



## STG - STM32 + FreeRTOS + LwIP

**Ce cours couvre la famille de MCU STM32 ARM, le système d'exploitation temps réel FreeRTOS, la pile LWIP TCP/IP et/ou la pil**

### Objectifs

- Obtenir un aperçu de l'architecture Cortex-M
- Comprendre l'implémentation et le débogage de logiciels sous l'architecture Cortex-M
- Apprendre à gérer les interruptions
- Obtenir une vue d'ensemble de l'architecture STM32F4
- Décrire les unités qui sont interconnectées à d'autres modules, comme l'horloge, le contrôleur d'interruption et le contrôleur DMA.
- Décrire certains modules d'E/S indépendants comme l'ADC et les GPIOs
- Démarrer avec les pilotes ST pour programmer les périphériques STM32 (la bibliothèque STM32Cube ou la bibliothèque standard de périphériques ST).
- Comprendre l'architecture FreeRTOS
- Découvrir les différents services et APIs de FreeRTOS
- Apprendre à développer et déboguer des applications FreeRTOS
- Démarrer avec la pile LwIP TCP/IP (Décrire le contrôleur Ethernet STM32, jeter un coup d'oeil sur le portage, décrire le paramétrage et développer des applications basées sur les protocoles UDP et TCP) (non disponible pour la famille STM32F0)
- L'aperçu des périphériques présenté dans ce cours peut être détaillé sur demande (cours [STR9 - STM32 Peripherals](#))

*Ce cours peut être basé sur les familles STM32F4xx, STM32F2xx, STM32F1xx ou STM32F0xx.*

*Sur demande, TouchGFX et EmWin peuvent être ajoutés dans une formation spécifique*

### Environnement du cours

- Cours théorique
  - Support de cours imprimé et au format PDF (en anglais)
  - Le formateur répond aux questions des stagiaires en direct pendant la formation et fournit une assistance technique et pédagogique
- Activités pratiques
  - Les activités pratiques représentent de 40% à 50% de la durée du cours
  - Elles permettent de valider ou compléter les connaissances acquises pendant le cours théorique.
  - Un PC pour deux stagiaires pour les activités pratiques
  - Une plateforme cible (base STM32) pour deux stagiaires (sauf en cas d'utilisation de qemu)
  - Accès à un serveur cloud privé
  - Exemples de code, exercices et solutions
  - Le formateur assiste les stagiaires pendant les exercices
- Au début de chaque demi-journée une période est réservée à une interaction avec les stagiaires pour s'assurer que le cours répond à leurs attentes et l'adapter si nécessaire

### Pré-requis

- Familiarité avec les concepts C et la programmation visant le monde embarqué
- Connaissance de base des processeurs embarqués
- Connaissance de base de l'ordonnancement multi-tâches
- Les cours suivants pourraient vous intéresser :
  - cours [AAM - Architecture ARM Cortex-M](#)
  - cours [STR7 - STM32 F4-Series implementation](#)
  - cours [L2 - C language for Embedded MCUs](#)
  - cours [L3 - C++ embarqué](#)
  - cours [STR9 - STM32 Peripherals](#)

## Plan

### Premier jour

#### **Cortex-M Architecture Overview**

- V7-M Architecture Overview
- Core Architecture
  - Harvard Architecture, I-Code, D-Code and System Bus
  - Write Buffer
  - Bit-Banding
  - Registers (Two stacks pointers)
  - States
  - Different Running-modes and Privileged Levels
  - System Control Block
  - SysTick Timer
  - MPU Overview
- Programming
  - Alignment and Endianness
  - CMSIS Library
- Exception / Interrupt Mechanism Overview
  - Vector Table
  - Interrupt entry and return Overview
  - Tail-Chaining
  - Pre-emption (Nesting)
  - NVIC Integrated Interrupt Controller
  - Exception Priority Management
  - Fault escalation
- Debug Interface

*Exercice : Becoming familiar with the IDE and clarifying the boot sequence*

*Exercice : Cortex-M4 Mode Privilege (with CMSIS library)*

*Exercice : Cortex-M4 Exception Management (put in evidence tail-chaining/nesting)*

