Programming basics

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Programming in Julia

- We will now dive straight into programming in Julia, starting with simple examples and concepts, progressing step-by-step to more complicated topics
- To follow this lecture, you need to have a working Julia installation: see the homework on Installing Julia
- For today, don't worry too much about whether what we do is useful – what we are doing is establishing a *foundation* for later for the actually useful stuff…

Plan

1. Variables and types
2. Arrays and broadcasting
3. Functions
4. Custom types
5. First look at random numbers
6. Interpreted vs. compiled languages

Variables and assignments

- In programming, a **variable** is a "storage box" that stores data for later use
- The data is **assigned** to the variable using the `=` operator
- Here, we assign the number 5 to a variable named `my_number`:

```
my_number = 5
```

- We can now do things such as:

```
my_number + my_number
```

```
10
```

Fundamental types

- Variables can store different **types** of data:
  - Integers: `1`, `2`, `-100`, …
  - Floating-point numbers ("floats"): `3.14`, `pi`, `1.0`, …
  - Booleans: `true`, `false`
  - Strings: `"John"`, `"Mary"`
  - Arrays: `[1, 2, 3, 4]`, `[1 2 3 4]`
  - And some others… we'll meet them later

Arithmetic operations

- Arithmetic operations are mostly self-explanatory. For example:

```
number1 = 15
number2 = 20
number3 = 10*(number1 + number2) - number1/number2
number3
```

```
349.25
```

String concatenation

- Julia overloads the `*` operator for strings too:

```
string1 = "This "
string2 = "is a"
string3 = " sentence"
string1 * string2 * string3 * "!"
```

```
"This is a sentence!"
```

Arrays

- An array is a (possibly multidimensional) collection of objects
  - A one-dimensional array is a vector, a two-dimensional array is a matrix, and so on
- Usually we work with arrays of numbers. They are easy to create:

```
my_array = [10, 20, 30, 40]
```

```
4-element Vector{Int64}:
 10
 20
 30
 40
```

Accessing array contents

- The elements of an array can be accessed one-by-one by referencing their location or **index** in the array:

```
my_array = [10, 20, 30, 40]
my_array[1]
```

```
10
```

or

```
my_array[2]
```

```
20
```

- The special keyword `end` fetches the last element:

```
my_array[end]
```

```
40
```

- Arrays can also be subsetted:

```
my_array[2:3]
```

```
2-element Vector{Int64}:
 20
 30
```

Broadcasting

- Suppose I want to add `1` to each number in `my_array`
- The following will **not** work:

```
my_array + 1
```

- Why? Because mathematically the operation "add a scalar into a vector" is undefined
- To apply an operator **elementwise** to each element in an array, we can prefix the operator with a period. In Julia-speak, this is called **broadcasting**.

```
my_array .+ 1
```

```
4-element Vector{Int64}:
 11
 21
 31
 41
```

Type mismatch

- Why does the following not work?

```
my_string = "My shoe size is: "
my_number = 41
my_string * my_number
```

- To make it work, we need to explicitly **convert** the integer into a string:

```
my_string = "My shoe size is: "
my_number = 41
my_string * string(my_number)
```

```
"My shoe size is: 41"
```

Functions

- A **function**, sometimes also known as a **subroutine**, is a **reusable** piece of code that performs, well, some function…
- We define it once and then can use it as many times as we like
- A function can (but need not) take inputs – these are known as the function's **arguments**
- A function can (but need not) give an output – this is known as the function's **return value**

Functions: example

- Here is a function that takes two arguments, an array and a scalar number, and adds the scalar to each element of the array
- I'm calling the function `add_elementwise`

```
function add_elementwise(array, scalar)
  result = array .+ scalar
  return result
end
```

```
add_elementwise (generic function with 1 method)
```

- We can now **call** the function on particular arrays and numbers:

```
my_array = [10, 20, 30, 40]
add_elementwise(my_array, 1)
```

```
4-element Vector{Int64}:
 11
 21
 31
 41
```

```
add_elementwise(my_array, -23.5)
```

```
4-element Vector{Float64}:
 -13.5
  -3.5
   6.5
  16.5
```

