



Arm[®] Keil[®] Microcontroller Development Kit (MDK)

Version v6

Getting Started Guide

Non-Confidential

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Arm® Keil® Microcontroller Development Kit (MDK) Getting Started Guide

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The product version is v6.

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Intended audience

This book is written for all developers who are involved in the development of embedded, IoT and Machine Learning software for Cortex-M devices.

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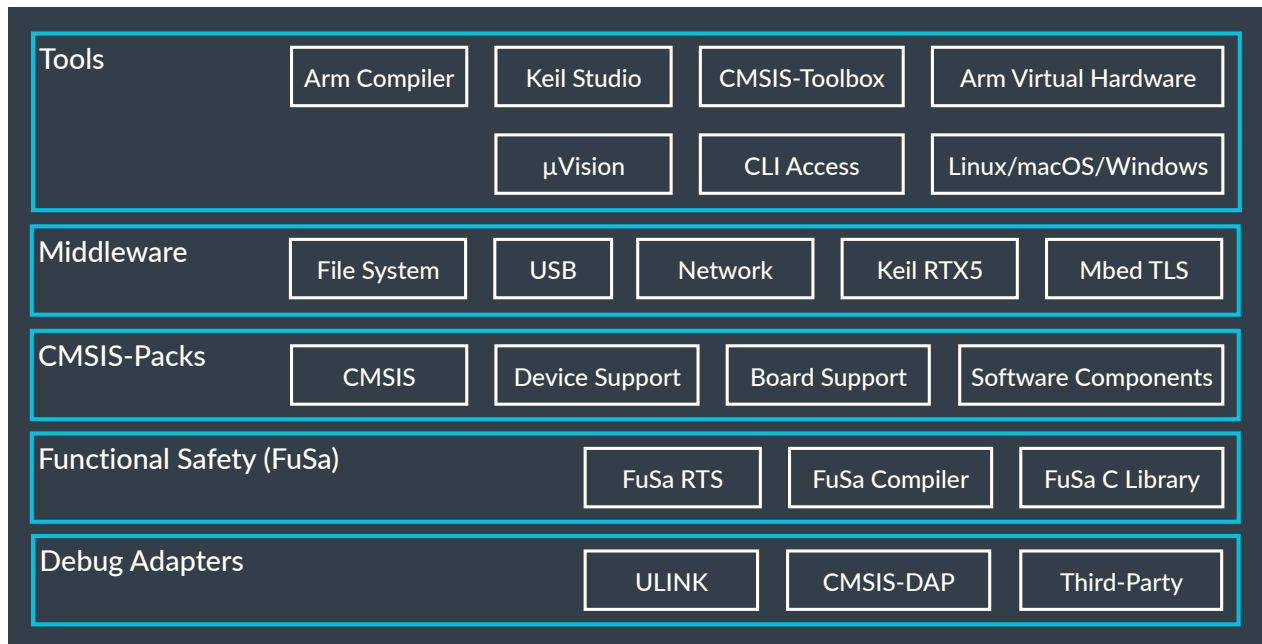
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1. What is MDK?

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 simplifies software engineering by offering you the flexibility to work with a CLI or a desktop-based or browser-based IDE. You can also deploy the tools into a continuous integration workflow.

Figure 1-1: MDK overview diagram



1.1 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.



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

1.2 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 a foundation for the application.

1.3 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 \(RTS\)](#)

1.4 Debug adapters

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

- [ULINKpro](#) allows you to program, debug, and analyze your applications using its unique streaming trace technology.
- [ULINKplus](#) 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, for example ST-Link, JLink, and others.

1.5 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). MDK-Professional also enables legacy tools like PK51, DK251, PK166, and Arm Compiler 5.

The [product selector](#) gives an overview of the features enabled in each edition.

1.6 License types

MDK is exclusively available through [user-based licensing \(UBL\)](#). All MDK editions require activation.

UBL 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 can use a single license with a service account to automatically build and test your products with Arm tools on multiple devices.

You can activate a license in two ways:

- 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 the following topics in the User-based Licensing User Guide:

- [Activate your product using an activation code](#)
- [Activate your product using a license server](#)

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. This topic explains how 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 using a product license that includes Keil MDK Professional.

1.7 Download options

MDK v6 contains various [tools](#) that you can download from different locations.

Table 1-1: Download options

Tool	keil.com	PDH	Artifactory	Other
µVision (MDK v5)	download	download		
Keil Studio				VS Code Marketplace
Arm Compiler for Embedded		download	download	
LLVM			download	GitHub
GCC		download	download	
Arm CMSIS-Toolbox			download	
Arm Debugger			download	
Arm License Manager			download	
Arm Virtual Hardware FVPs			download	
µVision Project Converter			download	
Arm Compiler for Embedded FuSa*		download		
Functional Safety Run-Time System*		download		
PK51*	download			
DK251*	download			
PK166*	download			



- All tools marked with an asterisk (*) are only available to you if you have purchased the MDK-Professional edition.
- You need an Arm account to access Product Download Hub (PDH).

Refer to the [installation section](#) to learn how to install the various tools.

Download with Artifactory

The easiest way to download tools from the Artifactory 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`.

1.8 Access the MDK documentation

MDK provides [documentation](#) for all of its components.

We recommend reviewing the following documents to get started with the tools:

- [Arm Keil Studio Visual Studio Code Extensions User Guide](#)
- [Arm Keil Studio Cloud User Guide](#)
- [µVision User's Guide](#)
- [Licensing User's Guide](#)

Get help

If you have suggestions or you discover an issue with any of the Keil® MDK products, report them to us. [Open a support case](#) and include your license code and product version when reporting an issue.

If you are a user of the free MDK-Community edition, please report any issues in the [Keil Support Forum](#).

Online learning

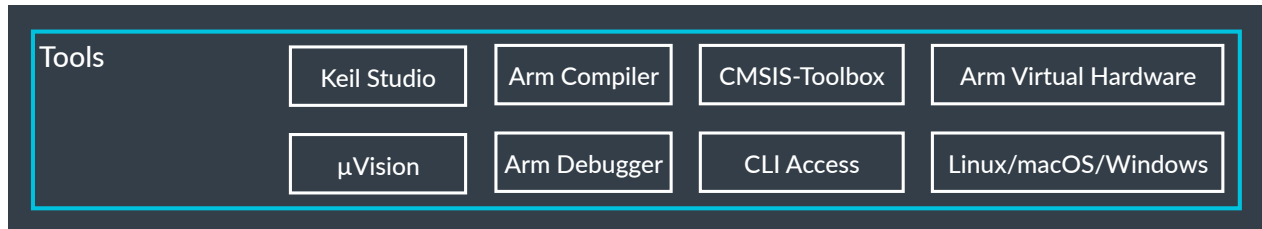
Our [Learning Paths](#) help you to learn more about the programming of Arm® Cortex®-based microcontrollers. The site contains tutorials for all levels of experience, from beginner to advanced.

[Videos](#) showing the tools and different aspects of software development help you to get started.

2. Tools

Learn more about the software tools included in MDK v6.

Figure 2-1: Tools overview diagram



2.1 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. The tool is available in the following formats:

- as a browser-based Integrated Development Environment (IDE) for development in the cloud
- 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 and 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 Chromium-based browsers without having to install any software.

2.1.1 Keil Studio Pack for Visual Studio Code

The Arm Keil Studio Pack includes extensions that enable you to manage your [CMSIS](#) solutions, also known as csolution projects. The pack also includes extensions that enable you 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](#).

2.2 Keil μVision

Keil® μVision® is a Windows-based software development platform that integrates all the tools needed to develop embedded applications quickly and successfully. μVision combines the following tools:

- a source code editor
- a project manager for creating and maintaining your projects
- a Make tool for assembling, compiling, and linking your embedded applications

μVision offers separate modes for building and debugging applications. You can debug applications using Arm Virtual Hardware simulation models. Alternatively, you can debug applications 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 information 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 process increases the consistency and transparency of your embedded application design.

