



## oL30 - Classic and Modern C++ for Embedded Systems

### Objectives

- Master the C++ language
- Use C++ Template (generic code) in Embedded Systems
- Master the C++ Advanced aspects such as polymorphism, single and multiple inheritances.
- Learn to redefine the C++ operators for dynamic memory allocation in embedded applications
- Manage C++ exceptions for Secure Embedded applications
- Use C++ objects to handle serial transmission / reception of character strings
- Discover the modern C++ features
- Learn the language changes in C++11, C++14, C++17 and C++20
- Discover the new functionalities added to the standard library
- Learn advanced modern C++ features like perfect forwarding
- Moving from traditional C++ to modern C++
- Emphasizing the essential modern C++ features used in embedded application

*Labs are conducted on a QEMU-emulated ARM-based board*

### Prerequisite

- C programming skills (see our [oL2 - C Language for Embedded MCU](#) course)

### Course Environment

- Theoretical course
  - PDF course material (in English).
  - Course dispensed using the Teams video-conferencing system.
  - The trainer answers trainees' questions during the training and provide technical and pedagogical assistance through the Teams video-conferencing system.
- Practical activities
  - Practical activities represent from 40% to 50% of course duration.
  - Code examples, exercises and solutions
  - One Online Linux PC per trainee for the practical activities.
  - The trainer has access to trainees' Online PCs for technical and pedagogical assistance.
  - Eclipse environment and GCC compiler.
  - QEMU Emulated board or physical board connected to the online PC (depending on the course).
  - Some Labs may be completed between sessions and are checked by the trainer on the next session.
- Downloadable preconfigured virtual machine for post-course practical activities
- At the start of each session the trainer will interact with the trainees to ensure the course fits their expectations and correct if needed

### Duration

- Total: 30 hours
- 5 sessions, 6 hours each (excluding break time)
- From 40% to 50% of training time is devoted to practical activities
- Some Labs may be completed between sessions and are checked by the trainer on the next session

### Target Audience

- Any embedded systems engineer or technician with the above prerequisites.

**Evaluation modalities**

- The prerequisites indicated above are assessed before the training by the technical supervision of the trainee in his company, or by the trainee himself in the exceptional case of an individual trainee.
- Trainee progress is assessed in two different ways, depending on the course:
  - For courses lending themselves to practical exercises, the results of the exercises are checked by the trainer while, if necessary, helping trainees to carry them out by providing additional details.
  - Quizzes are offered at the end of sections that do not include practical exercises to verify that the trainees have assimilated the points presented
- At the end of the training, each trainee receives a certificate attesting that they have successfully completed the course.
  - In the event of a problem, discovered during the course, due to a lack of prerequisites by the trainee a different or additional training is offered to them, generally to reinforce their prerequisites, in agreement with their company manager if applicable.

**Plan****First Session****Introduction to C++ for industrial systems**

- Introduction to object oriented programming
- History and definition
- Overview on C++98/C++03/C++11/C++14/C++17/C++20
- Modern C++ objectives
- Switch from C to C++
- Embedded C++
- How to write optimized embedded code

*Exercise: Understand function mangling*

*Exercise: Function inlining*

*Exercise: Volatile variable handling*

**C++ and embedded systems**

- Object Oriented Programming in C++
  - Encapsulation
  - Classes and objects
  - Attributes and member functions
  - Object construction and destruction
  - Construction parameters
  - Copy constructor
  - Object composition and container
  - Scope qualifier operator

*Exercise: Declaring classes and methods*

*Exercise: Working with default, copy and parameterized constructors*

*Exercise: Understand the differences between composition and aggregation*

**Second Session****Operator Overloading**

- Optimizing parameter object passing
- Overloading operators by member functions
- Overloading operators by friend functions
- Memory management operators overloading

*Exercise: The assignment operator*

*Exercise: overloading operators*

## Simple Inheritance

- Specialization by addition and substitution
- Derivation and access rules
- Construction during inheritance
- Inheritance polymorphism
- Virtual methods

*Exercise: Understand inheritance*

## Persistent and flashable objects

- Constant and partially constant objects
- Persistent objects
- Flashable objects

