

- zipped project folders for Exercise1, Exercise2
- this lab track completed and converted to pdf format.

Exercise 1) Experiment the SVC instruction.

- Download the **template project** for Keil μ Vision “01 SVC” from the course material.

Write, compile, and execute a code that invokes an SVC instruction in the main (in main.c) as following:

```
call_svc();
```

The `call_svc` is a [naked function \(LINK\)](#) written in assembly (i.e., no save and restore of registers) declared into a code, read only AREA called `svc_code`. It calls the `svc` with a fixed SVC number.

Q1: Where is the code of the function when the AREA is declared as READONLY?

When the function Area is declared READONLY we have:

Code: 496 bytes; RO : 272 bytes; RW: 0 bytes; ZI: 1632 bytes

By looking at the **MAP file** generated by the Linker in the Listings folder of my project, I see that the Area “myAsmFunctions” is positioned in the **Read-Only Execution Region (ER_RO)**.

Q2: Where is the code of the function when the AREA is declared as READWRITE?

When the function Area is declared READONLY we have:

Code: 532 bytes; RO : 248 bytes; RW: 0 bytes; ZI: 1632 bytes

By looking at the **MAP file** generated by the Linker in the Listings folder of my project, I see that the Area “myAsmFunctions” is positioned in the **Read-Write Execution Region (ER_RW)**.

You must set the control to `user mode(unprivileged)` before leaving the `Reset_Handler` function.

By means of invoking a SuperVisor Call, implement an error-correction method to enable a fault-tolerant data transmission by leveraging **Repetition Coding**. The same bit is transmitted multiple times to increase reliability in data transmission, particularly in noisy communication channels. Instead of sending each data bit once, the bit is repeated several times, allowing the receiver to determine the original bit based on majority voting among the received bits.

For example, suppose that we send the message «10101» with a **repetition code (3,1)**. It will be encoded in the following sequence of data «111000111000111», where each transmitted bit is repeated three times.

Correct Transmission	Received Message
111000111000111	10101
Faulty Transmission	Received Message
111010111000101000	10101

It can correct a message when one of the transmitted bits is flipped - a single bit error - meaning that the **correcting ability of this code is 1 bit**.

You are required to implement the following ASM code.

- Use a SuperVisor Call (SVC) to request encoding of a binary message.
- The message to be encoded is stored in the first 8 bits of the SVC instruction (bit 0 through 7).
- In SVC handler, implement the **repetition code (3,1)** on the input message.
- For each bit in the 8-bit message:
 - Repeat each bit **three times** to create an encoded output.

- This repetition ensures each bit is represented as three identical bits (e.g., "1" becomes "111" and "0" becomes "000").
- Return the encoded message using the stack.

Example:

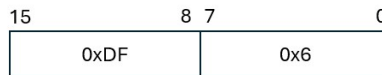


Figure 1: SVC format

SVC 0x5; 2_0101binary value of the SVC number

Returning from the SVC, the process ToS (Top of the stack) must contain the value "000111000111".

Q3: Describe how the stack structure is used by your project. Where is the return value? Please provide the addresses for the stack structures.

At the beginning, when I am in the Reset Handler, I switch to user unprivileged mode and to the PSP. so when I call the main() in the C file and the call_svc() functions I always use the PSP. In the call_svc() I raise the svc and before executing the SVC Handler the system switches to handler mode and to the MSP. Beware: the system saves the registers r0-r3, r12, LR, PC, PSR to the PSP before executing the SVC Handler. Then in this handler I operate with the MSP by stacking the registers r4-r12, lr in there. I am interested in returning the final value at the top of the PSP, not the MSP. So before calling the svc I save register r13 to a temporary register. r13 is the stack pointer pointing to the top of the PSP, where I have to return the final value.

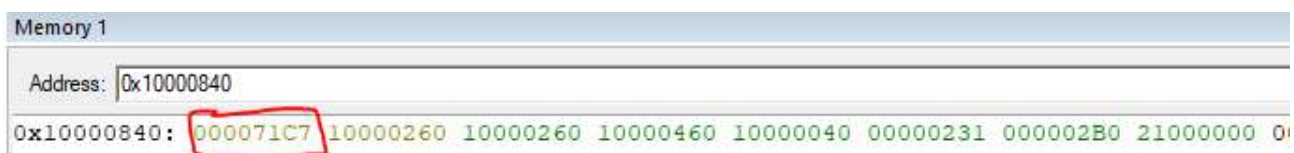
At the end of the SVC Handler, by means of a LDR instruction, I write the result directly to the top of the PSP having in mind that it's a full-descending stack and I've got all the other registers already saved in there so the top of stack will be at an offset equal to -32.

