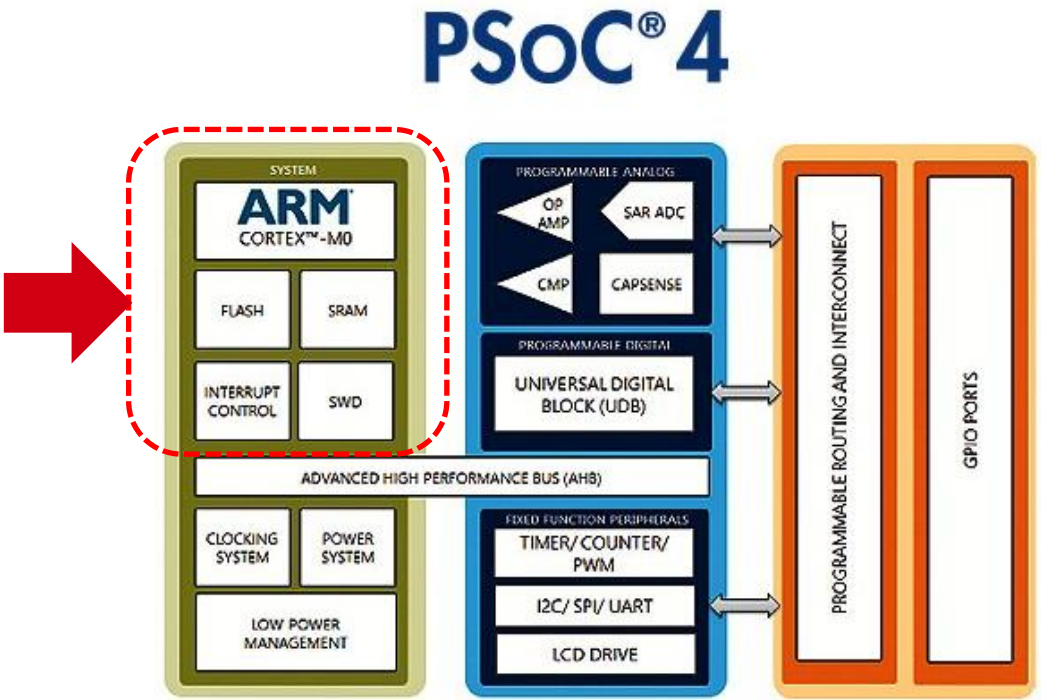
Embedded Computer

Overview

Components


PSoC® 4
SYSTEM
ARM
CORTEX™-M0
FLASH
SRAM
INTERRUPT CONTROL
SWD
CLOCKING SYSTEM
POWER SYSTEM
LOW POWER MANAGEMENT
PROGRAMMABLE ANALOG
OP AMP
SAR ADC
CMP
CAPSENSE
PROGRAMMABLE DIGITAL
UNIVERSAL DIGITAL BLOCK (UDB)
ADVANCED HIGH PERFORMANCE BUS (AHB)
FIXED FUNCTION PERIPHERALS
TIMER/ COUNTER/ PWM
I2C/ SPI/ UART
LCD DRIVE
PROGRAMMABLE ROUTING AND INTERCONNECT
GPIO PORTS

Details

Non-Volatile

Volatile

Processor ALU Registers

Executes Program Instruction

- **Clock Frequency (Max/ Min)**
- **Clock Cycles per Instruction**
- **Clock Freq vs. Power Consumption**
- **Supported Power Modes**
- **No of Cores, 8/32/64 bits**

Memory

FLASH	**Stores Program Instruction**
RAM	**Stores Runtime Variables**
ROM	**Stores Silicon IDs and Non-Programmable SoC Component Settings**
EEPROM	**For Backing Up Data During Run-Time. Non-Volatile**