For more information, see the [μVision documentation](#).

2.3 Arm Compiler for Embedded

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

Arm Compiler for Embedded is developed alongside the Arm architecture, and therefore provides early, comprehensive, and accurate support for the latest architectural features and extensions.

This support enables you to evaluate which Arm solution best suits your requirements and to verify your design.

Leading companies across a wide variety of industries use Arm Compiler for Embedded, including consumer electronics, networking, storage, telecommunications, security, and safety-critical systems.

Arm Compiler for Embedded consists of the following toolchain components:

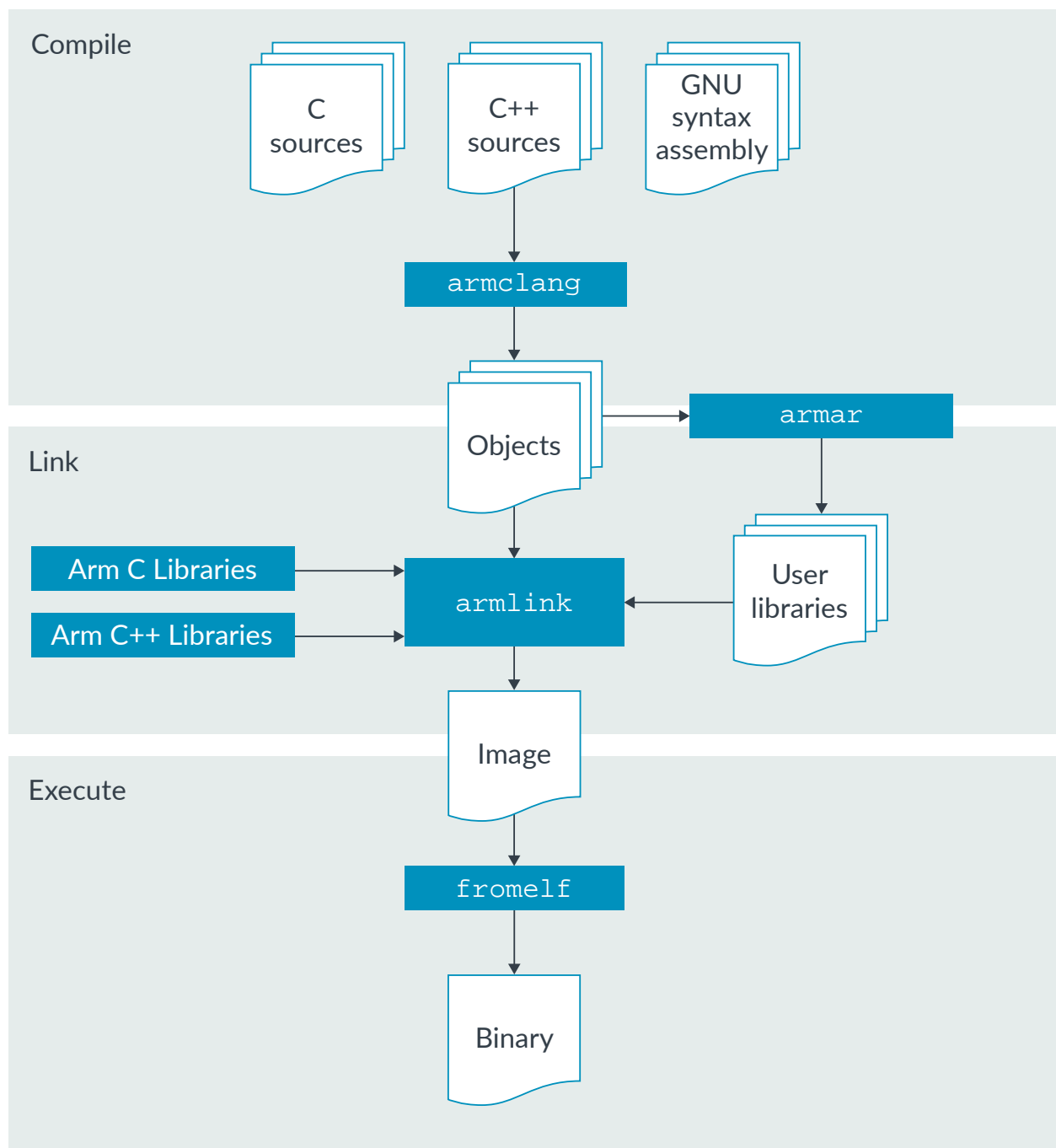
- **armclang.** A compiler and integrated assembler based on modern LLVM and Clang technology. The armclang compiler supports GNU syntax assembly and the latest language standards, including C++17. The compiler is highly compatible with source code originally written for GCC, and implements specifications including the following:
 - ANSI C
 - ISO C
 - C++
 - ABI for the Arm architecture
 - ABI for the 64-bit Arm architecture
 - 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.** A safety-qualified C and C++ toolchain that is suitable for developing embedded software for safety-critical markets including automotive, industrial, medical, railways, and aviation.
- **FuSa C libraries.**



Arm Compiler for Embedded FuSa and the FuSa C libraries are available only in the MDK-Professional edition.

