Julia introduction

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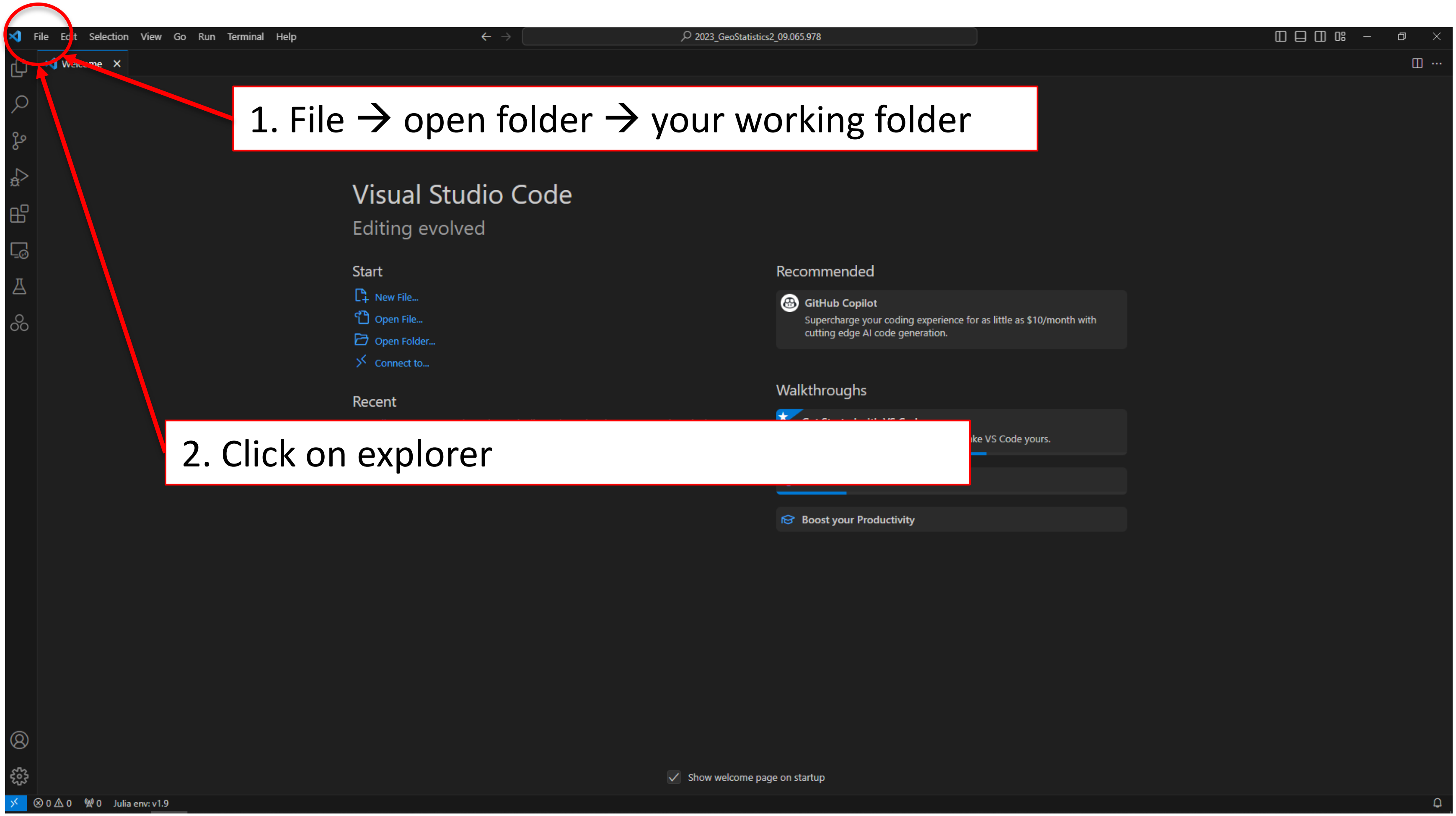
VS Code


