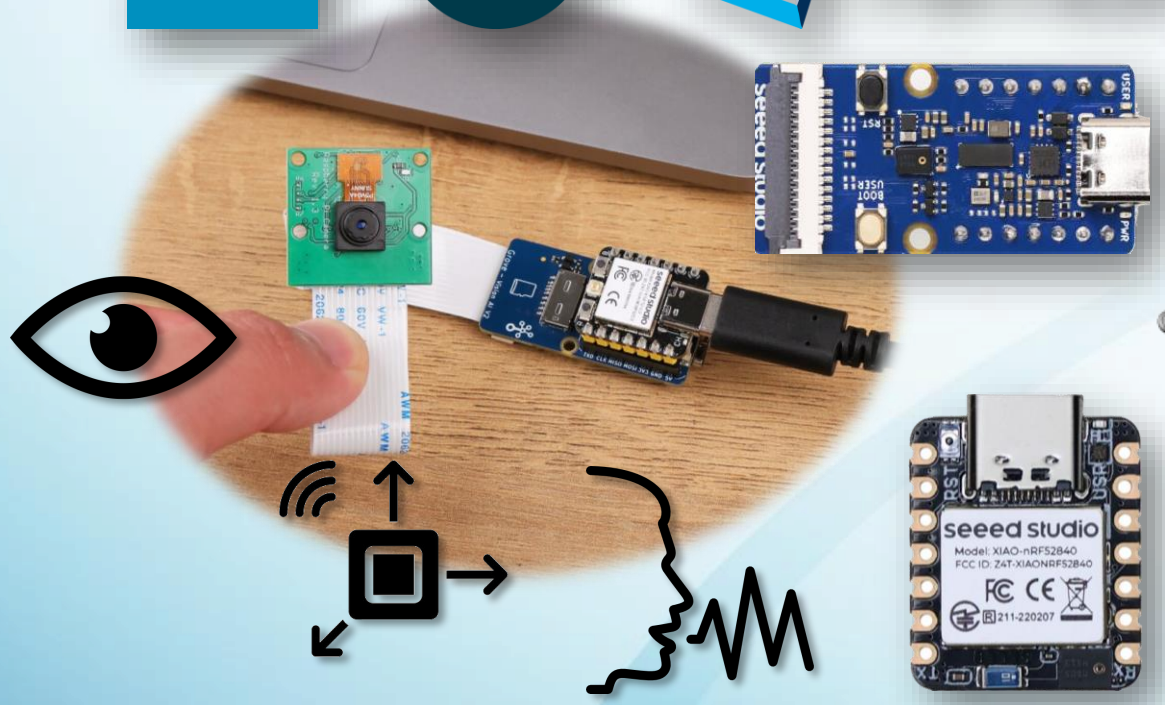
OmniXRI TinyML 小學堂 2025



Cortex-M Processor

Ethos-U MicroNPU

【第 5 講】

通用微控制器軟體介面標準 (CMSIS)

歐尼克斯實境互動工作室 (OmniXRI Studio)
許哲豪 (Jack Hsu)

簡報大綱

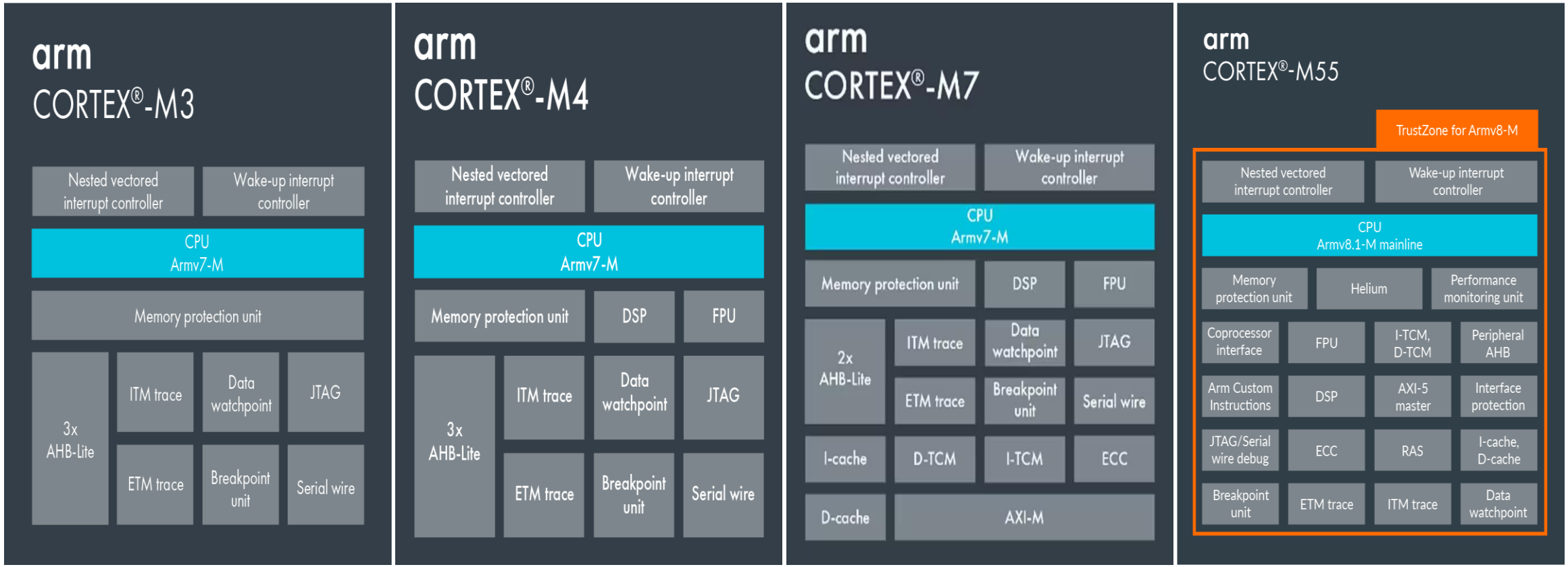
- 5.1. CMSIS 基本介紹
- 5.2. CMSIS-Core & Driver
- 5.3. CMSIS-DSP
- 5.4. CMSIS-NN

本課程完全免費，請勿移作商業用途！
歡迎留言、訂閱、點讚、轉發，讓更多需要的朋友也能一起學習。

完整課程大綱： https://omnixri.blogspot.com/2025/03/omnixri-tinyml-2025-0.html
課程直播清單： https://www.youtube.com/@omnixri1784/streams

5.1. CMSIS 基本介紹

arm Cortex-M 架構差異



MCU 的多樣性
造成開發的問題

矽 智 財：內核不同、週邊不同、記憶體位址不同、安全性不同 …
實體晶片：封裝不同、接腳數不同、電氣性能不同 …
開發工具：IDE不同、程式語言不同、編譯器不同 …

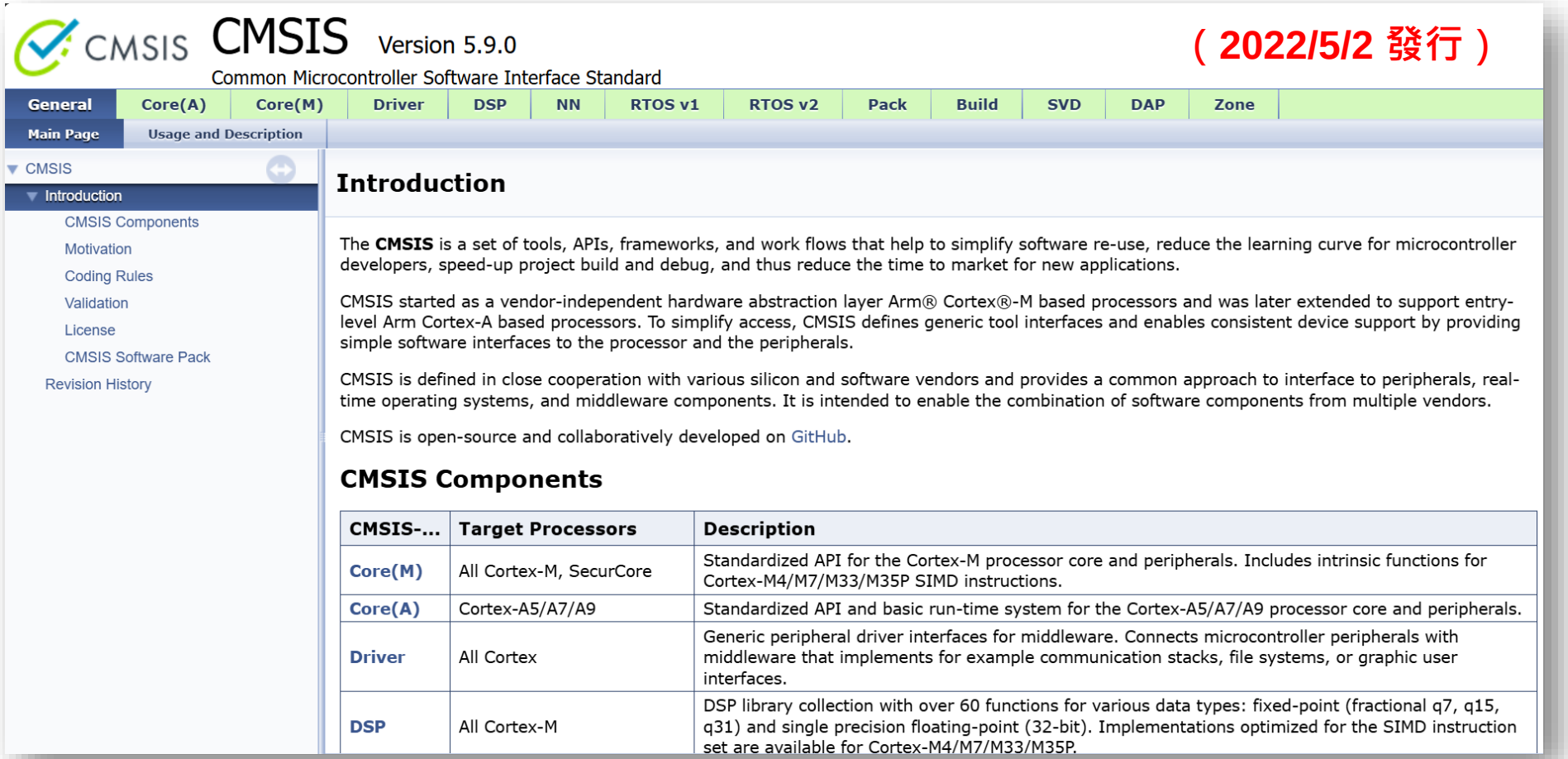
何謂 arm CMSIS

arm Cortex 微控制器（單晶片）軟體介面標準

(Cortex Microcontroller Software Interface Standard, CMSIS)

- 供應商無關之硬體抽象層，提供統一的外部設備（Peripheral, 簡稱外設）軟體介面。
- 符合 ANSI C (C99) 及 C++ (C++03) 語法，支援多種編譯器。
- 提升軟體重用性及移植性、加快學習時間、降低開發成本。

