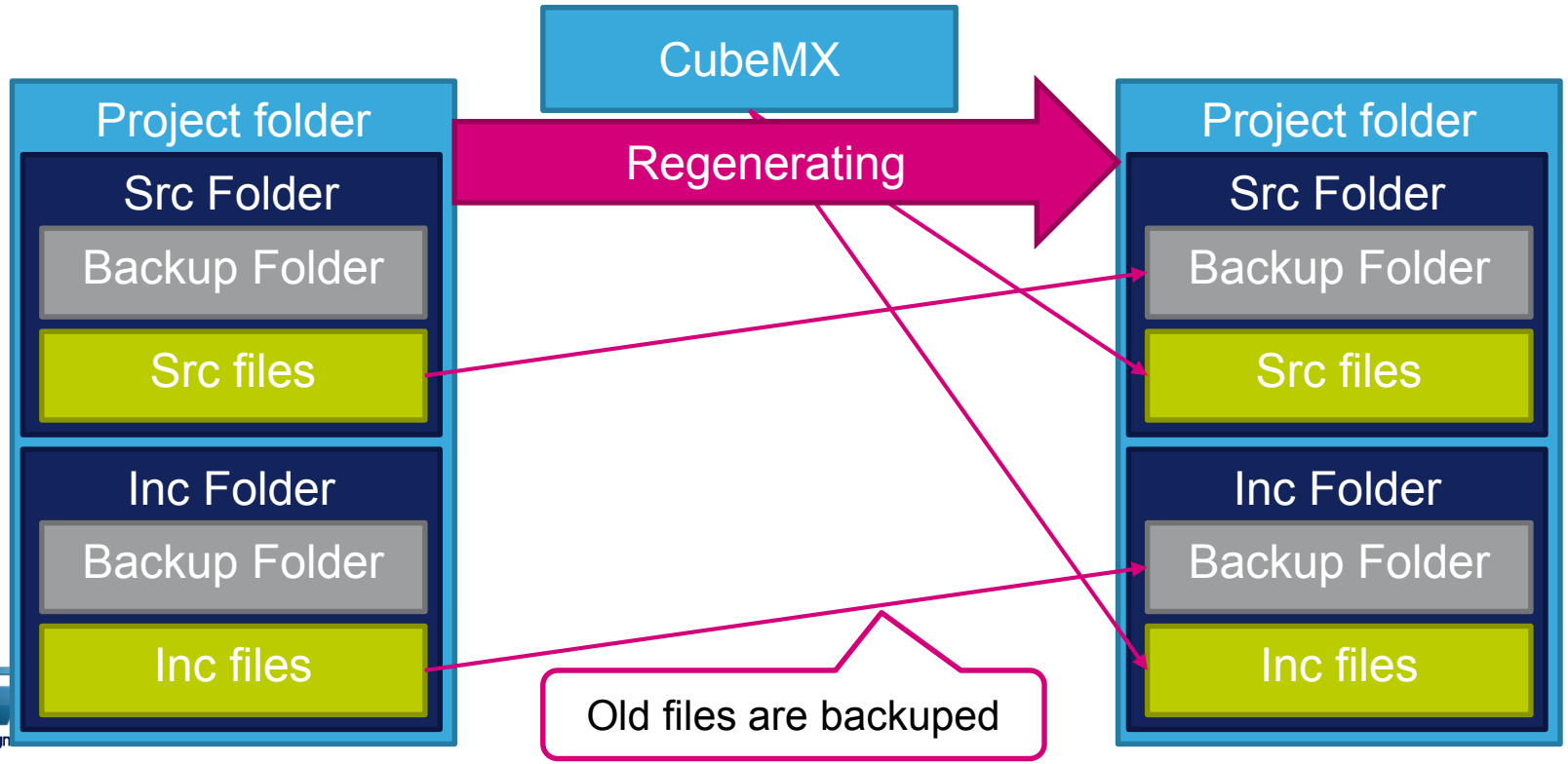
- Generate dedicated initialization .c and .h file for each periphery
- Advantage is that with .h file we can call MX_XXX init functions from every file in project not only from main.c



Backup previously generated files when re-generating



- Backup old files from **Src** and **Inc** folder into **Backup** folder

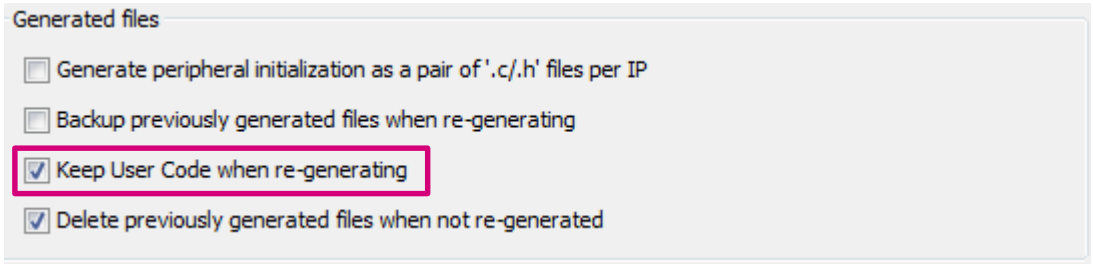


Keep User Code when re-generating

- Generated code contains USER CODE areas
- This areas are reserved in new code generation, if this option is selected

```
/* USER CODE BEGIN PFP */

/* USER CODE END PFP */
/* USER CODE BEGIN 0 */

/* USER CODE END 0 */
int main(void)
{
  /* USER CODE BEGIN 1 */

  /* USER CODE END 1 */
  /* MCU Configuration--------------------------------------------------------*/
  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();
  /* Configure the system clock */
  SystemClock_Config();
  /* Initialize all configured peripherals */
  /* USER CODE BEGIN 2 */

  /* USER CODE END 2 */
  /* USER CODE BEGIN 3 */
  /* Infinite loop */
  while (1)
  {

  }
  /* USER CODE END 3 */
}
```

Here can user put his code, code will be preserved during project generation

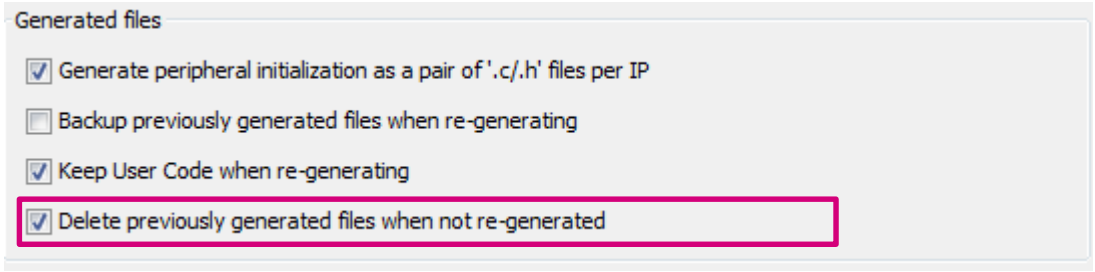


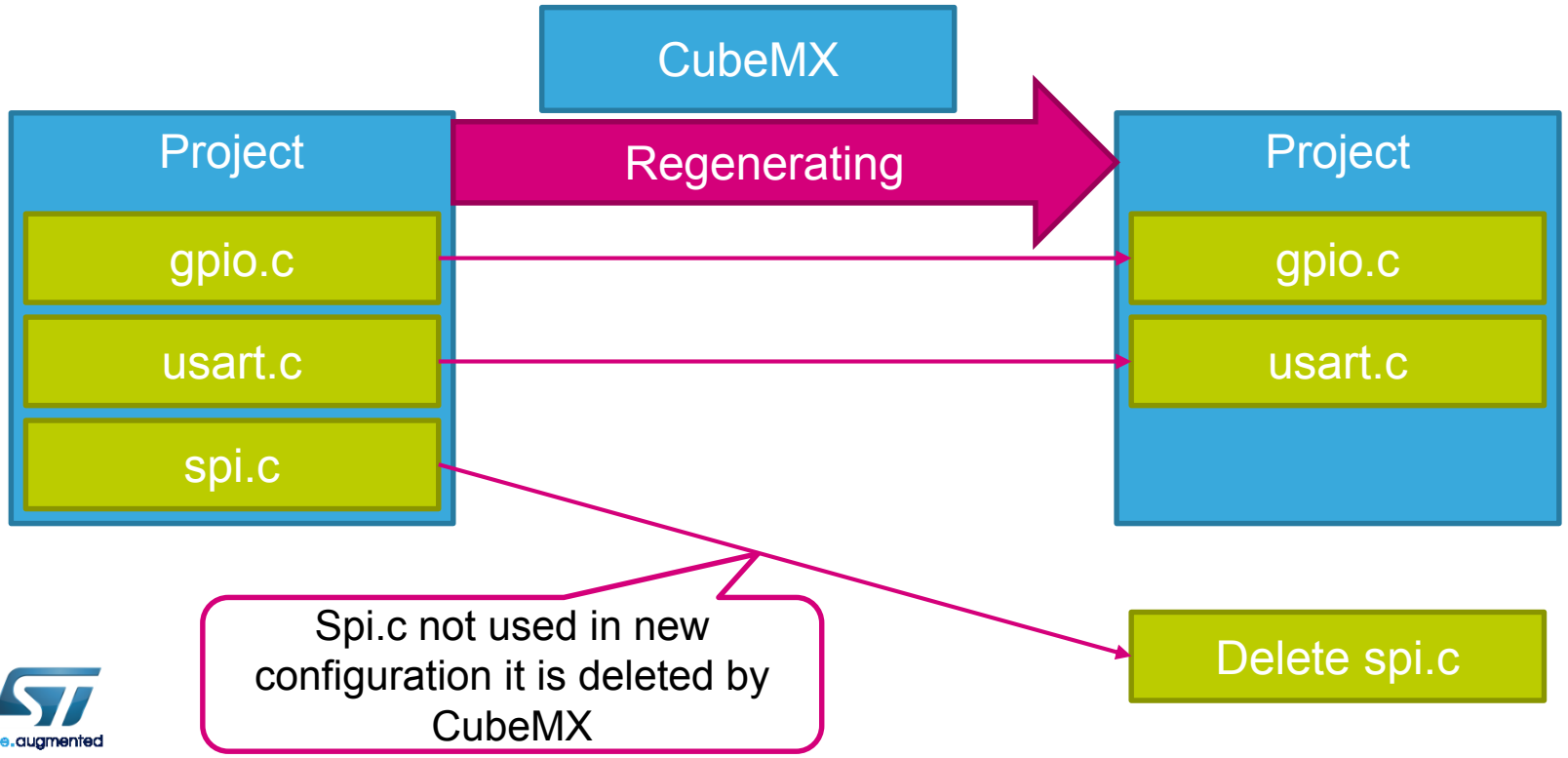
Keep User Code when re-generating

- Generated code contains USER CODE areas
- This areas are reserved in new code generation, if this option is selected
- Areas present in files generated by CubeMX
  - Main.c
  - Stm32f4xx_it.c
  - Stm32f4xx_hal_msp.c
- Areas cover important areas used for:
  - Includes
  - Variables
  - Function prototypes
  - Functions

```
/* USER CODE BEGIN PFP */

/* USER CODE END PFP */
/* USER CODE BEGIN 0 */

/* USER CODE END 0 */
```

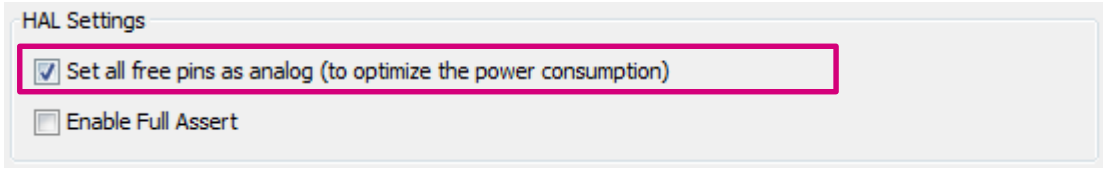
Delete previously generated files when re-generating

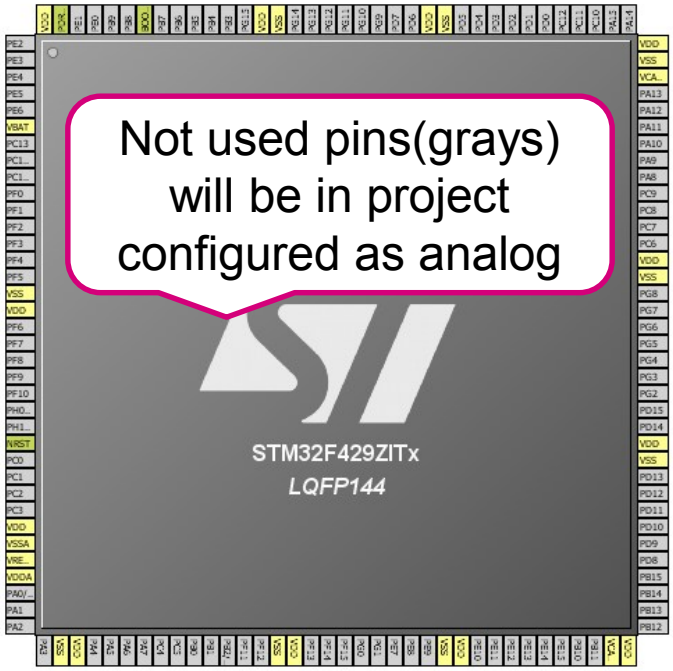


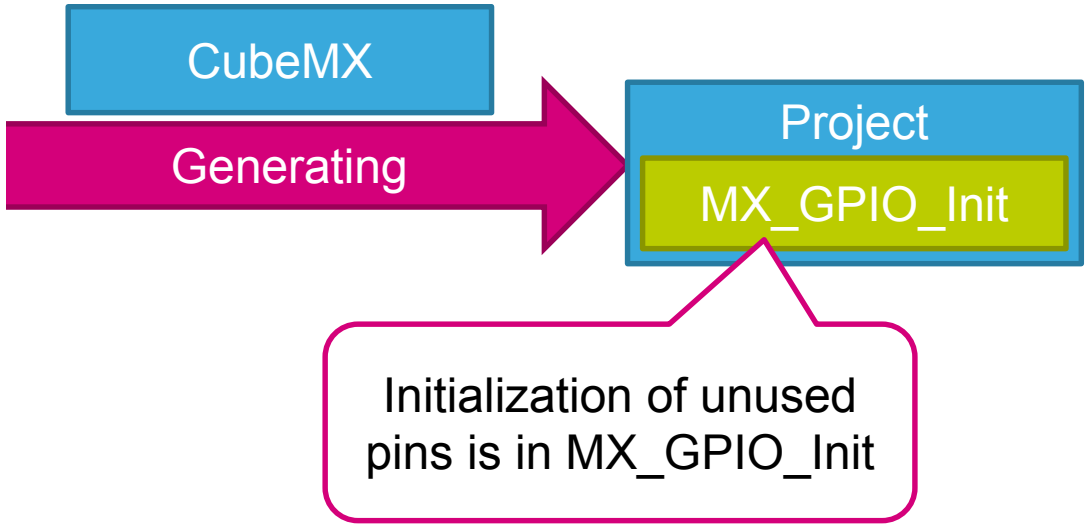


Set all free pins as analog

- This settings optimize power consumption of unused pins







- If the **JTAG/SWD is not selected** in CubeMX, MX_GPIO_Init reconfigure JTAG/SWD pins to analog and this **disable debug possibilities**

Enable Full Assert

- Feature very useful during debugging
- Function input parameters are checked if they are in correct range, if not application jump into assert_failed function in main.c

```
/* USER CODE BEGIN 2 */
 HAL_GPIO_TogglePin(GPIOA,(0x1<<17));
 /* USER CODE END 2 */
```

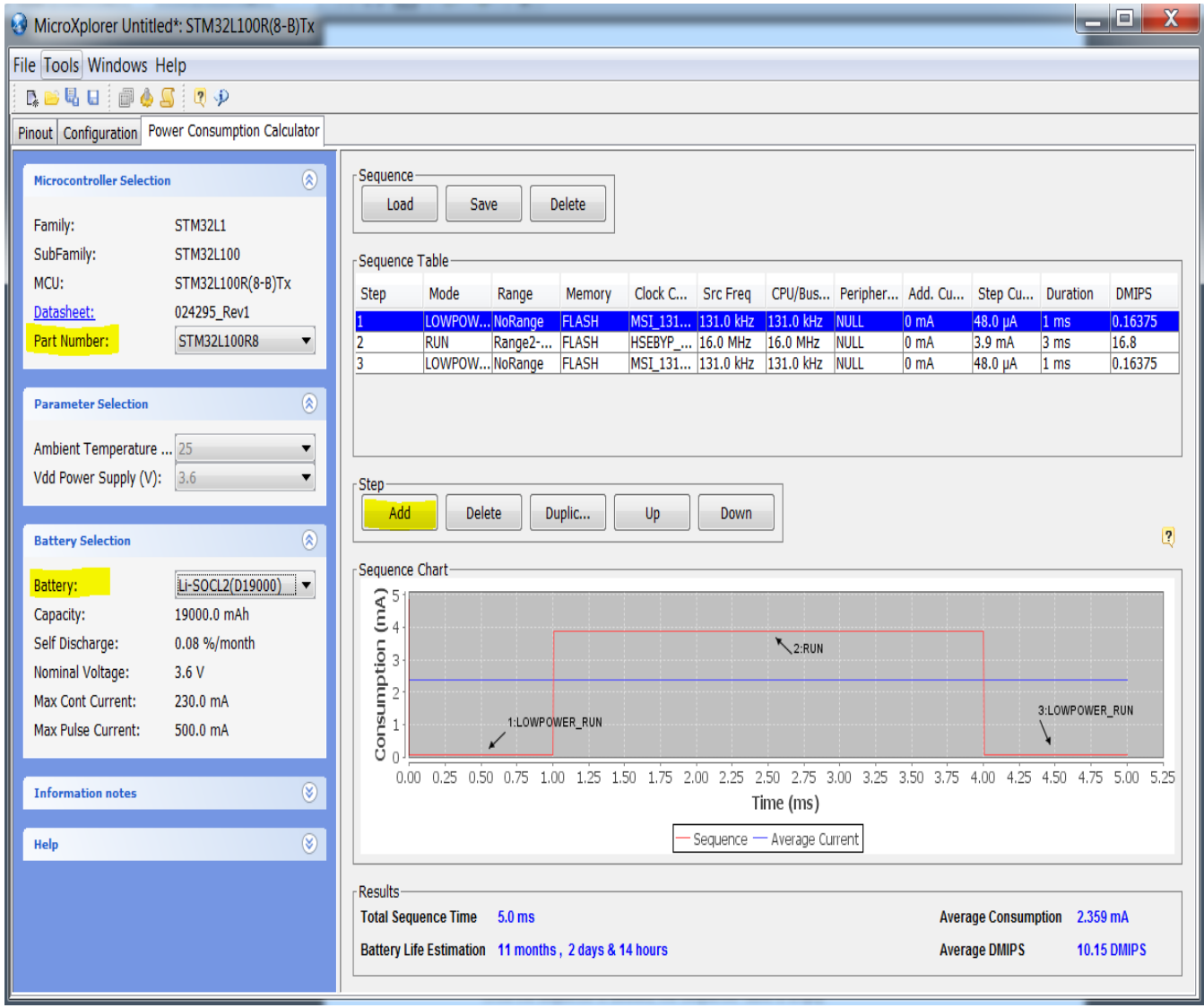
This function trying to configure not existing pin PA17

If parameter is not in valid range program jump into assert_failed function

```
void assert_failed(uint8_t* file, uint32_t line)
{
  /* USER CODE BEGIN 6 */
  /* User can add his own implementation to report the file name and line number,
    ex: printf("Wrong parameters value: file %s on line %d\r\n", file, line) */
  /* USER CODE END 6 */
}
```

STM32CubeMX: Power consumption calculator

- Power step definitions
- Battery selection
- Creation of consumption graph
- Display of
  - Average consumption
  - Average DMIPS
  - Battery lifetime



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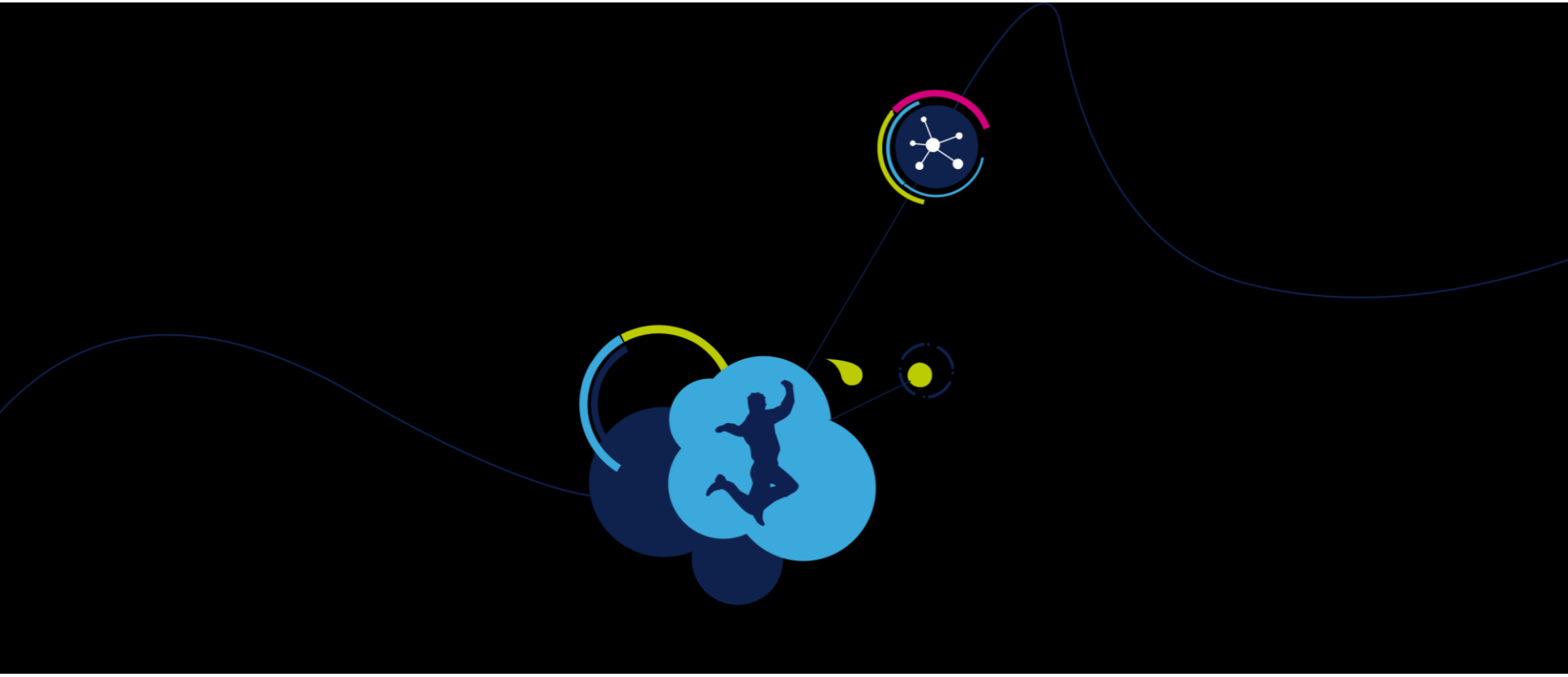
STM32CubeMX Documentation

Document	Description
UM1718: *STM32CubeMX for STM32 configuration and initialization C code generation*	Description how use CubeMX tool
RN0094: *STM32CubeMX release 4.8.0*	Changes made in new versions



GPIO Test Lab

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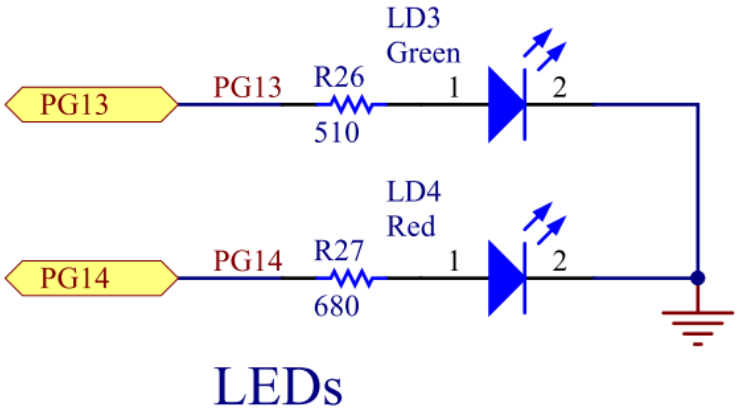
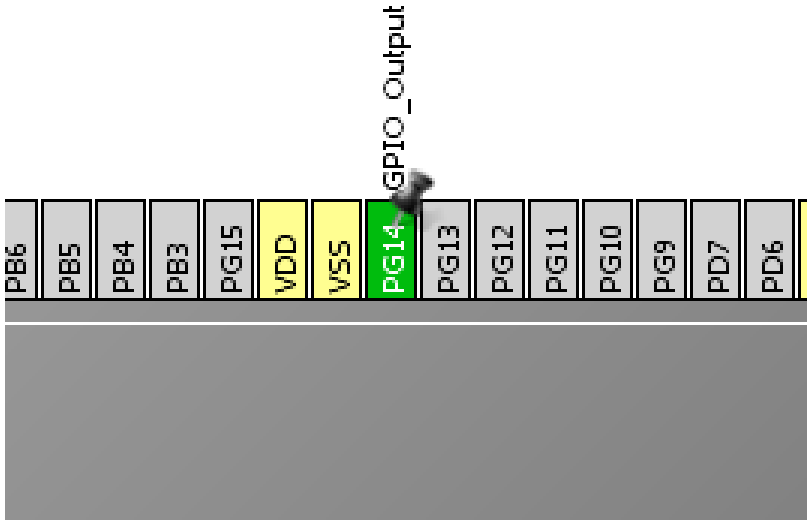
Configure GPIO for LED toggling

- Objective
  - Learn how to setup pin and GPIO port in CubeMX
  - How to Generate Code in CubeMX and use HAL functions
- Goal
  - Configure GPIO pin in CubeMX and Generate Code
  - Add in to project HAL_Delay function and HAL_GPIO_Toggle function
  - Verify the correct functionality on toggling LED

Configure GPIO for LED toggling

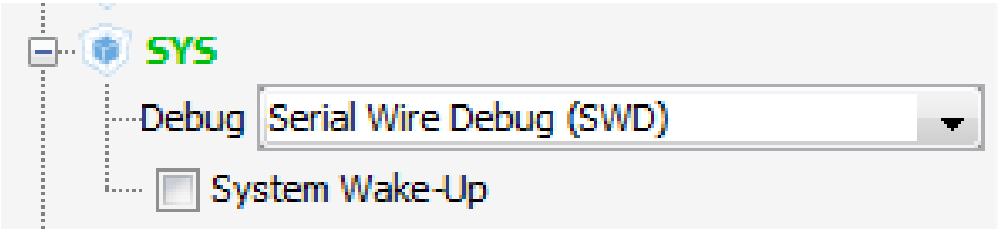
- Create project in CubeMX
  - Menu > File > New Project
  - Select STM32F4 > STM32F429/439 > LQFP144 > STM32F439ZITx
- Configure LED pin as GPIO_Output

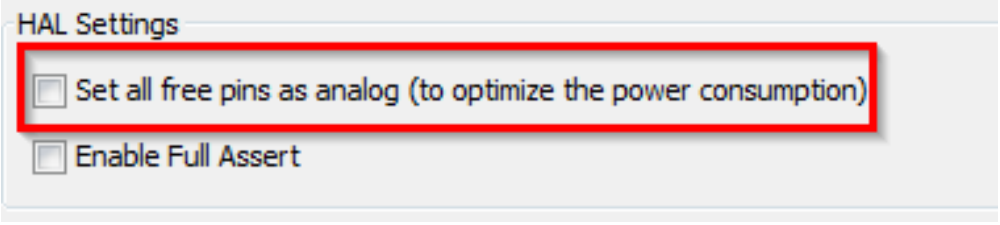


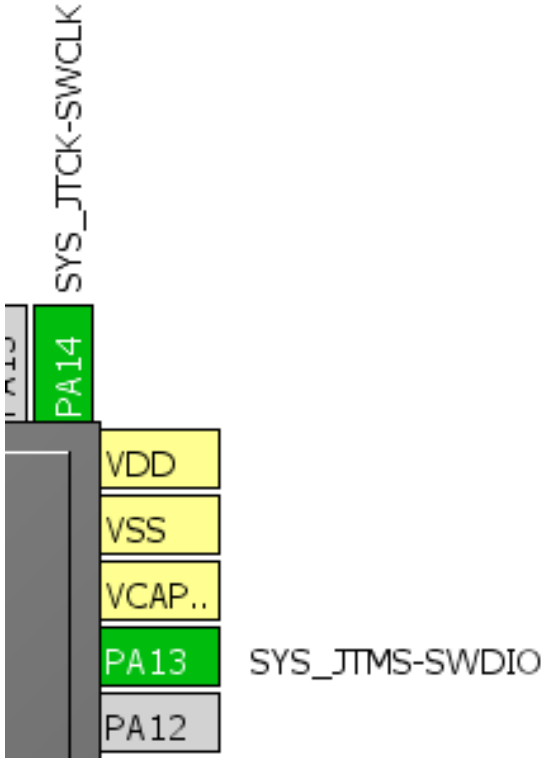


Configure GPIO for LED toggling

- For debug purpose is recommended to select debug pins SWD or JTAG
  - Select can be done in TAB>Pinout>SYS
  - On discovery is available only SWD option
  - If **SWD/JTAG is not selected** and the **Set all free pins as analog** (MENU>Project>Settings>TAB>Code Generator) is selected**, debug is not possible**

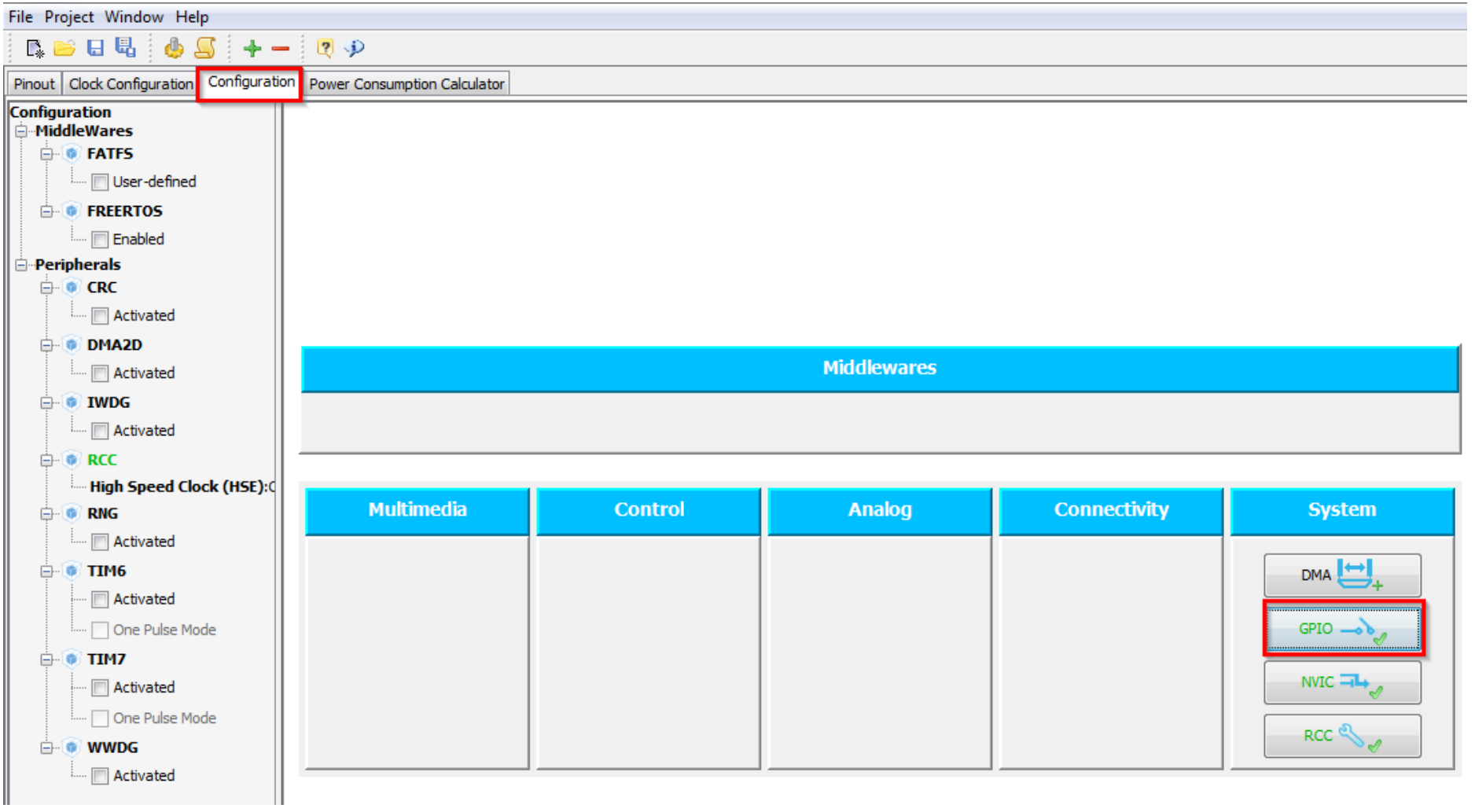






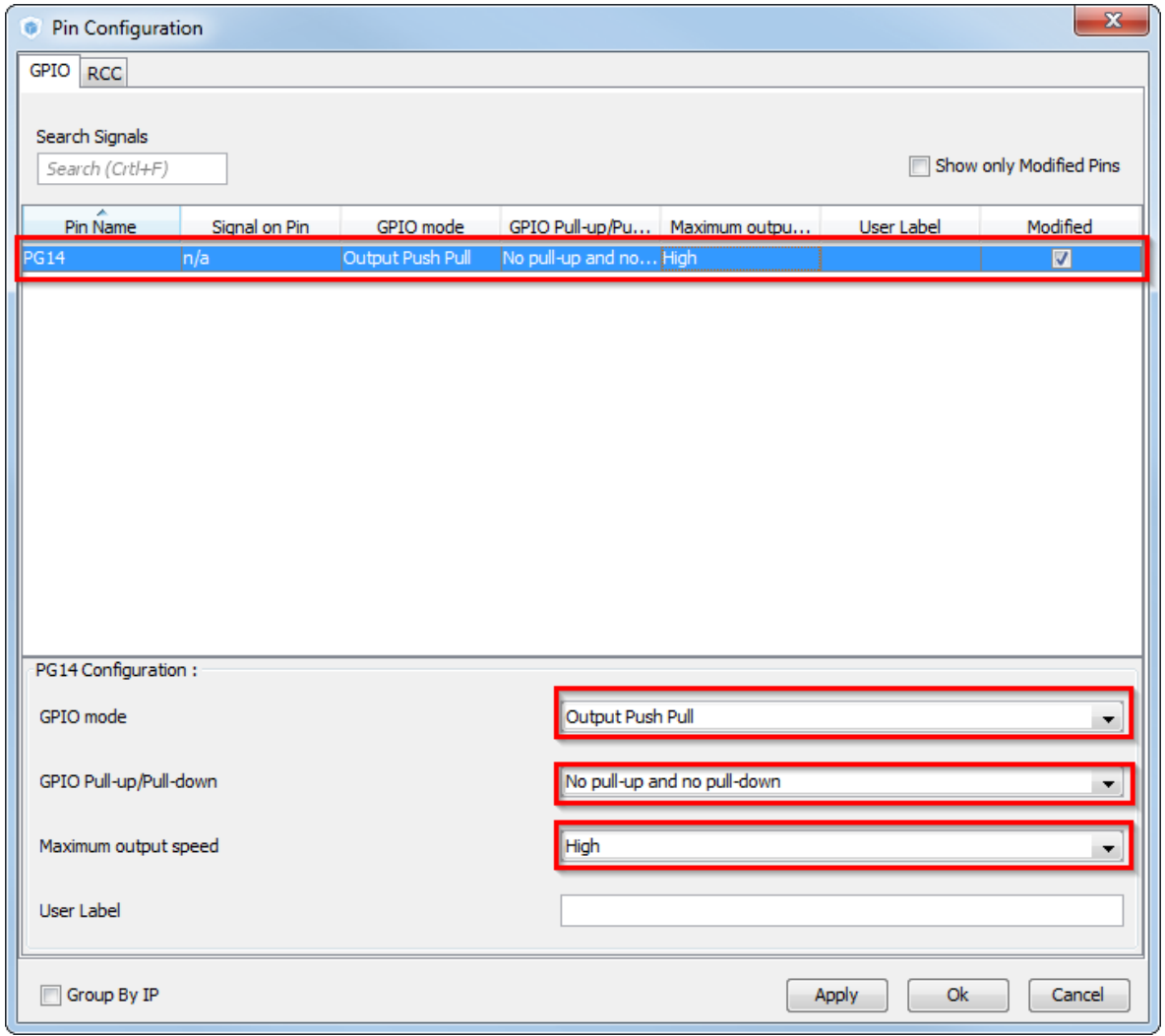
Configure GPIO for LED toggling

- GPIO Configuration
  - TAB>Configuration>System>GPIO



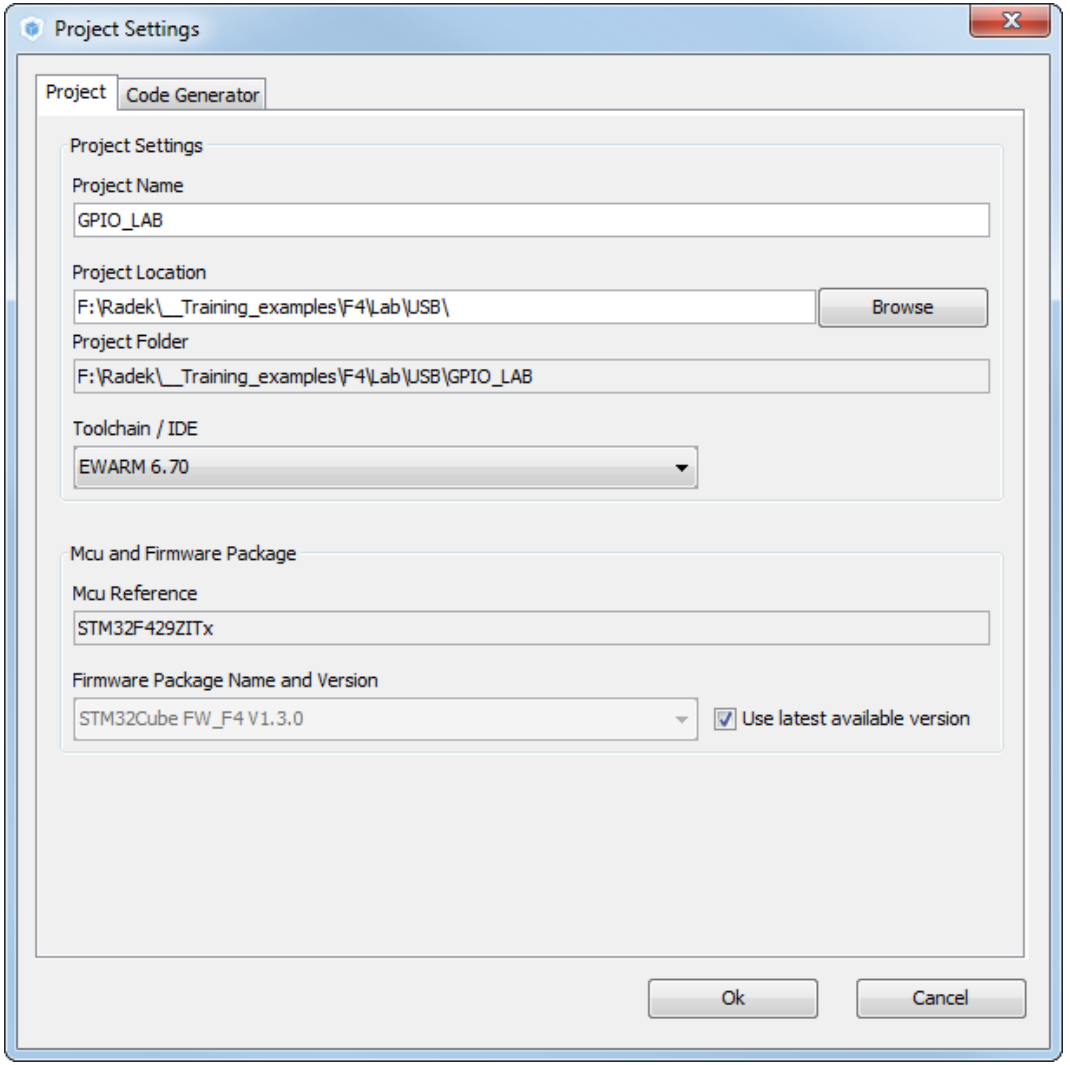
Configure GPIO for LED toggling

- GPIO(Pin) Configuration
  - Select Push Pull mode
  - No pull-up and pull-down
  - Output speed to HIGH
    Is important for faster peripheries like SPI, USART
  - Button OK



Configure GPIO for LED toggling

- Now we set the project details for generation
  - Menu > Project > Project Settings
  - Set the project name
  - Project location
  - Type of toolchain
- Now we can Generate Code
  - Menu > Project > Generate Code

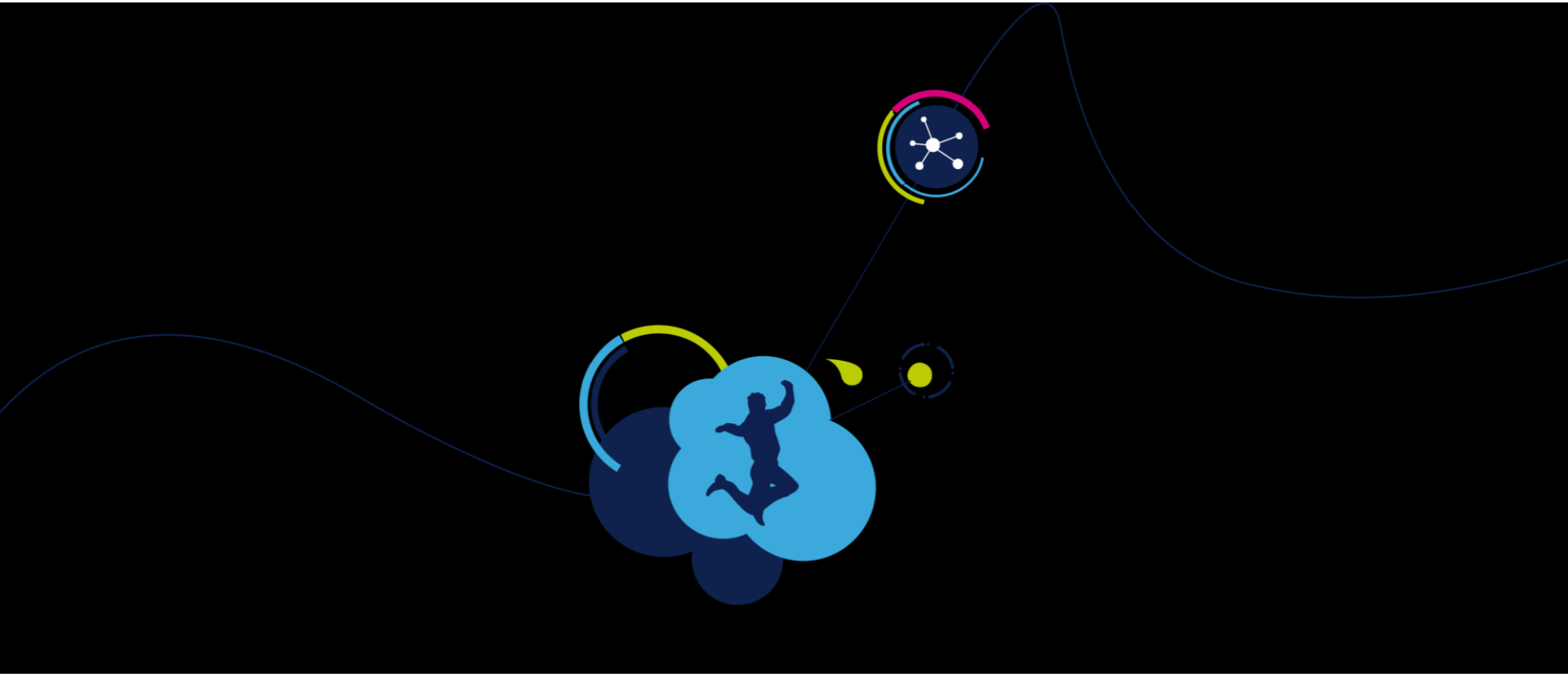


Configure GPIO for LED toggling

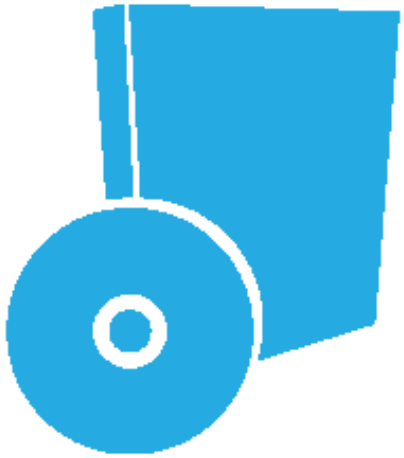
- Now we open the project in our IDE
  - The functions we want to put into main.c
  - Between */* USER CODE BEGIN 3 */* and */* USER CODE END 3 */* tags
  - Into infinite loop *while(1){ }*
- For toggling we need to use this functions like this:

```
/* USER CODE BEGIN 3 */
 /* Infinite loop */
 while (1)
 {
   HAL_GPIO_TogglePin(GPIOG, GPIO_PIN_14);
   HAL_Delay(500);
 }
 /* USER CODE END 3 */
```

- Now compile the code
- Download it intro STM32 and RUN



STM32Cube HAL package



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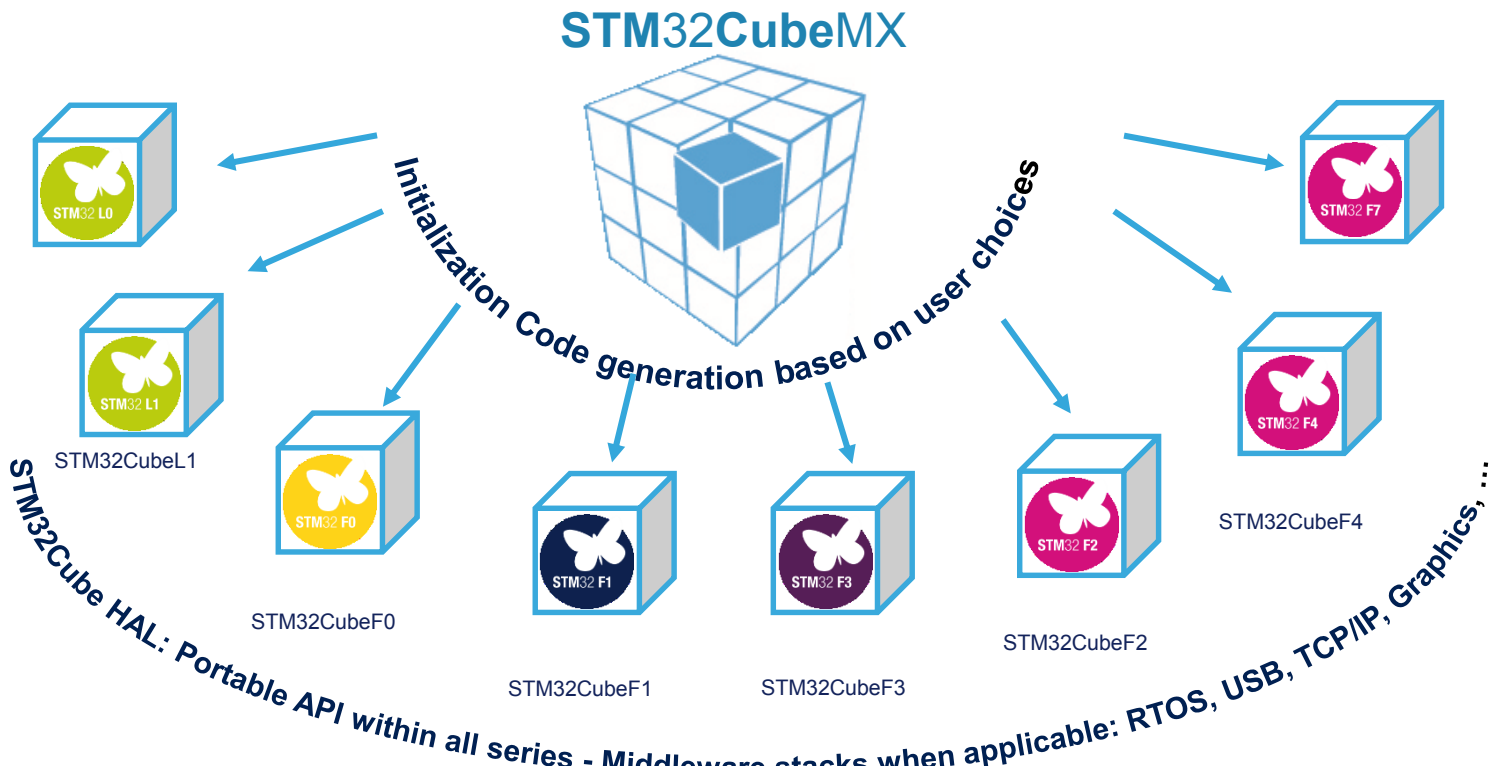
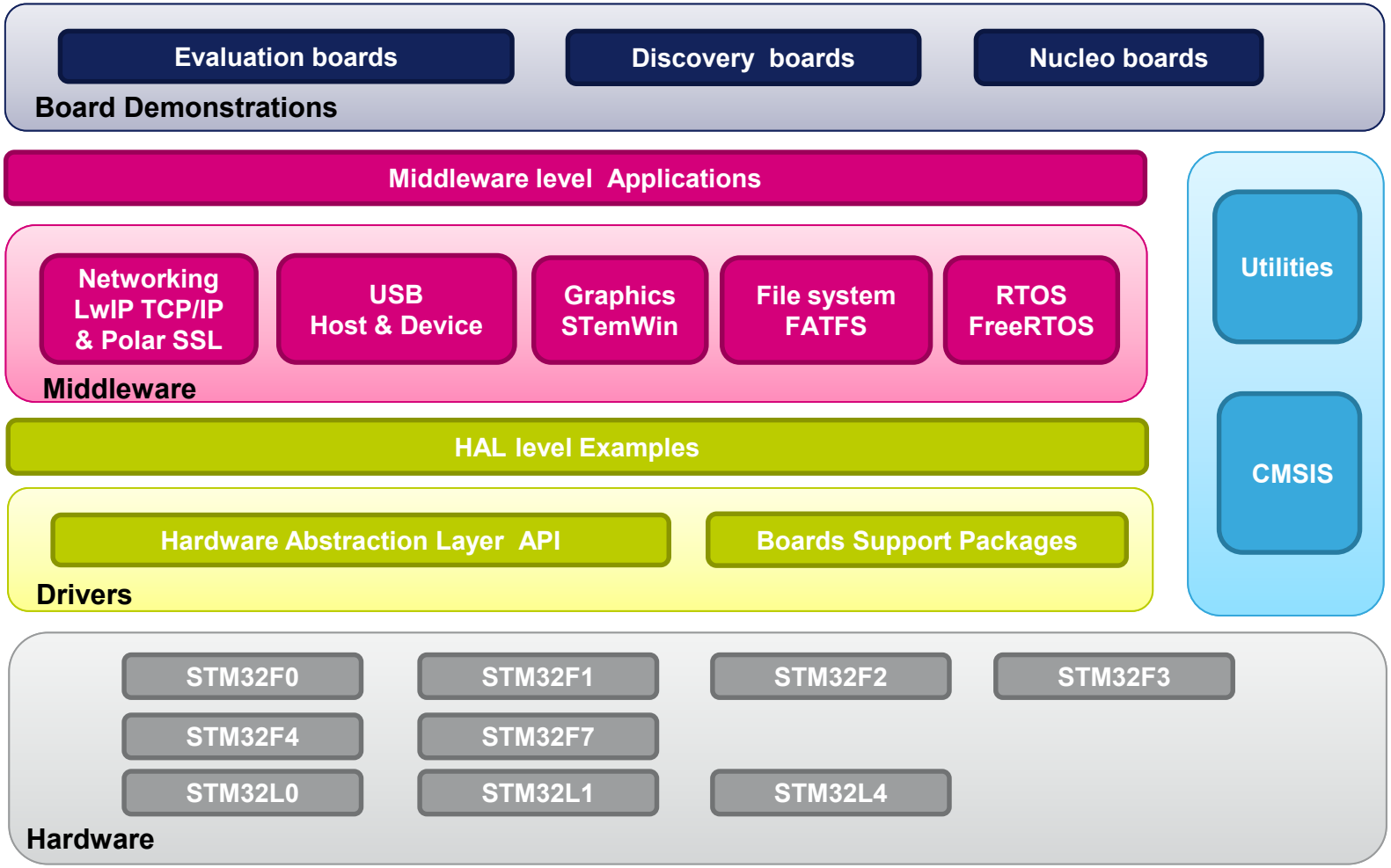
STM32Cube™ V1 Introduction