File
Edit
Selection
View
Go
Run
Terminal
Help
2023_GeoStatistics2_09.065.978
1. File → open folder → your working folder
Visual Studio Code
Editing evolved
Start
New File...
Open File...
Open Folder...
Connect to...
Recent
Recommended
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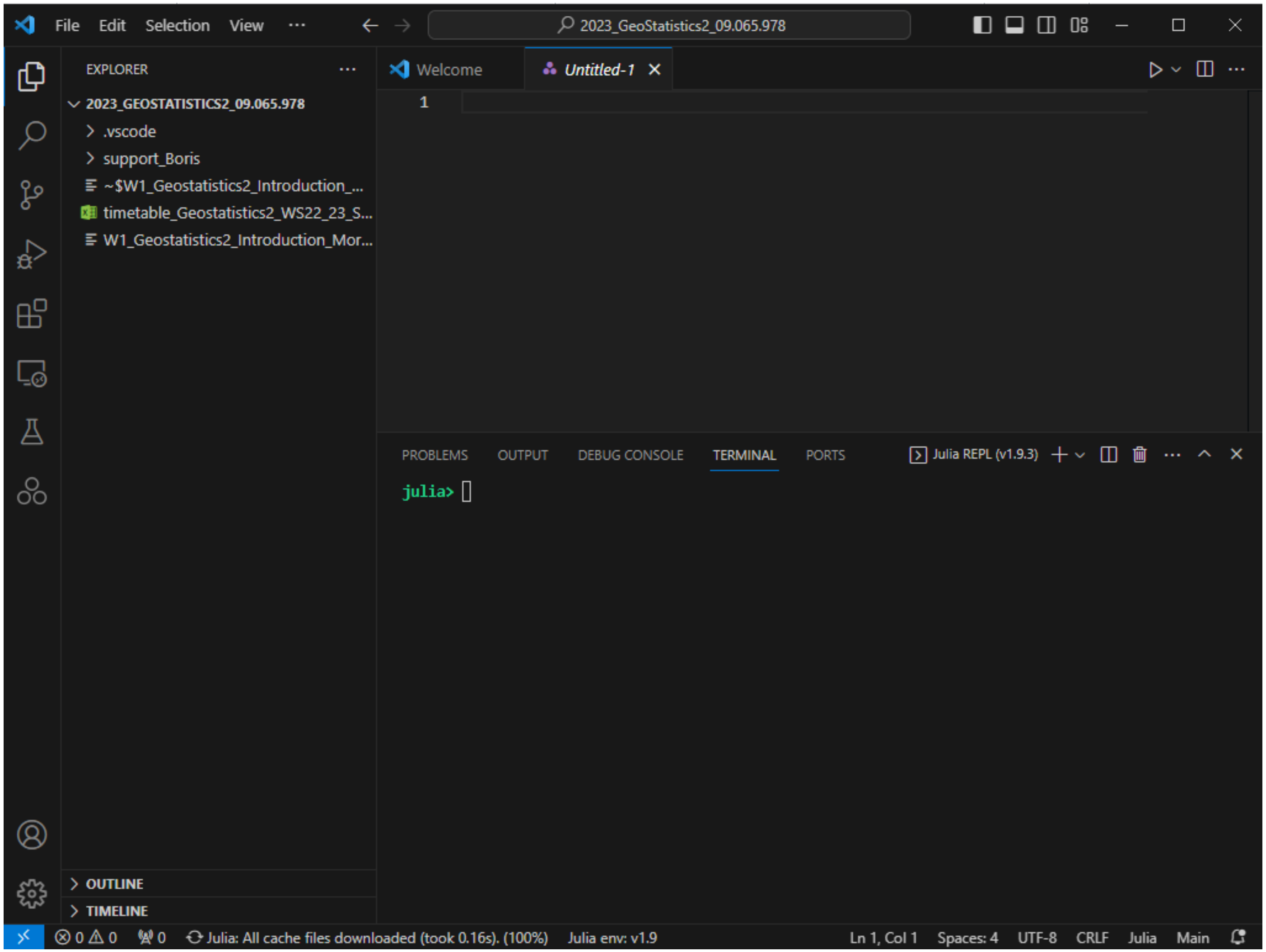
Supercharge your coding experience for as little as $10/month with cutting edge AI code generation.
Walkthroughs
2. Click on explorer
Boost your Productivity
Show welcome page on startup
Julia env: v1.9

Julia REPL (demonstration)



Julia REPL (read-eval-print loop)

Terminal or prompt pasting

- Julia terminal

  computation space, execute scripts…

```
[ Info: Precompiling VSCodeServer [9f5989ce-84fe-42d4-91ec-6a7a8d53ed0f]
julia> 
```

-] package manager

  add/update packages

```
[ Info: Precompiling VSCodeServer [9f5989ce-84fe-42d4-91ec-6a7a8d53ed0f]
(@v1.9) pkg> 
```

- ; shell

  Changing directories

```
[ Info: Precompiling VSCodeServer [9f5989ce-84fe-42d4-91ec-6a7a8d53ed0f]
shell> 
```

- ? help

  provide help with functions

```
help?> minimum
search: minimum minimum! DimensionMismatch

  minimum(f, itr; [init])

  Return the smallest result of calling function f on each element of itr.
```

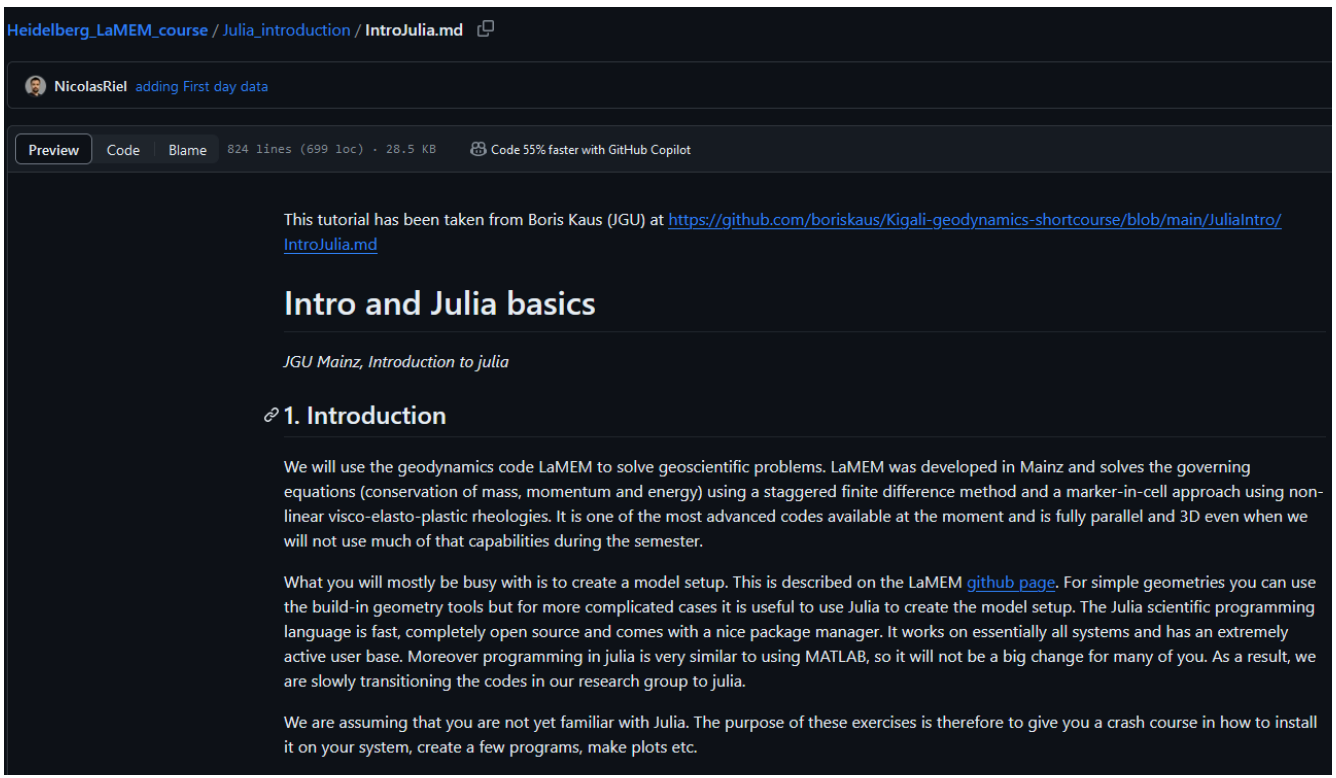
- Backspace

  back to julia terminal

Julia introduction

- Access the following link and complete the Julia introduction

https://github.com/NicolasRiel/Heidelberg_LaMEM_course/blob/main/Julia_introduction/IntroJulia.md


