Julia introduction

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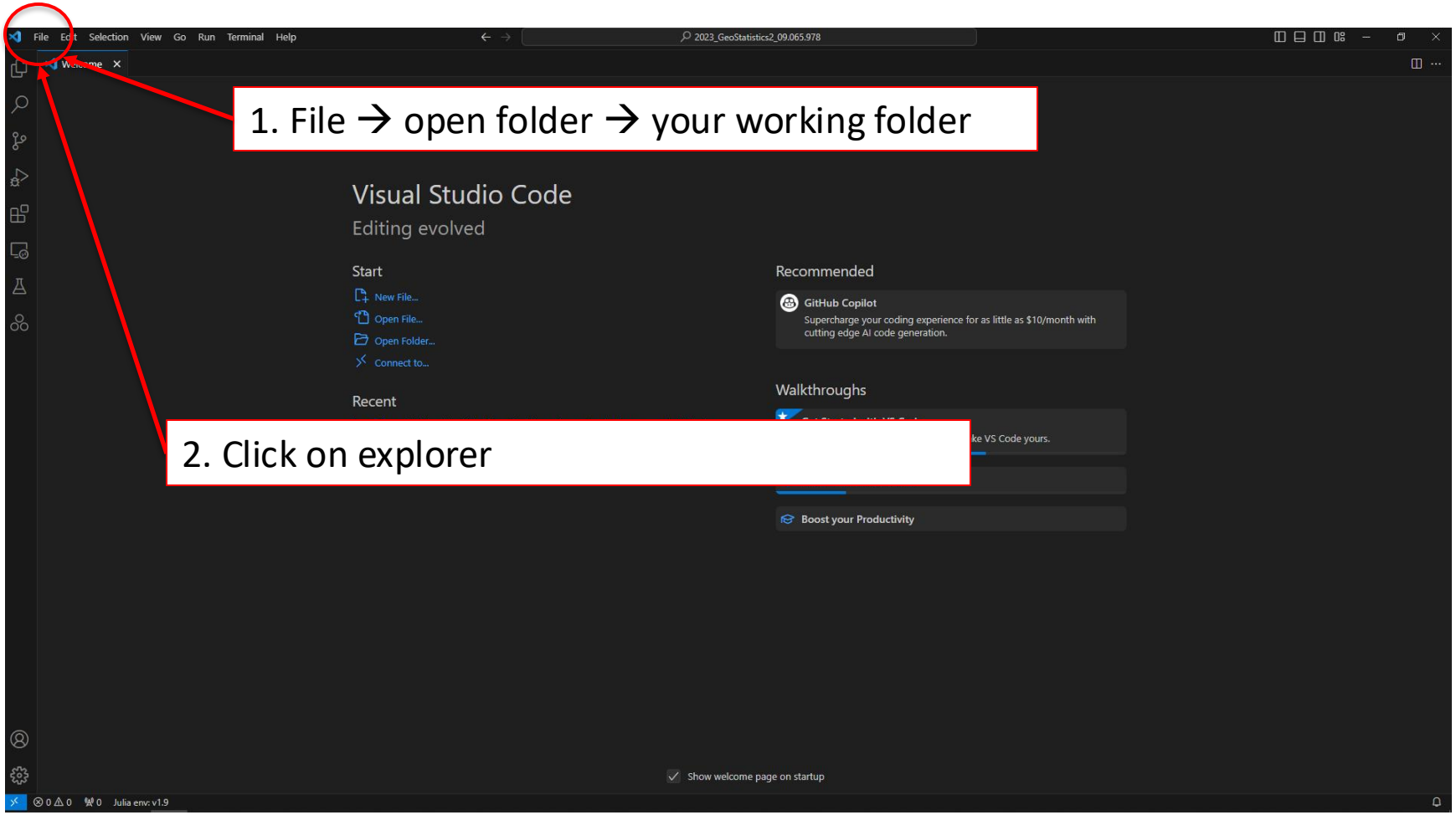
VS Code


