Arm® Keil® Microcontroller Development Kit (MDK)

v6

Getting Started Guide

Non-Confidential

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Getting Started Guide

Release information

Document history

Issue	Date	Confidentiality	Change
0000-04	8 May 2024	Non-Confidential	Revised section on creating an application using the Keil Studio extensions for Visual Studio Code, updates to installation instructions, and new sections on installing µVision on Windows and creating applications with µVision.
0000-03	23 April 2024	Non-Confidential	Updates
0000-02	8 April 2024	Non-Confidential	Updates
0000-01	21 March 2024	Non-Confidential	First release

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Inclusive language commitment

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Contents

1. Introduction

1.1 Conventions

The following subsections describe conventions used in Arm documents.

Glossary

The Arm Glossary is a list of terms used in Arm documentation, together with definitions for those terms. The Arm Glossary does not contain terms that are industry standard unless the Arm meaning differs from the generally accepted meaning.

See the Arm Glossary for more information: developer.arm.com/glossary.

Typographic conventions

Arm documentation uses typographical conventions to convey specific meaning.

Convention	Use
italic	Citations.
bold	Interface elements, such as menu names. Terms in descriptive lists, where appropriate.
monospace	Text that you can enter at the keyboard, such as commands, file and program names, and source code.
monospace <u>underline</u>	A permitted abbreviation for a command or option. You can enter the underlined text instead of the full command or option name.
<and>	Encloses replaceable terms for assembler syntax where they appear in code or code fragments. For example: MRC p15, 0, <Rd>, <CRn>, <CRm>, <Opcode_2>
SMALL CAPITALS	Terms that have specific technical meanings as defined in the *Arm® Glossary*. For example, IMPLEMENTATION DEFINED, IMPLEMENTATION SPECIFIC, UNKNOWN, and UNPREDICTABLE.

Caution

We recommend the following. If you do not follow these recommendations your system might not work.

Warning	Your system requires the following. If you do not follow these requirements your system will not work.

Danger	You are at risk of causing permanent damage to your system or your equipment, or harming yourself.

Note	This information is important and needs your attention.

Tip	A useful tip that might make it easier, better or faster to perform a task.

Remember	A reminder of something important that relates to the information you are reading.

1.2 Other information

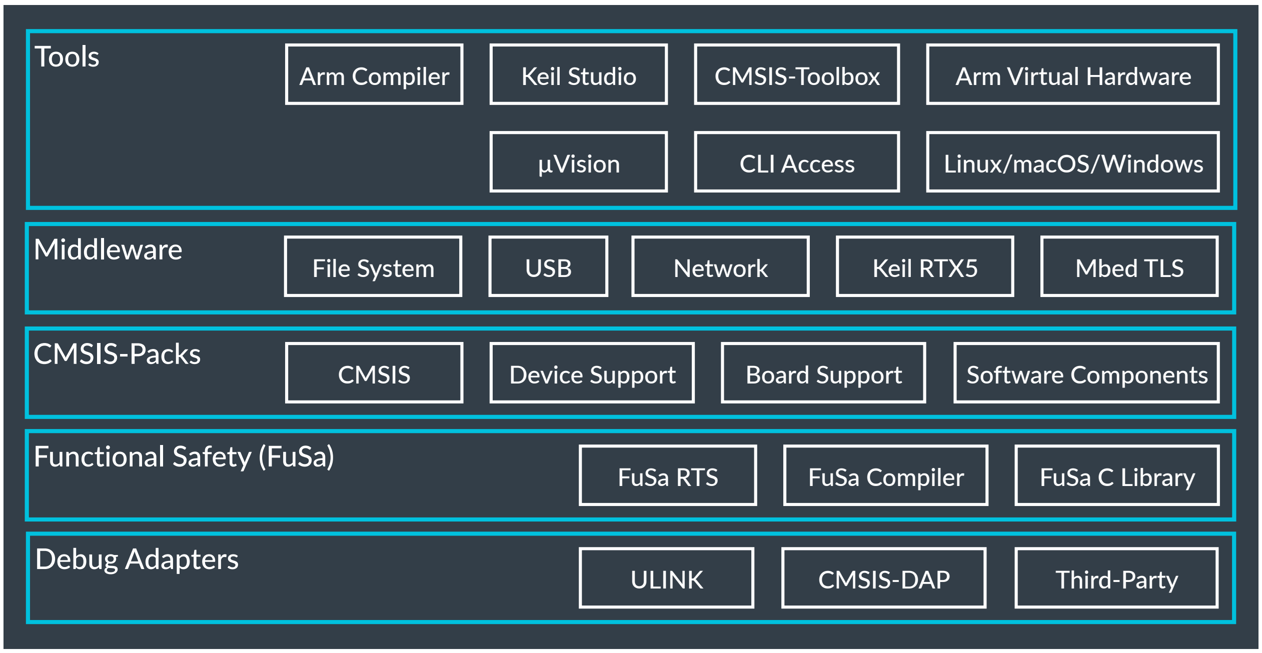
See the Arm website for other relevant information.

- Arm® Developer.
- Arm® Documentation.
- Technical Support.
- Arm® Glossary.

2. What is MDK?

Arm® Keil® Microcontroller Development Kit (MDK) is a collection of software tools for developing embedded applications based on Arm Cortex®-M and Ethos™-U processors. MDK makes software engineering easy and productive by offering you the flexibility to work with a CLI or an IDE (desktop-based or browser-based), or by deploying the tools into a continuous integration workflow.

Figure 2-1: MDK overview diagram



2.1 A family of tools

MDK includes:

- Keil Studio
- Keil µVision®
- Arm Compiler for Embedded. Version 6 is based on the innovative LLVM and Clang technologies and supports the latest language standards, including C++17.
- Arm Virtual Hardware (AVH)

MDK uses development flows based on the Common Microcontroller Software Interface Standard (CMSIS). Embedded systems frequently require several years of product development, so MDK supports the entire product lifecycle from initiation to completion and maintenance.

MDK offers host support for Linux, macOS, and Windows.

Note

Arm Virtual Hardware simulation models (Fixed Virtual Platform models, or FVPs) are currently not available on macOS, and µVision runs on Windows only.

2.2 CMSIS-Packs

CMSIS-Packs contain device and board support, software components, middleware, code templates, and example projects. You can add them to the tools at any time, which means that support for new devices and middleware updates are independent from the toolchain. The IDEs and CLI tools manage the software components that you can use as building blocks for the application.

2.3 Functional safety (FuSa)

The MDK-Professional edition includes components that you need for functional safety applications:

- Arm Compiler for Embedded FuSa
- A certified C library
- FuSa Run-Time System (RTS)

2.4 Debug adapters

MDK works with Arm's ULINK™ family of debug and trace adapters:

- ULINKpro, a debug and trace unit that allows you to program, debug, and analyze your applications using its unique streaming trace technology.
- ULINKplus, which combines isolated debug connection, power measurement, and I/O for test automation.
- ULINK2.

You can also expand MDK with various third-party tools, starter kits, and debug adapters (such as ST-Link, JLink, and others).

2.5 MDK editions

MDK is available in the following editions:

- **MDK-Community**. For non-commercial use by evaluators, hobbyists, makers, academics, and students.

- **MDK-Essential**. For commercial development of Arm Cortex-M-based microcontroller projects.
- **MDK-Professional**. For professionals with functional safety (FuSa) requirements and the need for DevOps using simulation models. This all-in-one solution includes Arm Compiler for Embedded FuSa, and grants access to all Arm Virtual Hardware Fixed Virtual Platforms (FVPs).

Figure 2-2: MDK editions

The product selector gives an overview of the features enabled in each edition.

2.6 License types

Apart from the **MDK-Community** edition, all MDK editions require activation using a license code.

MDK supports user-based licensing (UBL), which binds the entitlement to use an Arm® product to the user. A user is entitled to use an Arm product license with no limits on concurrent usage, including using the same product on multiple devices. For example, you could use a single license with a service account to automatically build and test your products with Arm development tools on any number of devices.

There are different ways to get a license:

- Using an activation code provided by Arm or your license administrator
- Accessing a local license server managed by your license administrator

For further details on license activation, see Activate your product using an activation code and Activate your product using a license server in the User-based Licensing User Guide.

If you are using Keil Studio for Visual Studio Code, see Activate your license to use Arm tools in the Arm Keil Studio Visual Studio Code Extensions User Guide to open the **Arm License Management Utility** user interface and provide an activation code or use a license server.

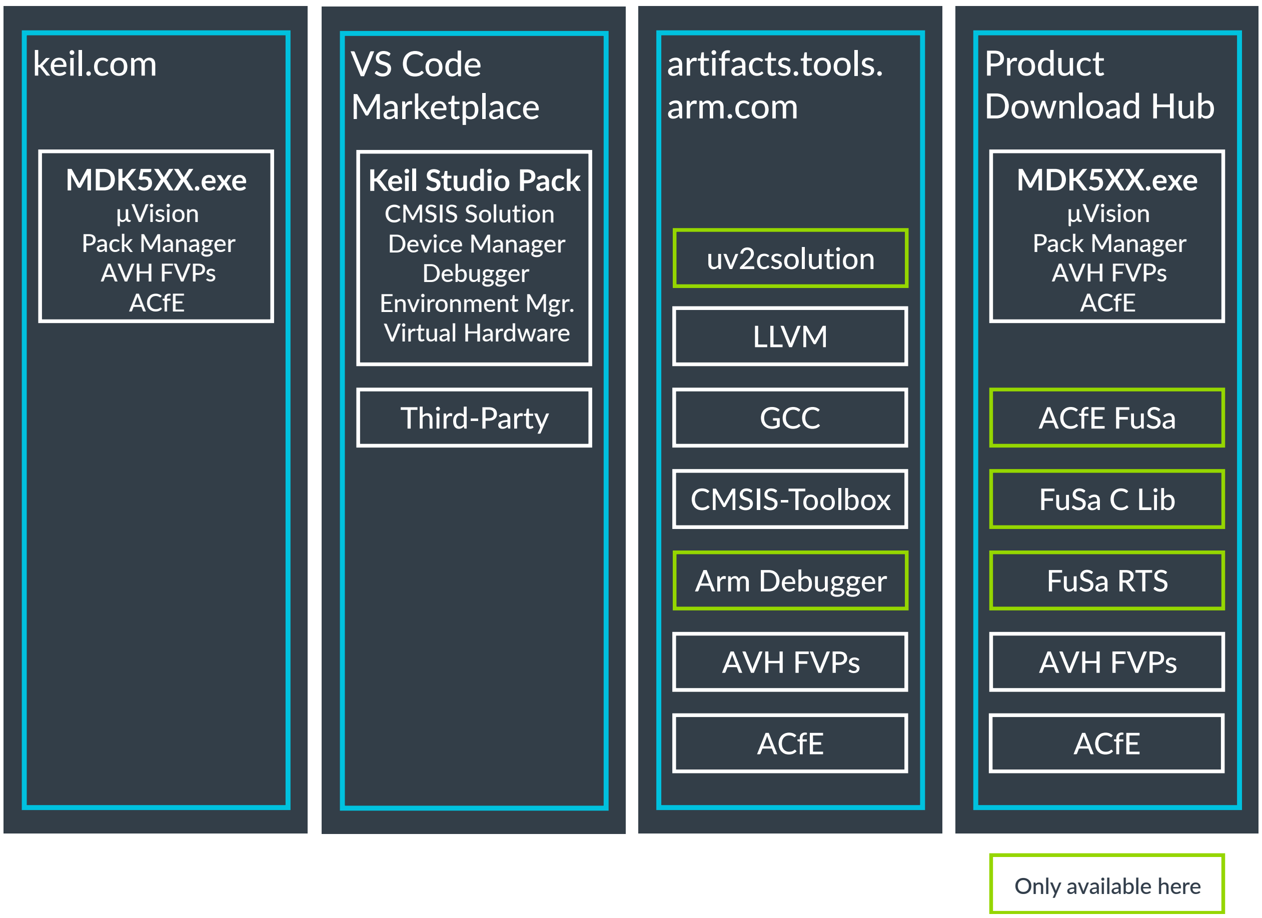
If you are an administrator and you need to add products to your account on the Arm user-based licensing portal using a serial number, or you need to add licenses to existing products, watch the Accessing the Arm License Portal video tutorial. More details are also available in the User-based Licensing Administration Guide. To create activation codes, watch the Cloud-based Licenses and Activation Codes video tutorial. See also the information available in the User-based Licensing Administration Guide.

For more details on user-based licensing support and backwards compatibility, see the User-based licensing User Guide. The Backwards compatibility topic explains how you can license older versions of MDK (MDK 5.36 and earlier), PK51, PK166, and DK251 using a product license that includes Keil MDK Professional.

2.7 Download options

MDK v6 contains various tools that you can install in different ways.

Figure 2-3: MDK v6 download options



µVision

The `MDK5XX.exe` installer contains the µVision® tool with Arm® Compiler for Embedded (ACfE) and the Arm Virtual Hardware-Fixed Virtual Platform (AVH-FVP) models. This installer is available on keil.com and the Product Download Hub. See the User's Guide for more information on how to install the tool.

Keil Studio extensions

Keil® Studio is a set of VS Code extensions that you can download from the VS Code Marketplace.