Heidelberg_LaMEM_course / Julia_introduction / IntroJulia.md

NicolasRiel adding First day data

Preview Code Blame 824 lines (699 loc) · 28.5 KB Code 55% faster with GitHub Copilot

This tutorial has been taken from Boris Kaus (JGU) at https://github.com/boriskaus/Kigali-geodynamics-shortcourse/blob/main/JuliaIntro/IntroJulia.md

Intro and Julia basics

JGU Mainz, Introduction to julia

1. Introduction

We will use the geodynamics code LaMEM to solve geoscientific problems. LaMEM was developed in Mainz and solves the governing equations (conservation of mass, momentum and energy) using a staggered finite difference method and a marker-in-cell approach using non-linear visco-elasto-plastic rheologies. It is one of the most advanced codes available at the moment and is fully parallel and 3D even when we will not use much of that capabilities during the semester.

What you will mostly be busy with is to create a model setup. This is described on the LaMEM github page. For simple geometries you can use the build-in geometry tools but for more complicated cases it is useful to use Julia to create the model setup. The Julia scientific programming language is fast, completely open source and comes with a nice package manager. It works on essentially all systems and has an extremely active user base. Moreover programming in julia is very similar to using MATLAB, so it will not be a big change for many of you. As a result, we are slowly transitioning the codes in our research group to julia.

We are assuming that you are not yet familiar with Julia. The purpose of these exercises is therefore to give you a crash course in how to install it on your system, create a few programs, make plots etc.

Extra tutorial (optional)

- For those who are fast, who want to go beyond what is needed within the scope of the course

“for” loops

- Open new Julia file and reproduce the following lines of codes

```julia
# example of for loops

n_iteration = 10
total       = 0.0

for i=1:n_iteration
    total = total + 1
end

print("total = $total\n")

# \n -> line break
# \t -> tabulation
```

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS

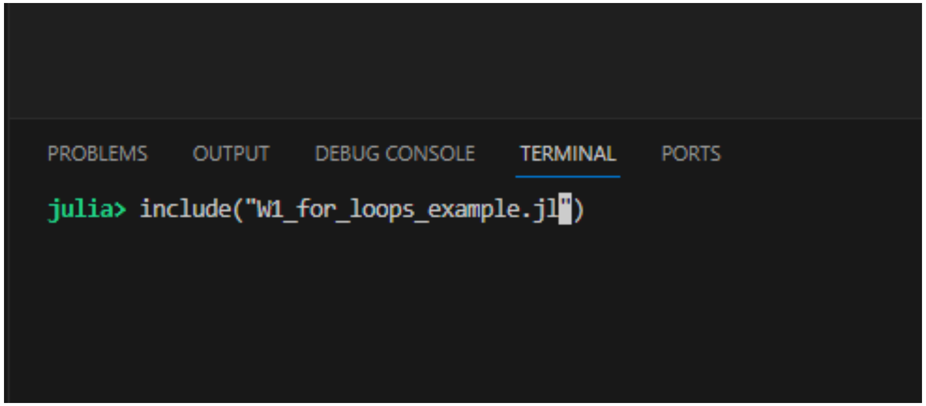
```
julia> total       = 0.0
0.0

julia>

julia> for i=1:n_iteration
           total = total + 1
       end

julia>

julia> print("total = $total\n")
total = 10.0

julia>
```

- Paste it in the terminal

“for” loops

- CTRL + L to clear the terminal
- Save the file as “meaningful_name.jl”

- Execute the scripts using “include”



First bug?

```
PROBLEMS    OUTPUT    DEBUG CONSOLE    TERMINAL    PORTS                                    Julia REPL (v1.9.3)

julia> include("W1_for_loops_example.jl")
┌ Warning: Assignment to `total` in soft scope is ambiguous because a global variable by the same name exists: `total` will be treated as a new local. Disambiguate by using `local total` to suppress this warning or `global to
tal` to assign to the existing global variable.
└ @ E:\Nextcloud\_RESEARCH\USB_DATA\7_teaching\2023_Mainz\2023_GeoStatistics2_09.065.978\W1_for_loops_example.jl:7
ERROR: UndefVarError: `total` not defined
Stacktrace:
 [1] top-level scope
   @ E:\Nextcloud\_RESEARCH\USB_DATA\7_teaching\2023_Mainz\2023_GeoStatistics2_09.065.978\W1_for_loops_example.jl:7

julia> 
```

- Here Julia does not know the “scope” of the variable total.
- Scope can be seen as the region of a code where the variable is visible/exists
- The main file here can been thought as an “open space”

→ The right way to solve the issue is to work in a “closed space” i.e. using functions!

```julia
# example of for loops

n_iteration = 10
total       = 0.0

for i=1:n_iteration
    total = total + 1
end

print("total = $total\n")

# \n -> line break
# \t -> tabulation
```

Functions

- Take one or multiple entries as arguments
- Return one of multiple variables

Terminal Help

Welcome | W1_demonstration.jl | W1_for_loops_example_function.jl

W1_for_loops_example_function.jl > ...

```julia
# example of for loops


function sum_iteration(n_iteration)
    total = 0.0

    for i=1:n_iteration
        total = total + 1
    end

    return total
end

total       = sum_iteration(n_iteration)


print("total = $total\n")

# \n -> line break
# \t -> tabulation
```

```
julia> include("W1_for_loops_example_function.jl")
total = 10.0

julia>
```

Solve the “scope” problem

Function file

- When developing a code is it useful to put the functions in other files to keep the main file readable
- Create a "functions_file.jl" and copy/paste the For loop example in it
- Add comment before the function definition as