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...
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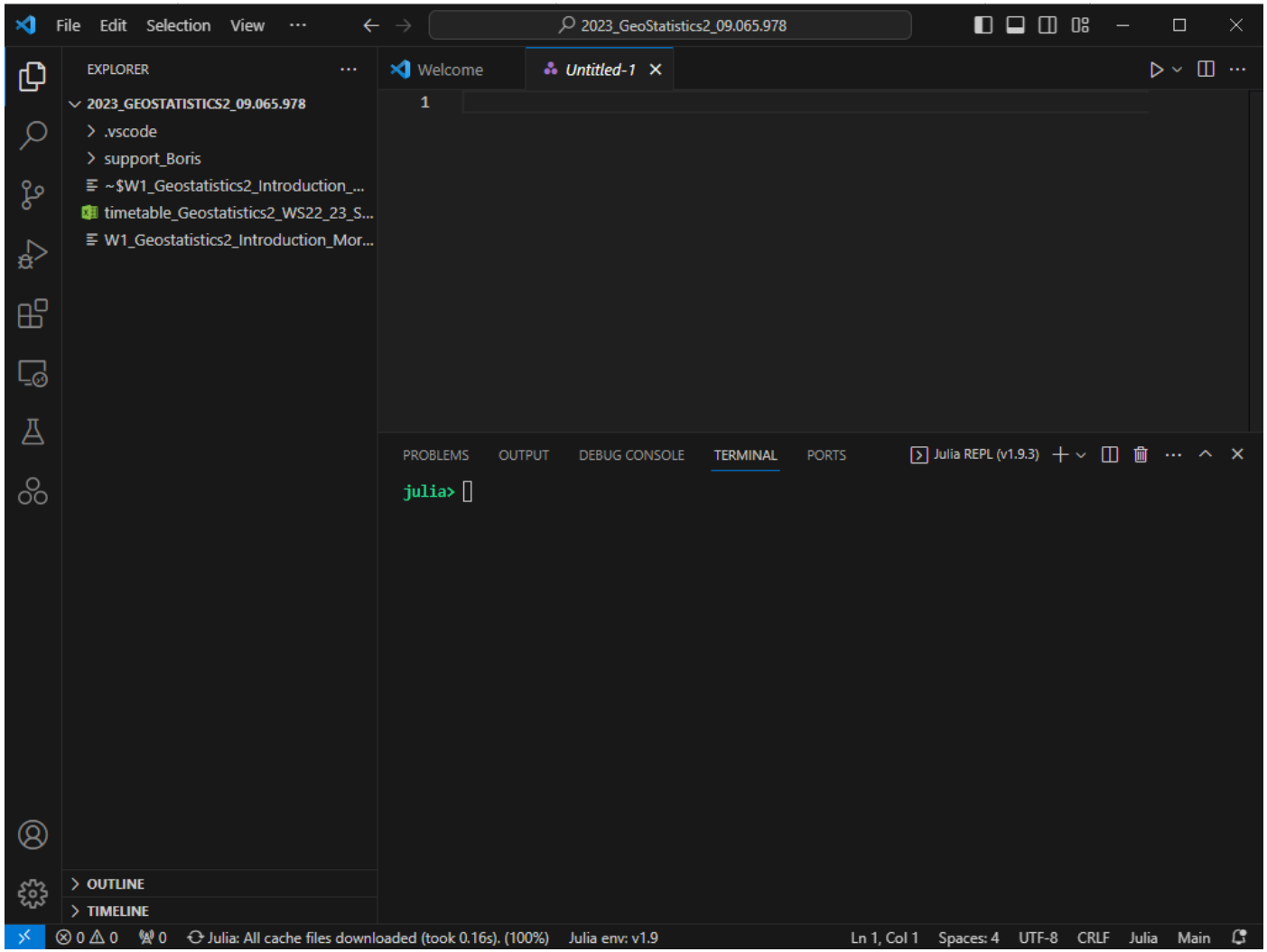
Walkthroughs
ke VS Code yours.
Boost your Productivity
2. Click on explorer
Show welcome page on startup
Julia env: v1.9

Julia REPL (demonstration)



Julia REPL (read-eval-print loop)