1. In VS Code, click **Extensions** in the Activity Bar.
2. Enter **Keil Studio Pack** in the search box.

3. In the search results, select **Arm Keil Studio Pack**.
4. Click **Install**.

When you are working with a CMSIS-based project, Keil Studio uses vcpkg to download additional tools (such as a toolchain and a debugger). These tools are served by Artifactory.

Functional safety (FuSa) tools

MDK-Professional users can download the building blocks that Arm offers for functional safety applications. These tools are available only through the Product Download Hub that serves tools based on entitlement. The following tools are available:

- Arm Compiler for Embedded FuSa: Arm's functional safety toolchain
- FuSa RTS: the functional safety run-time system that offers software components for FuSa applications
- FuSa C Lib: a C library certified for usage in FuSa applications

Other tools

The broadest set of tools is available through the new Artifactory repository manager. Artifactory serves automated downloads of tools, using either vcpkg or direct download through scripting. The following tools are available on Artifactory:

- GCC: an open-source toolchain for Arm CPUs
- Arm Compiler for Embedded: Arm's toolchain
- LLVM Embedded Toolchain: an open-source toolchain for Arm CPUs
- Arm Debugger: a command-line debug server for Arm CPUs
- Arm Virtual Hardware: models for Cortex®-M based on Fast Models technology
- uv2csolution: an MDK µVision project converter
- Arm CMSIS-Toolbox: command-line tools for CMSIS projects

For a full list of all versions of these tools, see Arm Tools Available in vcpkg.

2.8 Access the MDK documentation

MDK provides documentation for all of its components on Arm Developer.

Get help

If you have suggestions or you have discovered an issue with any of the Keil® MDK products, please report them to us. Go to the keil.arm.com support page and use the links under **Get Help or Report Issues**.

Include your license code (if you have one) and product version when reporting a µVision® issue.

Online learning

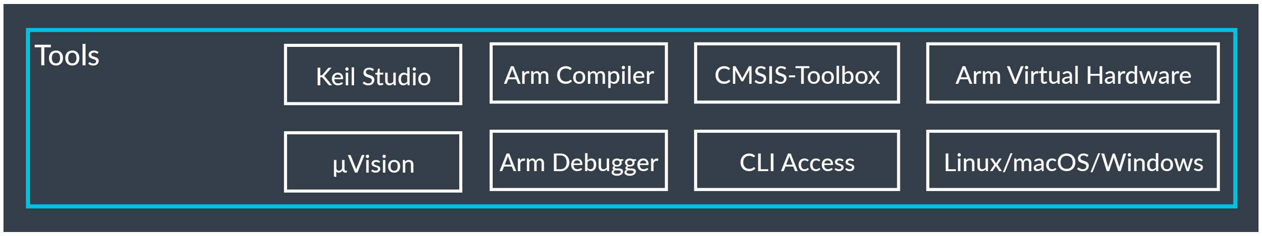
Our Learning Paths help you to learn more about the programming of Arm® Cortex®-based microcontrollers. The site contains tutorials for all levels of experience, from beginner to advanced.

Videos showing the tools and different aspects of software development are available at Arm's Youtube channel.

3. Tools

Learn more about the software tools included in MDK v6.

Figure 3-1: Tools overview diagram



3.1 Keil Studio

Keil® Studio is a complete development tool for the evaluation and development of embedded, IoT, and machine learning software for Cortex®-M devices. It is available as a browser-based Integrated Development Environment (IDE) for development in the cloud, or as a set of extensions for desktop development with Visual Studio Code.

Keil Studio Cloud offers a cloud-hosted workspace for your code, comprehensive version control system integration, and a powerful C/C++ editor. You can:

- edit your projects from any computer, share them with colleagues, and export them for desktop usage
- compile projects using Arm® Compiler for Embedded
- run the projects directly on supported development boards
- debug from supported browsers (Chromium-based browsers) without having to install any software.

3.1.1 Keil Studio Pack for Visual Studio Code

The Arm Keil Studio Pack includes extensions that enable you to manage your CMSIS solutions (csolution projects), and to create, build, test, and debug embedded applications on your chosen hardware using Visual Studio Code.

For more information on available extensions, and to install the pack in Visual Studio Code, see Arm Keil Studio Pack for Visual Studio Code. For information on how to set up your working environment and get started, see Get started with an example project.

3.2 Keil µVision

Keil® µVision® is a Windows-based software development platform that integrates all the tools needed to develop embedded applications quickly and successfully. It combines a source code editor, a project manager for creating and maintaining your projects, and a Make tool for assembling, compiling, and linking your embedded applications.

µVision offers separate modes for building and debugging applications. You can debug applications either using Arm Virtual Hardware simulation models or directly on hardware (for example, using the Arm® Keil ULINK™ family of debug and trace adapters). You can also use third-party debug probes to analyze applications. The ULINK debug and trace adapters work with preconfigured Flash programming algorithms for downloading the application program into Flash.

µVision provides statistical data and execution analysis reports to help you to test and validate your applications thoroughly. This is particularly important if you are working on safety-critical systems.

µVision also includes:

- **System Viewer**. View information about peripheral registers and change property values manually at run time.
- **Logic Analyzer**. View changes of values on a time graph, study signal and variable changes and view their dependency or correlation.
- **Template editor**. Create common text sequences, header descriptions, and generic code blocks.
- **Source Browser**. Navigate coded procedures quickly.
- **Configuration Wizard**. Use a graphical interface to maintain device and start-up code settings.
- **Multi-Project Manager**. Combine µVision projects, which logically depend on each other, into one single Multi-Project. This increases the consistency and transparency of your embedded application design.

For more information, see the µVision documentation.

3.3 Arm Compiler for Embedded

Arm® Compiler for Embedded is the most advanced embedded C and C++ compilation toolchain for the development and optimization of embedded bare-metal software, firmware, and real-time operating system (RTOS) applications, ranging from small sensors to 64-bit devices.

Because Arm Compiler for Embedded is developed alongside the Arm architecture, it provides the earliest, most complete, and most accurate support for the latest architectural features and extensions, so that you can evaluate which Arm solution best suits your requirements and verify your design.

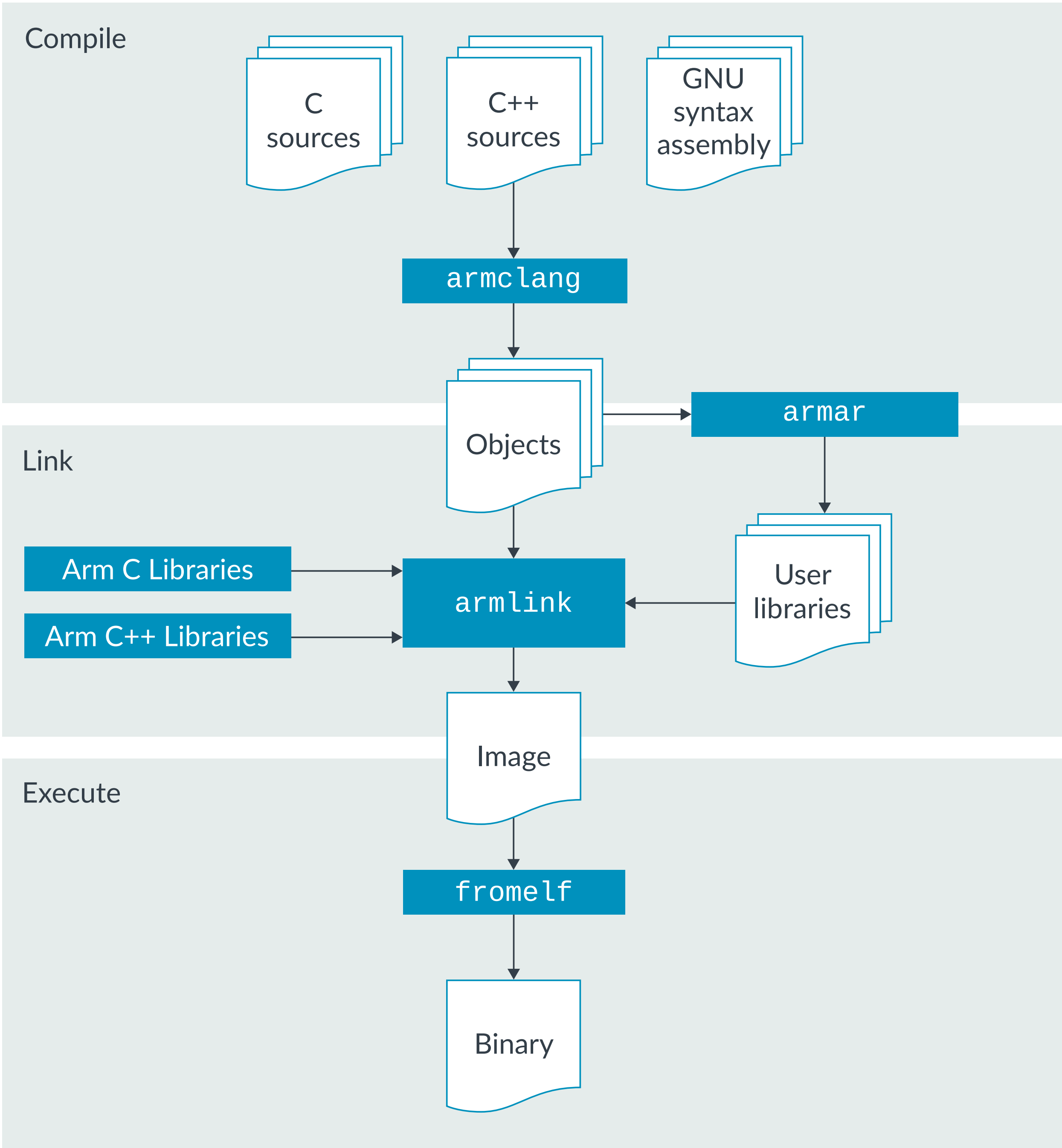
Arm Compiler for Embedded is used by leading companies in a wide variety of industries, including consumer electronics, networking, storage, telecommunications, security, and safety-critical systems.

Arm Compiler for Embedded consists of the following toolchain components:

- **armclang**. A compiler and integrated assembler based on modern LLVM and Clang technology. The armclang compiler supports GNU syntax assembly and the latest language standards, including C++17. It is highly compatible with source code originally written for GCC. It implements specifications including ANSI/ISO C and C++, ABI for the Arm architecture, ABI for the 64-bit Arm architecture, and Arm C Language Extensions (ACLE).
- **armlink**. A linker that combines objects and libraries to produce an executable.
- **Arm C libraries**. Runtime support libraries for embedded systems. These libraries include optimizations for performance and code density.
- **Arm C++ libraries**. Libraries based on the LLVM libc++ project.
- **fromelf**. An image conversion tool and disassembler.
- **armar**. An archiver that enables you to collect sets of ELF object files together.
- **Arm Compiler for Embedded FuSa**. (MDK-Professional edition only) A safety-qualified C/C++ toolchain that is suitable for developing embedded software for safety-critical markets including automotive, industrial, medical, railways, and aviation.
- **FuSa C libraries**. (MDK-Professional edition only)

The following diagram shows how the different toolchain components interact with each other in the build process for a typical embedded application:

Figure 3-2: Arm Compiler workflow diagram

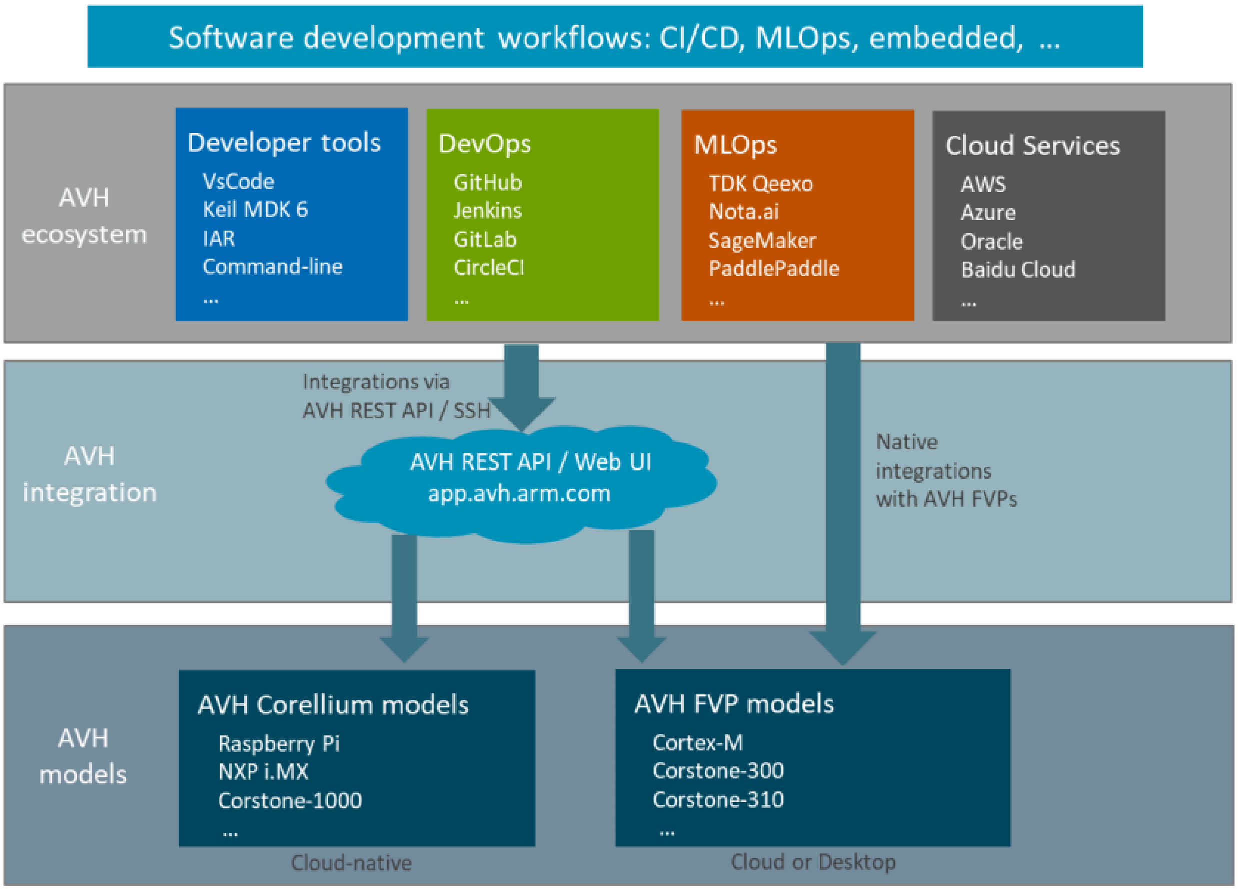


For more information, see the Arm Compiler for Embedded documentation.

