

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