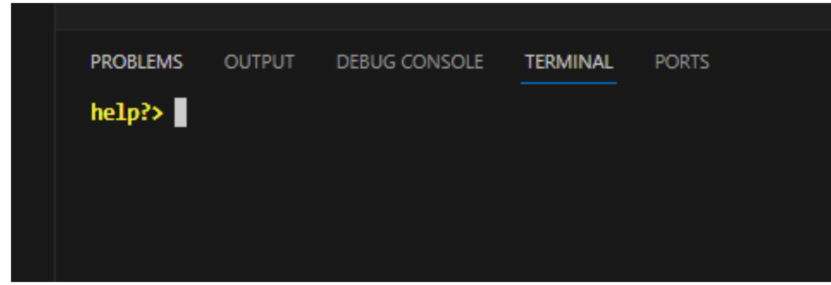
```
"""
    sum_iteration(n_iteration)
        where n_iteration is an integer
        return sum(n_iteration)
"""
```

1. The """ mark the start and ending of the comment
2. The first lines should be the function first lines copied and pasted
3. Subsequent lines describe the input/output and role of the function

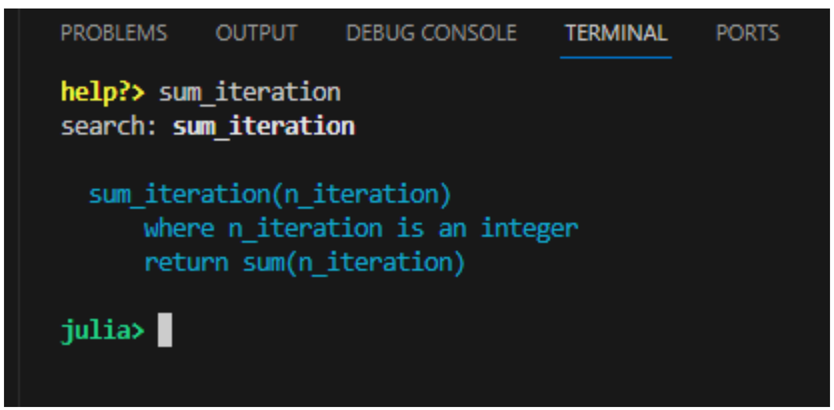
```julia
"""
    test function sum_iteration(n_iteration)
        where n_iteration is an integer
        return sum(n_iteration)
"""
function sum_iteration(n_iteration)
    total = 0.0

    for i=1:n_iteration
        total = total + 1
    end

    return total
end
```

Forgot what the function(s) does?

- Open the help in the REPL (terminal) with **?**



- Type sum_iteration and enter (or sum_i +DOUBLE TAB)



This displays the comment of your function. Very useful:

- When your code becomes big (many files)
- When you did not use your code for a while
- When you share your code!

“while” loops

- Generalization of the for loop: loops until the looping condition is broken

- Reproduce the following code in the functions_file.jl (after sum_iteration function)

- In the REPL include “W1_functions_file.jl” and define M and n_iteration then call the function

```
julia> include("W1_functions_file.jl")
exercice_3

julia> n_iteration = 10
10

julia> M = 50
50

julia> M = while

while       while_loop
julia> M = while_loop(n_iteration,M)
```

Or using default values

```
julia> M = while_loop()
```

```julia
"""
while_loop(n_iteration,M)

        where n_iteration is an integer, M is an integer
        return M + sum( (n_iteration-1)*10 )
"""
function while_loop(n_iteration=10,M=50)

    i=1
    while i < n_iteration
        M += 10
        i -= 1
        print("i = $i, M = $M\n")
    end

    return M
end
```

Note that default values can be defined as such:

Will this program stop or run forever?

“if elseif else” statement

- Check the state of a condition (true or false) and perform different computation depending on the case

- Reproduce code in “functions_file.jl”

- And test it
  (re-include “W1_functions_file.jl”)

```
M = check_M(M)

print("check_M(M) = $M\n")

```

```

"""
    check_M(M)
        where...

"""
function check_M(M)

    if M < 10
        M += 25
    elseif M == 10
        M = M^2
    else
        M = 0
    end

    return M
end
```

Arrays (Vector)

- There is several different ways to declare a Vector in Julia for instance:

```
julia> array = [0,1,2,3,4]
5-element Vector{Int64}:
 0
 1
 2
 3
 4
```

This creates and fill the Vector with given values

```
julia> zeros(5)
5-element Vector{Float64}:
 0.0
 0.0
 0.0
 0.0
 0.0
```

This creates a Vector of length 5 and fill it with zeros

```
julia> zeros(Int64,5)
5-element Vector{Int64}:
 0
 0
 0
 0
 0
```

The type can be specified

Note: you can also use: ones()

Access/Modify Arrays (Vector)

- **Access**

```
julia> array = [0,1,2,3,4]
5-element Vector{Int64}:
 0
 1
 2
 3
 4
```

```
julia> array[1]
0
```

By position

```
julia> array[1:4]
4-element Vector{Int64}:
 0
 1
 2
 3
```

Using range

```
julia> array[[1,2,3,4]]
4-element Vector{Int64}:
 0
 1
 2
 3
```

Using vector of positions

- **Modify**

```
julia> array[1] = 4
4
```

Don't forget the dot (pointwise)

```
julia> array[1:4] .= 4
4-element view(::Vector{Int64}, 1:4) with eltype Int64:
 4
 4
 4
 4
```

```
julia> array[[1,2,3,4]] .= 4
4-element view(::Vector{Int64}, [1, 2, 3, 4]) with eltype Int64:
 4
 4
 4
 4
```

Arrays (Matrix)

- There is several different ways to declare an array in Julia for instance:

```
julia> array2D = [0 1 2 3 4; 5 6 7 8 9]
2x5 Matrix{Int64}:
 0  1  2  3  4
 5  6  7  8  9
```

This creates and fill the matrix with given values

```
julia> zeros(2,5)
2x5 Matrix{Float64}:
 0.0  0.0  0.0  0.0  0.0
 0.0  0.0  0.0  0.0  0.0
```