3.4 Arm Virtual Hardware

Arm® Virtual Hardware (AVH) enables software development on Arm-based processors using virtual targets. AVH can help simplify, automate, and accelerate the development process, and reduce maintenance costs. This enables faster prototyping, build, and deployment cycles, and reduces time to market for embedded applications.

Figure 3-3: Arm Virtual Hardware overview diagram



You can start developing and testing your applications on AVH ahead of silicon availability, and without having to spend time and money setting up and maintaining physical board farms. AVH provides an accurate simulation of Arm-based SoCs, enabling seamless transfer from a virtual model to your target hardware.

AVH enables continuous integration and continuous delivery environments for embedded and IoT projects, and supports development processes like MLOps. Moving IoT engineers and data scientists to such development processes is key to scaling the Internet of Things to thousands or potentially millions of devices. With AVH, you can launch multiple virtual boards in seconds, and rapidly experiment with and test complex multidevice configurations.

With increased adoption of ML and edge compute in embedded applications, the ability to estimate how fast an ML model could run on a device is critical. You can use AVH to explore different network architectures and optimizations much more quickly and effectively than on physical hardware.

AVH in MDK

MDK enables you to download, install, and run AVH based on Fixed Virtual Platform models (FVPs). FVPs are precise simulation models of Arm Cortex-M based cores and reference platforms, such as Corstone™-300 or Corstone™-310.

FVP models are standalone programs that run in your target environment. They are available for cloud-native and desktop environments, and can be run from the command line or in your development tools.

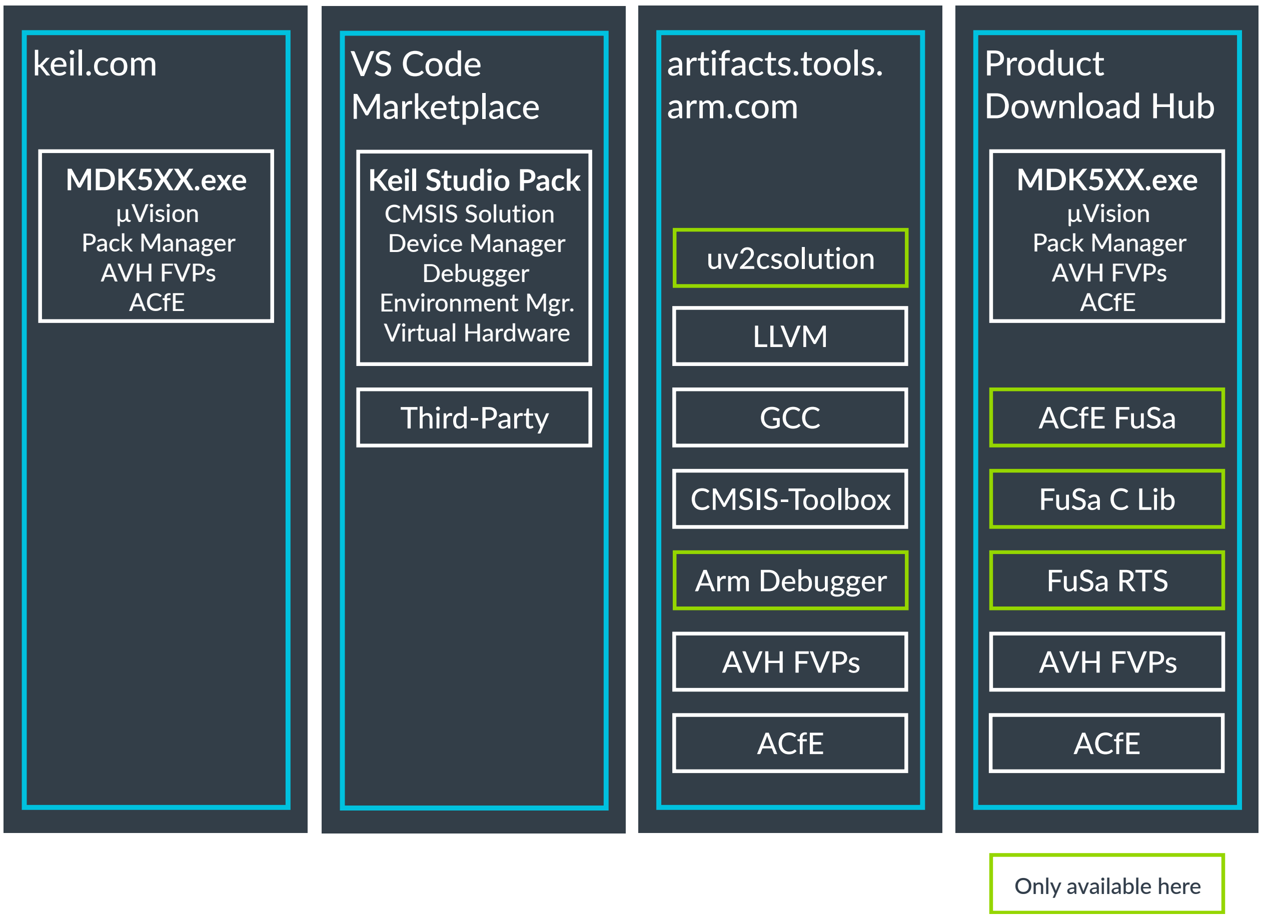
For more information, including currently available board models and usage examples, see the AVH User Guide and Solutions Overview.

4. Installation

Learn how to install the software tools included in MDK v6.

MDK v6 does not offer a single installer anymore. Instead, it offers flexible ways to install the tools that you need in your next development project.

Figure 4-1: Tools installation overview diagram



These are the installation options:

- If you are running on Windows, you can still download the installer for µVision that includes all other tools. Refer to Keil µVision installation on Windows.
- You can install Keil Studio on a desktop machine from within Visual Studio Code using the extensions Marketplace. Refer to Keil Studio installation. This requires the installation of additional tools using Artifactory.
- Installing additional tools for Keil Studio or running them on a server, you can access compilers, models, the CMSIS-Toolbox, and the Arm Debugger using Artifactory. Refer to Installing other tools.

- Access to functional safety components like the Arm Compiler for Embedded FuSa or the FuSa C lib is available only on Arm's Product Download Hub.

4.1 Software and hardware requirements

MDK has the following minimum hardware and software requirements:

- A PC running a current 64-bit desktop operating system (Linux, macOS, Windows)
- 4 GB RAM and 8 GB hard-disk space
- 1280 x 720 pixels or higher screen resolution
- A mouse or other pointing device

4.2 Keil µVision installation on Windows

Download MDK from keil.com/download/product/ and run the installer. Follow the instructions to install MDK (µVision) on your local computer. The installation also adds the software packs for Arm CMSIS and MDK-Middleware. After the installation is complete, the Pack Installer starts automatically, which allows you to add supplementary software packs. As a minimum, you need to install a software pack that supports your target microcontroller device.

After the installation has finished, you must add a license to µVision. If you have not purchased a license, follow these instructions to get a free-of-charge MDK-Community license for evaluation purposes.

4.3 Keil Studio installation

Keil Studio is installed by adding the Arm Keil Studio Pack (a collection of extensions) to Visual Studio Code. The pack provides the software development environment for embedded systems and IoT software development on Arm-based microcontroller (MCU) devices.

In Visual Studio Code, go to **View - Extensions** and enter "Keil Studio Pack" in the search box to find the pack. Click the **Install** button to download and install the set of extensions.

Refer to Arm Keil Studio Pack to learn more about each extension that is included.

Continue with Create a new solution using the Keil Studio VS Code extensions to start with your first project.

4.4 Installing other tools

Arm has created an instance of Artifactory that contains software tools that are required to create, manage, build, and debug embedded applications. The following tools are available:

- Arm CMSIS-Toolbox

- Arm Compiler for Embedded
- Arm Debugger
- Arm Virtual Hardware for Cortex®-M based on Fast Models
- GCC compiler for Arm CPUs
- LLVM Embedded Toolchain for Arm CPUs
- MDK Vision project converter

The easiest way to download these tools is to use vcpkg. vcpkg is a package management utility that you can use to easily build or recreate a development environment. Download and install the tools either through the CLI or the Arm Environment Manager extension for VS Code (available as part of the Keil Studio Pack).

The Install tools on the command line using vcpkg learning path explains how to add vcpkg to your PC or server and how to download tools using the `vcpkg-configuration.json` file.

Official examples from Arm come with a preconfigured `vcpkg-configuration.json` file. This file is also created when converting `.uvpmw/.uvprojx` files in Visual Studio Code using the Keil Studio Pack.

To add or change a tool in your environment, add the package that you want to install to the `"requires"` section of your `vcpkg-configuration.json` file. When the file is saved, newly specified packages are downloaded and activated.

You can also download the tools directly using applications like curl or wget.

4.4.1 Product Download Hub

The following components from MDK v6 require a separate download from the Product Donwload Hub (PDH).

- Arm Compiler for Embedded FuSa
- Arm FuSa C Library
- Arm FuSa Run-Time System (RTS)

Note

You need an Arm account to access PDH. To download these components, your account must be connected with a valid MDK-Professional license.

5. CMSIS components

The Common Microcontroller Software Interface Standard (CMSIS) is a set of libraries, APIs, software components, and tools that enable you to write code for Arm® Cortex®-M based processors.

CMSIS is supported by many microcontroller manufacturers and provides a standardized way to write code for microcontrollers without having to know the internal details of different microcontrollers. Using CMSIS makes the process of writing and reusing code easier. It speeds up the development process, as you can port code written for one microcontroller to another microcontroller without having to modify it.

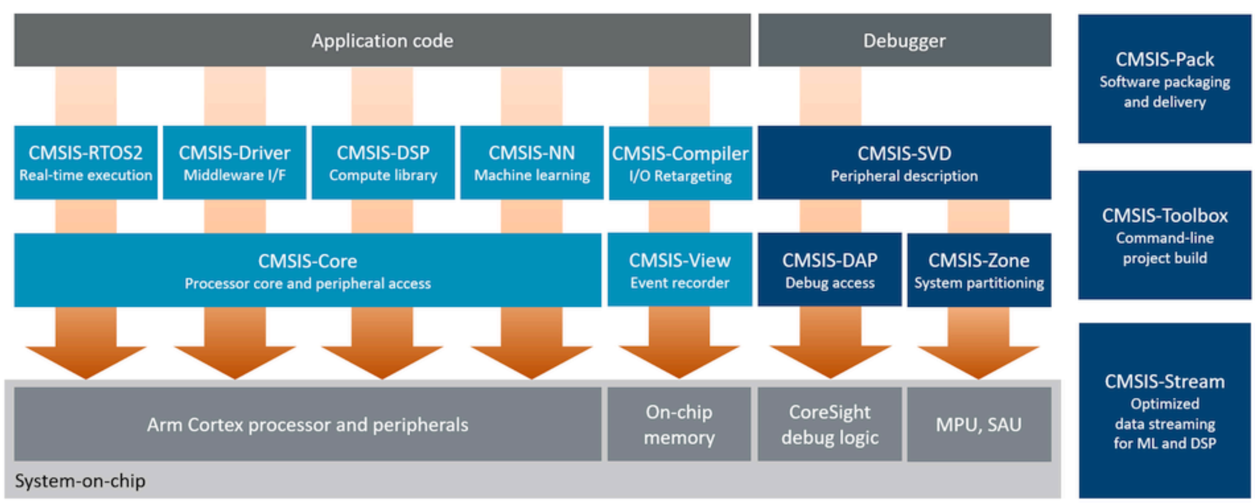
You can use the prewritten functions and libraries in CMSIS to control the hardware resources of different microcontrollers without having to learn how to manipulate those resources directly for each microcontroller. This reduces the time taken to build and debug projects, and speeds up the process of bringing new applications to market.

CMSIS also contains components that make it easier to extend the functionality of applications by adding features like digital signal processing, machine learning and neural networks, or managing multiple tasks and resources.

CMSIS is available under an Apache 2.0 license and is publicly developed on GitHub.

CMSIS overview

Figure 5-1: CMSIS structure



Important developer-facing CMSIS components are:

- CMSIS-Core: Standardizes access to the processor core and device peripherals to make it easier to write code that runs across different Cortex-M controllers.