Terminal or prompt pasting

- Julia terminal

  computation space, execute scripts…

-] package manager

  add/update packages

- ; shell

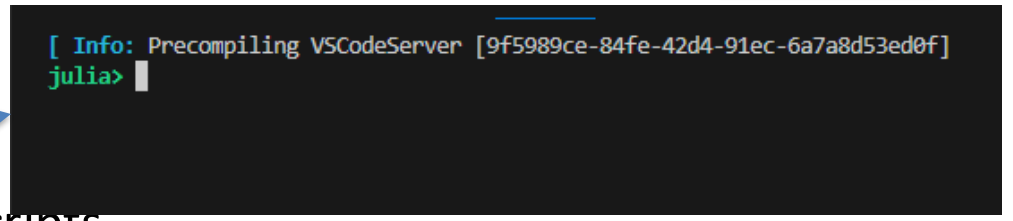
  Changing directories

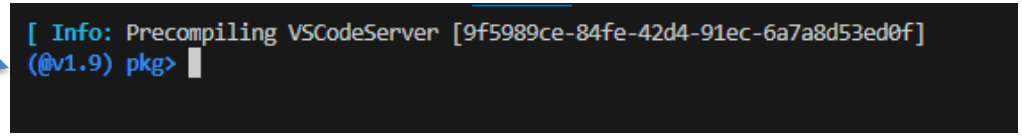
- ? help

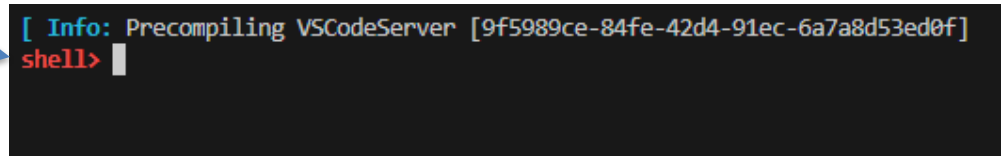
  provide help with functions

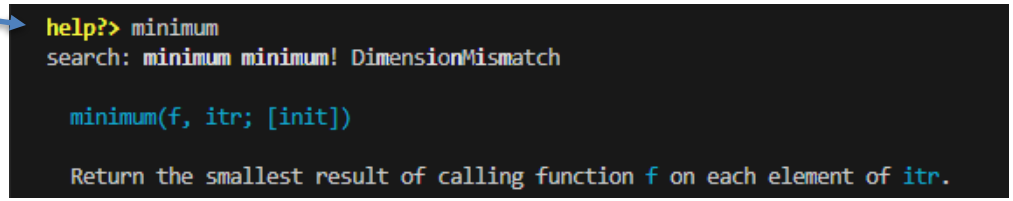
- Backspace

  back to julia terminal





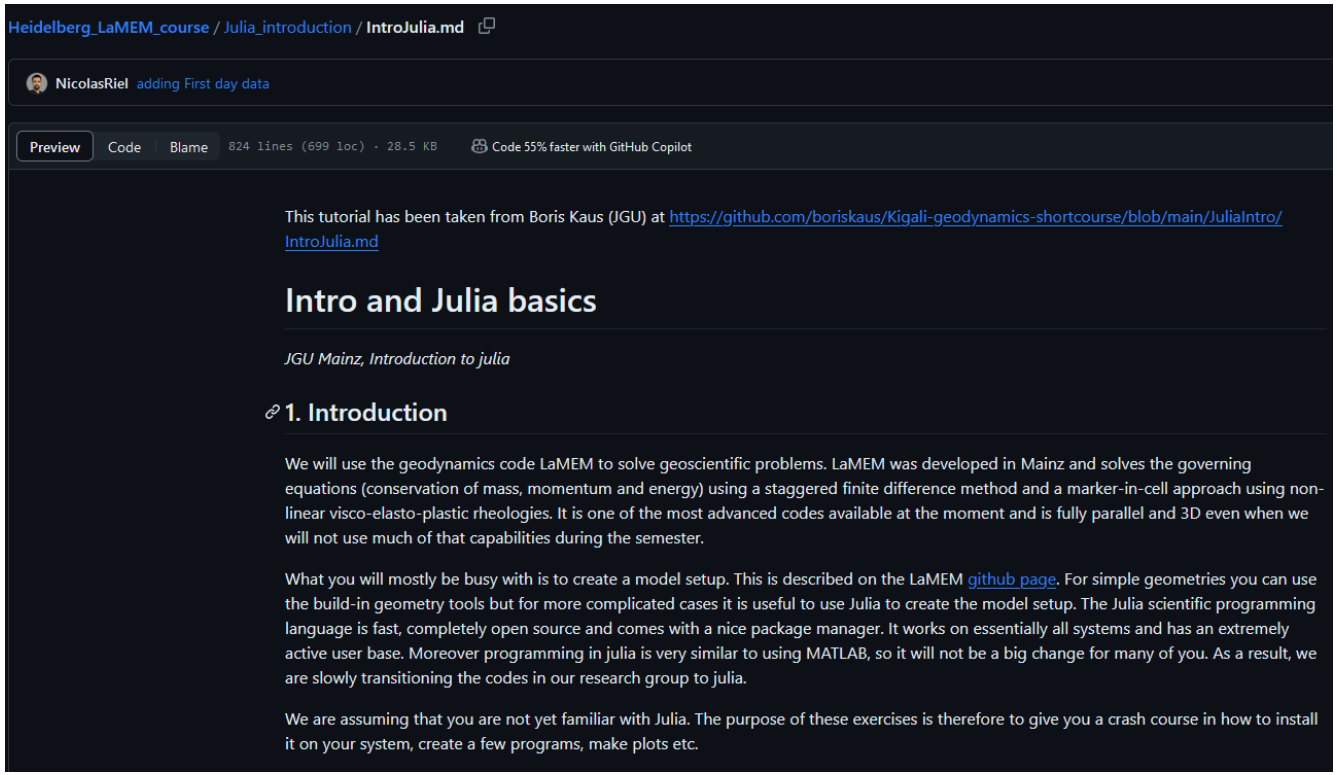




Julia introduction

- Access the following link and complete the Julia introduction

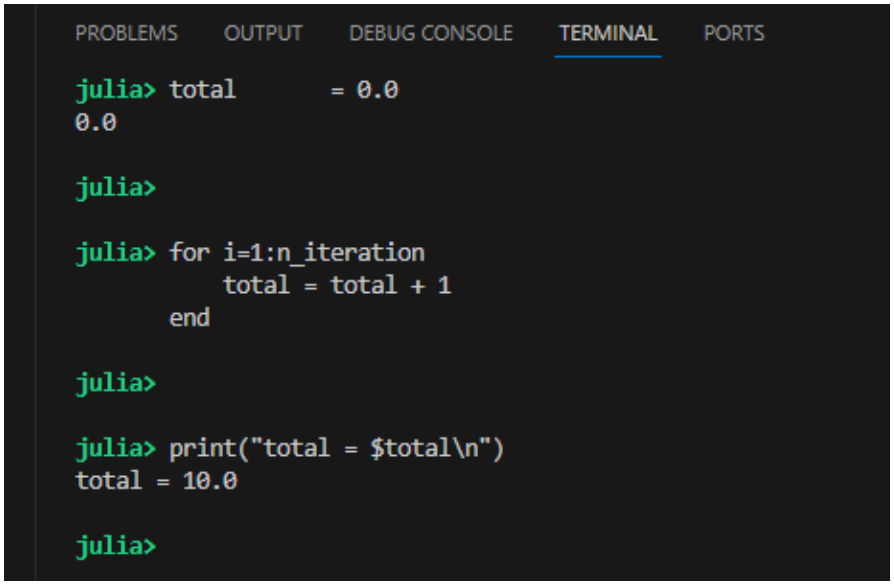
https://github.com/NicolasRiel/Heidelberg_LaMEM_course/blob/main/Julia_introduction/IntroJulia.md