*Exercise: Creating constant, mutable, persistent and ROMable objects*

## Enhancing security with exceptions

- Launching, capturing and handling exceptions
- Retriggering exception
- Exceptions specifications
- Handling unexpected exception
- Exception objects of the C++ standard library

*Exercise: Handle errors using exceptions*

*Exercise: Unexpected exceptions management*

## Third Session

## C++ advanced techniques

- Member pointers
- Generic objects and templates
  - Classes and generic functions
  - Templates overloading
  - Specializing templates
  - STL (Standard Template Library)
  - Templates in embedded systems
- Polymorphic objects
- Virtual objects and abstract classes
- Specializing objects by simple inheritance
  - Building derivate objects
  - Access control rules for inherited objects
  - Specializing objects by multiple inheritance
  - Conflicts resolution by scope operator
  - Virtual inheritance

*Exercise: Generic classes and functions*

*Exercise: Understand virtual methods by subclassing a generic Device class*

*Exercise: Understand multiple inheritance and virtual bases*

## Fourth Session

## Introduction to modern C++

- Overview
- Storage class specifiers
- Uniform initialization
- C++ Named Requirements

- Automatic type deduction
  - The auto keyword
  - The auto keyword as a return type from a function
  - Using auto for declaring function signatures
  - Automatic constant references
  - Forwarding references
  - Advantages of using auto in embedded systems

*Exercise: Using auto to declare variables*

## Keywords

- Enum class
- override and final
- Inline variables
- nullptr
- static\_assert
- noexcept
- constexpr and if constexpr
- decltype
- Defaulted and deleted functions
  - Implementing a thread-safe singleton

*Exercise: Using modern C++ keywords*

*Exercise: Create a singleton using modern C++*

## New functionalities

- Structured binding
- Range-based for loops
- Nested namespaces and namespace aliases
- Alignment
  - Alignas
  - Alignof
- Move semantics and r-value references
  - Copy-constructing and Move-constructing
  - r-value references
  - Perfect forwarding

*Exercise: Using the new for loop syntax*

*Exercise: Using std::tuple*

*Exercise: Move semantics performance advantages on embedded systems*

## Modern C++ Standard Library

- Standard Library
  - std::optional
  - std::variant
  - std::any
  - std::byte
  - std::hash
  - Filesystem library
- Literals
  - Cooked literals
  - Standard literal operators
  - Raw literals
  - Raw string literals
- Random number generation
  - Random number generation engines
  - Random number generation distributors
- Containers
  - std::array
  - std::forward\_list

- Unordered associative containers

*Exercise: Using the new elements added to the standard library*

*Exercise: Using std::optional*

## **Fifth Session**

### **String Manipulation**

- New string Types
  - std::u16string
  - std::u32string
- Basic string view
- Converting between numeric and string types
- Elementary string conversions
- Input/output manipulators
  - std::get\_money, std::put\_money
  - std::get\_time, std::put\_time
  - std::quoted
- Regular expressions
  - Format of a string
  - Parsing the content of a string
  - Replacing the content of a string

*Exercise: Using String class and String literals*

### **Concurrency and Multithreading**

- Introduction
- Thread
- Atomic operations
  - Atomic features
  - Non-class functions
  - Atomic flag
  - Memory order
- Mutex
  - Avoiding using recursive mutexes
- Sending notifications between threads
- Condition variables
- Future and Promise
- Task and Async
- Modern C++ and RTOS

*Exercise: Blink synchronously 4 Leds*

### **Lambda functions**

- Syntax of lambdas
- Defining lambdas
- Using lambdas
  - Using lambdas with standard algorithms
  - Assigning lambdas to function pointers
  - Lambdas and std::function
  - Writing a function that accepts a lambda as parameter
- Polymorphic lambdas
- Recursive lambdas

*Exercise: Understanding lambda*

*Exercise: Using lambda to modify and display a vector*

### **Dynamic memory management**

- Memory Management

- Memory Errors
- Smart Pointers
  - Raw Pointers
  - Automatic pointers
  - Unique Pointers
  - Shared Pointers
  - Weak Pointers

*Exercise: Override new and delete*

*Exercise: Understanding unique and shared pointers*

## Renseignements pratiques

**Inquiry : 30 hours**