- CMSIS-RTOS2: A generic real-time operating system interface for devices based on the Arm Cortex processor. CMSIS-RTOS2 simplifies the process of managing and coordinating multiple tasks and resources. It can also help the process of migrating between different RTOS kernels.
- CMSIS-Driver: Provides a standardized API for configuring and controlling peripherals and devices. CMSIS-Driver is designed to be platform-independent, making it easy to reuse code across a wide range of supported microcontroller devices.
- CMSIS-Compiler: Provides software components for retargeting I/O operations in standard C run-time libraries, as well as a standardized API for core functions such as exceptions and interrupt handling.
- CMSIS-View: Provides visibility into the internal operations of microcontrollers, peripherals, hardware components, and software components during the development and debugging of embedded applications.
- CMSIS-DSP: A wide range of digital signal processing functions and routines. CMSIS-DSP algorithms are optimized for efficiency, helping you to maximize the performance of your applications and minimize resource usage. You can also use CMSIS-DSP as a basis for custom digital signal processing routines.
- CMSIS-NN: A collection of efficient neural network kernels developed to maximize the performance and minimize the memory footprint of neural networks on Arm Cortex-M processors. You can use the set of neural network operations that CMSIS-NN provides, or you can deploy your own specialized models.

  CMSIS-NN enables you to perform inference at the edge rather than in the cloud. Edge computing can improve privacy and security, and reduce latency and bandwidth.
- CMSIS-Stream: A Python package and a set of C++ headers to use on embedded devices to process streams of samples. CMSIS-Stream provides low memory usage, minimal overhead, deterministic scheduling, and a modular design. It also provides a graphical representation.
- CMSIS-Toolbox: Command-line tools to work with software packs in Open-CMSIS-Pack format. This format is the basis for the csolution project format that is used in Keil Studio Cloud and the Keil Studio extensions in Visual Studio Code.
- CMSIS-Zone: A tool that helps to simplify partitioning, memory management, and access permisisons in embedded applications.
- CMSIS-DAP: Provides access to the Debug Access Port (DAP) and enables communication over USB between a microprocessor and a debug tool on a host computer.

5.1 CMSIS basic concepts

This section summarizes some useful concepts to be aware of before you start working with CMSIS, and provides links to more detailed information.

5.1.1 CMSIS-Pack

CMSIS-Pack is a standardized packaging format for distributing software components for Arm® Cortex®-based microcontrollers. It simplifies the integration of components into projects, supports versioning, and ensures compatibility across various devices, toolchains, and development environments.

CMSIS-Packs can include device-specific information, middleware components that provide common functionality, or application-level components such as code libraries for specific use cases.

CMSIS-Packs are a specific type of software pack.

5.1.2 Software pack

A set of ready-to-use components and tools tailored for a specific hardware platform or for a specific purpose. This set is bundled together with a **Pack Description (PDSC) file** that describes the content that is included in the pack, and provides information on version history and any dependencies.

MDK provides tools that facilitate product lifecycle management with software packs. Additionally, you can use CMSIS-Toolbox to work with software packs in the Open-CMSIS-Pack format. This format is the basis for the csolution project format that is used in Keil Studio Cloud and the Keil Studio extensions in Visual Studio Code.

Software packs are designed to provide general-purpose resources for embedded development. There are also more specialized types of software packs called **Device Family Packs (DSP)** and **Board Support Packs (BSP)**, which are fine-tuned to provide support for specific microcontroller families or hardware boards.

For information on how working with basic software packs, DSPs, and BSPs, see the Pack Tutorials section of the Open-CMSIS-Pack documentation.

5.1.3 Software component

In embedded system development, a **software component** is a modular and reusable piece of software that fulfills a specific function within the wider system. Multiple components can be bundled together into a software pack or a CMSIS-Pack. For more information, see the Overview of additional software components section of this guide.

5.1.4 CMSIS solutions

CMSIS solutions (also known as csolutions) are groups of related projects that are part of a larger application and that can be built separately. You can define a solution by editing a `*.csolution.yaml` file.

CMSIS-Toolbox takes the `*.csolution.yaml` and the *.cproject.yaml files as user input during the application build process.

For more information and example projects, see the CMSIS-Toolbox documentation and the Work with CMSIS solutions section of the Keil Studio Cloud User Guide.

The CMSIS Solution extension in the Keil® Studio Visual Studio Code extension pack, Arm Keil Studio Pack, also provides support for working with solutions. For more information, see the Arm Keil Studio Visual Studio Code Extensions User Guide.

Note

If you are using µVision®, you can use the csolution build tool in CMSIS-Toolbox to convert a `csolution` project into the `CPRJ` file format.

5.1.5 CMSIS projects

A **CMSIS project** is an individual project that can be built independently. Projects are defined by editing a `*.cproject.yaml` file to specify the files and components to include.

CMSIS-Toolbox takes the *.csolution.yaml file and the `*.cproject.yaml` file as user input during the application build process.

For more information and example projects, see the CMSIS-Toolbox documentation and the Work with CMSIS solutions section of the Keil Studio Cloud User Guide.

The CMSIS Solution extension in the Keil® Studio Visual Studio Code extension pack, Keil Studio Pack, also provides support for working with CMSIS solutions. For more information, see the Arm Keil Studio Visual Studio Code Extensions User Guide.

Note

If you are using µVision®, you can use the csolution build tool in CMSIS-Toolbox to convert a `csolution` project into the `CPRJ` file format.

5.2 Overview of CMSIS software components

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- CMSIS-RTOS2: A generic real-time operating system interface for devices based on the Arm® Cortex processor. CMSIS-RTOS2 simplifies the process of managing and coordinating multiple tasks and resources. It can also help the process of migrating between different RTOS kernels.
- CMSIS-Driver: Provides a standardized API for configuring and controlling peripherals and devices. CMSIS-Driver is designed to be platform-independent, making it easy to reuse code across a wide range of supported microcontroller devices.
- CMSIS-Compiler: Provides software components for retargeting I/O operations in standard C run-time libraries, as well as a standardized API for core functions such as exceptions and interrupt handling.

- CMSIS-View: Provides visibility into the internal operations of microcontrollers, peripherals, hardware components, and software components during the development and debugging of embedded applications.
- CMSIS-DSP: A wide range of digital signal processing functions and routines. CMSIS-DSP algorithms are optimized for efficiency, helping you to maximize the performance of your applications and minimize resource usage. You can also use CMSIS-DSP as a basis for custom digital signal processing routines.
- CMSIS-NN: A collection of efficient neural network kernels developed to maximize the performance and minimize the memory footprint of neural networks on Arm Cortex-M processors.
- CMSIS-Stream: A Python package and a set of C++ headers to use on embedded devices to process streams of samples. CMSIS-Stream provides low memory usage, minimal overhead, deterministic scheduling, and a modular design. It also provides a graphical representation.
- CMSIS-Toolbox: Command-line tools to work with software packs in Open-CMSIS-Pack format. This format is the basis for the csolution project format that is used in Keil Studio Cloud and the Keil Studio extensions in Visual Studio Code.
- CMSIS-Zone: CMSIS-Zone helps to reduce the complexity of specifying partitioning, memory management, and access permissions in embedded applications using Arm Cortex-M processors.
- CMSIS-DAP: CMSIS-DAP is a protocol specification and an open-source firmware implementation that provides standardized access to the CoreSight™ Debug Access Port (DAP) available on many Arm Cortex processors as part of the CoreSight debug and trace functionality.

5.3 Overview of CMSIS base software components

The CMSIS base software components provide software abstractions for the basic functionality of microcontroller devices. These components are delivered in the Arm::CMSIS software pack.

5.3.1 CMSIS-Core

CMSIS-Core (Cortex®-M) implements the basic run-time system for a Cortex-M device and gives you access to the processor core and the device peripherals. It defines the following features:

- A hardware abstraction layer (HAL) for Cortex-M processor registers
- Standard system exception names to use when interfacing with system exceptions, making it easier to ensure compatibility across different platforms
- Methods to use to organize header files, and naming conventions for device-specific interrupts. Standardizing in this way makes it easy to learn new Cortex-M microcontroller products and improves software portability.
- Methods for system initialization to be used by each microcontroller vendor. For example, the standardized `SystemInit()` function is essential for configuring the clock system of the device.

- Intrinsic functions to use to generate specific CPU instructions that are not available through standard C functions.
- A standardized variable to determine the system clock frequency, which simplifies the setup of the `SysTick` timer.

Learn how to use CMSIS-Core in embedded applications.

5.3.2 CMSIS-RTOS2

CMSIS-RTOS2 provides generic RTOS interfaces for devices based on the Arm® Cortex® microprocessor, and provides a standardized API for software components that require RTOS functionality. Using a standardized API moves the decision about which RTOS to use to a later stage in the design process and offers more flexibility. For more information, see the CMSIS-RTOS2 documentation.

CMSIS-RTOS2 provides a set of basic features that are required in many applications, which reduces learning efforts and simplifies the sharing of software components. Middleware components that use CMSIS-RTOS2 are RTOS-agnostic and are easier to adapt.

CMSIS also provides project templates for CMSIS-RTOS2 which can be included in open-source CMSIS-RTOS2 implementations to provide a starting point for further development.

Benefits of an RTOS design

There are two basic design concepts for embedded applications, an **infinite loop** design (suitable for simple applications) and an **RTOS** design. An RTOS-based design has various benefits:

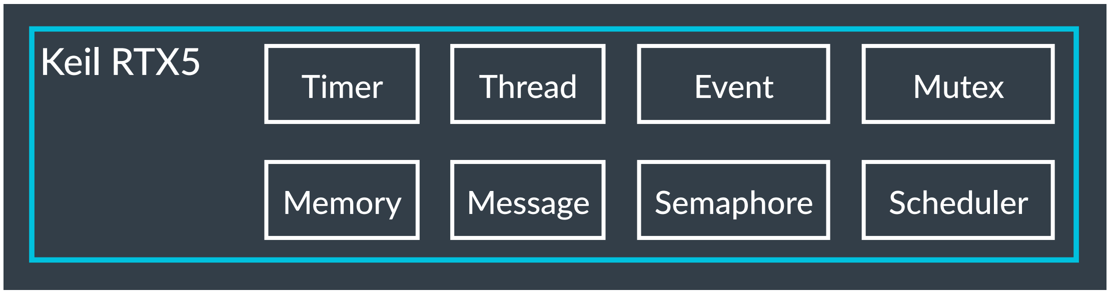
- The RTOS handles thread priority and run-time scheduling reliably.
- The RTOS provides a well-defined interface for communication between threads.
- A pre-emptive RTOS reduces the complexity of interrupt functions, because high-priority threads can perform time-critical data processing.
- Pre-emptive multitasking simplifies the ongoing enhancement of an application even across a larger development team, because you can add new functionality without risking the response time of more critical threads.
- Applications based on an infinite loop often poll for occurred interrupts. By contrast, RTOS kernels themselves are interrupt-driven and can largely eliminate polling. This enables the CPU to sleep or process threads more often.
- In the real world, your application must fulfill multiple different tasks. An RTOS-based application recreates this model in your software.

Modern RTOS kernels are designed to work closely with the interrupt system. This is essential for embedded systems and systems with real-time requirements, which must respond to interrupts (signals from hardware components such as buttons, sensors, timers, or peripherals) efficiently and promptly.

Keil RTX5

Keil RTX version 5 (RTX5) is a real-time operating system (RTOS) for Arm Cortex-M and Cortex-A processor-based devices that implements the CMSIS-RTOS2 API as its native interface.

Figure 5-2: RTX5 overview diagram



For more information, review the Theory of Operation and get started with this tutorial.

5.3.3 CMSIS-Driver

The CMSIS-Driver API describes peripheral driver interfaces for middleware stacks and user applications. The API is designed to be generic and independent of a specific RTOS, making it reusable across a wide range of supported microcontroller devices. It covers a wide range of use cases for the supported peripheral types, but cannot take every potential use case into account. For more information, see the CMSIS-Driver documentation.

The CMSIS software pack publishes the API under the **CMSIS-Driver** component class, with header files and documentation. These header files are the reference for the implementation of the standardized peripheral driver interfaces.

These implementations are typically published in the Device Family Pack (DFP) of a family or series of related microcontrollers under the **CMSIS-Driver** component class. A DFP might contain further device-specific interfaces in the **Device** component class, such as memory bus, General Purpose Input/Output (GPIO), or Direct Memory Access (DMA), in addition to the set of standard peripheral drivers covered by the specification.

The standard peripheral driver interfaces connect microcontroller peripherals to middleware that implements communication stacks, file systems, or graphical user interfaces. Each interface provides multiple instances representing physical interfaces of the same type in a device. For example, two physical Serial Peripheral Interfaces (SPIs) would have separate access structs to use to connect the driver to middleware or to the user application.

For more information, review the Theory of Operation.

5.4 Overview of CMSIS extended software components

The CMSIS extended software components implement specific functionality optimized to run on Arm® processors. Each component is delivered in a separate CMSIS-Pack.