E.g.,

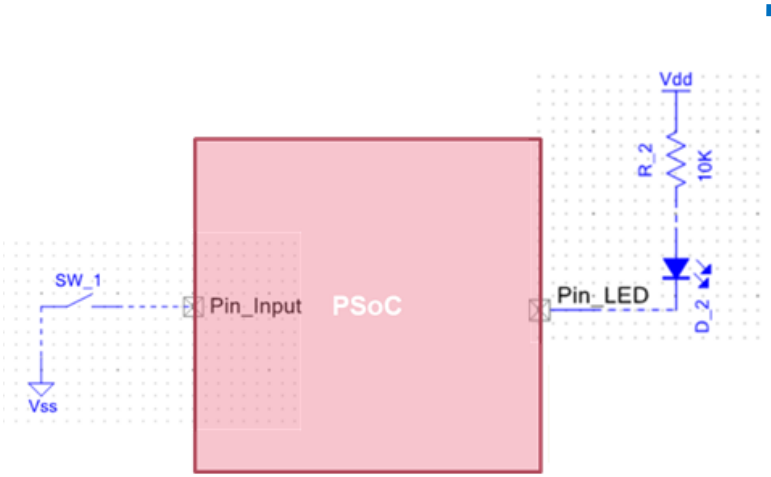
```c
#include "project.h"

const uint8_t NUM_SAMPLES = 3; // Number of samples to average

uint8_t adc_samples[NUM_SAMPLES]; // Array to store ADC samples
uint8_t sample_index = 0; // Index to store new ADC samples
uint16_t filtered_sample = 0; // Filtered sample value

int main(void)
{
    CyGlobalIntEnable; /* Enable global interrupts. */

    ADC_SAR_Start();
    ADC_SAR_StartConvert();
    UART_Start();

    for(;;)
    {
        while(!ADC_SAR_IsEndConversion(ADC_SAR_WAIT_FOR_RESULT)); // Wait for ADC conversion to complete

        adc_samples[sample_index] = ADC_SAR_GetResult8();
        sample_index = (sample_index + 1) % NUM_SAMPLES;

        // Calculate moving average of ADC samples
        filtered_sample = (adc_samples[0] + adc_samples[1] + adc_samples[2]) / NUM_SAMPLES;

        // Send filtered sample via UART-Tx in byte format
        uint8_t tx_data[1];
        tx_data[0] = filtered_sample;
        UART_PutArray(tx_data, 1);

        CyDelay(1000); // Sample ADC every 1 second
    }
}
```

Question: Identify the variables which are stored in Flash, and which are in RAM

A program to read ADC, then perform a 2nd order moving average and transfer the result via UART.