- STM32Cube™ Version 1:
  - A configuration tool, STM32CubeMX generating initialization code from user choices
  - A full embedded software offer, delivered per series (like STM32CubeF4) with:
    - An STM32 Abstraction Layer embedded software: STM32Cube HAL
    - A consistent set of Middlewares: RTOS, USB, TCP/IP, Graphics, …
  - Available at st.com as free solution



STM32Cube HAL



STM32Cube HAL Documentation

Document	Description
UM1725: *Description of STM32F4xx HAL drivers*	Important document with list of HAL functions and description
UM1730: *Getting started with STM32CubeF4 firmware package for STM32F4 Series*	Simple description of HAL package

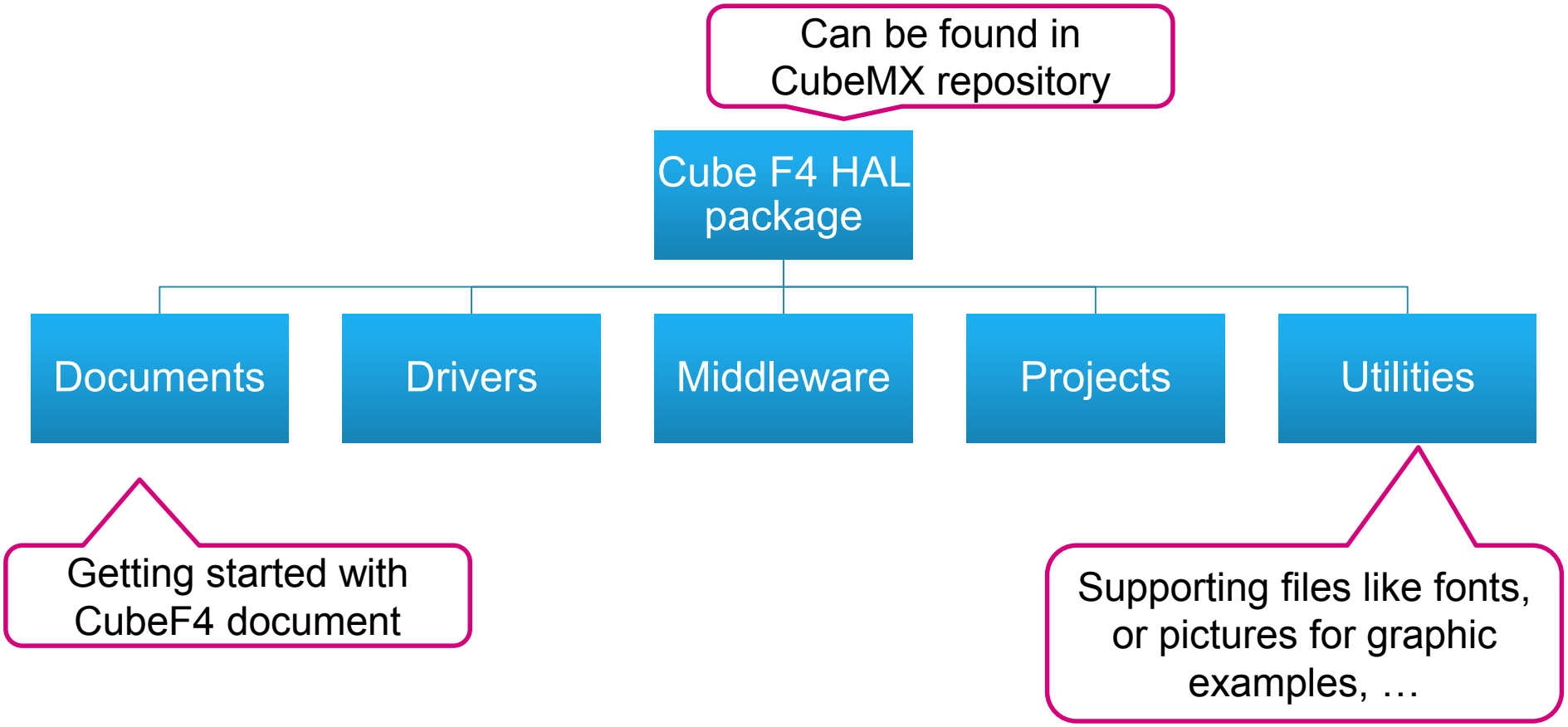
STM32Cube HAL Middleware doc

Document	Description
UM1713: *Developing applications on STM32Cube with LwIP TCP/IP stack*	Use LwIP stack with STM32Cube
UM1721: *Developing Applications on STM32Cube with FatFs*	Possibility of file system
UM1722: *Developing Applications on STM32Cube with RTOS*	How to work together with Cube and RTOS
UM1734: *STM32Cube USB device library*	USB device library possibility explanation
UM1720: *STM32Cube USB host library*	USB host library possibility explanation

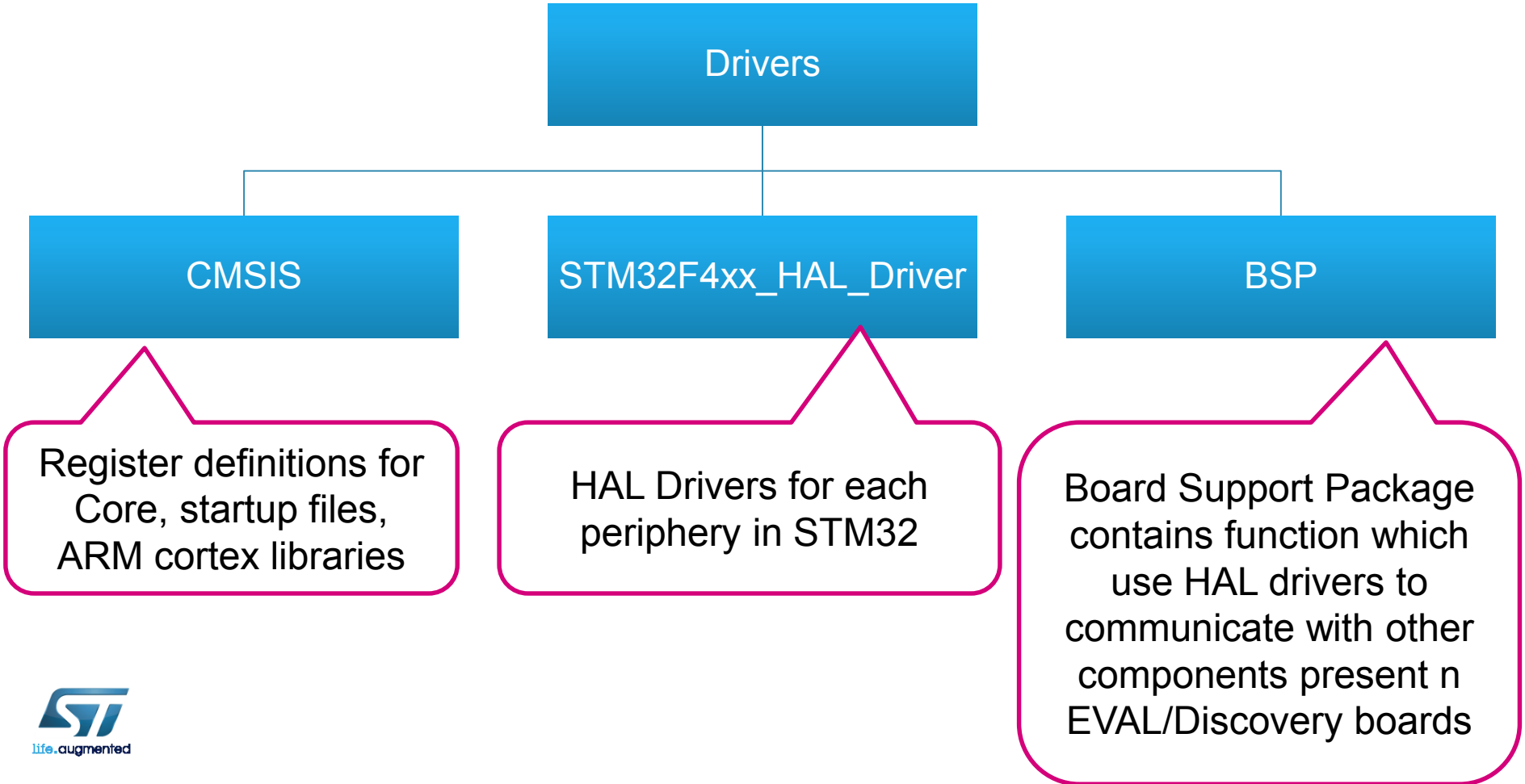
STM32Cube HAL Example doc

Document	Description
UM1709: *STM32Cube Ethernet IAP example*	Description of IAP example
UM1743: *STM32CubeF4 demonstration platform*	Explanation of demonstration examples
UM1723: *STM32Cube PolarSSL example*	Explanation of PolarSSL example

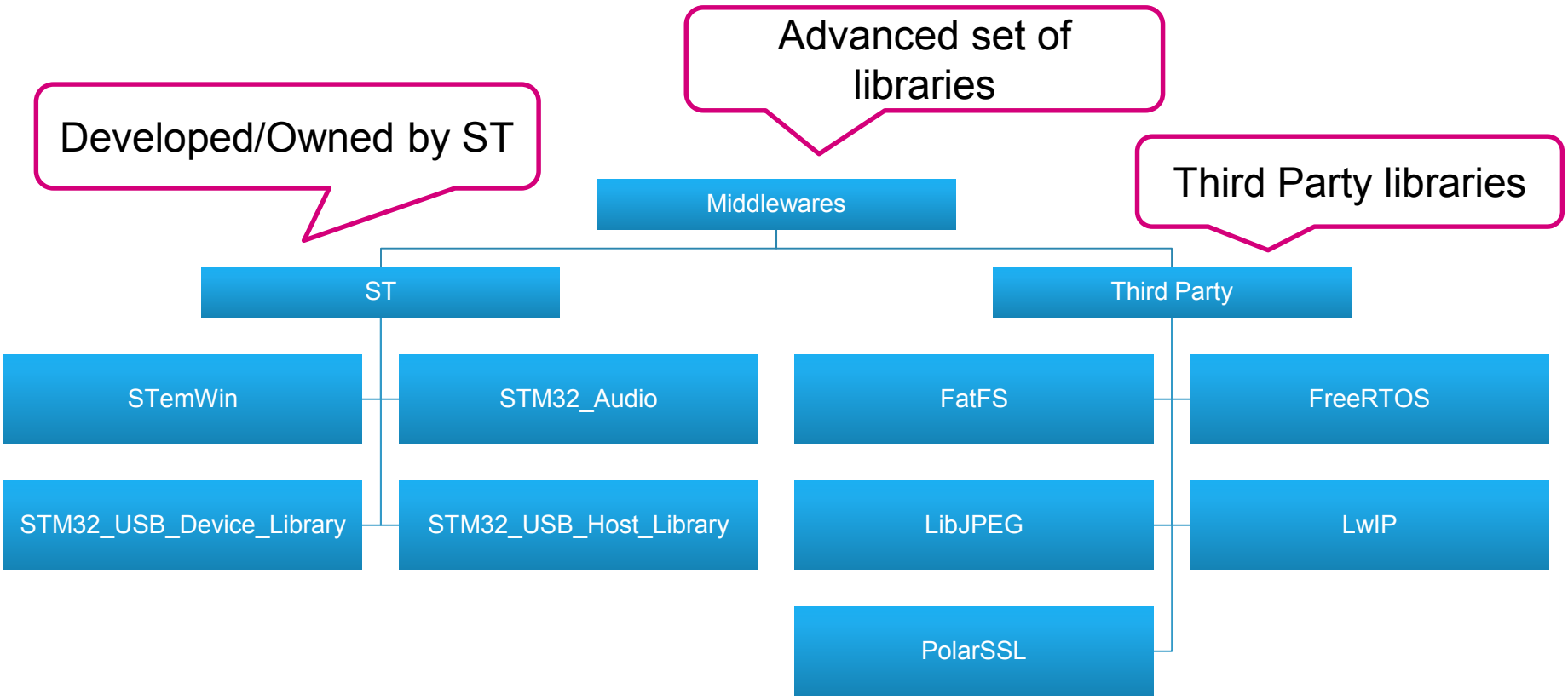
STM32Cube FW Package Organization



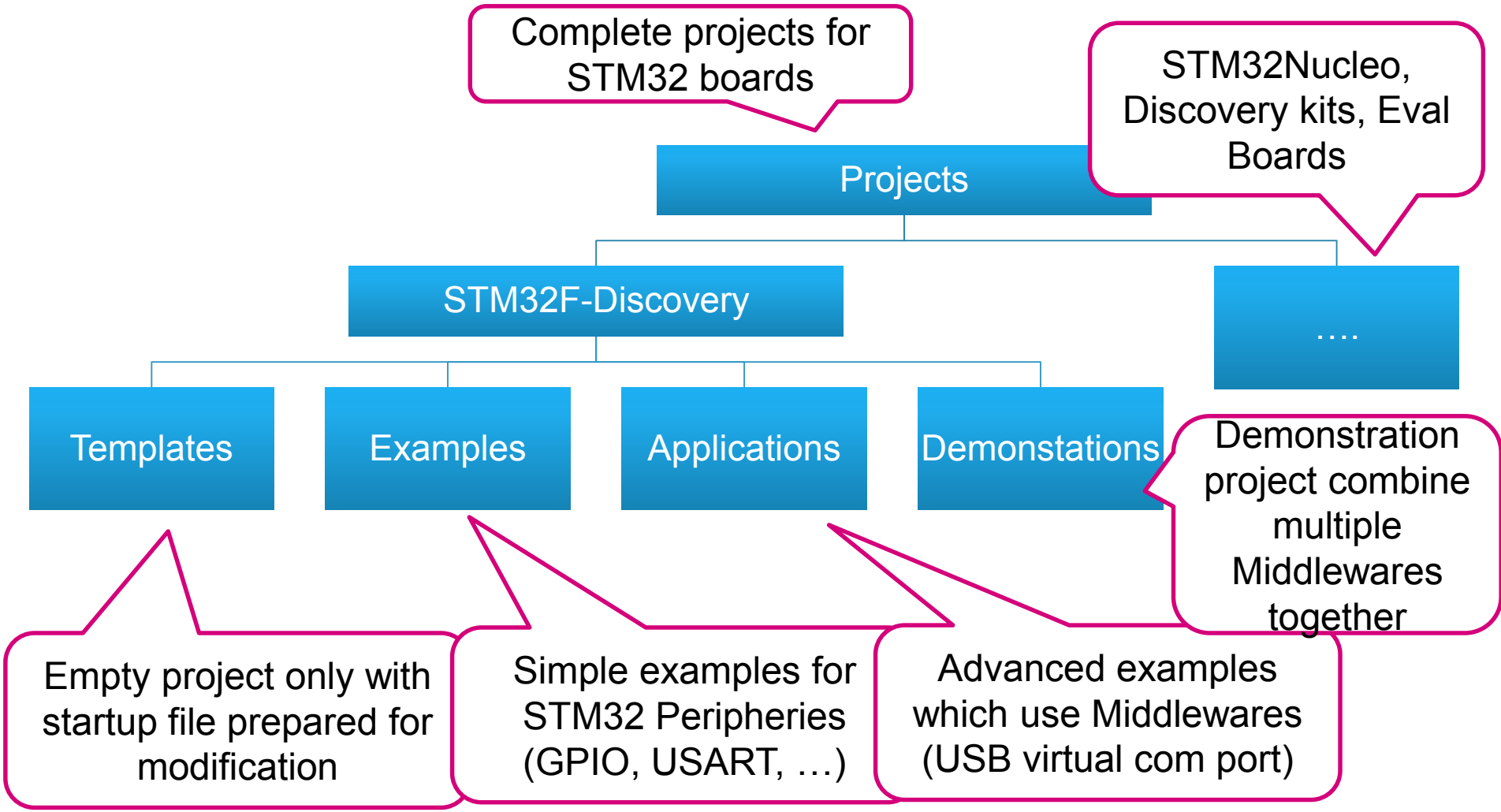
STM32Cube FW Package Drivers

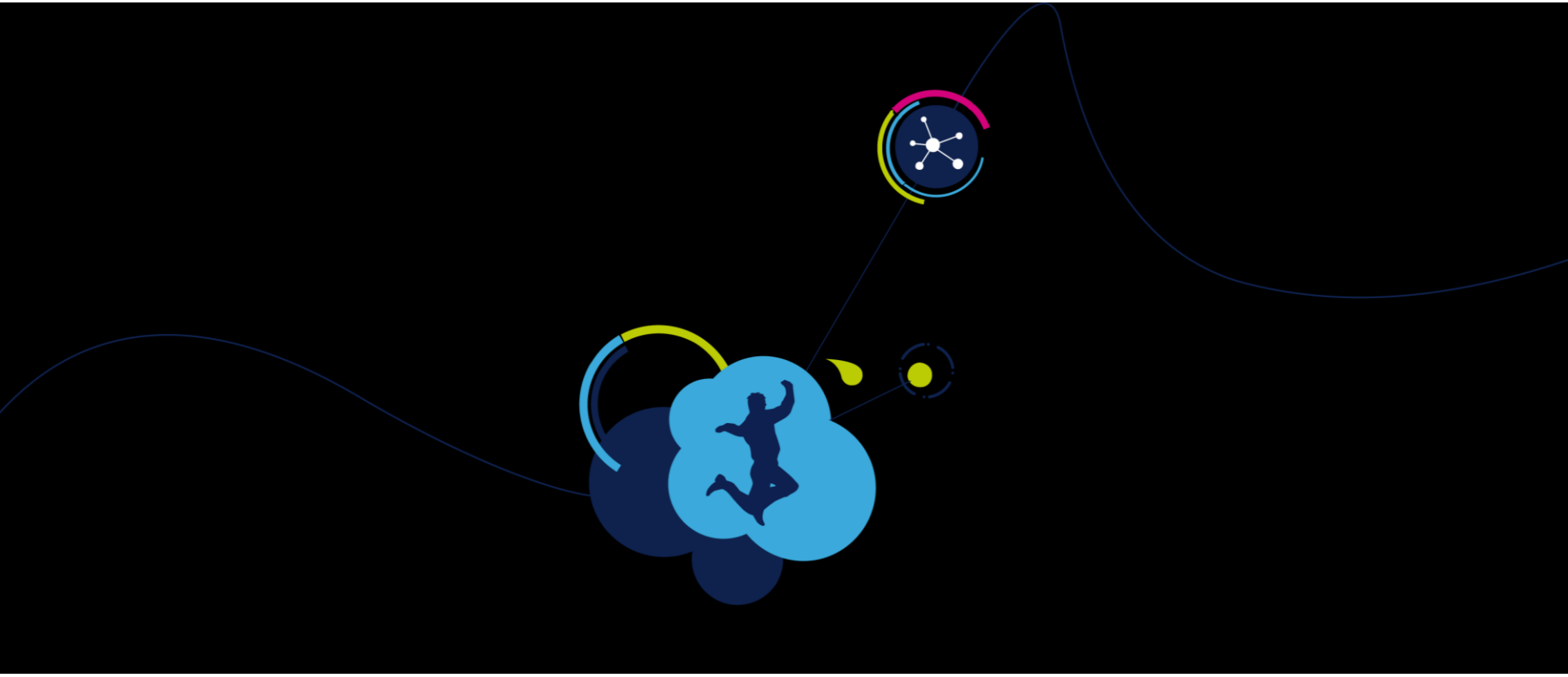


STM32Cube FW Package Middlewares



STM32Cube FW Package Projects





STM32Cube Hardware Abstraction Layer (HAL)

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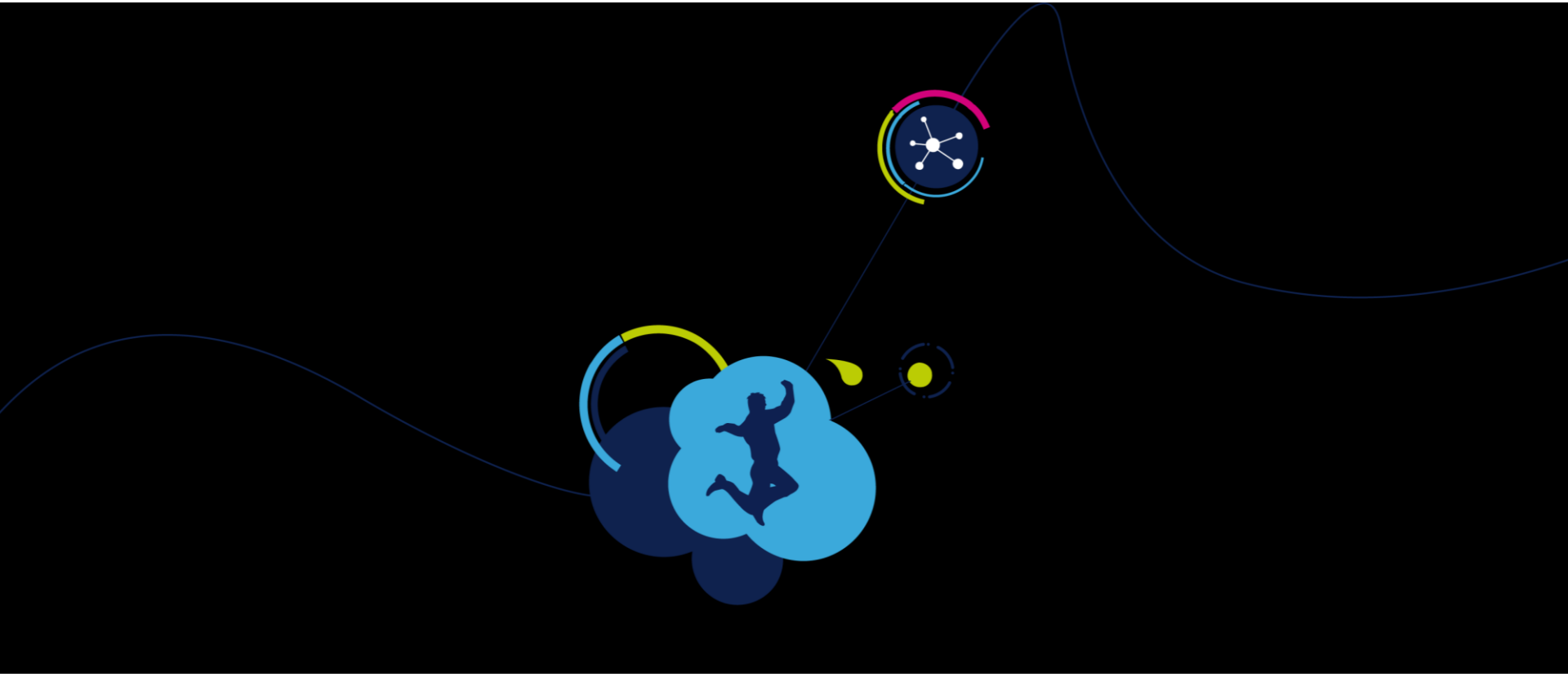

HAL general concepts

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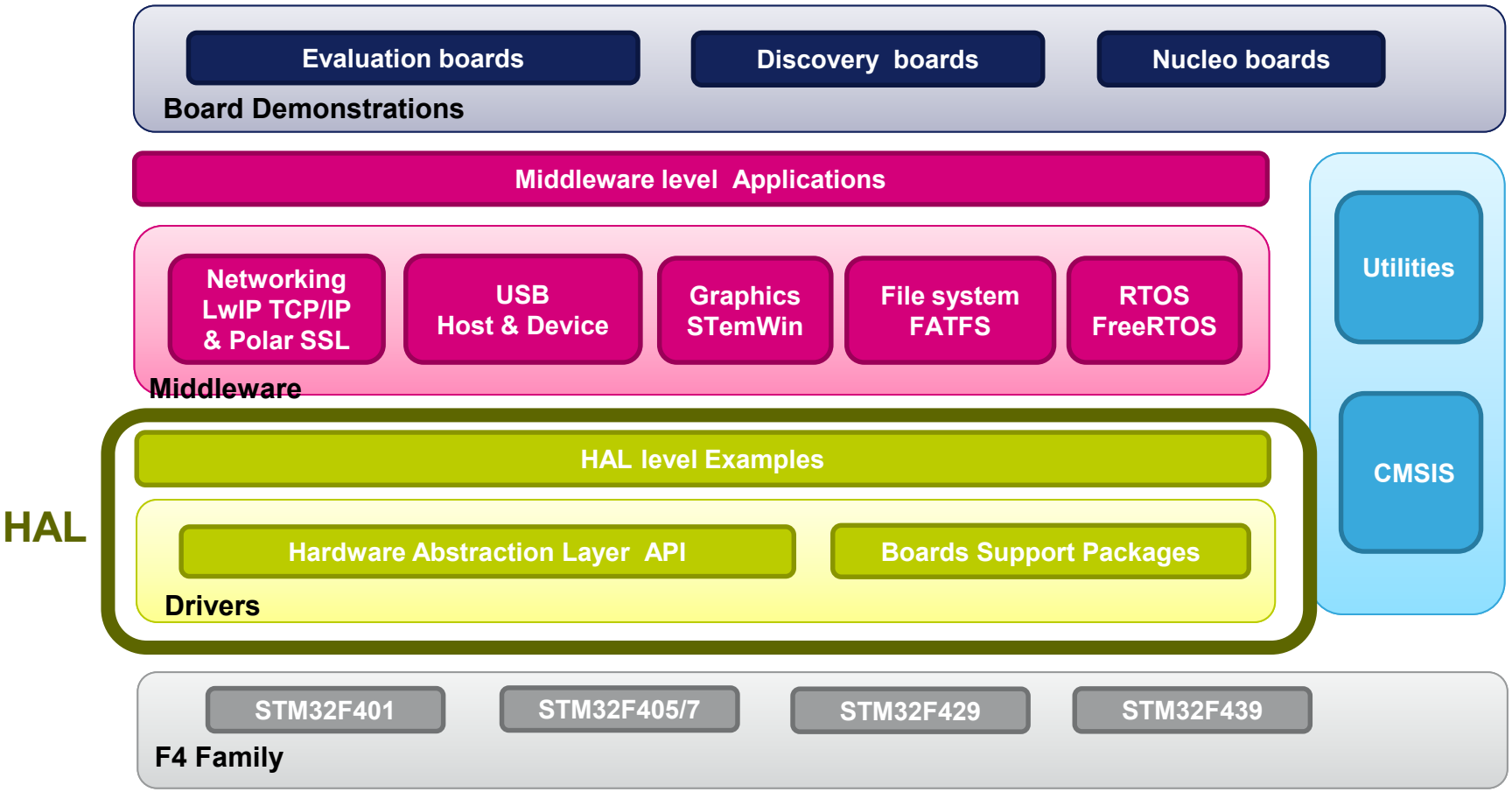
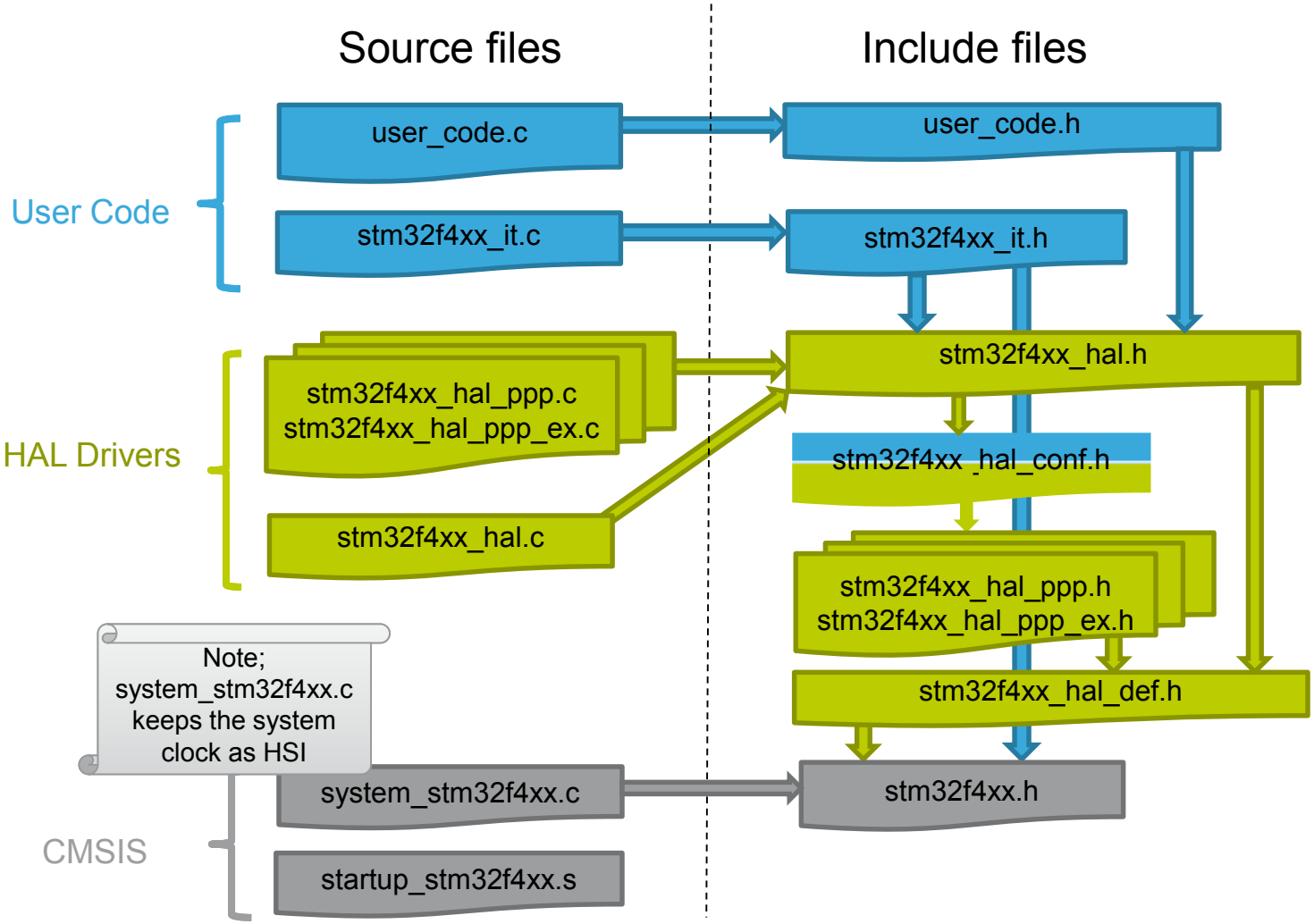
HAL general concepts
The HAL in STM32Cube FW package



HAL general concepts
Introduction to HAL

- The STM32Cube Hardware abstraction layer (HAL) is the replacement for the standard peripheral library
- The main objectives of the HAL is to offer
  - **User friendly APIs** that **hide the HW complexity** and focus on the **functionality**
  - **Portable APIs** that allowing **easy migration** of user application across different product families
- All HAL drivers follow a strict C coding rules and were tested using CodeSonar C code static analysis tool from GrammaTech
- HAL documentation is provided as a PDF manual based on Doxygen extracts

HAL general concepts
HAL based project organization



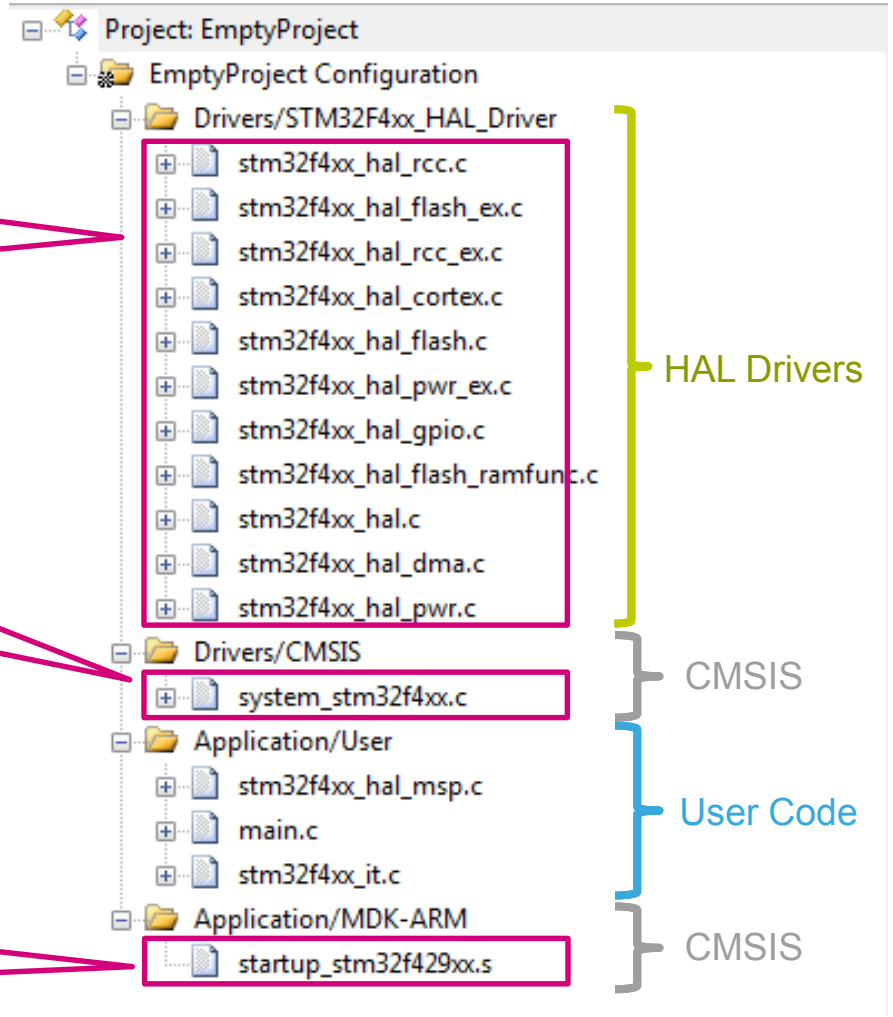
HAL general concepts
Introduction to HAL

- Structure of project generated with CubeMX with HAL

CubeMX copy used HAL drivers from repository

Use standard system_stm32f4xx.c from CMSIS

Default startup file for selected microcontroller



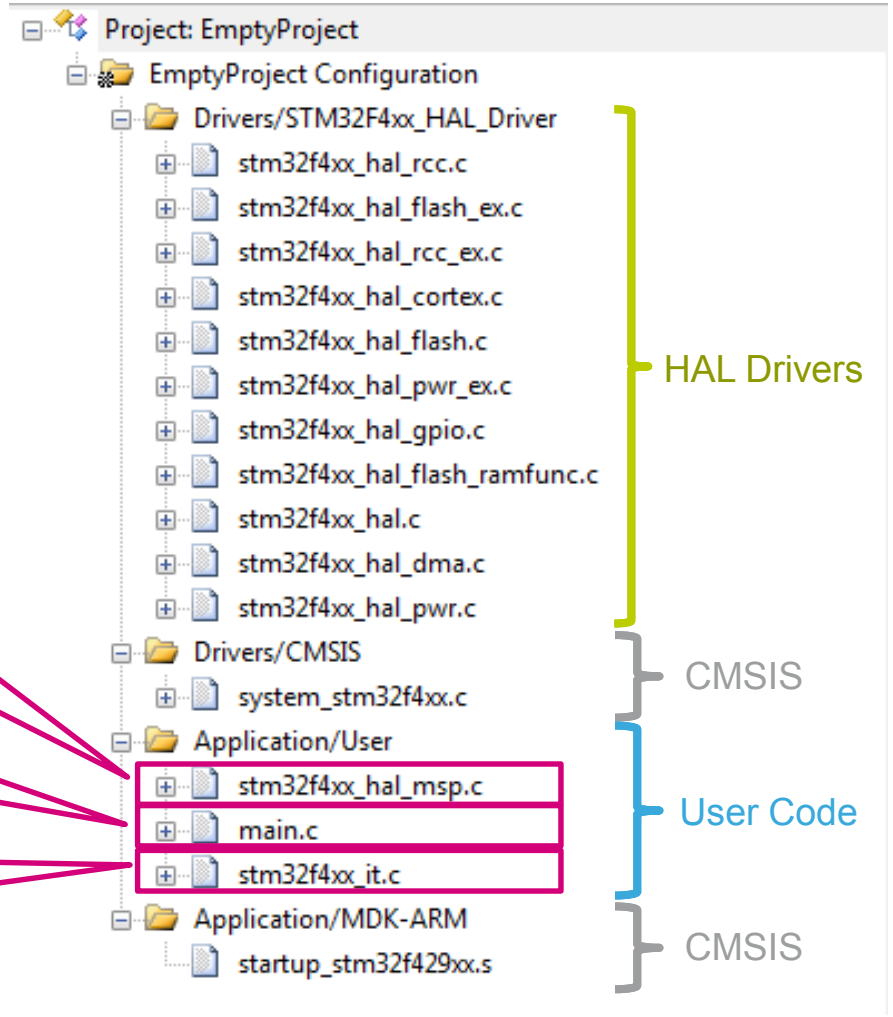
HAL general concepts
Introduction to HAL

- Structure of project generated with CubeMX with HAL

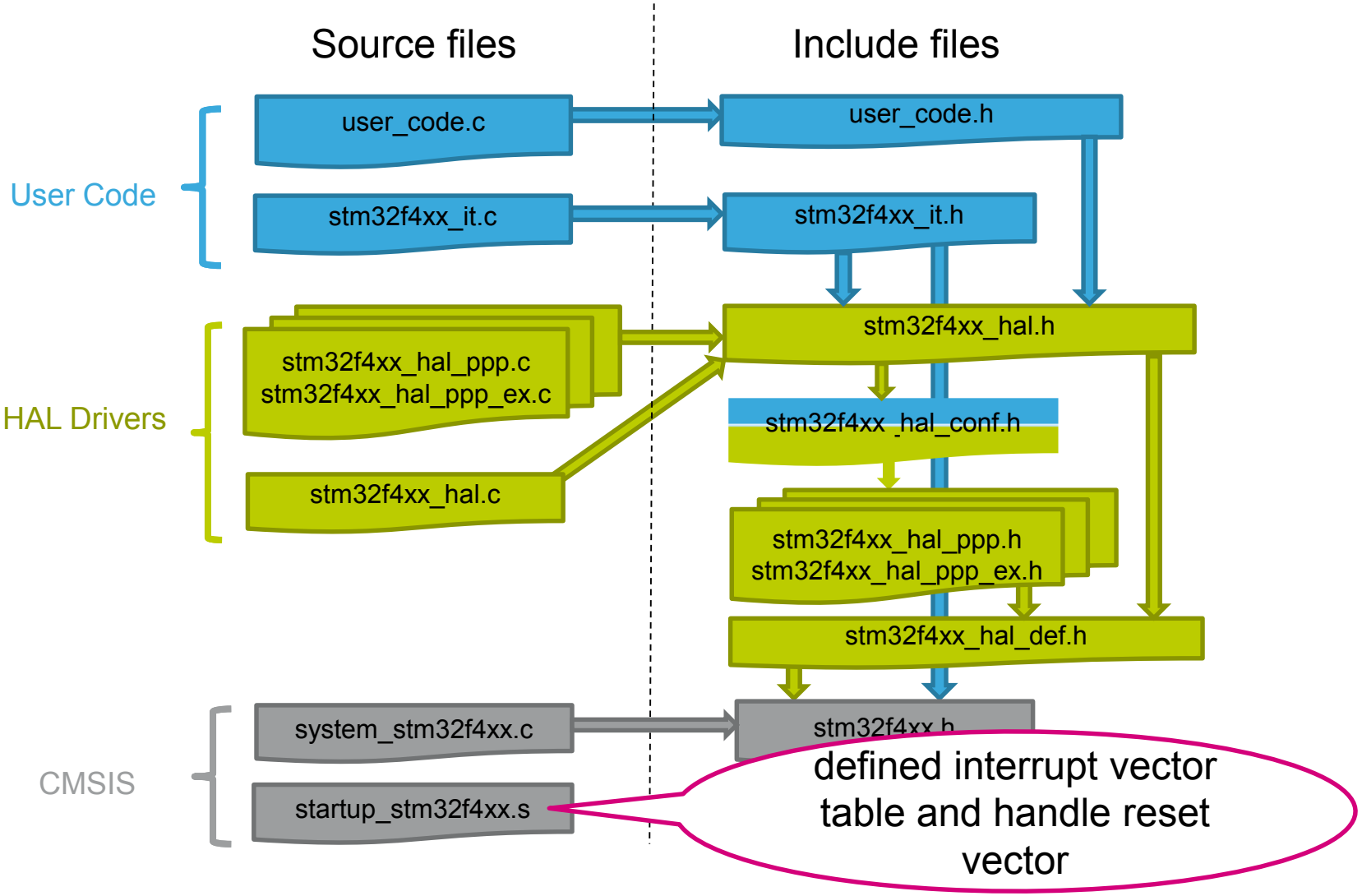
Stm32f4xx_hal_msp.c contains initialization of service peripherals (RCC, GPIO, DMA, …)

Main function have default initialization of all peripherals selected in CubeMX

Prepare stm32f4xx_it.c and define interrupts used in CubeMX



HAL general concepts
HAL based project organization



HAL general concepts
HAL based project organization


```
; Vector Table Mapped to Address 0 at Reset
                AREA    RESET, DATA, READONLY
                EXPORT  __Vectors
                EXPORT  __Vectors_End
                EXPORT  __Vectors_Size

__Vectors       DCD     __initial_sp              ; Top of Stack
                DCD     Reset_Handler             ; Reset Handler
                DCD     NMI_Handler               ; NMI Handler
                DCD     HardFault_Handler         ; Hard Fault Handler
                DCD     MemManage_Handler         ; MPU Fault Handler
                DCD     BusFault_Handler          ; Bus Fault Handler
                DCD     UsageFault_Handler        ; Usage Fault Handler
                DCD     0                         ; Reserved
                DCD     0                         ; Reserved
                DCD     0                         ; Reserved
                DCD     0                         ; Reserved
                DCD     SVC_Handler               ; SVCall Handler
                DCD     DebugMon_Handler          ; Debug Monitor Handler
                DCD     0                         ; Reserved
                DCD     PendSV_Handler            ; PendSV Handler
                DCD     SysTick_Handler           ; SysTick Handler

                ; External Interrupts
                DCD     WWDG_IRQHandler           ; Window WatchDog
                DCD     PVD_IRQHandler            ; PVD through EXTI Line detection
                DCD     TAMP_STAMP_IRQHandler     ; Tamper and TimeStamps through the EXTI line
```

Interrupt vector table definition

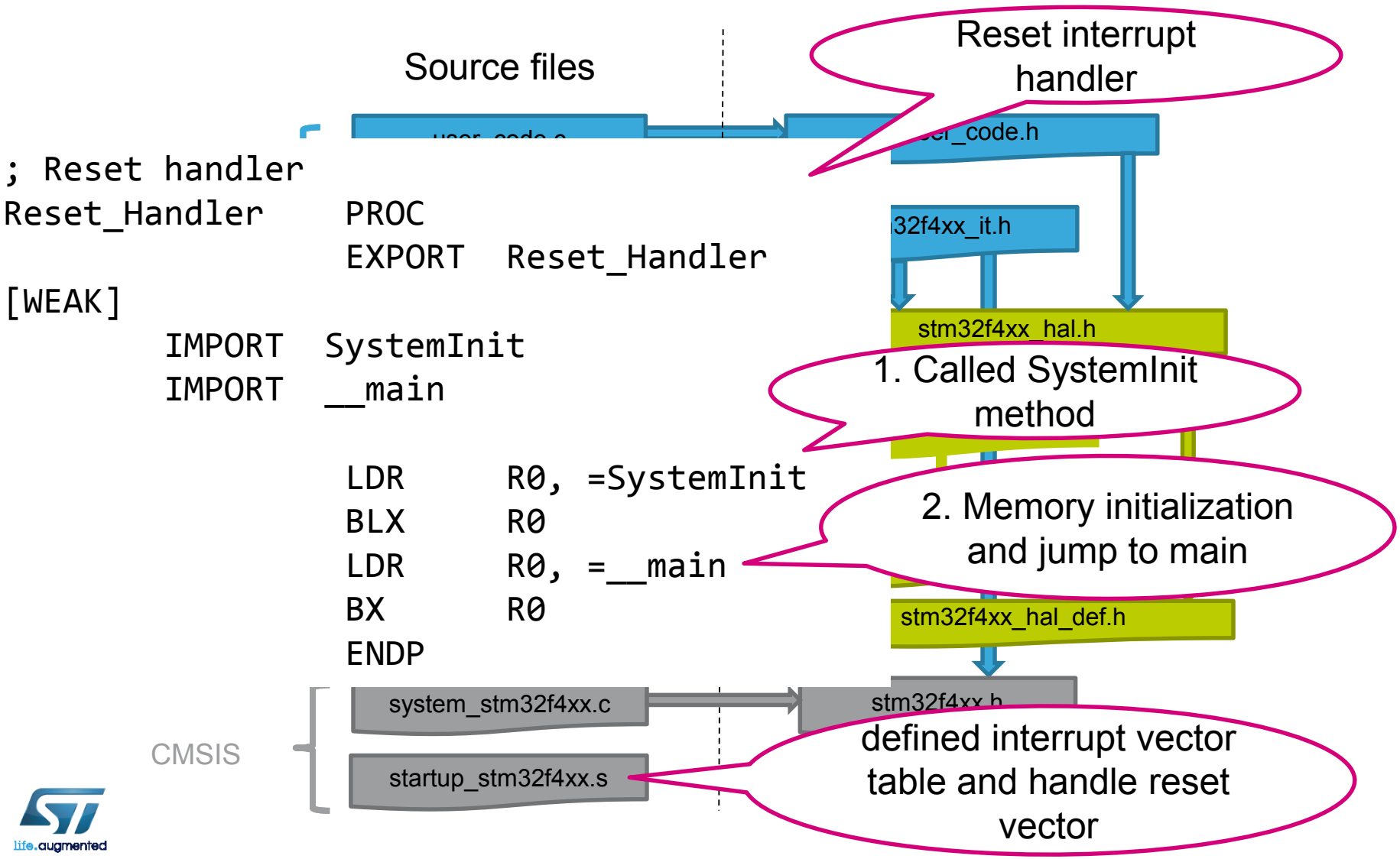
Name of interrupts method which can be used in user program __weak by default