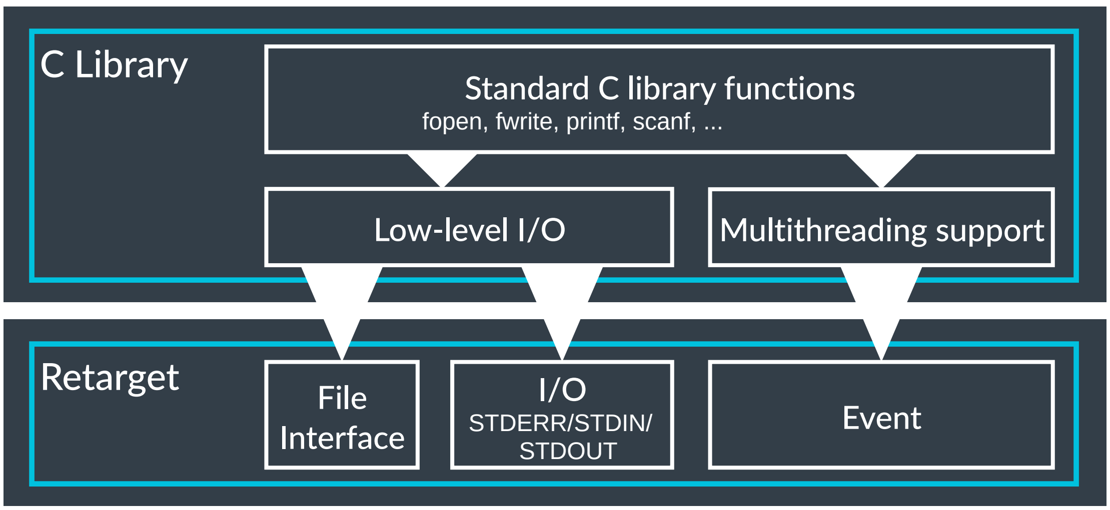
5.4.1 CMSIS-Compiler

CMSIS-Compiler provides software components that help you to adapt the input/output (I/O) operations in standard C runtime libraries to work with the specific I/O interfaces of your microcontroller or development board (a process known as retargeting).

CMSIS-Compiler supports the following interfaces for retargeting:

- A file interface for reading and writing files
- An I/O interface for standard I/O stream retargeting (stderr, stdin, stdout)
- An OS interface for multithread safety using an arbitrary RTOS

Figure 5-3: CMSIS-Compiler overview diagram



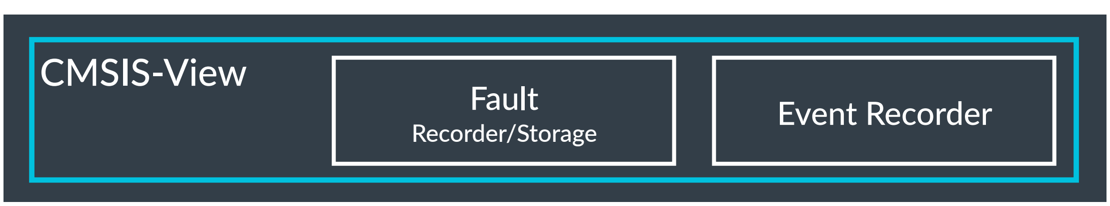
Standard C library functions are platform-independent, but multithreading support and the implementations of the low-level I/O are tailored to the target compiler toolchains.

See the CMSIS-Compiler documentation and get started using a template.

5.4.2 CMSIS-View

CMSIS-View provides methodologies, software components, and utilities to help you to analyze the operation of embedded software programs on devices with Arm® Cortex®-M processors.

Figure 5-4: CMSIS-View overview diagram



CMSIS-View helps you to see how your embedded systems are operating, with minimal memory and timing overhead. The event statistics functions enable you to collect and analyze statistical data about the execution of your code.

CMSIS-View works on all Cortex-M devices, with only simple debug adapters necessary. The compiler-agnostic implementation allows simple integration with your application projects. CMSIS-View also enables RTOS-aware debugging for CMSIS-RTX and CMSIS-FreeRTOS, as well as logging capabilities for use in regression tests on Arm Virtual Hardware Fixed Virtual Platform (FVP) models (through semihosting).

See the CMSIS-View documentation and review the available example projects.

5.4.3 CMSIS-DSP

CMSIS-DSP is an open-source software library that implements common digital signal processing (DSP) functions optimized for use on Arm® Cortex®-M and Cortex®-A processors.

CMSIS-DSP covers a range of compute categories, and provides kernels with several datatypes. A Python wrapper is also available, helping you to design your algorithm in Python using an API as close as possible to the C API.

See the CMSIS-DSP documentation for more information, or get started with this learning path.

5.4.4 CMSIS-NN

The CMSIS-NN open-source software library maximizes performance and minimizes memory usage for neural networks running on Arm® Cortex®-M processors, through its collection of efficient neural network kernels. You can use the set of neural network operations that CMSIS-NN provides, or you can deploy your own specialized models.

CMSIS-NN enables you to perform inference at the edge rather than in the cloud. Edge computing can improve privacy and security, and reduce latency and bandwidth.

CMSIS-NN functions have several variants. CMSIS-NN automatically selects the best solution during compilation depending on the features of the target processor architecture.

For full details of available functions, see the CMSIS-NN documentation, or get started with this example.

5.5 Overview of CMSIS tools

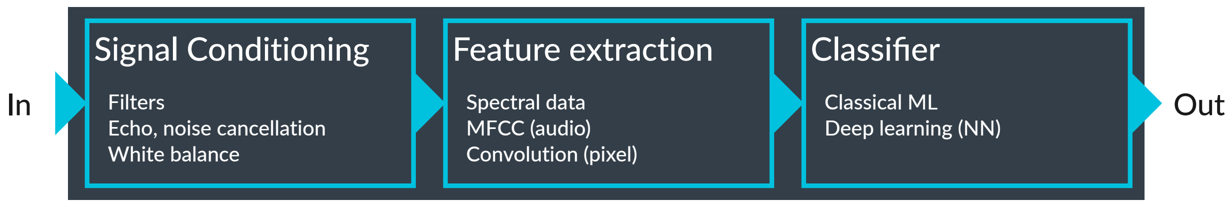
MDK also includes useful tools for working with CMSIS-based components.

5.5.1 CMSIS-Stream

CMSIS-Stream is a Python package that optimizes data block streaming between the processing steps in DSP/ML applications. It enables modular design, which makes it easier to develop and maintain DSP pipelines. The tools optimize scheduling of the processing nodes at build time, reducing memory usage. This process creates a clear representation of the design in the form of a compute graph.

The compute graph is a directed graph that shows the structure and sequence of data flows between processing nodes or components within the application. It uses a Python script file to describe the data formats, First In First Out (FIFO) buffers, data streams, and processing steps. The CMSIS-Stream tools convert the compute graph into optimized processing steps at build time.

Figure 5-5: CMSIS-Stream overview diagram



CMSIS-Stream provides tools to create optimized DSP pipelines, which are required to optimize ML software stacks. The visual representation that a compute graph provides can be helpful in complex DSP or ML workflows with multiple interconnected components, such as the one shown in the following diagram.

By optimizing signal conditioning and feature extraction, the complexity of the ML classifier. More DSP preprocessing helps by lowering the overall performance that is required for an ML application.

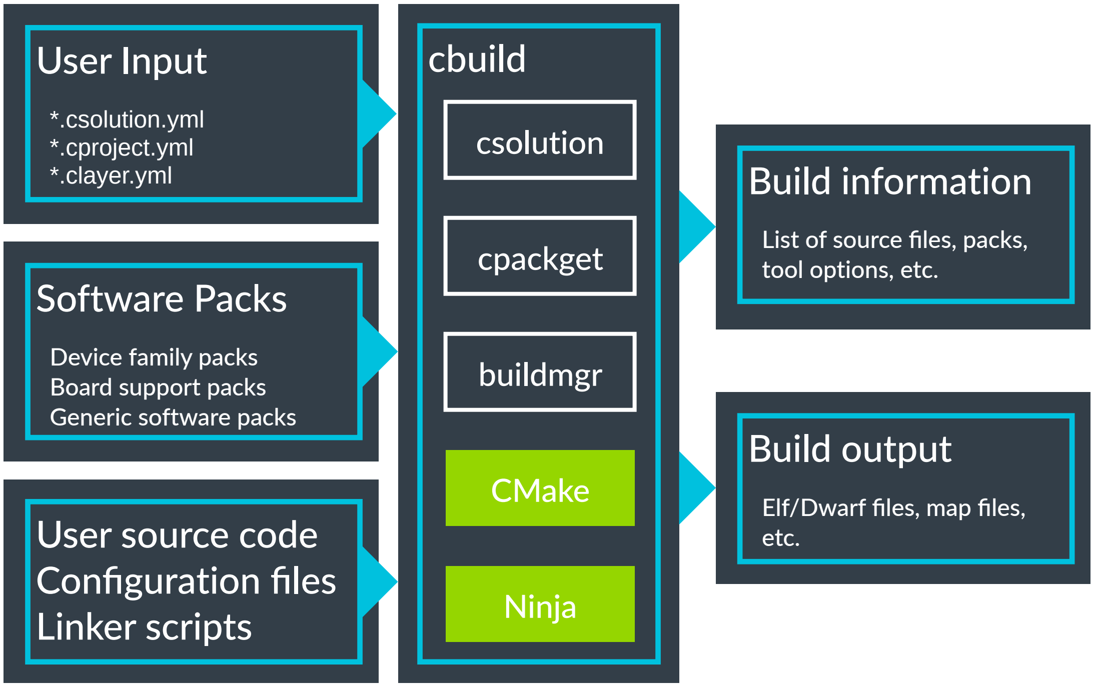
CMSIS-Stream also provides interfaces, header files, templates, and methods for data management that also work on asymmetric multiprocessing (AMP) systems, and usage examples to help you to get started.

See the CMSIS-Stream documentation and review the examples.

5.5.2 CMSIS-Toolbox

CMSIS-Toolbox provides command-line tools for creating and building embedded applications based on CMSIS-Packs. CMSIS-Toolbox supports multiple compilation tools, such as Arm Compiler for Embedded, GCC, IAR, and LLVM. The tools also help you to create, maintain, and distribute CMSIS-Packs that include software components or software and hardware support.

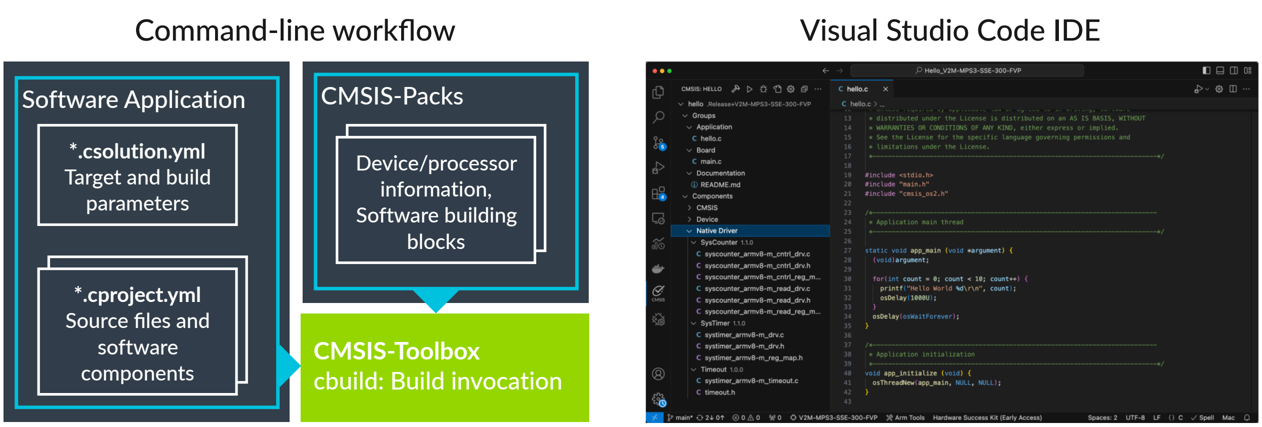
Figure 5-6: CMSIS-Toolbox overview diagram



You can use the command-line tools either standalone or integrated into the extensions for Visual Studio Code or DevOps systems for Continuous Integration (CI). Tools are available for all host platforms (Windows, Mac, and Linux) and are deployable in a flexible way.

For more information on how to use the `cbuild`, `csolution`, and `cpackget` tools from the command line, including syntax details and usage examples, see the Build tools documentation.

Figure 5-7: CLI and IDE workflow



Software packs make it easier to set up tools by enabling you to select devices or boards and to create projects that provide access to reusable software components.

The ability to organize solutions into independently-managed projects simplifies many use cases, including multi-processor applications or unit testing.

CMSIS-Toolbox also makes provisions for product lifecycle management (PLM), with configuration file management and versioned software packs that are easy to update.

Software layers enable code reuse across similar applications, with a preconfigured set of source files and software components.

CMSIS-Toolbox offers support for:

- Multiple hardware targets, enabling you to deploy your application to different hardware (test board, production hardware, virtual hardware, and so on).
- Multiple build types, to support software testing and verification (debug build, test build, release build, and so on).
- Multiple toolchains (even within the same set of user input files) and command-line options that enable you to select different toolchains during verification.

CMSIS-Toolbox uses a CMake back end for the build process. Using CMake with CMSIS-Toolbox simplifies the generation of `compile_commands.json` files for solutions. These JSON files contain a list of project files and the compiler commands used in the build process, and can be used by various Visual Studio Code extensions to power IntelliSense.

See the CMSIS-Toolbox documentation for more information.

5.5.3 CMSIS-Zone

CMSIS-Zone helps to reduce the complexity of specifying partitioning, memory management, and access permissions in embedded applications using Arm® Cortex®-M processors.