“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
```

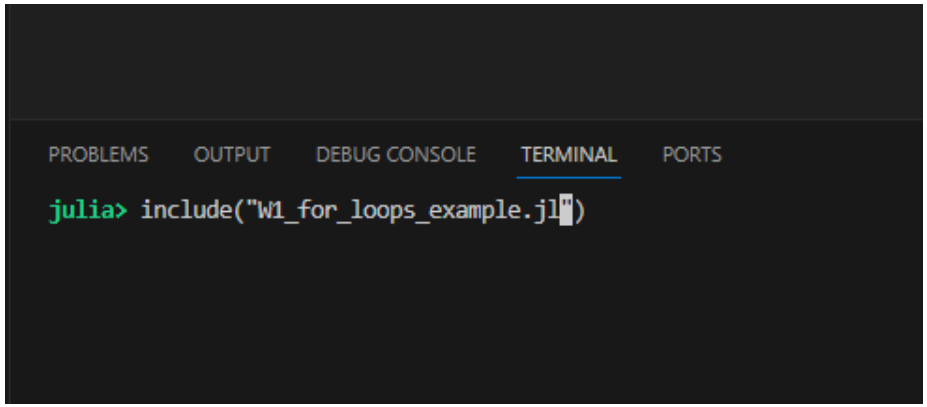


- Paste it in the terminal

“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 total` 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>
```

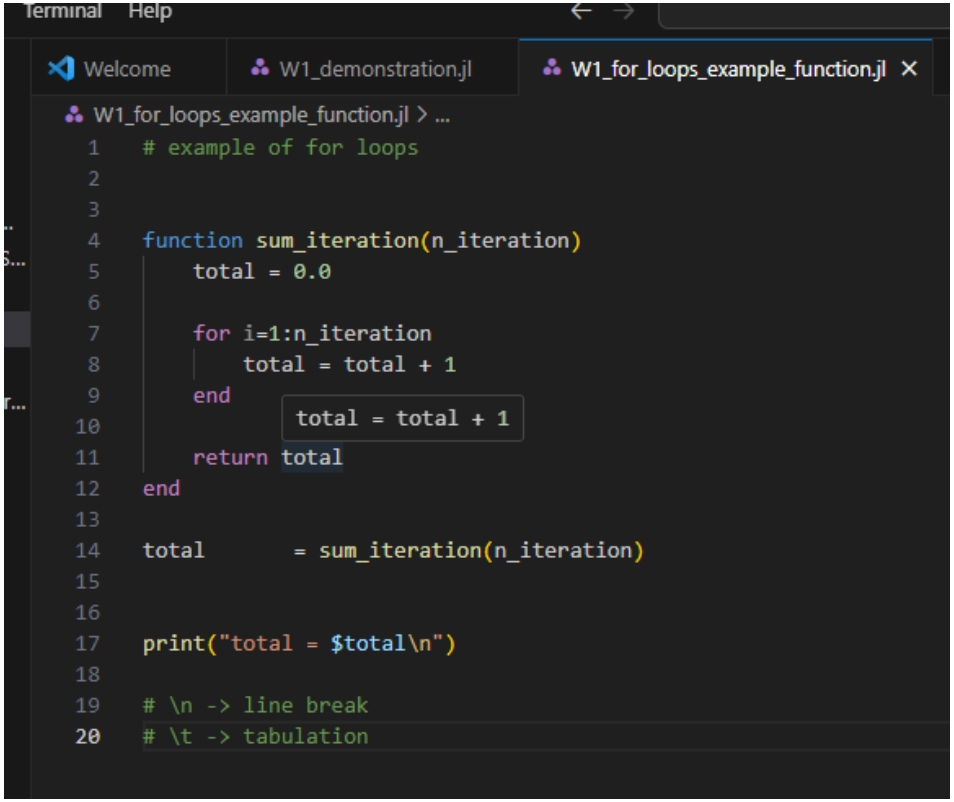
- Here Julia does not know the “scope” of the variable total.
- Scope can be seen as the region of a code where the variable is visible/exists
- The main file here can been thought as an “open space”

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

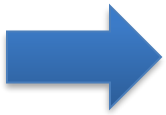
```
1   # example of for loops
2
3   n_iteration = 10
4   total       = 0.0
5
6   for i=1:n_iteration
7       total = total + 1
8   end
9
10  print("total = $total\n")
11
12  # \n -> line break
13  # \t -> tabulation
```