Exercise

Write a function with the following properties:

- The function's name is `announce_age`
- The function takes two arguments, the first a person's name, the second a number that is that person's age
- The function's return value is a string which announces the person's age in this format: `"John is 40 years old"`

Answer

Here is the function definition:

```
function announce_age(name, age)
  return name * " is " * string(age) * " years old"
end
```

```
announce_age (generic function with 1 method)
```

Let's test it:

```
announce_age("John", 40)
```

```
"John is 40 years old"
```

Custom types ("classes" and "objects")

- Idea of **object-oriented programming** (OOP): we can make custom types (**classes**) which are instantiated as **objects**
  - Programming ABMs in a language that does not support this would be very cumbersome
- In Julia, custom types are defined by way of a special keyword, `struct`
- A custom type is effectively a combination of variables called the type's **fields**
- If the fields need to be modifiable later in the program, we use `mutable struct` instead of `struct`

Custom types: example

- Suppose we want to represent a person by way of their name, their age and their shoe size
- Since these fields (at least age) need to be modifiable, we use a `mutable struct`:

```
mutable struct Person
  name::String
  age::Int
  shoesize::Float64
end
```

- Here,
  - `name::String` means the field called `name` is of type string, etc.
  - `Int` is an integer
  - in `Float64`, the number specifies the precision of the floating-point number (related to how many decimals it can store)
- We can now **construct** an instance of the `Person` custom type, a `Person` object, and store it in a variable:

```
jane = Person("Jane", 35, 39.5)
```

```
Person("Jane", 35, 39.5)
```

- To **access** the fields of an object, we use the following dot syntax:

```
jane.name
```

```
"Jane"
```

Exercise

Write three functions:

1. A function that takes a `Person` object as argument and returns their shoe size
2. A function that takes a `Person` object and a string as argument, and sets the person's name to be the string supplied as argument
3. A function that increments a `Person` object's age by one

Answer

```julia
function get_shoesize(x)
  return x.shoesize
end

function set_name(x, y)
  x.name = y
end

function become_older(x)
  x.age = x.age + 1
end
```

Explicit type specifications

Note that it is possible (and often good practice) to explicitly set the types of function arguments:

```julia
function get_shoesize(x::Person)
  return x.shoesize
end

function set_name(x::Person, y::String)
  x.name = y
end

function become_older(x::Person)
  x.age = x.age + 1
end
```

Getters and setters

- Functions that return an object's field are sometimes known as **getters**. Functions that set a field are known as **setters**.
- In Julia, it is customary to append an exclamation point to the name of every setter function. This is to warn users of the function that the function modifies something in the object.
- Thus, we would rather write:

```
function set_name!(x::Person, y::String)
  x.name = y
end
```

Array comprehensions

- What if we wanted to create 3 `Person`s? Easy:

```
person1 = Person("Jane", 35, 39.5)
person2 = Person("John", 44, 43.0)
person3 = Person("Bob", 65, 42.33)
```

- What if we wanted to create 1000 `Person`s?

- Here we can use a powerful feature known as an **array comprehension**. The following creates 1000 persons, each with the same default fields (we'll later see how to modify this), and places them in an array. The array is returned and stored in the `population` variable:

```
population = [Person("M. Musterperson", 0, 0.0) for i in 1:1000]
```

- The `i` variable is a dummy variable that only exists for the duration of the array comprehension.

- We can now access individual persons by indexing them from the array:

```
population[1]
```

```
Person("M. Musterperson", 0, 0.0)
```

- We can also access their fields:

```
population[1].name
```

```
"M. Musterperson"
```

- And we can set them:

```
set_name(population[1], "Bob the Builder")
population[1].name
```

```
"Bob the Builder"
```

Broadcasting functions

- Earlier, we saw how operators such as + can be broadcast over arrays
- The same can be done with functions, for example:

```
alice = Person("Alice", 25, 40.0)
bob = Person("Robert", 55, 45.0)
carly = Person("Carly", 55, 39.0)

speakers = [alice, bob, carly]

get_shoesize.(speakers)
```

```
3-element Vector{Float64}:
 40.0
 45.0
 39.0
```

Random numbers

- To get a (pseudo)random number from between 0 and 1, simply call:

```
rand()
```

```
0.0944818524907508
```

Exercise

How can you obtain a random number from between 0 and 50?