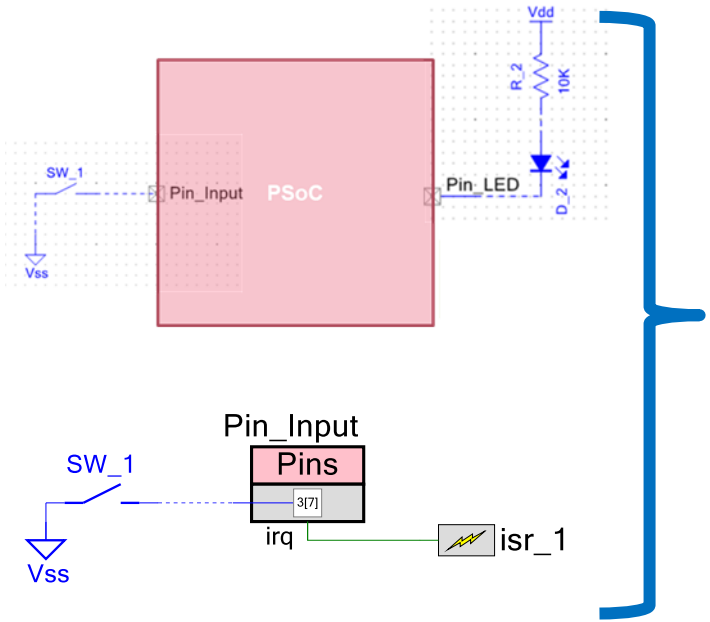
Interrupts

Interrupts – The Need



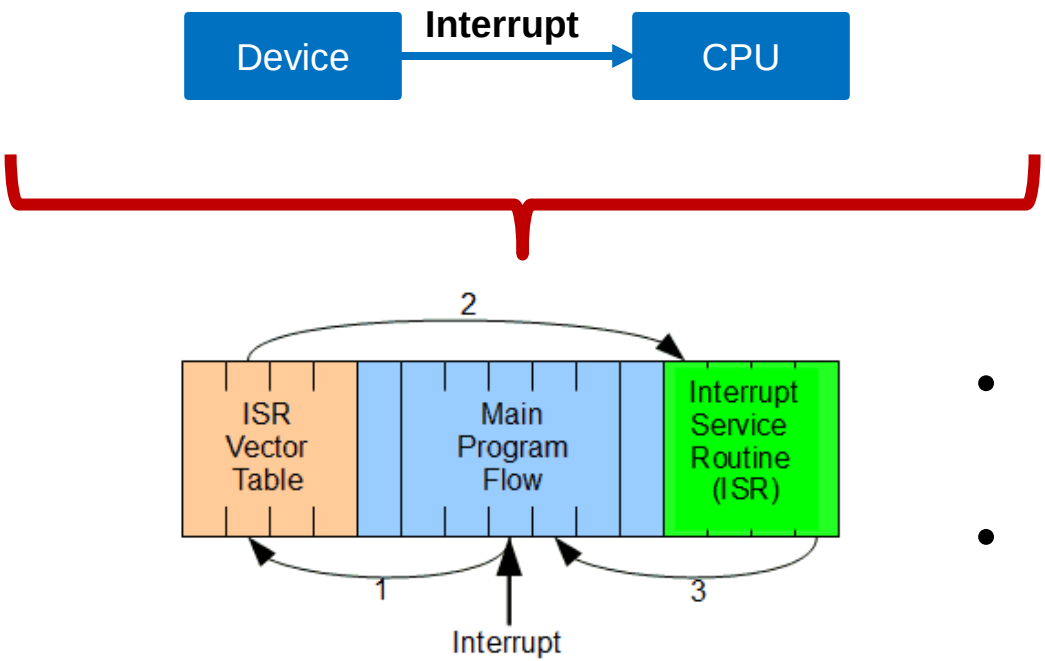

```c
#include "project.h"

int main(void)
{
    CyGlobalIntEnable; /* Enable global interrupts. */

    for(;;)
    {
        /* Check if switch is pressed */
        if (Pin_Input_Read() == 0) {
            /* Toggle LED */
            Pin_LED_Write(!Pin_LED_Read());
        }
    }
}
```

Using GPIO Interrupt




```
#include "project.h"

CY_ISR ( my_isr_code )
{
    // toggling the LED
    Pin_LED_Write(~Pin_LED_Read());

    // clear the pin interrupt
    Pin_Input_ClearInterrupt();
}

int main(void)
{
    CyGlobalIntEnable; /* Enable global interrupts. */

    /* Place your initialization/startup code here (e.g. MyInst_Start()) */
    isr_1_StartEx(my_isr_code);

    for(;;)
    {
        /* Place your application code here. */
    }
}
```

Interrupt Handling



- **Interrupt Vector Table ?**
- **Stack Overflow ?**

Image Credit: https://embedds.com/basic-understanding-of-microcontroller-interrupts/

Interrupt Controller

Priority ?
Interrupt Vectors ?