You can use CMSIS-Zone to specify access and security permissions to memory regions, in both secure and non-secure modes. You can then use the XML-based zone files to generate the header files for memory management and partition generation in your application.

For more information, see the CMSIS-Zone documentation.

5.5.4 CMSIS-DAP

CMSIS-DAP provides embedded software developers with standardized access to the CoreSight™ Debug Access Port (DAP) available on many Arm® Cortex® processors as part of the CoreSight on-chip debug and trace functionality.

CMSIS-DAP enables standardized communication between the microprocessor where an embedded application is run, and a debug tool running on a host computer. CMSIS-DAP provides the interface firmware for a debug unit that connects the debug port of the device to the USB port.

With it, a software debug tool that runs on a host computer can connect using USB and the debug unit.

For more information, see the CMSIS-DAP documentation.

6. Other software components and packs

Designing and implementing software for embedded systems requires a modular architecture using multiple components. Software packs are collections of components bundled together for a specific purpose (for example, middleware, source code, libraries, or example projects).

Packs are used to provide ready-to-use components for specific microcontroller families or development platforms. They can simplify the process of setting up a development environment and writing code for a particular embedded system.

CMSIS-Packs are a specific type of software pack. They adhere to the CMSIS standard, which defines a consistent interface for accessing and configuring core features of Arm® Cortex®-M processors, and enable you to easily integrate and maintain software components in your projects.

A CMSIS-Pack includes metadata about the files that belong to a software component, preserving the information from the original vendor of the component. Metadata can include dependency information for toolchains, devices, and processors, which simplifies integration into applications.

Another benefit of the CMSIS-Pack system is that it enables a consistent software component upgrade process, and identifies incompatible configuration files that might be part of the user application. In addition, software component providers can specify the interfaces and their relationship to other software components.

Arm maintains a list of CMSIS-Packs that are publicly available.

For more information, see the CMSIS-Pack documentation.

6.1 Product lifecycle management with software packs

MDK enables you to install multiple versions of a software pack. This enables product lifecycle management (PLM), which is common for many projects.

Figure 6-1: Diagram showing the stages of PLM

There are four phases of PLM:

- **Concept**: Definition of major project requirements and exploration with a functional prototype
- **Design**: Prototype testing and implementation of the product based on the final technical features and requirements
- **Release**: The product is manufactured and brought to market

- **Service**: Maintenance of the products, including support for customers. Finally, phase-out or end-of-life.

In the concept and design phases, you normally use the latest software packs so that you can incorporate new features and bug fixes quickly. Before product release, you freeze the software components to a known tested state. In the service phase, you use the fixed versions of the software components to support customers in the field.

The strict semantic versioning of CMSIS-Packs makes it easier to manage the installed versions of software packs that you use in your projects.

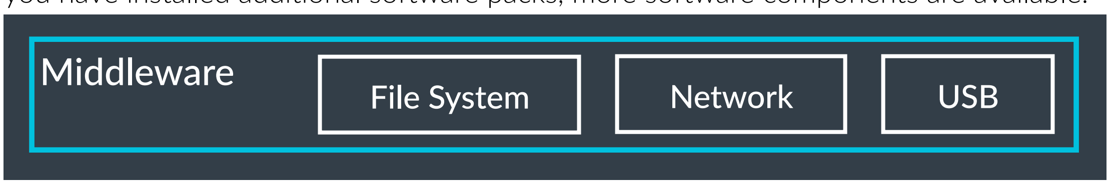
6.2 Overview of additional software components

The following table lists software components that are frequently used in embedded applications, including the components in the MDK-Middleware software pack.

Table 5-1: Frequently used software components

Software component	Description
CMSIS-FreeRTOS	A CMSIS-RTOS2 adaptation of the FreeRTOS kernel
CMSIS-mbedTLS	An MbedTLS fork delivered in a CMSIS-Pack
Synchronous Data Stream (SDS)	A data stream management framework
Network	An MDK-Middleware component for TCP/IP networking using Ethernet or serial protocols
File System	An MDK-Middleware component for file access on various storage types
USB	An MDK-Middleware component for USB host and device communication, supporting standard USB device classes
IoT Clients	Open-source clients for various cloud service providers.
Open-source components	Open-source components that you can use to extend the functionality of your applications

The following figure shows the components in the MDK-Middleware software pack; if you have installed additional software packs, more software components are available.



6.2.1 CMSIS-FreeRTOS

FreeRTOS is a market-leading real-time operating system (RTOS) for embedded microcontrollers. It is professionally developed, strictly quality controlled, robust, fully supported and documented, free to use in commercial products without a requirement to expose proprietary source code, and has no IP infringement risk.

Arm® has created an implementation of FreeRTOS that supports the CMSIS-RTOS2 API for real-time operating systems (RTOS). Using this software pack, you can choose between a native

FreeRTOS implementation or one that adheres to the CMSIS-RTOS2 API and uses FreeRTOS internally. The CMSIS-RTOS2 API enables programmers to create portable application code to use with different RTOS kernels (for example, Keil RTX5).

See the CMSIS-FreeRTOS documentation and get started with an example project.

6.2.2 CMSIS-mbedTLS

Mbed TLS is a C library that implements cryptographic primitives, X.509 certificate manipulation, and the SSL/TLS and DTLS protocols. It is particularly suitable for embedded systems because of its small code size.

See the CMSIS-mbedTLS GitHub repository for more information.

6.2.3 Synchronous Data Stream (SDS) framework

The Synchronous Data Stream (SDS) framework implements a data stream management system and provides methods and tools for developing and optimizing embedded applications that integrate digital signal processing (DSP) and machine learning (ML) algorithms. You can use the framework with the compute graph streaming in the CMSIS-DSP library.

SDS implements flexible data stream management for sensor and audio data interfaces. It supports data streams from multiple interfaces, including provisions for time drifts. You can also use it to record real-world data for analysis and development, or to play back real-world data for algorithm validation by using Arm Virtual Hardware. SDS data files have several use cases, such as:

- To provide input to DSP development tools such as filter designers
- To provide input to ML model classification, training, and performance optimization
- To verify that a DSP algorithm runs on Cortex®-M targets with offline tools

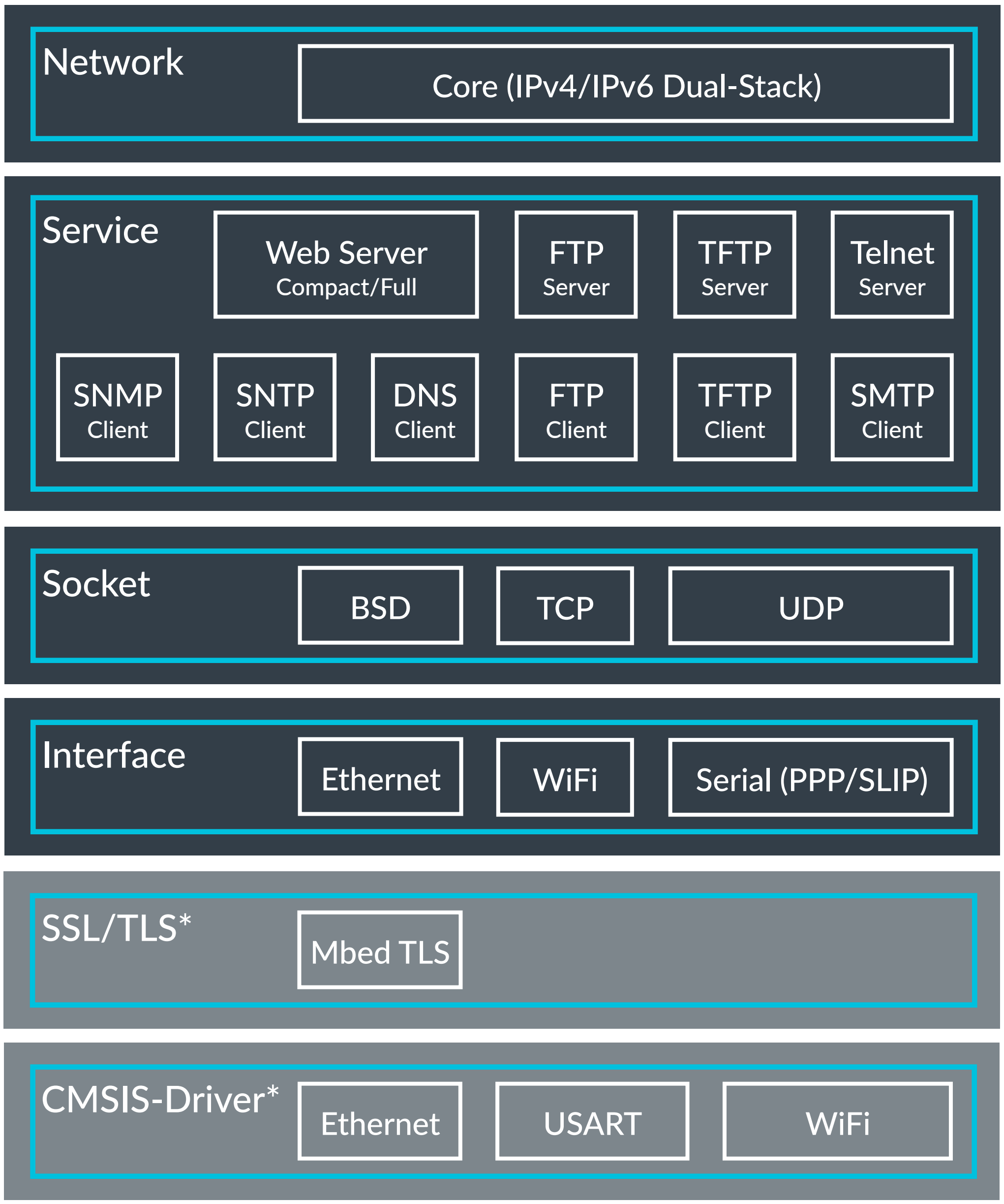
SDS defines a binary data format with a YAML-based metadata file. It also includes Python-based tools for recording, playback, visualization, and data conversion.

See the SDS-Framework documentation and get started by using an example.

6.2.4 Network component

The Network component in the MDK-Middleware pack contains services, protocol sockets, and physical communication interfaces for creating IPv4 and IPv6 networking applications.

Figure 6-2: MDK-Middleware Network component overview diagram



*These components are not part of the Network component

Note

The **Mbed TLS**, **Ethernet**, **USART**, and **Wi-Fi** components work with the Network component, but are part of separate packs.

The services provide program templates for common networking tasks.

All services rely on a network socket for communication. The Network component supports Tenable Security Center (TSC), User Datagram Protocol (UDP), and Berkeley Software Distribution (BSD) sockets.

The physical interface can be either Ethernet, WiFi, or a serial connection using Serial Line Internet Protocol (SLIP) or Point-to-Point Protocol (PPP).

A driver provides the interface to the microcontroller peripherals or external components:

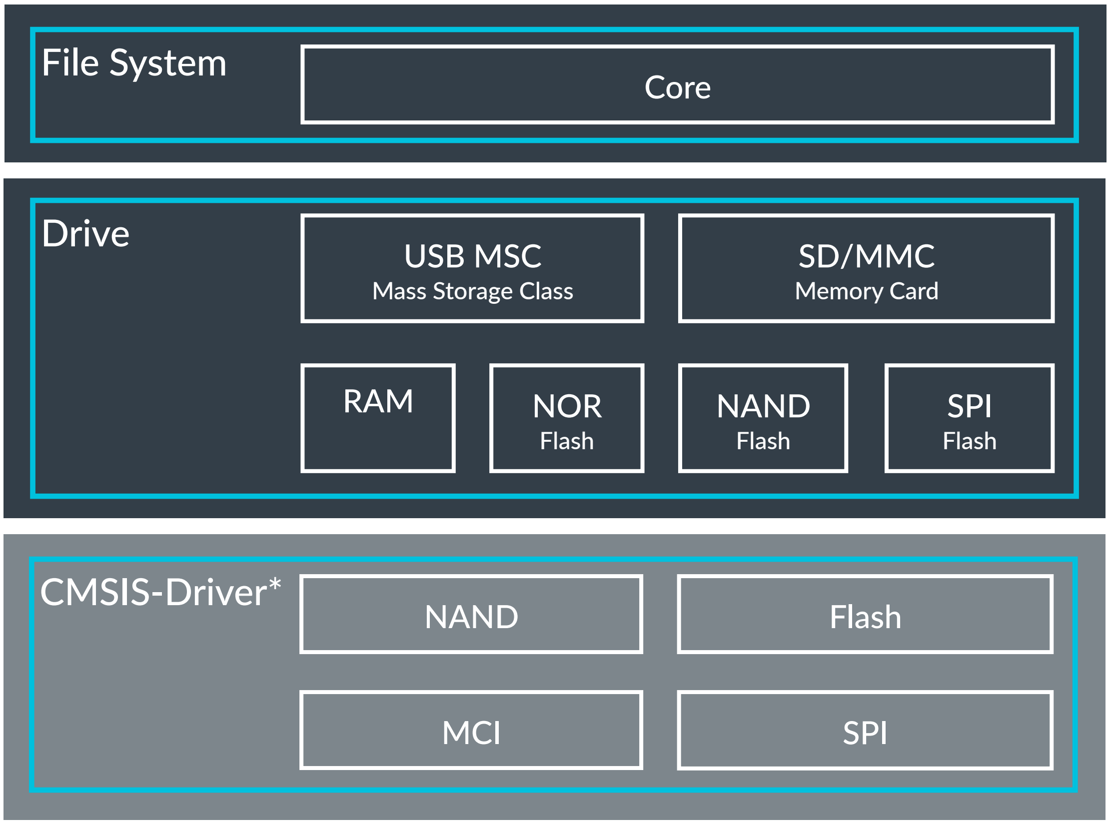
- Ethernet requires an Ethernet Media Access Control (MAC) address and an Ethernet physical layer (PHY) driver
- PPP or SLIP interfaces use a universal synchronous/asynchronous receiver/transmitter (USART) and a modem
- WiFi interfaces require a WiFi module driver

See the Network component documentation and get started by using an example.