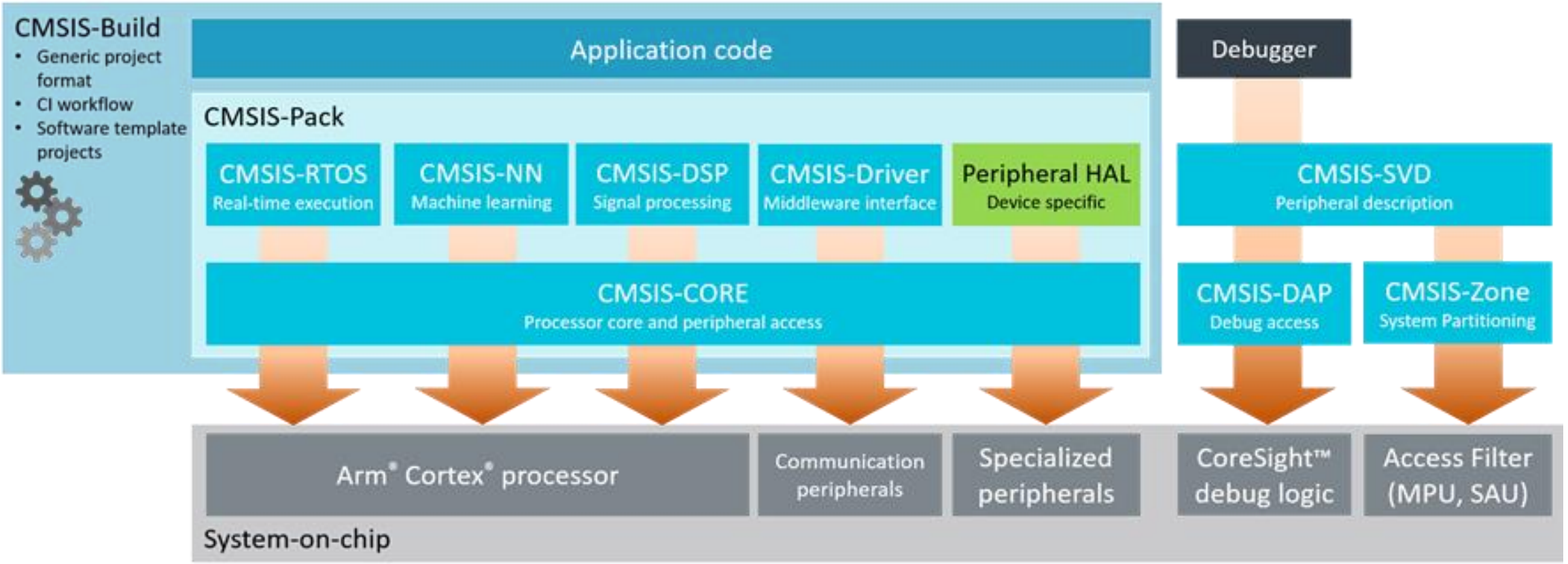
CMSIS-5



Core(A)
Core(M)
Driver
DSP
NN
RTOS v1
RTOS v2
Pack
Build
SVD
DAP
Zone

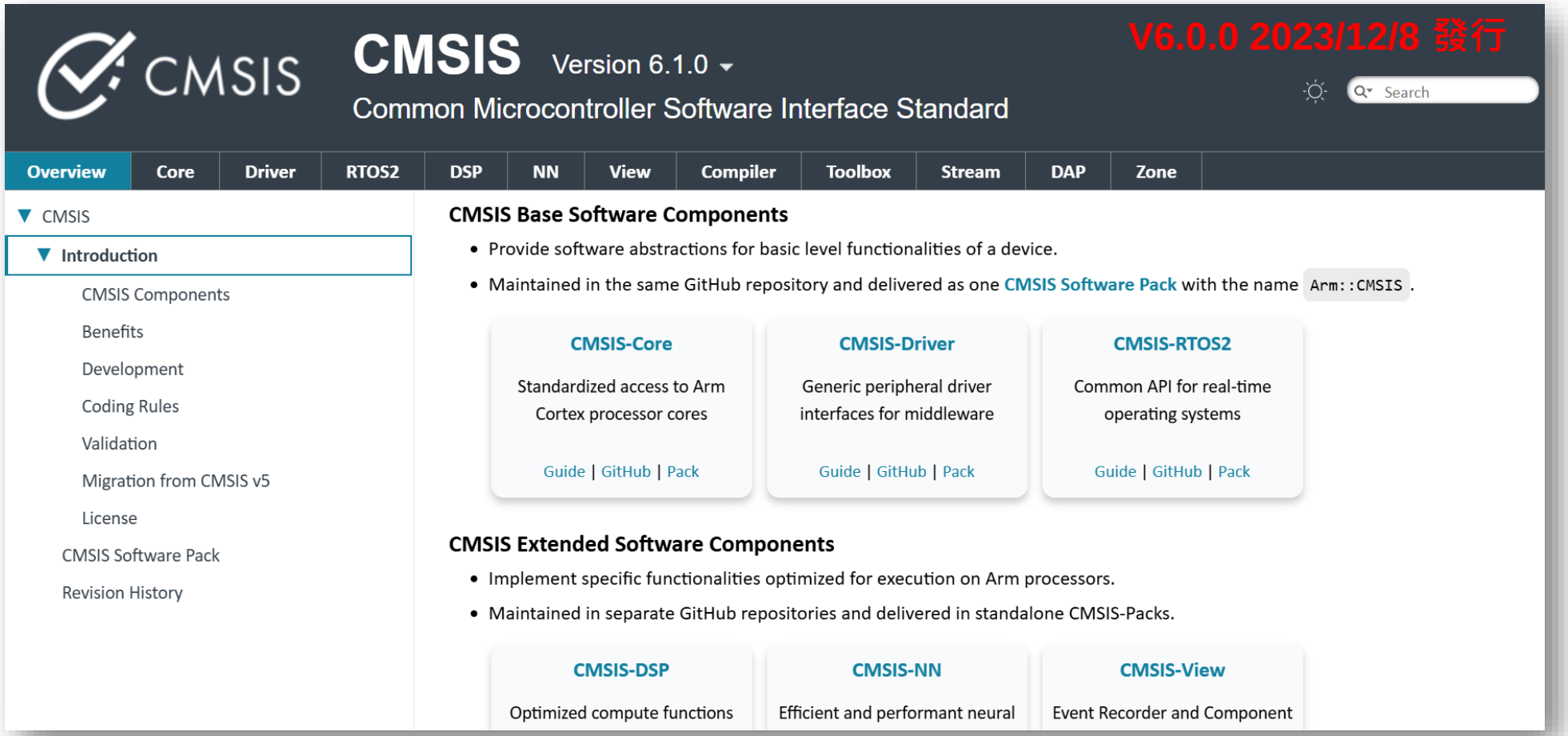
https://arm-software.github.io/CMSIS_5/latest/General/html/index.html

CMSIS-5 架構圖



資料來源：https://arm-software.github.io/CMSIS_5/latest/General/html/index.html

CMSIS-6



Core
Driver
RTOS2
DSP
NN
View
Compiler
Toolbox
Stream
DAP
Zone

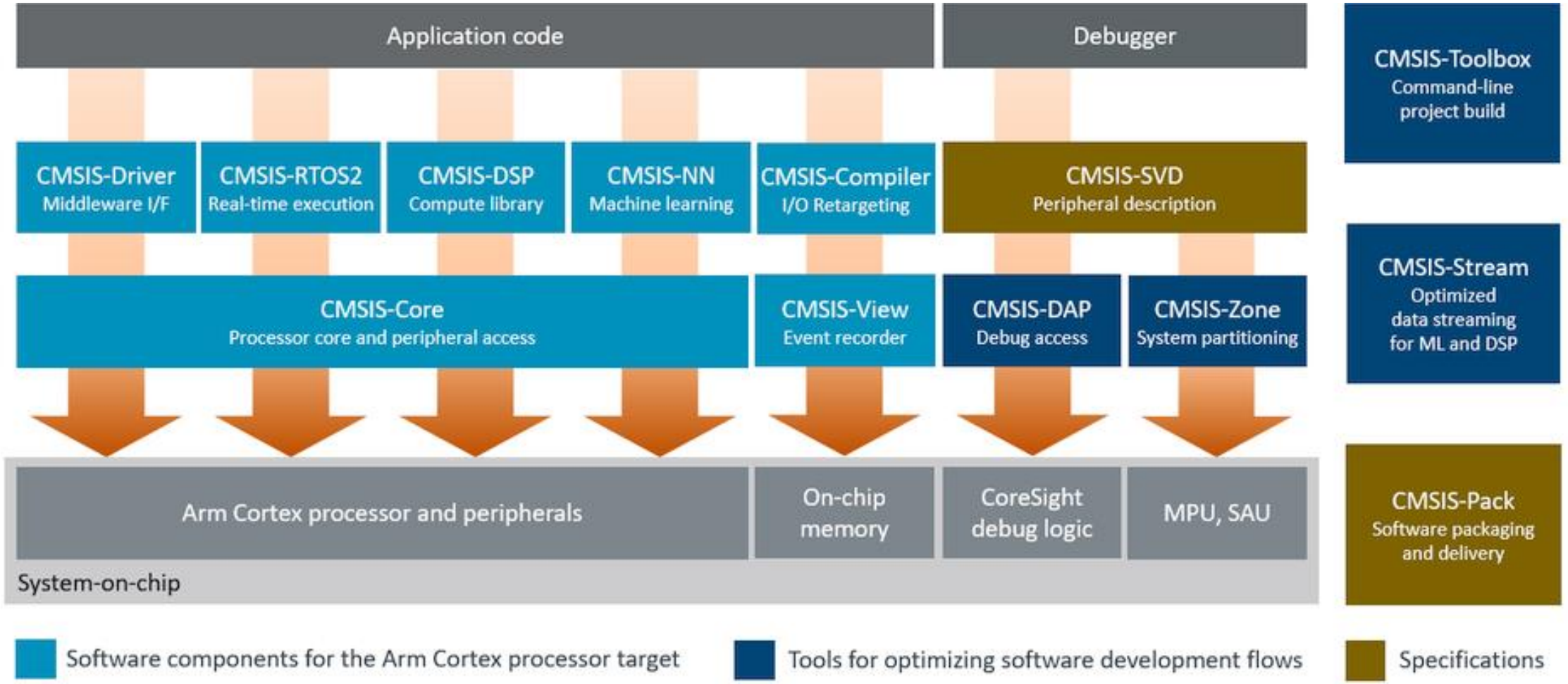
https://arm-software.github.io/CMSIS_6/latest/General/index.html

CMSIS-6 主要元件功能

元件名稱	功能說明	元件名稱	功能說明
Core	對Cortex內核的標準化處理	**Toolbox**	一套用於套件的命令行工具
Driver	中間層通用外設驅動介面	**Stream**	用於優化DSP/ML區塊數據流工具
RTOS2	即時作業系統通用API	**DAP**	連接到除錯埠除錯之韌體
DSP	嵌入式系統最佳化計算函式	**Zone**	定義用於描述系統並分區的方法
NN	高效及高性能神經網路內核	**Pack**	軟體元件和設備支援交付機制
View	事件記錄器及元件觀察器技術	**SVD**	用於除錯設備的外圍設備描述
Compiler	重定向標準C運行時庫的I/O函數		

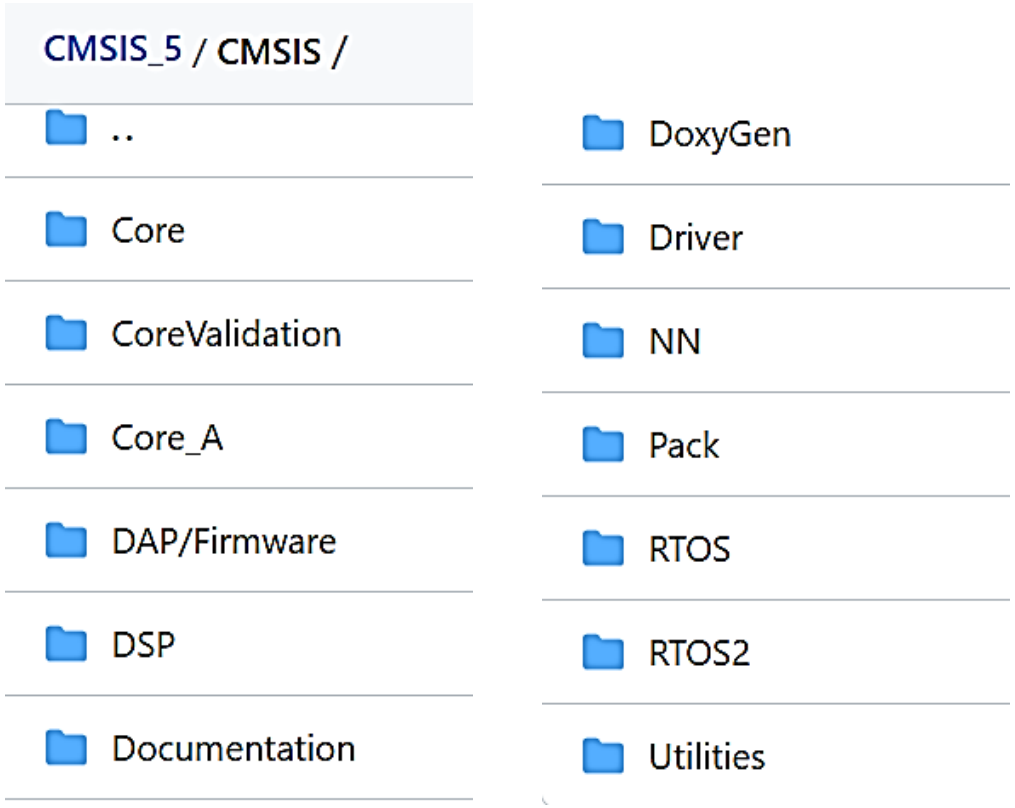
資料來源：https://arm-software.github.io/CMSIS_6/latest/General/index.html

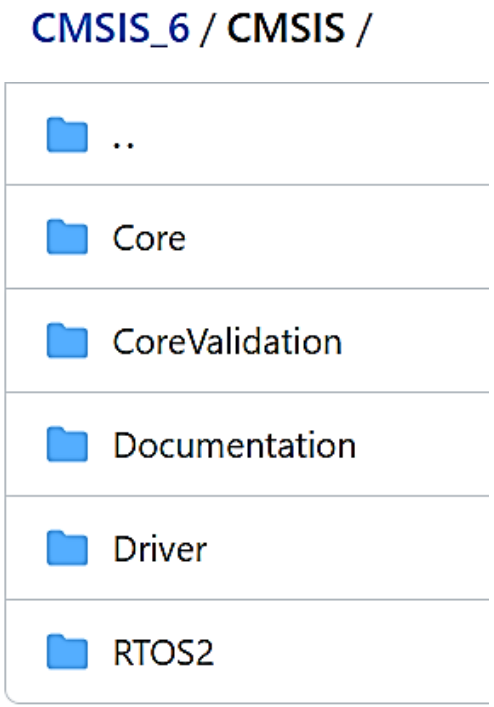
CMSIS-6 架構圖



資料來源：https://arm-software.github.io/CMSIS_6/latest/General/index.html

CMSIS 5 / 6 Github 比較





https://github.com/ARM-software/CMSIS_5/tree/develop/CMSIS

https://github.com/ARM-software/CMSIS_6/tree/main/CMSIS

CMSIS 5 / 6 主要差異

項目	CMSIS-5	CMSIS-6
支持硬體	Cortex-M0,M0+,M3,M4,M7	新增Cortex-M23,M33,M55,M85
安全特性	不支持 TrustZone	原生支持 TrustZone
CMSIS-Pack改進	基礎功能	改進和MDK及其它IDE的整合
DSP & ML	提供基礎DSP, NN功能	擴展NN庫，滿足更複雜模型
工具鏈和兼容性	支援 GCC, IAR, Keil	改善現代工具鏈兼容性便於遷移
配置文件和標準化	基礎設備頭文件及啟動碼	改善設備配置文件更靈活應用