Addresses:

The top of the PSP, at the beginning of the Reset Handler, is located at 0x10000460.

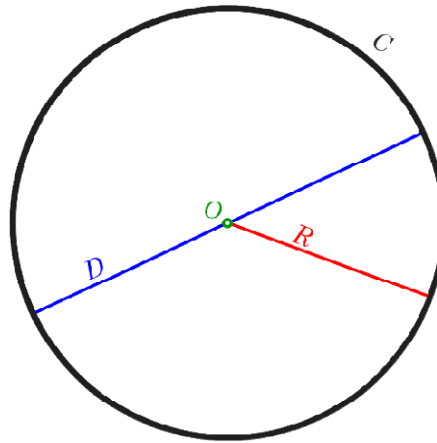
The result will be saved at this value with an offset of – 32, so at **0x10000840**.

The image shows the PSP which is currently storing all the other registers and, on top of those, at address **0x10000840**, the **final result** of the **repetition code (3,1) applied to the input value 10101**.
0x000071C7 = 2_111000111000111



Exercise 2) – Compute the value of π using the circle method.

- Download the template project for Keil μ Vision “ABP” from the course material.



Pythagoreans called a set of points equally spaced from a given origin *Monad* (from Ancient Greek μονάς (*monas*) 'unity', and μόνος (*monos*) 'alone'). As originally conceived by the Pythagoreans, the *Monad* is the Supreme Being, divinity, the totality of all things, or the unreachable perfection by human beings (but we can at least try 😊). The *Monad* (aka circle) in geometry is strongly intertwined with π (a mathematical transcendental irrational constant), commonly defined as the ratio between a circle's circumference and diameter.

$$\pi = \frac{C}{D}$$

An irrational number cannot be expressed exactly as a ratio of two integers. Consequently, its decimal representation never ends!

3.14159265358979323846264338327950288419716939937510...

However, **mathematical operations in computers are finite!** In the literature, some interesting methods and algorithms to compute an approximated value of π have been developed.

One of the most intuitive methods is the circle method (not the best in terms of performance). It is based on the following observations.

- The area of the circle is:

$$A = \pi r^2 (\text{Eq. 1})$$

- Where π can be computed as:

$$\pi = \frac{A}{r^2} (\text{Eq. 2})$$

- The assumption is to have a circle of radius **r** **centered in the origin (0,0)**.

Therefore, the Pythagoras theorem states that the distance from the origin is:

$$d^2 = x^2 + y^2 (\text{Eq. 3})$$

The cartesian plane can be built thinking of unitary squares centered in every (x, y) point, where x and y are the integers between $-r$ and r .

Squares whose center belongs within or on the circumference contribute to the final area. They must satisfy the following:

$$x^2 + y^2 \leq r^2 (\text{Eq. 4})$$

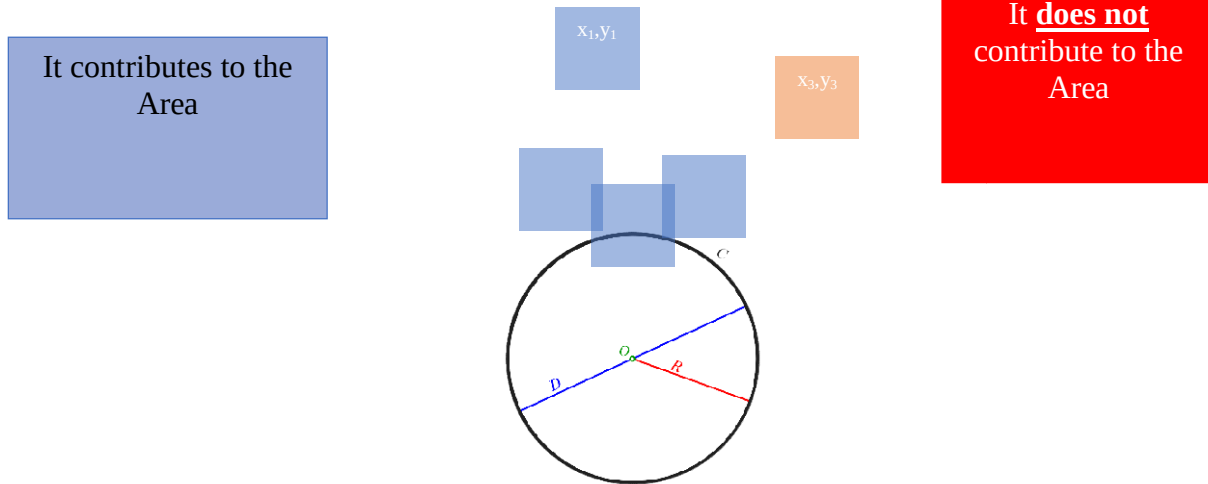
The number of points that satisfy the above condition (Eq. 4) approximates the area of the circle.