6.2.5 File System component

The File System component in the MDK-Middleware pack enables your embedded applications to create, save, read, and modify files in storage devices such as RAM, Flash, memory cards, or USB memory devices.

Figure 6-3: MDK-Middleware File System component overview diagram



*These components are not part of the File System component

The File System component is structured as follows:

- Storage devices are referenced as drives which you can access
- You can implement multiple instances of the same storage device (for example, you might want to have two SD cards attached to your system)
- The File System Core supports thread-safe operation and uses an Embedded File System (EFS) for NOR and Serial Peripheral Interface (SPI) Flashes, or a File Allocation Table (FAT) file system. The FAT file system is available in two variants:
    - The long file name variant supports up to 255 characters
    - The short file name variant supports only file names in 8.3 format
- The Core allows simultaneous access to multiple storage devices (for example, backing up data from internal flash to an external USB device)
- To access the drives, drivers are in place to support the following storage devices:

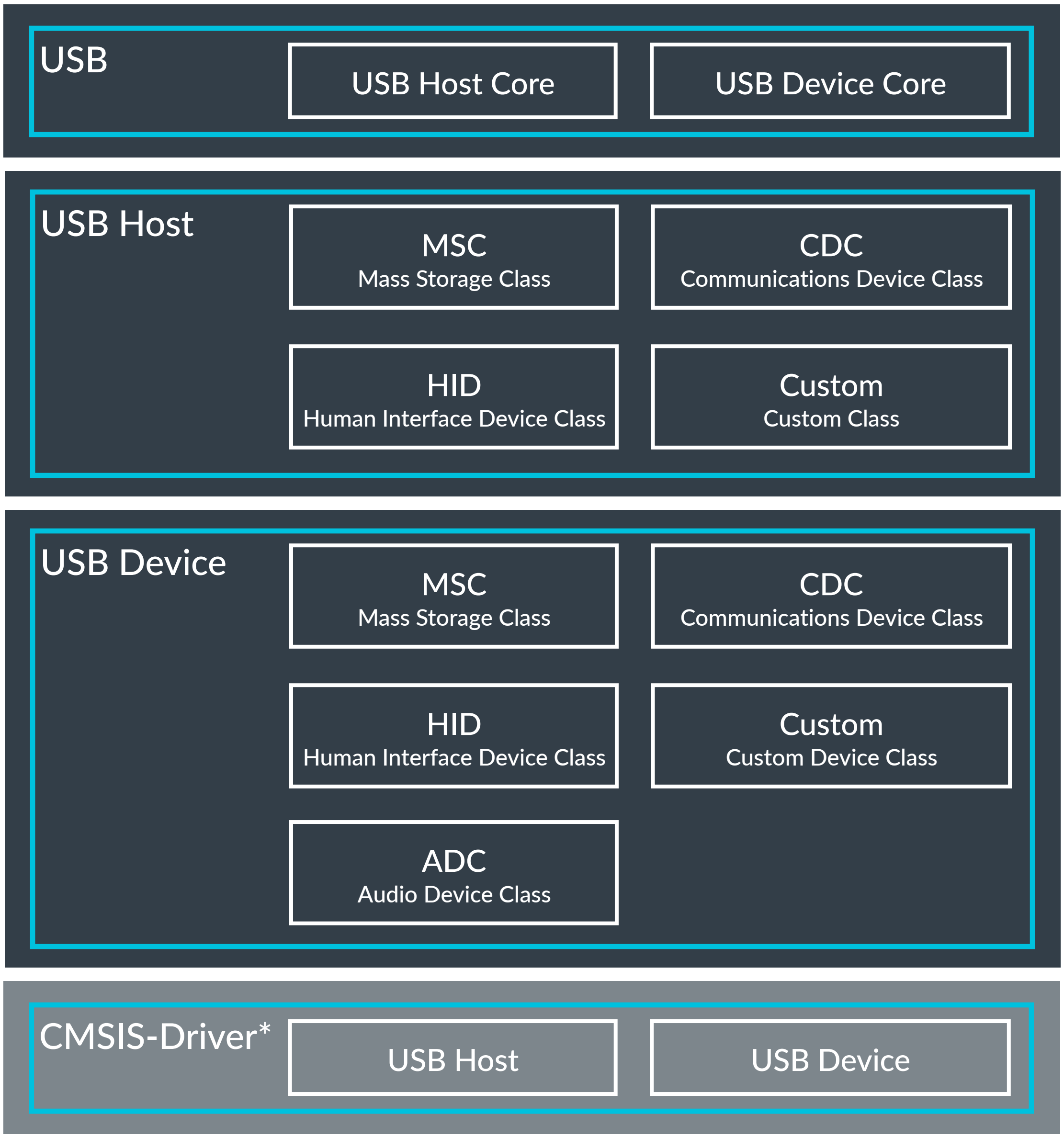
- Flash chips (NAND, NOR, and SPI)
- Memory card interfaces (SD/SDxC/MMC/eMMC)
- USB devices
- On-chip RAM, Flash, and external memory interfaces

Review the Theory of Operation and get started by using an example.

6.2.6 USB component

The USB component in the MDK-Middleware pack enables you to create USB device and USB host applications. The USB component handles the USB protocol so that you can focus on your application needs.

Figure 6-4: MDK-Middleware USB component overview diagram



*These components are not part of the USB component

The USB component is structured as follows:

- USB Host (MDK-Professional only) is used to communicate to other USB device peripherals over the USB bus

- USB Device implements a device peripheral that you can connect to a USB Host
- The USB API for USB Host and USB Device provides the interface to the microcontroller peripherals

The following USB classes are supported:

- Human Interface Device (HID)
- Mass Storage Class (MSC)
- Communication Device Class (CDC)
- Audio Device Class (ADC) (USB Device only)
- Custom Class (for implementing new or unsupported USB Classes)
- Composite USB Devices that support multiple device classes.

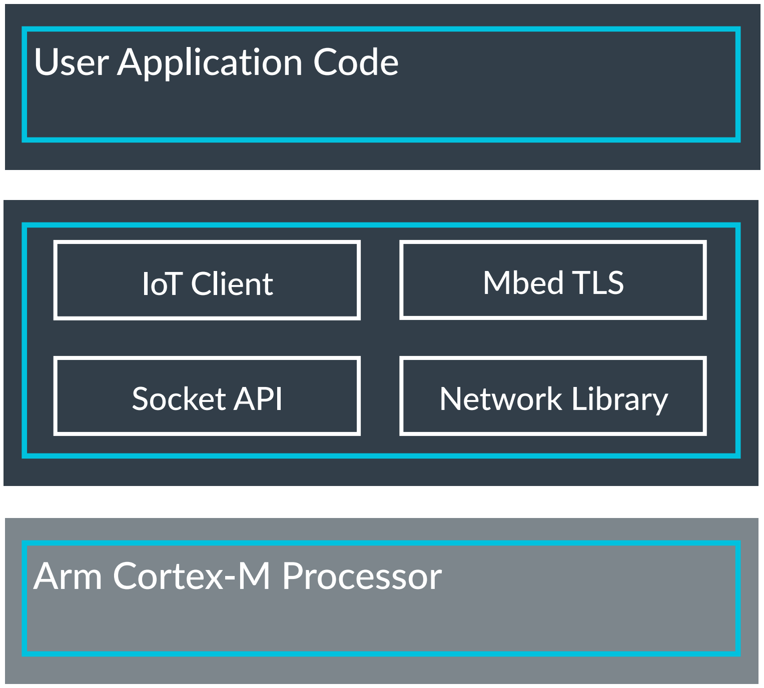
See the USB component documentation and get started by using a USB Device example or a USB Host example.

6.2.7 IoT clients

The Internet of Things (IoT) describes connected end-node devices that collect, process, and exchange data. These devices are connected over the Internet to a cloud service that provides processing power, data analytics, and storage capabilities. An IoT client is a software interface which runs on the end-node device and establishes the connection to a cloud service.

Many cloud service providers offer open-source software that implements an IoT client for an embedded system. Arm® adapted these clients to use the reliable MDK-Middleware Network component for communication with the cloud service. Alternatively, you can use WiFi devices that are supported by a CMSIS-WiFi driver.

Figure 6-5: IoT application software stack



Most IoT clients use the Message Queuing Telemetry Transport (MQTT) protocol, which is a lightweight messaging protocol for IoT applications. It communicates over TCP/IP using a TCP socket (for a non-secure connection) or a TLS socket (for a secure connection with encryption).

MDK provides a CMSIS-Pack to give you the basic building blocks that are required to connect to Amazon Web Services. The Amazon AWS IoT pack provides an SDK for connecting to AWS IoT from a device using embedded C.

Software packs are generic (device-independent) and are listed in the pack index.

6.2.8 Overview of open-source components

There are many open-source components that you can use in MDK v6 to extend the functionality of your embedded applications. This section outlines a small selection of open-source components that are available on the market.

LVGL

LVGL (Light and Versatile Graphics Library) is an embedded graphics library that you can use to create graphical user interfaces with a low memory footprint, suitable for use in embedded systems. You can use LVGL with any microcontroller, microprocessor, and display type.

Download the pack, or for more information see the LVGL repository or the documentation.

lwIP

lwIP is a lightweight implementation of the TCP/IP protocol suite. It supports most common TCP/IP protocols in full, but reduces resource usage, making it ideal for use in embedded applications.

Download the pack, or for more information see the lwIP repository or the documentation.

7. Create new applications

Learn more about how to create and build applications using CMSIS with MDK.

7.1 Create a new solution using the Keil Studio VS Code extensions

This section describes the basic workflow for creating, running, and debugging a simple "Hello world" example solution with the Keil Studio VS Code extensions, and provides links to more detailed instructions in the Arm Keil Studio Visual Studio Code Extensions User Guide. The workflow involves the following steps:

- Create a solution
- Manage software tools
- Add software components to your solution
- Add the source code files to your solution
- Configure virtual hardware
- Build the solution
- Run the solution
- Debug the solution

7.1.1 Create a solution

Create a new solution with all the basic files that you need for the hardware that you select. For more detailed information, see Create a solution in the Arm Keil Studio Visual Studio Code Extensions User Guide.

Note

This procedure describes creating a solution for the Arm V2M-MPS3-SSE-300-FVP virtual hardware. Adapt the steps for other starter kits or boards.

---

1. Install the Keil Studio Pack in Visual Studio Code.
2. Click **CMSIS** in the Activity Bar to open the **CMSIS** view.
3. Click **Create a New Solution**. The **Create New Solution** view opens.
4. In the **Target Board** drop-down list, find the V2M-MPS3-SSE-300-FVP virtual hardware, and then click **Select**.
5. In the **Templates and Examples** drop-down list, select **Blank solution**.

6. Enter a name for the project to include in your solution (for example, `helloworld`).
7. Enter a solution name.
8. Specify the location where you want to store your solution files.
9. Click **Create**. A confirmation dialog box opens. Click **Open** to open the new solution and see the files in the **Explorer** view.
10. An **Arm Environment Activation** dialog box displays. Confirm that the Environment Manager extension can automatically activate the workspace and download the tools specified in the `vcpkg-configuration.json` file that was generated when you created the solution.

7.1.2 Manage software tools

A new solution comes with a set of software tools that are automatically downloaded using vcpkg. The download of the tools is controlled using the `vcpkg-configuration.json` file that was generated when you created the solution. For this example, you must specify the virtual hardware models to use in the `vcpkg-configuration.json` file.

1. Open the `vcpkg-configuration.json` file.
2. Keil Studio offers a graphical user interface for this JSON file. Click **Open Preview to the Side** in the top-right corner.
3. In the **Arm Tools** editor, find the **Arm Virtual Hardware for Cortex-M based on Fast Models** entry and select the latest version. Note that the following line at the end of the `"requires":` block is added to the `vcpkg-configuration.json` file:

```
"arm:models/arm/avh-fvp": "^11.22.39",
```

After you have saved the file, the Arm Environment Manager reads it and activates the environment. You can see the number of Arm tools installed in the status bar of VS Code.

Note

Using the `vcpkg-configuration.json` file, you can specify which tools to use. If you specify an exact version, only this version is downloaded and used. If you use the `^` specifier, any version beginning with the one specified can be used. Use the `*` specifier to always use the latest version of the tool.

7.1.3 Add software components to your solution

Select the relevant software components that you want to use. For more detailed information, see Manage software components.

1. In the **CMSIS** view, move your mouse over the Project header and click . The **Software Components** view opens.
2. In the **Software packs: Solution** drop-down list, select **All packs**.