註：大多數應用使用 CMSIS-5 就能滿足，若要應用於 MCU AI 則建議改用 CMSIS-6

5.2. CMSIS-Core & Driver

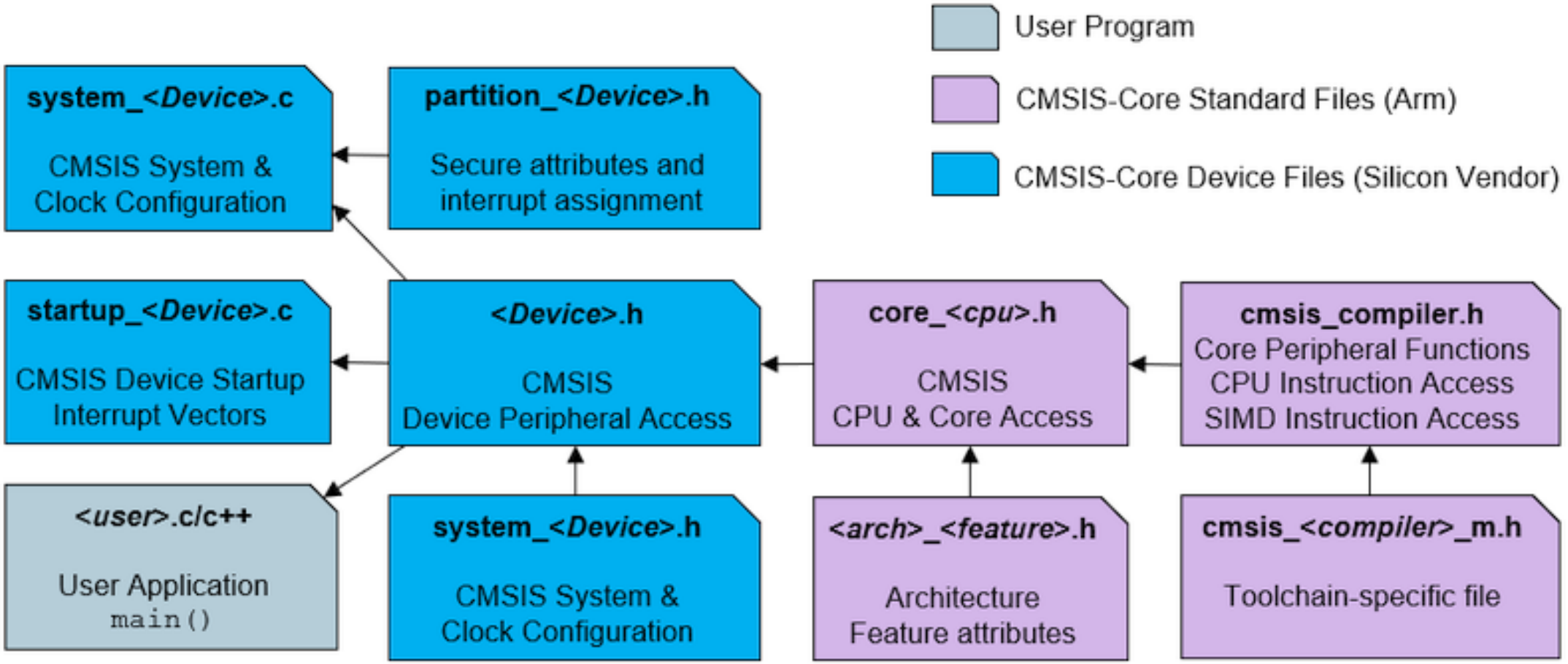
CMSIS-6 Core

CMSIS-Core（Cortex-M）元件實現了 Arm Cortex-M 設備的基本運行時系統，並允許使用者訪問處理器內核(Core)和週邊裝置(Peripherals)。

Directory	Content
CMSIS	CMSIS Base software components folder
├ Documentation/html/Core	A local copy of this CMSIS-Core (M) documentation
└ Core	CMSIS-Core files
├ Include	CMSIS-Core Processor Files.
└ m-profile	Header files specific for Arm M-Profile. See CMSIS-Core Compiler Files and CMSIS-Core Architecture Feature Files.
└ Template	Device Template Files

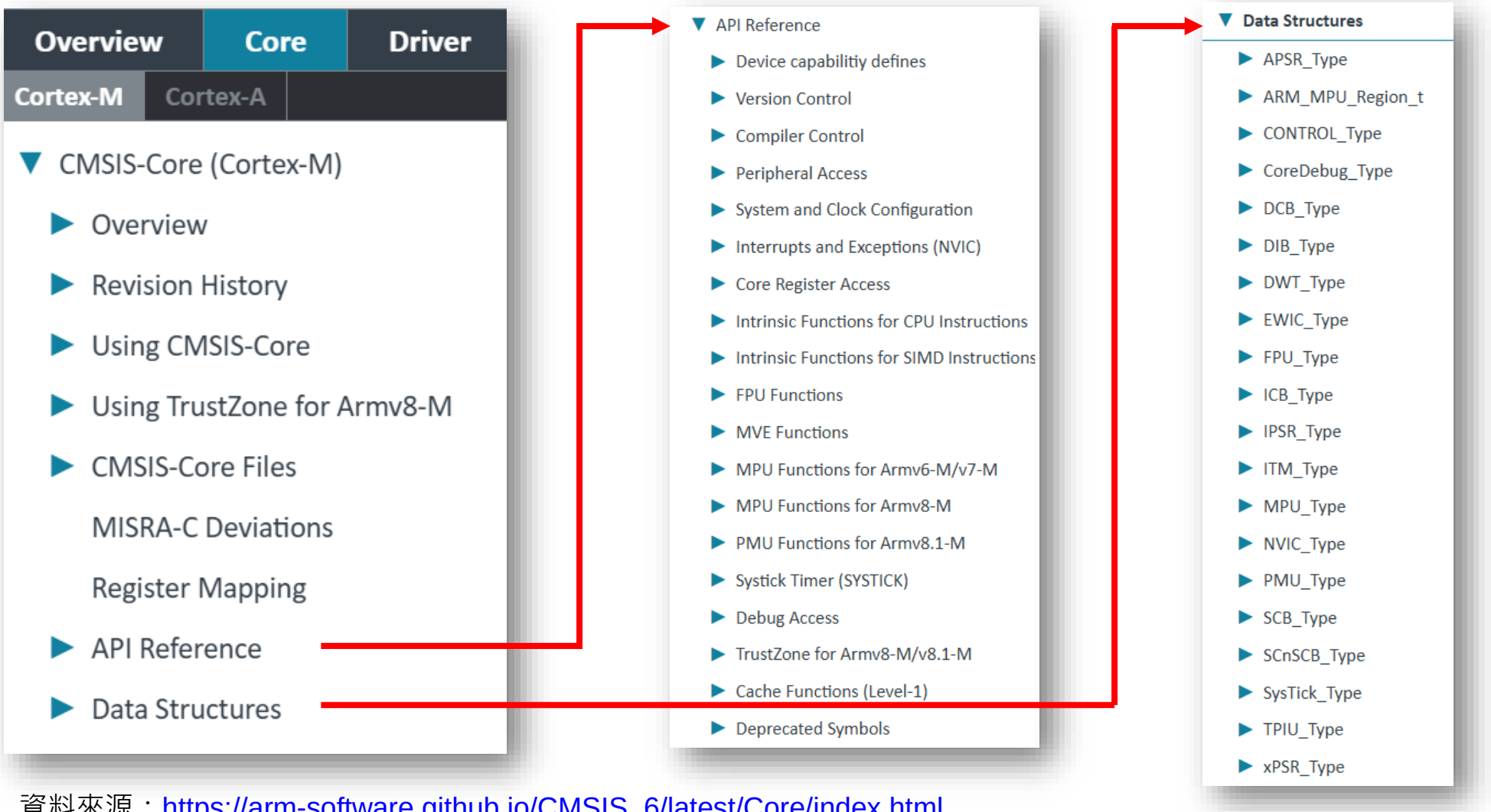
資料來源：https://arm-software.github.io/CMSIS_6/latest/Core/index.html

CMSIS-6 Core 相關檔案



資料來源：https://arm-software.github.io/CMSIS_6/latest/Core/index.html

CMSIS-6 Core 說明文件



資料來源：https://arm-software.github.io/CMSIS_6/latest/Core/index.html

CMSIS-6 Core 範例程式

```c
#include <stm32f10x.h>

uint32_t volatile msTicks;

void SysTick_Handler (void) {
  msTicks++;
}

void WaitForTick (void)  {
  uint32_t curTicks;

  curTicks = msTicks;
  while (msTicks == curTicks)  {
    __WFE ();
  }
}

void TIM1_UP_IRQHandler (void) {
  ;
}

void timer1_init(int frequency) {
  NVIC_SetPriority (TIM1_UP_IRQn, 1);
  NVIC_EnableIRQ (TIM1_UP_IRQn);
}
```

```c
void Device_Initialization (void)  {             // Configure & Initialize MCU
  if (SysTick_Config (SystemCoreClock / 1000)) { // SysTick 1mSec
       : // Handle Error
  }
  timer1_init ();                                // setup device-specific timer
}


// The processor clock is initialized by CMSIS startup + system file
void main (void) {                               // user application starts here
  Device_Initialization ();                      // Configure & Initialize MCU
  while (1)  {                                   // Endless Loop (the Super-Loop)
    __disable_irq ();                            // Disable all interrupts
    Get_InputValues ();                          // Read Values
    __enable_irq ();                             // Enable all interrupts
    Calculation_Response ();                     // Calculate Results
    Output_Response ();                          // Output Results
    WaitForTick ();                              // Synchronize to SysTick Timer
  }
}
```

基於 STM32F10x MCU，使用 CMSIS 範例。

資料來源：https://arm-software.github.io/CMSIS_6/latest/Core/index.html

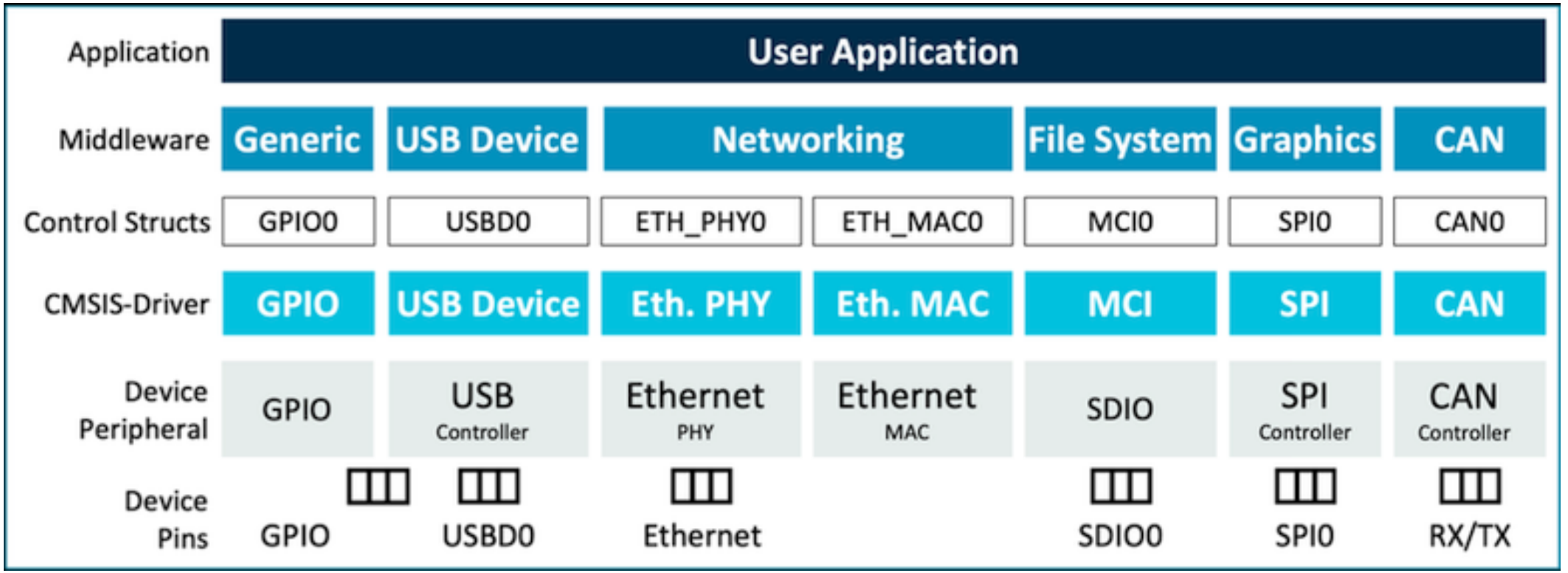
CMSIS-6 Driver

使用者應用程式和中間件元件可以使用 CMSIS-Driver API 控制此類週邊設備，從而在各種生態系統中實現更好的代碼重用和更簡單的集成。

Directory	Content
CMSIS	CMSIS Base software components folder
├ Documentation/html/Driver	A local copy of this CMSIS-Driver documentation
├ Driver	Directory with CMSIS-Driver component, see CMSIS-Driver Files
├ DriverTemplates	Driver Template files (Driver_*interface*.c)
├ Include	API header files (Driver_*interface*.h, Driver_Common.h)
└ VIO	Implementation of virtual Input/Output interface (VIO)