CMSIS

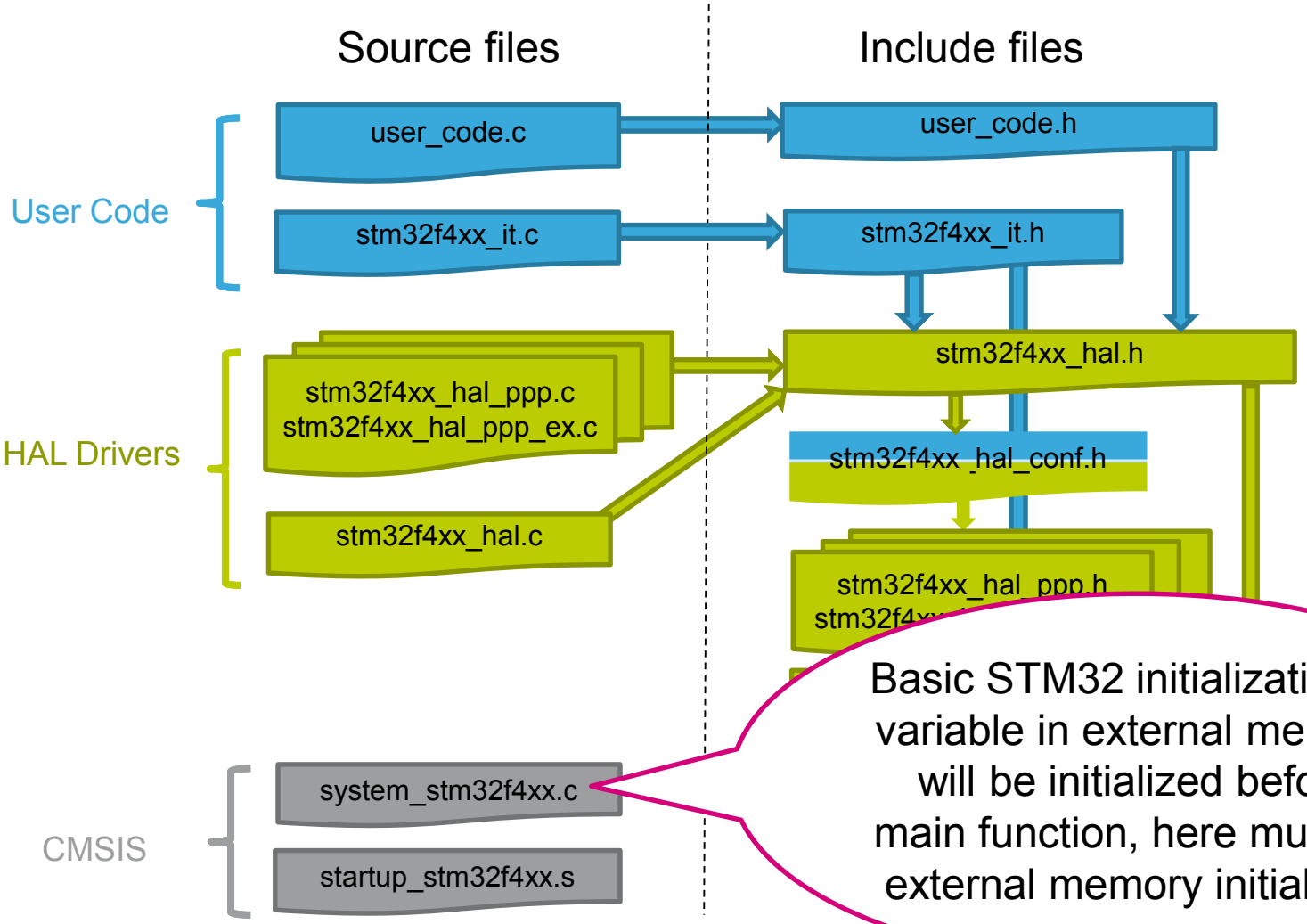
startup_stm32f4xx.s

defined interrupt vector table and handle reset vector

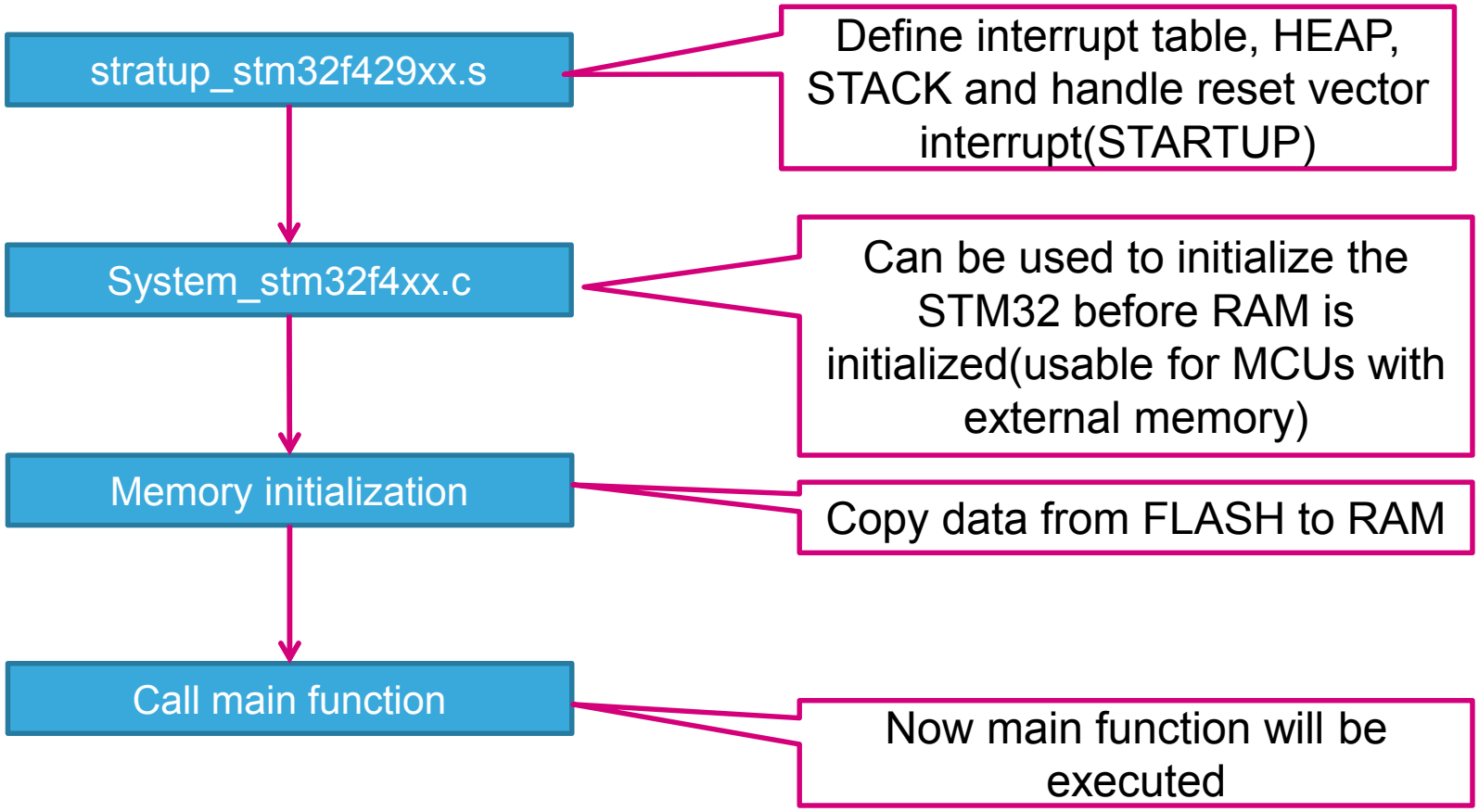
HAL general concepts
HAL based project organization



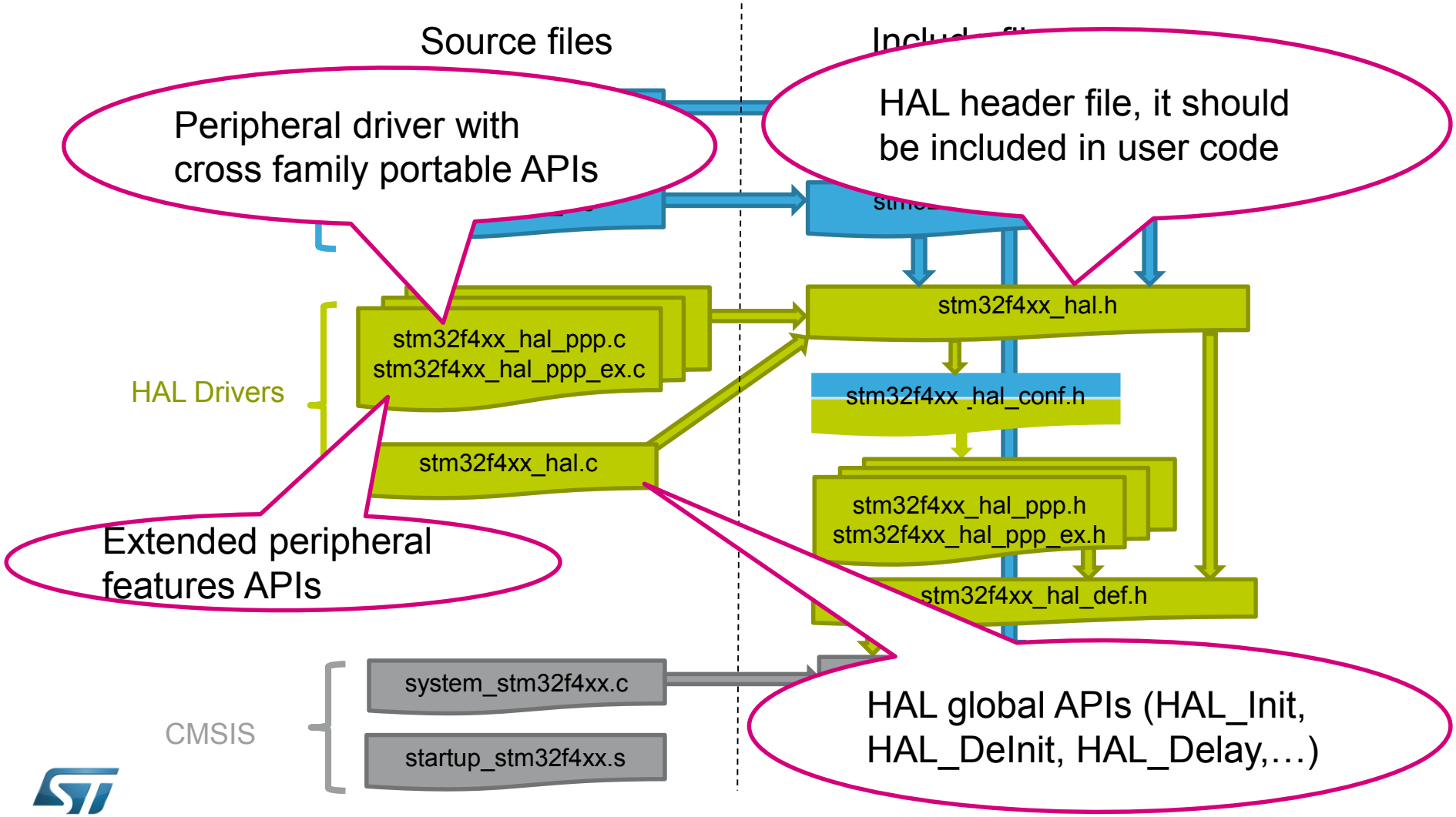
HAL general concepts
HAL based project organization



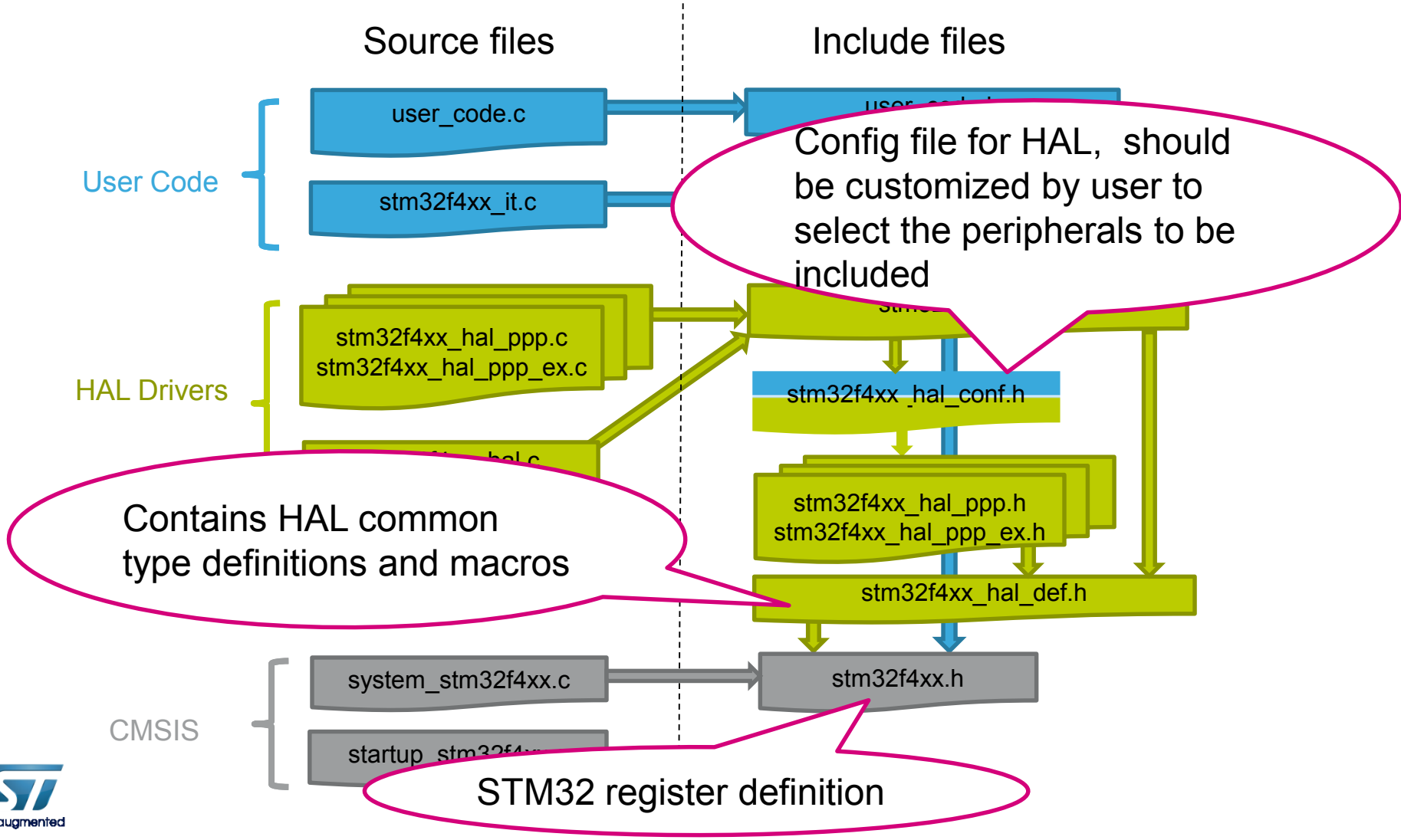
HAL general concepts
STM32 startup



HAL general concepts
HAL based project organization

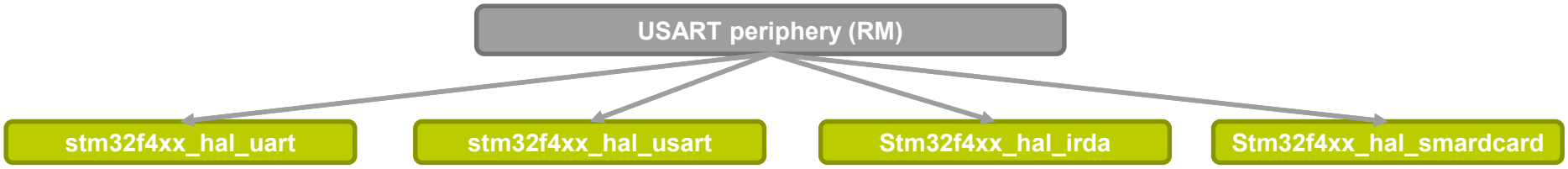


HAL general concepts
HAL based project organization



HAL general concepts
HAL drivers Vs. Refman peripherals

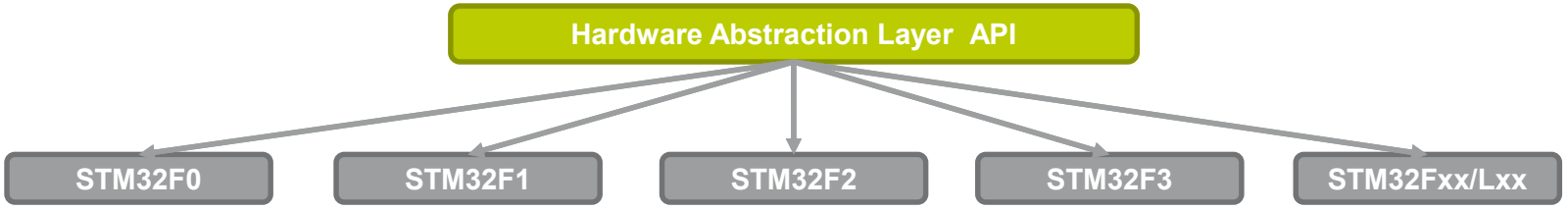
- In order to offer easy to use APIs, each HAL driver **handles a unique usage** of the peripheral
  - For example in F4x reference manual you have SPI peripheral which can be used as SPI or I2S. In this case the two **HAL module drivers** are defined:
    - stm32f4xx_hal_spi.c and stm32f4xx_i2s.c
  - In F4x family, this is also the case for
    - USART which can be: USART, UART, IRDA or Smartcard
    - FMC which can be: NOR, NAND, SRAM ,SDRAM or PCCARD
    - SDIO which can be: SD or SDMMC
- The system peripherals SYSCFG and EXTI do not have dedicated HAL drivers, they are intrinsically managed in the HAL



HAL general concepts
Compatibility Across STM32 Series

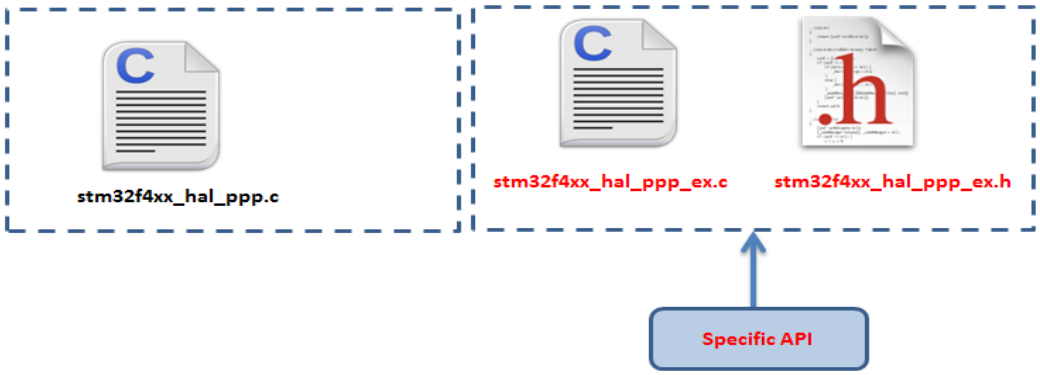
- The HAL offers Portable APIs across all the STM32 Series for what concerns the functional operations and routines of a given peripheral.

- However, considering the IPs specificities and implementation differences from one STM32 Serie to the other, the only discrepancies that may be found would be in the peripheral initialization (i.e. PPP_InitTypeDef) and in the RCC configuration (i.e. RCC_OscInitTypeDef and RCC_ClkInitTypeDef)



HAL general concepts
HAL extension APIs(1/3)

- **Case1**: APIs that are specific to **particular part** numbers within a product family



Example: case of Flash APIs which depend on part number in F4x family

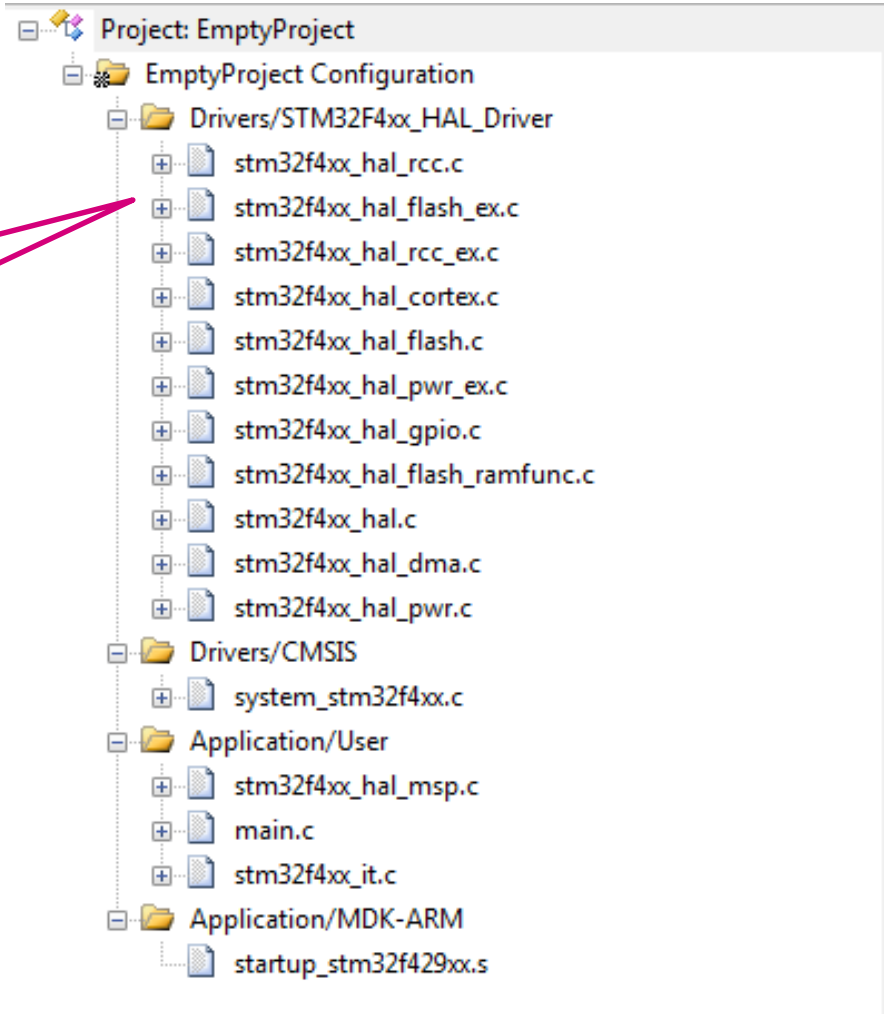
```
/* Extension Program operation functions  ***********************************/
#if defined(STM32F427xx) || defined(STM32F437xx) || defined(STM32F429xx) || defined(STM32F439xx) ||\
    defined(STM32F401xC) || defined(STM32F401xE) || defined(STM32F411xE)
HAL_StatusTypeDef HAL_FLASHEx_AdvOBProgram (FLASH_AdvOBProgramInitTypeDef *pAdvOBInit);
void              HAL_FLASHEx_AdvOBGetConfig(FLASH_AdvOBProgramInitTypeDef *pAdvOBInit);
HAL_StatusTypeDef HAL_FLASHEx_OB_SelectPCROP(void);
HAL_StatusTypeDef HAL_FLASHEx_OB_DeSelectPCROP(void);
#endif /* STM32F427xx || STM32F437xx || STM32F429xx || STM32F439xx || STM32F401xC || STM32F401xE || STM32F411xE */

#if defined(STM32F427xx) || defined(STM32F437xx) || defined(STM32F429xx)|| defined(STM32F439xx)
uint16_t          HAL_FLASHEx_OB_GetBank2WRP(void);
#endif /* STM32F427xx || STM32F437xx || STM32F429xx|| STM32F439xx */
```

HAL general concepts
HAL extension APIs(1/3)

- **Case1**: APIs that are specific to **particular part** numbers within a product family

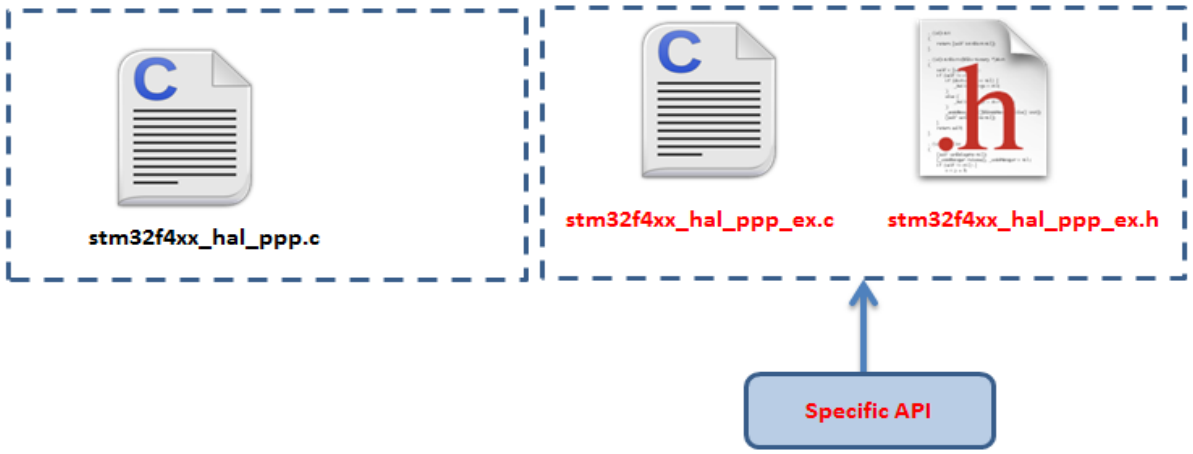
Example: case of Flash APIs which depend on part number in F4x family

Extension file with specific functions for F4xx parts



HAL general concepts
HAL extension APIs(2/3)

- **Case2**: APIs that are specific to **a product family**



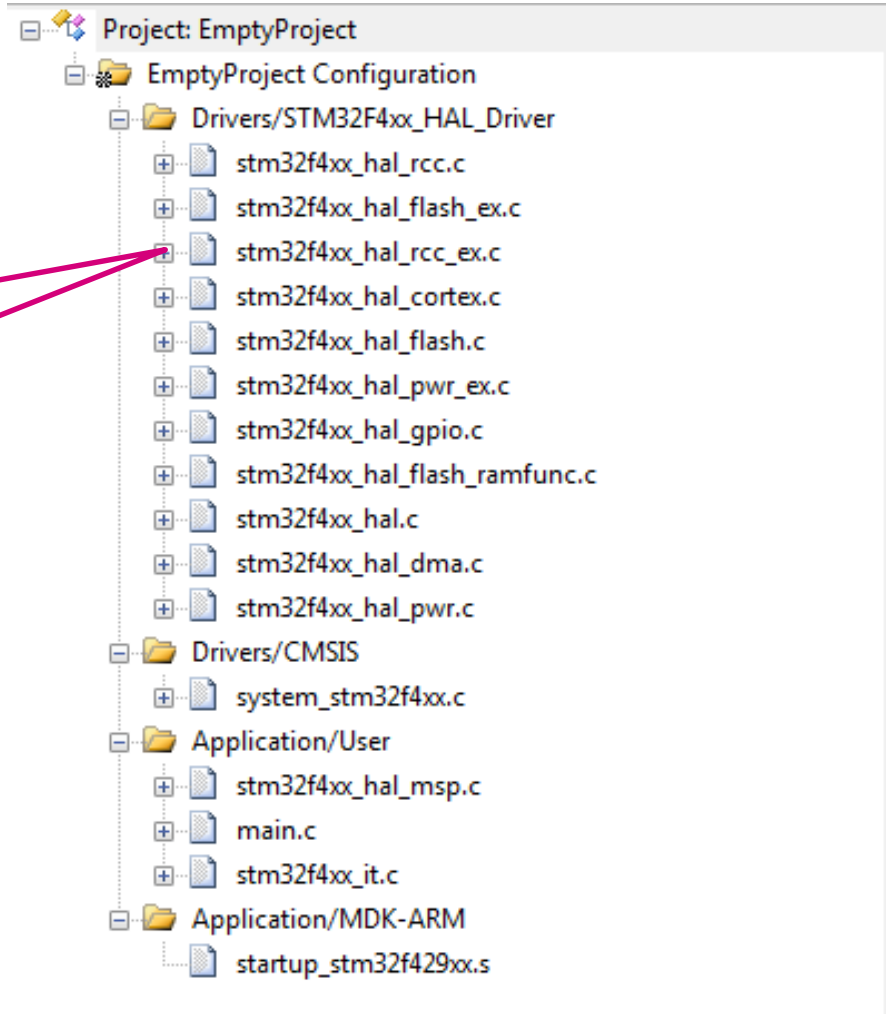
Example: case of RCC extension APIs for F4x family

```
/* Exported functions ---------------------------------------------------------*/
HAL_StatusTypeDef HAL_RCCEx_PeriphCLKConfig(RCC_PeriphCLKInitTypeDef  *PeriphClkInit);
void HAL_RCCEx_GetPeriphCLKConfig(RCC_PeriphCLKInitTypeDef  *PeriphClkInit);
```

HAL general concepts
HAL extension APIs(2/3)

- **Case2**: APIs that are specific to **a product family**

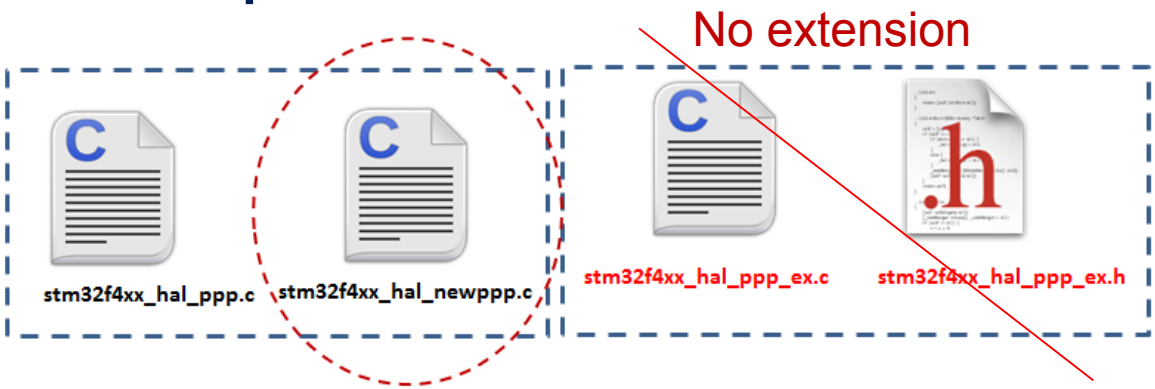
Example: case of RCC extension APIs for F4x family



Extension file with specific functions for F4xx family

HAL general concepts
HAL extension APIs(3/3)

- **Case3:** In case a peripheral is present in particular **part numbers** of **one single family**, **no extension files** are used but simply a **new module driver is provided**

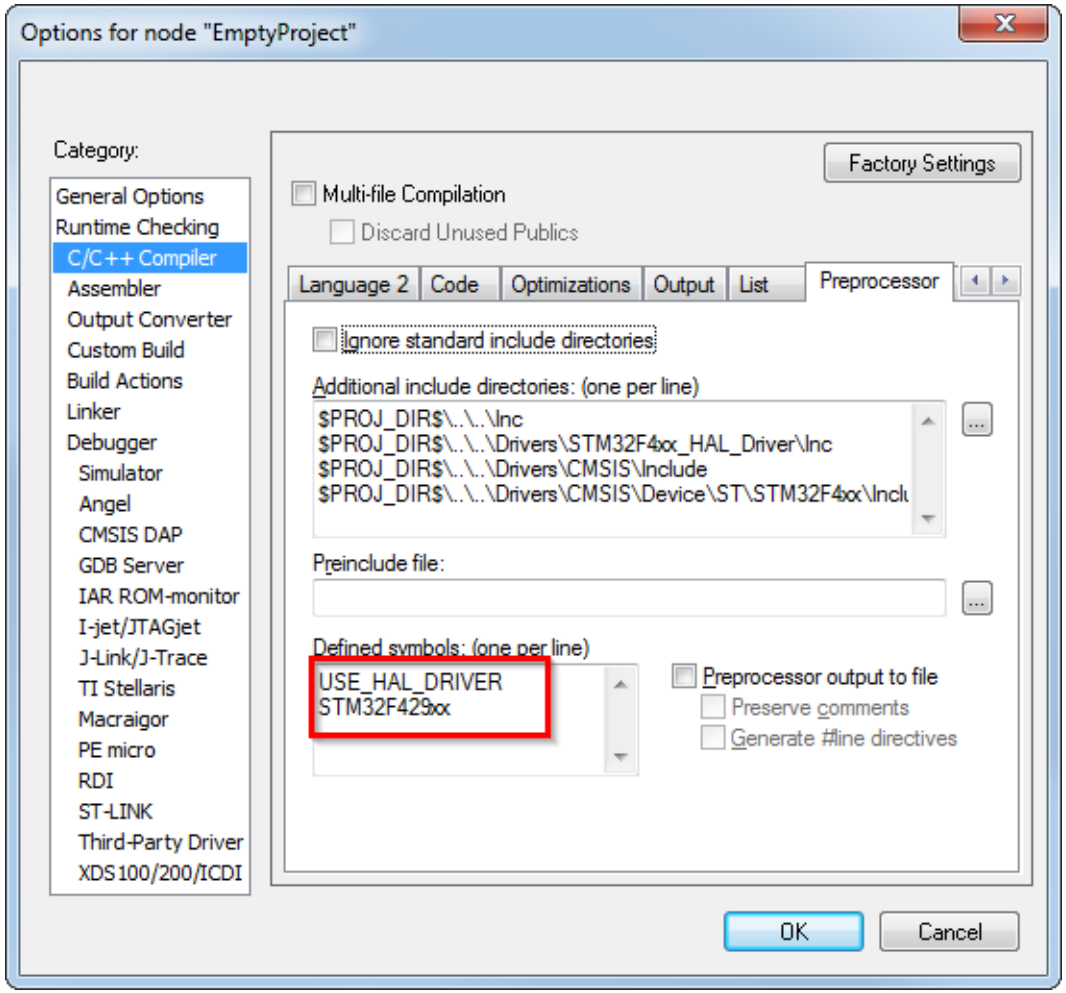


Example: LTDC is only present in F4x family in STM32F429 or STM32F439

```
#ifdef HAL_LTDC_MODULE_ENABLED

#if defined(STM32F429xx) || defined(STM32F439xx)

/* Private typedef -----------------------------------------------------------*/
/* Private define ------------------------------------------------------------*/
/* Private macro -------------------------------------------------------------*/
/* Private variables ---------------------------------------------------------*/
/* Private function prototypes -----------------------------------------------*/
```

HAL general concepts
Root part number selection

- The selection of root part number should be done through the project configuration by using specific P/N defines:



HAL general concepts
HAL configuration file

- The HAL config file stm32f4xx_hal_conf.h allows to select the modules to include:

```
/* ########################## Module Selection ############################## */
/**
  * @brief This is the list of modules to be used in the HAL driver
  */
#define HAL_MODULE_ENABLED
//#define HAL_ADC_MODULE_ENABLED
//#define HAL_CAN_MODULE_ENABLED
//#define HAL_CRC_MODULE_ENABLED
//#define HAL_CRYP_MODULE_ENABLED
//#define HAL_DAC_MODULE_ENABLED
//#define HAL_DCMI_MODULE_ENABLED
//#define HAL_DMA2D_MODULE_ENABLED
//#define HAL_ETH_MODULE_ENABLED
//#define HAL_NAND_MODULE_ENABLED
//#define HAL_NOR_MODULE_ENABLED
```

- It defines also some system and HAL parameters including
  - HSE clock/HSI clock values
  - Instruction/data cache and prefetch queue setting
  - VDD voltage value

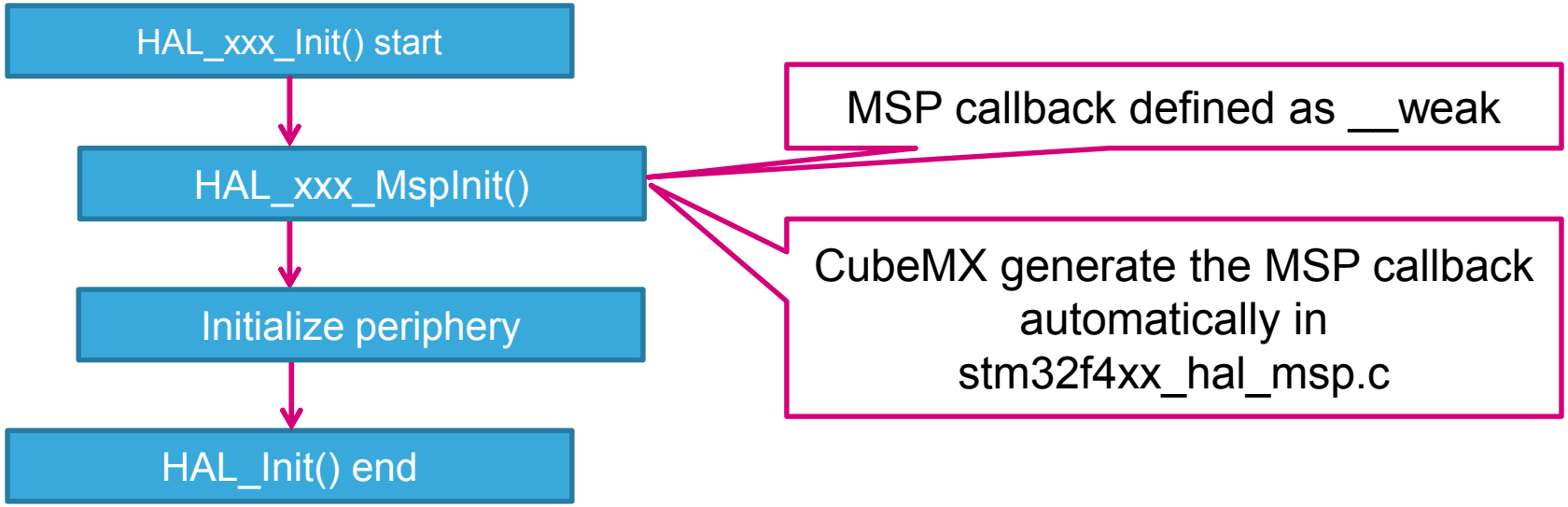
HAL general concepts
Callbacks

- Cube HAL library use the callbacks
  - To inform application about interrupts
  - About periphery initialization/deinitialization
- The callback functions are defined as __weak
- You can find them in stm32f4xx_hal_xxx.c

```
/**
  * @brief Tx Transfer completed callbacks
  * @param  hspi: pointer to a SPI_HandleTypeDef structure that contains
  *               the configuration information for SPI module.
  * @retval None
  */
__weak void HAL_SPI_TxCpltCallback(SPI_HandleTypeDef *hspi)
{
  /* NOTE : This function Should not be modified, when the callback is needed,
            the HAL_SPI_TxCpltCallback could be implemented in the user file
   */
}
```

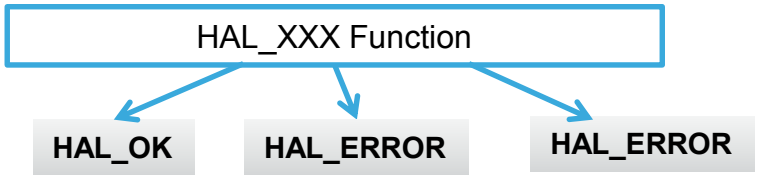
HAL general concepts
Init functions

- HAL_XXX_Init() functions
- Inside init function are written data from input parameters/structure into registers
- Before the register write is processed HAL_XXX_MspInit callback is called



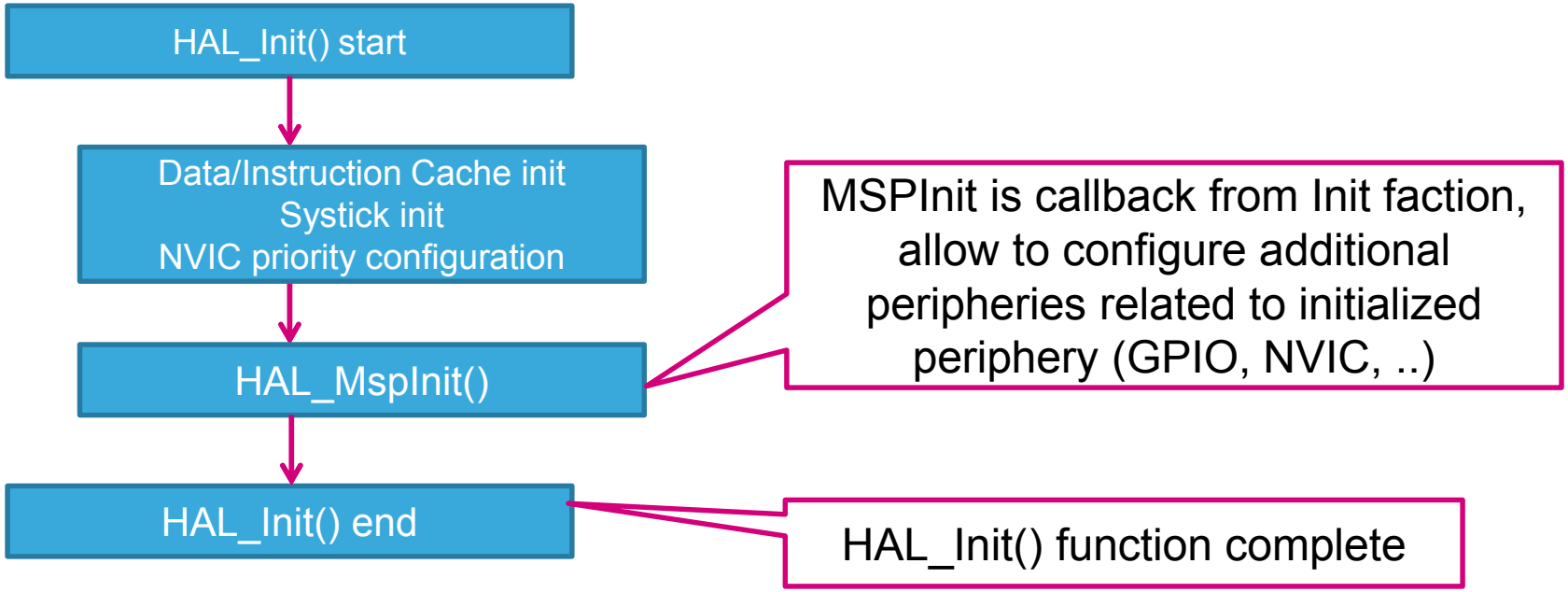
HAL general concepts
HAL API returns parameters

- A HAL API can return a value of enumerated type HAL_StatusTypeDef:
  - HAK_OK : API executed with success
  - HAL_ERROR : API call parameters error or operation execution error
  - HAL_BUSY : API was not executed because peripheral is busy with other operation
  - HAL_TIMEOUT : API timeout error



HAL general concepts
HAL global APIs HAL_Init()

- HAL_Init() : **need to be called as first function in main**
  - Initializes data/instruction cache and pre-fetch queue
  - Sets Time base to generate interrupt each 1ms with lowest priority , it can use systick (default) or other time source
  - Sets priority grouping to 4 preemption bits
  - Calls function HAL_MspInit() which a is user callback function to do MCU system level initializations (Clocks, GPIOs, DMA, Interrupts).



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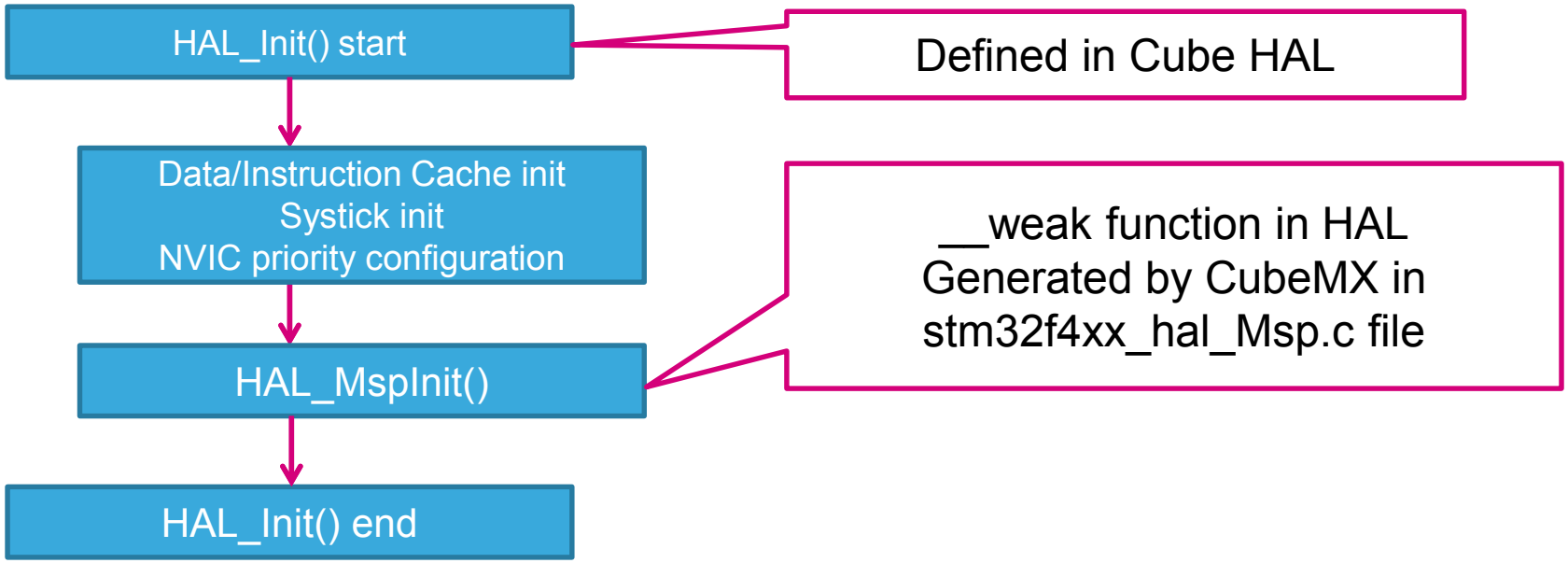


HAL general concepts
HAL global APIs HAL_Init()

- HAL_Init() : **need to be called as first function in main**

```
HAL_StatusTypeDef HAL_Init(void)
{
  /* Configure Flash prefetch, Instruction cache, Data cache */
#if (INSTRUCTION_CACHE_ENABLE != 0)
   __HAL_FLASH_INSTRUCTION_CACHE_ENABLE();
#endif /* INSTRUCTION_CACHE_ENABLE */
#if (DATA_CACHE_ENABLE != 0)
   __HAL_FLASH_DATA_CACHE_ENABLE();
#endif /* DATA_CACHE_ENABLE */
#if (PREFETCH_ENABLE != 0)
  __HAL_FLASH_PREFETCH_BUFFER_ENABLE();
#endif /* PREFETCH_ENABLE */
  /* Set Interrupt Group Priority */
  HAL_NVIC_SetPriorityGrouping(NVIC_PRIORITYGROUP_4);
  /* Use systick as time base source and configure 1ms tick (default clock after Reset is HSI) */
  HAL_InitTick(TICK_INT_PRIORITY);
  /* Init the low level hardware */
  HAL_MspInit();
  /* Return function status */
  return HAL_OK;
}
```

Instruction/data cache and prefetch initialization based on stm32f4xx_hal_conf.h

HAL general concepts
HAL global APIs HAL_Init()

- HAL_Init() : **need to be called as first function in main**

```
HAL_StatusTypeDef HAL_Init(void)
{
  /* Configure Flash prefetch, Instruction cache, Data cache */
#if (INSTRUCTION_CACHE_ENABLE != 0)
   __HAL_FLASH_INSTRUCTION_CACHE_ENABLE();
#endif /* INSTRUCTION_CACHE_ENABLE */
#if (DATA_CACHE_ENABLE != 0)
   __HAL_FLASH_DATA_CACHE_ENABLE();
#endif /* DATA_CACHE_ENABLE */
#if (PREFETCH_ENABLE != 0)
  __HAL_FLASH_PREFETCH_BUFFER_ENABLE();
#endif /* PREFETCH_ENABLE */
  /* Set Interrupt Group Priority */
  HAL_NVIC_SetPriorityGrouping(NVIC_PRIORITYGROUP_4);
  /* Use systick as time base source and configure 1ms tick (default clock after Reset is HSI) */
  HAL_InitTick(TICK_INT_PRIORITY);
  /* Init the low level hardware */
  HAL_MspInit();
  /* Return function status */
  return HAL_OK;
}
```

NVIC priority grouping setup

Default systick init with default interrupt priority 0 (HIGH priority)

HAL general concepts
HAL global APIs HAL_Init()

- HAL_Init() : **need to be called as first function in main**

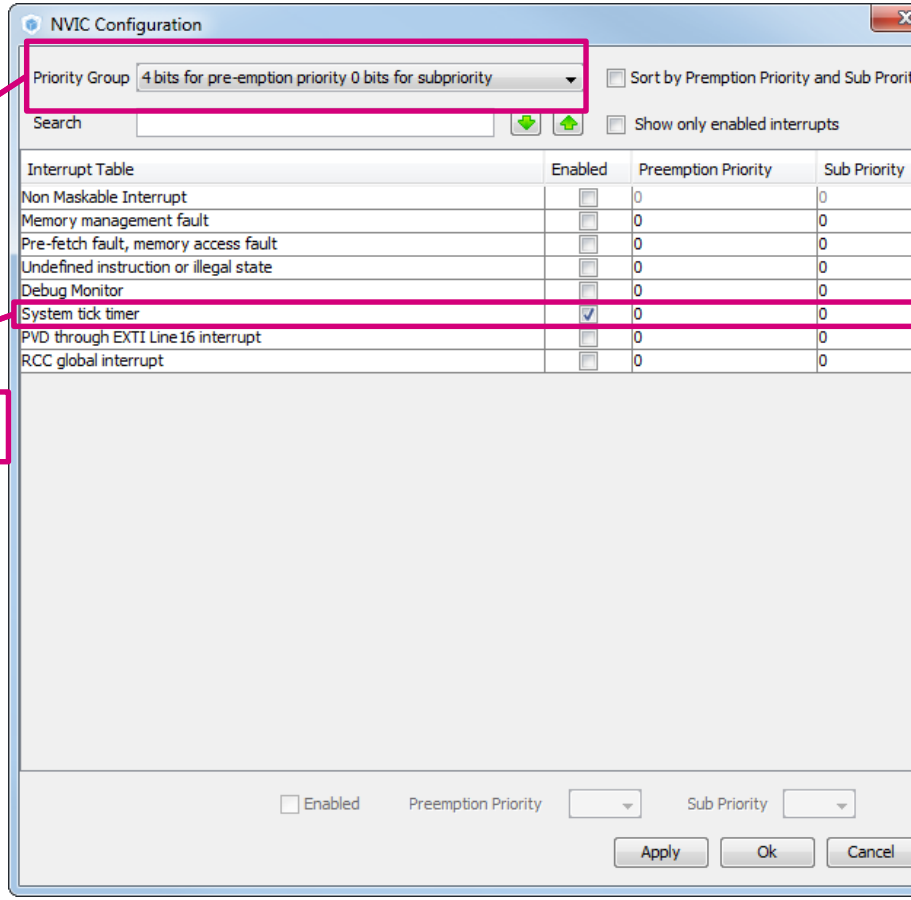
```
HAL_StatusTypeDef HAL_Init(void)
{
  /* Configure Flash prefetch, Instruction cache, Data cache */
#if (INSTRUCTION_CACHE_ENABLE != 0)
   __HAL_FLASH_INSTRUCTION_CACHE_ENABLE();
#endif /* INSTRUCTION_CACHE_ENABLE */
#if (DATA_CACHE_ENABLE != 0)
   __HAL_FLASH_DATA_CACHE_ENABLE();
#endif /* DATA_CACHE_ENABLE */
#if (PREFETCH_ENABLE != 0)
  __HAL_FLASH_PREFETCH_BUFFER_ENABLE();
#endif /* PREFETCH_ENABLE */
  /* Set Interrupt Group Priority */
  HAL_NVIC_SetPriorityGrouping(NVIC_PRIORITYGROUP_4);
  /* Use systick as time base source and configu                    is HSI) */
  HAL_InitTick(TICK_INT_PRIORITY);
  /* Init the low level hardware */
  HAL_MspInit();
  /* Return function status */
  return HAL_OK;
}
```

