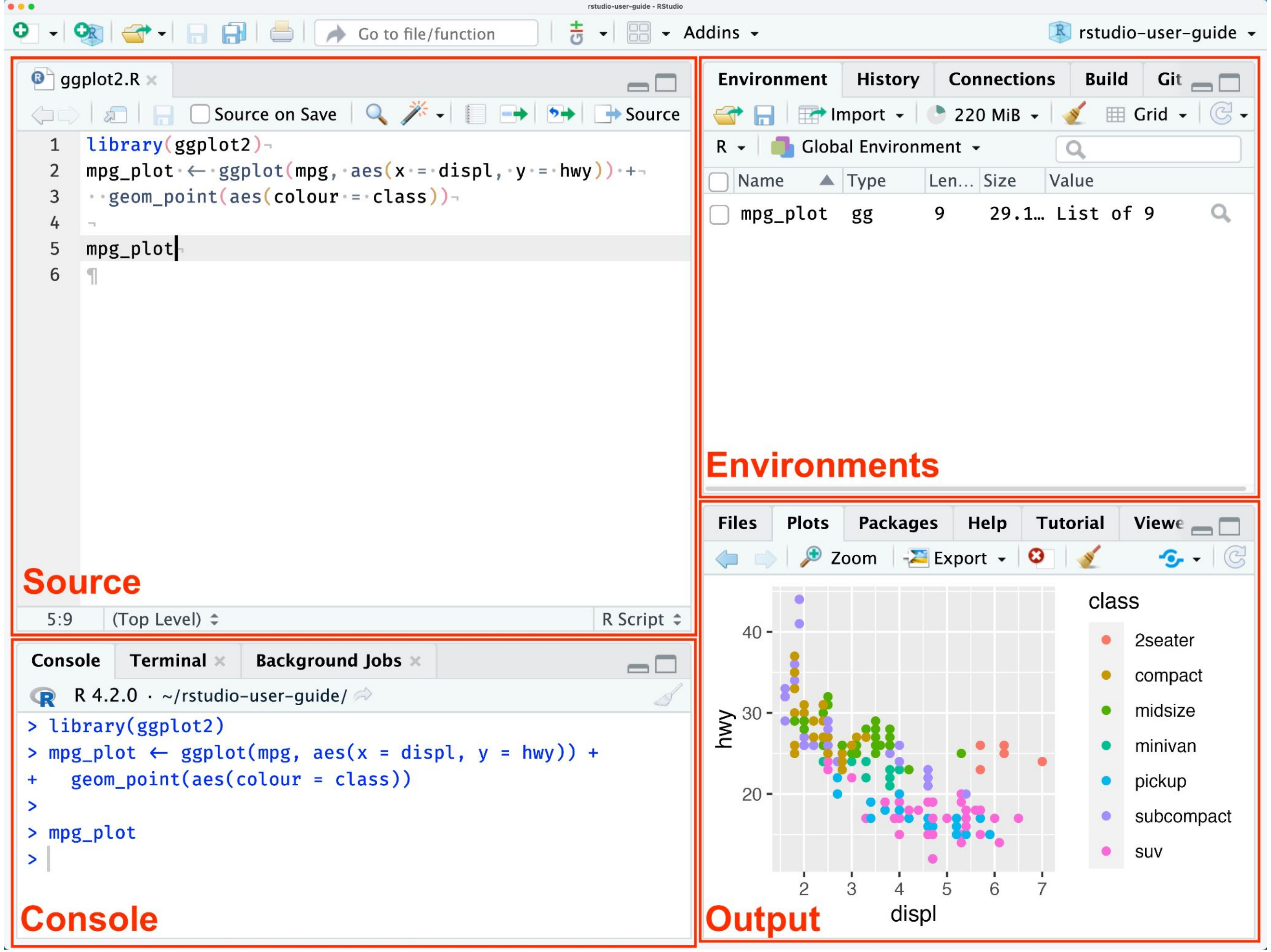
A short introduction to

individual-based simulations

on R



lab-mullon.github.io/SAF : Exercise session 0 → RStudio Desktop installation

Reminder

$$L = \begin{pmatrix} 0.32 & 0.57 & 0.57 & 0.57 & 0.57 & 0.57 & 0.57 \\ 0.46 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.77 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.65 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.67 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.64 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.88 & 0 \end{pmatrix}$$

$$\boldsymbol{n}_{t+1} = L\boldsymbol{n}_t$$

$$\boldsymbol{n}_1 = L\boldsymbol{n}_0$$
$$\boldsymbol{n}_2 = L\boldsymbol{n}_1 = L^2\boldsymbol{n}_0$$
$$\boldsymbol{n}_3 = L\boldsymbol{n}_2 = L^3\boldsymbol{n}_0$$
$$\vdots$$
$$\boldsymbol{n}_t = L^t\boldsymbol{n}_0$$

Age *a* (years)	p_a	m_a	f_a
0	0.25		
1	0.46	1.28	0.32
2	0.77	2.28	0.57
3	0.65	2.28	0.57
4	0.67	2.28	0.57
5	0.64	2.28	0.57
6	0.88	2.28	0.57
7		2.28	0.57

Individual-based simulation

- An individual-based simulation (IBS) is a **computational model/tool** that simulates the behavior and interactions of individuals within a population.