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

Figure 2-2: Arm Compiler workflow diagram

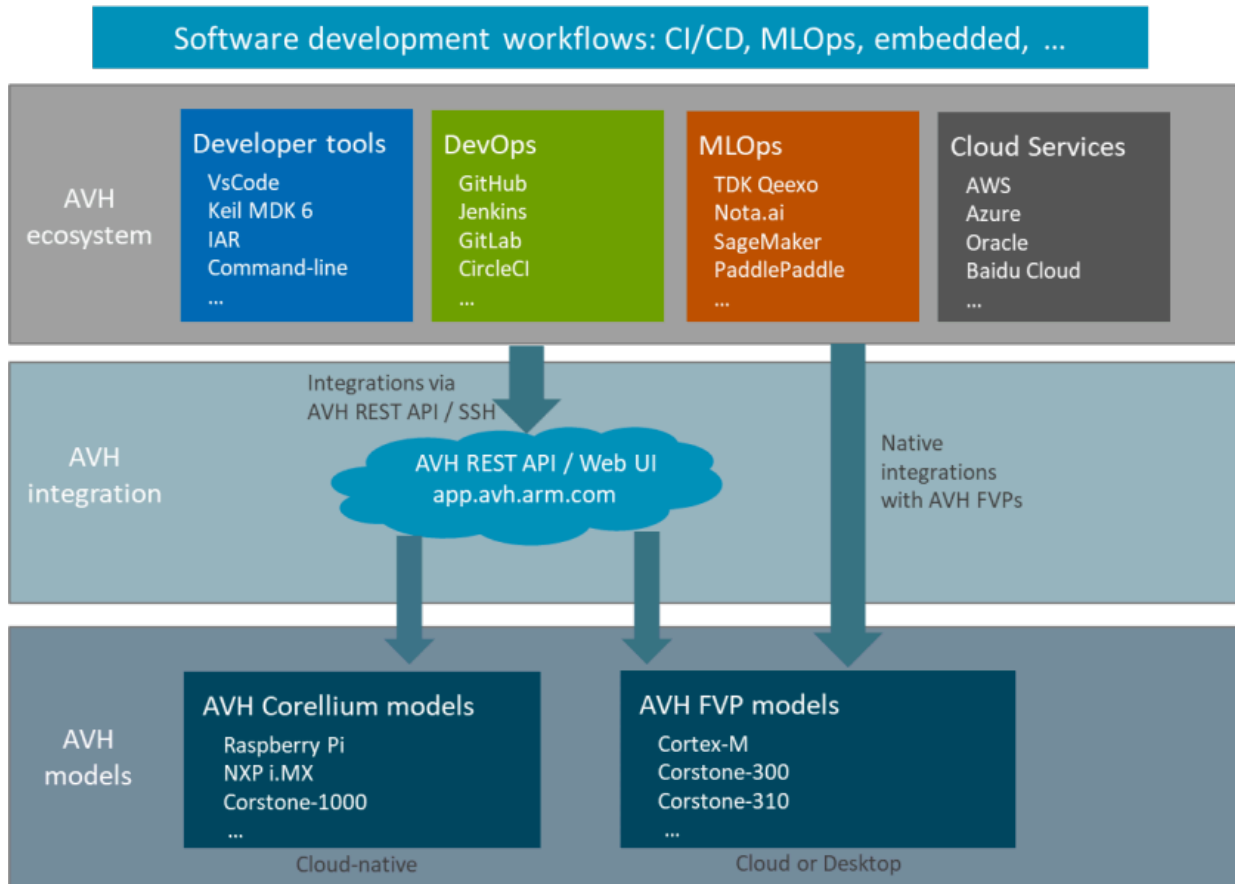


For more information, see the [Arm Compiler for Embedded documentation](#).

2.4 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 support enables faster prototyping, build, and deployment cycles, and reduces time to market for embedded applications.

Figure 2-3: Arm Virtual Hardware overview diagram



You can start developing and testing your applications on AVH ahead of silicon availability. This capability means that you do not have 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. AVH also 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 the speed of a model on different devices 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, for example 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. You can run them 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](#).

3. 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.

- If you are running on Windows, you can still download the installer for μ Vision that includes all other tools. Refer to [Keil \$\mu\$ Vision installation](#).
- You can install Keil Studio on a desktop machine from within Visual Studio Code using the extensions Marketplace. Refer to [Keil Studio installation](#). This process 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, CMSIS-Toolbox, and 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](#).

3.1 Software and hardware requirements

MDK has the following minimum hardware and software requirements:

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

3.2 Installing Keil μ Vision

This section explains how to install and activate Keil® μ Vision.

Keil μ Vision installation

[Download MDK](#) and run the installer. To install MDK (μ Vision) on your local computer, follow the instructions. 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 must install a software pack that supports your target microcontroller device.

Keil μ Vision activation

After the installation has finished, you must add a license to μ Vision. If you have not purchased a license, [follow these instructions](#) to get a free MDK-Community license for evaluation purposes.

µVision supports [user-based licensing \(UBL\)](#) starting with MDK v5.37. You can activate previous versions, including legacy tools like PK51, DK251, and PK166, only by using a Keil node-locked license or a FlexNet floating license. If you require access to older versions of the tools, purchase the [MDK-Professional edition](#) which gives access to older versions of µVision.

This [Keil Quick Tip](#) shows the process in a short video.



If you have installed multiple versions of Keil IDEs into the same folder, please note that activating a UBL will override all other licenses registered in µVision. Because of that, you must install other Keil toolchains (PK51/DK251/PK166) into a different installation folder than the Keil MDK folder, with an activated UBL license. Refer to the [Keil Licensing User's Guide](#) for more information.

Create a new project

To start your development, continue with [Create a project using µVision](#).

3.3 Installing Keil Studio

This section explains how to install and activate Keil® Studio.

Keil Studio installation

To install Keil Studio, add the [Arm Keil Studio Pack](#) 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 **Install** to download and install the set of extensions.

Refer to the [Arm Keil Studio Pack](#) documentation to learn more about each extension that is included.

Keil Studio activation

After the installation finishes, you must add a license. Keil Studio only supports [user-based licensing \(UBL\)](#). If you have not purchased a license, [follow these instructions](#) to get a free-of-charge MDK-Community license for evaluation purposes.

This [Keil Quick Tip](#) shows the process in a very short video.

Create a solution

Continue with [Create new applications](#) to start with your first project.

3.4 Installing other tools

Follow the links to learn how to install the other tools:

- [Arm CMSIS-Toolbox](#)
- [Arm Compiler for Embedded](#)
- [Arm Virtual Hardware FVPs](#)
- [Arm GNU Toolchain \(GCC\)](#)
- [LLVM Embedded Toolchain](#)
- [Arm Compiler for Embedded FuSa](#)
- [Arm Debugger](#)
- [MDK \$\mu\$ Vision project converter](#)

4. 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.

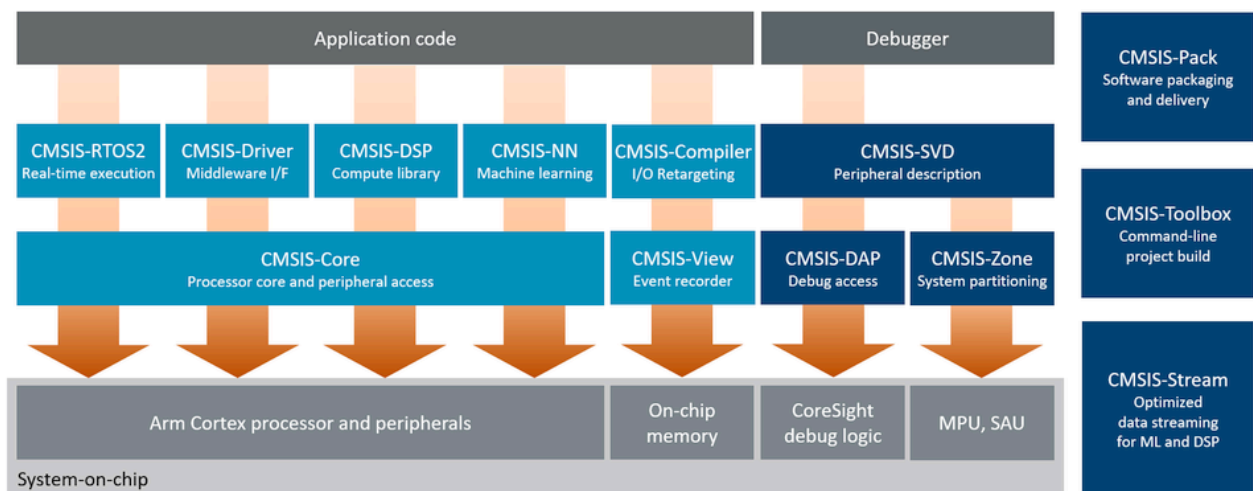
You can use the prewritten functions and libraries in CMSIS to control the hardware resources of different microcontrollers without having to learn how to manipulate those resources directly for each microcontroller. This reduces the time taken to build and debug projects, and speeds up the process of 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 4-1: 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 permissions 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.

4.1 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.

4.1.1 CMSIS-Pack

CMSIS-Pack is a standardized packaging format for distributing software components for Arm® Cortex®-based microcontrollers. The format 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 like code libraries for specific use cases.

CMSIS-Packs are a specific type of [software pack](#).

4.1.2 Software pack

A set of ready-to-use components and tools tailored for a specific hardware platform or for a specific purpose. A **Pack Description (PDSC) file** 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 Visual Studio Code extensions.

Software packs are designed to provide general-purpose resources for embedded development. More specialized **Device Family Packs (DFPs)** and **Board Support Packs (BSPs)** are also available. DFPs and BSPs 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.

4.1.3 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. You can bundle multiple components together into a [software pack](#) or a [CMSIS-Pack](#). For more information, see the [Overview of additional software components](#) section of this guide.

4.1.4 CMSIS solutions

CMSIS solutions, also known as csolutions, are groups of related projects that are part of a larger application and that you can build 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](#).

