

## L2 - C language for Embedded MCUs

*Learning how to program a Microcontroller (especially the Cortex-M based ones)*

### Objectives

- Reviewing the C language standard
- Putting in evidence the essential C features used in embedded application
- Discovering the Embedded context through several bare-metal labs running on an STM32F4 MCU (Cortex-M4 core based)
- Discovering the Debug features
- Understanding the different steps of a toolchain
- Understanding how to configure a linker script to place code and data in memory
- Getting an Overview on STM32F4 Architecture
- Understanding the Cortex-M4 Application level programmers model
- Reviewing the boot sequence
- Analyzing the compiler optimization and how to write optimized code
- Interfacing C and Assembly
- Learning how to handle interrupts
- Programming a serial communication
- Configuring DMA transfers
- Working with an ADC

### Course environment

- Convenient course material with space for taking notes
- Example code, labs and solutions
- A STM32F2 (Cortex-M3) Board for Labs
- A PC for two trainees with the free System Workbench for STM32 IDE to flash and debug applications

### Prerequisites

- Basic knowledge of C language (or another low-level language)
- Knowledge of binary arithmetic
- The knowledge of embedded processor philosophy is recommended

### 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.
  - Exemples de code, exercices et solutions
  - Un PC (Linux ou Windows) par binôme de stagiaires (si plus de 6 stagiaires) pour les activités pratiques avec, si approprié, une carte cible embarquée.
  - Le formateur accède aux PC des stagiaires pour l'assistance technique et pédagogique.
- Une machine virtuelle préconfigurée téléchargeable pour refaire les activités pratiques après le cours
- 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

## Audience visée

- Tout ingénieur ou technicien en systèmes embarqués possédant les prérequis ci-dessus.

# Plan du cours

## First Day

### Analyzing the different Toolchain elements

- Using cross compilation
- Compiler, Assembler and Linker Purpose
- C source program structure
- Preprocessor
  - #define, #include instructions
  - Writing Macros with precaution
  - Writing Header files with precaution
- Reviewing the different object file sections
- Library inclusion
- Startup file
- GCC compiler options
- Configuring the linker to place code and data in the memory, executing code from RAM
- Makefile

**Exercise :** Following the different build steps of a simple program

**Exercise :** Working with Conditional Compilation

**Exercise :** Working with the linker, placing code and data in the memory

### Lab Environment

- Creating a project from scratch
- Debug probe
- Communicating with the Target
- Debugger Windows : Source (C and Disassembly), Memory, Stack, Variables, Registers
- Breakpoints

### Types and Operators

- Variable storage class (static, automatic, register et extern) with their location and lifetime
- Local and global variable declaration
- Scalar types (char, halfword, int, float and double)
- Constants
- Strings
- Type conversion, casting
- The volatile attribute
- C operators (logical, arithmetical and relational)
- Operator priority

**Exercise :** Working with types and operators

## Second Day

### Control structures

- If/else structure
- Switch/case structure

- While, do/while and for loop
- Break, continue and go instructions

**Exercise :** Working with control structures

## Pointers and Arrays

- Pointer definition
- Pointer Initialization, pointer access, pointer operations
- Constant and volatile pointer
- The restrict attribute
- One- and Multi-dimensional arrays
- Array initialization, array access, array operations
- Pointer array

**Exercise :** Working with pointers

**Exercise :** Working with arrays

## Structures and unions

- Structure variable declaration
- Structure variable pointer declaration
- Structure field access
- Padding, #pragma pack compilation directive
- Big and little endian format
- Bit field structure declaration
- Modeling peripheral register
- Structure array
- Typedef type
- Enum type
- Union declaration
- Union initialization and operation

**Exercise :** Modeling a STM32F2 timer to program it

## Functions

- Function prototype (arguments, return value)
- Function definition and declaration
- Function visibility
- Function pointer
- Function call
- Passing parameter
- Stack operation
- Stack frame, call stack
- The recursivity and the stack
- Macro vs function
- Pipeline and branch
- Function inlining
- Interfacing C and Assembler

**Exercise :** Passing parameter to function

**Exercise :** Analyzing the stack utilization

## Standard library Overview

- Stdio library
- Getchar and putchar functions
- Malloc function
- Printf and scanf functions
- File access function review

## Third Day

### Data structures

- Programming FIFOs
- Programming Linked list (simple and double)

**Exercise :** Working with linked list

### Dynamic allocation

- Dynamic allocation functions: malloc, free function
- sizeof operator
- Dynamic memory allocation vs static memory allocation
- Stack vs Heap
- Memory management algorithms overview
  - Buddy System
  - Best fit / First Fit
  - Pools Management
- Memory management errors

**Exercise :** Using dynamic allocation

### Embedded Context

- Peripheral Programming
- Peripheral register access and Memory access
- Signed vs unsigned
- Memory latency
- Cache
- Synchronization
- Interruption necessity in an embedded context
- Level and pulse triggered interrupts
- Interrupt clearance
- Interrupt handler writing
- Vector table
- Vector installation

### Cortex-M Architecture Overview

- V7-M Architecture Overview
- Harvard Architecture, I-Code, D-Code and System Bus
- Registers (Two stacks pointers)
- States
- Different Running-modes and Privileged Levels
- System Control Block
- SysTick Timer
- 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
- Debug Interface Overview
- Clarifying the boot sequence

**Exercise :** Timer Interrupt Management

## Fourth Day

### Compiler Hints and Tips for Cortex-M

- Compiler optimizations
- Mixing C and Assembly
- AAPCS
- Function inlining
- Unaligned Accesses, padding
- Local and global data issues, alignment, Structure

**Exercise :** Interfacing C and Assembler

**Exercise :** Demo: Long Branch, Function inlining, padding

### STM32F4 MCUs Architecture Overview

- ARM core based architecture
- Description of STM32F407X 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
  - Internal SRAMs
  - Concurrent access to 112 KB and 16 KB blocks
- SoC mapping
- Flash Programming methods
- Boot Configuration
- Power, Reset and Clocking Overview
- DMA Overview
- UART Overview

**Exercise :** Get Metrics for a data copy using the DMA or not

**Exercise :** Programming the UART to redirect the printf on the serial port

**Exercise :** Displaying ADC value on LCD