資料來源：https://arm-software.github.io/CMSIS_6/latest/Driver/index.html

CMSIS-6 Driver 架構圖



包括 CAN, Ethernet, I2C, MCI, NAND, Flash, SAI, API, Storage, USART, USB, GPIO, VIO, WiFi 等驅動定義

資料來源：https://arm-software.github.io/CMSIS_6/latest/Driver/index.html

CMSIS-6 Driver 工作流程

中間層軟體

確認 API 版本

獲取驅動特徵

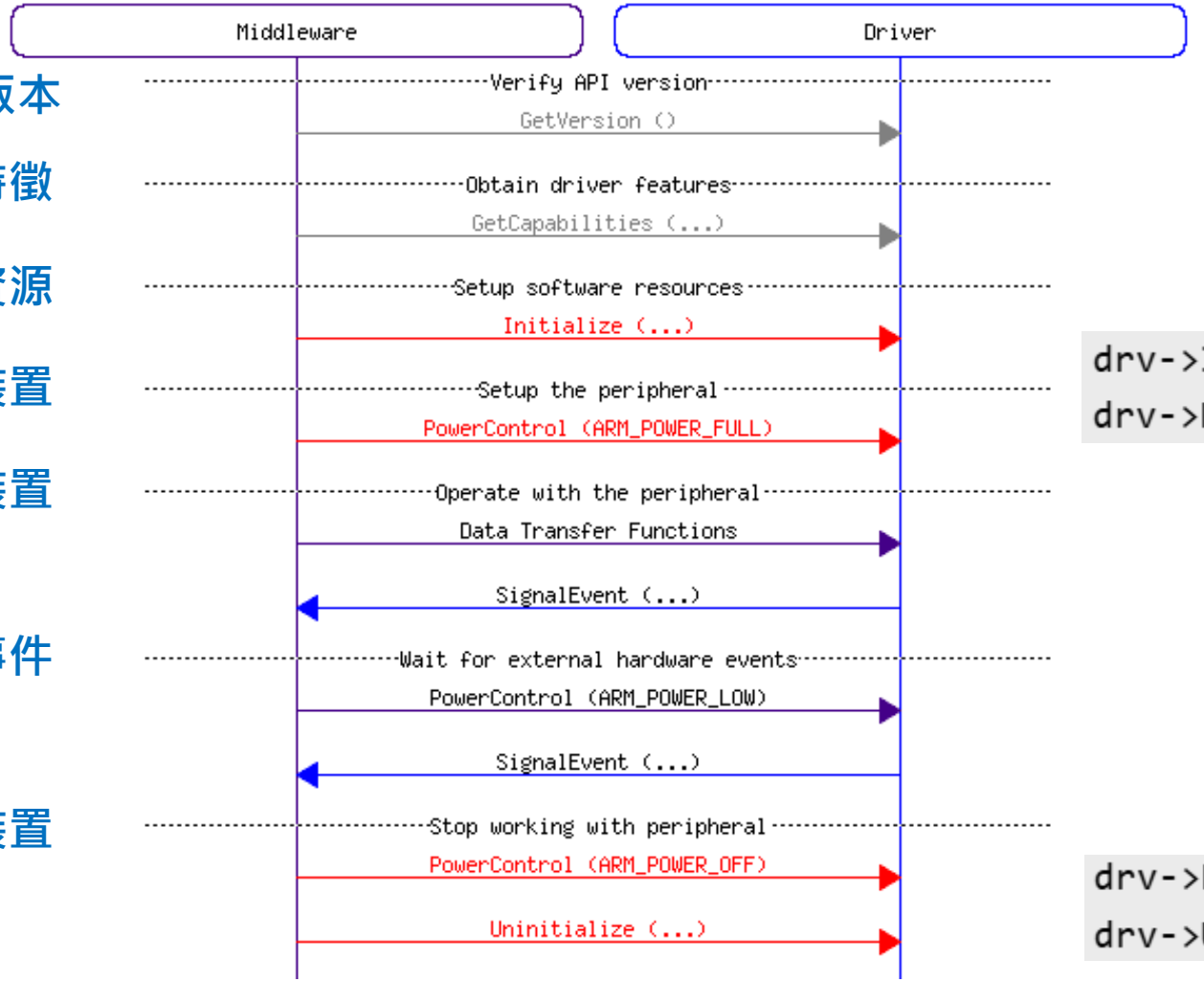
設定軟體資源

設定週邊裝置

操作週邊裝置

等待硬體事件

停止週邊裝置



驅動程式

```
drv->Initialize (...);
drv->PowerControl (ARM_POWER_FULL);
```

```
drv->PowerControl (ARM_POWER_OFF);
drv->Uninitialize (...);
```

資料來源：https://arm-software.github.io/CMSIS_6/latest/Driver/index.html

CMSIS-6 Driver 相關檔案

Header File	Template File	API Reference
Driver_Common.h	Not applicable	Common Driver Definitions
Driver_CAN.h	Driver_CAN.c	CAN Interface
Driver_ETH.h	-	Ethernet Interface
Driver_ETH_MAC.h	Driver_ETH_MAC.c	Ethernet MAC Interface
Driver_ETH_PHY.h	Driver_ETH_PHY.c	Ethernet PHY Interface
Driver_Flash.h	Driver_Flash.c	Flash Interface
Driver_GPIO.h	Driver_GPIO.c	GPIO Interface
Driver_I2C.h	Driver_I2C.c	I2C Interface
Driver_MCI.h	Driver_MCI.c	MCI Interface
Driver_NAND.h	Driver_NAND.c	NAND Interface
Driver_SAI.h	Driver_SAI.c	SAI Interface
Driver_SPI.h	Driver_SPI.c	SPI Interface
Driver_Storage.h	Driver_Storage.c	Storage Interface
Driver_USART.h	Driver_USART.c	USART Interface
Driver_USB.h	-	USB Interface
Driver_USBD.h	Driver_USBD.c	USB Device Interface
Driver_USBH.h	Driver_USBH.c	USB Host Interface
Driver_WiFi.h	Driver_WiFi.c	WiFi Interface

資料來源：https://arm-software.github.io/CMSIS_6/latest/Driver/index.html

CMSIS-6 Driver – GPIO 為例

CMSIS_6 / CMSIS / Driver / Include / **Driver_GPIO.h**

Code | Blame | 154 lines (127 loc) · 5.49 KB

```
37   */
38   typedef uint32_t ARM_GPIO_Pin_t;
39
40   /**
41   \brief GPIO Direction
42   */
43   typedef enum {
44     ARM_GPIO_INPUT,                ///< Input (default)
45     ARM_GPIO_OUTPUT                ///< Output
46   } ARM_GPIO_DIRECTION;
47
48   /**
49   \brief GPIO Output Mode
50   */
51   typedef enum {
52     ARM_GPIO_PUSH_PULL,            ///< Push-pull (default)
53     ARM_GPIO_OPEN_DRAIN            ///< Open-drain
54   } ARM_GPIO_OUTPUT_MODE;
55
56   /**
57   \brief GPIO Pull Resistor
58   */
59   typedef enum {
60     ARM_GPIO_PULL_NONE,            ///< None (default)
61     ARM_GPIO_PULL_UP,              ///< Pull-up
62     ARM_GPIO_PULL_DOWN             ///< Pull-down
63   } ARM_GPIO_PULL_RESISTOR;
```

GPIO方向

GPIO輸出模式

GPIO上拉電阻

CMSIS_6 / CMSIS / Driver / DriverTemplates / **Driver_GPIO.c**

Code | Blame | 154 lines (130 loc) · 3.37 KB

```
19   #include "Driver_GPIO.h"
20
21   // Pin mapping
22   #define GPIO_MAX_PINS           64U
23   #define PIN_IS_AVAILABLE(n)     ((n) < GPIO_MAX_PINS)
24
25
26   // Setup GPIO Interface
27   static int32_t GPIO_Setup (ARM_GPIO_Pin_t pin, ARM_GPIO_SignalEvent_t cb_event) {
28     int32_t result = ARM_DRIVER_OK;
29
30     if (PIN_IS_AVAILABLE(pin)) {
31     } else {
32       result = ARM_GPIO_ERROR_PIN;
33     }
34
35     return result;
36   }
37
38   // Set GPIO Direction
39   static int32_t GPIO_SetDirection (ARM_GPIO_Pin_t pin, ARM_GPIO_DIRECTION direction) {
40     int32_t result = ARM_DRIVER_OK;
41
42     if (PIN_IS_AVAILABLE(pin)) {
43       switch (direction) {
44         case ARM_GPIO_INPUT:
45           break;
```