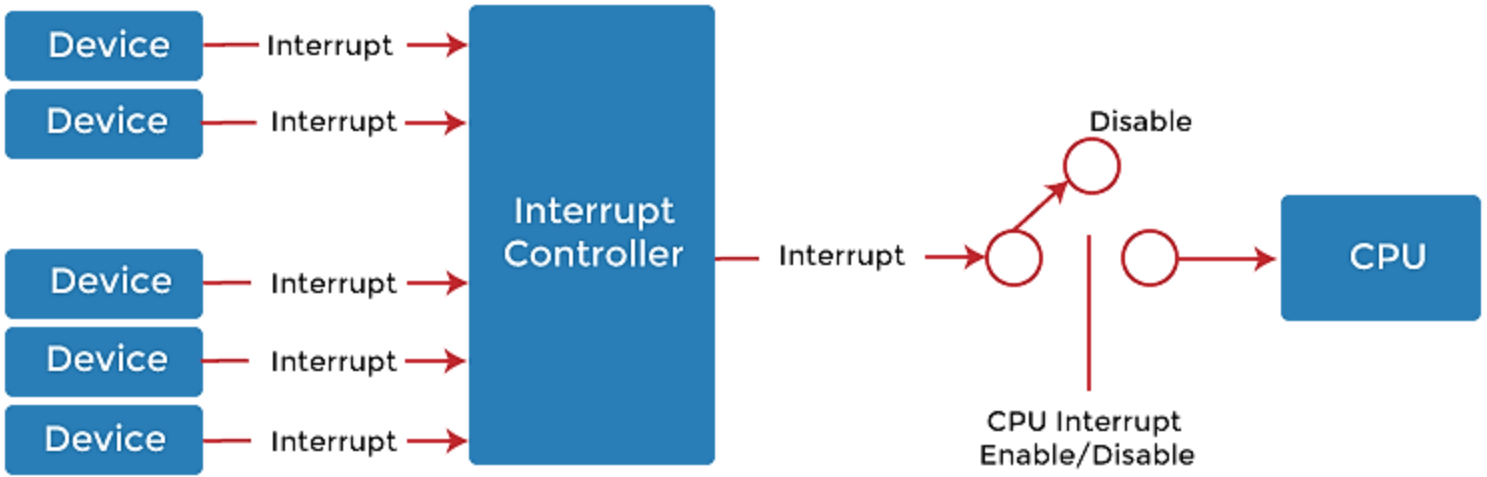
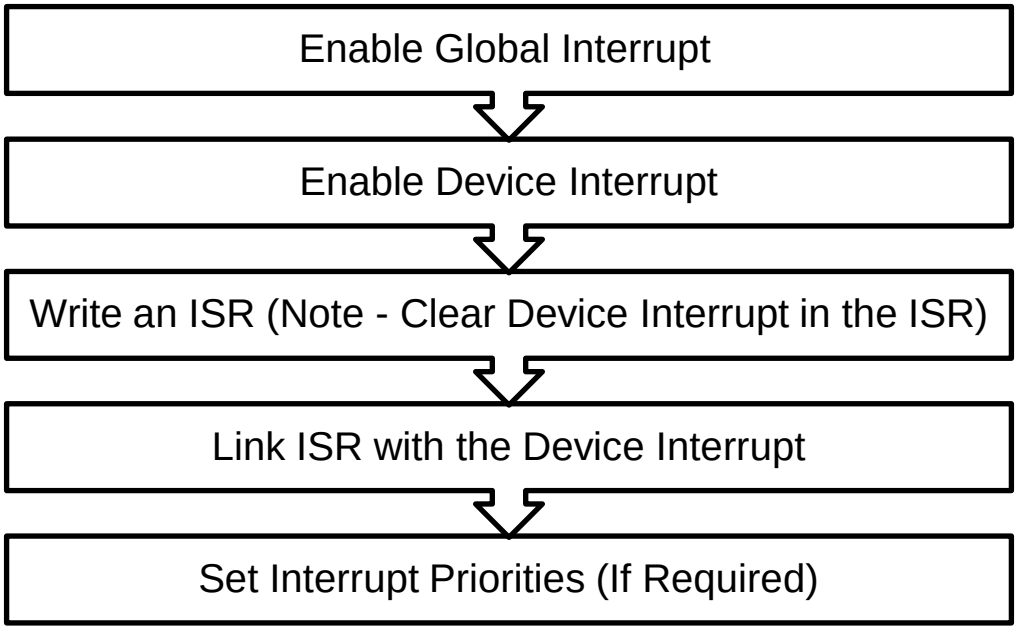


Image Credit: https://www.javatpoint.com/what-is-interrupt-in-os

Interrupt Workflow



The Need for RTOS

Task Scheduling

- Toggle an LED every 1 second.
- Toggle another LED every 2 second.
- Toggle another LED every 1.5 second.
- Toggle couple of other LED's 3 seconds, 4.1 seconds, and 4.5 seconds
- Add breathing effect to an LED. (i.e., increase/decrease the intensity of LED over time)
- Add …

RTOS – How To ?

Define Tasks → Create Tasks → Call the Scheduler

```c
#include "project.h"
#include "FreeRTOS.h"
#include "task.h"

void vLED1Task(void *pvParameters)
{
    for (;;)
    {
        /* Toggle LED1 */
        Cy_GPIO_Write(LED1_PORT, LED1_NUM, ~Cy_GPIO_Read(LED1_PORT, LED1_NUM));
        vTaskDelay(1000 / portTICK_PERIOD_MS); /* Delay for 1 second */
    }
}

void vLED2Task(void *pvParameters)
{
    for (;;)
    {
        /* Toggle LED2 */
        Cy_GPIO_Write(LED2_PORT, LED2_NUM, ~Cy_GPIO_Read(LED2_PORT, LED2_NUM));
        vTaskDelay(2000 / portTICK_PERIOD_MS); /* Delay for 2 seconds */
    }
}

void vLED3Task( void *pvParameters )
{
    for(;;)
    {
        /* Toggle LED3 */
        Cy_GPIO_Write(LED3_PORT, LED3_NUM, ~Cy_GPIO_Read(LED3_PORT, LED3_NUM));
        vTaskDelay(3200 / portTICK_PERIOD_MS); /* Delay for 3.2 seconds */
    }
}
```

```c
int main(void)
{
    /* Enable global interrupts. */
    CyGlobalIntEnable;

    /* Create tasks */
    xTaskCreate(vLED1Task, "LED1 Task", configMINIMAL_STACK_SIZE, NULL, 1, NULL);
    xTaskCreate(vLED2Task, "LED2 Task", configMINIMAL_STACK_SIZE, NULL, 1, NULL);
    xTaskCreate(vLED3Task, "LED3 Task", configMINIMAL_STACK_SIZE, NULL, 1, NULL);

    /* Start the FreeRTOS scheduler */
    vTaskStartScheduler();

    /* The scheduler should never return */
    for (;;);
}
```