The CMSIS Solution extension provides support for working with solutions. For more information, see the [CMSIS solutions](#) section of the Arm® Keil Studio Visual Studio Code Extensions User Guide. For Keil Studio Cloud, refer to the [Keil Studio Cloud User Guide](#).

To create a solution, you can select one of these options:

- **Templates:** Use a blank solution or a TrustZone solution as a starting point. Templates are projects that you can use to get started. Templates do not include application-specific code.
- **Reference Applications:** Use a reference application. Reference applications are not dependent on specific hardware. You can deploy them to various evaluation boards using additional software layers that provide driver APIs for specific target hardware. Layers are provided using CMSIS-Packs.
- **Csolution Examples:** CMSIS solution examples are targeted at a specific board or Fixed Virtual Platform (FVP) model. The examples are fully configured and ready for use.
- **µVision Examples:** Use a µVision example in *.uvprojx format as a starting point. µVision examples are converted automatically.

See [Create a solution](#) for more details. See also [Create new applications](#) in this guide.

4.1.5 CMSIS projects

Each **CMSIS solution** requires at least one **CMSIS project**, that is an individual project that you can build independently.

You define projects by editing *.cproject.yaml files to specify the files and components to include.

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

For more information and example projects, see the [CMSIS-Toolbox documentation](#)

4.2 Overview of CMSIS software 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 without having to know the internal details of different microcontrollers. Using CMSIS makes writing and reusing code easier, because you can port code written for one microcontroller to another microcontroller without having to modify it.

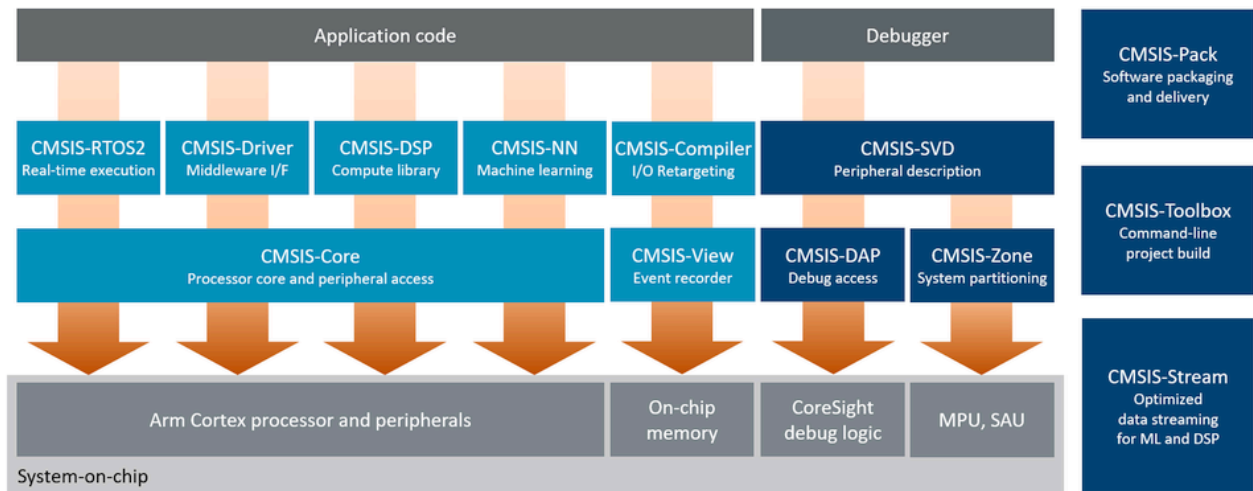
You can use the functions and libraries in CMSIS to control hardware resources for different microcontrollers without having to learn specific details for each one. This process reduces the time that it takes to build and debug projects, and speeds up the process of bringing new applications

to market. CMSIS also includes components that make it easier to add features like digital signal processing, machine learning, neural networks, task management, and resource management.

CMSIS is available under an Apache 2.0 license and is publicly developed on [GitHub](#).

CMSIS overview

Figure 4-2: CMSIS structure



Important developer-facing CMSIS components are:

- **CMSIS-Core:** This component 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. This component can also help the process of migrating between different RTOS kernels.
- **CMSIS-Driver:** This component 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:** This component provides software components for retargeting I/O operations in standard C run-time libraries. CMSIS-Compiler also provides a standardized API for core functions like exceptions and interrupt handling.
- **CMSIS-View:** This component 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 instead of in the cloud. Edge computing provides the following benefits:

- Improved privacy and security
- Reduced 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. CMSIS-Stream 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 Visual Studio Code extensions.
- **CMSIS-Zone**: A tool that helps to simplify partitioning, memory management, and access permissions in embedded applications.
- **CMSIS-DAP**: This component provides access to the Debug Access Port (DAP) and enables communication over USB between a microprocessor and a debug tool on a host computer.

4.3 Overview of CMSIS base software components

The CMSIS base software components provide software abstractions for the basic functionality of microcontroller devices. The Arm::CMSIS software pack delivers these components.

4.3.1 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. CMSIS-Core 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](#).

4.3.2 CMSIS-RTOS2

The CMSIS-RTOS2 component provides generic RTOS interfaces for devices that are based on the Arm® Cortex® microprocessor. The component also 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 you can include in open-source CMSIS-RTOS2 implementations to provide a starting point for further development.

Benefits of an RTOS design

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

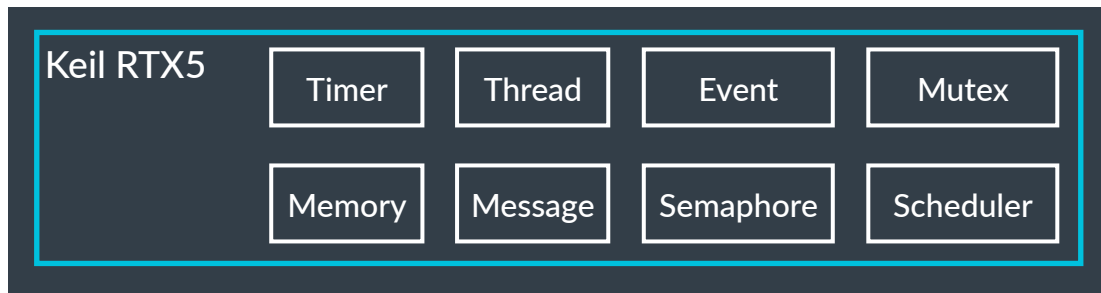
- The RTOS handles thread priority and run-time scheduling reliably.
- The RTOS provides a well-defined interface for communication between threads.
- A pre-emptive RTOS reduces the complexity of interrupt functions, because high-priority threads can perform time-critical data processing.
- Pre-emptive multitasking simplifies application development even with large teams, because you can add new functionality without risking the response time of 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, which 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 4-3: RTX5 overview diagram



For more information, review the [Theory of Operation](#) and [get started with this tutorial](#).

4.3.3 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. CMSIS-Driver 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. In addition to the set of standard peripheral drivers covered by the specification, a DFP might contain the following interfaces:

- memory bus
- General Purpose Input/Output (GPIO)
- Direct Memory Access (DMA)

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](#).