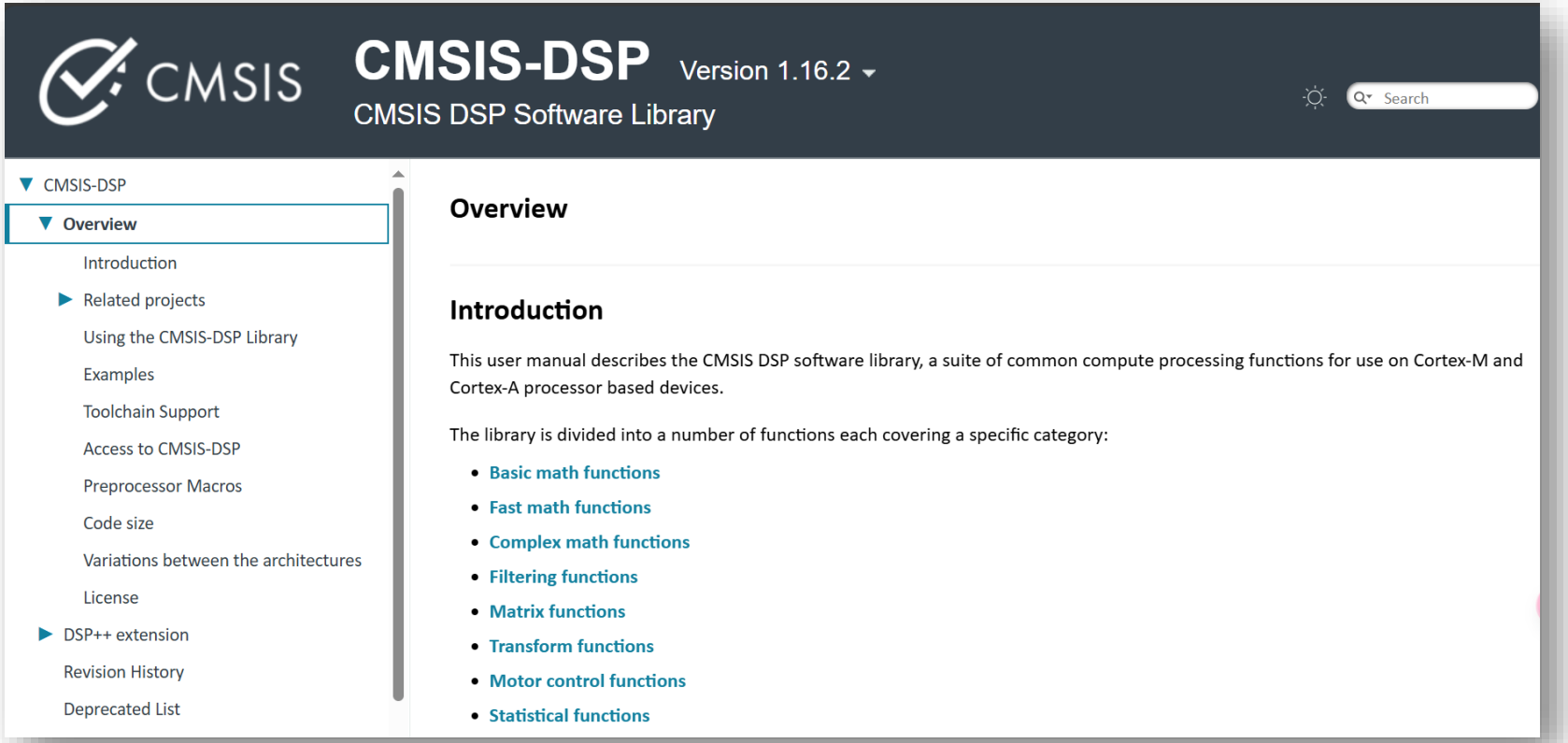
設定GPIO介面

設定GPIO方向

5.3. CMSIS-DSP

CMSIS-6 DSP

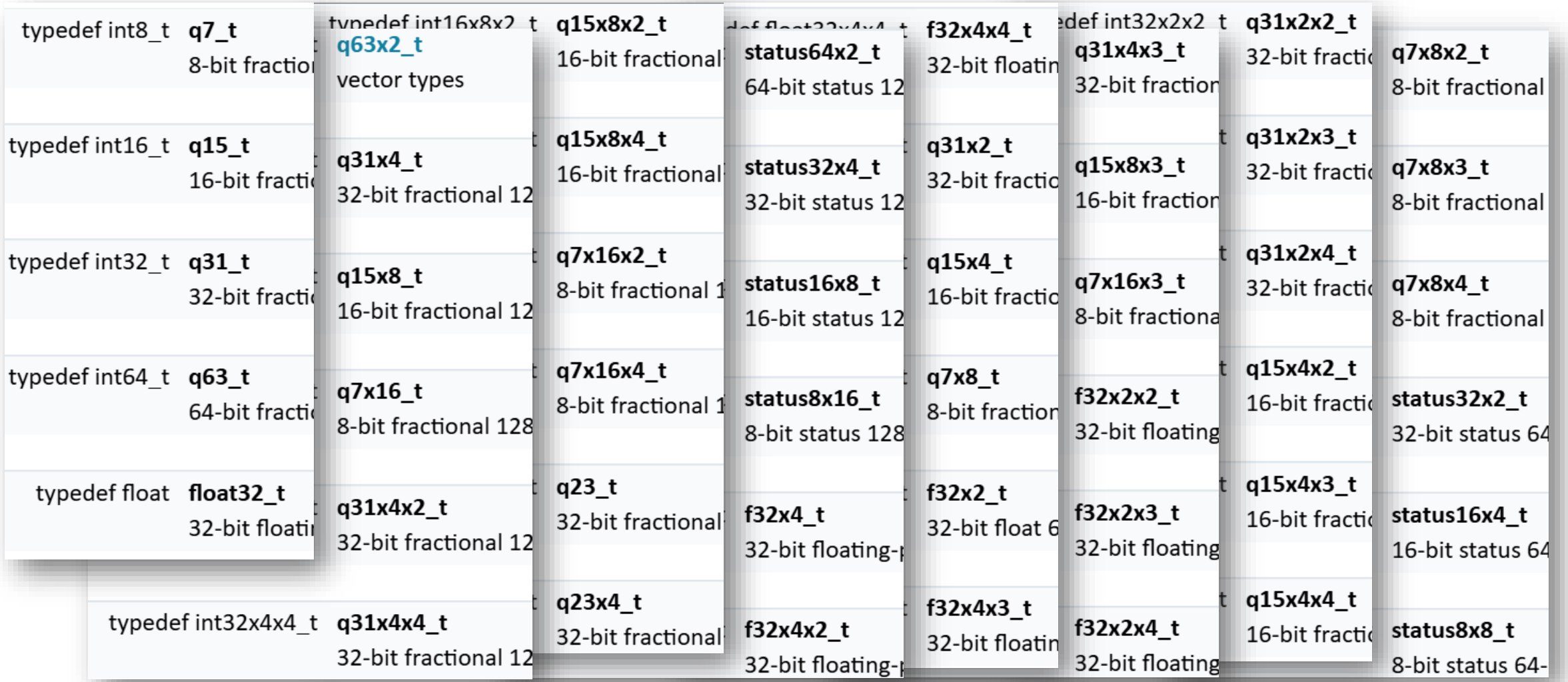
CMSIS-DSP 是一個開源軟體庫（在Github已獨立），可實現針對 Arm Cortex-M 和 Cortex-A 處理器進行了優化的常見計算處理功能。



- 基本數學函數
- 快速數學函數
- 複數數學函數
- 濾波器函數
- 矩陣函數
- 變換函數
- 馬達控制函數
- 統計函數
- 支援函數
- 插值函數
- 支持向量機函數
- 貝葉斯分類器函數
- 距離函數
- 四元數函數
- 視窗函數

資料來源：https://arm-software.github.io/CMSIS-DSP/latest/

CMSIS-6 DSP – 通用格式



資料來源：https://arm-software.github.io/CMSIS-DSP/latest/

CMSIS-6 DSP – 數學函數

基本數學函式

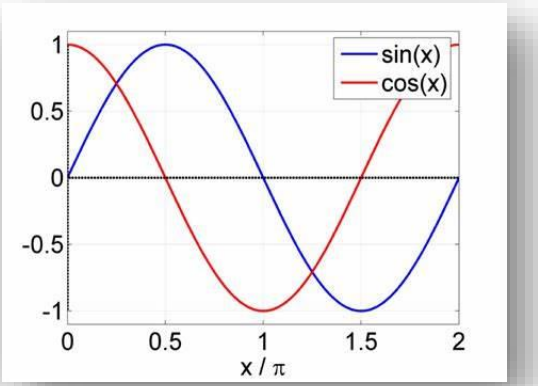
Vector Absolute Value
Vector Addition
Vector bitwise AND
Elementwise clipping
Vector Dot Product
Vector Multiplication
Vector Negate
Vector bitwise NOT
Vector Offset
Vector bitwise inclusive OR
Vector Scale
Vector Shift
Vector Subtraction
Vector bitwise exclusive OR

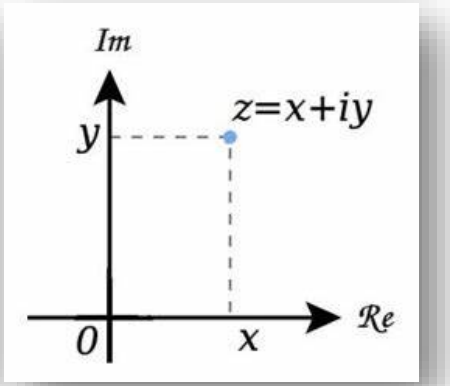
快速數學函式

ArcTan2
Cosine
Fixed point division
Sine
Vector Exponential
Vector Log
Square Root

複數數學函式

Complex Conjugate
Complex Dot Product
Complex Magnitude
Complex Magnitude Squared
Complex-by-Complex Multiplication
Complex-by-Real Multiplication

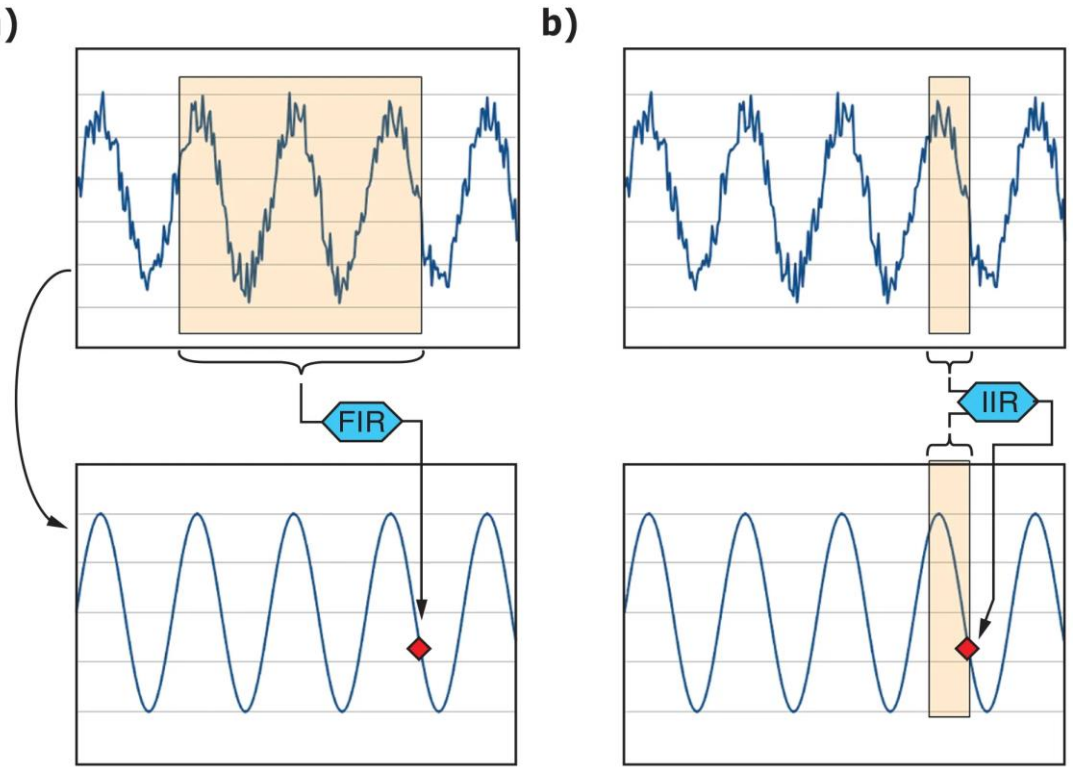




資料來源：https://arm-software.github.io/CMSIS_6/latest/DSP/index.html

CMSIS-6 DSP – 濾波器函數

High Precision Q31 Biquad Cascade Filter
Biquad Cascade IIR Filters Using Direct Form I Structure
Biquad Cascade IIR Filters Using a Direct Form II Transposed Structure
Convolution
Partial Convolution
Correlation
Finite Impulse Response (FIR) Decimator
Finite Impulse Response (FIR) Filters
Finite Impulse Response (FIR) Lattice Filters
Finite Impulse Response (FIR) Sparse Filters
Infinite Impulse Response (IIR) Lattice Filters
Levinson Durbin Algorithm
Least Mean Square (LMS) Filters
Normalized LMS Filters
Finite Impulse Response (FIR) Interpolator