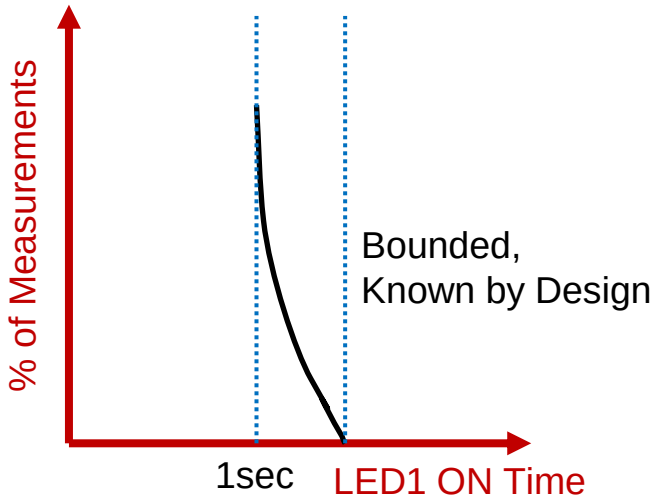
Note: Code is Generated by ChatGPT

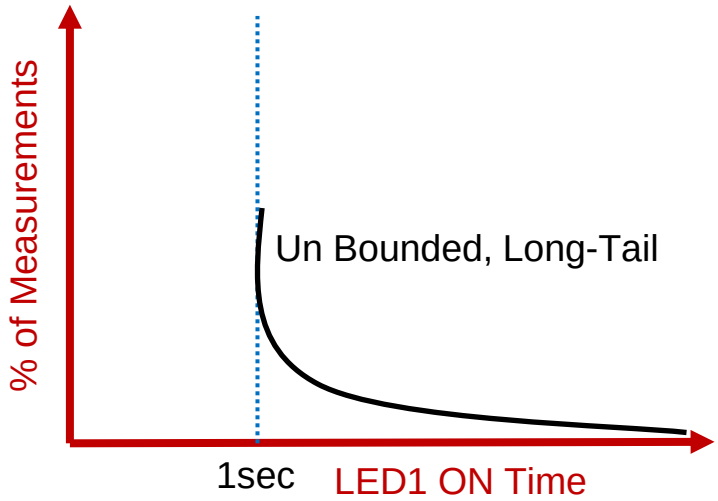
Question: RTOS vs OS. What's the difference ?

Task-1, Task-2, and Task-3 toggles LED-1,2, and 3 every 1, 2 and 3.2 seconds respectively.

RTOS vs. Generic OS

```c
void vLED1Task(void *pvParameters)
{
    for (;;)
    {
        /* Toggle LED1 */
        Cy_GPIO_Write(LED1_PORT, LED1_NUM, ~Cy_GPIO_Read(LED1_PORT, LED1_NUM));
        vTaskDelay(1000 / portTICK_PERIOD_MS); /* Delay for 1 second */
    }
}
```





Semaphores –The Need

```c
// Shared resource
int shared_array[ARRAY_SIZE];

void task1(void *parameter)
{
    while (1)
    {
        // Generate random numbers and update the first
        // five elements of the array
        for (int i = 0; i < 5; i++)
        {
            shared_array[i] = rand() % 100;
        }
        // Sleep for some time
        vTaskDelay(1000 / portTICK_PERIOD_MS);
    }
}

void task2(void *parameter)
{
    while (1)
    {
        // Calculate checksum of the first five elements of the array
        int checksum = 0;
        for (int i = 0; i < 5; i++)
        {
            checksum += shared_array[i];
        }

        // Store checksum in the sixth element of the array
        shared_array[5] = checksum;

        // Sleep for some time
        vTaskDelay(1000 / portTICK_PERIOD_MS);
    }
}
```

- Task-1 updates first five indices of **shared_array**.
- Task-2 computes checksum of the first five indices and store it in the sixth index of **shared_array**.