Functions

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




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

julia>
```



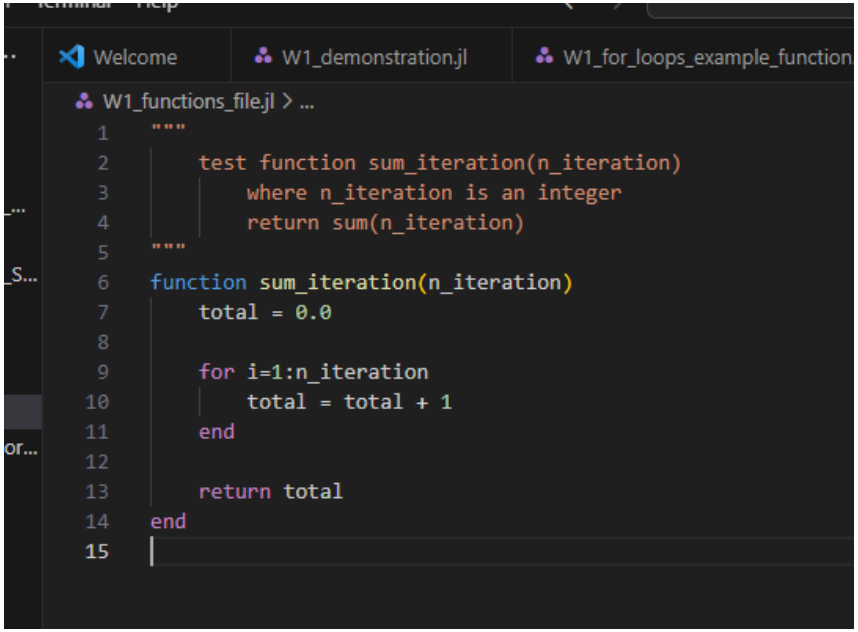
Solve the “scope” problem

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

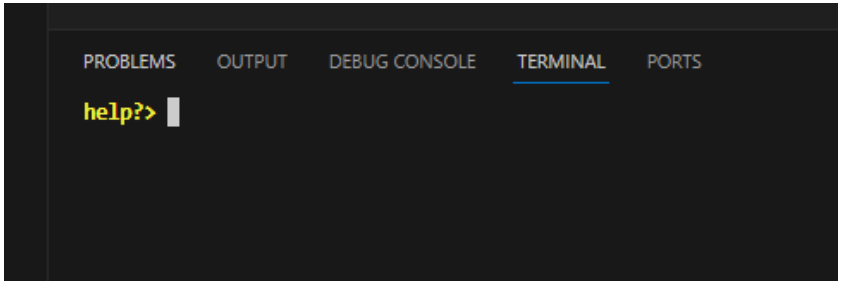
```
"""
    sum_iteration(n_iteration)
        where n_iteration is an integer
        return sum(n_iteration)
"""
```

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

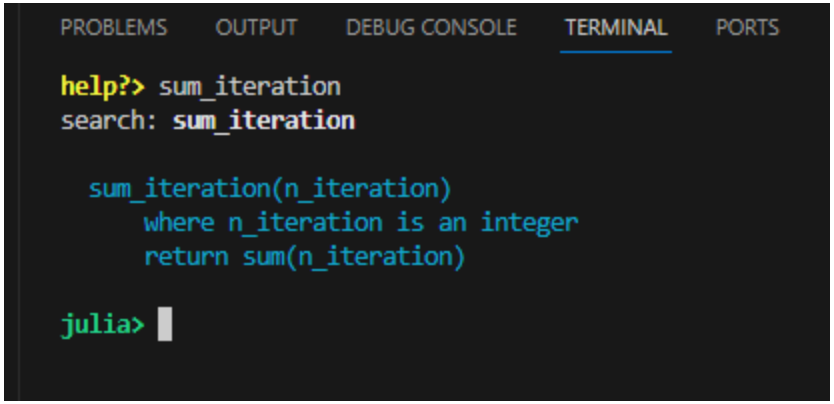


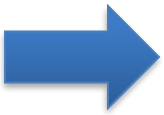
Forgot what the function(s) does?

- 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()
```

```
23  """
24  while_loop(n_iteration,M)
25
26      where n_iteration is an integer, M is an integer
27      return M + sum( (n_iteration-1)*10 )
28  """
29  function while_loop(n_iteration=10,M=50)
30
31      i=1
32      while i < n_iteration
33          M += 10
34          i -= 1
35          print("i = $i, M = $M\n")
36      end
37
38      return M
39  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”)

```
22  M = check_M(M)
23
24  print("check_M(M) = $M\n")
25
```

```
37
38  """
39      check_M(M)
40          where...
41
42  """
43  function check_M(M)
44
45      if M < 10
46          M += 25
47      elseif M == 10
48          M = M^2
49      else
50          M = 0
51      end
52
53      return M
54  end
```

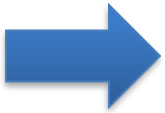
Arrays (Vector)

- 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
```

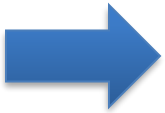
This creates and fill the Vector with given values

```
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

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

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

By position

Using range

Using vector of positions

- **Modify**

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

Don’t forget the dot (pointwise)

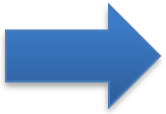
```
julia> array[1:4] .= 4
4-element view(::Vector{Int64}, 1:4) with eltype Int64:
 4
 4
 4
 4
```

```
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)

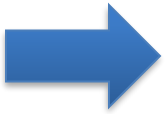
- There is several different ways to declare an array in Julia for instance:

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



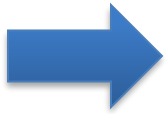
This creates and fill the matrix with given values

```
julia> zeros(2,5)
2×5 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)
2×5 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]
2×5 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]
2×5 Matrix{Int64}:
 0  1  2  3  4
 5  6  7  8  9

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