HAL_MspInit callback function generated by CubeMX in stm32f4xx_hal_msp.c

HAL general concepts
HAL global APIs HAL_Init()

- HAL_MspInit() generated by CubeMX
- contains setup selected in CubeMX

```
/**
  * Initializes the Global MSP.
  */
void HAL_MspInit(void)
{
  /* USER CODE BEGIN MspInit 0 */

  /* USER CODE END MspInit 0 */

  HAL_NVIC_SetPriorityGrouping(NVIC_PRIORITYGROUP_4);

  /* System interrupt init*/
/* SysTick_IRQn interrupt configuration */
  HAL_NVIC_SetPriority(SysTick_IRQn, 0, 0);

  /* USER CODE BEGIN MspInit 1 */

  /* USER CODE END MspInit 1 */
}
```



HAL general concepts
HAL global APIs HAL_Init()

- HAL_MspInit() generated by CubeMX
- contains setup selected in CubeMX

```
/**
  * Initializes the Global MSP.
  */
void HAL_MspInit(void)
{
  /* USER CODE BEGIN MspInit 0 */

  /* USER CODE END MspInit 0 */

  HAL_NVIC_SetPriorityGrouping(NVIC_PRIORITYGROUP_4);

  /* System interrupt init*/
/* SysTick_IRQn interrupt configuration */
  HAL_NVIC_SetPriority(SysTick_IRQn, 0, 0);

  /* USER CODE BEGIN MspInit 1 */

  /* USER CODE END MspInit 1 */
}
```

Space for additional user initialization

Space for additional user initialization

HAL general concepts
HAL global APIs (1/2)

- Implemented in file **stm32f4x_hal.c**, main function are:

- HAL_DeInit()
  - Resets all peripherals
  - Calls function HAL_MspDeInit() which a is user callback function to do system level De-Initalizations. HAL_MspDeInit() is defined as “weak” empty function in HAL

- HAL_GetTick()
  - Get current tick counter (incremented in Time base interrupt)
  - **Used by peripherals drivers for timeout management**

- HAL_Delay()
  - Implements a delay in ms

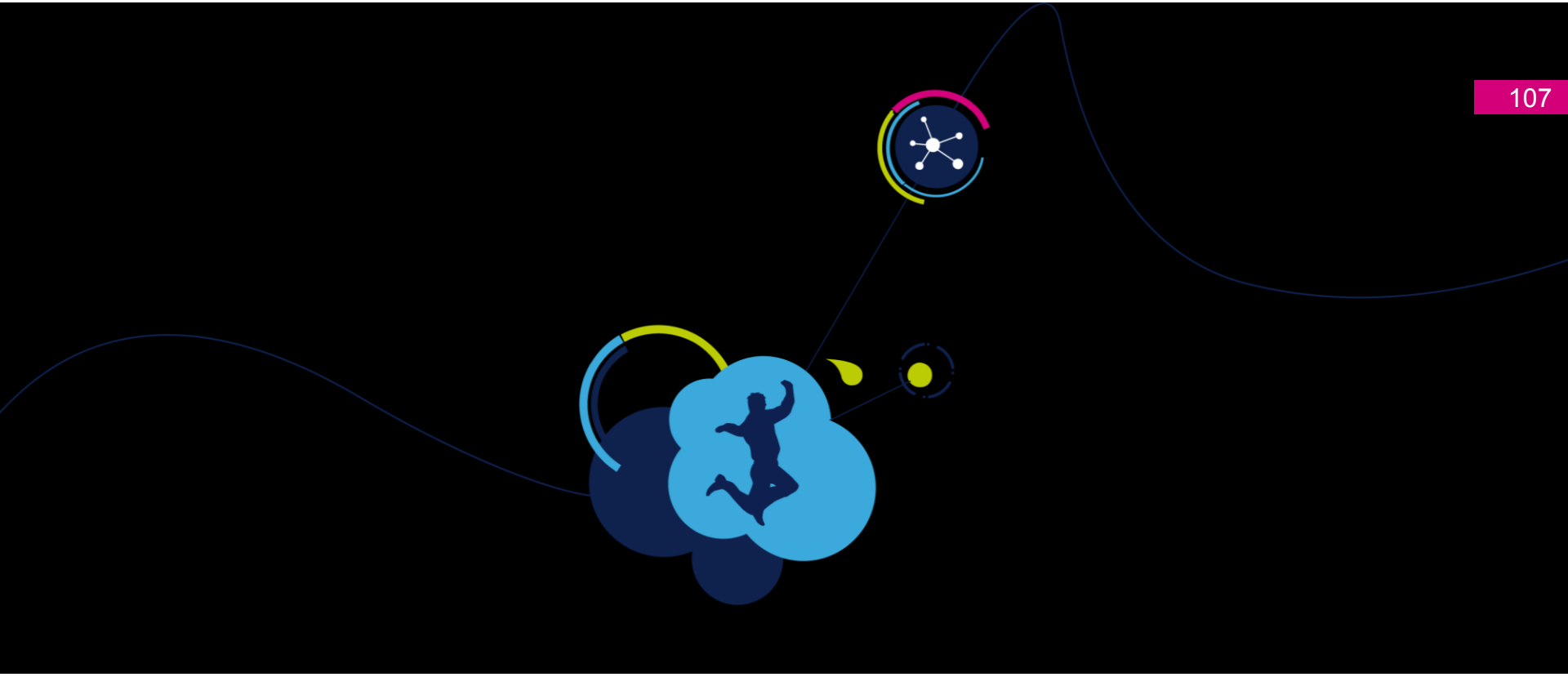
- HAL_InitTick()
  - Weak function that configures the source of the time base, by default it is systick but can be redefined by user

HAL general concepts
HAL global APIs (2/2)

- HAL_IncTick()
  - Increment a global variable "uwTick" used as application time base . Should be called from Time base ISR (systick, timer, …)
- HAL_SuspendTick() / HAL_ResumeTick()
  - Suspend Tick increment
  - Resume Tick increment.
- HAL_GetHalVersion()
  - Returns the HAL revision

HAL general concepts
HAL Tick functions

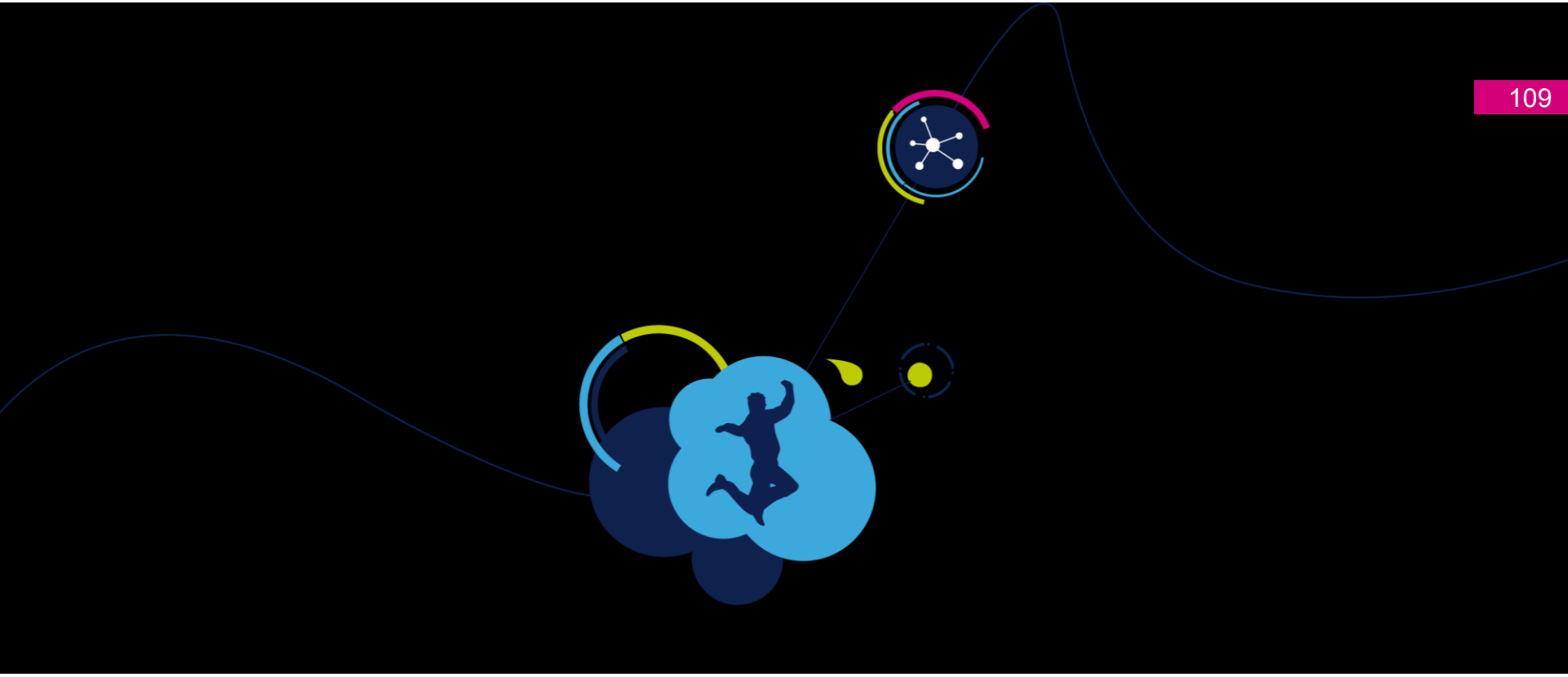
- Are defined as __weak by default used systick clocked from AHB
- In case you want change the clock source you need to change all Tick methods
  - HAL_GetTick
  - HAL_InitTick
  - HAL_SuspendTick()
  - HAL_ResumeTick()
- Use HAL_SuspendTick before MCU enter into low power mode, interrupt can wake up STM32 from LP mode
- After wakeup use again HAL_ResumeTick for enable time domain



HAL service peripherals

HAL service peripherals Introduction

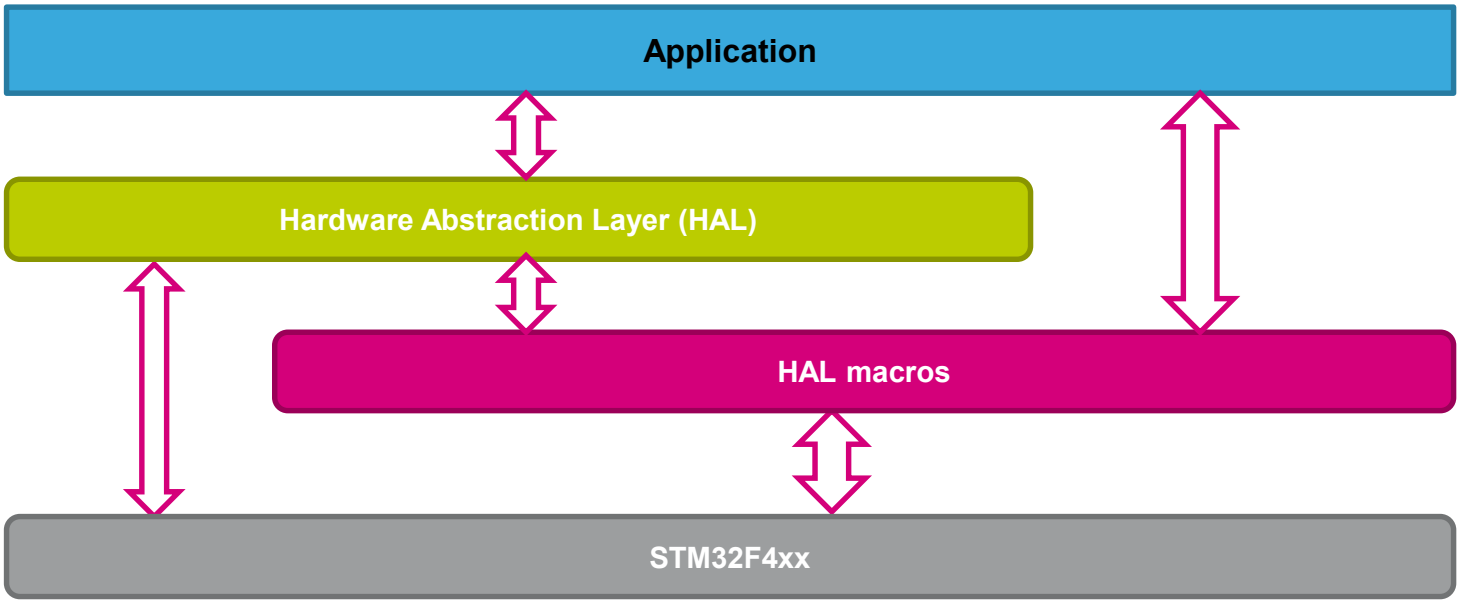
- HAL service peripherals the main system IPs , including:
  - GPIO
  - RCC
  - DMA
  - Cortex (NVIC and Systick APIs)
  - PWR (power management APIs)
- The HAL offers simple to use, portable APIs for above system IPs with extensions provided also for non common features (ex: product specific low power mode, specific clock configurations ,…)



HAL service peripherals - RCC Reset and Clock Control

HAL functions/macros

- In stm32f4xx_hal_xxx.c are defined function for specific periphery
- In stm32f4xx_hal_xxx.h are defined macros which can be used to control the periphery
- Macros require better knowledge of periphery functions



HAL service peripherals
RCC macros

- Simple macros for RCC operations
  - Enabling peripheral clocks (_CLK_ENABLE)
  - Disabling peripheral clocks (_CLK_DISABLE))
  - Force periphery reset (_FORCE_RESET)
  - Release periphery reset (RELEASE_RESET)

- RCC macro example:

__PERIPH_ACTION();

Name of periphery:
GPIOA, USART1,
TIM1, …

Enable peripheral clock
Ex.:
__GPIOA_CLK_ENABLE();

Disable peripheral clock
Ex.:
__GPIOA_CLK_DISABLE();

Force periphery reset
Ex.:
__GPIOA_FORCE_RESET();

Release periphery reset
Ex.:
__GPIOA_RELEASE_RESET();

HAL service peripherals
Enabling Peripherals

- All peripherals clocks can be enabled using the RCC macros
- A peripheral clock should be enabled before being used.

```
/* Exported macro ------------------------------------------------------------*/

/** @brief  Enable or disable the AHB1 peripheral clock.
  * @note   After reset, the peripheral clock (used for registers read/write access)
  *         is disabled and the application software has to enable this clock before
  *         using it.
  */
#define __GPIOA_CLK_ENABLE()           (RCC->AHB1ENR |= (RCC_AHB1ENR_GPIOAEN))
#define __GPIOB_CLK_ENABLE()           (RCC->AHB1ENR |= (RCC_AHB1ENR_GPIOBEN))
#define __GPIOC_CLK_ENABLE()           (RCC->AHB1ENR |= (RCC_AHB1ENR_GPIOCEN))
#define __GPIOD_CLK_ENABLE()           (RCC->AHB1ENR |= (RCC_AHB1ENR_GPIODEN))
#define __GPIOE_CLK_ENABLE()           (RCC->AHB1ENR |= (RCC_AHB1ENR_GPIOEEN))
#define __GPIOH_CLK_ENABLE()           (RCC->AHB1ENR |= (RCC_AHB1ENR_GPIOHEN))
#define __CRC_CLK_ENABLE()             (RCC->AHB1ENR |= (RCC_AHB1ENR_CRCEN))
#define __BKPSRAM_CLK_ENABLE()         (RCC->AHB1ENR |= (RCC_AHB1ENR_BKPSRAMEN))
#define __CCMDATARAMEN_CLK_ENABLE()    (RCC->AHB1ENR |= (RCC_AHB1ENR_CCMDATARAMEN))
#define __DMA1_CLK_ENABLE()            (RCC->AHB1ENR |= (RCC_AHB1ENR_DMA1EN))
#define __DMA2_CLK_ENABLE()            (RCC->AHB1ENR |= (RCC_AHB1ENR_DMA2EN))

#define __GPIOA_CLK_DISABLE()          (RCC->AHB1ENR &= ~(RCC_AHB1ENR_GPIOAEN))
#define __GPIOB_CLK_DISABLE()          (RCC->AHB1ENR &= ~(RCC_AHB1ENR_GPIOBEN))
#define __GPIOC_CLK_DISABLE()          (RCC->AHB1ENR &= ~(RCC_AHB1ENR_GPIOCEN))
#define __GPIOD_CLK_DISABLE()          (RCC->AHB1ENR &= ~(RCC_AHB1ENR_GPIODEN))
#define __GPIOE_CLK_DISABLE()          (RCC->AHB1ENR &= ~(RCC_AHB1ENR_GPIOEEN))
#define __GPIOH_CLK_DISABLE()          (RCC->AHB1ENR &= ~(RCC_AHB1ENR_GPIOHEN))
#define __CRC_CLK_DISABLE()            (RCC->AHB1ENR &= ~(RCC_AHB1ENR_CRCEN))
#define __BKPSRAM_CLK_DISABLE()        (RCC->AHB1ENR &= ~(RCC_AHB1ENR_BKPSRAMEN))
#define __CCMDATARAMEN_CLK_DISABLE()   (RCC->AHB1ENR &= ~(RCC_AHB1ENR_CCMDATARAMEN))
#define __DMA1_CLK_DISABLE()           (RCC->AHB1ENR &= ~(RCC_AHB1ENR_DMA1EN))
#define __DMA2_CLK_DISABLE()           (RCC->AHB1ENR &= ~(RCC_AHB1ENR_DMA2EN))
```

In file stm32f4xx_hal_rcc.

Enable Periphery register access

Disable periphery register access

life.augm

HAL service peripherals
Reset Peripherals

- All peripherals can be reset to their default start using the RCC macros
- After Force periphery rese the reset must be release otherwise the periphery will not react on changes

```
/** @brief  Force or release AHB1 peripheral reset.
  */
#define __AHB1_FORCE_RESET()    (RCC->AHB1RSTR = 0xFFFFFFFF)
#define __GPIOA_FORCE_RESET()   (RCC->AHB1RSTR |= (RCC_AHB1RSTR_GPIOARST))
#define __GPIOB_FORCE_RESET()   (RCC->AHB1RSTR |= (RCC_AHB1RSTR_GPIOBRST))
#define __GPIOC_FORCE_RESET()   (RCC->AHB1RSTR |= (RCC_AHB1RSTR_GPIOCRST))
#define __GPIOD_FORCE_RESET()   (RCC->AHB1RSTR |= (RCC_AHB1RSTR_GPIODRST))
#define __GPIOE_FORCE_RESET()   (RCC->AHB1RSTR |= (RCC_AHB1RSTR_GPIOERST))
#define __GPIOH_FORCE_RESET()   (RCC->AHB1RSTR |= (RCC_AHB1RSTR_GPIOHRST))
#define __CRC_FORCE_RESET()     (RCC->AHB1RSTR |= (RCC_AHB1RSTR_CRCRST))
#define __DMA1_FORCE_RESET()    (RCC->AHB1RSTR |= (RCC_AHB1RSTR_DMA1RST))
#define __DMA2_FORCE_RESET()    (RCC->AHB1RSTR |= (RCC_AHB1RSTR_DMA2RST))

#define __AHB1_RELEASE_RESET()  (RCC->AHB1RSTR = 0x00)
#define __GPIOA_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIOARST))
#define __GPIOB_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIOBRST))
#define __GPIOC_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIOCRST))
#define __GPIOD_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIODRST))
#define __GPIOE_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIOERST))
#define __GPIOF_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIOFRST))
#define __GPIOG_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIOGRST))
#define __GPIOH_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIOHRST))
#define __GPIOI_RELEASE_RESET() (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_GPIOIRST))
#define __CRC_RELEASE_RESET()   (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_CRCRST))
#define __DMA1_RELEASE_RESET()  (RCC->AHB1RSTR &= ~(RCC_AHB1RSTR_DMA1RST))
```

Held periphery in RESET, periphery registers are in default state

In file stm32f4xx_hal_rcc.h

Release RESET, periphery can be now enabled

life.augment

HAL service peripherals
RCC – macros

- RCC macros are defined in stm32f4xx_hal_rcc.h file, **they are needed** for peripherals clock gating, reset control and sleep mode clock config
  - Peripheral clock enable/disable: __TIM1_CLK_ENABLE() / __TIM1_CLK_DISABLE()
  - Peripheral reset enable/disable: __GPIOA_FORCE_RESET()/ __GPIOA_RELEASE_RESET()
  - Peripheral Sleep mode clock enable/disable: __SPI3_CLK_SLEEP_ENABLE()/ SPI3_CLK_SLEEP_DISBALE()

- Other RCC macros are available for direct register access, they can be used in the application instead of the HAL clock config APIs, for example, when restoring clock after Stop mode, user can use directly below macros
  - __HAL_RCC_HSE_CONFIG
  - __HAL_RCC_PLL_ENABLE
  - __HAL_RCC_GET_FLAG

HAL structures

- HAL function sometime require structure as parameter
- For example:
  - void HAL_GPIO_Init(GPIO_TypeDef *GPIOx, GPIO_InitTypeDef *GPIO_Init)
- Precise name of structure we will found in stm32f4xx_hal_xxx.c
- The structure definition is in stm32f4xx_hal_xxx.h header file
  - We can use go to definition option of IDE

stm32f4xx_hal_gpio.c

stm32f4xx_hal_gpio.h

```
/**
  * @brief GPIO Init structure definition
  */
typedef struct
{
  uint32_t Pin;       /*!< Specifies the GPIO pins to be configured.
                           This parameter can be any value of @ref GPIO_pins_define */
  uint32_t Mode;      /*!< Specifies the operating mode for the selected pins.
                           This parameter can be a value of @ref GPIO_mode_define */
  uint32_t Pull;      /*!< Specifies the Pull-up or Pull-Down activation for the selected pins.
                           This parameter can be a value of @ref GPIO_pull_define */
  uint32_t Speed;     /*!< Specifies the speed for the selected pins.
                           This parameter can be a value of @ref GPIO_speed_define */
  uint32_t Alternate;  /*!< Peripheral to be connected to the selected pins.
                            This parameter can be a value of @ref GPIO_Alternate_function_selection */
}GPIO_InitTypeDef;
```

HAL structures

stm32f4xx_hal_gpio.h

```
/**
  * @brief GPIO Init structure definition
  */
typedef struct
{
  uint32_t Pin;       /*!< Specifies the GPIO pins to be configured.
                           This parameter can be any value of @ref GPIO_pins_define */

  uint32_t Mode;      /*!< Specifies the operating mode for the selected pins.
                           This parameter can be a value of @ref GPIO_mode_define */

  uint32_t Pull;      /*!< Specifies the Pull-up or Pull-Down activation for the selected pins.
                           This parameter can be a value of @ref GPIO_pull_define */

  uint32_t Speed;     /*!< Specifies the speed for the selected pins.
                           This parameter can be a value of @ref GPIO_speed_define */

  uint32_t Alternate;  /*!< Peripheral to be connected to the selected pins.
                            This parameter can be a value of @ref GPIO_Alternate_function_selection */
}GPIO_InitTypeDef;
```

- To discover what parameter fill into structure find the @ref name

```
/** @defgroup GPIO_pins_define GPIO pins define
  * @{
  */
#define GPIO_PIN_0                 ((uint16_t)0x0001)  /* Pin 0 selected    */
#define GPIO_PIN_1                 ((uint16_t)0x0002)  /* Pin 1 selected    */
#define GPIO_PIN_2                 ((uint16_t)0x0004)  /* Pin 2 selected    */
#define GPIO_PIN_3                 ((uint16_t)0x0008)  /* Pin 3 selected    */
#define GPIO_PIN_4                 ((uint16_t)0x0010)  /* Pin 4 selected    */
#define GPIO_PIN_5                 ((uint16_t)0x0020)  /* Pin 5 selected    */
#define GPIO_PIN_6                 ((uint16_t)0x0040)  /* Pin 6 selected    */
#define GPIO_PIN_7                 ((uint16_t)0x0080)  /* Pin 7 selected    */
#define GPIO_PIN_8                 ((uint16_t)0x0100)  /* Pin 8 selected    */
#define GPIO_PIN_9                 ((uint16_t)0x0200)  /* Pin 9 selected    */
#define GPIO_PIN_10                ((uint16_t)0x0400)  /* Pin 10 selected   */
#define GPIO_PIN_11                ((uint16_t)0x0800)  /* Pin 11 selected   */
```

stm32f4xx_hal_gpio.h

HAL service peripherals
RCC - clock configuration (1/2)

- Two functions needed for clock configuration
  - HAL_RCC_OscConfig
  - HAL_RCC_ClockConfig

- HAL_RCC_OscConfig (RCC_OscInitTypeDef *RCC_OscInitStruct)
  - Configures/Enables multiple clock sources : HSE, HSI, LSE, LSI, PLL

```
/**
  * @brief  RCC Internal/External Oscillator (HSE, HSI, LSE and LSI) configuration structure definition
  */
typedef struct
{
  uint32_t OscillatorType;       /*!< The oscillators to be configured.
                                      This parameter can be a value of @ref RCC_Oscillator_Type                    */
  uint32_t HSEState;             /*!< The new state of the HSE.
                                      This parameter can be a value of @ref RCC_HSE_Config                         */
  uint32_t LSEState;             /*!< The new state of the LSE.
                                      This parameter can be a value of @ref RCC_LSE_Config                         */
  uint32_t HSIState;             /*!< The new state of the HSI.
                                      This parameter can be a value of @ref RCC_HSI_Config                         */
  uint32_t HSICalibrationValue;  /*!< The calibration trimming value.
                                      This parameter must be a number between Min_Data = 0x00 and Max_Data = 0x1F */
  uint32_t LSIState;             /*!< The new state of the LSI.
                                      This parameter can be a value of @ref RCC_LSI_Config                         */
  RCC_PLLInitTypeDef PLL;        /*!< PLL structure parameters                                                     */
}RCC_OscInitTypeDef;
```

HAL service peripherals
RCC - clock configuration (1/2)

- Two functions needed for clock configuration
  - HAL_RCC_OscConfig
  - HAL_RCC_ClockConfig

- HAL_RCC_OscConfig (RCC_OscInitTypeDef *RCC_OscInitStruct)
  - Configures/Enables multiple clock sources : HSE, HSI, LSE, LSI, PLL

```
/**
  * @brief  RCC Internal/External (
  */
typedef struct
{
  uint32_t OscillatorType;       /
  uint32_t HSEState;             /
  uint32_t LSEState;             /
  uint32_t HSIState;             /
  uint32_t HSICalibrationValue;  /
  uint32_t LSIState;             /
  RCC_PLLInitTypeDef PLL;        /
}RCC_OscInitTypeDef;
```

```
/**
  * @brief  RCC PLL configuration structure definition
  */
typedef struct
{
  uint32_t PLLState;   /*!< The new state of the PLL.
                            This parameter can be a value of @ref RCC_PLL_Config
  uint32_t PLLSource;  /*!< RCC_PLLSource: PLL entry clock source.
                            This parameter must be a value of @ref RCC_PLL_Clock_Source
  uint32_t PLLM;       /*!< PLLM: Division factor for PLL VCO input clock.
                            This parameter must be a number between Min_Data = 0 and Max_Data = 63
  uint32_t PLLN;       /*!< PLLN: Multiplication factor for PLL VCO output clock.
                            This parameter must be a number between Min_Data = 192 and Max_Data =
  uint32_t PLLP;       /*!< PLLP: Division factor for main system clock (SYSCLK).
                            This parameter must be a value of @ref RCC_PLLP_Clock_Divider
  uint32_t PLLQ;       /*!< PLLQ: Division factor for OTG FS, SDIO and RNG clocks.
                            This parameter must be a number between Min_Data = 0 and Max_Data = 63

}RCC_PLLInitTypeDef;
```

HAL service peripherals
RCC - clock configuration (2/2)

- HAL_RCC_ClockConfig (RCC_ClkInitTypeDef *RCC_ClkInitStruct, uint32_t FLatency)
  - Selects system clock source
  - Configures AHB, APB1 and APB2 clock dividers
  - Configures Flash Wait States
  - Updates systick config following HCLK clock changes to generate 1ms timebase

```
/**
  * @brief  RCC System, AHB and APB busses clock configuration structure definition
  */
typedef struct
{
  uint32_t ClockType;             /*!< The clock to be configured.
                                       This parameter can be a value of @ref RCC_System_Clock_Type      */

  uint32_t SYSCLKSource;          /*!< The clock source (SYSCLKS) used as system clock.
                                       This parameter can be a value of @ref RCC_System_Clock_Source    */

  uint32_t AHBCLKDivider;         /*!< The AHB clock (HCLK) divider. This clock is derived from the system clock (SYSCLK).
                                       This parameter can be a value of @ref RCC_AHB_Clock_Source       */

  uint32_t APB1CLKDivider;        /*!< The APB1 clock (PCLK1) divider. This clock is derived from the AHB clock (HCLK).
                                       This parameter can be a value of @ref RCC_APB1_APB2_Clock_Source */

  uint32_t APB2CLKDivider;        /*!< The APB2 clock (PCLK2) divider. This clock is derived from the AHB clock (HCLK).
                                       This parameter can be a value of @ref RCC_APB1_APB2_Clock_Source */

}RCC_ClkInitTypeDef;
```

HAL service peripherals
RCC - clock configuration (2/2)

- HAL_RCC_ClockConfig (RCC_ClkInitTypeDef *RCC_ClkInitStruct, uint32_t FLatency)
  - Selects system clock source
  - Configures AHB, APB1 and APB2 clock dividers
  - Configures Flash Wait States
  - Updates systick config following HCLK clock changes to generate 1ms timebase

```
/**
  * @brief  RCC System, AHB and APB busses clock configuration structure definition
  */
typedef struct
{
  uint32_t ClockType;             /*!< The clock to be configured.
                                       This parameter can be a value of @ref RCC_System_Clock_Type      */

  uint32_t SYSCLKSource;          /*!< The clock source (SYSCLKS) used as system clock.
                                       This parameter can be a value of @ref RCC_System_Clock_Source    */

  uint32_t AHBCLKDivider;         /*!< The AHB clock (HCLK) divider. This clock is derived from the system clock (SYSCLK).
                                       This parameter can be a value of @ref RCC_AHB_Clock_Source       */

  uint32_t APB1CLKDivider;        /*!< The APB1 clock (PCLK1) divider. This clock is derived from the AHB clock (HCLK).
                                       This parameter can be a value of @ref RCC_APB1_APB2_Clock_Source */

  uint32_t APB2CLKDivider;        /*!< The APB2 clock (PCLK2) divider. This clock is derived from the AHB clock (HCLK).
                                       This parameter can be a value of @ref RCC_APB1_APB2_Clock_Source */

}RCC_ClkInitTypeDef;
```

HAL service peripherals RCC– APIs

- Main function structure, generated by CubeMX

```
int main(void)
{
  /* USER CODE BEGIN 1 */

  /* USER CODE END 1 */
  /* MCU Configuration----                                    ----------*/
  /* Reset of all peri                                    ace and the Systick. */
  HAL_Init();
  /* Configure the system clock */
  SystemClock_Config();
  /* Initialize all configu
  MX_GPIO_Init();
  /* USER CODE BEGIN 2 */

  /* USER CODE END 2 */
  /* USER CODE BEGIN 3 */
  /* Infinite loop */
  while (1)
  {

  }
  /* USER CODE END 3 */
}
```

Initialize Systick, NVIC, and call HAL_Init_MSP

Initialize STM32 clock tree, based on Clock Configuration in CubeMX

HAL service peripherals
RCC – APIs

- MX_GPIO_Init function structure, generated by CubeMX

```
/** System Clock Configuration
*/
void SystemClock_Config(void)
{

  RCC_OscInitTypeDef RCC_OscInitStruct;
  RCC_ClkInitTypeDef RCC_ClkInitStruct;

  __PWR_CLK_ENABLE();

  __HAL_PWR_VOLTAGESCALING_CONFIG(PWR_REGULATOR_VOLTAGE_SCALE1);

  RCC_OscInitStruct.OscillatorType = RCC_OSCILLATORTYPE_HSE;
  RCC_OscInitStruct.HSEState = RCC_HSE_ON;
  RCC_OscInitStruct.PLL.PLLState = RCC_PLL_ON;
  RCC_OscInitStruct.PLL.PLLSource = RCC_PLLSOURCE_HSE;
  RCC_OscInitStruct.PLL.PLLM = 8;
  RCC_OscInitStruct.PLL.PLLN = 336;
  RCC_OscInitStruct.PLL.PLLP = RCC_PLLP_DIV2;
  RCC_OscInitStruct.PLL.PLLQ = 4;
  HAL_RCC_OscConfig(&RCC_OscInitStruct);

  RCC_ClkInitStruct.ClockType = RCC_CLOCKTYPE_SYSCLK|RCC_CLOCKTYPE_PCLK1
                              |RCC_CLOCKTYPE_PCLK2;
  RCC_ClkInitStruct.SYSCLKSource = RCC_SYSCLKSOURCE_PLLCLK;
  RCC_ClkInitStruct.AHBCLKDivider = RCC_SYSCLK_DIV1;
  RCC_ClkInitStruct.APB1CLKDivider = RCC_HCLK_DIV4;
  RCC_ClkInitStruct.APB2CLKDivider = RCC_HCLK_DIV2;
  HAL_RCC_ClockConfig(&RCC_ClkInitStruct, FLASH_LATENCY_5);

}
```

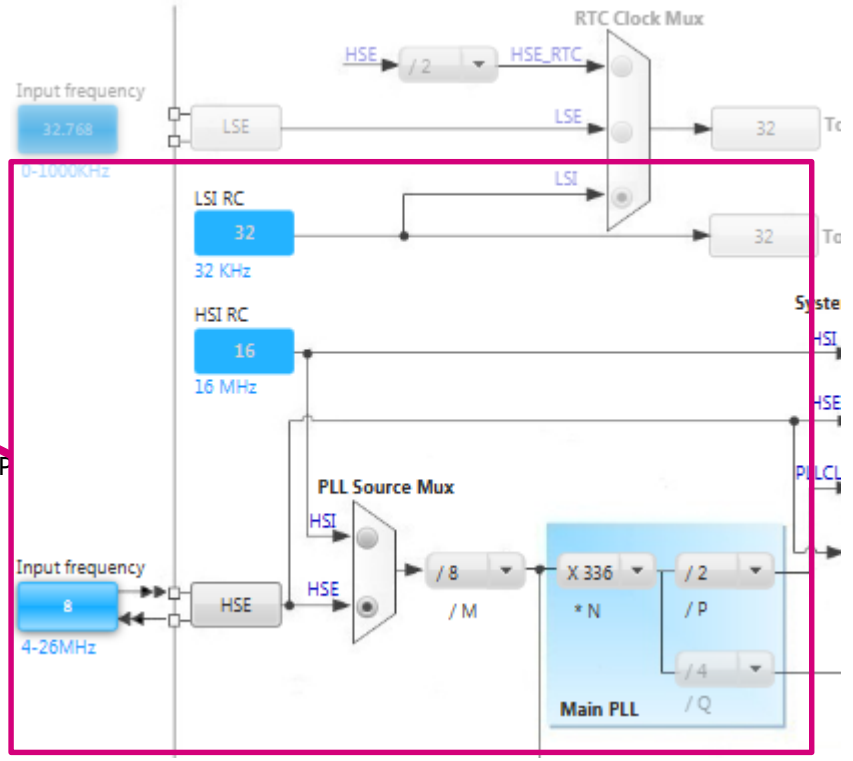
Enable clocks for PWR periphery

Configure voltage scale (refer RM)

HAL service peripherals
RCC – APIs

- SystemClock_Config function structure, generated by CubeMX

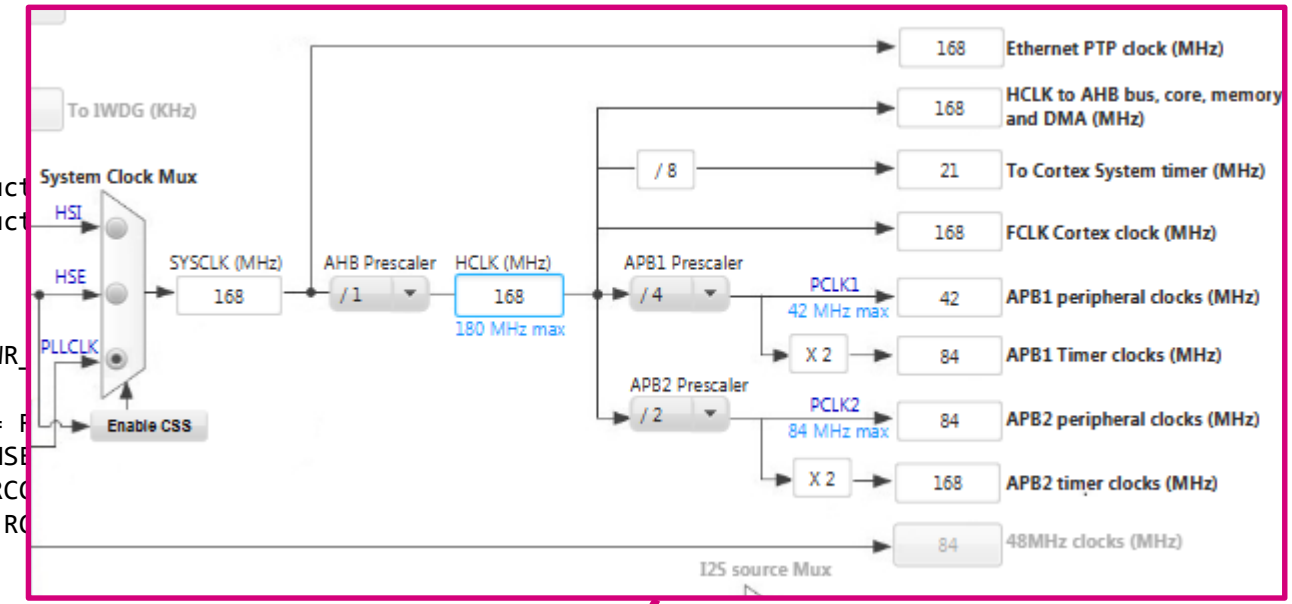
```
/** System Clock Configuration
*/
void SystemClock_Config(void)
{

  RCC_OscInitTypeDef RCC_OscInitStruct;
  RCC_ClkInitTypeDef RCC_ClkInitStruct;

  __PWR_CLK_ENABLE();

  __HAL_PWR_VOLTAGESCALING_CONFIG(PWR_REGULATOR_VOLTAGE_SCALE1);

  RCC_OscInitStruct.OscillatorType = RCC_OSCILLATORTYPE_HSE;
  RCC_OscInitStruct.HSEState = RCC_HSE_ON;
  RCC_OscInitStruct.PLL.PLLState = RCC_PLL_ON;
  RCC_OscInitStruct.PLL.PLLSource = RCC_PLLSOURCE_HSE;
  RCC_OscInitStruct.PLL.PLLM = 8;
  RCC_OscInitStruct.PLL.PLLN = 336;
  RCC_OscInitStruct.PLL.PLLP = RCC_PLLP_DIV2;
  RCC_OscInitStruct.PLL.PLLQ = 4;
  HAL_RCC_OscConfig(&RCC_OscInitStruct);

  RCC_ClkInitStruct.ClockType = RCC_CLOCKTYPE_SYSCLK|RCC_CLOCKTYP
                              |RCC_CLOCKTYPE_PCLK2;
  RCC_ClkInitStruct.SYSCLKSource = RCC_SYSCLKSOURCE_PLLCLK;
  RCC_ClkInitStruct.AHBCLKDivider = RCC_SYSCLK_DIV1;
  RCC_ClkInitStruct.APB1CLKDivider = RCC_HCLK_DIV4;
  RCC_ClkInitStruct.APB2CLKDivider = RCC_HCLK_DIV2;
  HAL_RCC_ClockConfig(&RCC_ClkInitStruct, FLASH_LATENCY_5);

}
```



HAL service peripherals
RCC – APIs

- SystemClock_Config function structure, generated by CubeMX

```
/** System Clock Configuration
*/
void SystemClock_Config(void)
{

  RCC_OscInitTypeDef RCC_OscInitStruct
  RCC_ClkInitTypeDef RCC_ClkInitStruct

  __PWR_CLK_ENABLE();

  __HAL_PWR_VOLTAGESCALING_CONFIG(PWR_

  RCC_OscInitStruct.OscillatorType = R
  RCC_OscInitStruct.HSEState = RCC_HSE
  RCC_OscInitStruct.PLL.PLLState = RCC
  RCC_OscInitStruct.PLL.PLLSource = RC
  RCC_OscInitStruct.PLL.PLLM = 8;
  RCC_OscInitStruct.PLL.PLLN = 336;
  RCC_OscInitStruct.PLL.PLLP = RCC_PLLP_DIV2;
  RCC_OscInitStruct.PLL.PLLQ = 4;
  HAL_RCC_OscConfig(&RCC_OscInitStruct);

  RCC_ClkInitStruct.ClockType = RCC_CLOCKTYPE_SYSCLK|RCC_CLOCKTYPE_PCLK1
                              |RCC_CLOCKTYPE_PCLK2;
  RCC_ClkInitStruct.SYSCLKSource = RCC_SYSCLKSOURCE_PLLCLK;
  RCC_ClkInitStruct.AHBCLKDivider = RCC_SYSCLK_DIV1;
  RCC_ClkInitStruct.APB1CLKDivider = RCC_HCLK_DIV4;
  RCC_ClkInitStruct.APB2CLKDivider = RCC_HCLK_DIV2;
  HAL_RCC_ClockConfig(&RCC_ClkInitStruct, FLASH_LATENCY_5);

}
```

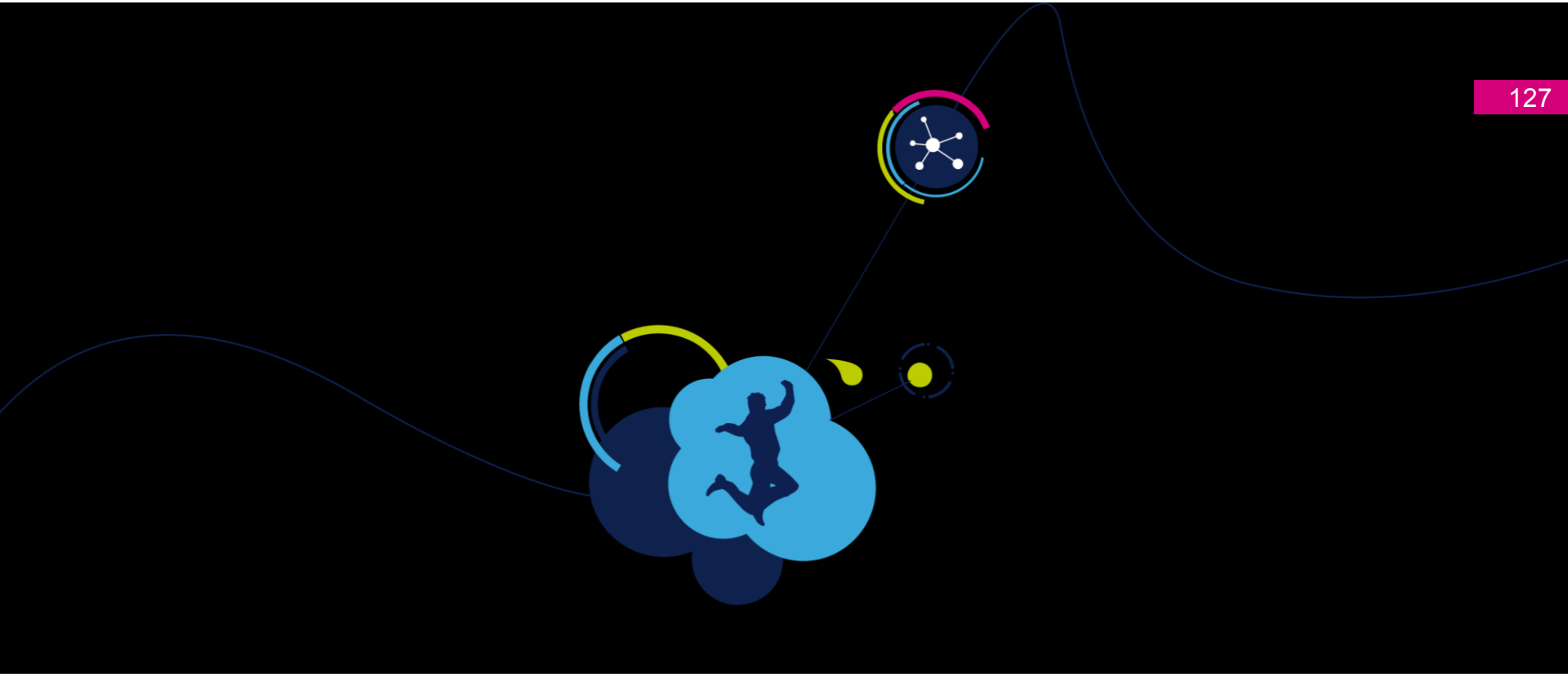


HAL service peripherals
RCC – other APIs

- Clock DeInit: returns to reset clock config
  - HAL_RCC_DeInit()
- Get Clock functions with config read from RCC registers
  - HAL_RCC_GetSysClockFreq()
  - HAL_RCC_GetHCLKFreq()
  - HAL_RCC_GetPCLK1Freq()
  - HAL_RCC_GetPCLK2Freq()
  - HAL_RCC_GetOscConfig()
  - HAL_RCC_GetClockConfig()
- MCO clock selection (it includes the GPIO AF config as MCO)
  - HAL_RCC_MCOConfig()
- CSS enable/disable and interrupt handling
  - HAL_RCC_EnableCSS() / HAL_RCC_DisableCSS()
  - HAL_RCC_NMI_IRQHandler()
  - HAL_RCC_CSSCallback()

HAL service peripherals
RCC – extension APIs

- For RCC block, the extension APIs cover specific product or family clock tree feature, for example
  - In F4x family, extension APIs (defined in file stm32f4xx_hal_rcc_ex.c) include:
    - Clock configuration of dedicated PLLs for SAI and I2S peripherals (PLLI2S, PLLSAI”
    - Clock source selection for RTC block
  - In L0x family, extension APIs (defined in stm32l0xx_hal_rcc_ex.c) include:
    - Clock source selection for some peripherals: USART1, USART2, LPUART, I2C, RTC, USB,…
    - LSE clock security system enable/disable
    - Clock Recovery system (CRS) config



HAL service peripherals – Core
Core peripherals handling

HAL service peripherals Cortex

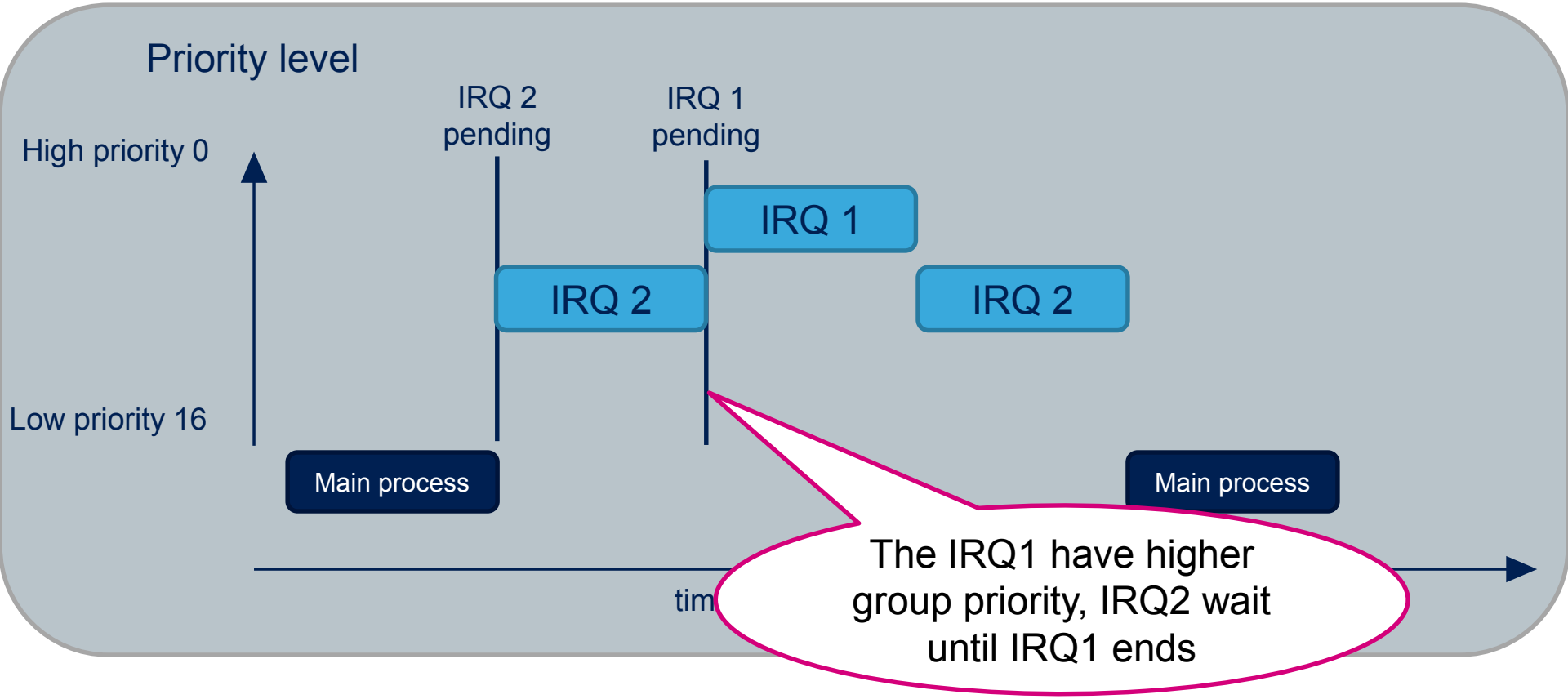
- Cortex HAL driver provides APIs for handling NVIC and Systick, supported APIs include
  - HAL_NVIC_SetPriorityGrouping
  - HAL_NVIC_SetPriority
  - HAL_NVIC_EnableIRQ /HAL_NVIC_DisableIRQ
  - HAL_SYSTICK_Config
  - HAL_SYSTICK_CLKSourceConfig