This creates a Matrix of 2 lines and 5 columns filled with 0.0

```
julia> zeros(Float64,2,5)
2x5 Matrix{Float64}:
 0.0  0.0  0.0  0.0  0.0
 0.0  0.0  0.0  0.0  0.0
```

As before the type can be specified

Access/Modify Arrays (Matrix)

- **Access**

```
julia> array2D = [0 1 2 3 4; 5 6 7 8 9]
2x5 Matrix{Int64}:
 0  1  2  3  4
 5  6  7  8  9
```

- **Modify**

2D arrays are row major

```
julia> array2D[2,4]
8

julia> array2D[1,2:4]
3-element Vector{Int64}:
 1
 2
 3

julia> array2D[1,[2,3,4]]
3-element Vector{Int64}:
 1
 2
 3
```

By position

```
julia> array2D[2,4] = 4
4
```

Using range

Don’t forget the dot (pointwise)

```
julia> array2D[1,2:4] .= 4
3-element view(::Matrix{Int64}, 1, 2:4) with eltype Int64:
 4
 4
 4
```

Using vector of positions

```
julia> array2D[1,[2,3,4]] .= 4
3-element view(::Matrix{Int64}, 1, [2, 3, 4]) with eltype Int64:
 4
 4
 4
```

Why does type matters?

- There is three main types in Julia: Int64, Float64 and String
- To find the type of any variable use “typeof”
- Using some of the previous array definition, this gives:

```
julia> array2D = [0 1 2 3 4; 5 6 7 8 9]
2x5 Matrix{Int64}:
 0  1  2  3  4
 5  6  7  8  9

julia> typeof(array2D)
Matrix{Int64} (alias for Array{Int64, 2})
```

```
julia> array = [0 1 2 3 4 5]
1x6 Matrix{Int64}:
 0  1  2  3  4  5

julia> typeof(array)
Matrix{Int64} (alias for Array{Int64, 2})
```

```
julia> array = zeros(Float64,2,5)
2x5 Matrix{Float64}:
 0.0  0.0  0.0  0.0  0.0
 0.0  0.0  0.0  0.0  0.0

julia> typeof(array)
Matrix{Float64} (alias for Array{Float64, 2})
```

```
julia> array = [0, 1, 2, 3, 4, 5]
6-element Vector{Int64}:
 0
 1
 2
 3
 4
 5

julia> typeof(array)
Vector{Int64} (alias for Array{Int64, 1})
```

```
julia> i = 1
1

julia> typeof(i)
Int64
```

Arrays with push!

- Another way to create array is to declare it empty and push elements to it

```
julia> r = []
Any[]

julia> push!(r,1.0)
1-element Vector{Any}:
 1.0

julia> push!(r,2.0)
2-element Vector{Any}:
 1.0
 2.0

julia> push!(r,3.0)
3-element Vector{Any}:
 1.0
 2.0
 3.0
```

Type Any
(can contain anything)

The type can be enforced too:

```
julia> r = Int64[]
Int64[]

julia> push!(r,1.0)
1-element Vector{Int64}:
 1

julia> push!(r,2.0)
2-element Vector{Int64}:
 1
 2

julia> push!(r,3)
3-element Vector{Int64}:
 1
 2
 3
```

Note that even if a Float is pushed, an integer is stored

This can also be done for Vectors (and Matrix)

```
julia> r = []
Any[]

julia> push!(r,[1,2,3])
1-element Vector{Any}:
 [1, 2, 3]

julia> push!(r,[1,2,3])
2-element Vector{Any}:
 [1, 2, 3]
 [1, 2, 3]
```

And converted to matrix using mapreduce function

```
julia> tmat = mapreduce(permutedims, vcat, r)
2x3 Matrix{Int64}:
 1  2  3
 1  2  3
```

Working with arrays

- Creates 2 arrays as follow:

```
julia> array1 = [4,3,2,1]
4-element Vector{Int64}:
 4
 3
 2
 1

julia> array2 = [4,3,2,1.0]
4-element Vector{Float64}:
 4.0
 3.0
 2.0
 1.0
```

Here no comma is used and the Vector is created using Integers

Here a single comma is used and the Vector is created using Float

- Go through the values of the array using a “for” loop

```
for i=1:length(array1)
    val = array1[i]

    # display value of array at position i, and the value of array at position val
    print("val: $(val) array1[val]: $(array1[val])\n")
end
```

What happens if we use array2 instead?

Working with arrays

- Position in an array has to be access with integers (positional index)

```
julia> for i=1:length(array2)
           val = array2[i]

           # display value of array at position i, and the value of array at position val
           print("val: $(val) array1[val]: $(array1[val])\n")
       end
ERROR: ArgumentError: invalid index: 4.0 of type Float64
Stacktrace:
 [1] to_index(i::Float64)
   @ Base .\indices.jl:300
 [2] to_index(A::Vector{Int64}, i::Float64)
   @ Base .\indices.jl:277
 [3] _to_indices1(A::Vector{Int64}, inds::Tuple{Base.OneTo{Int64}}, I1::Float64)
   @ Base .\indices.jl:359
 [4] to_indices
   @ .\indices.jl:354 [inlined]
 [5] to_indices
   @ .\indices.jl:345 [inlined]
 [6] getindex(A::Vector{Int64}, I::Float64)
   @ Base .\abstractarray.jl:1296
 [7] top-level scope
   @ .\REPL[60]:5
```

- Luckily Floats (including Vector{Float64}) can be converted to integer as:

```
julia> array2 = Int64.(array2)
4-element Vector{Int64}:
 4
 3
 2
 1
```

First Julia plot

- First add a plotting package “Plots”

  ] add Plots

  “]” opens the package manager

```
(@v1.9) pkg> add Plots
   Resolving package versions...
```