4.4 Overview of CMSIS extended software components

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

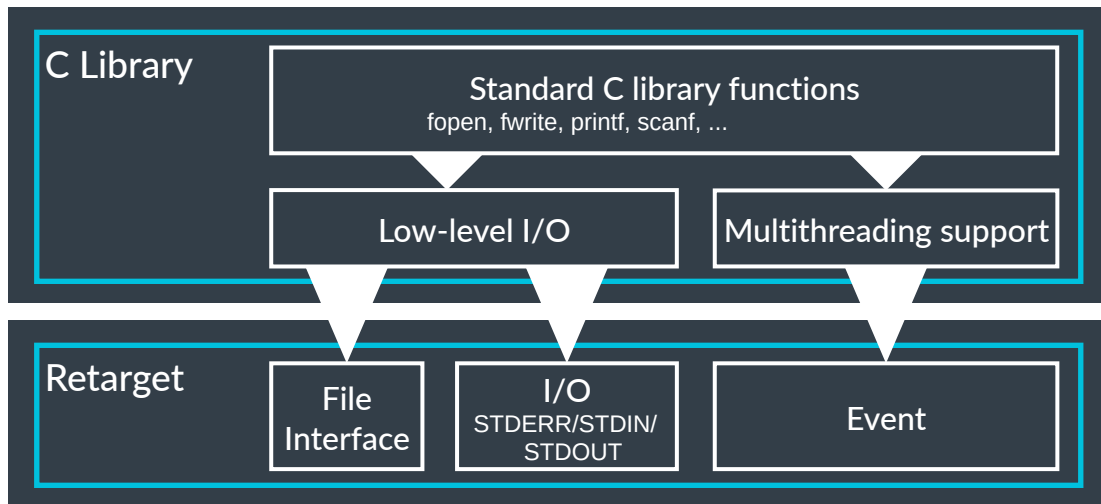
4.4.1 CMSIS-Compiler

CMSIS-Compiler helps you to adapt the input/output operations in standard C runtime libraries so that they can communicate with the I/O operations of your hardware. This process is 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, including stderr, stdin, and stdout
- An OS interface for multithread safety using an arbitrary RTOS

Figure 4-4: CMSIS-Compiler overview diagram



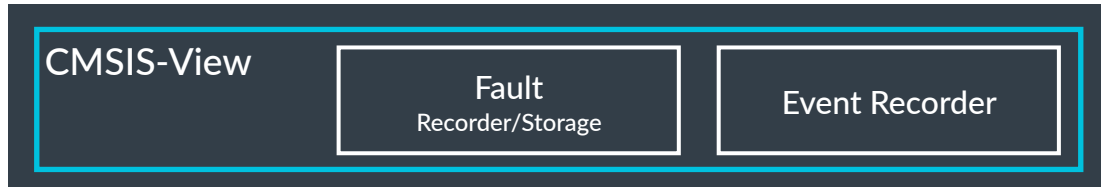
Standard C library functions are platform-independent, but multithreading support and the implementations of the low-level I/O are tailored to the target compiler toolchains.

See the [CMSIS-Compiler documentation](#) and get started using a [template](#).

4.4.2 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 4-5: 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 the following functionality:

- RTOS-aware debugging for CMSIS-RTX and CMSIS-FreeRTOS
- 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](#).

4.4.3 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](#).

4.4.4 CMSIS-NN

The CMSIS-NN open-source software library enhances performance and cuts memory usage for neural networks on Arm® Cortex®-M processors through its 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 instead of in the cloud. Edge computing provides the following benefits:

- Improved privacy and security
- Reduced 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](#).

4.5 Overview of CMSIS tools

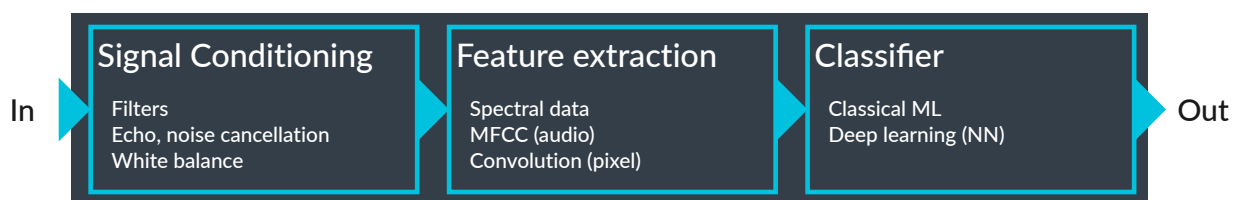
MDK also includes useful tools for working with CMSIS-based components.

4.5.1 CMSIS-Stream

CMSIS-Stream is a Python package that optimizes data block streaming between the processing steps in DSP or ML applications. CMSIS-Stream enables modular design, which makes it easier to develop and maintain DSP pipelines. The tools optimize the 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. The graph 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 4-6: 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.

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.

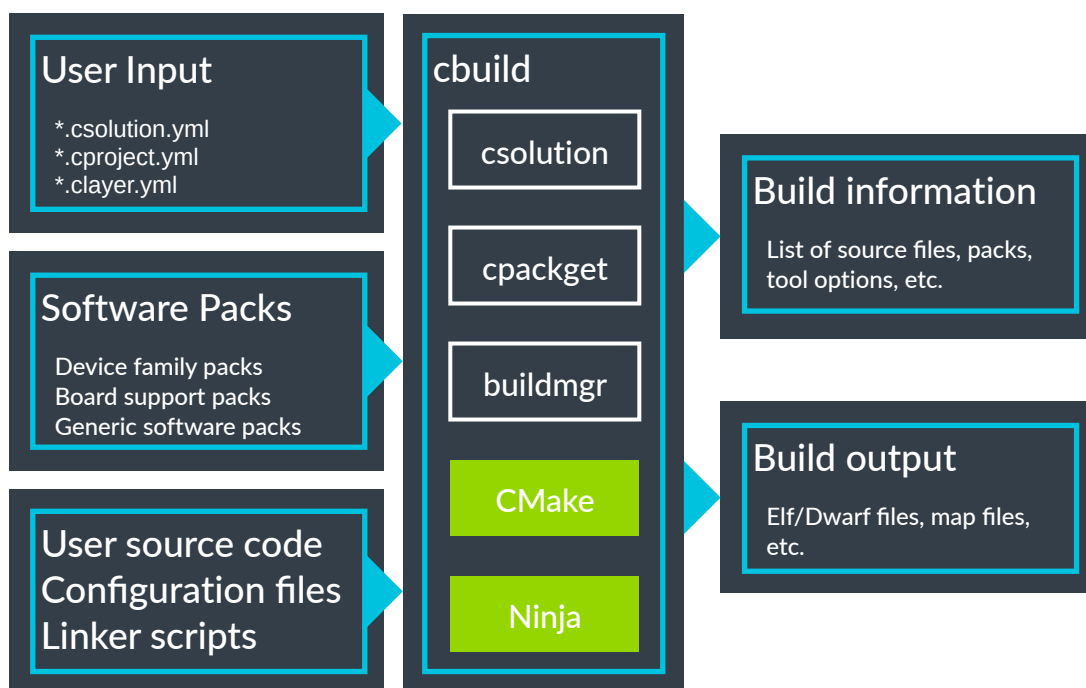
CMSIS-Stream also provides interfaces, header files, templates, and methods for data management that also work on asymmetric multiprocessing (AMP) systems, and usage examples to help you to get started.

See the [CMSIS-Stream documentation](#) and review the [examples](#).

4.5.2 CMSIS-Toolbox

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

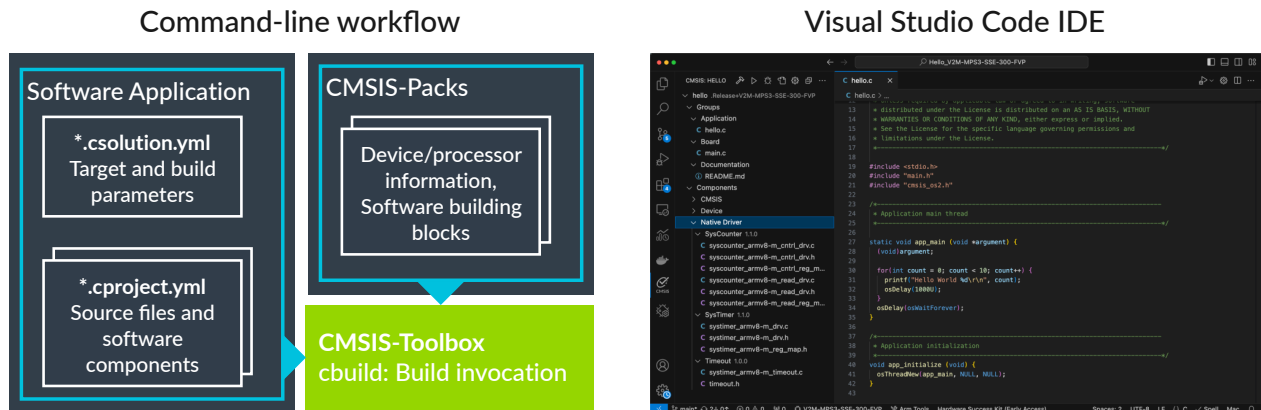
Figure 4-7: CMSIS-Toolbox overview diagram



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 Windows, Mac, and Linux, and are deployable in a flexible way.