- Each individual possesses unique **features** and follows **predefined rules** governing its behavior (e.g. reproduction, movement, and interaction with other individuals and the environment).

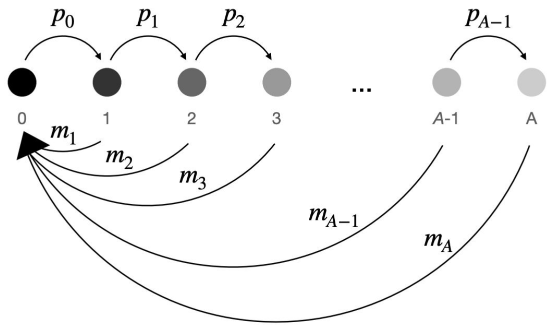
- It helps simulate **complex evolutionary scenarios** and understand how various factors contribute to the emergence of specific traits or adaptations within a population.

Today's goal:

We model the dynamics of a population, including **reproduction**, **aging** and **death**.

For simplicity, we assume individuals cannot live for more than six years, such that the population is structured into a newborn age-class (year 0) and six reproducing age-classes (from year 1 to year 6).

The fecundity and survival probability are equal across all ages.



INDIVIDUAL

What is an individual?

Which **features** characterize an individual?

AGE in the range 1, 2, 3, 4, 5, 6

1	6	3	4	1	2	1	4	1	2	1

Population

```
> possible_ages = c(1, 2, 3, 4, 5, 6)
> possible_ages
[1] 1 2 3 4 5 6
> A = sample(possible_ages, 10, replace = T)
> A
 [1] 6 6 3 2 4 6 2 1 6 4
> A[1]
[1] 6
> A[5]
[1] 4
> length(A)
[1] 10
```

INDIVIDUAL

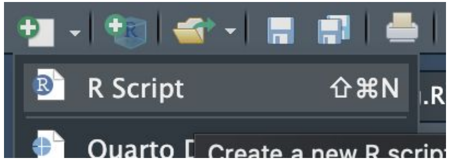
What is an individual?

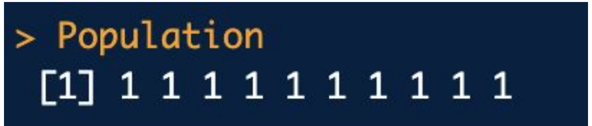
Which **features** characterize an individual?

AGE in the range 1, 2, 3, 4, 5, 6

1	6	3	4	1	2	1	4	1	2	1

Population





INDIVIDUAL

What is an individual?

Which **features** characterize an individual?

What does the individual do?

What is the **life-cycle** of such individuals?
How does time progress?

Reproduce

F_{ec} = **1**

P_{suv} = **0.5**

```
# Reproduction
fec = 1

no_offspring = rpois(n = 1, lambda = fec)
```

```
> no_offspring
[1] 3
```

INDIVIDUAL

What is an individual?

Which **features** characterize an individual?

What does the individual do?

What is the **life-cycle** of such individuals?
How does time progress?

Reproduce

F_{ec} = **1**

P_{suv} = **0.5**

```
# Reproduction
fec = 1
psuv = 0.5
no_offspring = rpois(n = 1, lambda = fec)
no_new_n1 = rbinom(1, size = no_offspring, prob = psuv)
```

```
> no_new_n1
[1] 2
```

INDIVIDUAL

What is an individual?

Which **features** characterize an individual?

What does the individual do?

What is the **life-cycle** of such individuals?
How does time progress?

Reproduce

F_{ec} = **1**

P_{suv} = **0.5**

```r
# Reproduction
fec = 1
psuv = 0.5
no_offspring = rpois(n = 1, lambda = fec)
no_new_n1 = rbinom(1, size = no_offspring, prob = psuv)
new_n1 = rep(1, no_new_n1)
```

```
> new_n1
[1] 1 1
```

INDIVIDUAL

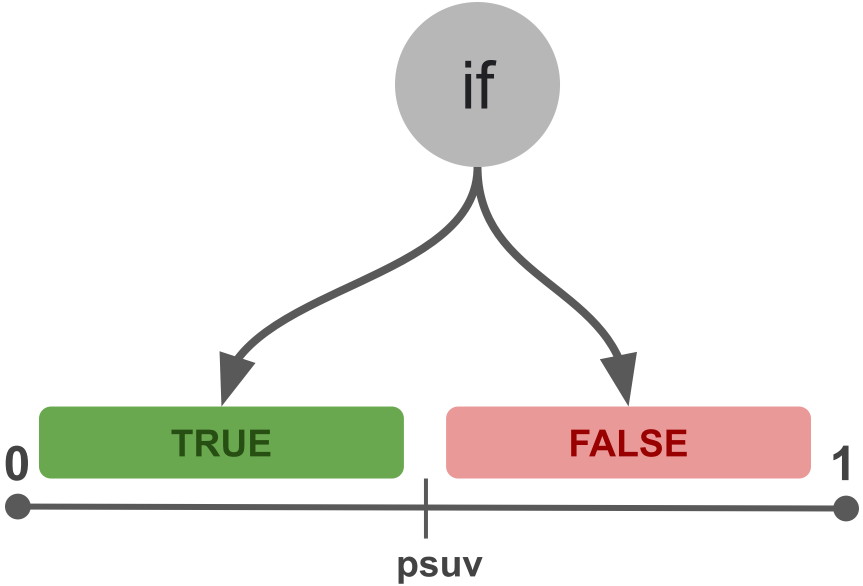
What does the individual do?