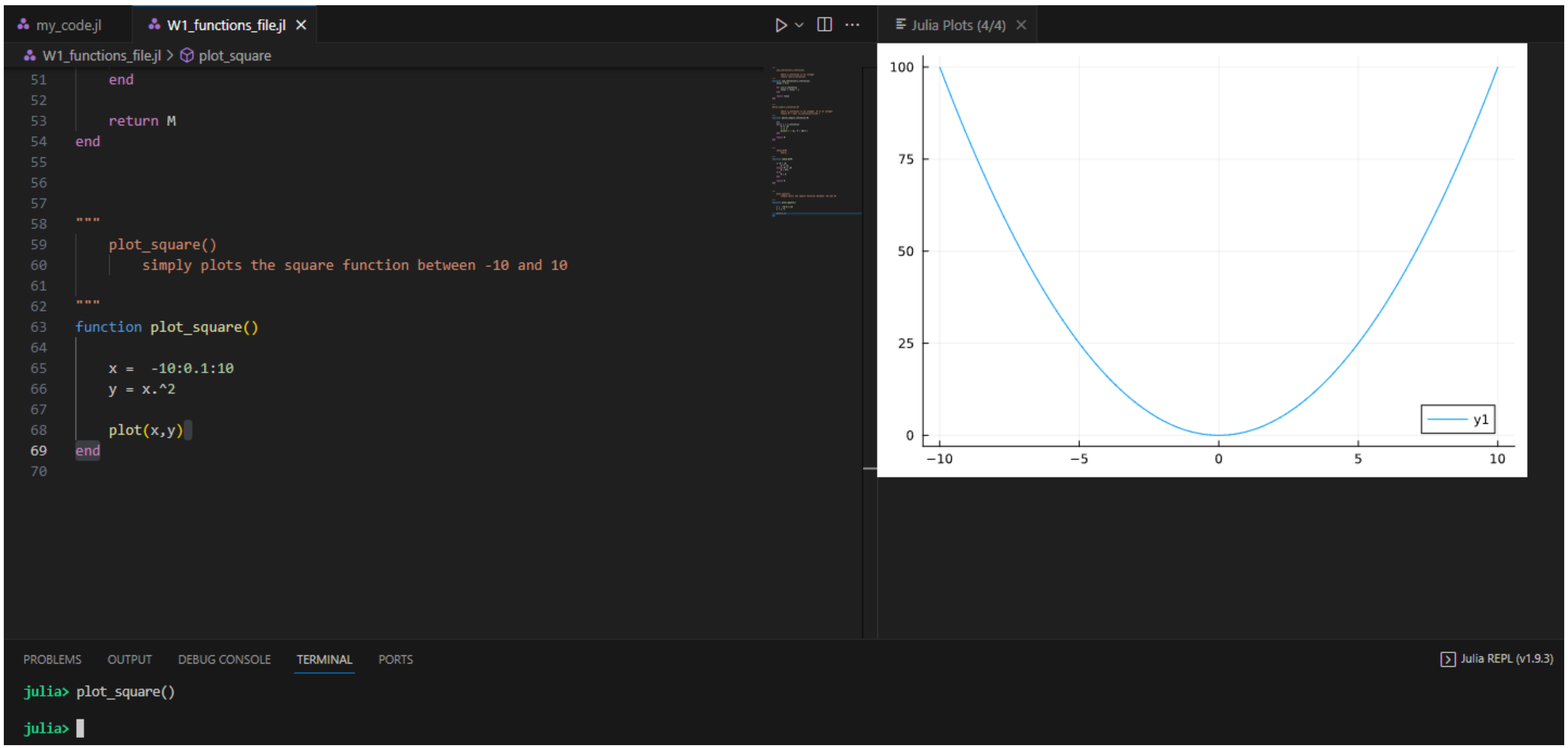
  It can take a few minutes as other default packages are updated

- Create a plot_square function (still in functions_file.jl)

```julia

"""
    plot_square()
        simply plots the square function between -10 and 10

"""
function plot_square()

    x =  -10:0.1:10
    y = x.^2

    plot(x,y)
end

```

First Julia plot

- Execute “my_code.jl”
- In the REPL (terminal) type: plot_square()

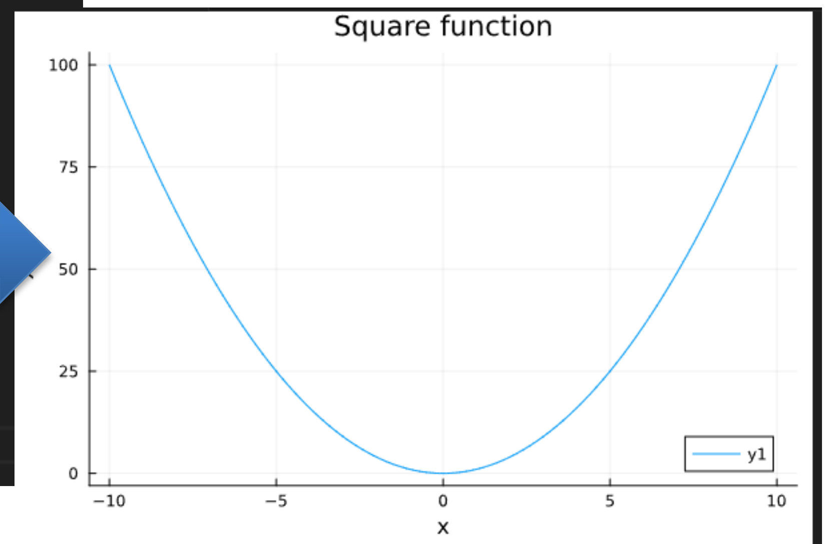


→ The figures are displayed within VS code in a dedicated window

Add title and label

- Modify the function as

```julia
"""
    plot_square()
        simply plots the square function between -10 and 10

"""
function plot_square()

    x =  -10:0.1:10
    y = x.^2

    plot(x,y)
    title!("Square function")
    xlabel!("x")
    ylabel!("x²")
end
```



→ Here the "**!**" means that the title, x- and y-labels will be added to previously declared plot.