```
julia> array = zeros(Float64,2,5)
2×5 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> i = 1
1

julia> typeof(i)
Int64
```

```
julia> array = [0 1 2 3 4 5]
1×6 Matrix{Int64}:
 0  1  2  3  4  5

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

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]
```

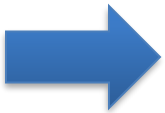
And converted to matrix using mapreduce function

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

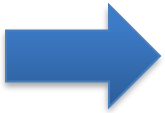
Working with arrays

- 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

```
1  for i=1:length(array1)
2      val = array1[i]
3
4      # display value of array at position i, and the value of array at position val
5      print("val: $(val) array1[val]: $(array1[val])\n")
6  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...
```

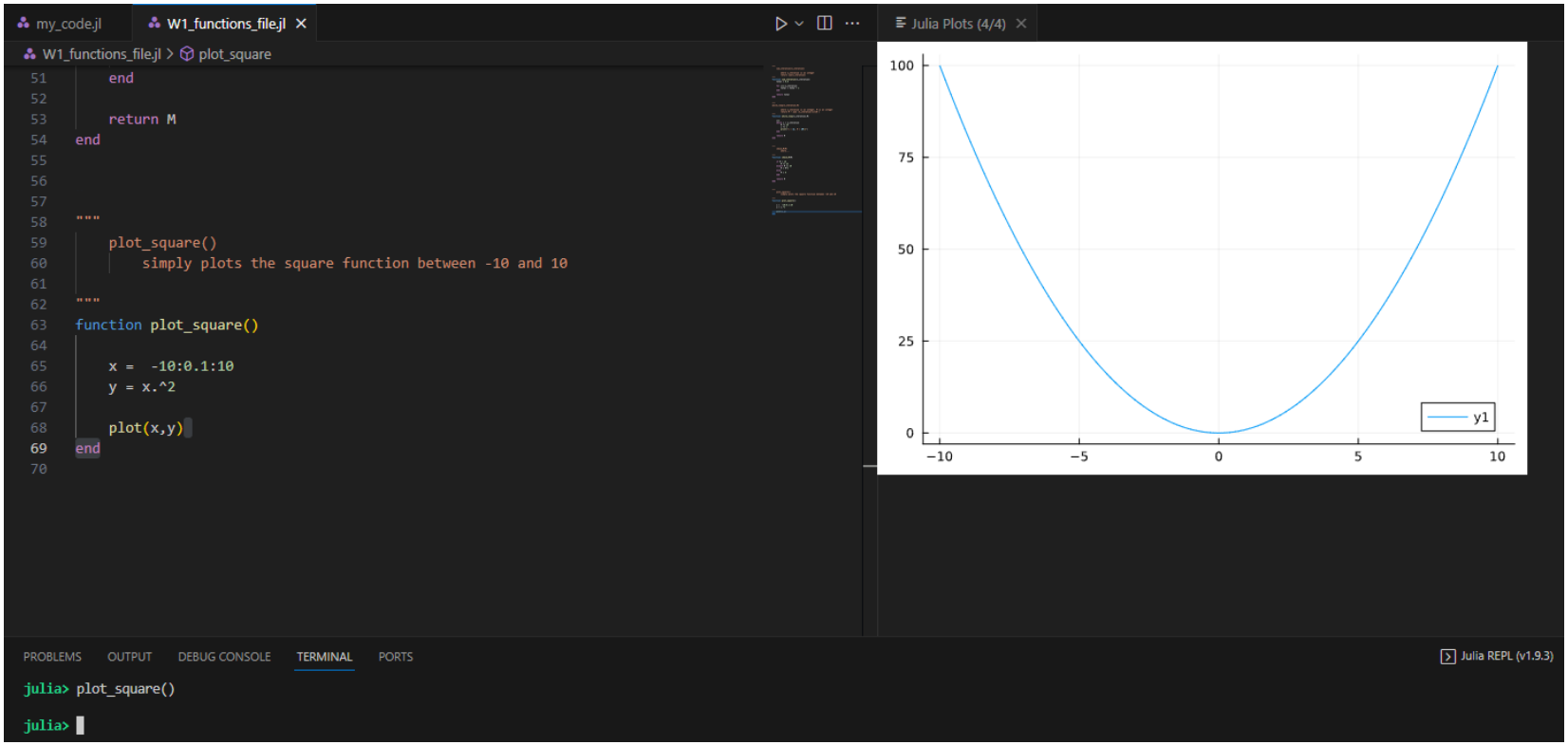
  It can take a few minutes as other default packages are updated

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