How about between 50 and 100?

Answer

Random number from between 0 and 50:

```
50*rand()
```

```
11.16417838284735
```

Random number from between 50 and 100:

```
50 + 50*rand()
```

```
61.9881208394355
```

Comments

- To improve code readability, we insert comments (these are ignored by the compiler)
- Single-line comment:

```
# the following variable stores my shoe size
shoesize = 41.5
```

- Multi-line comment:

```
#=
The following variable
stores my shoe size
=#
shoesize = 41.5
```

Packages

- Basic Julia functionality is extended by **packages**
- These are installed through a package manager called **Pkg**
- E.g. to install the *Agents* package (and all its dependencies), we issue these commands:

```
using Pkg
Pkg.add("Agents")
```

- Once the package has been installed, we can load it by:

```
using Agents
```

Why is Julia sometimes slow?

- CPUs and computer memory consist of binary devices, they are either "on" or "off"[1]

- But humans write source code which is understandable to humans (well, mostly anyway...)[2]

[1]Photo of replica of the first transistor from Wikimedia Commons. Public domain.
[2]Cartoon from geek & poke. CC-BY-3.0.

- So translation is needed.
- Imagine you need to translate cooking recipes (algorithms) from English (source code) to Spanish (machine code). You have roughly two options:
  - Every time a particular instruction is called for, you translate it anew (**interpreted languages**)
  - You translate the entire recipe and give it to the cook (the CPU) (**compiled languages**)

Why is Julia sometimes slow?

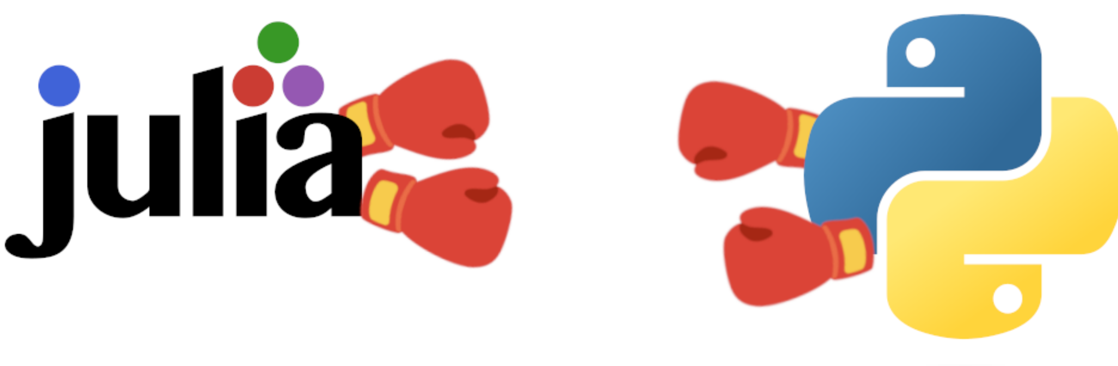
- Julia is a **just-in-time (JIT) compiled language**
- Meaning roughly: code blocks are compiled as they are encountered
- Compiled code is stored for later use
- Initial compilation takes time

Why is Julia sometimes fast?

- However, all subsequent executions are fast!
- This is because the translations have already been made and stored
- Furthermore, code can be optimized during the initial compilation
  - Since your Spanish cook (the CPU) knows that "cdta." stands for "cucharadita" (teaspoon), the compiler can use the shorter translation instead of the long one

Speed in practice

- In practice, these differences mean that:
  - Running a function once may be quicker in Python
  - Running the same function 1000 times will be quicker in Julia
- A lot of the attractiveness of Julia for ABM comes from this fact – that it compiles into fast machine code on many different processor architectures



Summary

- Here you've learned some of the basics of the Julia language
- There is much more… we will learn it as we go along
- We will make heavy use of array comprehensions, functions and custom types, so make sure you understand these concepts
- You get to practice them in this week's homework