For more information on using `cbuild`, `csolution`, and `cpackget` from the command line, including syntax details and usage examples, see the [Build Tools documentation](#).

Figure 4-8: CLI and IDE workflow



Software packs simplify tools setup 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, for example test boards, production hardware, or virtual hardware.
- Multiple build types, for example debug build, test build, or release build, to support software testing and verification.
- 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. Various Visual Studio Code extensions use these files to power IntelliSense.

For more information, see the [CMSIS-Toolbox documentation](#).

4.5.3 CMSIS-Zone

CMSIS-Zone reduces 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](#).

4.5.4 CMSIS-DAP

CMSIS-DAP provides standardized access to the CoreSight™ Debug Access Port 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 runs, 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](#).

5. 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 that are 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. CMSIS-Packs 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.

The CMSIS-Pack system 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](#).

5.1 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 5-1: Diagram showing the stages of PLM



PLM consists of four phases:

- **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.

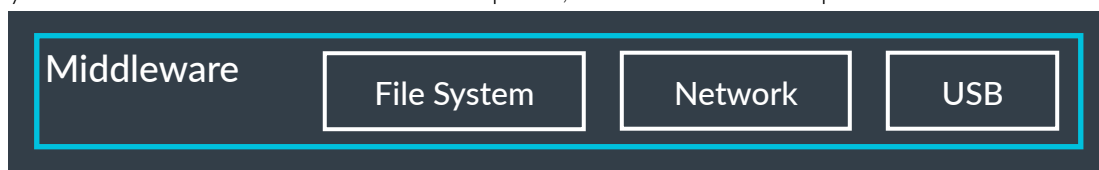
5.2 Overview of additional software components

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.



5.2.1 CMSIS-FreeRTOS

FreeRTOS is a market-leading real-time operating system (RTOS) for embedded microcontrollers.

- FreeRTOS is professionally developed, strictly quality controlled, robust, fully supported, and documented.

- FreeRTOS is free to use in commercial products without a requirement to expose proprietary source code.
- There is no risk of IP infringement.

The Arm® implementation of FreeRTOS 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 like Keil RTX5. See the [CMSIS-FreeRTOS documentation](#) and get started with an [example project](#).

5.2.2 CMSIS-mbedTLS

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

See the [CMSIS-mbedTLS GitHub repository](#) for more information.

5.2.3 Synchronous Data Stream (SDS) framework

The Synchronous Data Stream (SDS) framework implements a data stream management system. The framework also 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. SDS supports data streams from multiple interfaces, including provisions for time drifts. You can record real-world data for analysis and development, or play back real-world data for algorithm validation by using Arm Virtual Hardware. SDS data files have several use cases:

- To provide input to DSP development tools like 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. SDS also includes Python-based tools for recording, playback, visualization, and data conversion.

See the [SDS-Framework documentation](#) and get started by using an [example](#).

5.2.4 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 5-2: MDK-Middleware Network component overview diagram



*These components are not part of the Network component



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

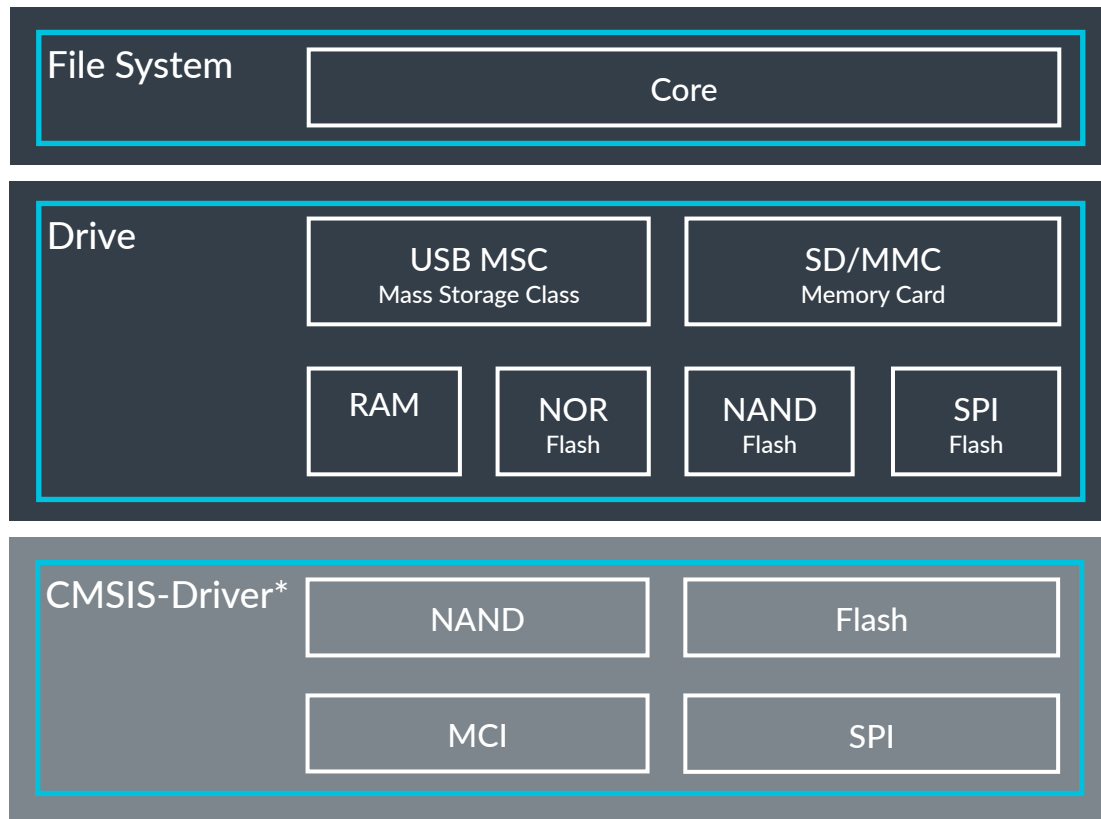
See the [Network component documentation](#) and get started by using an [example](#).