*Exercice : Cortex-M4 MPU*

#### **STM32F4 MCUs Architecture Overview**

- ARM core based architecture
- Description of STM32Fx SoC architecture
- Clarifying the internal data and instruction paths: Bus Matrix, AHB-lite interconnect, peripheral buses, AHB-to-APB bridges, DMAs
- Memory Organization
  - Flash memory read interface
  - Adaptive Real-Time memory accelerator, instruction prefetch queue and branch cache
  - Sector and mass erase

- Concurrent access to RAM blocks
- SoC mapping
- Flash Programming methods
- Boot Configuration

## Deuxième jour

### **Reset, Power and Clocking**

- Reset
  - Reset sources
  - Boot configuration, physical remap
  - Embedded boot loader
- Clocking
  - Clock sources, HSI, HSE, LSI, LSE
  - Integrated PLLs
  - Clock outputs
  - Clock security system
- Power control
  - Power supplies, integrated regulator
  - Battery backup domain, backup SRAM
  - Independent A/D converter supply and reference voltage
  - Power supply supervisor
  - Brownout reset
  - Programmable voltage detector
- Low power modes
  - Entering a low power mode, WFI vs WFE
  - Sleep mode
  - Stop mode
  - Standby mode

*Exercise : Configure the system to measure the current consumption in different low-power modes*

*Exercise : How to configure the programmable BOR thresholds using the FLASH option bytes*

*Exercise : How to enter the Standby mode and wake up from this mode by using an external reset/WKUP pin*

*Exercise : How to enter the Stop mode and wake up from this mode by using the RTC wakeup timer event or an interrupt*

### **ST Firmware Library Description**

#### **DMA**

- Dual AHB master bus architecture, one dedicated to memory accesses and one dedicated to peripheral accesses
- 8 streams for each DMA controller, up to 8 channels (requests) per stream
- Priorities between DMA stream requests
- FIFO structure
- Independent source and destination transfer width
- Circular buffer management
- Double buffer mode
- DMA1 and DMA2 request mapping

*Exercise : DMA FIFO mode*

*Exercise : Flash To RAM using DMA*

#### **Hardware implementation**

- Power pins
- Pinout
  - Pin Muxing, alternate functions

- GPIO module
  - Configuring a GPIO
  - Speed selection
  - Locking mechanism
  - Analog function
  - Integrated pull-up / pull-down
  - I/O pin multiplexer and mapping
- System configuration controller
  - I/O compensation cell
  - External Interrupts / Wakeup lines selection
  - Ethernet PHY interface selection
- External Interrupts

*Exercise : Configure an external Interrupt*

### **12-bit Analog-to-Digital Converter**

- 12-bit, 10-bit, 8-bit or 6-bit configurable resolution
- Regular channel group vs Injected channel group
- Single and continuous conversion modes
- Scan mode for automatic conversion of channel 0 to channel 'n'
- External trigger option with configurable polarity for both regular and injected conversions
- Discontinuous mode
- Analog watchdog's guarded area
- Dual/Triple mode (on devices with 2 ADCs or more)
- Configurable delay between conversions in Dual/Triple interleaved mode
- DMA request generation during regular channel conversion

*Exercise : Get voltage from the potentiometer using, DMA transfer generation, display the result on LCD screen*

### **Optional: Timers Overview**

- Advanced-control timers TIM1 and TIM8
  - 16-bit up, down, up/down auto-reload counter; 16-bit programmable prescaler
  - Input Capture, Output Compare, PWM generation, One-pulse mode
  - Synchronization circuit/ Controlling Timers external signals / Interconnecting several timers
  - Interrupt/DMA generation
- Real Time Clock
  - Independent BCD timer/counter; 16-bit programmable prescaler
  - Daylight saving compensation programmable by software
  - Two programmable alarms with interrupt function
  - Automatic wakeup unit
  - Reference clock detection / Digital calibration circuit
  - Tamper detection

*Exercise : How to use DMA with TIM1 Update request to transfer Data from memory to TIM1*

*Exercise : Configuring the RTC*

### **Troisième jour**

### **The FreeRTOS source code**

- Introduction to FreeRTOS
  - The FreeRTOS architecture and features
- Getting FreeRTOS source code
  - Files and directories structure
- Data types and coding style
  - Naming conventions
- FreeRTOS on the Cortex/M processors