資料來源：https://arm-software.github.io/CMSIS_6/latest/DSP/index.html

CMSIS-6 DSP – 矩陣函式

Householder transform of a vector

Matrix Addition

Cholesky and LDLT decompositions

Complex Matrix Multiplication

Complex Matrix Transpose

Matrix Initialization

Matrix Inverse

Matrix Multiplication

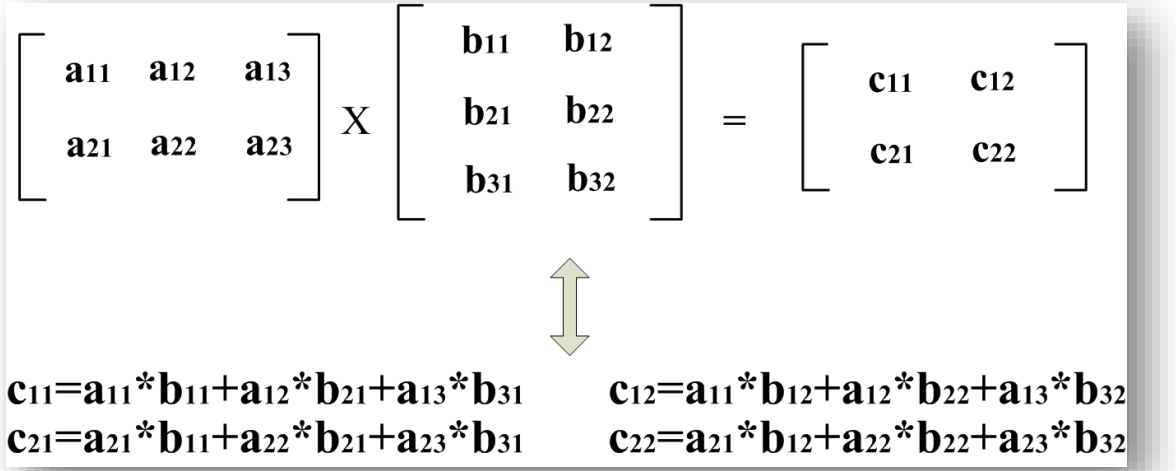
QR decomposition of a Matrix

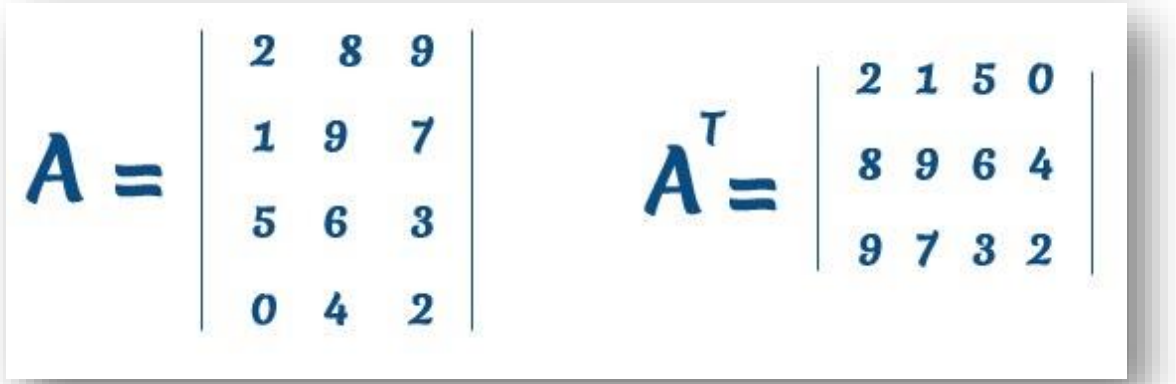
Matrix Scale

Matrix Subtraction

Matrix Transpose

Matrix Vector Multiplication





資料來源：https://arm-software.github.io/CMSIS_6/latest/DSP/index.html

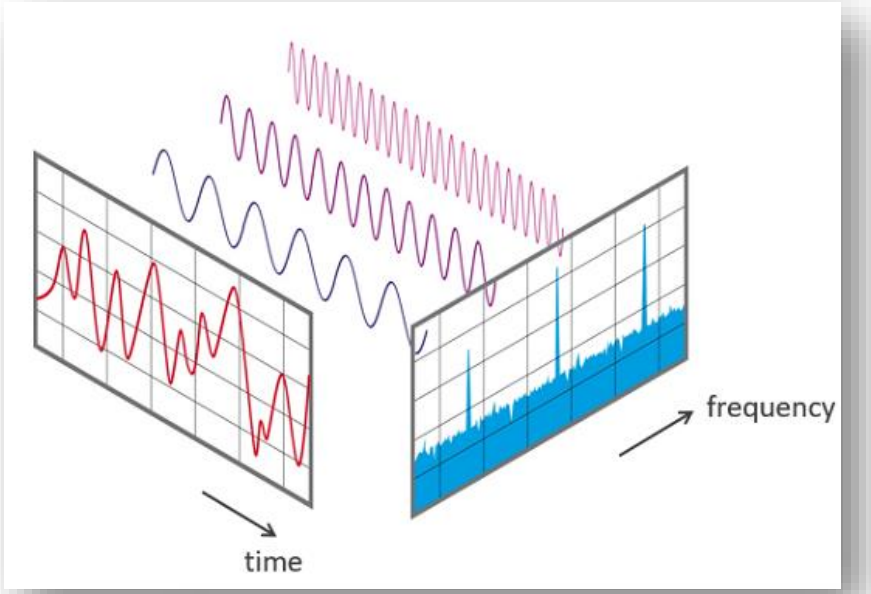
CMSIS-6 DSP – 變換函式

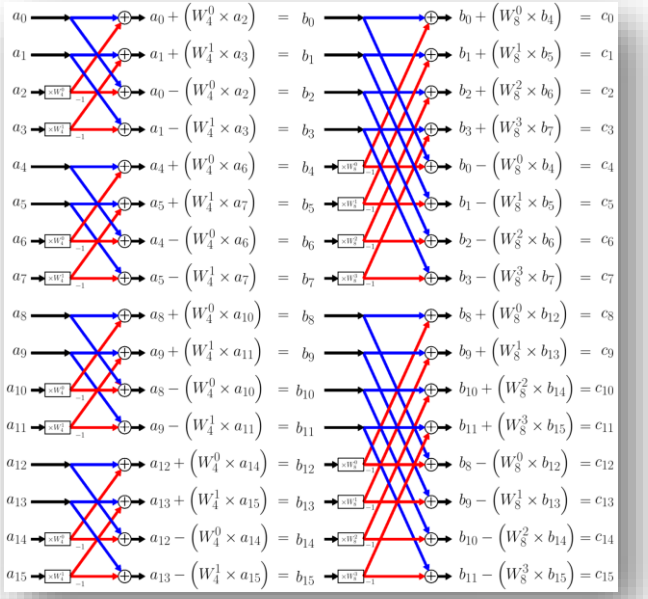
Complex FFT Functions

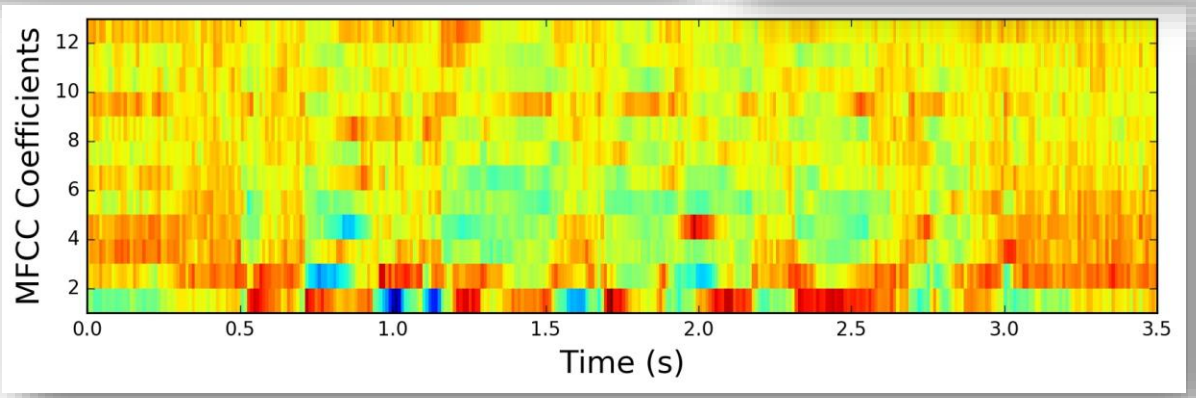
DCT Type IV Functions

MFCC

Real FFT Functions







資料來源：https://arm-software.github.io/CMSIS_6/latest/DSP/index.html

CMSIS 5 / 6 DSP 比較

主要函數差異不大，CMSIS-6 新增部份函數。

[+] New [-] Remove

Functions	CMSIS v5 (DSP v1.10.0)	v6 (DSP v1.15.0)
Basic math	Vector Absolute Value Vector Addition Vector bitwise AND Elementwise clipping Vector Dot Product Vector Multiplication Vector Negate Vector bitwise NOT Vector Offset Vector Scale Vector Shift Vector Subtraction Vector bitwise inclusive OR Vector bitwise exclusive OR	
Bayes classifier	gaussian_naive_bayes_predict	
Complex math	Complex Conjugate Complex Dot Product Complex Magnitude Complex Magnitude Squared Complex-by-Complex Multiplication Complex-by-Real Multiplication	
Controller	PID Motor Control Vector Park Transform Vector Inverse Park transform Vector Clarke Transform Vector Inverse Clarke Transform Sine Cosine	
Distance	Float Distances Boolean Distances	
Fast math	ArcTan2 Cosine Fixed point division Sine Vector Log Square Root	[+] Vector Exponential
Filtering	Biquad Cascade IIR Filters Using Direct Form I Structure Biquad Cascade IIR Filters Using a Direct Form II Transposed Structure Convolution Partial Convolution Correlation Levinson Durbin Algorithm Least Mean Square (LMS) Filters Normalized LMS Filters High Precision Q31 Biquad Cascade Filter Finite Impulse Response (FIR) Decimator Finite Impulse Response (FIR) Filters Finite Impulse Response (FIR) Lattice Filters Finite Impulse Response (FIR) Sparse Filters Infinite Impulse Response (IIR) Lattice Filters Finite Impulse Response (FIR) Interpolator	
Interpolation	Bilinear Interpolation Linear Interpolation Cubic Spline Interpolation	
Matrix	Matrix Addition Matrix Initialization Matrix Inverse Matrix Multiplication Matrix Scale Matrix Subtraction Matrix Transpose Cholesky and LDLT decompositions Complex Matrix Multiplication Complex Matrix Transpose Matrix Vector Multiplication	[+] Householder transform of a vector [+] QR decomposition of a Matrix
Quaternion	Quaternion conversions Quaternion Conjugate Quaternion Inverse Quaternion Norm Quaternion normalization Quaternion Product	
Statistical	Absolute Maximum Absolute Minimum Entropy LogSumExp Maximum Mean Minimum Power Variance Mean Square Error Kullback-Leibler divergence Root mean square (RMS) Standard deviation	[+] Accumulation functions
Support	Typecasting Barycenter Vector Copy Vector Fill Weighted Sum Vector sorting algorithms Convert 16-bit floating point value Convert 32-bit floating point value Convert 16-bit fixed point value Convert 32-bit fixed point value Convert 8-bit fixed point value	[+] Convert 64-bit floating point value
SVM	Linear SVM Polynomial SVM RBF SVM Sigmoid SVM	
Transform	Complex FFT Functions DCT Type IV Functions MFCC Real FFT Functions	
Window	none	[+] Flat-top window [+] Regular windos

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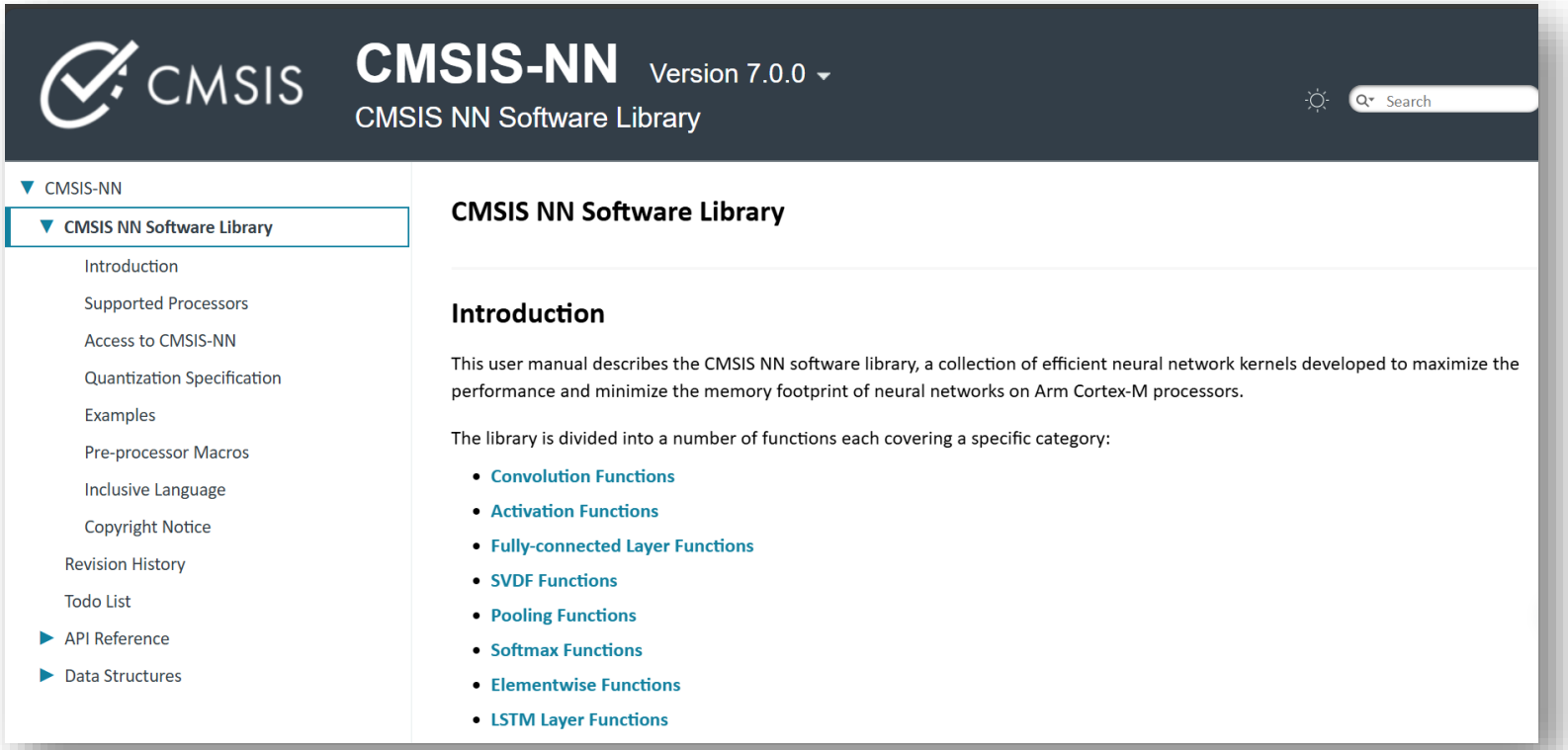
資料來源：https://omnixri.blogspot.com/2024/02/tinyml-arm-cmsis-6-dsp-nn.html

5.4. CMSIS-NN

CMSIS-6 NN

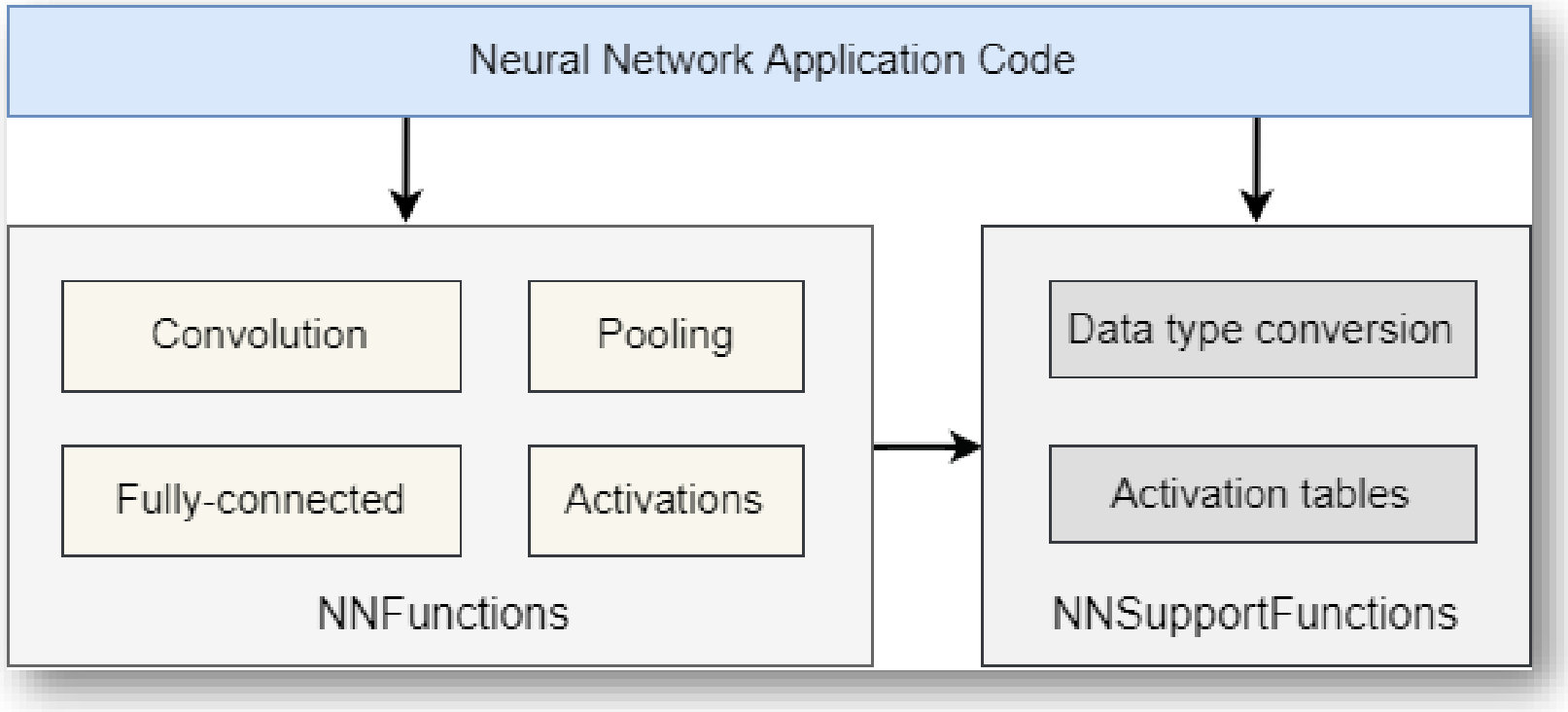
CMSIS-NN 是一個開源軟體庫（在Github已獨立），它提供了一組高效的神經網路（NN）內核，這些內核旨在最大限度地提高在 Arm Cortex-M 處理器上運行的神經網路的性能並最大限度地減少記憶體佔用。



