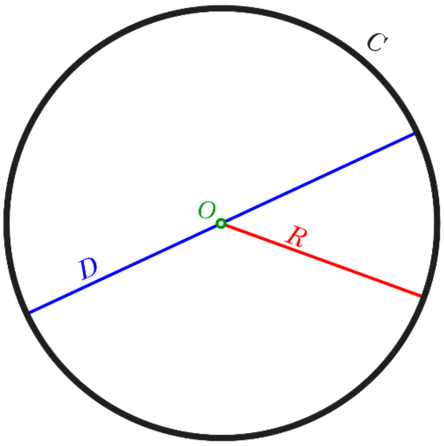
Architetture dei Sistemi Di Elaborazione **Laboratory 8**	Delivery date: 9th December 2022 Expected delivery of lab_08.zip must include: - zipped project folder - this lab track completed and converted to pdf format.

Download the template project for Keil µVision "*ABI_C+ASM*" from the course material. NB: Deliver a single Keil project including Exercise 1 and Exercise 2.

Exercise 1) – Compute the value of π using the circle method.



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 <u>cannot</u> be expressed <u>exactly</u> 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:

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

Where π can be computed as:

$$\pi = {}^{A}/{r2} \ (Eq. 2)$$

- 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:

$$d^2 = x^2 + y^2 (Eq. 3)$$

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:

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

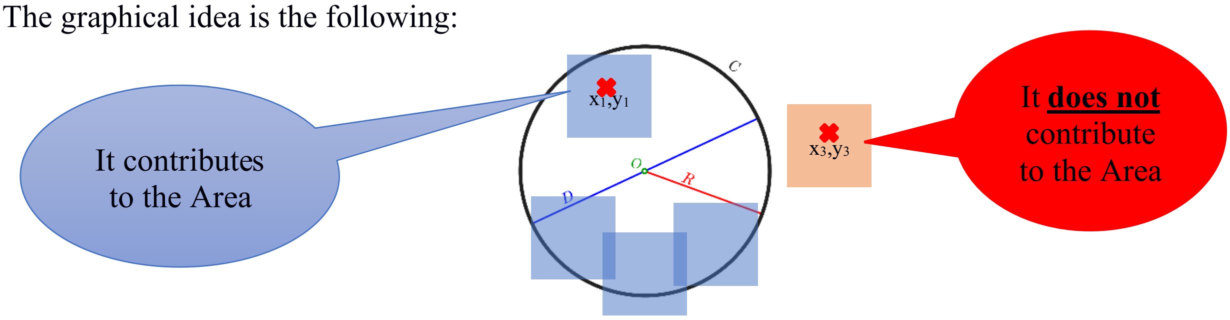
The number of points that satisfy the above condition (Eq. 4) approximates the area of the circle.

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

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

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

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;
```

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:

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

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-floatingpoint-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 __eabi_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	3.25	15120
3	29	3.22	15120
5	81	3.24	23220

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

Exercise 2) – SuperVisorCall (SVC)

Enhance the program developed in Exercise 1 by using the **SVC** instruction after the computation of π.
Copy part of the template project for Keil µVision "*SVC*".
You must set the control to `user mode(unprivileged)` and use the Process Stack Pointer.

2.1) Starting from Exercise 1, write a code to compute a **signature** by calling the SVC with ***0xCA***.

In safety-critical domains, such as the automotive one, functional test programs based on CPU instructions are developed to verify the correct in-field behavior of microprocessor-based systems. This safety process is also known as online testing. A possible way to assess if a functional test program has executed its computations correctly is to introduce a signature computation to be checked at the end of the test program.

A signature typically accumulates into one register the others' values by means of an arithmetic operation. For example, suppose you have `R0, R1, R2, R3, R4, R5,` and you want to compute the signature into `R0`.

```
XOR R0, R0, R1
XOR R0, R0, R2
XOR R0, R0, R3
XOR R0, R0, R4
XOR R0, R0, R5
```

Implement an SVC call to compute the signature between Registers from 0 to 12, the LR and XPSR with the XOR instruction.
This must be done by calling the SVC at the end of Exercise 1.

```
__asm__("svc 0xca");
```

The computed signature value must be accumulated into R0 and returned from the SVC through the PSP stack (as shown in the figure below).

	Stack
	result_here
+28	xPSR
+24	PC
+20	LR
+16	R12
+12	R3
+8	R2
+4	R1
SP→	R0

2.2) Starting from Exercise 1, write a code for **memory compaction** by calling the SVC with ***0xFE***.

Compute the memory footprint of *Matrix_Coordinates* in bytes in Exercise 1.

Data	Size [bytes]
Matrix_Coordinates	968

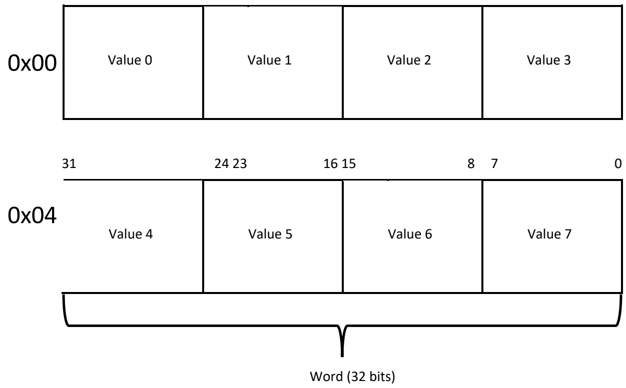
In this case, it can be safely assumed that points are always in the range [-128,127]. Therefore, data can be compacted (4 values for each word).

Implement a SVC call to compact *Matrix_Coordinates* and store its compacted version into an empty optimized data structure called *Opt_M_Coordinates* (declared into an assembly file as Read/Write region), you have to calculate the required size!
This must be done by calling the SVC at the end of Exercise 1.

```
__asm__("svc 0xfe");
```

The idea is:

31 24 23 16 15 8 7 0



Then compute the memory footprint.

Data	Size [bytes]	Memory saved [bytes]
Matrix_Coordinates	968	0
Opt_M_Coordinates	242	726