## Task Management

- Prioritized Pre-emptive Scheduling / Co-operative scheduling
- The Task life-cycle
  - Task Functions
  - Creating tasks
  - Using the task parameter
  - The Task State Machine
  - Deleting tasks
- Task Priorities
  - Assigning task priorities
  - Changing task priorities
- The idle task
  - Idle task hook
- Blocking a task for a specific delay
- Editing the FreeRTOSConfig.h header file
- Suspending a task
- The Kernel Structures Overview
- FreeRTOS Debug Capabilities (Hook, Trace)

*Exercise : Understand the notion of task context and the context switch mechanism*

*Exercise : Create a debug configuration to debug your program using a FreeRTOS-aware debugging mode*

*Exercise : Periodic Tasks*

*Exercise : Task Statistics*

## Memory Management

- FreeRTOS-provided memory allocation schemes
    - Choosing the heap\_x.c file depending on the application
  - Adding an application-specific memory allocator
  - Checking remaining free memory
  - Stack monitoring
  - Dimensioning Stack and Heap
- Exercise : Direct Context Switch measurement and Stack Overflow Detection*
- Exercise : Debugging memory*

## Quatrième jour

### Queue Management

- Blocking on queue Reads
  - Blocking on queue Writes
  - Queue Creation
  - Sending on a queue
  - Receiving from a queue
  - Sending compound types
  - Transferring large data
  - Queue Set Overview/ Blocking on multiple objects
  - Semaphores and Events Introduction
- Exercise : Synchronizing and communicating between tasks through queues to send datas to a bus communication*

### Resource Management

- Conflict examples
- Mutual exclusion
- Critical sections

- Disabling the interrupts
- Suspending (locking) the scheduler
- Mutexes
  - Mutual exclusion scenario
  - API functions for Mutexes
  - Recursive Mutexes
  - Priority inversion
  - Priority inheritance
  - Deadlock
- Gatekeeper tasks

*Exercise : Readers / Writers Problem*

*Exercise : Producer / Consumer Problem*

*Exercise : Understand deadlock and starvation*

## **Interrupt Management**

- Binary semaphore used for interrupt synchronization
  - API function for binary semaphore
- Counting semaphores
- Using queues within an ISR
- Interrupt Nesting
  - Interrupts on Cortex-M
- Low Power Support

*Exercise : Synchronize Interrupts with tasks*

*Exercise : Low-Power FreeRTOS Support (Tickless Mode)*

## **Cinquième jour**

### **Software Timer**

- The Timer Daemon Task
- Timer Configuration
- One-shot / Auto-reload Timer
- Software Timer API

*Exercise : Understand the use of software timers*

### **FreeRTOS MPU**

- User Mode and Privilege Mode
  - Access Permission Attributes
- Defining an MPU region
- Creating a non-privileged task
- Linker configuration
- Practical Usage Tips

## **STM32 Fast Ethernet Controller Overview**

- Architecture of the MAC
- Connection to PHY, RMII / MII
- Transmit and receive FIFO threshold setting
- Multicast and unicast address filtering
- Management interface
- Buffer and Buffer Descriptor organization
- Low level Drivers for STM32

## LwIP TCP/IP Stack Presentation

- Overview
- Buffer and memory management
- LwIP configuration options
- Network interfaces
- MAC and IP address settings
- IP processing
- UDP processing
- TCP processing
- Interfacing the stack
- Application Program Interface (API)
  - Standalone
  - Netconn and BSD socket library
- STM32/FreeRTOS Port Overview

*Exercice : Run an http server application based on Netconn API of LwIP TCP/IP stack*

*Exercice : http server application based on Socket API of LwIP TCP/IP stack*

*Exercice : TCP Echo Client/Server*

*Exercice : In-Application Programming (IAP) over Ethernet using TFTP or HTTP*

## Optional : EmWin GUI Stack Presentation

- Library and package description
- How to use the library
  - Configuration
  - Initialization
  - Core functions
  - Developing a multi-task application with EmWin
  - Working with some widgets (as the Windows, Buttons, Multipage, Image, ListBox, CheckBox)
  - Using the EmWinGuiBuilder software

*Exercice : Getting started with the emWin stack, create a GUI to control input/output from the touch screen*

## Optional: TouchGFX

- Basic Application Development
- Advanced Application Development
- Application Configuration
- Widgets
- Integration
- Getting Started with CubeMX and TouchGFX
- Deploying your application using ST-Link

*Exercice : How to configure and use TouchGFX under FreeRTOS (Demo)*

## Renseignements pratiques

**Durée : 5 jours**  
**Prix : 2810 € HT**