HAL service peripherals
NVIC Priority Grouping

- STM32 allow to use up to 4bits for Interrupt priorities
- User can decide how many bits will be used for Pre-empt (Group) priorities and for Subpriorities
  - By default set in HAL_Init() to 4bit for Group priorities
- Possible settings:

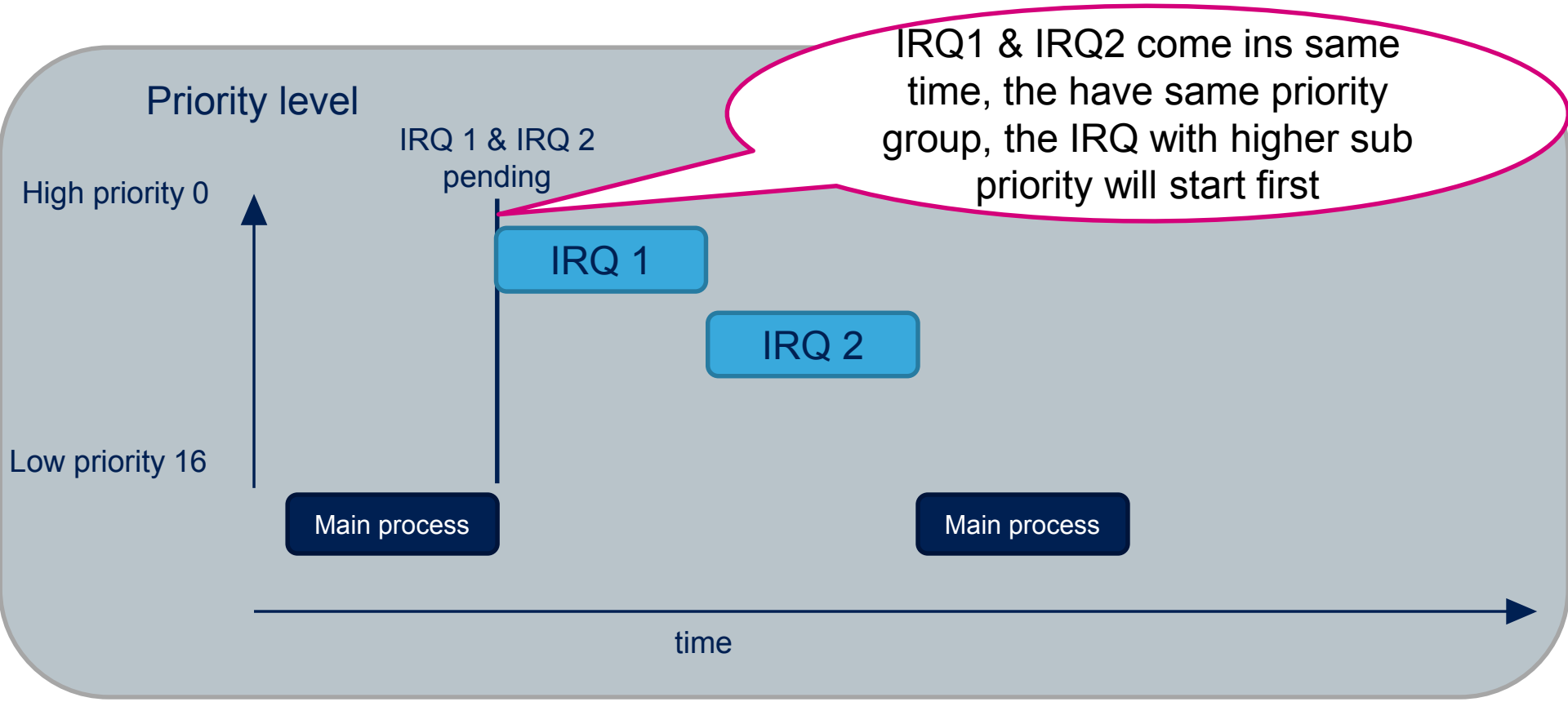
NVIC_PRIORITYGROUP_0	Subpriority bit 3	Subpriority bit 2	Subpriority bit 1	Subpriority bit 0
NVIC_PRIORITYGROUP_1	Pre-emption bit 0	Subpriority bit 2	Subpriority bit 1	Subpriority bit 0
NVIC_PRIORITYGROUP_2	Pre-emption bit 1	Pre-emption bit 0	Subpriority bit 1	Subpriority bit 0
NVIC_PRIORITYGROUP_3	Pre-emption bit 2	Pre-emption bit 1	Pre-emption bit 0	Subpriority bit 0
NVIC_PRIORITYGROUP_4	Pre-emption bit 3	Pre-emption bit 2	Pre-emption bit 1	Pre-emption bit 0

Group priority



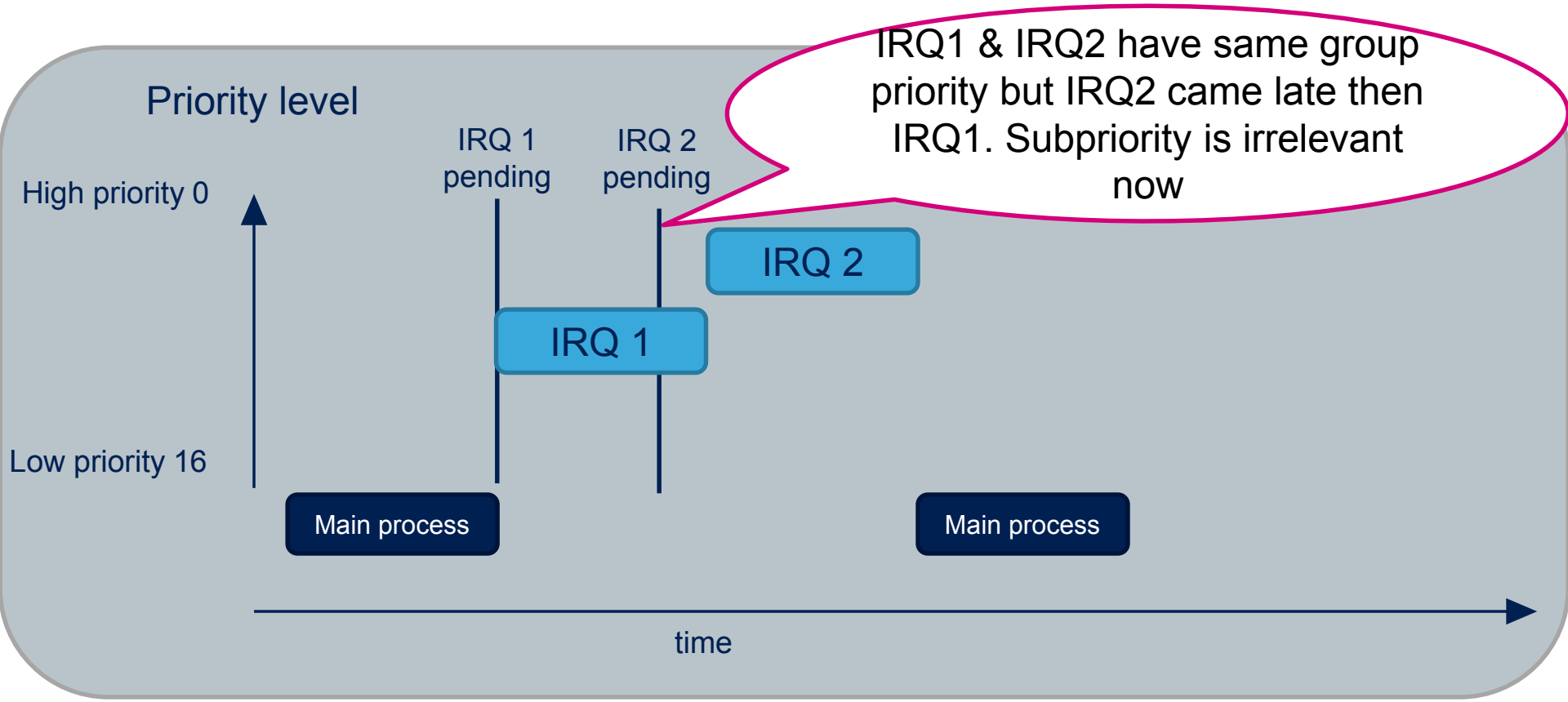
- IRQ1 - Group priority 0
- IRQ2 - Group priority 1

Sub priority



- IRQ1 - Group priority 0, Sub priority 0
- IRQ2 - Group priority 0, Sub priority 1

Sub priority



- IRQ1 - Group priority 0, Sub priority 1
- IRQ2 - Group priority 0, Sub priority 0

HAL service peripherals NVIC interrupt settings

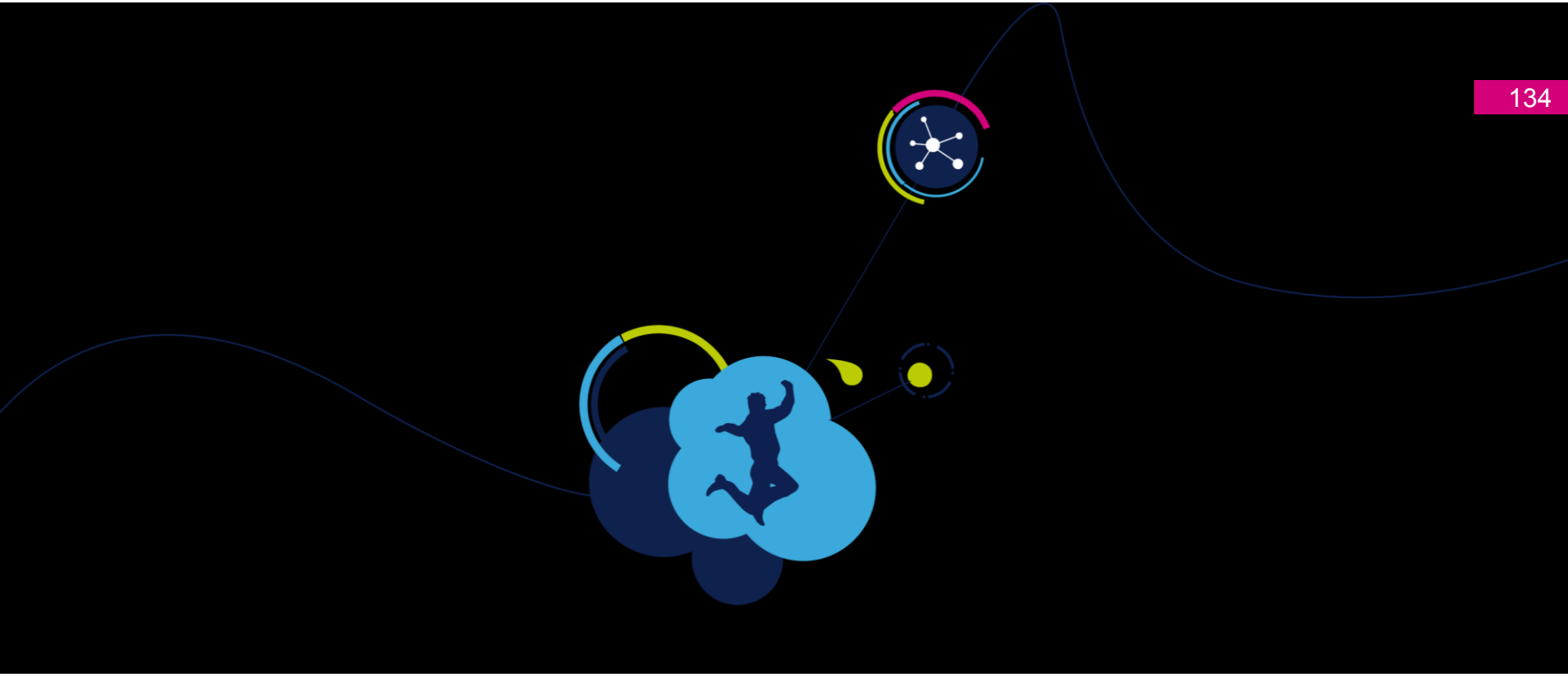
- For Interrupt Priority settings and for enable and disable are used:
  - HAL_NVIC_SetPriority
  - HAL_NVIC_EnableIRQ /HAL_NVIC_DisableIRQ
- Most important is the IRQn_Type which describe which interrupt will be set/enabled/disabled
- This parameter is defined in stm32f4xx.h

For STM32F429 in file stm32f429.h

```
/**
 * @brief STM32F4XX Interrupt Number Definition, according to the selected device
 *        in @ref Library_configuration_section
 */
typedef enum
{
/******  Cortex-M4 Processor Exceptions N                                    ******************************************/
  NonMaskableInt_IRQn         = -14,    /*!< 2 Non                                                                */
  MemoryManagement_IRQn       = -12,    /*!< 4 Cortex-M4 Memory Management Interrupt                              */
  BusFault_IRQn               = -11,    /*!< 5 Cortex-M4 Bus Fault Interrupt                                      */
  UsageFault_IRQn             = -10,    /*!< 6 Cortex-M4 Usage Fault Interrupt                                    */
  SVCall_IRQn                 = -5,     /*!< 11 Cortex-M4 SV Call Interrupt                                       */
  DebugMonitor_IRQn           = -4,     /*!< 12                                                                   */
  PendSV_IRQn                 = -2,     /*!<                                                                      */
  SysTick_IRQn                = -1,     /*!<                                                                      */
/******  STM32 specific Interrupt Numbers                                   ******************************************/
  WWDG_IRQn                   = 0,      /*!< Window WatchDog Interrupt                                            */
  PVD_IRQn                    = 1,      /*!< PVD through EXTI Line detection Interrupt                            */
  TAMP_STAMP_IRQn             = 2,      /*!< Tamper and TimeStamp interrupts through the EXTI line                */
```

Defined by ARM

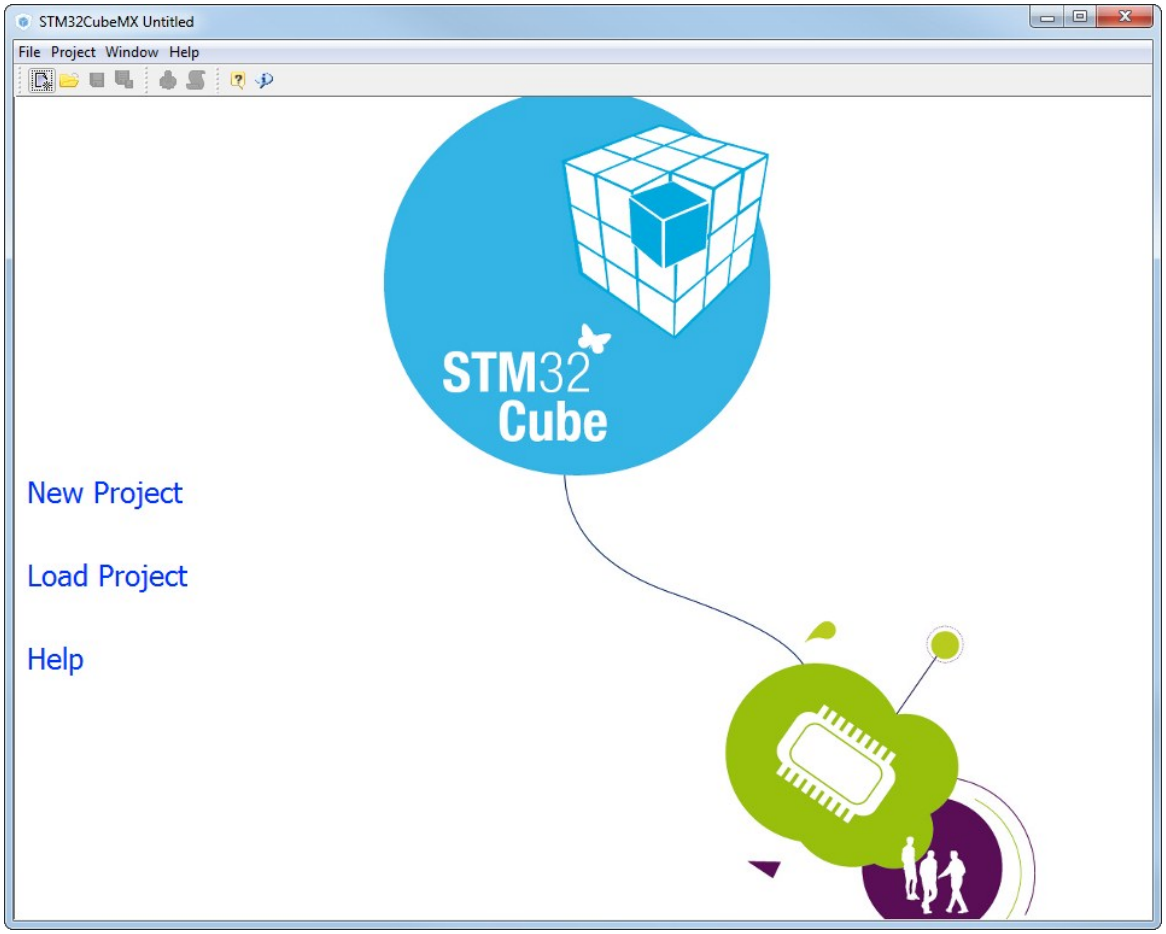
Specific for STM32F429



HAL service peripherals - GPIO
General purpose I/Os

Use GPIO lab

- Use GPIO lab to create project with GPIO
- We use this project for better demonstration how the HAL library works



HAL service peripherals
GPIO - initialization structure

- Two new features compared to std library GPIO driver
  - A pin can be configured as EXTI with interrupt or event generation
  - Alternate field allows selection of the Alternate function for a pin (AFxx)

```
/**
  * @brief   GPIO Init structure definition
  */
typedef struct
{
  uint32_t Pin;       /*!< Specifies the GPIO pins to be configured.
                           This parameter can be any value of @ref GPIO_pins_define */

  uint32_t Mode;      /*!< Specifies the operating mode for the selected pins.
                           This parameter can be a value of @ref GPIO_mode_define */

  uint32_t Pull;      /*!< Specifies the Pull-up or Pull-Down activation for the selected pins.
                           This parameter can be a value of @ref GPIO_pull_define */

  uint32_t Speed;     /*!< Specifies the speed for the selected pins.
                           This parameter can be a value of @ref GPIO_speed_define */

  uint32_t Alternate;  /*!< Peripheral to be connected to the selected pins.
                            This parameter can be a value of @ref GPIO_Alternat_function_selection
*/
}GPIO_InitTypeDef;
```

HAL service peripherals
GPIO – initialization – GPIO Mode

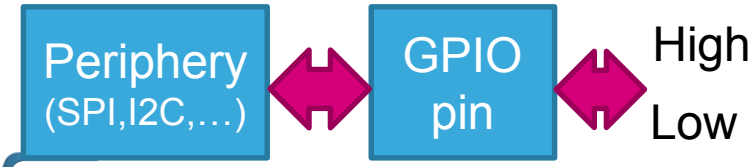
GPIO_MODE_OUTPUT_PP

GPIO_MODE_OUTPUT_OD

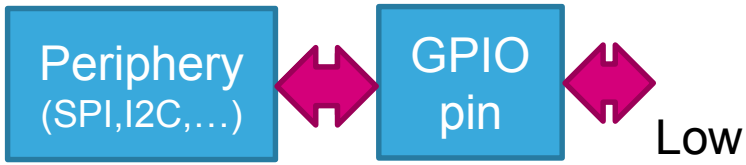
GPIO_MODE_INPUT

GPIO_MODE_ANALOG

GPIO_MODE_AF_PP



GPIO_MODE_AF_OD



HAL service peripherals
GPIO – initialization – GPIO Mode

GPIO_MODE_IT_RISING

GPIO_MODE_IT_FALLING

GPIO_MODE_IT_RISING_FALLING

GPIO_MODE_EVT_RISING

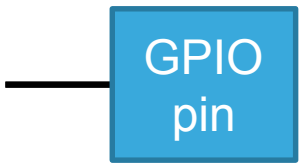
GPIO_MODE_EVT_FALLING

GPIO_MODE_EVT_RISING_FALLING

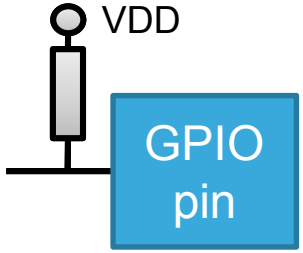
life.augmented

HAL service peripherals
GPIO – initialization – GPIO Pull

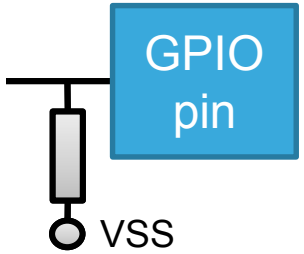
GPIO_NOPULL



GPIO_PULLUP



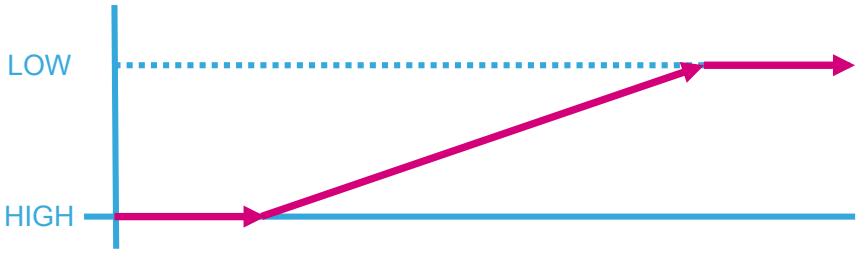
GPIO_PULLDOWN



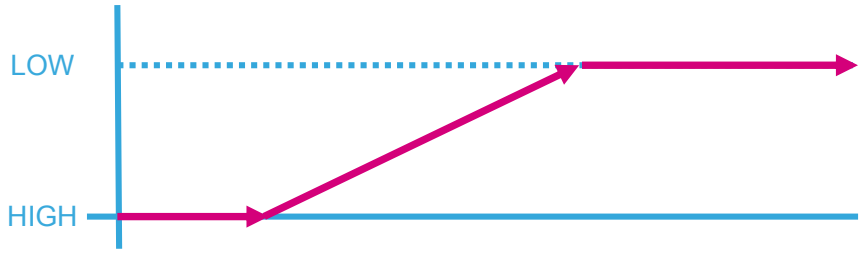
HAL service peripherals
GPIO – initialization – GPIO Speed

- GPIO(Pin) output speed configuration
  - Change the rising and falling edge when pin change state from high to low or low to high
  - **Higher** GPIO speed increase **EMI noise** from STM32 and increase STM32 **consumption**
  - It is good to adapt GPIO speed with periphery speed. Ex.: Toggling GPIO on 1Hz is LOW optimal settings, but SPI on 45MHz the HIGH must be set

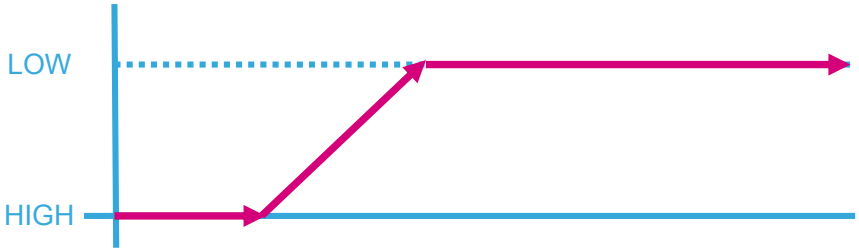
GPIO output LOW speed



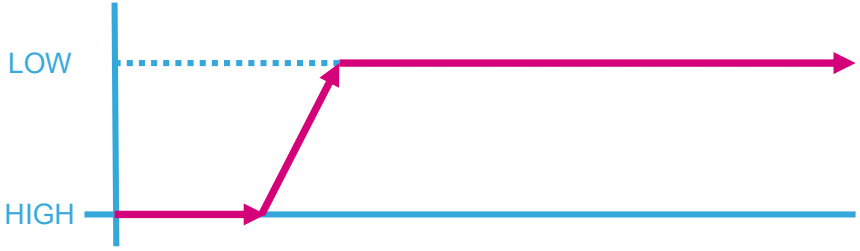
GPIO output MEDIUM speed



GPIO output FAST speed

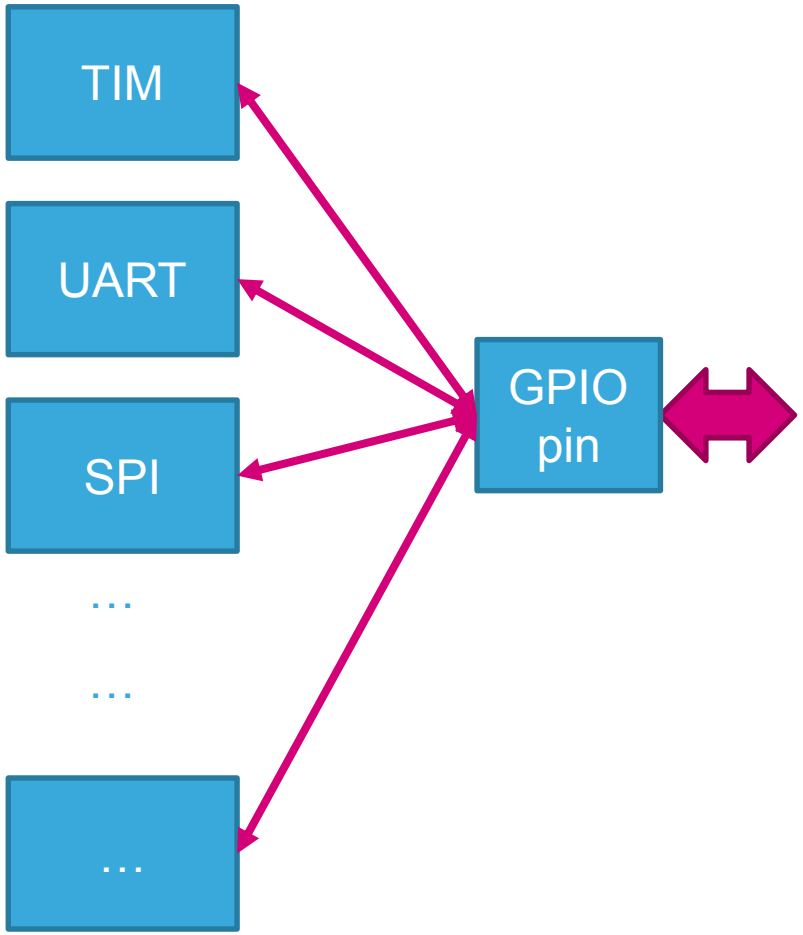


GPIO output HIGH speed



HAL service peripherals
GPIO – initialization – GPIO Alternate

Select alternate function for GPIO



HAL service peripherals
GPIO – APIs

- The following APIs are provided

HAL_GPIO_Init()	Initialize the GPIO pins with parameters in initialization structure
HAL_GPIO_DeInit()	Deinitialize the GPIO to default state
HAL_GPIO_ReadPin()	Read the state on selected pin
HAL_GPIO_WritePin()	Change state of selected pin
HAL_GPIO_TogglePin()	Change state on selected pin to oposite

HAL service peripherals GPIO – APIs

- Main function structure, generated by CubeMX

```
int main(void)
{
  /* USER CODE BEGIN 1 */

  /* USER CODE END 1 */
  /* MCU Configuration----                                    ----------*/
  /* Reset of all peri                                    ace and the Systick. */
  HAL_Init();
  /* Configure the system clock */
  SystemClock_Config();
  /* Initialize all configu
  MX_GPIO_Init();
  /* USER CODE BEGIN 2 */

  /* USER CODE END 2 */
  /* USER CODE BEGIN 3 */
  /* Infinite loop */
  while (1)
  {

  }
  /* USER CODE END 3 */
}
```

Initialize Systick, NVIC, and call HAL_Init_MSP

Initialize STM32 clock tree, based on Clock Configuration in CubeMX

Initialize GPIO which are not used with any other periphery

HAL service peripherals
GPIO – APIs

- MX_GPIO_Init function structure, generated by CubeMX

```
/** Configure pins as
        * Analog
        * Input
        * Output
        * EVENT_OUT
        * EXTI
*/
void MX_GPIO_Init(void)
{

  GPIO_InitTypeDef GPIO_InitStruct;

  /* GPIO Ports Clock Enable
  __GPIOG_CLK_ENABLE();

  /*Configure GPIO pin : PG14 */
  GPIO_InitStruct.Pin = GPIO_PIN_14;
  GPIO_InitStruct.Mode = GPIO_MODE_OUTPUT_PP;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  GPIO_InitStruct.Speed = GPIO_SPEED_LOW;
  HAL_GPIO_Init(GPIOG, &GPIO_InitStruct);

}
```

Enable clock for GPIO port

Initialize the GPIO pin configured in CubeMX

Initialize the GPIO registers

HAL service peripherals
GPIO – APIs

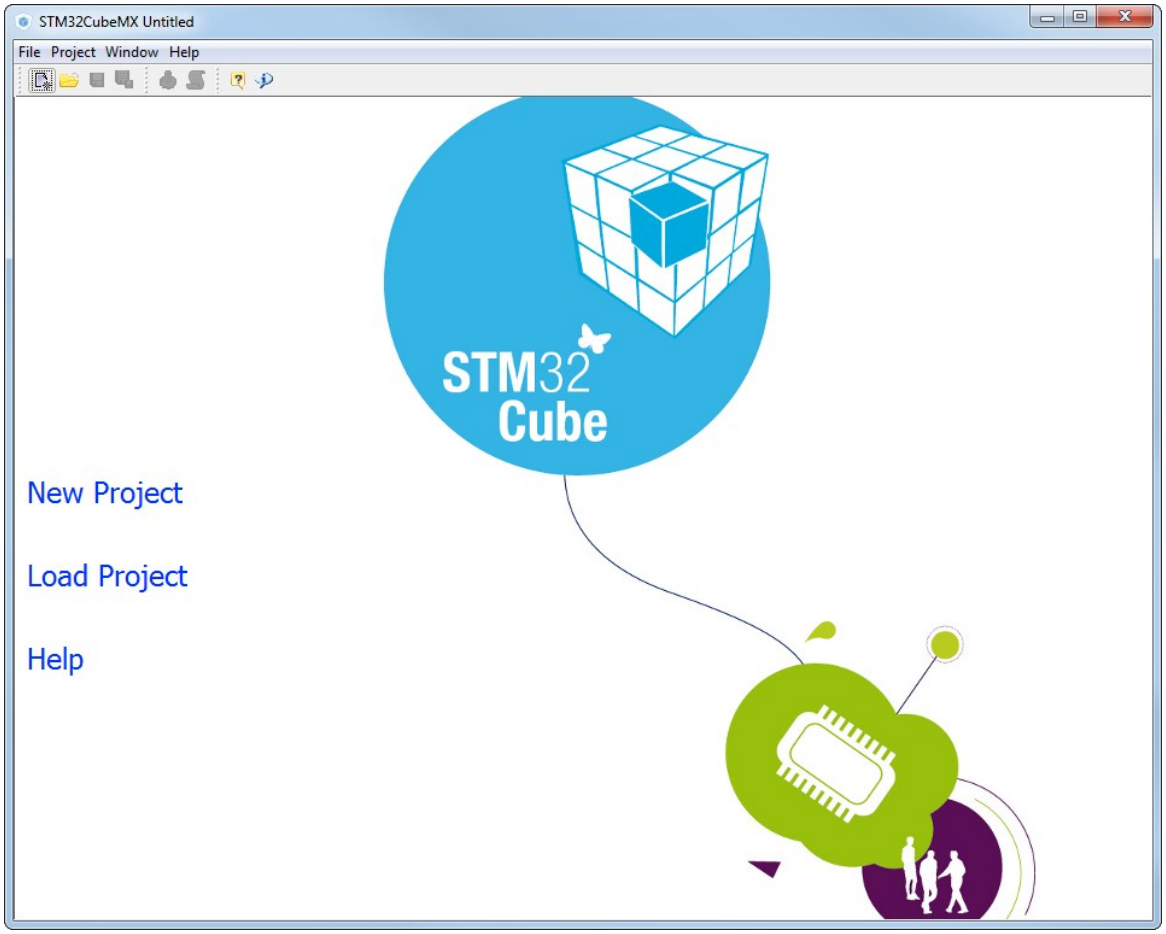
- MX_GPIO_Init function structure, generated by CubeMX

```
/** Configure pins as
        * Analog
        * Input
        * Output
        * EVENT_OUT
        * EXTI
*/
void MX_GPIO_Init(void)
{

  GPIO_InitTypeDef GPIO_InitStruct;

  /* GPIO Ports Clock Enable */
  __GPIOG_CLK_ENABLE();

  /*Configure GPIO pin : PG14 */
  GPIO_InitStruct.Pin = GPIO_PIN_14;
  GPIO_InitStruct.Mode = GPIO_MODE_OUTPUT_PP;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  GPIO_InitStruct.Speed = GPIO_SPEED_LOW;
  HAL_GPIO_Init(GPIOG, &GPIO_InitStruct);

}
```

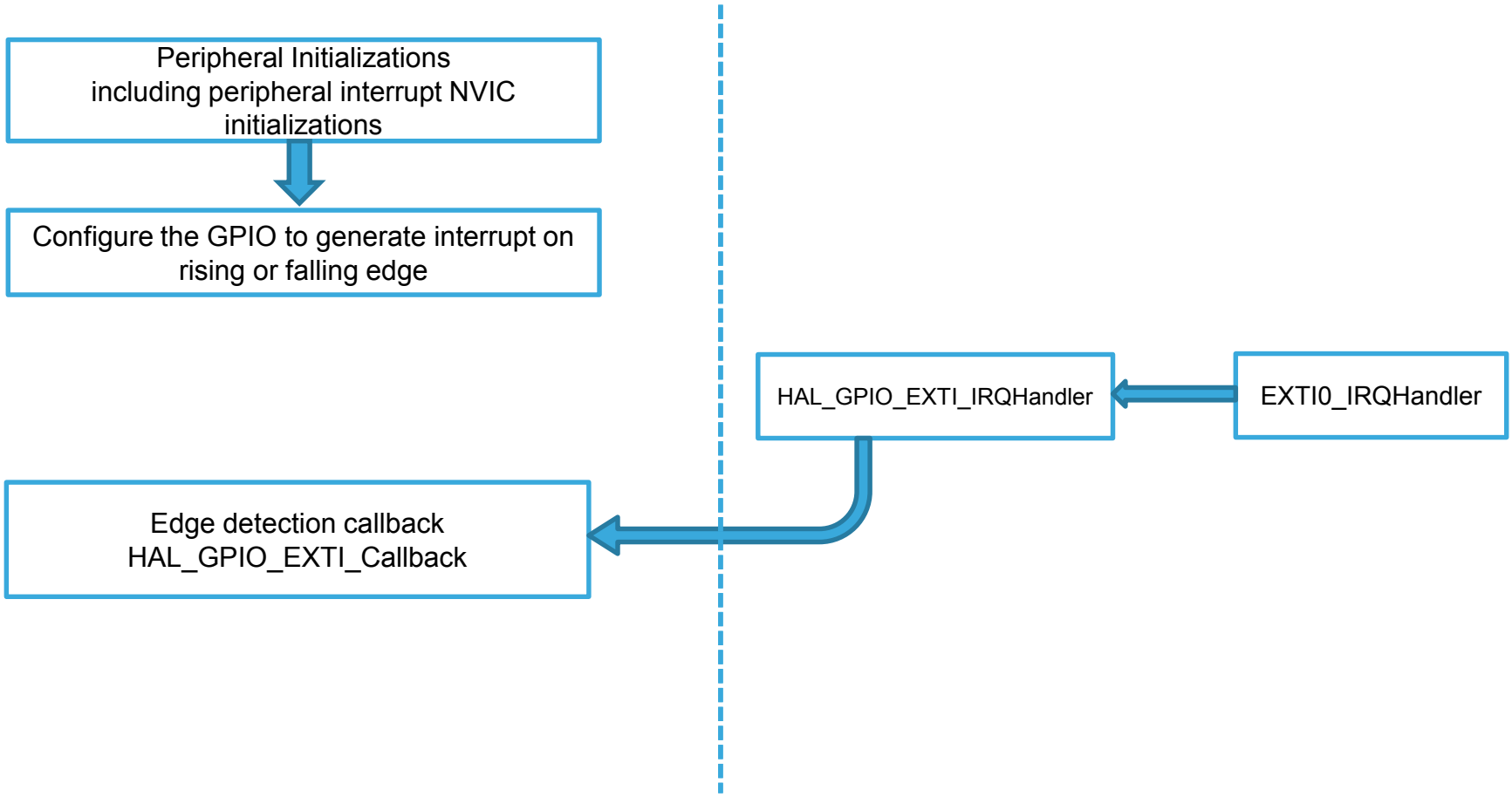
Like other Service init functions HAL_GPIO_Init have **no MSP** function

Use EXTI lab

- Use EXTI lab to create project with GPIO
- We use this project for better demonstration how the HAL library works



HAL EXTI workflow



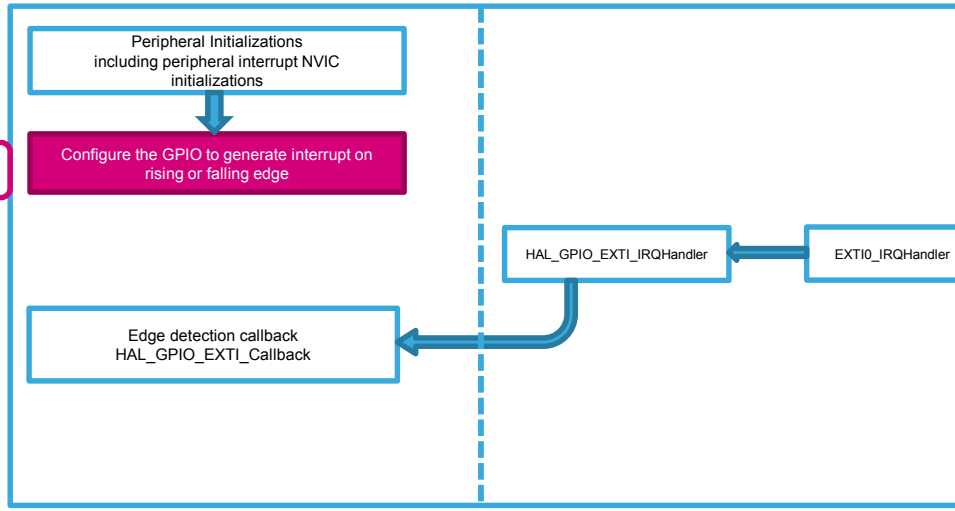
Use EXTI lab

- GPIO with EXTI initialization in main.c

```
/** Configure pins as
        * Analog
        * Input
        * Output
        * EVENT_OUT
        * EXTI
*/
void MX_GPIO_Init(void)
{
  GPIO_InitTypeDef GPIO_InitStruct;
  /* GPIO Ports Clock Enable */
  __GPIOA_CLK_ENABLE();
  /*Configure GPIO pin : PA0 */
  GPIO_InitStruct.Pin = GPIO_PIN_0;
  GPIO_InitStruct.Mode = GPIO_MODE_IT_RISING;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);
  /* EXTI interrupt init*/
  HAL_NVIC_SetPriority(EXTI0_IRQn, 0, 0);
  HAL_NVIC_EnableIRQ(EXTI0_IRQn);
}
```

Rising edge with interrupt mode select

NVIC configuration

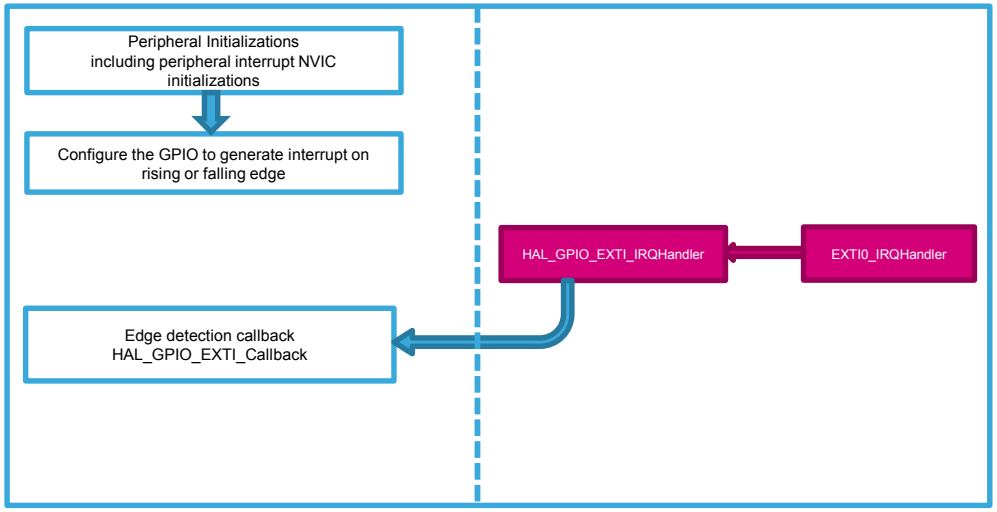


Use EXTI lab

- Interrupt handling in stm32f4xx_it.c

```
/**
* @brief This function handles EXTI Line0 interrupt.
*/
void EXTI0_IRQHandler(void)
{
  /* USER CODE BEGIN EXTI0_IRQn 0 */

  /* USER CODE END EXTI0_IRQn 0 */
  HAL_GPIO_EXTI_IRQHandler(GPIO_PIN_0);
  /* USER CODE BEGIN EXTI0_IRQn 1 */

  /* USER CODE END EXTI0_IRQn 1 */
}
```

Call HAL_GPIO_EXTI_IRQHandler parameter is pin for which we want check the interrupt state GPIO/EXTI don't need any handler



Use EXTI lab

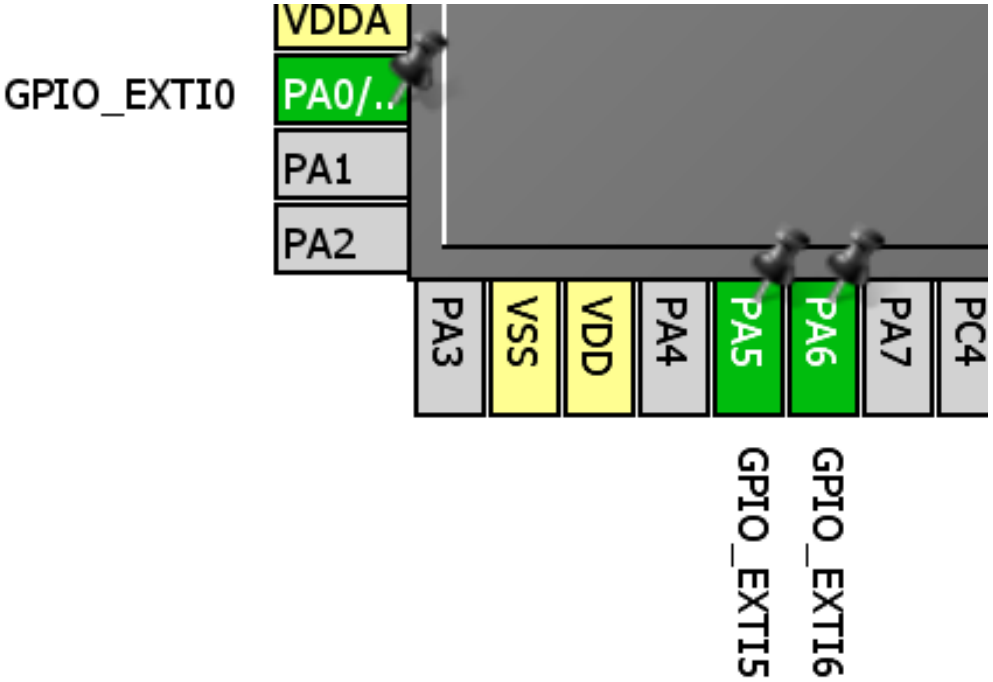
- EXTI interrupt callback
- Need to by defined by user, in default defined as __weak
- Can be found in hal_stm32f4xx_gpio.c

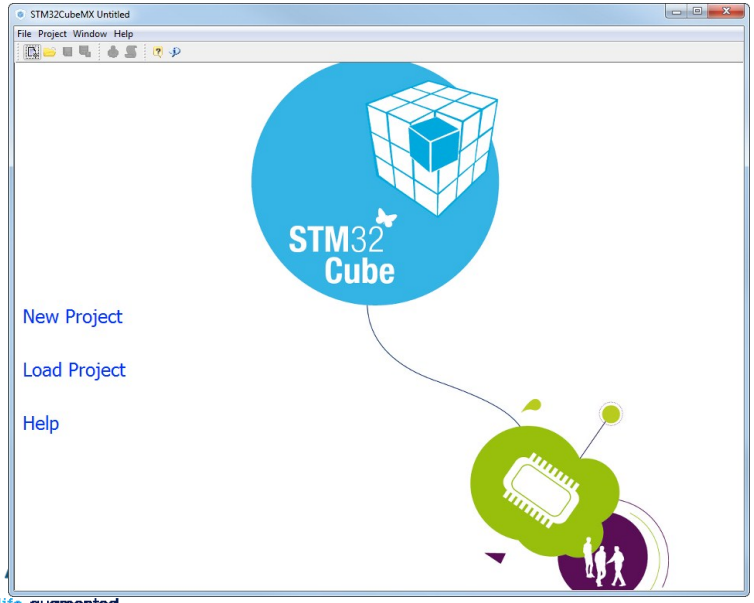
```
/**
  * @brief  EXTI line detection callbacks.
  * @param  GPIO_Pin: Specifies the pins connected EXTI line
  * @retval None
  */
__weak void HAL_GPIO_EXTI_Callback(uint16_t GPIO_Pin)
{
  /* NOTE: This function Should not be modified, when the callback is needed,
           the HAL_GPIO_EXTI_Callback could be implemented in the user file
   */
}


/* USER CODE BEGIN 4 */
void HAL_GPIO_EXTI_Callback(uint16_t GPIO_Pin)
{

}
/* USER CODE END 4 */
```

User defined in main.c

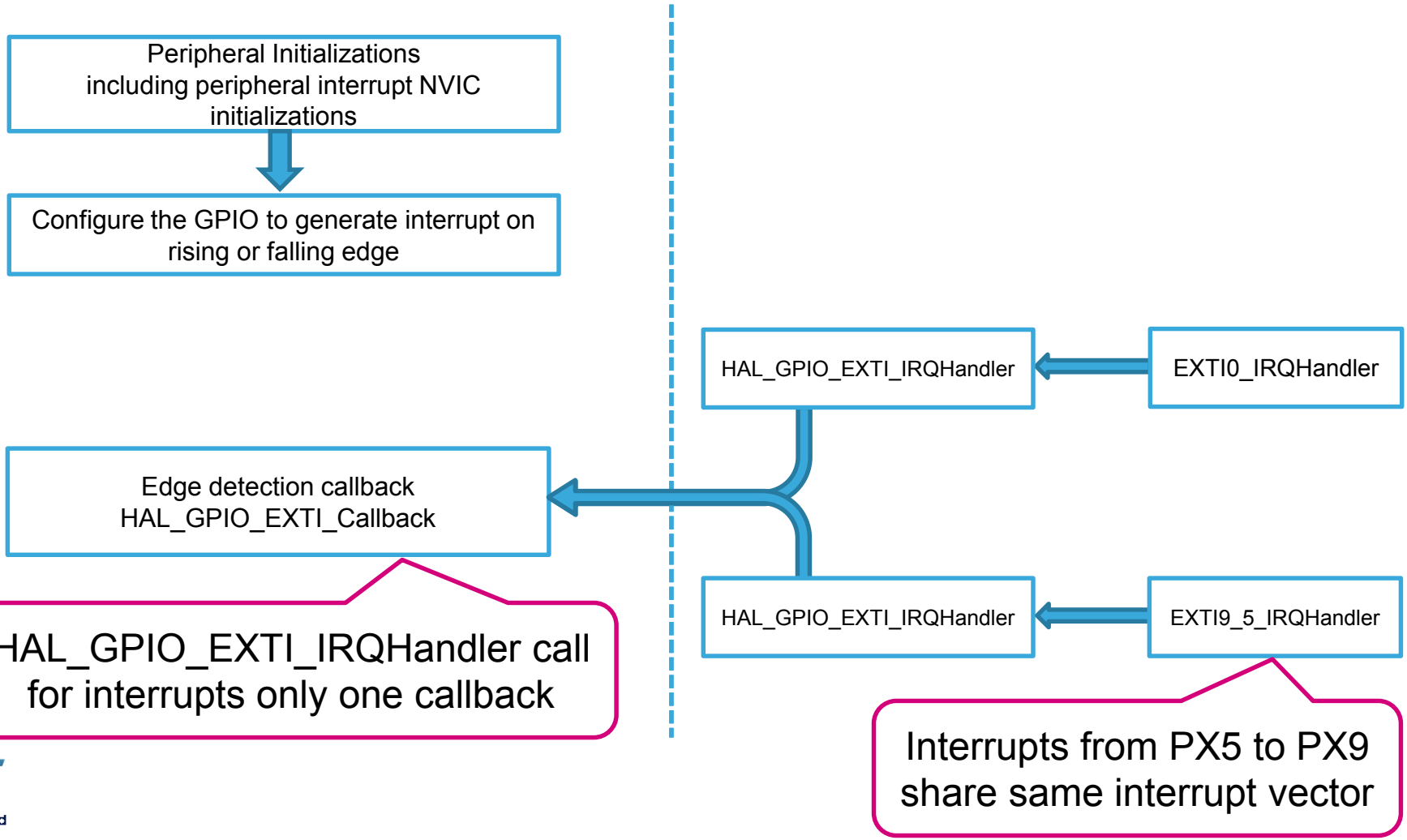
Use EXTI lab

- EXTI lab extension
- Use now the same example but now use two or more EXTI pins
- You can use only EXTI with different number