Adding another curve to existing plot

- Modify the function as

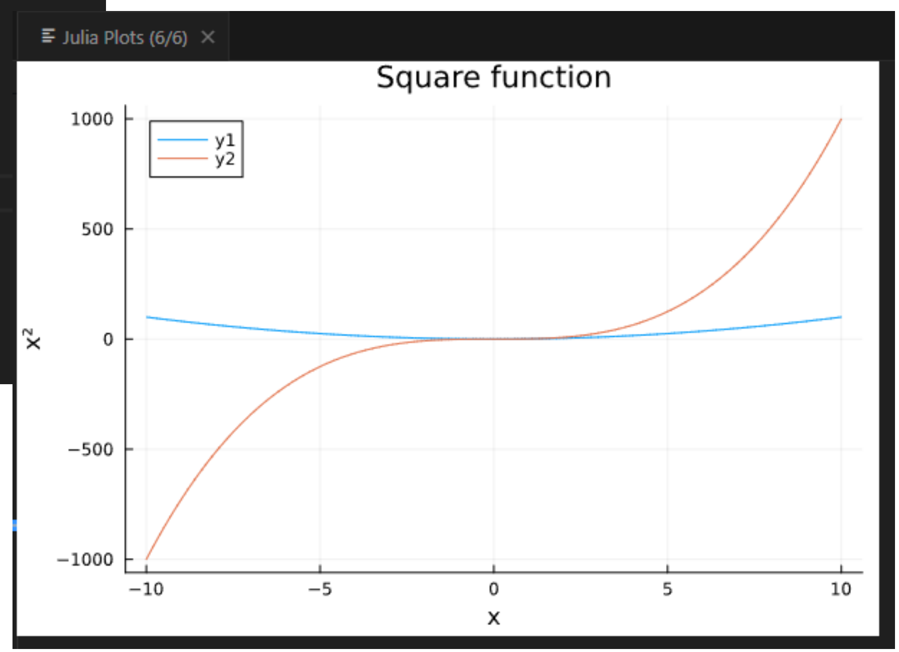
```julia
"""
    plot_square()
        simply plots the square function between -10 and 10

"""
function plot_square()

    x  =  -10:0.1:10
    y  = x.^2
    yp = x.^3

    plot(x,y)
    plot(x,yp)
    title!("Square function")
    xlabel!("x")
    ylabel!("x²")
end
```

What happens here?

Adding another curve to existing plot

- The “!” is also used to add curves to an existing plot

```julia
"""
    plot_square()
        simply plots the square function between -10 and 10
"""
function plot_square()

    x  =  -10:0.1:10
    y  = x.^2
    yp = x.^3

    plot(x,y)
    plot!(x,yp)
    title!("Square function")
    xlabel!("x")
    ylabel!("x²")
end
```



Exercise 1a

Assume we have an initial amount of money on the bank (M=1000) and each year we save some money (dM=100)

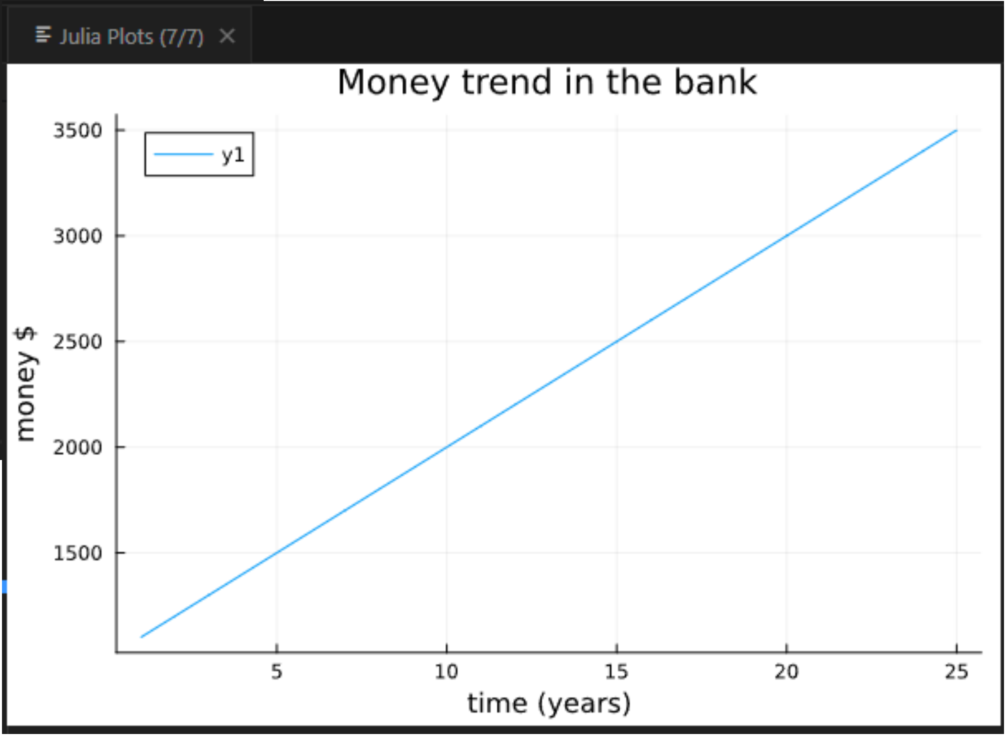
1. What will the amount of money be after 25 years? Create Julia function for this.
2. Plot the total amount of money (M) versus time in years.

Example of solution

```julia
"""
    exercice_1(M, dM, n_years)
        Assumes we have an initial amount of money on the bank (M=1000)
            and each year we save some money (dM=100)
        M is starting_money
        dM is yearly_savings
        n_years is the number fo years of savings
"""
function exercice_1(M, dM, n_years)

    Mtotal = zeros(n_years)

    for i=1:n_years
        M = M + dM;
        Mtotal[i] = M
    end

    plot(Mtotal)
    title!("Money trend in the bank")
    xlabel!("time (years)")
    ylabel!("money \$")
end
```

```
help?> exercice_1
search: exercice_1

  exercice_1(M, dM, n_years)
      Assumes we have an initial amount of money on the bank (M=1000)
          and each year we save some money (dM=100)
      M is starting_money
      dM is yearly_savings
      n_years is the number fo years of savings
```

```
julia> include("W1_functions_file.jl")
exercice_1

julia> exercice_1(1000, 100,25)
```