5.2.5 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 including the following:

- RAM
- Flash
- memory cards
- USB devices

Figure 5-3: 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:

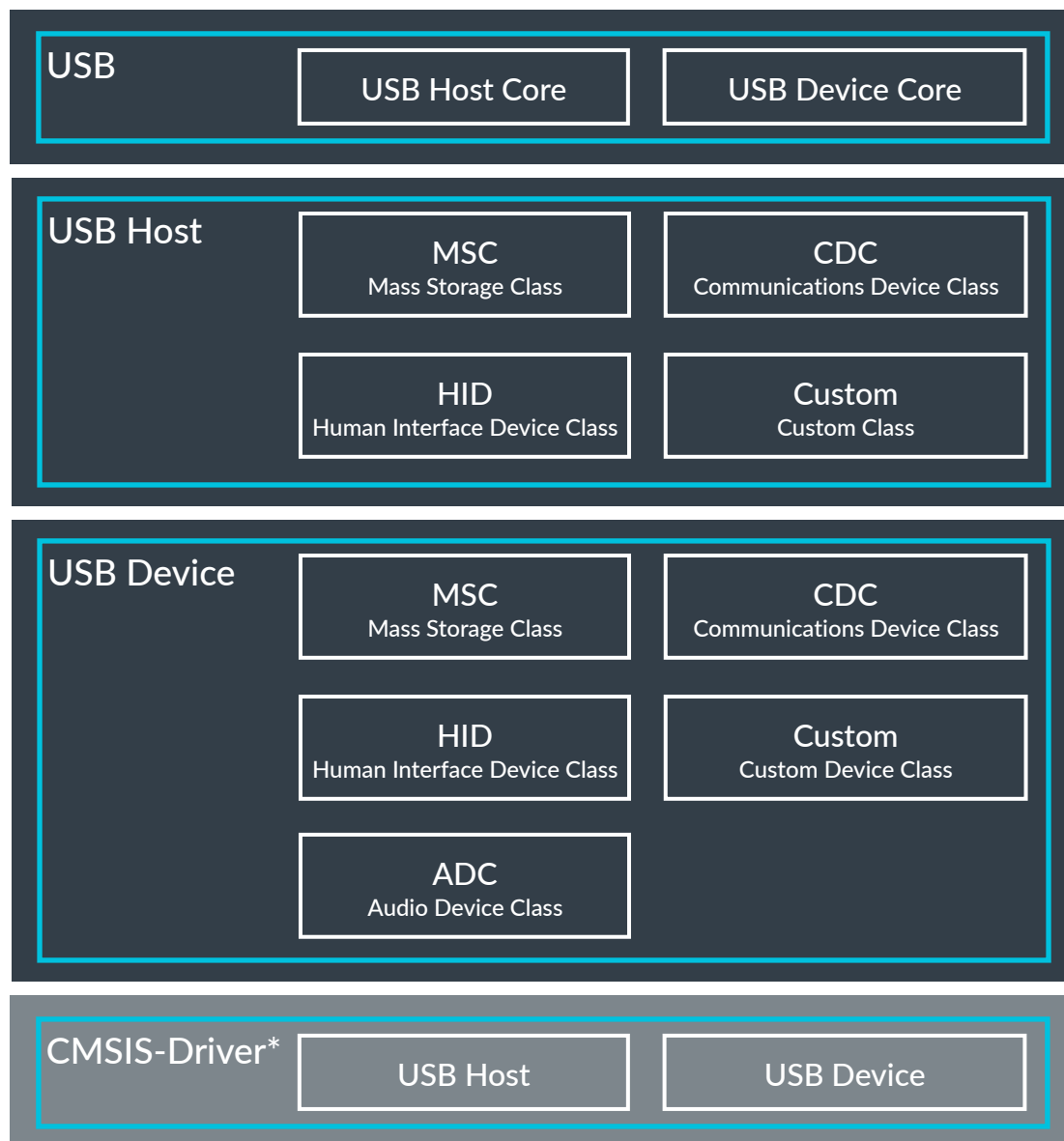
- Storage devices are referenced as drives which you can access
- You can implement multiple instances of the same storage device (for example, you might want to have two SD cards attached to your system)
- The File System Core supports thread-safe operation. It uses an Embedded File System (EFS) for 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](#).

5.2.6 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 5-4: MDK-Middleware USB component overview diagram



*These components are not part of the USB component

The structure of the USB component is as follows:

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



The USB Host is available only with the [MDK-Professional](#) edition.

- 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

MDK supports the following USB classes:

- 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.

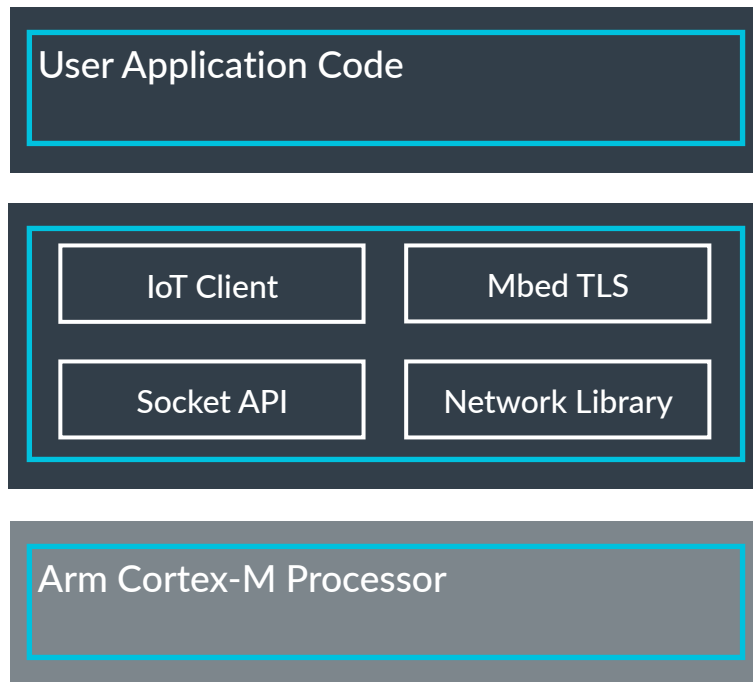
See the [USB component documentation](#) and get started by using a [USB Device example](#) or a [USB Host example](#).

5.2.7 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 5-5: IoT application software stack



Most IoT clients use the Message Queuing Telemetry Transport (MQTT) protocol, which is a lightweight messaging protocol for IoT applications. The protocol 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 foundation 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](#).

5.2.8 Overview of open-source components

You can use open-source components 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. You can use the library 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](#).

6. Create new applications

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

6.1 Create a solution from a blank template 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. For more detailed instructions, see 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](#)
- [Build the solution](#)
- [Run the solution](#)
- [Debug the solution](#)

6.1.1 Create a solution

Create a 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.




This procedure describes creating a solution for the Holtek ESK32-31401 starter kit. Adapt the steps for other starter kits or boards.

1. In the **CMSIS** view , click **Create a New Solution**.
2. In the **Target Board** drop-down list, find **ESK32-31401 (HT32F49395) (Ver 1.0)**, and then click **Select**.
3. In the **Templates, Reference Applications, and Examples** drop-down list, select **Blank solution**.
4. Enter a name for the project to include in your solution, for example, **helloworld**.
5. Enter a solution name.

6. Enter a folder name and specify the location where you want to store your solution files.
7. With the **Initialize Git repository** checkbox, you can initialize the solution as a Git repository. Clear the checkbox if you do not want to turn your solution into a Git repository.
8. Click **Create**.
9. An **Arm Environment Activation** dialog box displays. Confirm that the Environment Manager extension can activate the workspace and download the tools specified in the `vcpkg-configuration.json` file generated when you created the solution.
10. If you have several compilers installed, the **Configure Solution** view opens automatically. Select a compiler.

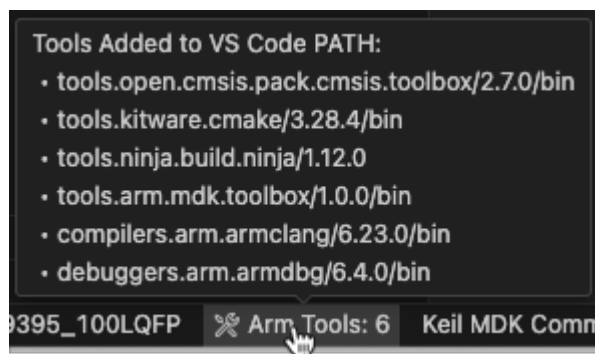
6.1.2 Manage software tools

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.