3. Click the arrows next to a heading in the **Software Components** view to browse the list of components. Make sure that the following components are selected:
   - **CMSIS** > **Core**, **OS Tick**, and **RTOS2** > **Keil RTX5** (with **Source** selected in the **Variant** drop-down list).
   - **Device** > **Definition** and **Startup**
   - **Device** > **Native driver** > **SysCounter**, **SysTimer**, and **Timeout**

Tip

If your solution requires some packs that are not installed, you are prompted to install them. Similarly, if the components that you add have dependencies that are not installed on your machine, you are prompted to add them.

7.1.4 Add the source code files to your solution

Add the `main.h` header file and the `helloworld.c` files to your project, and add project-specific code to the files.

1. In the **CMSIS** view, in the project outline, go to **Groups** > **Source Files**.
2. Click **+** next to the **Source Files** heading, and then click **Add New File**.
3. In the dialog box that opens, name the file `main.h`, and then click **Save**.
4. Copy and paste the following code into the `main.h` file:

```
#ifndef MAIN_H__
#define MAIN_H__

/* Prototypes */
extern void app_initialize (void);

#endif
```

5. Click **+** next to the **Source Files** heading, and then click **Add New File**.
6. In the dialog box that opens, name the file `helloworld.c`, and then click **Save**.
7. Copy and paste the following code into the `helloworld.c` file:

```
#include <stdio.h>
#include "main.h"
#include "cmsis_os2.h"

/*----------------------------------------------------------------------------
 * Application main thread
 *----------------------------------------------------------------------------*/

static void app_main (void *argument) {
  (void)argument;

  for(int count = 0; count < 10; count++) {
    printf("Hello World %d\r\n", count);
    osDelay(1000U);
  }
  osDelay(osWaitForever);
}
```

```
/*---------------------------------------------------------------------------
 * Application initialization
 *---------------------------------------------------------------------------*/
void app_initialize (void) {
  osThreadNew(app_main, NULL, NULL);
}
```

8. Open the `main.c` file. Delete the existing code, and replace it with the following:

```
#include "RTE_Components.h"
#include CMSIS_device_header
#include "cmsis_os2.h"
#include "main.h"

int main() {
  osKernelInitialize();                  // Initialize CMSIS-RTOS2
  app_initialize();                      // Initialize application
  osKernelStart();                       // Start thread execution

    for (;;) {
    }
}
```

7.1.5 Configure virtual hardware

To build and run projects on virtual hardware such as V2M-MPS3-SSE-300-FVP used in this example, you must add a configuration file in the project directory, and specify the models to use in the `vcpkg-configuration.json` file.

Note

Arm Virtual Hardware simulation models (Fixed Virtual Platform models, or FVPs) are currently not available on macOS. You can use Docker to run them on macOS in a Linux container. Refer to this learning path.

---

1. In the Activity bar, click **Explorer**.
2. In the project header, click **New File...**.
3. Enter `fvp_config.txt` as the name of the new file.
4. Open the `fvp_config.txt` file and copy and paste the following code into it:

```
# Parameters:
# instance.parameter=value       #(type, mode) default = 'def value' :
 description : [min..max]
#----------------------------------------------------------------------------
cpu0.semihosting-enable=1                          # (bool, init-time) default
 = '0': Enable semihosting SVC traps.
mps3_board.visualisation.disable-visualisation=1    # (bool, init-time) default
 = '0': Enable/disable visualisation
#----------------------------------------------------------------------------
```

7.1.6 Build the solution

To build the solution, click . A new **Terminal** view opens and shows the build operation.

For more options to build a project, see Build the example project in the Arm Keil Studio Visual Studio Code Extensions User Guide.

7.1.7 Run the solution

Before running the application on the AVH FVP, you must create a corresponding task. Do the following:

1. Go to **Terminal** > **Configure Tasks...** and select `virtual-hardware run: Run Program`.
2. In the `tasks.json` file, create a new line after `"problemMatcher": [],` and enter these two lines:

```
"config": "${workspaceFolder}/fvp_config.txt",
"args": ["--simlimit", "20"],
```

3. Save the file.

To run the application on virtual hardware:

1. Go to the **Device Manager** view and select “Corstone SSE 300 Ethos U55”.
2. Go to the **CMSIS** view and click .
3. Select the `virtual-hardware: Run Program` run task.
4. On Windows, you might need to enable running the model with the user access control (UAC).
5. Observe the output in the **Terminal** tab.

7.1.8 Debug the solution

Before you can start debugging on the AVH FVP, you must create a corresponding launch configuration.

1. Go to **Run** > **Add Configuration...** and select `Arm Debugger: Launch FVP`.
2. Click to open the **Run and Debug Configuration** visual editor for the`launch.json` file.
3. In the **FVP Parameters** section, enter: `"fvpParameters": "\"${workspaceFolder}\"/fvp_config.txt"`
4. In the **Target** section, expand the **Configuration Database Entry** and select “Corstone SSE-300 Ethos-U55 (MPS3) - Cortex-M55” as your target.
5. Save the `launch.json` file.

To start a debug session:

1. Click at the top of the **CMSIS** view.

2. Select the **Arm Debugger FVP** configuration.
3. On Windows, you might need to enable running the model with the user access control (UAC).
4. The debugger stops at `main`. You can now debug the application.

7.2 Create a new project using µVision

This section describes the basic workflow for creating, running, and debugging a simple "Hello world" example project with µVision, and provides links to more detailed instructions in the µVision User's Guide. The workflow involves the following steps:

- Create a project
- Add software components to your project
- Add the source code files to your project
- Adjust project settings
- Build the project
- Configure virtual hardware in µVision
- Run or debug the project

7.2.1 Create a project

Create a new project with all the basic files that you need for the hardware that you select. For more detailed information, see Creating Applications in the µVision User's Guide.

Note

This procedure describes creating a project for the Arm V2M-MPS3-SSE-300-FVP virtual hardware. Adapt the steps for other starter kits or boards.

1. Install µVision.
2. From the µVision menu bar, select **Project** > **New µVision Project**.
3. Select an empty folder and enter the project name (for example, `hello`). Click **Save**, which creates an empty project file with the specified name (`hello.uvprojx`). The **Select Device for Target** dialog box opens.
4. Select SSE-300-MPS3 and click **OK**.

The device selection defines essential tool settings such as compiler controls, the memory layout for the linker, and the Flash programming algorithms.

7.2.2 Add software components to your project

The **Manage Run-Time Environment** dialog box opens and shows the software components that are installed and available for the selected device.

Select the relevant software components that you want to use. For more detailed information, see Managing Run-Time Environment.

Select the following components:

- ::CMSIS:CORE
- ::CMSIS:OS Tick (API):SysTick
- ::CMSIS:RTOS2 API:Keil RTX5:Source
- ::CMSIS-Driver:USAART (API):USART (set to '1')
- ::CMSIS-Compiler:CORE
- ::CMSIS-Compiler:STDOUT (API):Custom
- ::Device:Definition
- ::Device:Startup:C Startup
- ::Device:USART Retarget
- ::Device:Native Driver:SysCounter
- ::Device:Native Driver:SysTimer
- ::Device:Native Driver:Timeout
- ::Device:Native Driver:UART

7.2.3 Add the source code files to your project

Add the `main.h` header file and the `helloworld.c` files to your project, and add project-specific code to the files.

1. In the **Project** window, right-click **Source Group 1** and open the **Add New Item to Group** dialog box.
2. Click **Header File (.h)**, add the name `main`, and then click **OK**.
3. Copy and paste the following code into the `main.h` file:

```
#ifndef MAIN_H__
#define MAIN_H__

/* Prototypes */
extern void app_initialize (void);
extern int  stdio_init     (void);

#endif
```

4. In the **Project** window, right-click **Source Group 1** and open the **Add New Item to Group** dialog box.

5. Click **C File (.c)**, add the name `helloworld`, and then click **OK**.
6. Copy and paste the following code into the `helloworld.c` file:

```
#include <stdio.h>
#include "main.h"
#include "cmsis_os2.h"

const osThreadAttr_t app_main_attr = {
  .attr_bits = osThreadPrivileged                //Set thread to privileged
};

/*----------------------------------------------------------------------------
 * Application main thread
 *---------------------------------------------------------------------------*/

static void app_main (void *argument) {
  (void)argument;

  for(int count = 0; count < 10; count++) {
    printf("Hello World %d\r\n", count);
    osDelay(1000U);
  }
  osDelay(osWaitForever);
}

/*----------------------------------------------------------------------------
 * Application initialization
 *---------------------------------------------------------------------------*/
void app_initialize (void) {
  osThreadNew(app_main, NULL, &app_main_attr);
}
```

7. In the **Project** window, right-click **Source Group 1** and open the **Add New Item to Group** dialog box.
8. Click **C File (.c)**, add the name `main`, and then click **OK**.
9. Copy and paste the following code into the `main.c` file:

```
#include "RTE_Components.h"
#include CMSIS_device_header
#include "cmsis_os2.h"
#include "main.h"

int main() {
 osKernelInitialize();                      // Initialize CMSIS-RTOS2
 app_initialize();                          // Initialize application
 osKernelStart();                           // Start thread execution

   for (;;) {
   }
}
```

7.2.4 Adjust project settings

Before you can build the project, adjust the following project settings.

1. From the µVision menu bar, select **Project** > **Options for target 'Target 1'** or click .
2. Go to the **Linker** tab.
3. Unselect **Use Memory Layout from Target Dialog**.

4. In the **disable Warnings** box, add “6314”.
5. Click **Edit** next to the **Scatter file**. Click **OK**.
6. Replace the content of `hello.sct` with the following code:

```
LR_ROM0 0x10000000 0x00200000 {

  ER_ROM0 0x10000000 0x00200000 {
    *.o (RESET, +First)
    *(InRoot$$Sections)
    *(+RO +XO)
  }

  RW_NOINIT 0x30000000 UNINIT (0x00020000 - 0x00000C00 - 0x00000200 - 0) {
    *.o(.bss.noinit)
    *.o(.bss.noinit.*)
  }

  RW_RAM0 AlignExpr(+0, 8) (0x00020000 - 0x00000C00 - 0x00000200 - 0 -
 AlignExpr(ImageLength(RW_NOINIT), 8)) {
    *(+RW +ZI)
  }

  ARM_LIB_HEAP (AlignExpr(+0, 8)) EMPTY 0x00000C00 { ; Reserve empty region for
 heap
  }

  ARM_LIB_STACK (0x30000000 + 0x00020000 - 0) EMPTY -0x00000200 { ; Reserve empty
 region for stack
  }

  RW_RAM1 0x00000000 0x00080000 {
   .ANY (+RW +ZI)
  }

  RW_RAM2 0x01000000 0x00100000 {
   .ANY (+RW +ZI)
  }

  RW_RAM3 0x20000000 0x00020000 {
   .ANY (+RW +ZI)
  }

}
```

7.2.5 Build the project

To build the project, click . The **Build Output** window shows the progress of the build.

For more options to build a project, see Build the Project in the µVision User’s Guide.

7.2.6 Configure virtual hardware in µVision

To run a project on virtual hardware such as the V2M-MPS3-SSE-300-FVP used in this example, you must configure the model.

1. From the µVision menu bar, select **Project** > **Options for target ‘Target 1’** or click .
2. Go to the **Debug** tab.

3. On the right-hand side, select "Models ARMv8-M Debugger" and click **Settings**. A new window opens. Enter the following settings:
    a. In the **Command** box, enter the path to your AVH FVP models, for example `c:\Keil_v5\ARM\avh-fvp\bin\models\FVP_Corstone_SSE-300.exe`.
    b. In the **Target** box, enter `cpu0`. Click **OK** twice.

7.2.7 Run or debug the project

To run or debug the application on virtual hardware:

1. From the µVision menu bar, select **Debug** > **Start/Stop Debug Session** or click . The µVision Debug view opens.

Note

On Windows, you might need to enable running the model with the user access control (UAC).

---

1. The debugger stops at `main`. You can now run the application.
2. From the µVision menu bar, select **Debug** > **Run** or click .
3. Observe the output in the **Telnet** window.
4. To debug the application, click , , or .
5. Click () to stop the program execution.
6. From the µVision menu bar, select **Debug** > **Start/Stop Debug Session** or click to exit the debug session.

7.2.8 Save the project in csolution format

If you want to use the project in Keil Studio, you must save it in csolution format. From the µVision menu bar, select **Project** > **Export** > **Save project to csolution format**. The csolution and cproject YAML files are saved in the project directory.

8. Terminology

This section provides brief definitions of important concepts in Keil Studio and CMSIS. For more information and links to more detailed resources, see CMSIS basic concepts.

CMSIS-Pack:

An open packaging standard for distributing embedded software libraries, documentation, device parameters, and evaluation board support. The CMSIS-Pack standard is now part of the Open-CMSIS-Pack project.

CMSIS-Toolbox:

Command-line tools for working with components defined in Open-CMSIS-Pack format. CMSIS-Toolbox includes tools for installing CMSIS-Packs, defining and scaling embedded software projects, and orchestrating builds.

CMSIS context:

A build configuration inside a CMSIS solution that combines a project, a build type (for example, `Debug` or `Release`), and a target (that is, hardware). A context is specified in the format `Project.BuildType+Target`. For more information, see the CMSIS context documentation.

CMSIS software components:

Embedded software abstractions and libraries, packaged inside a CMSIS-Pack. For more information, see the CMSIS components section of this guide.

CMSIS solution (also known as a csolution):

The YAML-based project format used by CMSIS-Toolbox. For more information, see CMSIS Solution Project File Format.