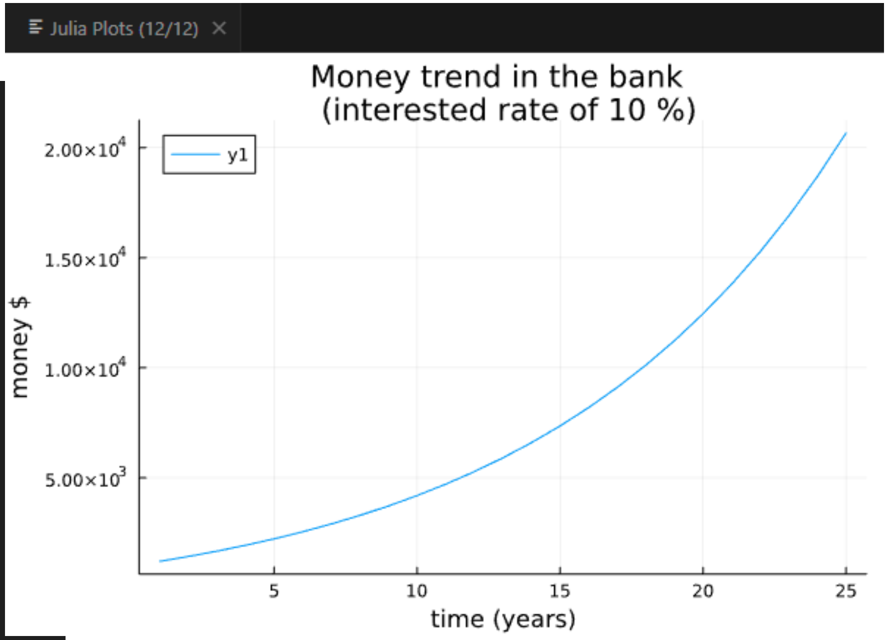
Exercise 1b

Most banks give an interest on the money you have and pay that at the end of the year. Let’s assume that the interest rate is 10%.

1. Duplicate the previous function and call it exercice_1b.
2. Modify the function to account for interest rate

Example of solution

```julia
"""
    exercice_1b(M, dM, n_years, interest_rate)
        Assumes we have an initial amount of money on the bank (M=1000)
            and each year we save some money (dM=100)
        M is starting_money
        dM is yearly_savings
        n_years is the number fo years of savings
        interest_rate is the interest rate of the bank in in %
"""
function exercice_1b(M, dM, n_years, interest_rate)

    Mtotal = zeros(n_years)

    for i=1:n_years
        M = M + M*interest_rate/100
        M = M + dM;
        Mtotal[i] = M
    end

    plot(Mtotal)
    title!("Money trend in the bank \n (interested rate of $interest_rate %)")
    xlabel!("time (years)")
    ylabel!("money \$")
end
```




```
julia> include("W1_functions_file.jl")
exercice_1b

julia> exercice_1b(1000, 100,25, 10)
```

Exercise 1c

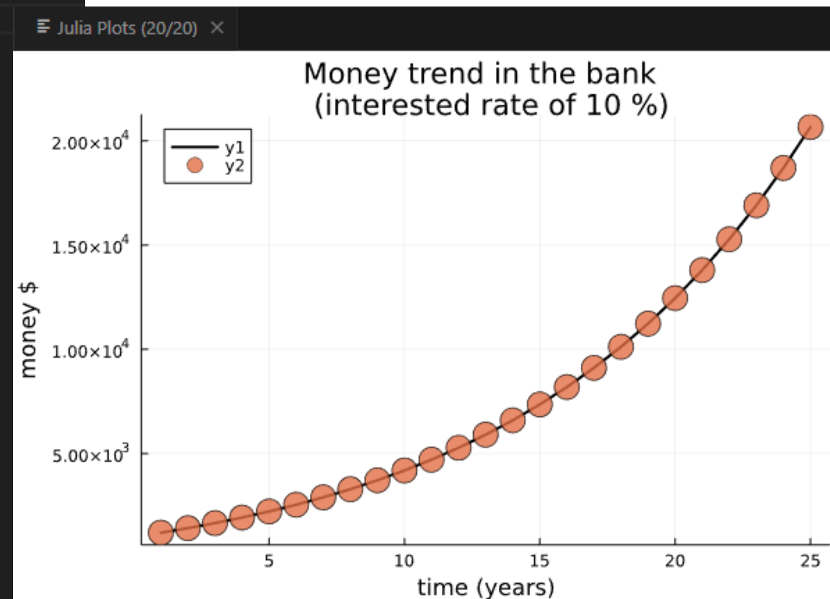
1. Explore plotting options (Plots.jl)

   use online doc:
   https://docs.juliaplots.org/latest/tutorial/

1. Improve "exercise_1b()" -> "exercise_1c()"
   1. Change colors of the curve
   2. Display points on top of the curve function (scatter)

Example of solution

```julia
"""
exercice_1c(M, dM, n_years, interest_rate)
    Assumes we have an initial amount of money on the bank (M=1000)
        and each year we save some money (dM=100)
    M is starting_money
    dM is yearly_savings
    n_years is the number fo years of savings
    interest_rate is the interest rate of the bank in in %
"""
function exercice_1c(M, dM, n_years, interest_rate)

    Mtotal = zeros(n_years)

    for i=1:n_years
        M = M + M*interest_rate/100
        M = M + dM;
        Mtotal[i] = M
    end

    plot(Mtotal, lc=:black, lw=2)
    scatter!(Mtotal, lc=:red, ms=10, ma=0.8)
    title!("Money trend in the bank \n (interested rate of $interest_rate %)")
    xlabel!("time (years)")
    ylabel!("money \$")
end
```



Save the plot to a file as:

```julia
julia> savefig("save_figure_test.png")
```

(The file is saved in the working directory)

To go further

- Exercise 1d: fit an equation through the datapoints

Copy function “exercise_1c()” to “exercice_1d()”

Use CurvFit.jl to fit the points
(julia>] add CurveFit)

```julia
using CurveFit

x = 0.0:0.02:2.0
y0 = @. 1 + x + x*x + randn()/10
fit = curve_fit(Polynomial, x, y0, 2)
y0b = fit.(x)
```

Use online doc and provided examples
https://juliapackages.com/p/curvefit

Try different polynomial exponent and plot the results using Plots.jl