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 **Configure Arm Tools Environment** visual editor, verify what tools have been installed. Add Arm Debugger if required.

You can also see the number of Arm tools installed in the status bar of VS Code.

Figure 6-1: Arm Tools in status bar




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.

6.1.3 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. **CMSIS > Core** and **Device > Startup** are already selected.
2. In the **Software packs: Solution** drop-down list, select **All installed packs**.
3. Click the arrows next to a heading in the **Software Components** view to browse the list of components. Select the following components:
 - **CMSIS > OS Tick > SysTick**, and **RTOS2 > FreeRTOS**
 - **Device > ht32f493x5_conf**
 - **Device > ht32f493x5_firmware_library > crm** and **misc**



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.

6.1.4 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 solution outline, go to **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 (;;) {
    }
}
```


6.1.5 Build the solution

To build the solution, click  from the **CMSIS** view. 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.


6.1.6 Run the solution

To run the solution:

1. Go to the **CMSIS** view and click .
2. Select the **Flash Device** in the drop-down list that opens at the top of the window.
3. On Windows, you might need to enable running the model with the user access control (UAC).
4. Observe the output in the **Terminal** tab.

6.1.7 Debug the solution

To start a debug session:

1. Click  at the top of the **CMSIS** view.
2. Select **Arm Debugger** in the drop-down list that opens at the top of the window.
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.

6.2 Create a solution from a reference example using the Keil Studio VS Code extensions

This section describes the basic workflow for creating, running, and debugging a simple reference application with the Keil Studio VS Code extensions. It also 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 reference application](#)
- [Manage software tools](#)
- [Build the solution](#)
- [Run the solution](#)
- [Debug the solution](#)

6.2.1 Create a reference application

Create a 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.




This procedure describes creating a reference application for the STMicroelectronics B-U585I-IOT02A board. Adapt the steps for other boards.

-
1. In the **CMSIS** view , click **Create a New Solution**.
 2. In the **Target Board** drop-down list, find the **B-U585I-IOT02A (Rev.C)** board, and then click **Select**.
 3. In the **Templates, Reference Applications, and Examples** drop-down list, select the **USB_Device** reference example.

4. Enter a folder name and specify the location where you want to store your solution files.
5. With the **Initialize Git repository** checkbox, you can initialize the solution as a Git repository. Clear the checkbox if you do not want to turn your solution into a Git repository.
6. Click **Create**.
7. 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.
8. The **Configure Solution** view displays automatically. Click **OK** to add a board layer to your reference application. If you have several compilers installed, you can also select a compiler from this view.

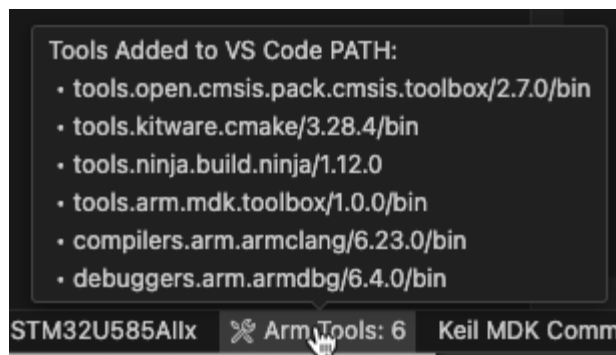
6.2.2 Manage software tools

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.

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 **Configure Arm Tools Environment** visual editor, verify what tools have been installed. Add Arm Debugger if required.

You can also see the number of Arm tools installed in the status bar of VS Code.


Figure 6-2: Arm Tools in status bar



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, Keil Studio can use any version starting from the one that you specify. Use the `*` specifier to always use the latest version of the tool.


6.2.3 Build the solution

To build the solution, click  from the **CMSIS** view. 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.


6.2.4 Run the solution

To run the solution on your board:

1. Go to the **CMSIS** view and click .
2. Select `Flash Device` in the drop-down list that opens at the top of the window.
3. On Windows, you might need to enable running the model with the user access control (UAC).
4. Observe the output in the **Terminal** tab.

6.2.5 Debug the solution

To start a debug session:

1. Click  at the top of the **CMSIS** view.
2. Select `Arm Debugger` in the drop-down list that opens at the top of the window.
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.

6.3 Create a project using μ Vision

This section describes the basic workflow for creating, running, and debugging a simple “Hello world” example project with μ Vision. For more detailed instructions, see the [\$\mu\$ Vision 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 \$\mu\$ Vision](#)
- [Run or debug the project](#)

6.3.1 Create a project

Create a project with all the basic files that you need for the hardware that you select. For more detailed information, see [Creating Applications](#) in the μ Vision User's Guide.



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 [\$\mu\$ Vision](#).
2. From the μ Vision menu bar, select **Project > New μ Vision 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 like compiler controls, the memory layout for the linker, and the Flash programming algorithms.

6.3.2 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:USART (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

6.3.3 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 (;;) {
    }
}
```

6.3.4 Adjust project settings

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

1. From the μ Vision 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)
}

}
```


6.3.5 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 μ Vision User's Guide.

6.3.6 Configure virtual hardware in μ Vision

To run a project on virtual hardware, you must configure the model.

1. From the μ Vision 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.


6.3.7 Run or debug the project






To run or debug the application on virtual hardware:

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



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 μ Vision 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 μ Vision menu bar, select **Debug** > **Start/Stop Debug Session** or click  to exit the debug session.

6.3.8 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 μ Vision menu bar, select **Project** > **Export** > **Save project to csolution format**. The csolution and cproject YAML files are saved in the project directory.

7. 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 that are 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 [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 [CSolution Project Format](#).

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PRE-1121-V1.0

Product and document information

Read the information in these sections to understand the release status of the product and documentation, and the conventions used in Arm documents.

Product status

All products and services provided by Arm require deliverables to be prepared and made available at different levels of completeness. The information in this document indicates the appropriate level of completeness for the associated deliverables.

Product completeness status

The information in this document is Final, that is for a developed product.

Revision history

These sections can help you understand how the document has changed over time.

Document release information

The Document history table gives the issue number and the released date for each released issue of this document.

Document history

Issue	Date	Confidentiality	Change
0000-06	30 January 2025	Non-Confidential	Revised information on licensing, reference applications described, links to external documents updated.
0000-05	15 July 2024	Non-Confidential	Revised information on licensing, help, and support.
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 μ Vision on Windows and creating applications with μ Vision.
0000-03	23 April 2024	Non-Confidential	Updates

Issue	Date	Confidentiality	Change
0000-02	8 April 2024	Non-Confidential	Updates
0000-01	21 March 2024	Non-Confidential	First release

Change history

For information about the functional changes to the Arm® Keil® Microcontroller Development Kit (MDK), see the Release Notes for each respective product.

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
<i>italic</i>	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: <code>MRC p15, 0, <Rd>, <CRn>, <CRm>, <Opcode_2></code>
SMALL CAPITALS	Terms that have specific technical meanings as defined in the <i>Arm® Glossary</i> . For example, IMPLEMENTATION DEFINED , IMPLEMENTATION SPECIFIC , UNKNOWN , and UNPREDICTABLE .



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



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



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



This information is important and needs your attention.



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



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

Useful resources

This document contains information that is specific to this product. See the following resources for other useful information.

Access to Arm documents depends on their confidentiality:

- Non-Confidential documents are available at developer.arm.com/documentation. Each document link in the following tables goes to the online version of the document.
- Confidential documents are available to licensees only through the product package.

Arm product resources	Document ID	Confidentiality
Arm Keil Studio Cloud CMSIS environment User Guide	109811	Non-Confidential
Arm Keil Studio Cloud User Guide (Classic)	102497	Non-Confidential
Arm Keil Studio Visual Studio Code Extensions User Guide	108029	Non-Confidential
μVision User Guide	101407	Non-Confidential