Question – Any Issues ?

Note: Code is Generated by ChatGPT

Using Semaphores

```c
int shared_array[ARRAY_SIZE];

// Semaphore to protect the shared resource
SemaphoreHandle_t semaphore;

void task1(void *parameter)
{
    while (1)
    {
        // Wait for semaphore to be available
        xSemaphoreTake(semaphore, portMAX_DELAY);

        // Generate random numbers and update the
        // first five elements of the array
        for (int i = 0; i < 5; i++)
        {
            shared_array[i] = rand() % 100;
        }

        // Release the semaphore
        xSemaphoreGive(semaphore);

        // Sleep for some time
        vTaskDelay(1000 / portTICK_PERIOD_MS);
    }
}
```

```c
void task2(void *parameter)
{
    while (1)
    {
        // Wait for semaphore to be available
        xSemaphoreTake(semaphore, portMAX_DELAY);

        // Calculate checksum of the first five elements of the array
        int checksum = 0;
        for (int i = 0; i < 5; i++)
        {
            checksum += shared_array[i];
        }

        // Store checksum in the sixth element of the array
        shared_array[5] = checksum;

        // Release the semaphore
        xSemaphoreGive(semaphore);

        // Sleep for some time
        vTaskDelay(1000 / portTICK_PERIOD_MS);
    }
}
```

Note: Code is Generated by ChatGPT

What Next ?