HAL multiple EXTI workflow



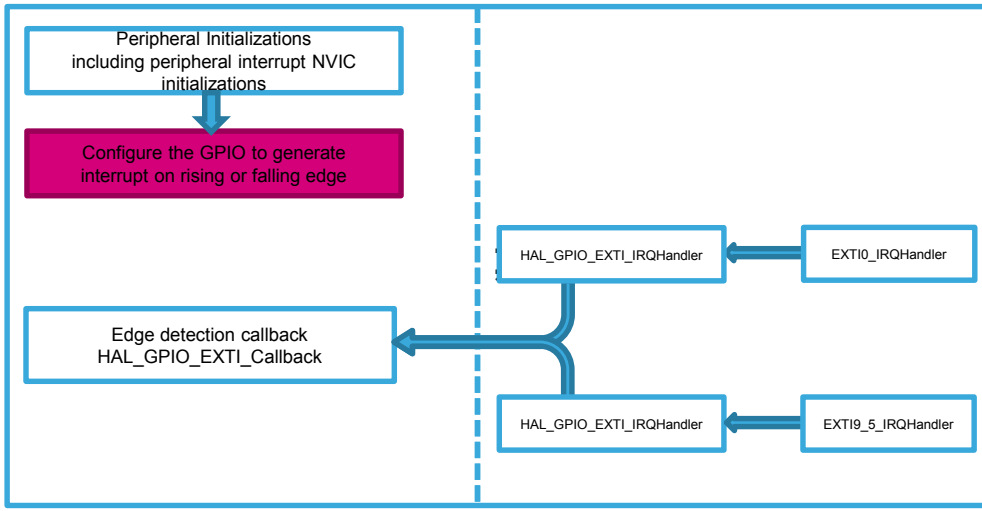
Use EXTI lab

- GPIO with EXTI initialization in main.c

```
/** Configure pins as
        * Analog
        * Input
        * Output
        * EVENT_OUT
        * EXTI
*/
void MX_GPIO_Init(void)
{
  GPIO_InitTypeDef GPIO_InitStruct;
  /* GPIO Ports Clock Enable */
  __GPIOA_CLK_ENABLE();
  /*Configure GPIO pins : PA0 PA5 PA6 */
  GPIO_InitStruct.Pin = GPIO_PIN_0|GPIO_PI       O_PIN_6;
  GPIO_InitStruct.Mode = GPIO_MODE_IT_RIS;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);
  /* EXTI interrupt init*/
  HAL_NVIC_SetPriority(EXTI0_IRQn, 0, 0);
  HAL_NVIC_EnableIRQ(EXTI0_IRQn);

  HAL_NVIC_SetPriority(EXTI9_5_IRQn, 0, 0);
  HAL_NVIC_EnableIRQ(EXTI9_5_IRQn);

}
```

Interrupt enable for PA0

Interrupt enable for PA5 and PA6

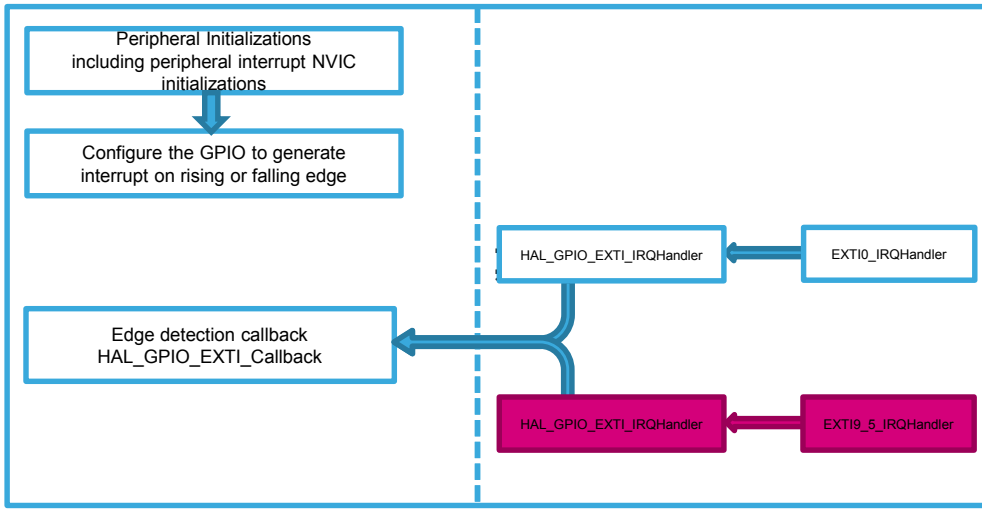


Use EXTI lab

- Interrupt handling in stm32f4xx_it.c

```
/**
* @brief This function handles EXTI Line[9:5] interrupts.
*/
void EXTI9_5_IRQHandler(void)
{
  /* USER CODE BEGIN EXTI9_5_IRQn 0 */

  /* USER CODE END EXTI9_5_IRQn 0 */
  HAL_GPIO_EXTI_IRQHandler(GPIO_PIN_5);
  HAL_GPIO_EXTI_IRQHandler(GPIO_PIN_6);
  /* USER CODE BEGIN EXTI9_5_IRQn 1 */

  /* USER CODE END EXTI9_5_IRQn 1 */
}
```

If EXTI interrupt handle multiple pins we must call HAL_GPIO_EXTI_IRQHandler for each of them



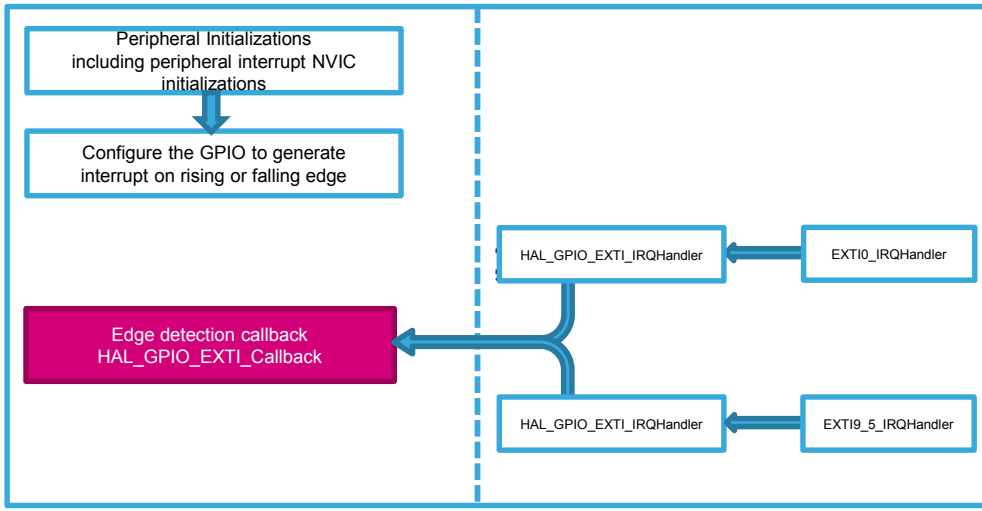
Use EXTI lab

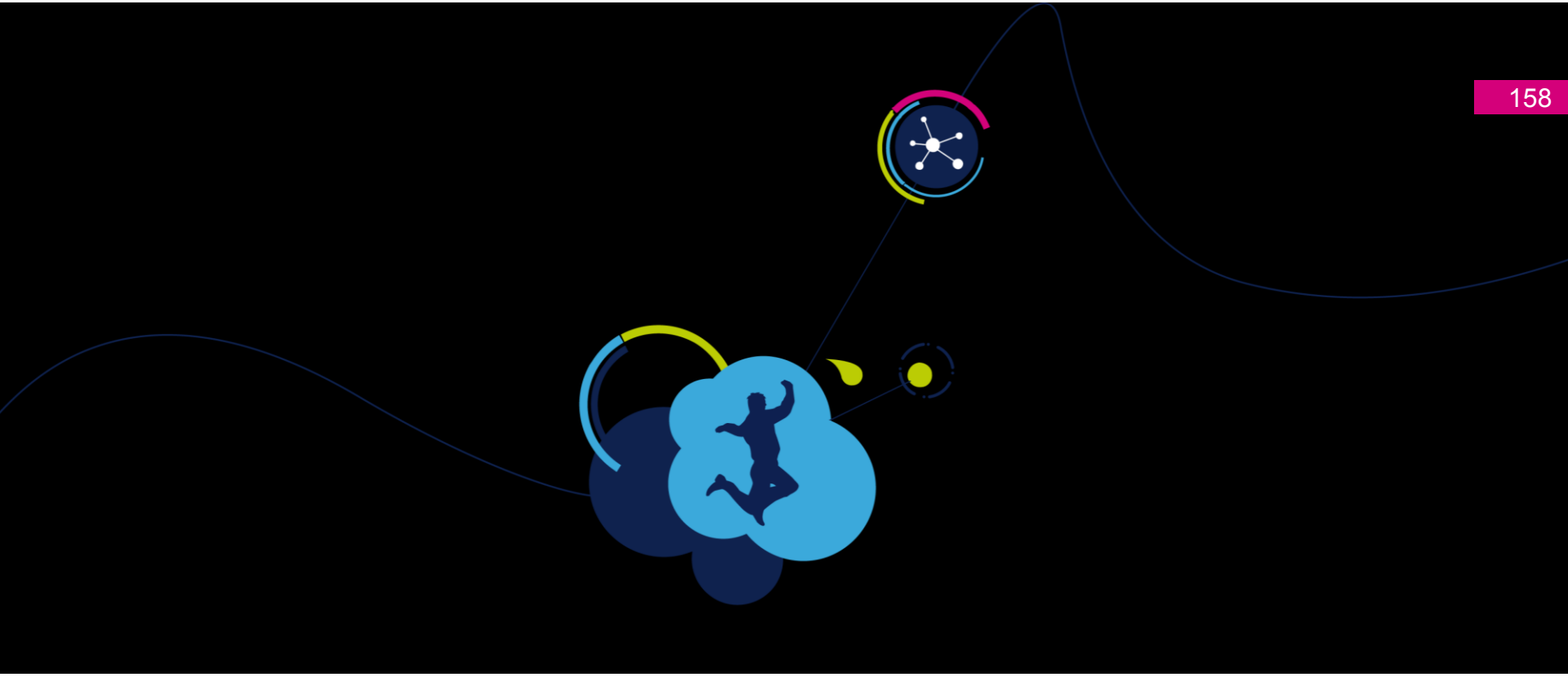
- Need to by defined by user, in default defined as __weak

```
/* USER CODE BEGIN 4 */
void HAL_GPIO_EXTI_Callback(uint16_t GPIO_Pin){
  switch(GPIO_Pin){
    case GPIO_PIN_0:
      /*GPIO_PIN_0 EXTI handling*/
      break;
    case GPIO_PIN_5:
      /*GPIO_PIN_5 EXTI handling*/
      break;
    case GPIO_PIN_6:
      /*GPIO_PIN_6 EXTI handling*/
      break;
    default:
      break;
  }
}
/* USER CODE END 4 */
```

HAL_GPIO_EXTI_IRQHandler use only one callback for all interrupts

Here we can use SWITCH to handle correct action for specific pin

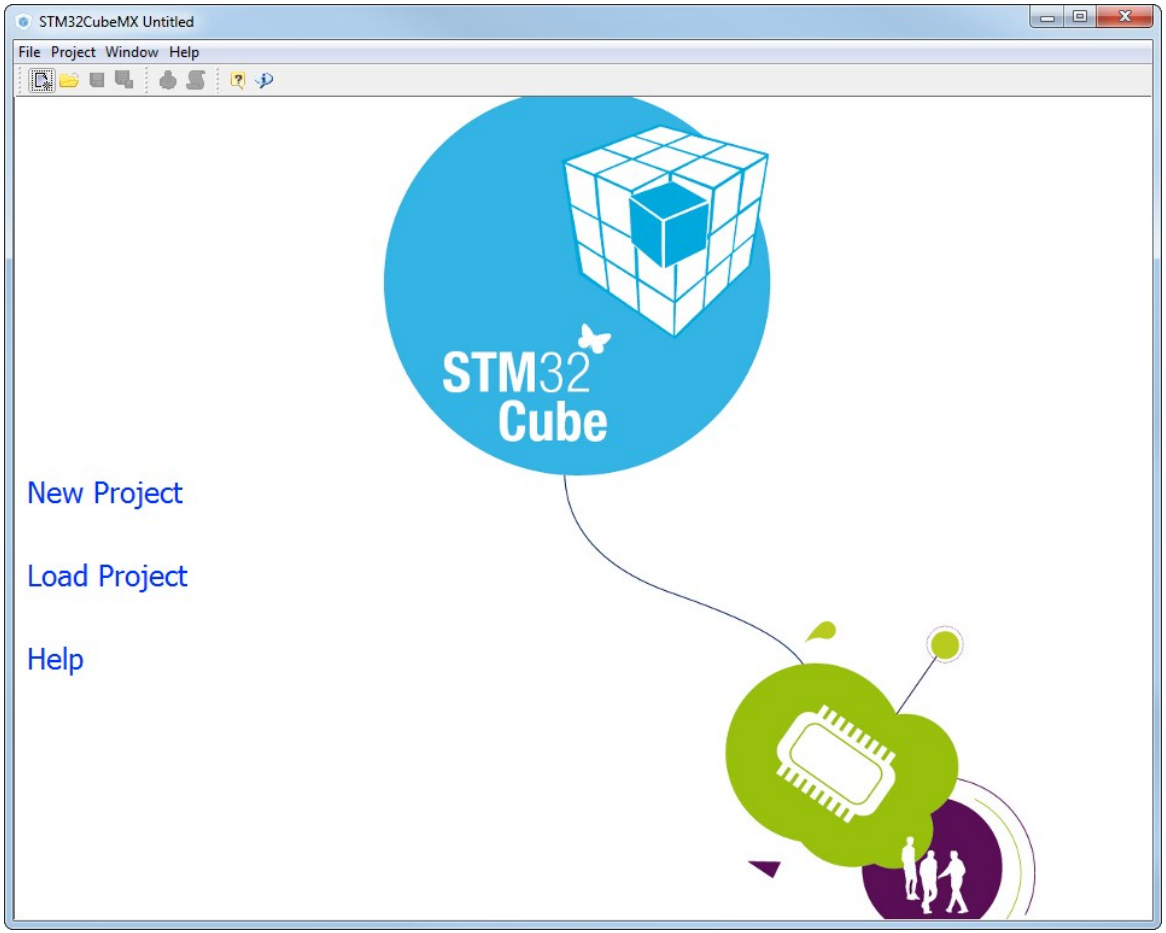




HAL service peripherals - DMA
DIRECT MEMORY ACCESS

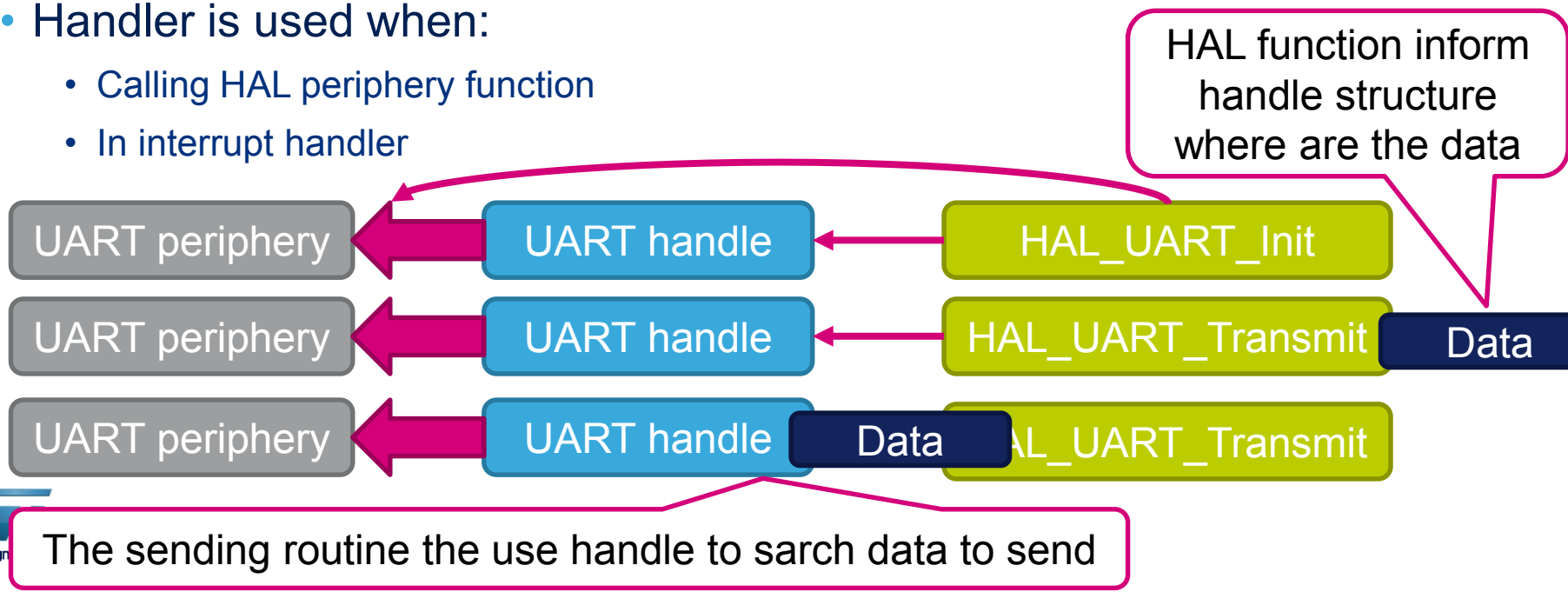
Use DMA Poll lab

- Use **DMA Poll** lab to create project with DMA
- We use this project for better demonstration how the HAL library works



Handle structures

- Many of Cube HAL function require handle for correct function(DMA, TIM, UART, …)
- Each periphery must have own handle
- Handle for periphery must be defined only once. CubeMX define it in main.c
- Handler is used when:
  - Calling HAL periphery function
  - In interrupt handler



Handle structures

- Handle is basic structure contains information about periphery
  - Instance
    - Define which periphery is it(ex. TIM1, or TIM5)
    - Only one instance per handler
  - Init
    - Here are stored initialization parameters for periphery(ex.: DMA: destination address)
  - Lock
    - Lock to periphery status, cannot be used from different function or thread
  - Status
    - Status of periphery(Ready, Busy or Error)
  - Error
    - Indicate which type of error was indicated during operation
  - Parent
    - If DMA work with other periphery(ex. SPI) this points to periphery handler
  - Callbacks
    - Callback to other functions (Complete callback, HalfTransferComplete callback, Error callback, …)
    - Depends on type of periphery
  - Periphery dependent parts
    - Unique for each periphery

HAL service peripherals
DMA – HAL APIs Handle structure

- DMA HAL APIs use a DMA Handle structure as parameter, it is defined as following:

Defined in stm32f4xx_hal_dma.h

```
/**
  * @brief  DMA handle Structure definition
  */
typedef struct __DMA_HandleTypeDef
{
  DMA_Stream_TypeDef        *Instance;                                                    /*!< Register base address                */
  DMA_InitTypeDef           Init;                                                        /*!< DMA communication parameters         */
  HAL_LockTypeDef           Lock;                                                        /*!< DMA locking object                   */
  __IO HAL_DMA_StateTypeDef State;                                                       /*!< DMA transfer state                   */
  void                      *Parent;                                                     /*!< Parent object state                  */
  void                      (* XferCpltCallback)( struct __DMA_HandleTypeDef * hdma);    /*!< DMA transfer complete callback       */
  void                      (* XferHalfCpltCallback)( struct __DMA_HandleTypeDef * hdma);/*!< DMA Half transfer complete callback  */
  void                      (* XferM1CpltCallback)( struct __DMA_HandleTypeDef * hdma);  /*!< DMA transfer complete Memory1 callback */
  void                      (* XferErrorCallback)( struct __DMA_HandleTypeDef * hdma);   /*!< DMA transfer error callback          */
  __IO uint32_t             ErrorCode;                                                   /*!< DMA Error code                       */
}DMA_HandleTypeDef;
```

Pointer to DMA stream instance (ex: DMA1_Stream0)

DMA channel init structure

DMA channel state

DMA parent

DMA channel callbacks

- **DMA channel callbacks need to be initialized by user only in case of memory to memory transfer.**

- For peripheral - memory transfers, the HAL peripheral driver offer APIs that handles DMA transfer for peripheral ((ex: HAL_USART_Receive_DMA()) these APIs will assign callback functions.

HAL service peripherals
DMA – HAL APIs Init structure


```
/**
  * @brief  DMA Configuration Structure definition
  */
typedef struct
{
  uint32_t Channel;             /*!< Specifies the channel used for the specified stream.
                                     This parameter can be a value of @ref DMA_Channel_selection
  uint32_t Direction;           /*!< Specifies if the data will be transferred from memory to periphe
                                     from memory to memory or from peripheral to memory.
                                     This parameter can be a value of @ref DMA_Data_transfer_dire
  uint32_t PeriphInc;           /*!< Specifies whether the Peripheral address register should be increme
                                     This parameter can be a value of @ref DMA_Peripheral_incremented_mo
  uint32_t MemInc;              /*!< Specifies whether the memory address register should be incremented or not.
                                     This parameter can be a value of @ref DMA_Memory_incremented_mode          */
  uint32_t PeriphDataAlignment; /*!< Specifies the Peripheral data width.
                                     This parameter can be a value of @ref DMA_Peripheral_data_size             */
  uint32_t MemDataAlignment;    /*!< Specifies the Memory data width.
                                     This parameter can be a value of @ref DMA_Memory_data_size                 */
  uint32_t Mode;                /*!< Specifies the operation mode of the DMAy Streamx.
                                     This parameter can be a value of @ref DMA_mode
                                     @note The circular buffer mode cannot be used if the memory-to-memory
                                           data transfer is configured on the selected Stream                   */
  uint32_t Priority;            /*!< Specifies the software priority for the DMAy Streamx.
                                     This parameter can be a value of @ref DMA_Priority_level                   */
  uint32_t FIFOMode;            /*!< Specifies if the FIFO mode or Direct mode will be used for the specified stream.
                                     This parameter can be a value of @ref DMA_FIFO_direct_mode
                                     @note The Direct mode (FIFO mode disabled) cannot be used if the
                                           memory-to-memory data transfer is configured on the selected stream  */
  uint32_t FIFOThreshold;       /*!< Specifies the FIFO threshold level.
                                     This parameter can be a value of @ref DMA_FIFO_threshold_level              */
  uint32_t MemBurst;            /*!< Specifies the Burst transfer configuration for the memory transfers.
                                     It specifies the amount of data to be transferred in a single non interruptable
                                     transaction.
                                     This parameter can be a value of @ref DMA_Memory_burst
                                     @note The burst mode is possible only if the address Increment mode is enabled. */
  uint32_t PeriphBurst;         /*!< Specifies the Burst transfer configuration for the peripheral transfers.
                                     It specifies the amount of data to be transferred in a single non interruptable
                                     transaction.
                                     This parameter can be a value of @ref DMA_Peripheral_burst
                                     @note The burst mode is possible only if the address Increment mode is enabled. */
}DMA_InitTypeDef;
```

IN this structure are stored information about DMA.
Define in stm32f4xx_hal_dma.h

HAL service peripherals
DMA M2M code from CubeMX

- CubeMX create DMA handler in main.c

```
/* Includes ------------------------------------------------------------------*/
#include "stm32f4xx_hal.h"

/* USER CODE BEGIN Includes */

/* USER CODE END Includes */

/* Private variables ---------------------------------------------------------*/
DMA_HandleTypeDef hdma_memtomem_dma2_stream0;

/* USER CODE BEGIN PV */
```

DMA handler type

DMA handler name

HAL service peripherals
DMA M2M code from CubeMX

- If M2M transfer is selected, CubeMX create and call MX_DMA_Init

```
int main(void)
{
  /* USER CODE BEGIN 1 */
  /* USER CODE END 1 */
  /* MCU Configuration--------------------------------------------------------*/
  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();
  /* Configure the system clock */
  SystemClock_Config();
  /* Initialize all configur
  MX_DMA_Init();
  /* USER CODE BEGIN 2 */
  /* USER CODE END 2 */
  /* USER CODE BEGIN 3 */
  /* Infinite loop */
  while (1)
  {
  }
  /* USER CODE END 3 */
}
```

Initialize DMA

HAL service peripherals
DMA M2M code from CubeMX

- Initialize DMA handler structure

```
/**
  * Enable DMA controller clock
  * Configure DMA for memory to memory transfers
  *   hdma_memtomem_dma2_stream0
  */
void MX_DMA_Init(void)
{
  /* DMA controller clock enable */
  __DMA2_CLK_ENABLE();
  /* Configure DMA request hdma_memtomem_dma2_stream0 on DMA2_Stream0 */
  hdma_memtomem_dma2_stream0.Instance = DMA2_Stream0;
  hdma_memtomem_dma2_stream0.Init.Channel = DMA_CHANNEL_0;
  hdma_memtomem_dma2_stream0.Init.Direction = DMA_MEMORY_TO_MEMORY;
  hdma_memtomem_dma2_stream0.Init.PeriphInc = DMA_PINC_ENABLE;
  hdma_memtomem_dma2_stream0.Init.MemInc = DMA_MINC_ENABLE;
  hdma_memtomem_dma2_stream0.Init.PeriphDataAlignment = DMA_PDATAALIGN_BYTE;
  hdma_memtomem_dma2_stream0.Init.MemDataAlignment = DMA_MDATAALIGN_BYTE;
  hdma_memtomem_dma2_stream0.Init.Mode = DMA_NORMAL;
  hdma_memtomem_dma2_stream0.Init.Priority = DMA_PRIORITY_LOW;
  hdma_memtomem_dma2_stream0.Init.FIFOMode = DMA_FIFOMODE_ENABLE;
  hdma_memtomem_dma2_stream0.Init.FIFOThreshold = DMA_FIFO_THRESHOLD_HALFFULL;
  hdma_memtomem_dma2_stream0.Init.MemBurst = DMA_MBURST_SINGLE;
  hdma_memtomem_dma2_stream0.Init.PeriphBurst = DMA_PBURST_SINGLE;
  HAL_DMA_Init(&hdma_memtomem_dma2_stream0);
  /* DMA interrupt init */
}
```

DMA clock enable

Store parameters which was selected in CubeMX into init structure

Write content of Init structure into DMA registers
Now is DMA **ready to use**

HAL service peripherals
DMA – APIs

- The following table lists the DMA APIs

DMA HAL APIs	Description
HAL_DMA_Init	Initializes a DMA channel
HAL_DMA_DeInit	De-initalizes a DMA channel
HAL_DMA_Start	Starts DMA transfer
HAL_DMA_Start_IT	Starts DMA channel with interrupt generation at end of transfer or half transfer or on DMA error
HAL_DMA_Abort	Aborts a DMA transfer
HAL_DMA_PollForTransfer	Blocking function that polls for transfer complete or half complete, this function can also return a Timeout or a DMA error
HAL_DMA_IRQHandler	Interrupt handler for DMA
HAL_DMA_GetState	Gets DMA channel state
HAL_DMA_GetError	Gets DMA error code

HAL service peripherals DMA – extension APIs

- Extension APIs for DMA are present in F4x family for handling double buffer feature, API include:

DMA HAL EX APIs	Description
HAL_DMAEx_MultiBufferStart	double buffer DMA transfer in polling mode
HAL_DMAEx_MultiBufferStart_IT	double buffer DMA transfer with Interrupt generation
HAL_DMAEx_ChangeMemory	allows changing non used buffer address on the fly

DMA Poll lab result

- Lab shows how start the DMA transfer

```
/* USER CODE BEGIN 0 */
uint8_t Buffer_Src[]={0,1,2,3,4,5,6,7,8,9};
uint8_t Buffer_Dest[10];
/* USER CODE END 0 */
```

```
/* USER CODE BEGIN 2 */
 HAL_DMA_Start(&hdma_memtomem_dma2_stream0, (uint32_t) (Buffer_Src), (uint32_t) (Buffer_Dest), 10);
 while(HAL_DMA_PollForTransfer(&hdma_memtomem_dma2_stream0, HAL_DMA_FULL_TRANSFER, 100) != HAL_OK)
 {
   __NOP();
 }
 /* USER CODE END 2 */
```

Handling of HAL return statuses

- Correct return handling of HAL function

```
status=HAL_DMA_PollForTransfer(&hdma_memtomem_dma2_stream0,HAL_DMA_FULL_TRANSFER,100);
/*ERROR*/
switch(status)
{
  case HAL_ERROR
    error=HAL_DMA_GetError(&hdma_memtomem_dma2_stream0);
    /*Handle ERROR*/
    switch(error){
      default:
        break;
    }
    break;
  case HAL_TIMEOUT:
    /*Handle TIMEOUT*/
    break;
  case HAL_BUSY:
    /*Handle BUSY*/
    break;
  case HAL_OK:
    /*Handle BUSY*/
    break;
 default:
    break;
}
```

Store function return status

If error detected

Discover what type of error was detected

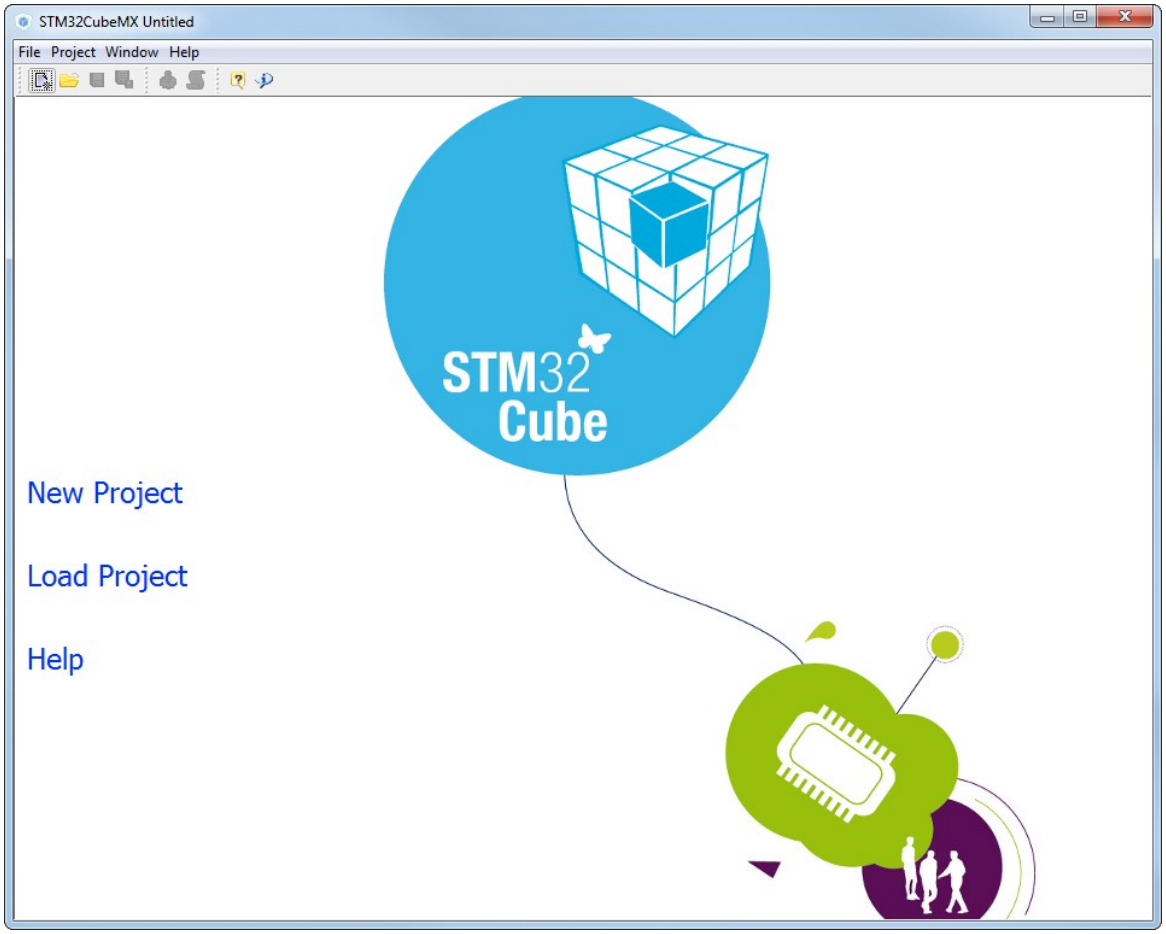
Function timeouted

Periphery is in use

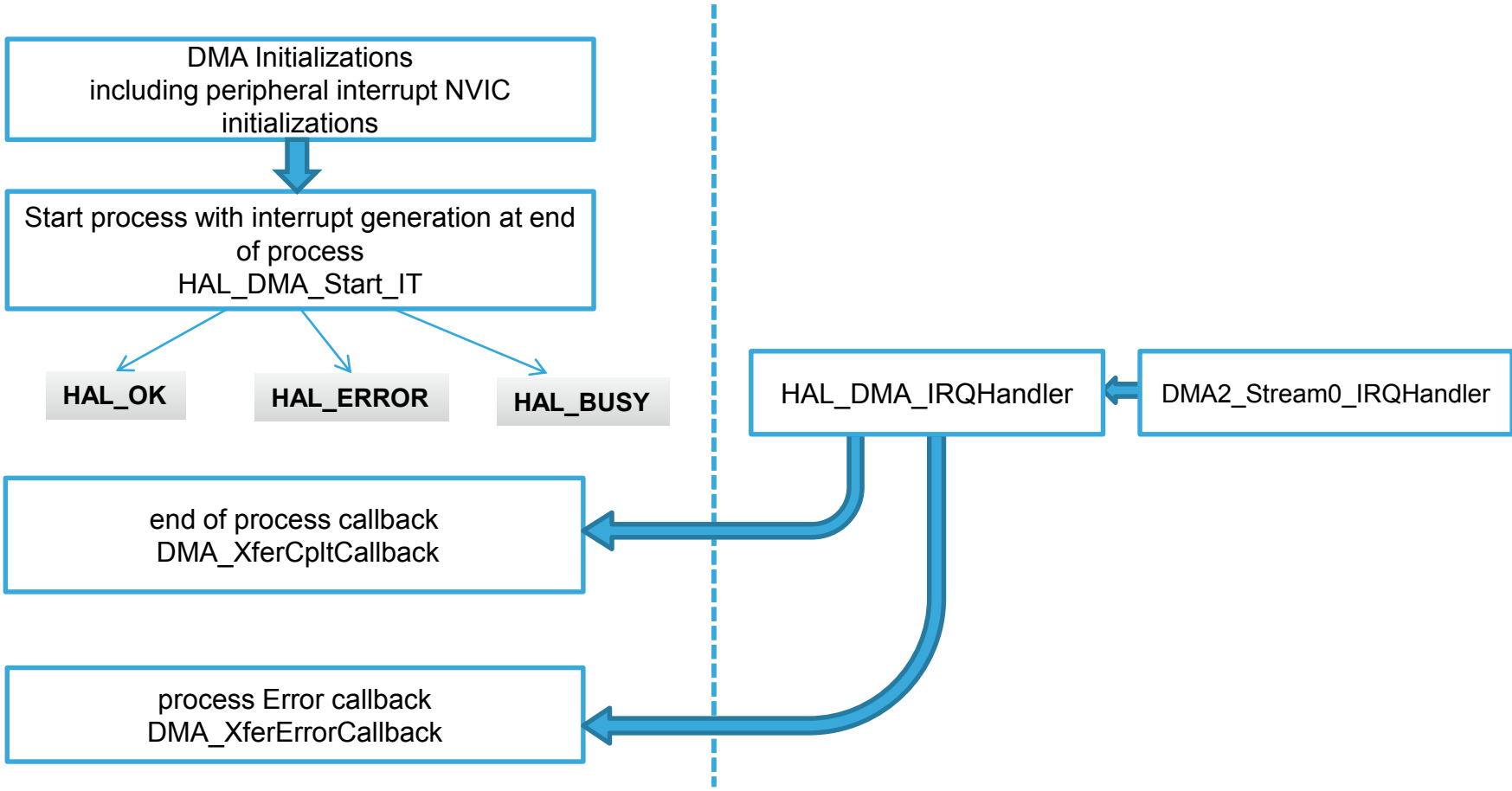
Function ends successfully

Use DMA with Interrupt lab

- Use **DMA with Interrupt** lab to create project with DMA
- We use this project for better demonstration how the HAL library works



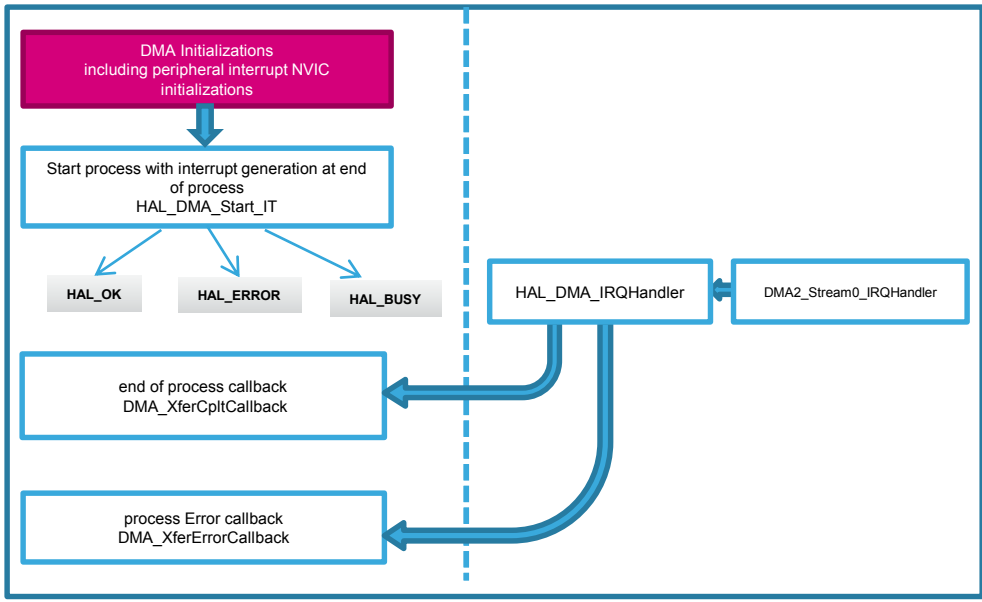
HAL Library DMA with IT flow



DMA with Interrupt lab

- Generated main.c is same as in DMA Poll lab

```
/* Private variables ---------------------------------------------------------*/
DMA_HandleTypeDef hdma_memtomem_dma2_stream0;


int main(void)
{
  /* USER CODE BEGIN 1 */
  /* USER CODE END 1 */
  /* MCU Configuration--------------------------------------------------------*/
  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();
  /* Configure the system clock */
  SystemClock_Config();
  /* Initialize all configured peripherals */
  MX_DMA_Init();
  /* USER CODE BEGIN 2 */
  /* USER CODE END 2 */
  /* USER CODE BEGIN 3 */
  /* Infinite loop */
  while (1)
  {
  }
  /* USER CODE END 3 */
}
```



life.augmented

DMA with Interrupt lab

- New is content of stm32f4xx_it.c

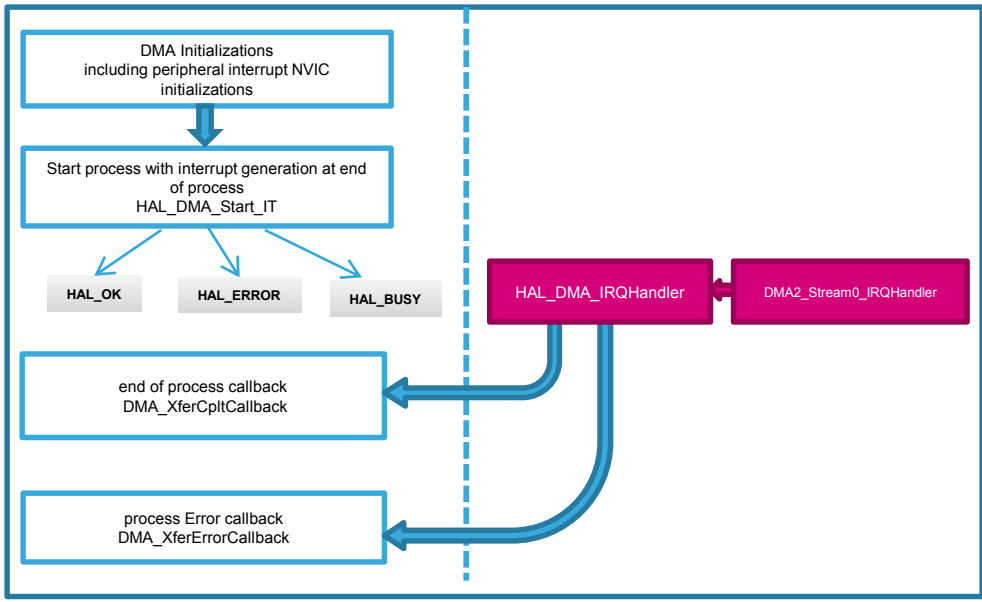
```
/* External variables ---------------------------------------------------------*/
extern DMA_HandleTypeDef hdma_memtomem_dma2_stream0;
```

DMA handler is exported
stm32f4xx_if.c HAL functions need it

```
/**
* @brief This function handles DMA2 Stream0 global interrupt.
*/
void DMA2_Stream0_IRQHandler(void)
{
  /* USER CODE BEGIN DMA2_Stream0_IRQn 0 */

  /* USER CODE END DMA2_Stream0_IRQn 0 */
  HAL_DMA_IRQHandler(&hdma_memtomem_dma2_stream0);
  /* USER CODE BEGIN DMA2_Stream0_IRQn 1 */

  /* USER CODE END DMA2_Stream0_IRQn 1 */
}
```

Standard DMA inrrupt handler
defined in startup_stm32f439xx.s

HAL DMA interrupt handling routine,
require **handler**



life.augmented

DMA with Interrupt lab

- If is DMA used with second periphery, their function assign callbacks to interrupt handlers

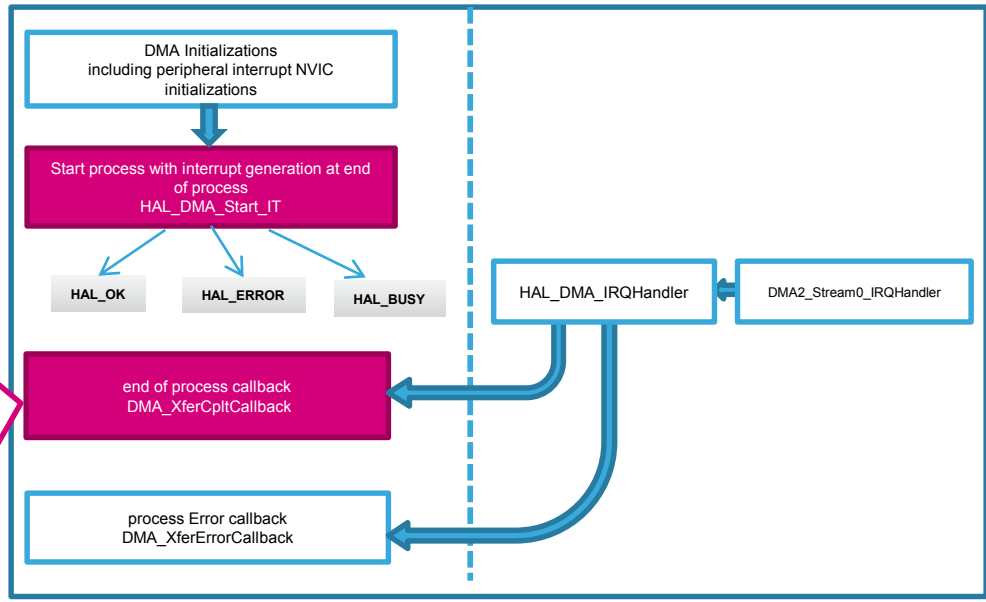
- We need to assign and create callback manually

Assign name of callback function directly to DMA handler

```
/* USER CODE BEGIN 2 */
hdma_memtomem_dma2_stream0.XferCpltCallback=&XferCpltCallback;
HAL_DMA_Start_IT(&hdma_memtomem_dma2_stream0,(uint32_t)Buffer_Src,(uint32_t)Buffer_Dest,10);
/* USER CODE END 2 */
```

Callback function name

Start DMA transfer
End of transfer is indicated interrupt callback



After callback assing HAL_DMA_IRQHandler can call correct callback function

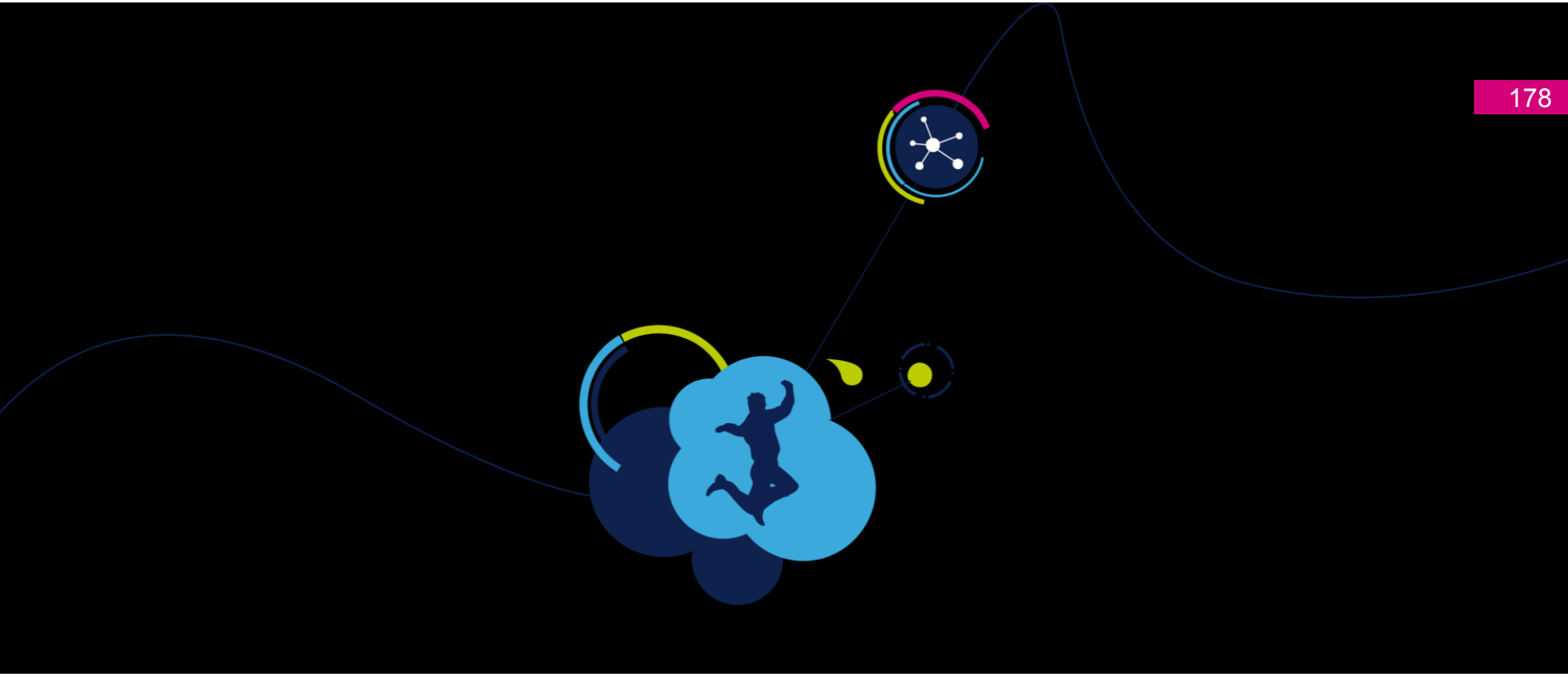
DMA with Interrupt lab

- DMA callback creation function prototype

```
/* USER CODE BEGIN 0 */
uint8_t Buffer_Src[]={0,1,2,3,4,5,6,7,8,9};
uint8_t Buffer_Dest[10];

void XferCpltCallback(DMA_HandleTypeDef *hdma);
/* USER CODE END 0 */
```

- DMA complete callback with nop where we can put breakpoint

```
/* USER CODE BEGIN 4 */
void XferCpltCallback(DMA_HandleTypeDef *hdma)
{
  __NOP();//we reach this only if DMA transfer was correct
}
/* USER CODE END 4 */
```