- 卷積函數
- 激勵函數
- 全連結層函數
- SVDF函數
- 池化函數
- Softmax函數
- 元素級別函式
- LSTM函數

資料來源：https://arm-software.github.io/CMSIS-NN/latest/

CMSIS-6 NN 架構圖



CMSIS-NN 可支援

- 沒有SIMD指令的處理器，如 Cortex-M0/0+
- 帶有DSP擴展指令的處理器，如 Cortex-M4/M7
- 帶有MVE指令的處理器，如 Cortex-M55/M85
- **不直接支援 MicroNPU Ehtos-U55/U65/U85**
- **不使用 CMSIS-NN 也可以使用傳統指令集執行相關計算，只是速度較慢。**

資料來源：https://arm-software.github.io/CMSIS-NN/latest/

CMSIS-6 NN – 卷積函式

arm_convolve_**XXX**

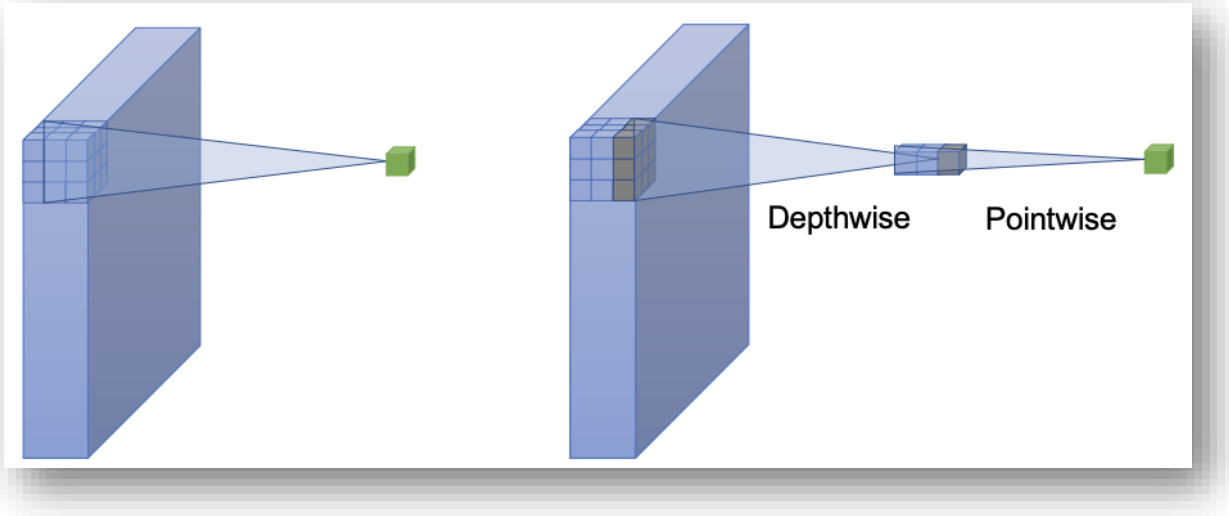
- **1_x_n_s4, 1_x_n_s8, 1x1_s4, 1x1_s4_fast, 1x1_s8, 1x1_s8_fast, even_s4, s16, s4, s8, wrapper_s16, wrapper_s4, wrapper_s8**

arm_depthwise_conv_**XXX**

- **3x3_s8, fast_s16, s16, s4, s4_opt, s8, s8_opt, wrapper_s16, wrapper_s4, wrapper_s8**

arm_transpose_conv_**XXX**

- **s8, wrapper_s8**



資料來源：https://arm-software.github.io/CMSIS-NN/latest/

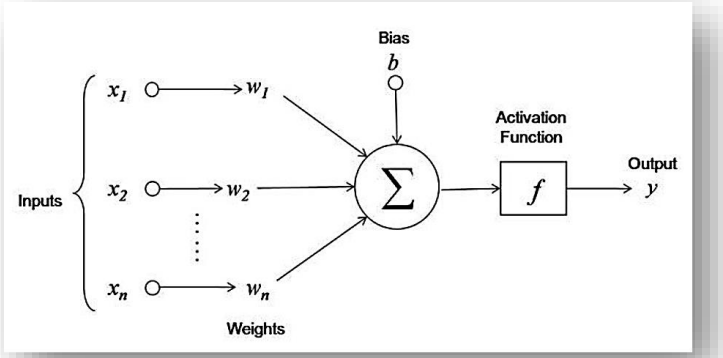
CMSIS-6 NN – 激勵函式

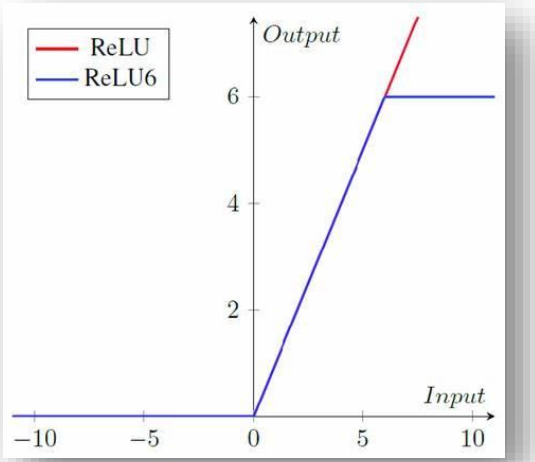
arm_nn_activation_s16 (ARM_SIGMOID, ARM_TANH)