```
57
58  """
59      plot_square()
60          simply plots the square function between -10 and 10
61
62  """
63  function plot_square()
64
65      x =  -10:0.1:10
66      y = x.^2
67
68      plot(x,y)
69  end
70
```

First Julia plot

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

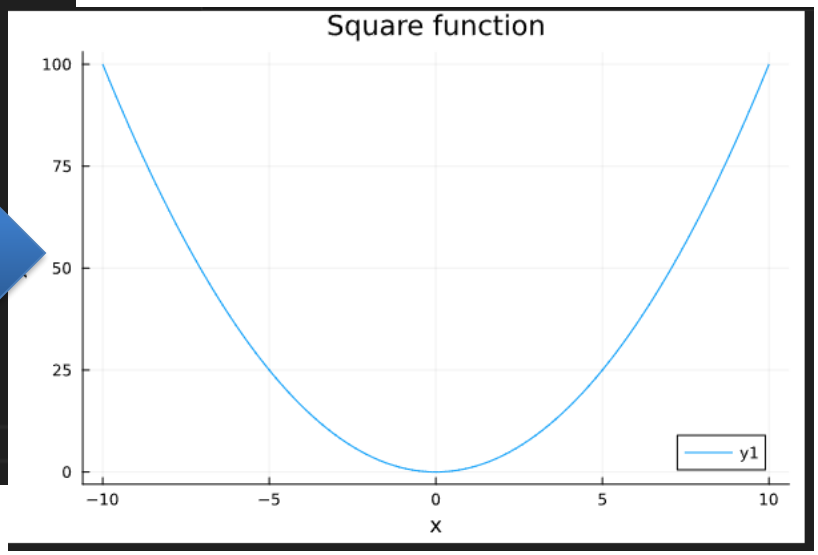


→ The figures are displayed within VS code in a dedicated window

Add title and label

- Modify the function as

```
"""
    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

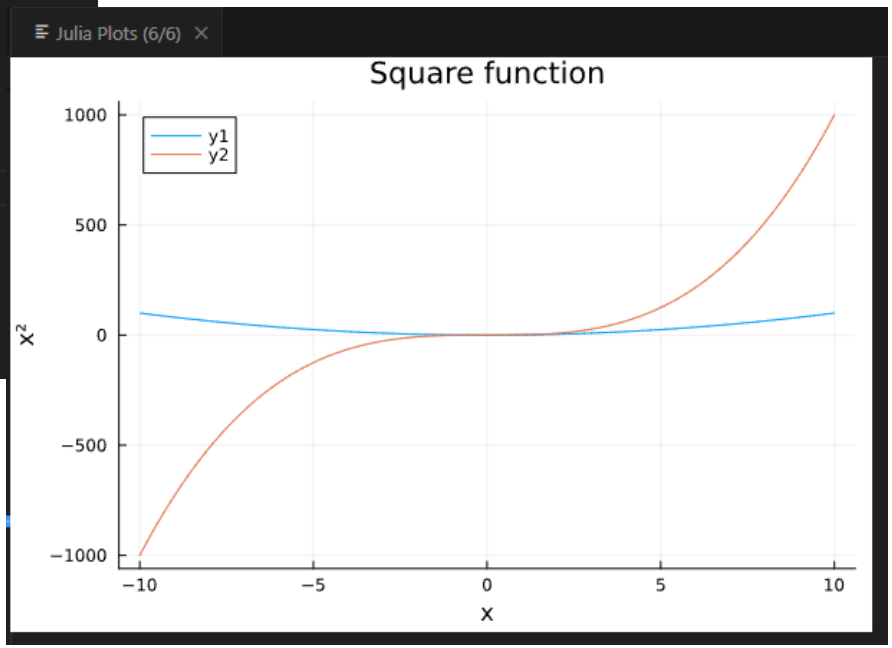
```
"""
    plot_square()
        simply plots the square function between -10 and 10

"""
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

```
"""
    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)

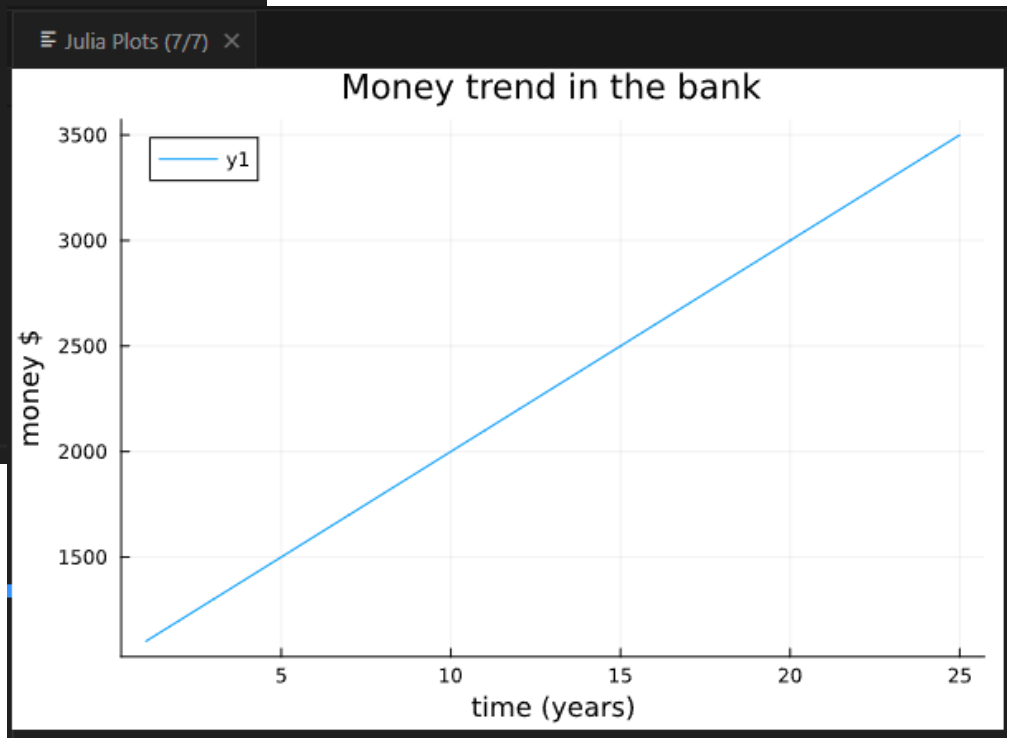
1. What will the amount of money be after 25 years? Create Julia function for this.
2. Plot the total amount of money (M) versus time in years.