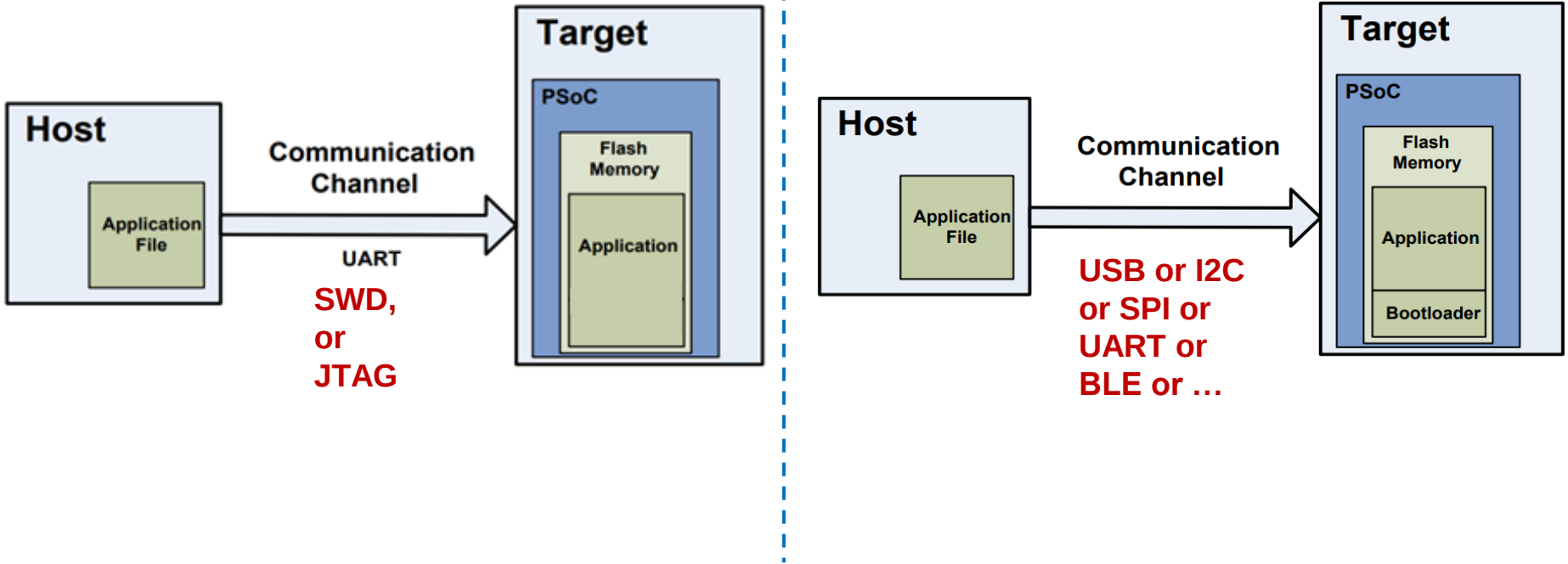
Only for interested students

- Learn running FreeRTOS on PSoC-4
- Understand the importance of the arguments in xTaskCreate
- Learn – What is stack for a task in RTOS
- Learn how to delete a task that is already created (to free up resources)
- Task Priority – how to ?
- Sharing data between tasks. How to ? (Usage of Semaphores and Mutexes)

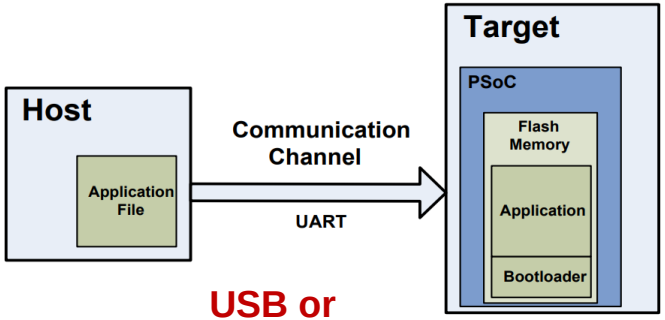
Programming & Bootloaders

Prof. Kurian Polachan, IIIT-Bangalore

The Difference



Bootloader E.g.,



USB or I2C or SPI or UART or BLE or …

Ref: AN68272 (Infineon)

Target Flash

0x0000	
0x0001	
…	
…	
0x2000	
0x2001	
…	
…	
…	

Bootloader Code

Application

Note: For simplicity, ISR vector table is not shown

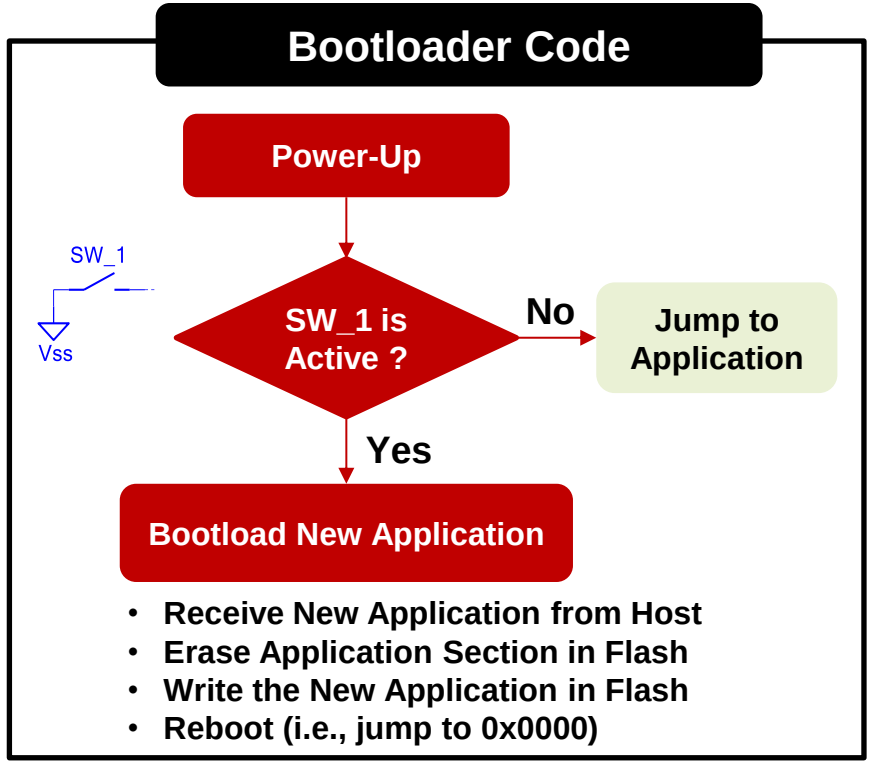
Bootloader E.g.,

Target Flash

0x0000	Instruction-1
0x0001	Instruction-2
…	…
…	…
0x2000	Instruction-1
0x2001	Instruction-2
…	…
…	…
…	…

Bootloader Section

Application Section



Note: Host should know the start address of the application section