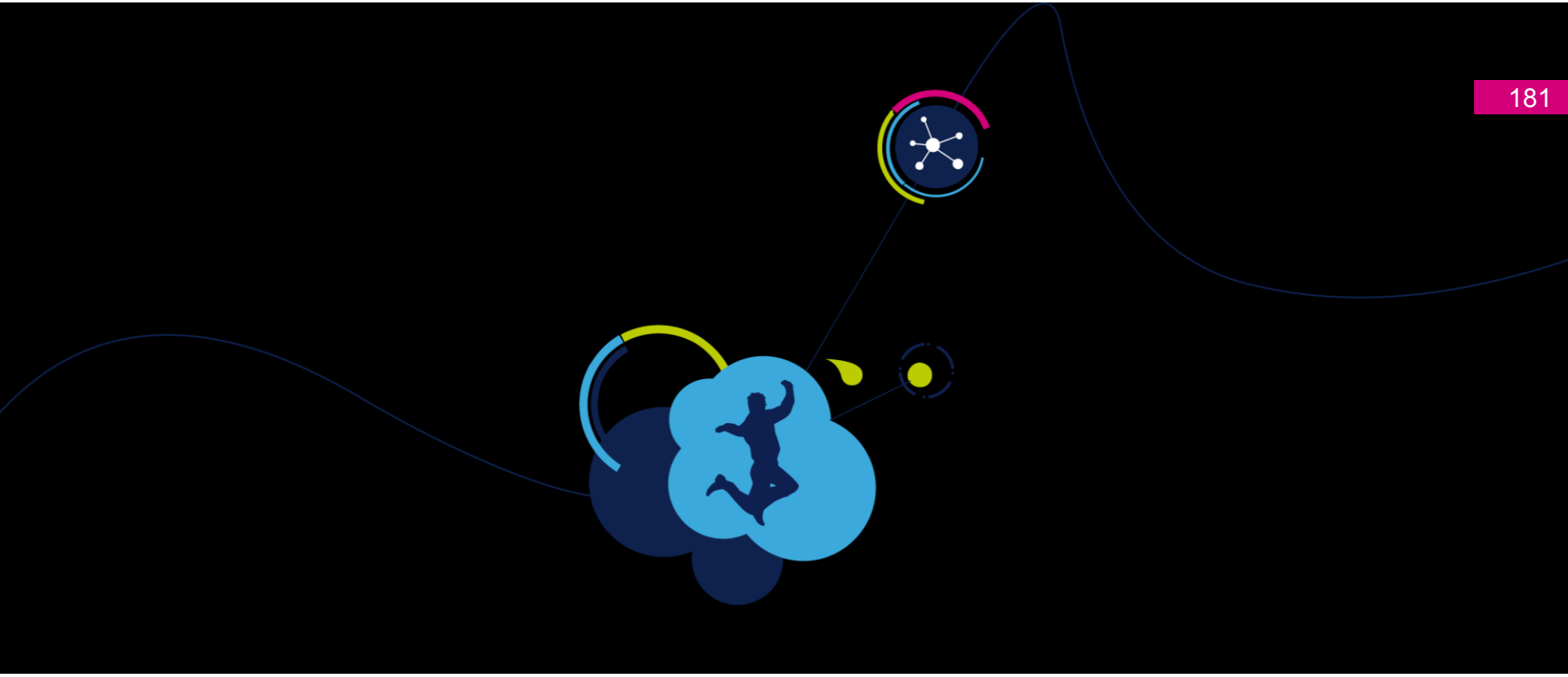
HAL service peripherals –PWR Power Controller

HAL service peripherals
PWR –main APIs

- PWR HAL driver handles power management features
  - PVD configuration, enabling/disabling and interrupt handling
    - HAL_PWR_PVDConfig()
    - HAL_PWR_EnablePVD() / HAL_PWR_DisablePVD()
    - HAL_PWR_PVD_IRQHandler()
    - HAL_PWR_PVDCallback()
  - Low power mode entry
    - HAL_PWR_EnterSLEEPMode()
    - HAL_PWR_EnterSTOPMode()
    - HAL_PWR_EnterSTANDBYMode()

HAL service peripherals PWR –extension APIs

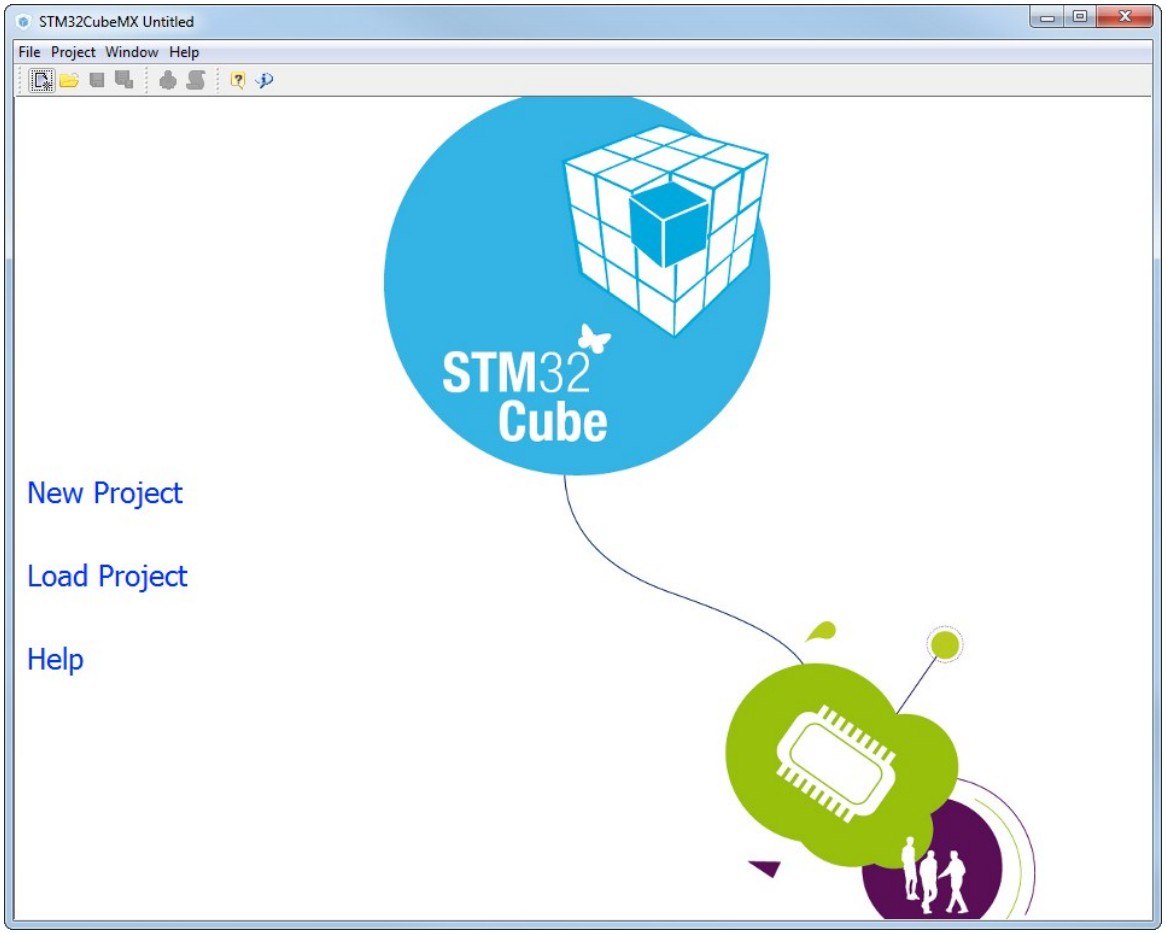
- For F4x family the following extension function are available
  - Flash overdrive control and flash power-down (for F429/F439 only)
    - HAL_PWREx_ActivateOverDrive()
    - HAL_PWREx_EnableFlashPowerDown()
  - Backup domain registers enable/disable
    - HAL_PWREx_EnableBkUpReg() / HAL_PWREx_DisableBkUpReg



Comunication Peripherals HAL driver model

Use UART Poll lab

- Use UART Poll lab to create project with UART
- We use this project for better demonstration how the HAL library works



Peripheral HAL driver model
HAL peripheral Handle


```
/**
  * @brief  UART handle Structure definition
  */
typedef struct
{
  USART_TypeDef                 *Instance;
  UART_InitTypeDef              Init;
  uint8_t                       *pTxBuffPtr;
  uint16_t                      TxXferSize;     /* UART Tx Transfer size             */
  uint16_t                      TxXferCount;    /* UART Tx Transfer Counter          */
  uint8_t                       *pRxBuffPtr;    /* Pointer to UART Rx transfer Buffer */
  uint16_t                      RxXferSize;     /* UART Rx Transfer size             */
  uint16_t                      RxXferCount;    /* UART Rx Transfer Counter          */
  DMA_HandleTypeDef             *hdmatx;        /* UART Tx DMA Handle parameters     */
  DMA_HandleTypeDef             *hdmarx;        /* UART Rx DMA Handle parameters     */
  HAL_LockTypeDef               Lock;           /* Locking object                    */
  __IO HAL_UART_StateTypeDef    State;
  __IO HAL_UART_ErrorTypeDef    ErrorCode;      /* */
}UART_HandleTypeDef;
```

USART instance (ex. USART1, USART2, …)

Initialization structure(baudrate, parity, …)

Lock

State (BUSY, TIMEOUT, ERROR)

Error code

Peripheral HAL driver model
HAL peripheral Handle


```
/**
  * @brief  UART handle Structure definition
  */
typedef struct
{
  USART_TypeDef                 *Instance;        /* UART registers base address        */

  UART_InitTypeDef              Init;             /* UART communication parameters      */

  uint8_t                       *pTxBuffPtr;      /* Pointer on data to send            */

  uint16_t                      TxXferSize;       /* Number of bytes to send            */

  uint16_t                      TxXferCount;      /* Count of bytes sent by UART        */

  uint8_t                       *pRxBuffPtr;      /* Pointer on received data           */

  uint16_t                      RxXferSize;       /* Number of bytes to receive         */

  uint16_t                      RxXferCount;      /* Count of bytes deceived by UART    */

  DMA_HandleTypeDef             *hdmatx;          /* Pointer on DMA transmit handler    */

  DMA_HandleTypeDef             *hdmarx;          /* Pointer on DMA receive handler     */

  HAL_LockTypeDef               Lock;             /* Locking object                     */

  __IO HAL_UART_StateTypeDef    State;            /* UART communication state           */

  __IO HAL_UART_ErrorTypeDef    ErrorCode;        /* UART Error code                    */

}UART_HandleTypeDef;
```

Peripheral HAL driver model
Driver API groups

- Peripheral drivers APIs are organized in four groups
  - Initialization and de-initialization APIs
  - Process APIs : can be polling, interrupt or DMA based
  - Peripheral subsystem configuration and feature control APIs
  - Peripheral GetState and Get Errors APIs

API group	examples
Initialization and de-initialization (HAL_PPP_Init()/_DeInit)	HAL_USART_Init() HAL_USAR_DeInit()
Process operation	HAL_SPI_Receive() HAL_SPI_Receive_IT() HAL_USART_Transmit_DMA()
Peripheral subsystem configuration Peripheral feature control	HAL_ADC_ConfigChannel() HAL_RTC_SetAlarm()
Peripheral GetState and GetError	HAL_I2C_GetState() HAL_I2C_GetError()

Peripheral HAL driver model
Interrupt handler & callback functions

- Besides the APIs, HAL peripheral drivers implement
  - The peripheral interrupt handler(ex: HAL_SPI_IRQHandler): should be called from stm32f4xx_it.c
  - User callback functions
- User callback functions are defined as empty functions with “weak” attribute , they need to be redefined in application code when used
- The following user callbacks functions are defined
  - Peripheral HAL_PPP_Init()/_DeInit() APIs call
    - **HAL_PPP_MspInit()/_DeInit :** these callback functions can be used by user to do system level initialization(de-initialization) of the peripheral (clock, GPIO, DMA, NVIC)
  - When using interrupt and DMA process APIs, the following callbacks are called
    - Process complete callback functions : **HAL_PPP_ProcessCpltCallback**
    - Error callback in case of peripheral or DMA error: **HAL_PPP_ErrorCallback**
  - Peripheral interrupt handler may signal events to user through callback functions
    - **HAL_PPP_PeripheralEvent_Callback**

UART Poll lab

- CubeMX generate UART handler structure in main.c

```
/* Private variables ---------------------------------------------------------*/
UART_HandleTypeDef huart1;
```

- In main we can find MX_USART1_UART_Init function

```
int main(void)
{
  /* USER CODE BEGIN 1 */
  /* USER CODE END 1 */
  /* MCU Configuration--------------------------------------------------------*/
  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();
  /* Configure the system clock */
  SystemClock_Config();
  /* Initialize all configured peripherals */
  MX_GPIO_Init();
  MX_USART1_UART_Init();
  /* USER CODE BEGIN 2 */
  /* USER CODE END 2 */
  /* USER CODE BEGIN 3 */
  /* Infinite loop */
  while (1)
  {
  }
  /* USER CODE END 3 */
}
```

Setup parameters which we selected in CubeMX

UART Poll lab

- CubeMX generate MX_USART1_UART_Init function in main.c

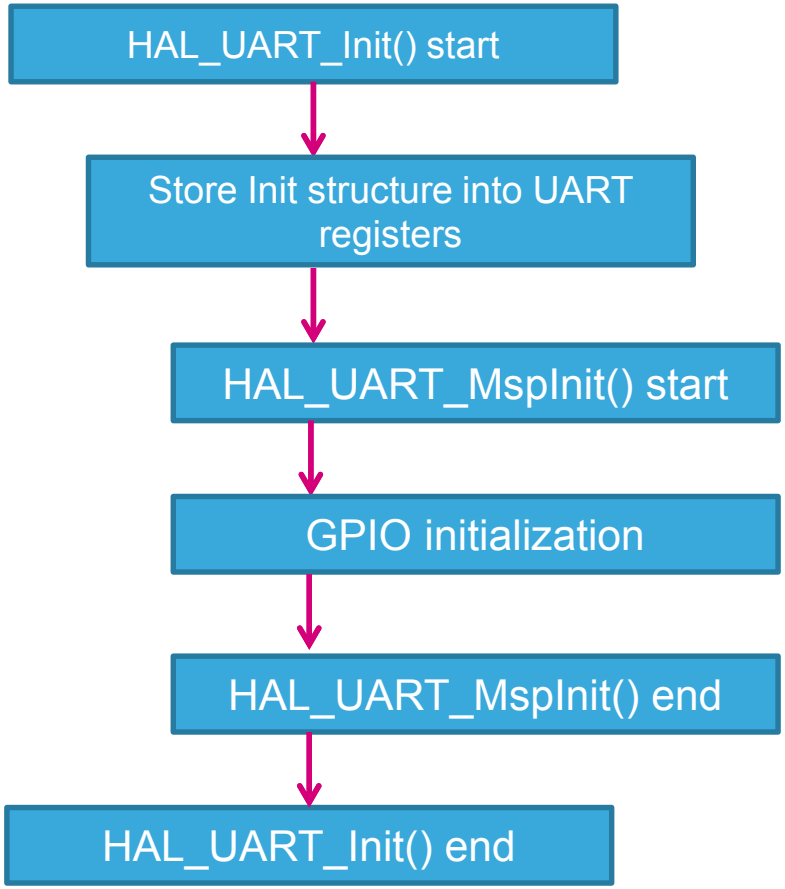
```
/* USART1 init function */
void MX_USART1_UART_Init(void)
{

  huart1.Instance = USART1;
  huart1.Init.BaudRate = 9600;
  huart1.Init.WordLength = UART_WORDLENGTH_8B;
  huart1.Init.StopBits = UART_STOPBITS_1;
  huart1.Init.Parity = UART_PARITY_NONE;
  huart1.Init.Mode = UART_MODE_TX_RX;
  huart1.Init.HwFlowCtl = UART_HWCONTROL_NONE;
  huart1.Init.OverSampling = UART_OVERSAMPLING_16;
  HAL_UART_Init(&huart1);

}
```

Store UART parameters into Init structure in UART handler

HAL UART initialization procedure

HAL Init structure

- HAL_UART_Init function details




```
void HAL_UART_MspInit(UART_HandleTypeDef* huart)
{

  GPIO_InitTypeDef GPIO_InitStruct;
  if(huart->Instance==USART1)
  {
  /* USER CODE BEGIN USART1_MspInit 0 */

  /* USER CODE END USART1_MspInit 0 */
    /* Peripheral clock enable */
    __USART1_CLK_ENABLE();

    /**USART1 GPIO Configuration
    PA9     ------> USART1_TX
    PA10     ------> USART1_RX
    */
    GPIO_InitStruct.Pin = GPIO_PIN_9|GPIO_PIN_10;
    GPIO_InitStruct.Mode = GPIO_MODE_AF_PP;
    GPIO_InitStruct.Pull = GPIO_PULLUP;
    GPIO_InitStruct.Speed = GPIO_SPEED_LOW;
    GPIO_InitStruct.Alternate = GPIO_AF7_USART1;
    HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);

  /* USER CODE BEGIN USART1_MspInit 1 */

  /* USER CODE END USART1_MspInit 1 */
  }

}
```

HAL HAL_UART_MspInit structure

All HAL_UART_Init functions calling same function HAL_UART_MspInit

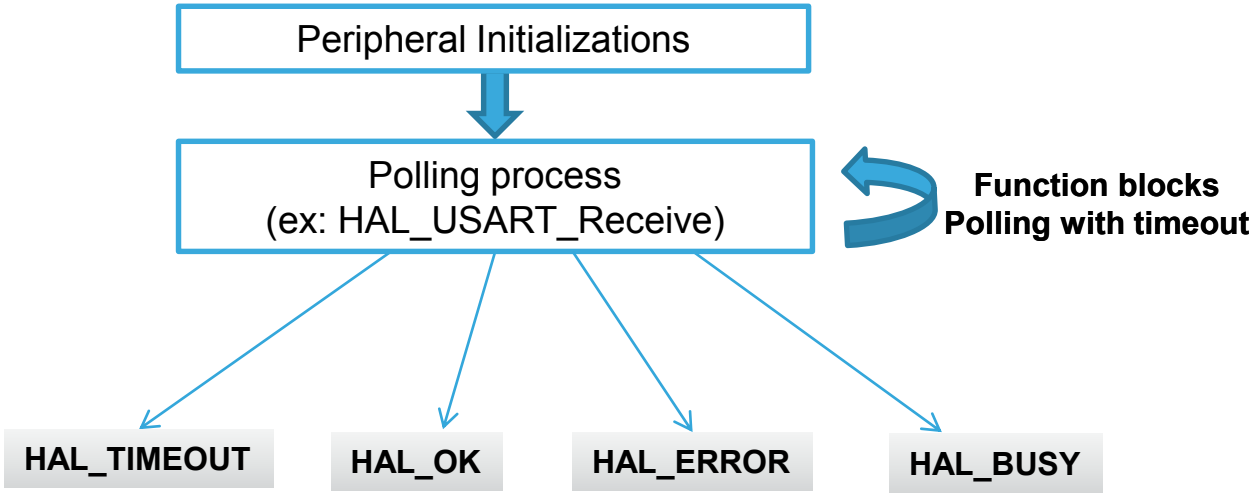
From handler instance parameter is discovered which UART need to be initialized

Initialize GPIO selected in CubeMX

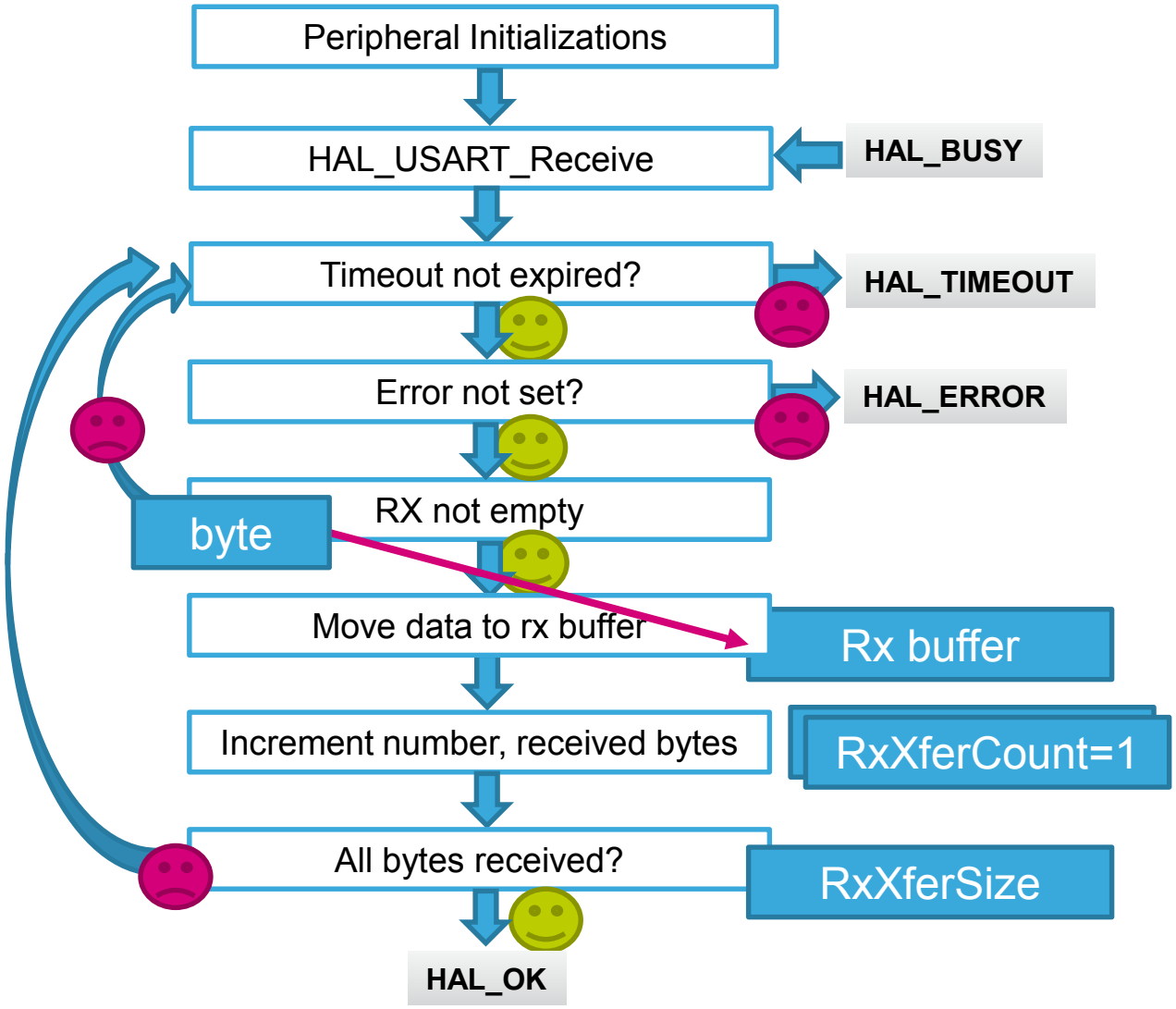
```
void HAL_UART_MspInit(UART_HandleTypeDef* huart)
{

  GPIO_InitTypeDef GPIO_InitStruct;
  if(huart->Instance==USART1)
  {
  /* USER CODE BEGIN USART1_MspInit 0 */

  /* USER CODE END USART1_MspInit 0 */
    /* Peripheral clock enable */
    __USART1_CLK_ENABLE();

    /**USART1 GPIO Configuration
    PA9     ------> USART1_TX
    PA10     ------> USART1_RX
    */
    GPIO_InitStruct.Pin = GPIO_PIN_9|GPIO_PIN_10;
    GPIO_InitStruct.Mode = GPIO_MODE_AF_PP;
    GPIO_InitStruct.Pull = GPIO_PULLUP;
    GPIO_InitStruct.Speed = GPIO_SPEED_LOW;
    GPIO_InitStruct.Alternate = GPIO_AF7_USART1;
    HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);

  /* USER CODE BEGIN USART1_MspInit 1 */

  /* USER CODE END USART1_MspInit 1 */
  }

}
```

Peripheral HAL driver model
Blocking polling process

- Blocking polling process APIs
  - Block until end of the process, or exit with timeout , error or busy
  - Ex: HAL_USART_Receive()

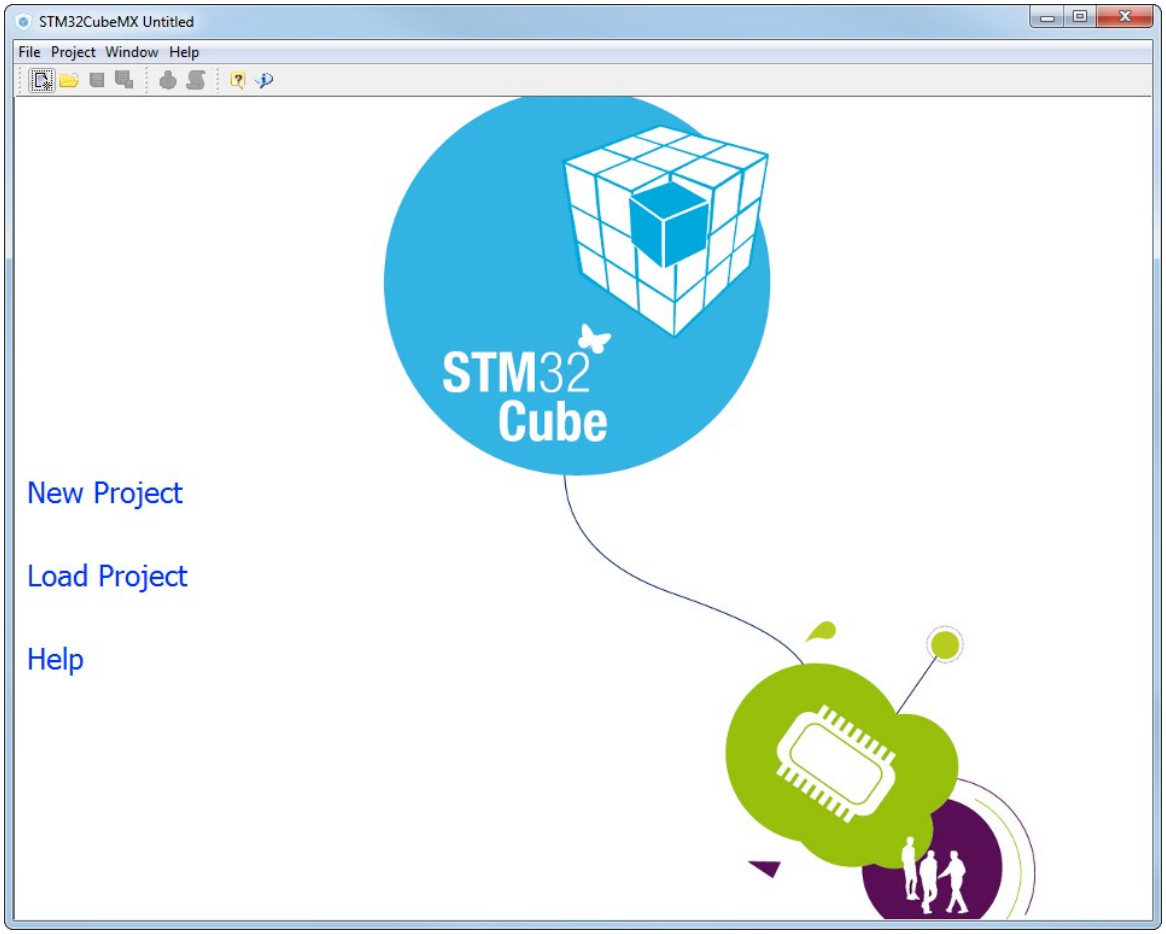


Pooling receive functionality



Use UART with Interrupt lab

- Use UART with Interrupt lab to create project with UART
- We use this project for better demonstration how the HAL library works



UART MSP file

- Main.c will be same as in USART Poll example
- MSP initialization is now different in stm32f4xx_hal_uart.c

```
void HAL_UART_MspInit(UART_HandleTypeDef* huart)
{
  GPIO_InitTypeDef GPIO_InitStruct;
  if(huart->Instance==USART1)
  {
  /* USER CODE BEGIN USART1_MspInit 0 */
  /* USER CODE END USART1_MspInit 0 */
    /* Peripheral clock enable */
    __USART1_CLK_ENABLE();
    /**USART1 GPIO Configuration
    PA9     ------> USART1_TX
    PA10     ------> USART1_RX     */
    GPIO_InitStruct.Pin = GPIO_PIN_9|GPIO_PIN_10;
    GPIO_InitStruct.Mode = GPIO_MODE_AF_PP;
    GPIO_InitStruct.Pull = GPIO_PULLUP;
    GPIO_InitStruct.Speed = GPIO_SPEED_LOW;
    GPIO_InitStruct.Alternate = GPIO_AF7_USART1;
    HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);
  /* System interrupt init*/
    HAL_NVIC_SetPriority(USART1_IRQn, 0, 0);
    HAL_NVIC_EnableIRQ(USART1_IRQn);
  /* USER CODE BEGIN USART1_MspInit 1 */
  /* USER CODE END USART1_MspInit 1 */
  }
}
```

USART1 interrupt is now enabled in NVIC.

Now function HAL_UART_Receive_IT or HAL_UART_Receive_IT will trigger interrupt

Interrupt handling

- Interrupt handling in stm32f4xx_it.c
  - UART Handler is imported from main.c

```
/* External variables ---------------------------------------------------------*/
extern UART_HandleTypeDef huart1;
```

  - USART1_IRQHandler is called if interrupt is triggered
  - HAL_UART_IRQHandler is hal function which manage UART interrupts

```
/**
* @brief This function handles USART1 global interrupt.
*/
void USART1_IRQHandler(void)
{
  /* USER CODE BEGIN USART1_IRQn 0 */
  /* USER CODE END USART1_IRQn 0 */
  HAL_UART_IRQHandler(&huart1);
  /* USER CODE BEGIN USART1_IRQn 1 */
  /* USER CODE END USART1_IRQn 1 */
}
```

As parameter is used USART1 handle

Callback creation

- Callbacks are defined as __weak in stm32f4xx_hal_uart.c

```
/**
  * @brief  Rx Transfer completed callbacks.
  * @param  huart: pointer to a UART_HandleTypeDef structure that contains
  *                the configuration information for the specified UART module.
  * @retval None
  */
__weak void HAL_UART_RxCpltCallback(UART_HandleTypeDef *huart)
{
  /* NOTE: This function Should not be modified, when the callback is needed,
           the HAL_UART_TxCpltCallback could be implemented in the user file
   */
}
```

- If we defined callback, for example in main.c, after successful reception HAL will jump into it

```
/* USER CODE BEGIN 4 */
void HAL_UART_RxCpltCallback(UART_HandleTypeDef
*huart)
{
}
/* USER CODE END 4 */
```

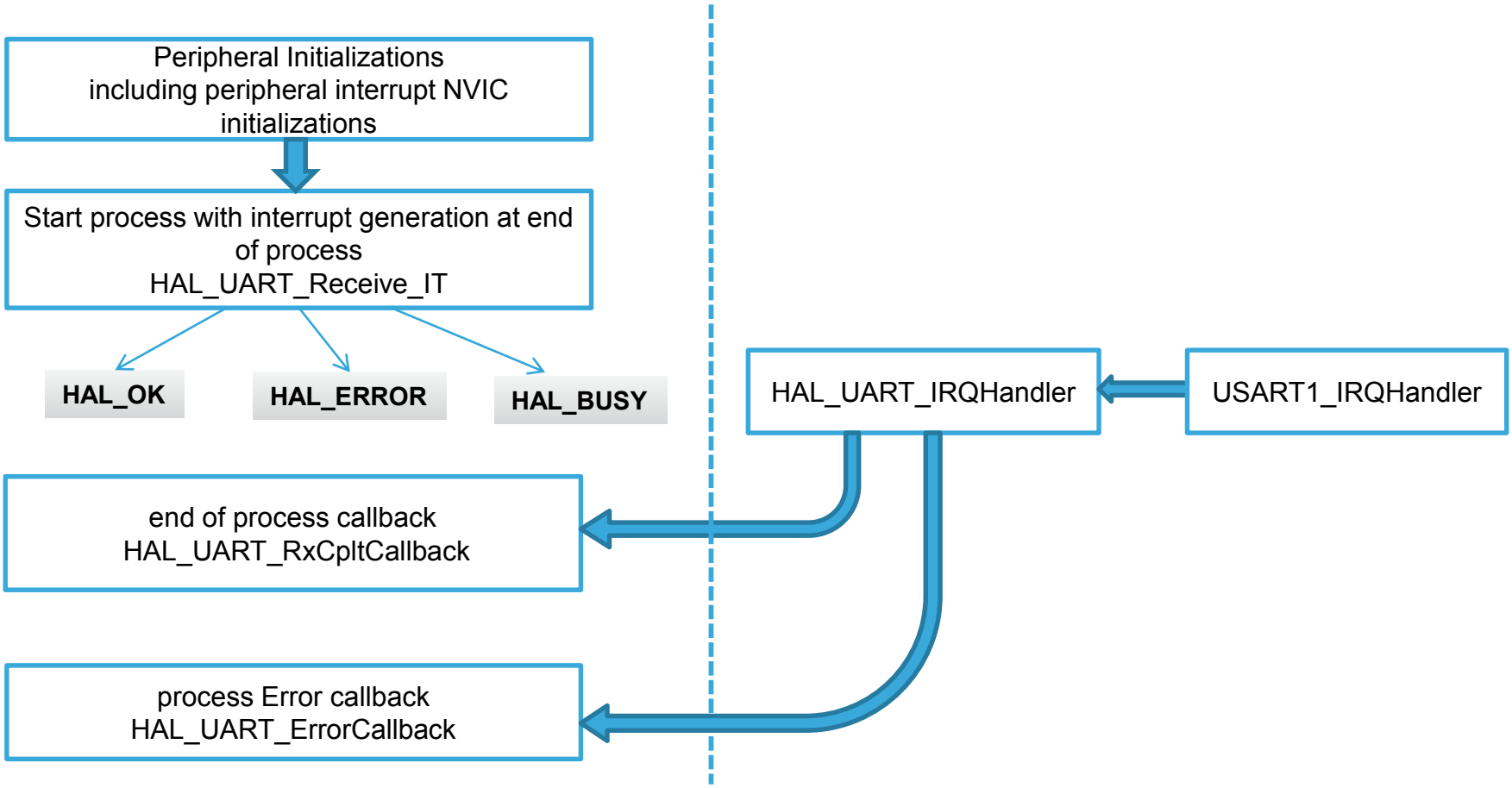
UART callback types

- Can be found in stm32f4xx_hal_uart.c (search for “__weak”)

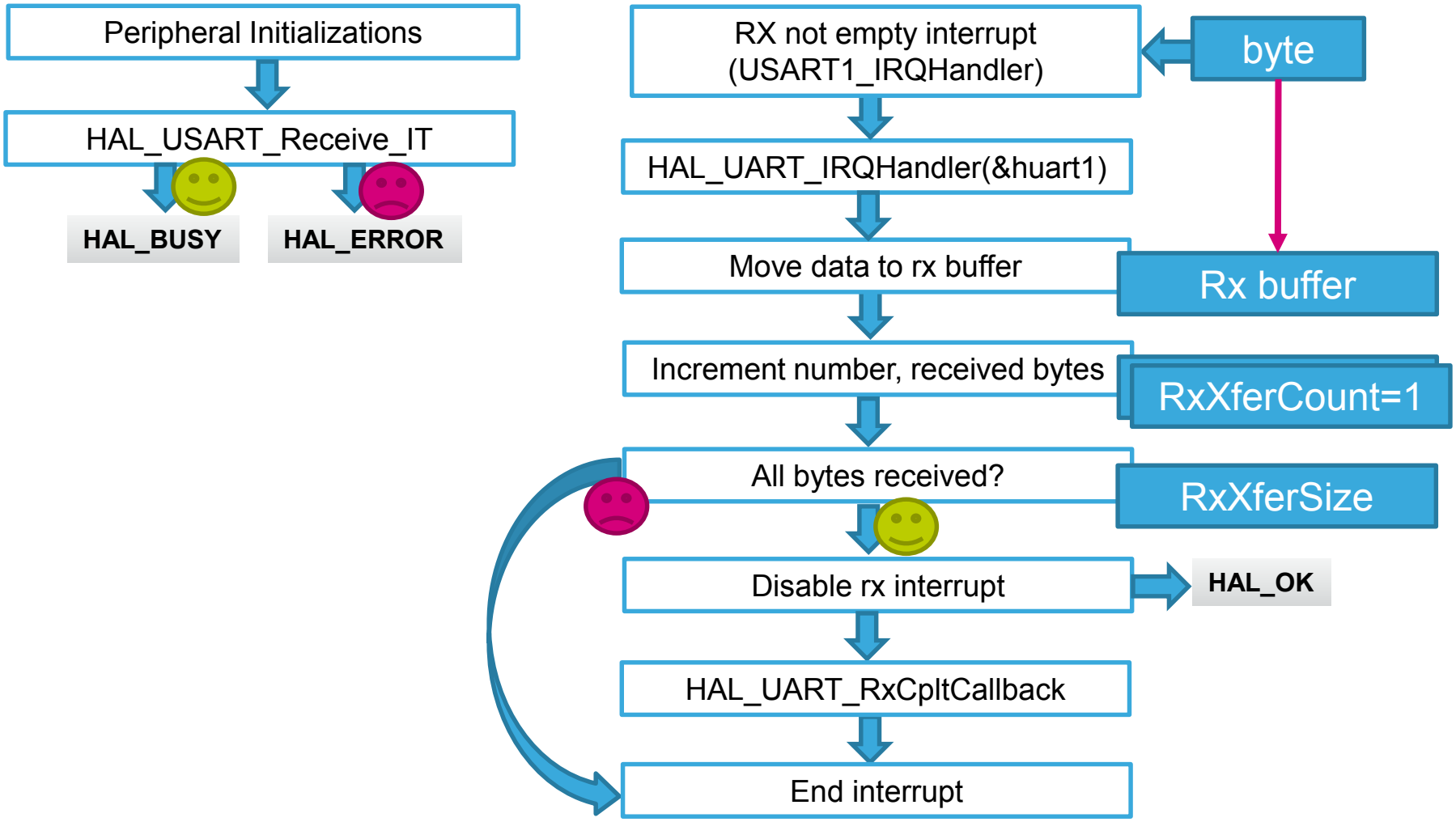
DMA HAL APIs	Description	Poll	IT	DMA
HAL_UART_MspInit	Initialize related system peripherals	X	X	X
HAL_UART_MspDeInit	Deinitialize related system peripherals	X	X	X
HAL_UART_TxCpltCallback	Called if complete buffer was transmitted		X	X
HAL_UART_TxHalfCpltCallback	Called if half of buffer was transmitted			X
HAL_UART_RxCpltCallback	Called if complete buffer was received		X	X
HAL_UART_RxHalfCpltCallback	Called if half of buffer was received		X	X
HAL_UART_ErrorCallback	Called if error occurred		X	X

Use UART with Interrupt lab

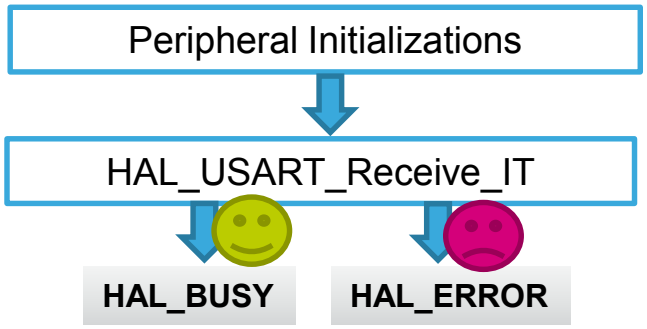
HAL Library UART with IT receive flow

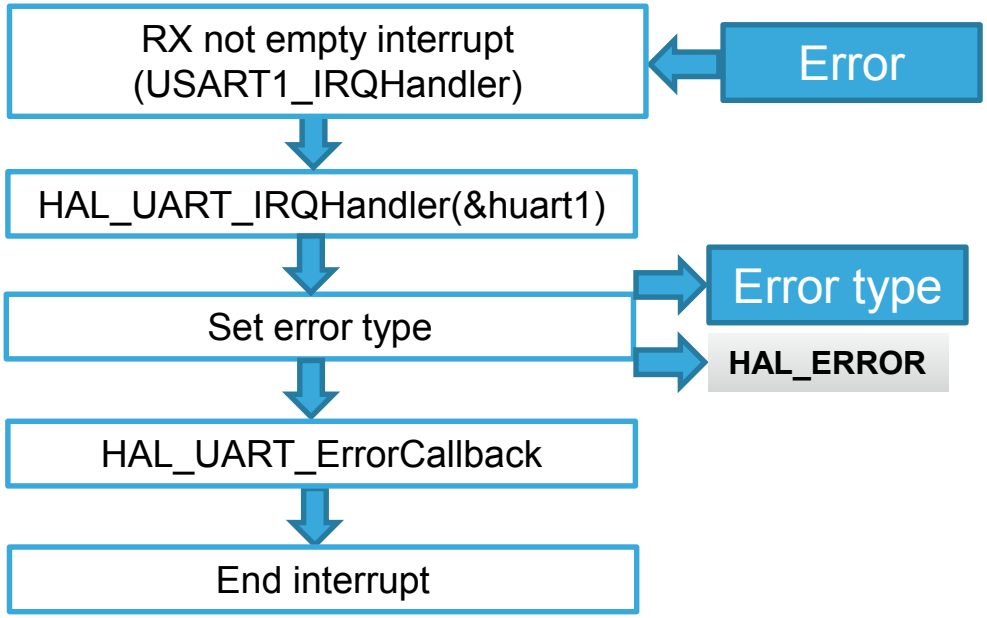


UART receive with interrupt



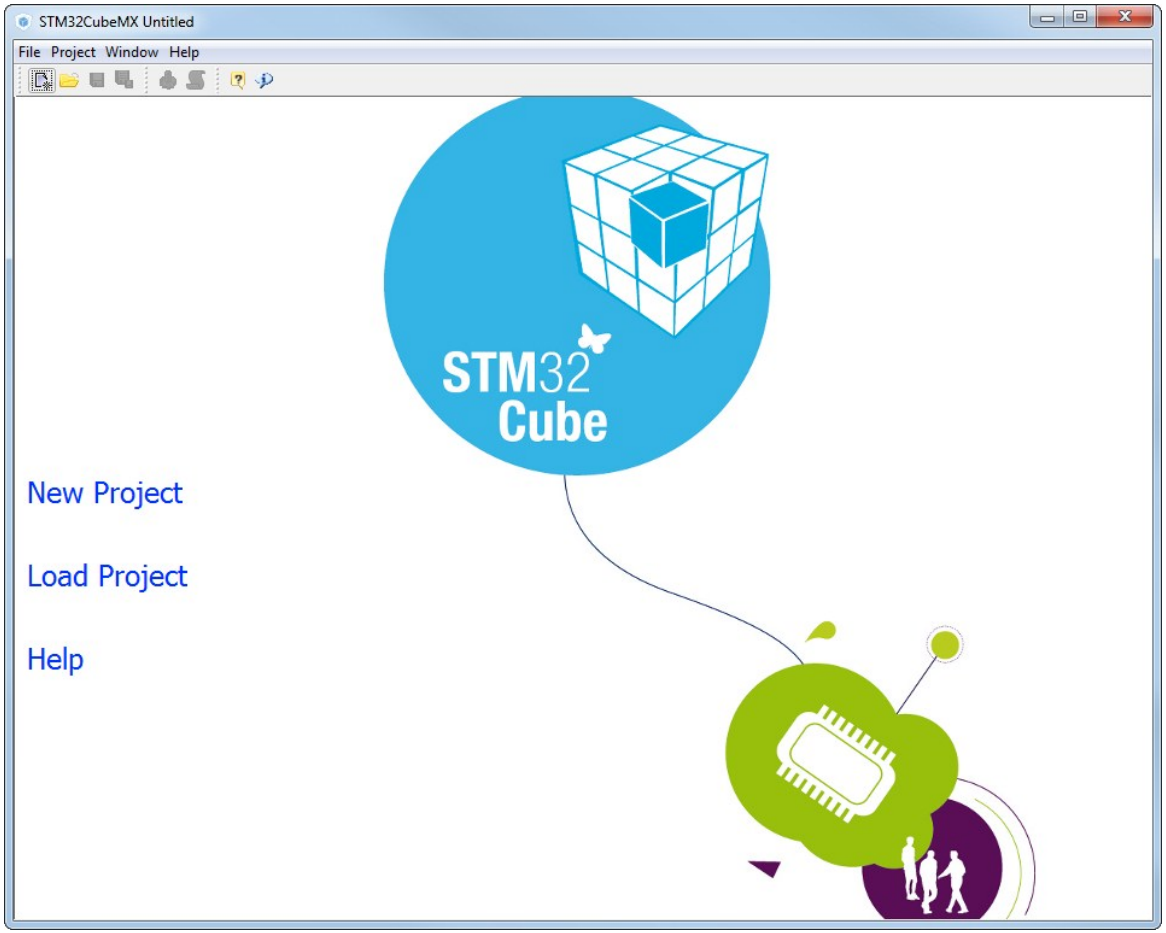
UART receive with interrupt





Use UART with DMA lab

- Use UART with DMA lab to create project with UART
- We use this project for better demonstration how the HAL library works



UART with DMA initialization

- In main.c is now defined UART handler and also DMA handlers

```
/* Private variables ---------------------------------------------------------*/
UART_HandleTypeDef huart1;
DMA_HandleTypeDef hdma_usart1_rx;
DMA_HandleTypeDef hdma_usart1_tx;
```

- In main function we can find additional initialization for DMA

```
int main(void)
{
  /* USER CODE BEGIN 1 */
  /* USER CODE END 1 */
  /* MCU Configuration--------------------------------------------------------*/
  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();
  /* Configure the system clock */
  SystemClock_Config();
  /* Initialize all configured peripherals */
  MX_GPIO_Init();
  MX_DMA_Init();
  MX_USART1_UART_Init();
  /* USER CODE BEGIN 2 */
  /* USER CODE END 2 */
  /* USER CODE BEGIN 3 */
  /* Infinite loop */
  while (1)
  {
  }
  /* USER CODE END 3 */
}
```

MX_DMA initialization

UART with DMA initialization

- In function MX_USART1_UART_Init is nothing new

```
/* USART1 init function */
void MX_USART1_UART_Init(void)
{

  huart1.Instance = USART1;
  huart1.Init.BaudRate = 9600;
  huart1.Init.WordLength = UART_WORDLENGTH_8B;
  huart1.Init.StopBits = UART_STOPBITS_1;
  huart1.Init.Parity = UART_PARITY_NONE;
  huart1.Init.Mode = UART_MODE_TX_RX;
  huart1.Init.HwFlowCtl = UART_HWCONTROL_NONE;
  huart1.Init.OverSampling = UART_OVERSAMPLING_16;
  HAL_UART_Init(&huart1);

}
```

UART with DMA initialization

- Function MX_DMA_Init enable DMA2 clock and enable DMA interrupt vectors

- If periphery use DMA to transfer data, the **NVIC interrupt** vectors must be **ENABLED** (DMA transfer use interrupts by default)

```
/**
  * Enable DMA controller clock
  */
void MX_DMA_Init(void)
{
  /* DMA controller clock enable */
  __DMA2_CLK_ENABLE();
  /* DMA interrupt init */
  HAL_NVIC_SetPriority(DMA2_Stream7_IRQn, 0, 0);
  HAL_NVIC_EnableIRQ(DMA2_Stream7_IRQn);
  HAL_NVIC_SetPriority(DMA2_Stream2_IRQn, 0, 0);
  HAL_NVIC_EnableIRQ(DMA2_Stream2_IRQn);
}
```

DMA clock enable

DMA NVIC vector initialiozation and enabling

UART with DMA - MSP file

- In stm32f4xx_hal_msp.c are now imported DMA handlers

```
extern DMA_HandleTypeDef hdma_usart1_rx;
extern DMA_HandleTypeDef hdma_usart1_tx;
```

- It is because we need to put information about DMA into UART handler

```
void HAL_UART_MspInit(UART_HandleTypeDef* huart)
```

- Without this UART cannot cooperate with DMA on HAL base library

UART with DMA - HAL_UART_MspInit

- Top of UART MSP function is still same only GPIO initalization

```
void HAL_UART_MspInit(UART_HandleTypeDef* huart)
{
  GPIO_InitTypeDef GPIO_InitStruct;
  if(huart->Instance==USART1)
  {
  /* USER CODE BEGIN USART1_MspInit 0 */
  /* USER CODE END USART1_MspInit 0 */
    /* Peripheral clock enable */
    __USART1_CLK_ENABLE();
    /**USART1 GPIO Configuration
    PA9     ------> USART1_TX
    PA10     ------> USART1_RX
    */
    GPIO_InitStruct.Pin = GPIO_PIN_9|GPIO_PIN_10;
    GPIO_InitStruct.Mode = GPIO_MODE_AF_PP;
    GPIO_InitStruct.Pull = GPIO_PULLUP;
    GPIO_InitStruct.Speed = GPIO_SPEED_LOW;
    GPIO_InitStruct.Alternate = GPIO_AF7_USART1;
    HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);
```

UART with DMA - HAL_UART_MspInit

- On the middle start DMA initialization based on CubeMX settings
- Most important part is the **__HAL_LINKDMA** macro which connects UART and DMA structures together

```
/* Peripheral DMA init*/
  hdma_usart1_rx.Instance = DMA2_Stream2;
  hdma_usart1_rx.Init.Channel = DMA_CHANNEL_4;
  hdma_usart1_rx.Init.Direction = DMA_PERIPH_TO_MEMORY;
  hdma_usart1_rx.Init.PeriphInc = DMA_PINC_DISABLE;
  hdma_usart1_rx.Init.MemInc = DMA_MINC_ENABLE;
  hdma_usart1_rx.Init.PeriphDataAlignment = DMA_PDATAALIGN_BYTE;
  hdma_usart1_rx.Init.MemDataAlignment = DMA_MDATAALIGN_BYTE;
  hdma_usart1_rx.Init.Mode = DMA_NORMAL;
  hdma_usart1_rx.Init.Priority = DMA_PRIORITY_LOW;
  hdma_usart1_rx.Init.FIFOMode = DMA_FIFOMODE_DISABLE;
  HAL_DMA_Init(&hdma_usart1_rx);

  __HAL_LINKDMA(huart,hdmarx,hdma_usart1_rx);
```

Stream selection, DMA direction, data width, …

__HAL_LINKDMA macro description

- In previous slides we work with DMA handler and UART handle
- There are three parameters in their structures which we need to know

```
/**
  * @brief  UART handle Structure definition
  */
typedef struct
{
  USART_TypeDef                 *Instance;        /*
  UART_InitTypeDef              Init;             /*
  uint8_t                       *pTxBuffPtr;      /*
  uint16_t                      TxXferSize;       /*
  uint16_t                      TxXferCount;      /*
  uint8_t                       *pRxBuffPtr;      /*
  uint16_t                      RxXferSize;       /*
  uint16_t                      RxXferCount;      /*
  DMA_HandleTypeDef             *hdmatx;          /*
  DMA_HandleTypeDef             *hdmarx;          /*
  HAL_LockTypeDef                                 /*
  __IO HAL_UART_StateTypeDe
  __IO HAL_UART_ErrorTypeD
}UART_HandleTypeDef;
```