Therefore, the final formula is (where the double sums are the Area):

$$\pi \approx \frac{1}{r^2} \sum_{x=-r}^r \sum_{y=-r}^r \check{\text{square}}(x, y, r) \quad (\text{Eq. 5})$$

$$\text{where } \check{\text{square}}(x, y, r) = \begin{cases} 1, \wedge x^2 + y^2 \leq r^2 \\ 0, \wedge x^2 + y^2 > r^2 \end{cases}$$

The graphical idea is the following:



Declare the coordinates as couples of (x, y) (signed integer) into a read-only memory region 2-byte aligned (into an assembly file) as follows:

```
Matrix_Coordinates DCD -5,5,-4,5,-3,5,-2,5,-1,5,0,5,1,5,2,5,3,5,4,5,5,5
DCD -5,4,-4,4,-3,4,-2,4,-1,4,0,4,1,4,2,4,3,4,4,4,5,4
DCD -5,3,-4,3,-3,3,-2,3,-1,3,0,3,1,3,2,3,3,3,4,3,5,3
DCD -5,2,-4,2,-3,2,-2,2,-1,2,0,2,1,2,2,2,3,2,4,2,5,2
DCD -5,1,-4,1,-3,1,-2,1,-1,1,0,1,1,1,2,1,3,1,4,1,5,1
DCD -5,0,-4,0,-3,0,-2,0,-1,0,0,0,1,0,2,0,3,0,4,0,5,0
DCD -5,-1,-4,-1,-3,-1,-2,-1,-1,-1,0,-1,1,-1,2,-1,3,-1,4,-1,5,-1
DCD -5,-2,-4,-2,-3,-2,-2,-2,-1,-2,0,-2,1,-2,2,-2,3,-2,4,-2,5,-2
DCD -5,-3,-4,-3,-3,-3,-2,-3,-1,-3,0,-3,1,-3,2,-3,3,-3,4,-3,5,-3
DCD -5,-4,-4,-4,-3,-4,-2,-4,-1,-4,0,-4,1,-4,2,-4,3,-4,4,-4,5,-4
DCD -5,-5,-4,-5,-3,-5,-2,-5,-1,-5,0,-5,1,-5,2,-5,3,-5,4,-5,5,-5
ROWS DCB 11
COLUMNS DCB 22
```

The parsing of Matrix_Coordinates must be done in C. Remember that the extern keyword must be used for referencing assembly data structures:

```
extern <datatype> _Matrix_Coordinates;
extern <datatype> _ROWS;
extern <datatype> _COLUMNS;
```

Also remember that any assembly data structure that you want to use in C must be EXPORTED!

In the loop body of Eq. 4, `check_square(x, y, r)` is called using an assembly function with the following prototype:

```
int check_square(int x, int y, int r)
```

which implements:

$$\check{\text{square}}(x, y, r) = \begin{cases} 1, \wedge x^2 + y^2 \leq r^2 \\ 0, \wedge x^2 + y^2 > r^2 \end{cases}$$

1.1) Moreover, the Arm Cortex-M3 does not provide hardware floating point support. Therefore, we can resort to software emulated floating-point algorithms, including the type `float`. As an example, Arm FPlib has the following EABI-compliant function for float division:

```
float __aeabi_fdiv (float a ,float b)      /* return a/b */
```

<https://developer.arm.com/documentation/dui0475/m/floating-point-support/the-software-floating-point-library--fplib/calling-fplib-routines?lang=en>

You are required to compute the division with r^2 in (Eq. 5) by calling a second assembly function with the following prototype:

```
float my_division(float* a, float* b)
```

The function body to implement is:

`my_division:`

```
/*save R4,R5,R6,R7,LR,PC*/  
/*obtain value of a and b and prepare for next function  
call*/  
/*call __aeabi_fdiv*/  
/*results has to be returned!*/  
/*restore R4,R5,R6,R7,LR,PC*/
```

1.2) Compute the value of π using a radius of 2,3,5 and store it into a variable.

Radius (r)	Area	Approximated value of π (3 decimal units)	Clock Cycle (xtal=18 MHz)
2	13	3.250	4673
3	29	3.222	4675
5	81	3.240	4675

I have observed that, declaring the Area variable in the code as float instead of int increases the required clock cycles to > 10.000 clock cycles. I think that this is related to how the function `int checkCoordinates(int x_, int y_, int r)` is executed and/or optimized by the compiler. If I declare the Area variable as int and only convert it to float before calling the `my_division` function, I lower the clock cycles by approximately 55%!

Converter from hex to FP (and viceversa): <https://gregstoll.com/~gregstoll/floattohex/>