Example of solution

```
"""
    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)
```



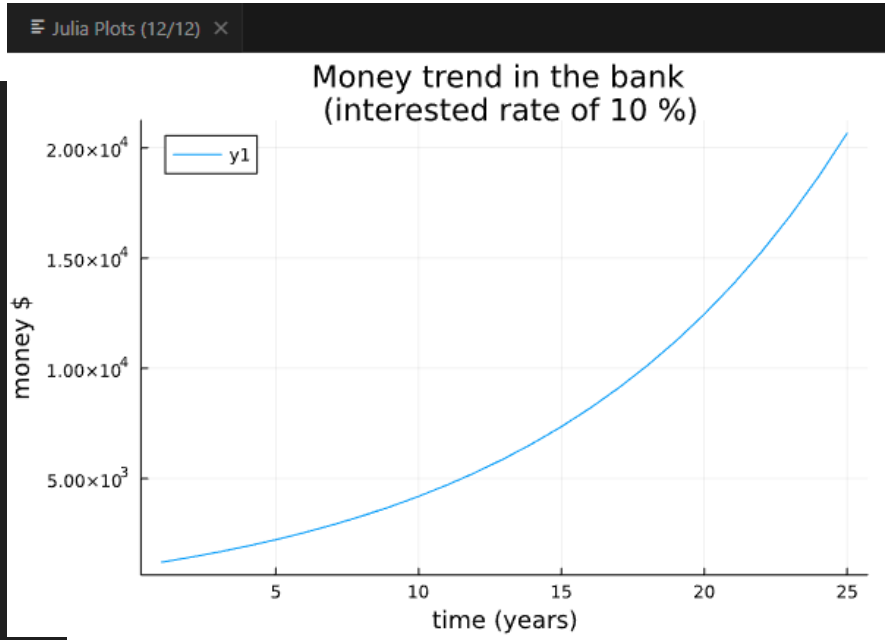
Exercise 1b

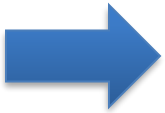
Most banks give an interest on the money you have and pay that at the end of the year. Let's assume that the interest rate is 10%.

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

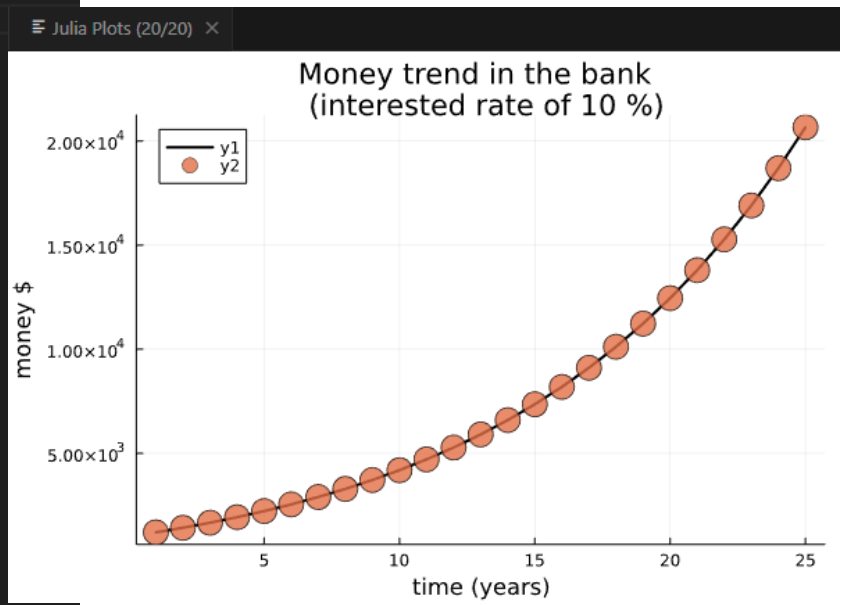
1. Explore plotting options (Plots.jl)

   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

```
129 """
130     exercice_1c(M, dM, n_years, interest_rate)
131         Assumes we have an initial amount of money on the bank (M=1000)
132             and each year we save some money (dM=100)
133         M is starting_money
134         dM is yearly_savings
135         n_years is the number fo years of savings
136         interest_rate is the interest rate of the bank in in %
137 """
138 function exercice_1c(M, dM, n_years, interest_rate)
139
140     Mtotal = zeros(n_years)
141
142     for i=1:n_years
143         M = M + M*interest_rate/100
144         M = M + dM;
145         Mtotal[i] = M
146     end
147
148     plot(Mtotal, lc=:black, lw=2)
149     scatter!(Mtotal, lc=:red, ms=10, ma=0.8)
150     title!("Money trend in the bank \n (interested rate of $interest_rate %)")
151     xlabel!("time (years)")
152     ylabel!("money \$")
153 end
```



Save the plot to a file as:

```
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)

```
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