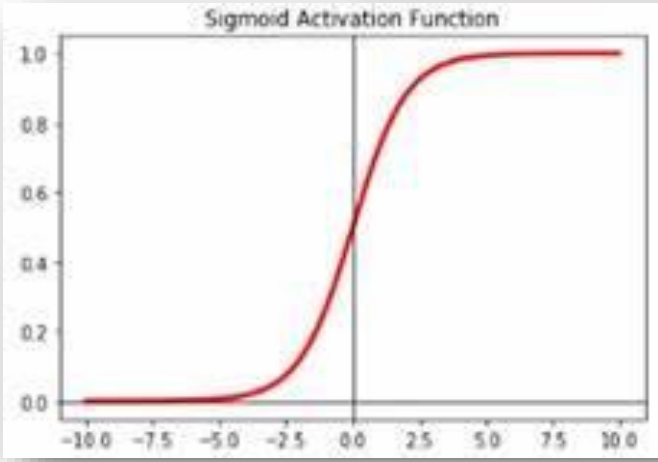
arm_relu6_s8

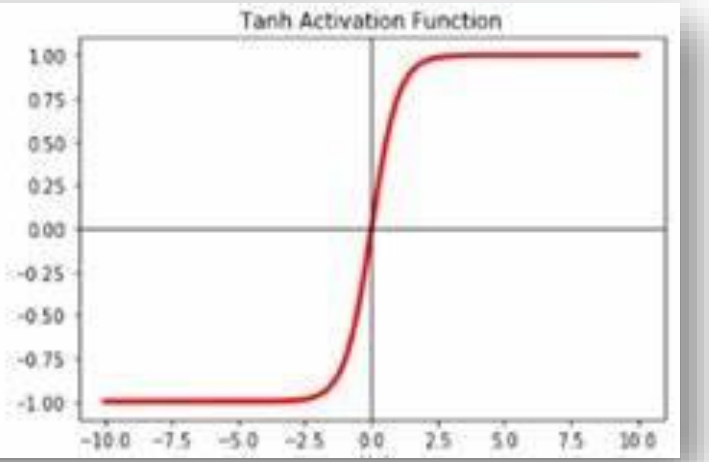
arm_relu_q15

arm_relu_q7









資料來源：https://arm-software.github.io/CMSIS-NN/latest/

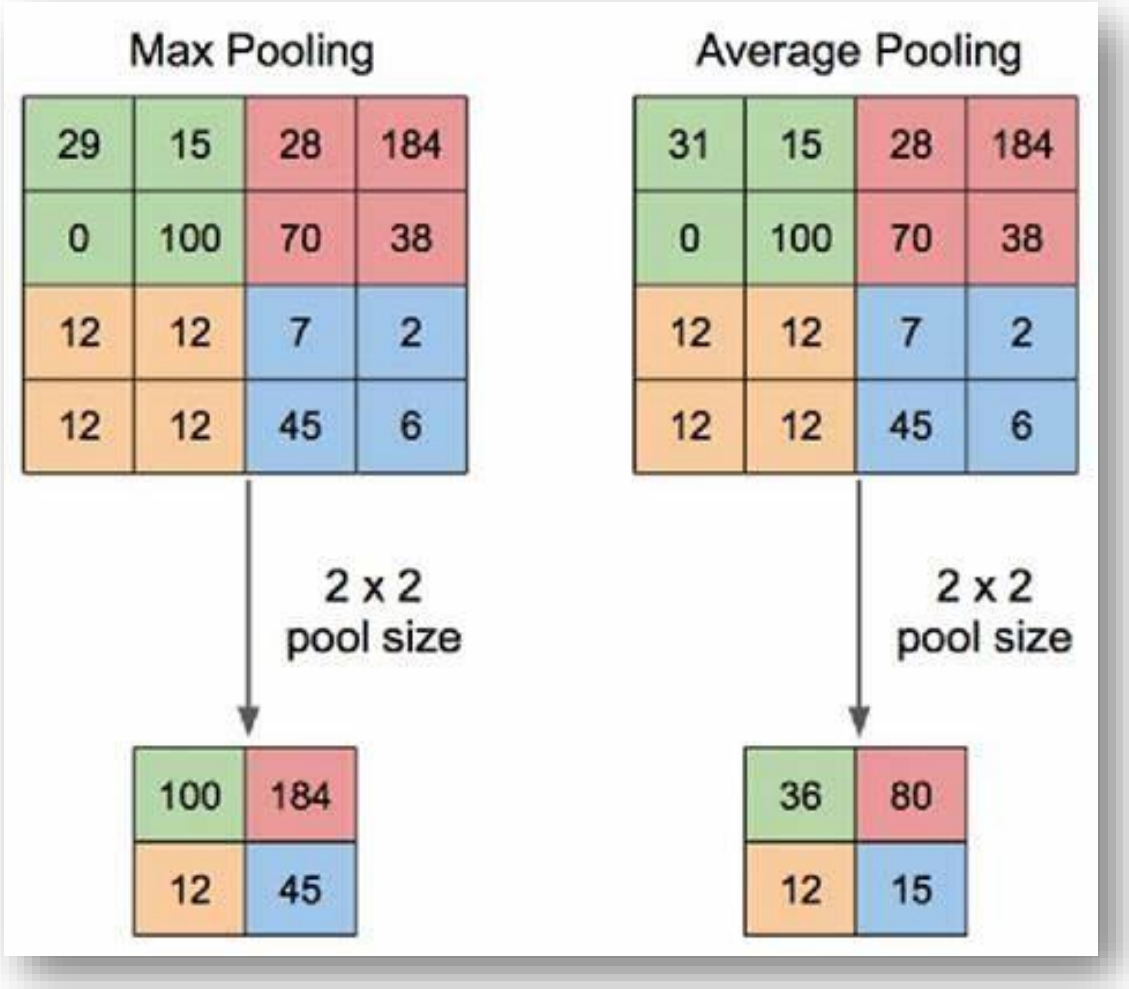
CMSIS-6 NN – 池化函式

arm_avgpool_s16

arm_avgpool_s8

arm_max_pool_s16

arm_max_pool_s8



資料來源：https://arm-software.github.io/CMSIS-NN/latest/

CMSIS-6 NN – 全連結層函式

arm_batch_matmul_s16

arm_batch_matmul_s8

arm_fully_connected_per_channel_s8

arm_fully_connected_s16

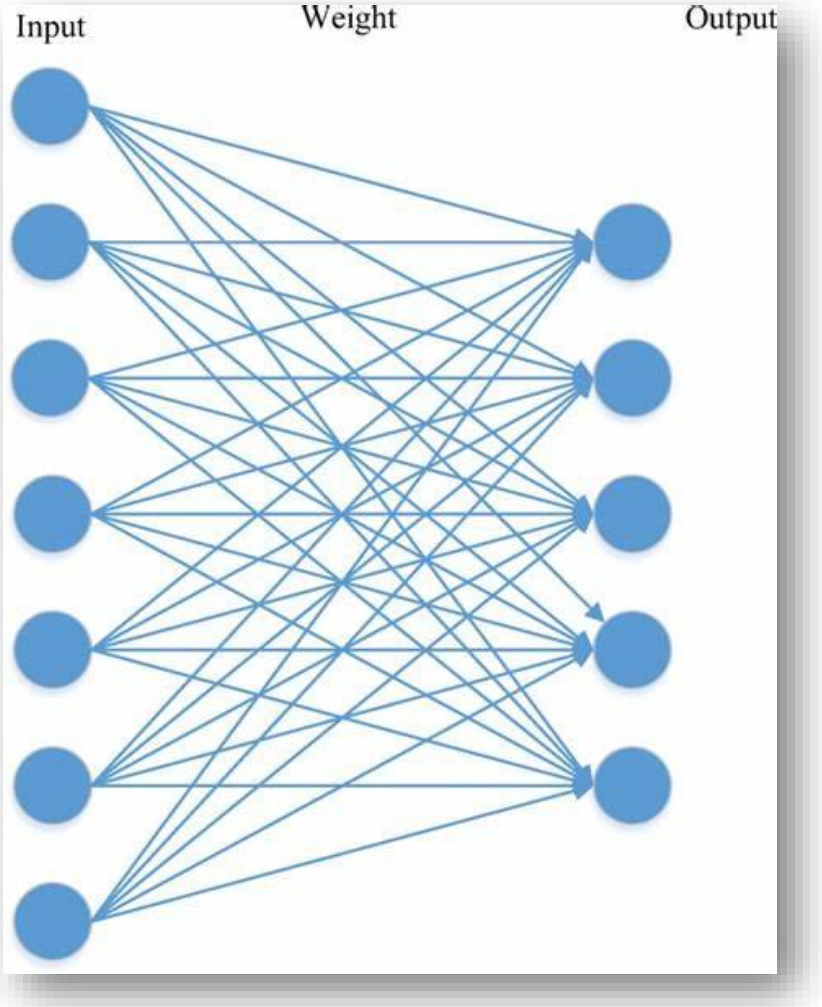
arm_fully_connected_s4

arm_fully_connected_s8

arm_fully_connected_wrapper_s8

arm_vector_sum_s8

arm_vector_sum_s8_s64



資料來源：https://arm-software.github.io/CMSIS-NN/latest/

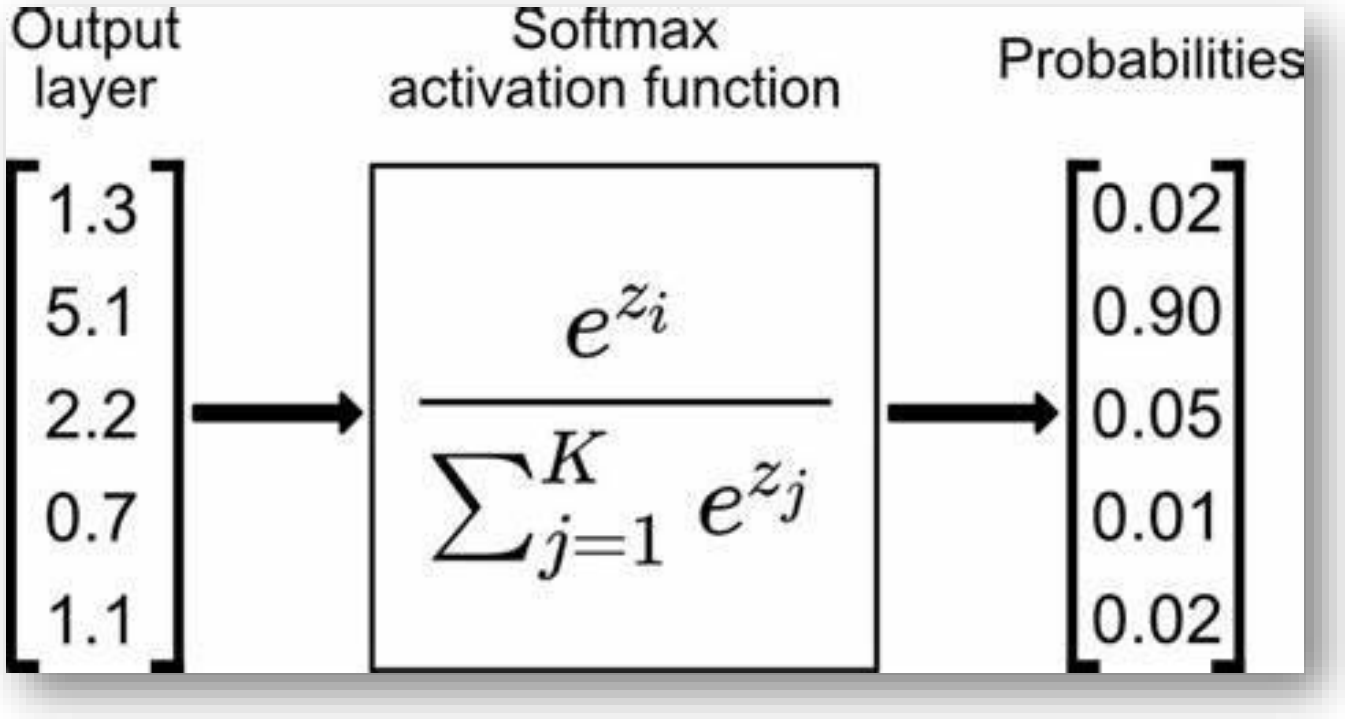
CMSIS-6 NN – Softmax函式

arm_softmax_s16

arm_softmax_s8

arm_softmax_s8_s16

arm_softmax_u8



資料來源：https://arm-software.github.io/CMSIS-NN/latest/

CMSIS 5 / 6 NN 比較

[+] New [-] Remove [*] private

Functions	CMSIS v5 (NN v3.1.0)		v6 (NN 5.0.0)
Activation	arm_nn_activations_direct_q15 arm_nn_activations_direct_q7	arm_relu6_s8 arm_relu_q15 arm_relu_q7	[+] ..._activation_s16
Basic math	arm_elementwise_add_s16 arm_elementwise_add_s8	arm_elementwise_mul_s16 arm_elementwise_mul_s8	Rename [Elementwise]
Concatenation	arm_concatenation_s8_w arm_concatenation_s8_x	arm_concatenation_s8_y arm_concatenation_s8_z	
Fully-connected	arm_fully_connected_mat_q7_vec_q15 arm_fully_connected_q15 arm_fully_connected_q7 arm_fully_connected_s16 arm_fully_connected_s8	arm_fully_connected_mat_q7_vec_q15_opt arm_fully_connected_q15_opt arm_fully_connected_q7_opt arm_fully_connected_s16_get_buffer_size arm_fully_connected_s8_get_buffer_size	[+] arm_fully_connected_s4 [+] arm_vector_sum_s8
LSTM Layer	None		[+]arm_lstm_unidirectional_s16_s8
Pooling	arm_avgpool_s16 arm_avgpool_s8 arm_max_pool_s16 arm_maxpool_q7_HWC	arm_avgpool_s16_get_buffer_size arm_avgpool_s8_get_buffer_size arm_max_pool_s8 arm_avepool_q7_HWC	
Reshape	arm_reshape_s8		
Softmax	arm_nn_softmax_common_s8 arm_softmax_q15 arm_softmax_q7 arm_softmax_s16	arm_softmax_s8 arm_softmax_s8_s16 arm_softmax_u8 arm_softmax_with_batch_q7	[*]arm_nn_softmax_common_s8
SVDF	arm_svdf_s8	arm_svdf_state_s16_s8	
Conversion	arm_q7_to_q15_no_shift arm_q7_to_q15_reordered_no_shift	arm_q7_to_q15_reordered_with_offset arm_q7_to_q15_with_offset	[*]arm_q7_to_q15_with_offset
Basic Math	arm_nn_accumulate_q7_to_q15 arm_nn_add_q7 arm_nn_depthwise_conv_nt_t_padded_s8 arm_nn_depthwise_conv_nt_t_s8 arm_nn_mat_mul_core_1x_s8 arm_nn_mat_mul_core_4x_s8	arm_nn_mat_mult_nt_t_s8 arm_nn_mult_q15 arm_nn_mult_q7 arm_nn_vec_mat_mult_t_s16 arm_nn_vec_mat_mult_t_s8 arm_nn_vec_mat_mult_t_svdf_s8	[*]arm_elementwise_mul_s16_s8

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[+] New [-] Remove [*] private

Functions	CMSIS v5 (NN v3.1.0)	v6 (NN 5.0.0)
Convolution	arm_convolve_1_x_n_s8 arm_convolve_1_x_n_s8_get_buffer_size arm_convolve_1x1_HWC_q7_fast_nonsquare arm_convolve_1x1_s8_fast arm_convolve_1x1_s8_fast_get_buffer_size arm_convolve_fast_s16 arm_convolve_fast_s16_get_buffer_size arm_convolve_HWC_q15_basic arm_convolve_HWC_q15_fast arm_convolve_HWC_q15_fast_nonsquare arm_convolve_HWC_q7_basic arm_convolve_HWC_q7_basic_nonsquare arm_convolve_HWC_q7_fast arm_convolve_HWC_q7_fast_nonsquare arm_convolve_HWC_q7_RGB arm_convolve_s16 arm_convolve_s16_get_buffer_size arm_convolve_s8 arm_convolve_s8_get_buffer_size arm_convolve_s8_get_buffer_size arm_convolve_wrapper_s16 arm_convolve_wrapper_s16_get_buffer_size arm_convolve_wrapper_s8 arm_convolve_wrapper_s8_get_buffer_size arm_depthwise_conv_3x3_s8 depthwise_conv_s16_generic_s16 arm_depthwise_conv_s16 depthwise_conv_s8_mult_4 depthwise_conv_s8_generic arm_depthwise_conv_s8 arm_depthwise_conv_s8_opt arm_depthwise_conv_s8_opt_get_buffer_size depthwise_conv_u8_mult_4 depthwise_conv_u8_generic arm_depthwise_conv_u8_basic_ver1 arm_depthwise_conv_wrapper_s8 arm_depthwise_conv_wrapper_s8_get_buffer_size arm_depthwise_separable_conv_HWC_q7 arm_depthwise_separable_conv_HWC_q7_nonsquare	arm_convolve_1_x_n_s8 [+] arm_convolve_1x1_s4 [+] arm_convolve_1x1_s4_fast [+] arm_convolve_1x1_s8 arm_convolve_1x1_s8_fast arm_convolve_fast_s16 arm_convolve_s16 [+] arm_convolve_s4 arm_convolve_s8 arm_convolve_wrapper_s16 [+] arm_convolve_wrapper_s4 arm_convolve_wrapper_s8 arm_depthwise_conv_3x3_s8 [+] arm_depthwise_conv_fast_s16 arm_depthwise_conv_s16 [+] arm_depthwise_conv_s4 [+] arm_depthwise_conv_s4_opt arm_depthwise_conv_s8 arm_depthwise_conv_s8_opt [+] arm_depthwise_conv_wrapper_s16 [+] arm_depthwise_conv_wrapper_s4 arm_depthwise_conv_wrapper_s8 [+] arm_transpose_conv_s8 V5 Basic Math move to V6 Convolution Private [*] arm_nn_depthwise_conv_nt_t_padded_s8 [*] arm_nn_depthwise_conv_nt_t_s8 [*] arm_nn_mat_mult_nt_t_s8 [*] arm_nn_mat_mul_core_1x_s8 [*] arm_nn_mat_mul_core_4x_s8

OmniXRI整理製作, 2024/02/16

差異頗大，許多函式被刪除或整併。

資料來源：https://omnixri.blogspot.com/2024/02/tinyml-arm-cmsis-6-dsp-nn.html

參考文獻

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- 許哲豪，OmniXRI's Edge AI & TinyML 小學堂 Youtube 直播課程總結

https://omnixri.blogspot.com/2024/06/omnixris-edge-ai-tinyml-youtube.html

- 許哲豪，歐尼克斯實境互動工作室系列發文—TinyML(MCU AI)系列

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- 許哲豪，TinyML 核心函式庫 Arm CMSIS 6 DSP & NN 更新比較

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延伸閱讀

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- arm, CMSIS-5 Document (Version 5.9.0)

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- arm, CMSIS-6 Document

https://arm-software.github.io/CMSIS_6/latest/General/index.html

- arm, CMSIS-DSP Document

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- arm, CMSIS-NN Document

https://arm-software.github.io/CMSIS-NN/latest/

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