UART handle

Pointers to DMA tx and RX heandles

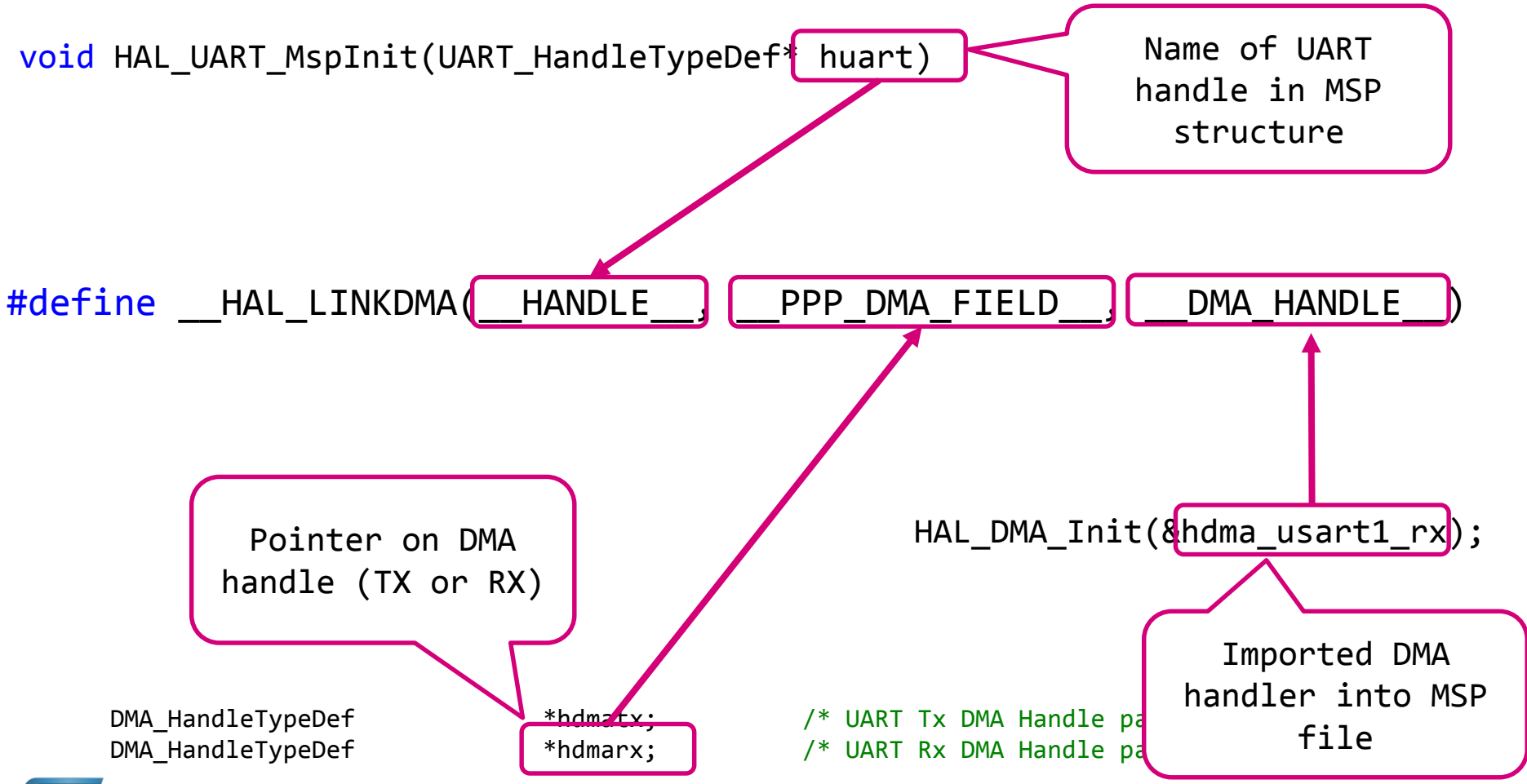
```
/**
  * @brief  DMA handle Structure definition
  */
typedef struct __DMA_HandleTypeDef
{
  DMA_Stream_TypeDef         *Instance;
  DMA_InitTypeDef            Init;
  HAL_LockTypeDef            Lock;
  __IO HAL_DMA_StateTypeDef  State;
  void                       *Parent;
  void                           XferCpltCallback)( struct __DMA_HandleTypeDef * hdma);
  void                           HalfCpltCallback)( struct __DMA_HandleTypeDef * hdma)
  void                           t __DMA_HandleTypeDef * hdma);
  void                           __DMA_HandleTypeDef * hdma);
  __IO uint32_t
                             ndleTypeDef;
                             or code                */
```

DMA handle

Pointer to handle which cooperate with DMA, now it will be UART

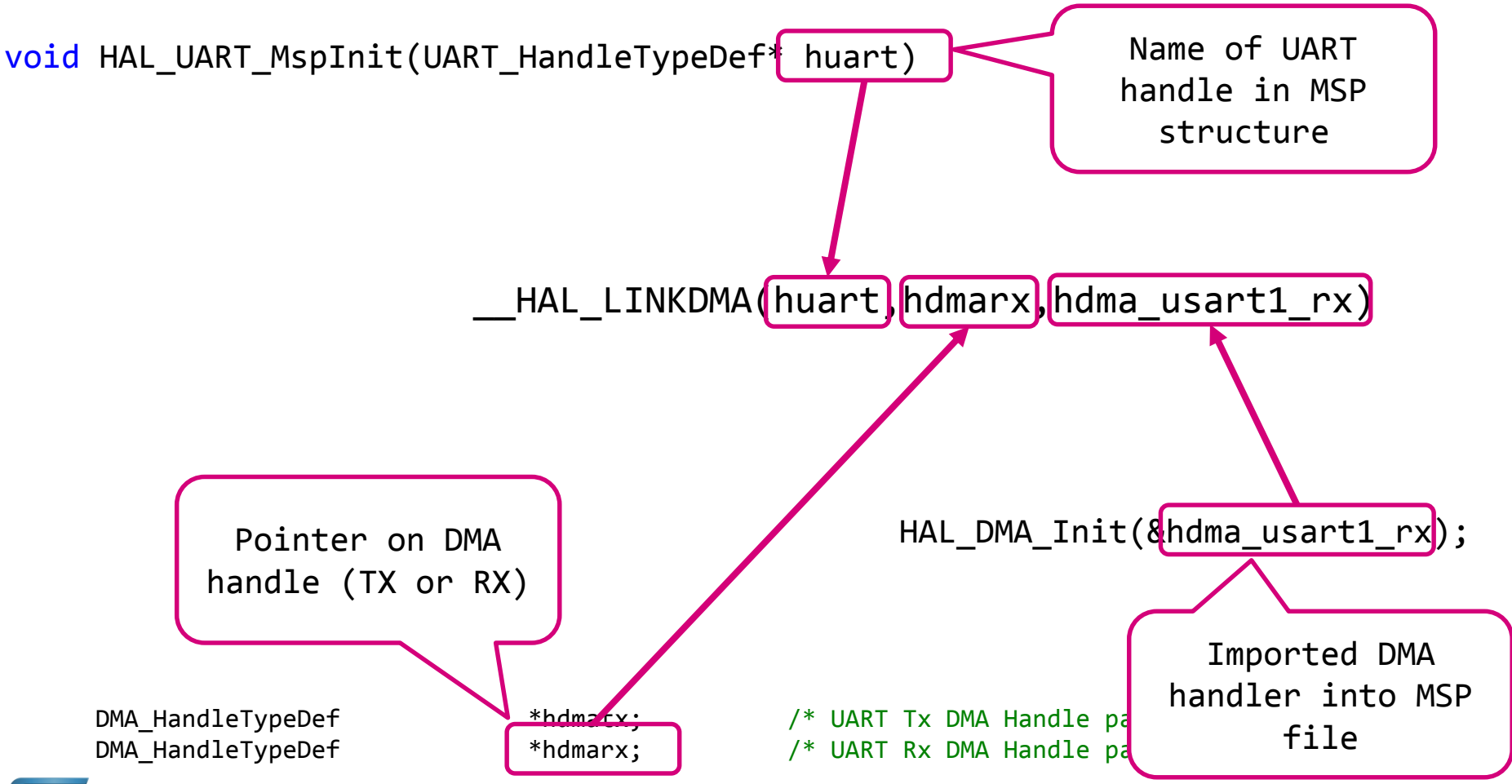
__HAL_LINKDMA macro description

- Definition of macro is in stm32f4xx_hal_def.h



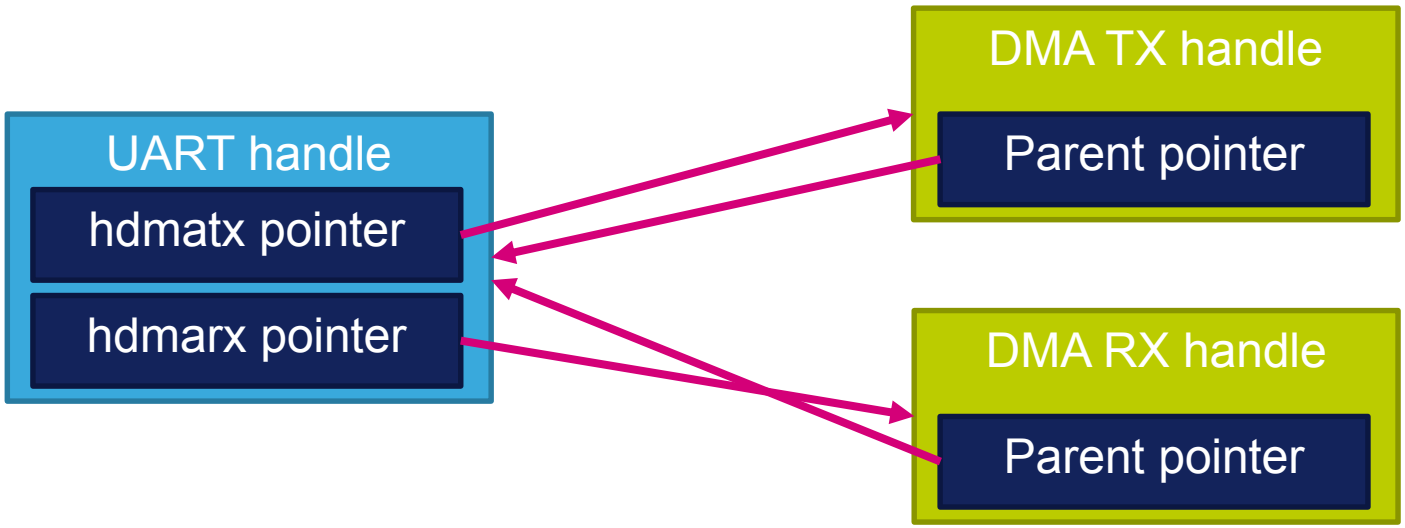
__HAL_LINKDMA macro description

- Definition of macro is in stm32f4xx_hal_def.h



__HAL_LINKDMA function description

- LINKDMA macro connects DMA and UART handle together
- Is possible get information about DMA from UART handle
- And UART handle from DMA



UART with DMA - HAL_UART_MspInit

- Transmit part of DMA initialization is similar to receiving part

```
    hdma_usart1_tx.Instance = DMA2_Stream7;
    hdma_usart1_tx.Init.Channel = DMA_CHANNEL_4;
    hdma_usart1_tx.Init.Direction = DMA_MEMORY_TO_PERIPH;
    hdma_usart1_tx.Init.PeriphInc = DMA_PINC_DISABLE;
    hdma_usart1_tx.Init.MemInc = DMA_MINC_ENABLE;
    hdma_usart1_tx.Init.PeriphDataAlignment = DMA_PDATAALIGN_BYTE;
    hdma_usart1_tx.Init.MemDataAlignment = DMA_MDATAALIGN_BYTE;
    hdma_usart1_tx.Init.Mode = DMA_NORMAL;
    hdma_usart1_tx.Init.Priority = DMA_PRIORITY_LOW;
    hdma_usart1_tx.Init.FIFOMode = DMA_FIFOMODE_DISABLE;
    HAL_DMA_Init(&hdma_usart1_tx);

    __HAL_LINKDMA(huart,hdmatx,hdma_usart1_tx);
  /* USER CODE BEGIN USART1_MspInit 1 */
  /* USER CODE END USART1_MspInit 1 */
  }
}
```

UART with DMA Interrupt

- DMA handles are imported into stm32f4xx_it.c

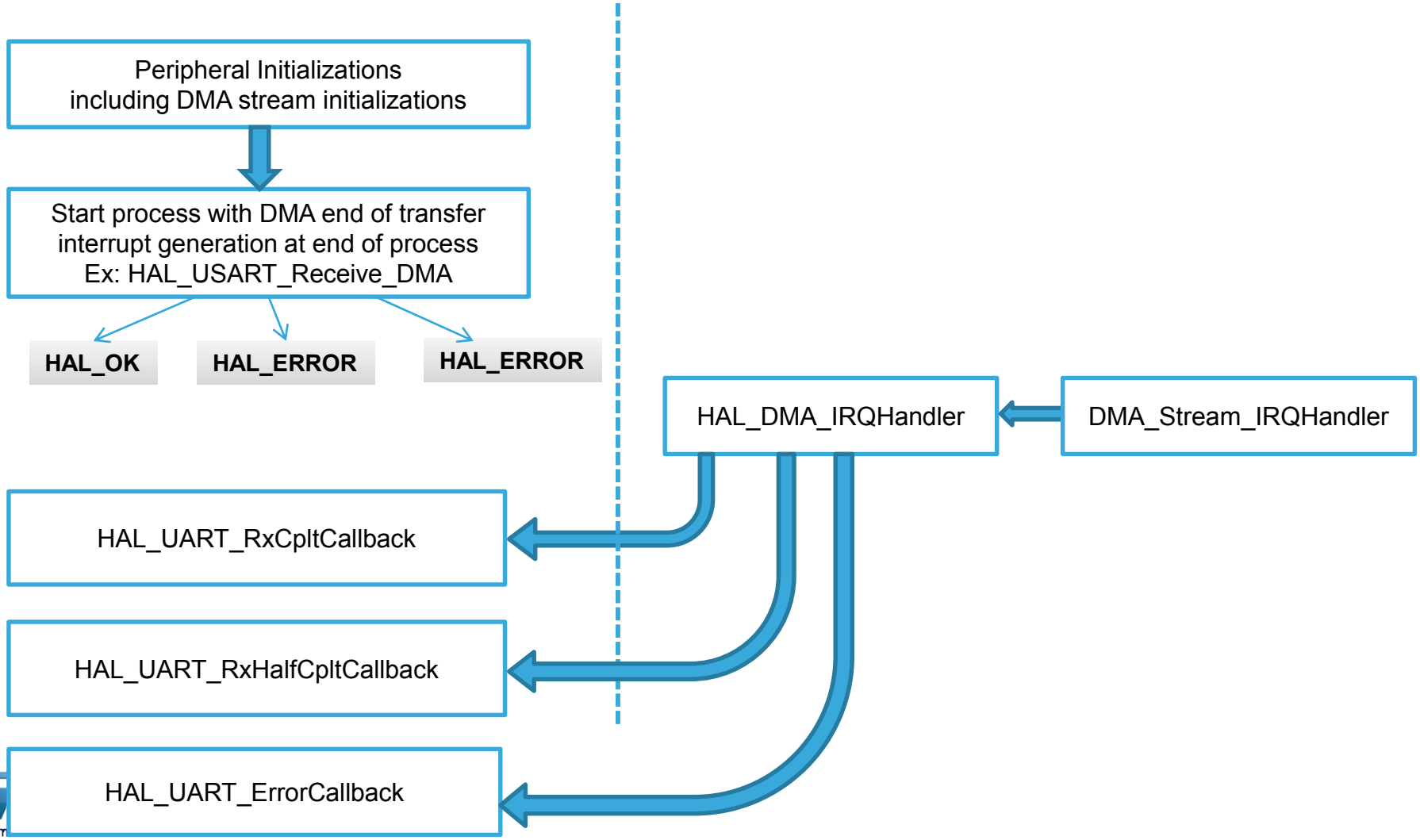
```
/* External variables --------------------------------------------------------*/
extern DMA_HandleTypeDef hdma_usart1_rx;
extern DMA_HandleTypeDef hdma_usart1_tx;
```

- DMA interrupt call HAL_DMA_IRQHandler not UART Handler

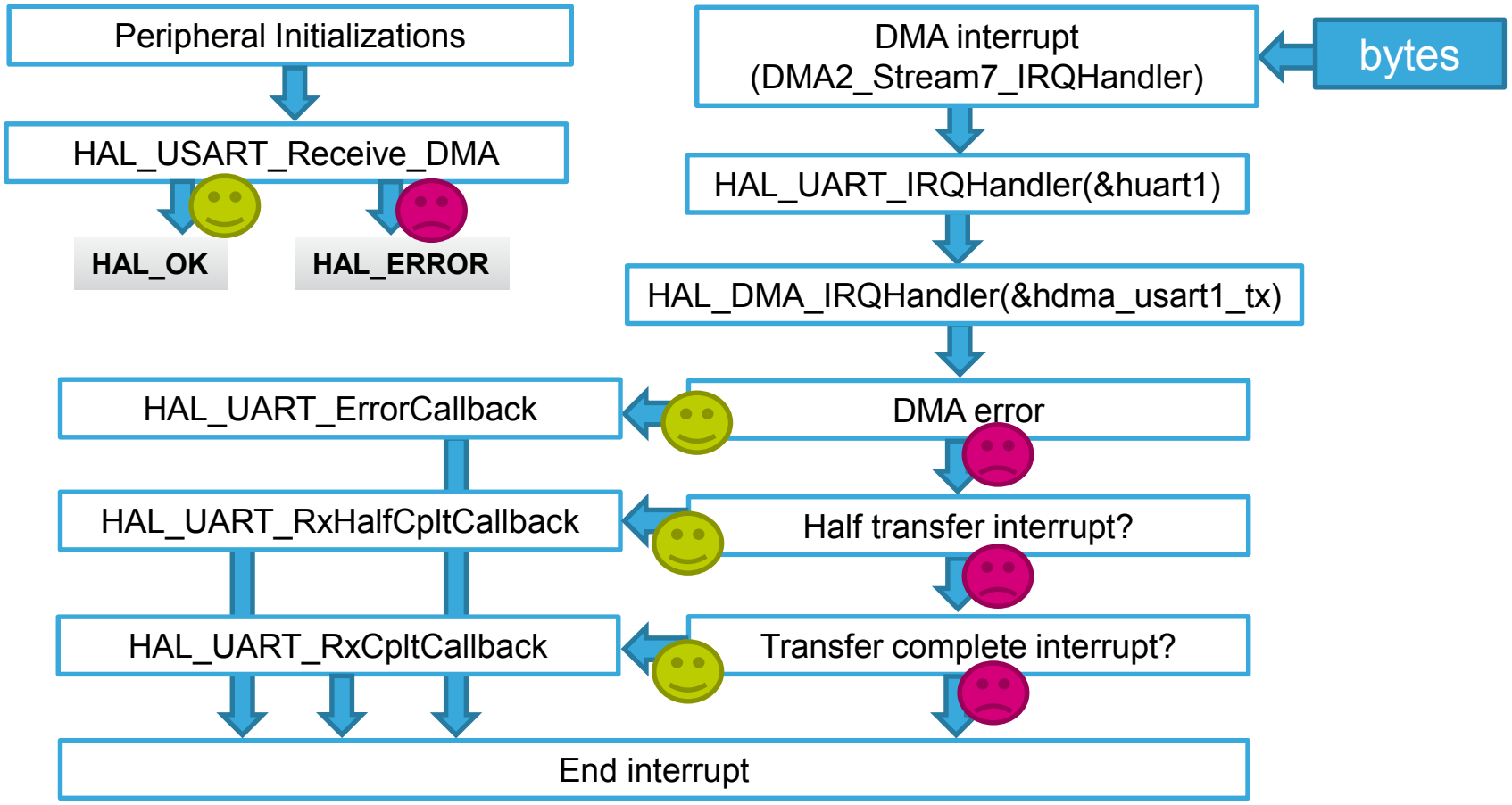
```
/**
* @brief This function handles DMA2 Stream7 global interrupt.
*/
void DMA2_Stream7_IRQHandler(void)
{
  /* USER CODE BEGIN DMA2_Stream7_IRQn 0 */
  /* USER CODE END DMA2_Stream7_IRQn 0 */
  HAL_DMA_IRQHandler(&hdma_usart1_tx);
  /* USER CODE BEGIN DMA2_Stream7_IRQn 1 */
  /* USER CODE END DMA2_Stream7_IRQn 1 */
}
/**
* @brief This function handles DMA2 Stream2 global interrupt.
*/
void DMA2_Stream2_IRQHandler(void)
{
  /* USER CODE BEGIN DMA2_Stream2_IRQn 0 */
  /* USER CODE END DMA2_Stream2_IRQn 0 */
  HAL_DMA_IRQHandler(&hdma_usart1_rx);
  /* USER CODE BEGIN DMA2_Stream2_IRQn 1 */
  /* USER CODE END DMA2_Stream2_IRQn 1 */
}
```

DMA interrupt handled by HAL_DMA_IRQHandler Internally is connected to UART callbacks

Peripheral HAL driver model
Non blocking process with DMA transfer

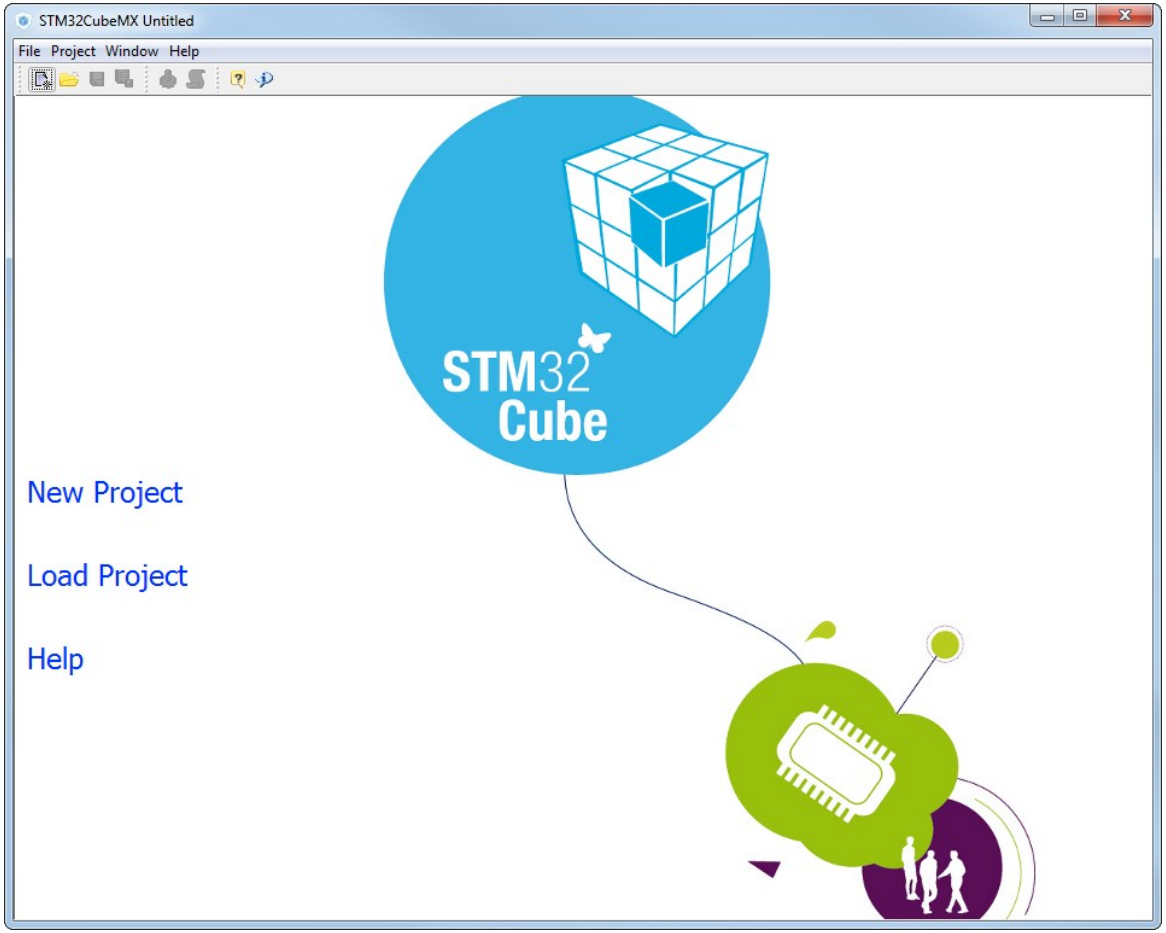


UART receive with DMA



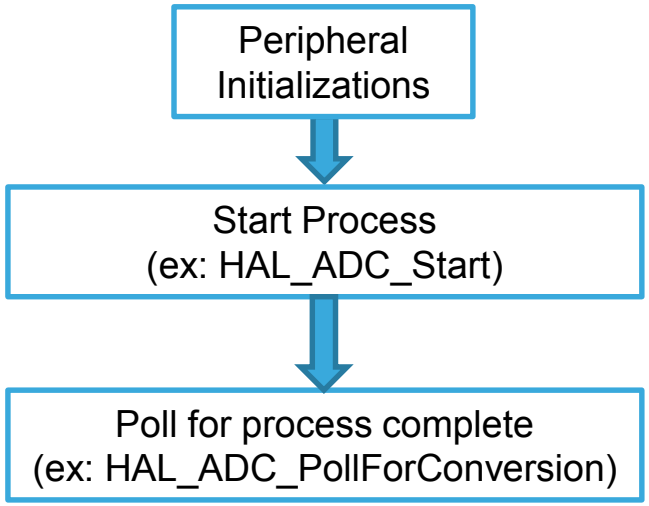
Examples for other peripherals

- SPI labs very similar like UART



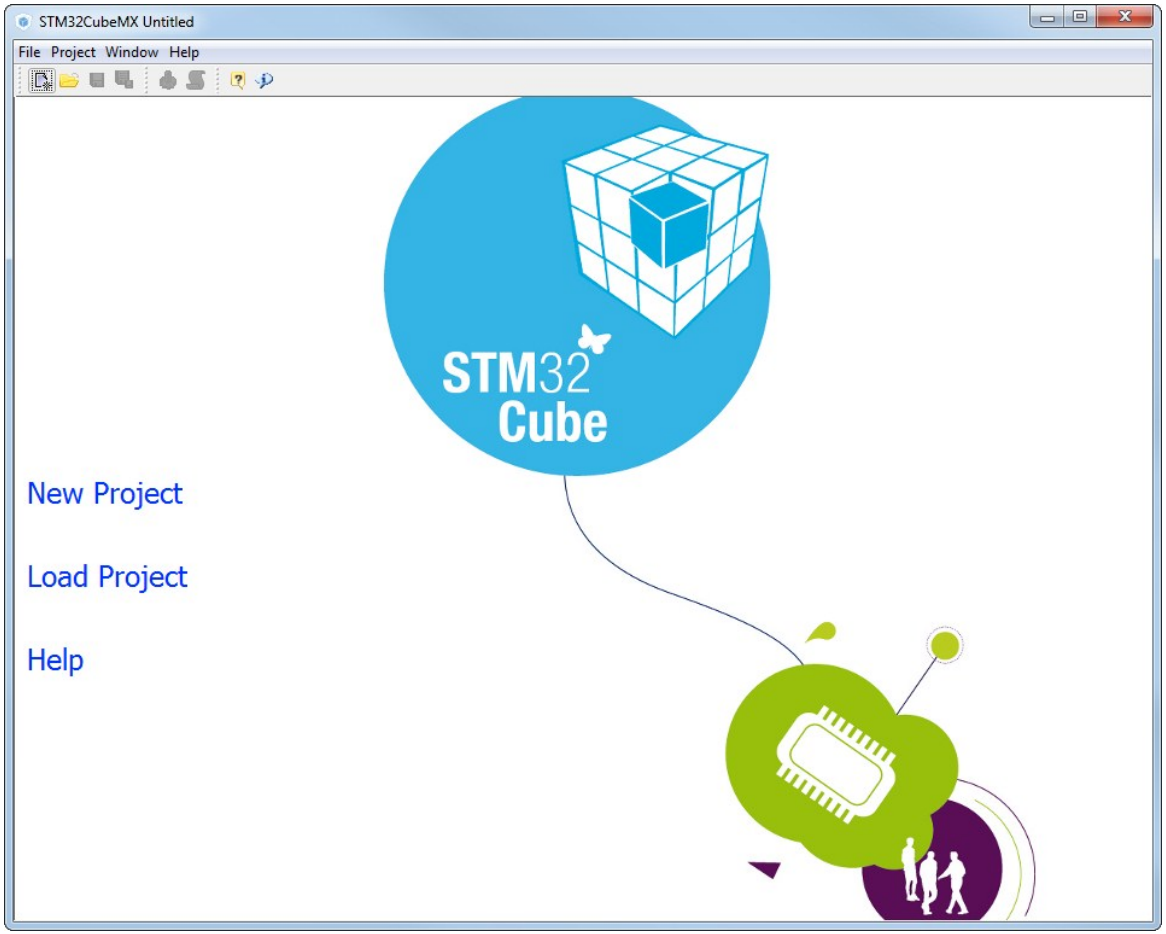
Peripheral HAL driver model
Non Blocking Start process

- Non blocking start process
  - Exits directly after starting the process
  - Used mainly for ADC,DAC, Timer
  - Ex: HAL_ADC_Start()



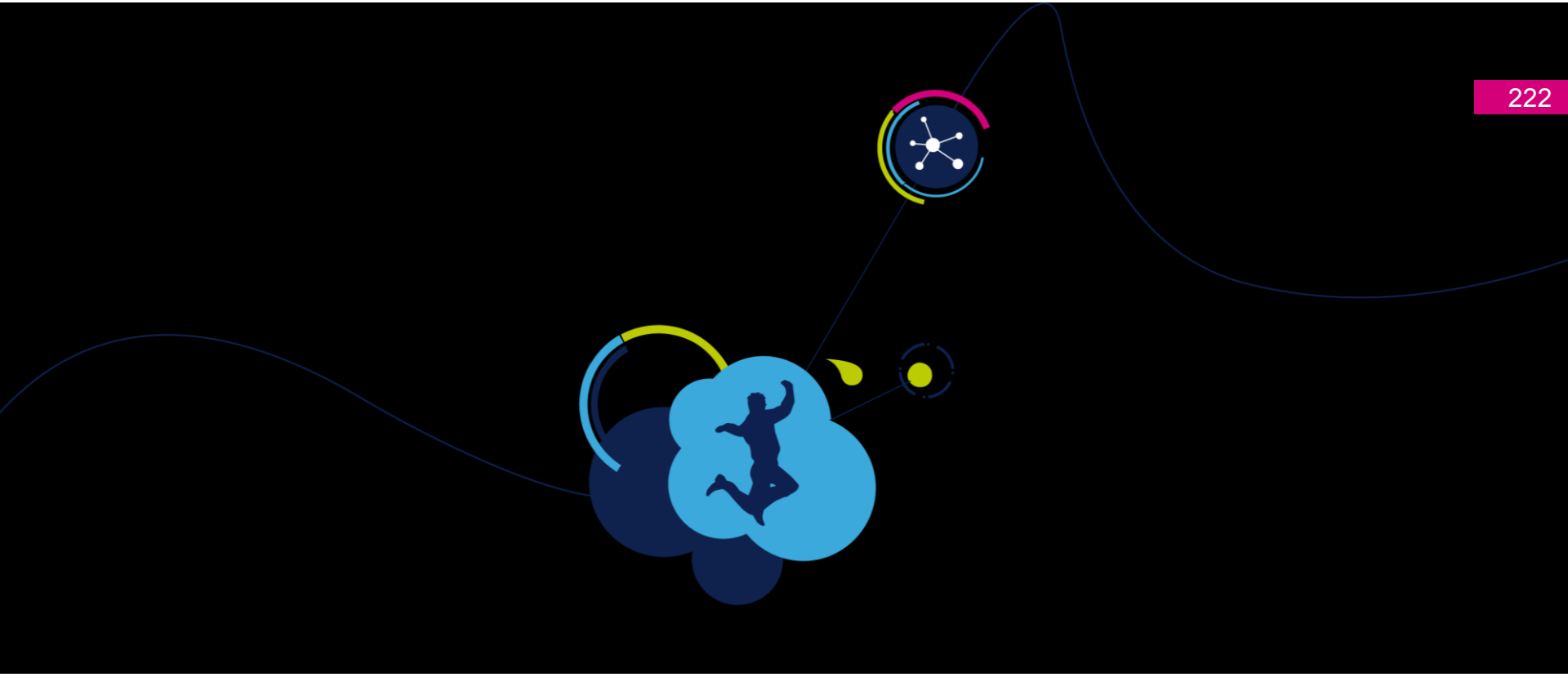
Examples for other peripherals

- For example TIM labs, DAC labs, ADC labs
- Very similar principle as UART



Guidelines for writing a HAL code

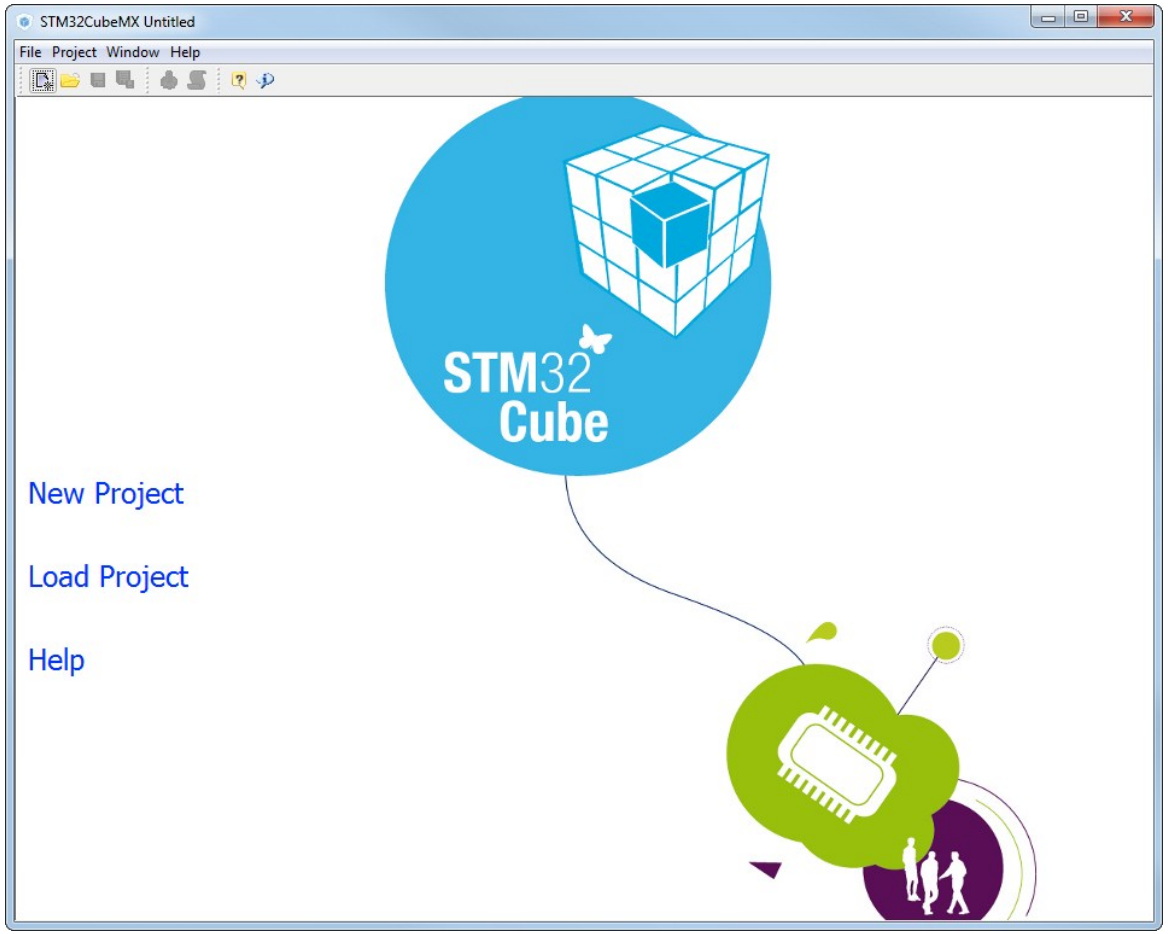
- You can start from the template project
- The template project includes all HAL files and implements a main.c files with startup code to initialize system clock (@ max speed)
- Start by writing the peripheral HAL_PPP_MspInit function, in this function you need to:
  - Enable the peripheral clock
  - Configure the peripheral GPIOs
  - configure DMA channel and enable DMA interrupt (if needed)
  - Enable peripheral interrupt (if needed)
- Edit the stm32f4xx_it.c to call required interrupt handlers (periph and DMA)
- Write process complete callback functions if you plan to use peripheral interrupt or DMA
- In your main.c file, initialize the peripheral handle structure then call function HAL_PPP_Init() to initialize your peripheral
- At this step you can call any peripheral process or control function



Recapitulation

What is CubeMX

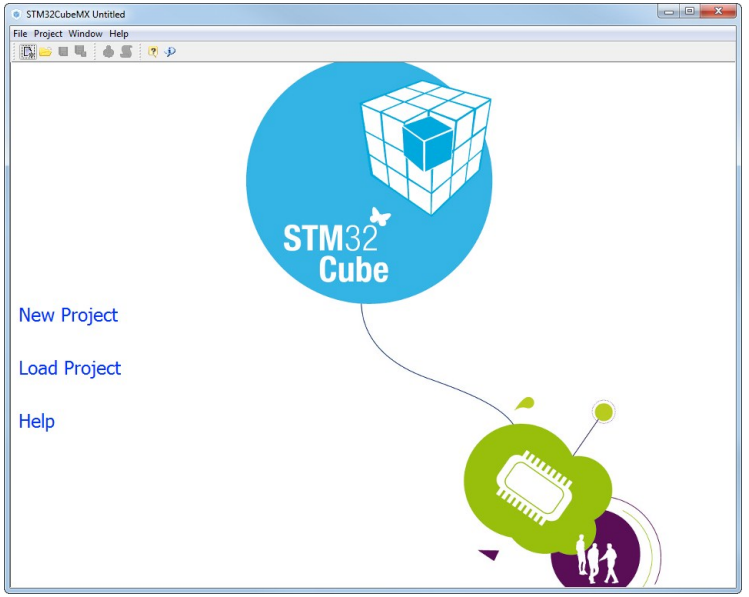
- MCU selector
- Pin out configurator
- Clock configurator
- Periphery configurator
- Code generator



Code generation

- Generate initialization for peripherals selected in CubeMX
- Create Interrupt handlers and use HAL handlers

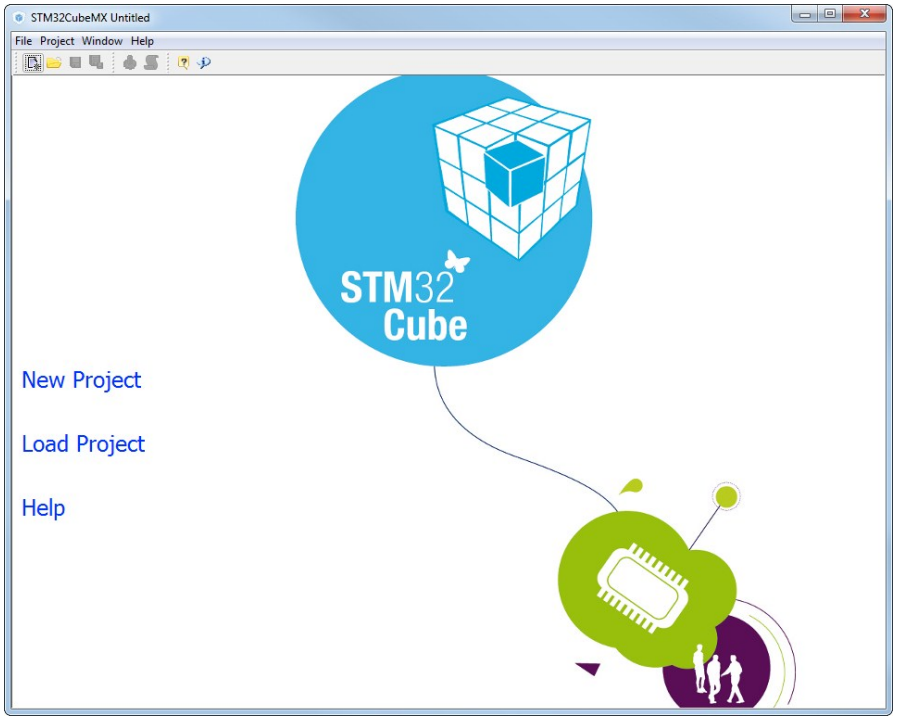
- Create not fully functional program
- User must still start peripheries or define handlers
- Create only initialization for options which are possible in CubeMX



Code generation

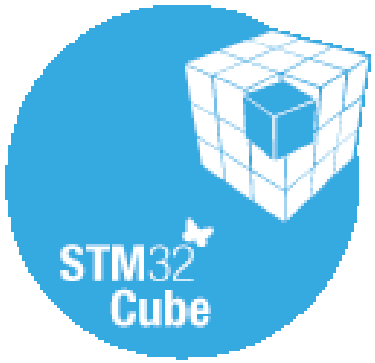
- Generate initialization for peripherals selected in CubeMX
- Create Interrupt handlers and use HAL handlers
- Help us faster create program draft then with STD

- Create not fully functional program
- User must still start peripheries or define handlers
- Create only initialization for options which are possible in CubeMX



Cube HAL library

- Handle based library
- HAL function are not low layer
- If function which you want not exists in HAL
  or work different way how you want,
  is very difficult to do it with HAL library
- HAL have no functions to access all functions
  Is possible access SR and some functional registers (TIM->CNT reg)

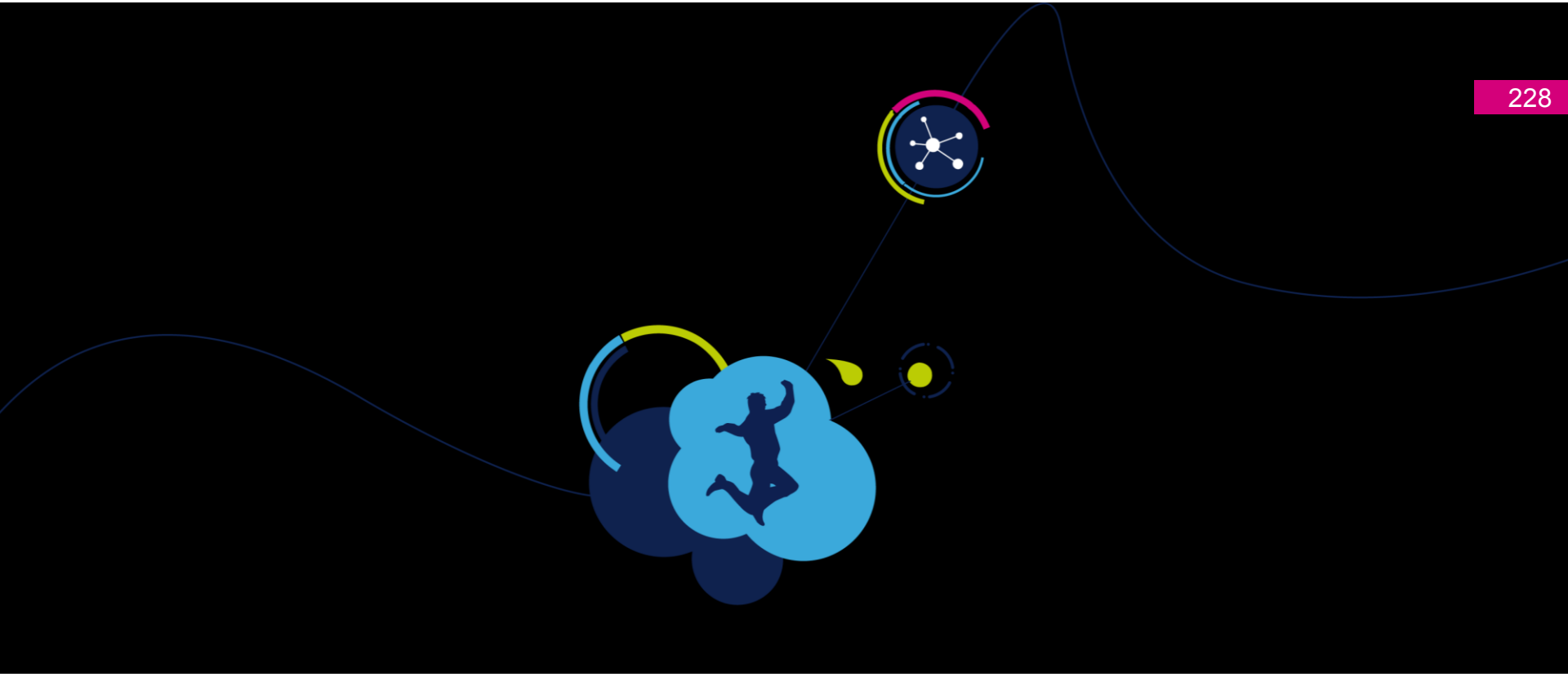


Solving HAL library limitation

- TIM trigger DMA transfer, which move data from RAM to GPIO (TIM DMA lab)
- Function HAL_TIM_Base_Start_DMA exists, but transfer data from RAM to TIM->ARR register
- If we want to transfer data from places which we want, we need to use more functions

```
/* USER CODE BEGIN 2 */
 __HAL_TIM_ENABLE_DMA(&htim1, TIM_DMA_UPDATE);
 HAL_DMA_Start(&hdma_tim1_up,(uint32_t)data,(uint32_t)&GPIOG>ODR,2);
 HAL_TIM_Base_Start(&htim1);
 /* USER CODE END 2 */
```

- We must use three HAL function to make it working
- They are also some situation where HAL functions not exists and we must use direct access into registers



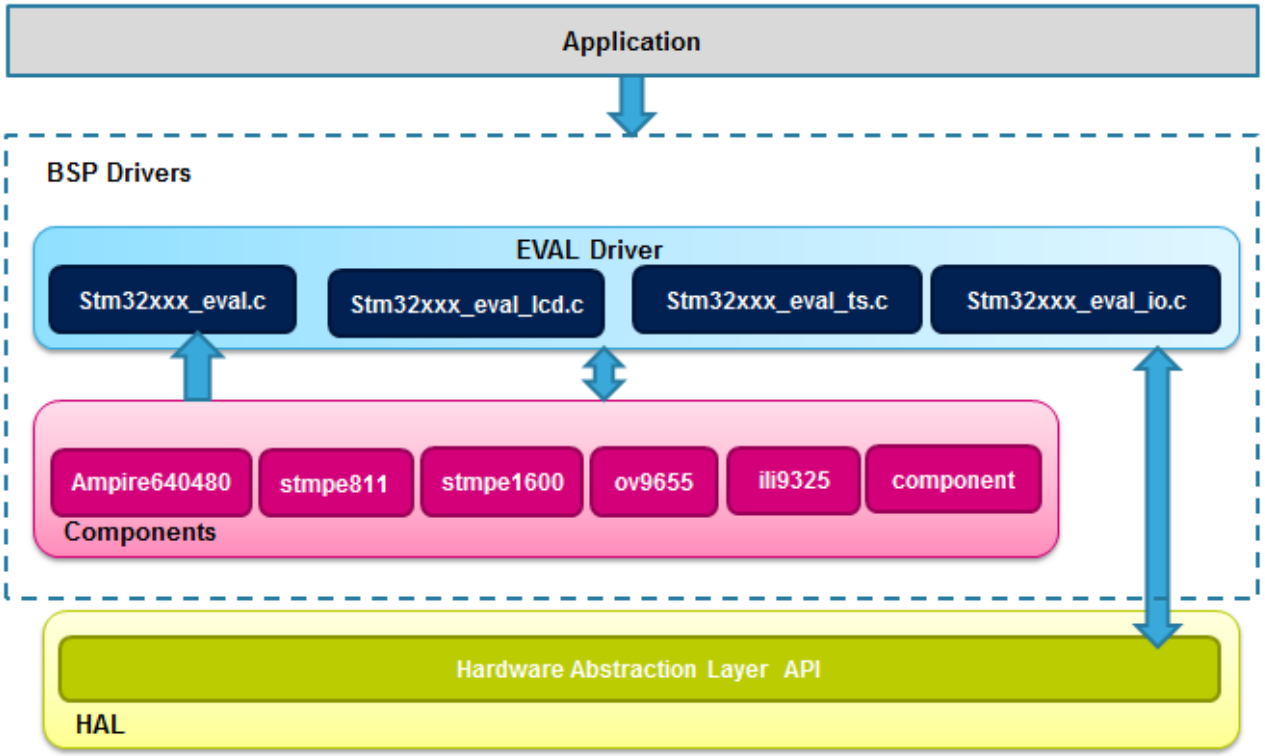
Board Support Package (BSP)

Board support package Overview

- A board support package is available per each product board (EVAL, Discovery, Nucleo)
- The board support package architecture was defined in order to allow easy portability and reuse of the same components (LCD, IO expander,…) on different boards
- This portability is achieved by defining component classes
  - LCD
  - Accelerometer
  - Gyroscope
  - Audio speaker codec
  - IO expander
  - Touch screen controller
- Drivers for the components present on the board are written according to the component class definition (see .h files in \Drivers\BSP\Components\Common) which is **board and MCU independent**
- A board support package is implemented by doing the link with a particular component driver and by associating to it a particular MCU peripheral and needed I/Os

Board support package Overview

- The BSP drivers are generally composed of two parts:
  - Component: is the driver relative to the external device on the board and not related to the STM32, the component driver provide specific APIs to the external components and could be portable on any other board.
  - Board Driver: the Board driver permits to link the component driver to a specific board and provides a set of friendly used APIs.



Examples with BSP

- How to import BSP into your project
- How use BSP examples:
  - FMC SDRAM BSP lab
  - LCD BSP Print text lab
  - I2C BSP EEPROM lab
  - SPI BSP GYROSCOPE lab