What is the **life-cycle** of such individuals?
How does time progress?

Try to survive to next year

P_{suv} = **0.5**

```r
if (runif(1) < psuv){
  # Survives and ages
} else {
  # Dies
}
```



INDIVIDUAL

What does the individual do?

What is the **life-cycle** of such individuals?
How does time progress?

Try to survive to next year

P_{suv} = **0.5**

```
> runif(1) < 0.5
[1] TRUE
> runif(1) < 0.5
[1] TRUE
> runif(1) < 0.5
[1] TRUE
> runif(1) < 0.5
[1] FALSE
> runif(1) < 0.5
[1] FALSE
> runif(1) < 0.5
[1] FALSE
> runif(1) < 0.5
[1] TRUE
> runif(1) < 0.5
[1] FALSE
```

INDIVIDUAL

What does the individual do?

What is the **life-cycle** of such individuals?
How does time progress?

Try to survive to next year

P_{suv} = **0.5**

```r
psuv = 0.5
age = 2
if (runif(1) < psuv){
  # Survives and ages
  age = age + 1
} else {
  # Dies
  age = NA
}
```

Reproduce

F_{ec} = **1.0**

Try to survive to next year

P_{suv} = **0.5**

```
IND_ACT = function(age, fec, psuv){
    # Reproduction
    no_offspring = rpois(n = 1, lambda = fec)
    no_new_n1 = rbinom(1, size = no_offspring, prob = psuv)
    new_n1 = rep(1, no_new_n1)

    # Try to survive
    if (runif(1) < psuv){
      # Survives and ages
      age = age + 1
    } else {
      # Dies
      age = NA
    }

  # Returns new adults and individual
  return(c(new_n1, age))
} # CTRL+Enter
```

Reproduce

F_{ec} = 1.0

Try to survive to next year

P_{suv} = 0.5

```
> IND_ACT(age = 1, fec = 1, psuv = 0.5)
[1]  1  1  1 NA
> IND_ACT(age = 1, fec = 1, psuv = 0.5)
[1] 1 2
> IND_ACT(age = 1, fec = 1, psuv = 0.5)
[1]  1 NA
> IND_ACT(age = 1, fec = 1, psuv = 0.5)
[1] NA
> IND_ACT(age = 1, fec = 1, psuv = 0.5)
[1] 2
> IND_ACT(age = 1, fec = 1, psuv = 0.5)
[1] 1 2
```

```
> IND_ACT(age = 6, fec = 1, psuv = 0.5)
[1] 7
```

Reproduce

F_{ec} = 1.0

Try to survive to next year

P_{suv} = 0.5

```r
IND_ACT = function(age, fec, psuv){
    # Reproduction
    no_offspring = rpois(n = 1, lambda = fec)
    no_new_n1 = rbinom(1, size = no_offspring, prob = psuv)
    new_n1 = rep(1, no_new_n1)

    # Try to survive
    if (runif(1) < psuv){
      # Survives and ages
      age = age + 1
      if (age > 6){ age = NA } # Caps max age at 6
    } else {
      # Dies
      age = NA
    }

  # Returns new adults and individual
  return(c(new_n1, age))
} # CTRL+Enter
```

```r
# This is a comment...

IND_ACT = function(age, fec, psuv){
    # Reproduction
    no_offspring = rpois(n = 1, lambda = fec)
    no_new_n1 = rbinom(1, size = no_offspring, prob = psuv)
    new_n1 = rep(1, no_new_n1)

    # Try to survive
    if (runif(1) < psuv){
      # Survives and ages
      age = age + 1
      if (age > 6){ age = NA } # Caps max age at 6
    } else {
      # Dies
      age = NA
    }

  # Returns new adults and individual
  return(c(new_n1, age))
} # CTRL+Enter

### Initialization
Population = rep(1, 10) # CTRL+Enter
```

```r
# This is a comment...

IND_ACT = function(age, fec, psuv){...} # CTRL+Enter

### Initialization
Population = rep(1, 10) # CTRL+Enter
```

```r
# This is a comment...

IND_ACT = function(age, fec, psuv){...} # CTRL+Enter

### Initialization
Population = rep(1, 100) # CTRL+Enter


NextPopulation = c()
for(i in 1:length(Population)){
  # Append to NextPopulation all "families"
  NextPopulation = c(NextPopulation, IND_ACT(age = Population[i], fec = 1.0, psuv = 0.5))
}
```

Let’s increase initial population size

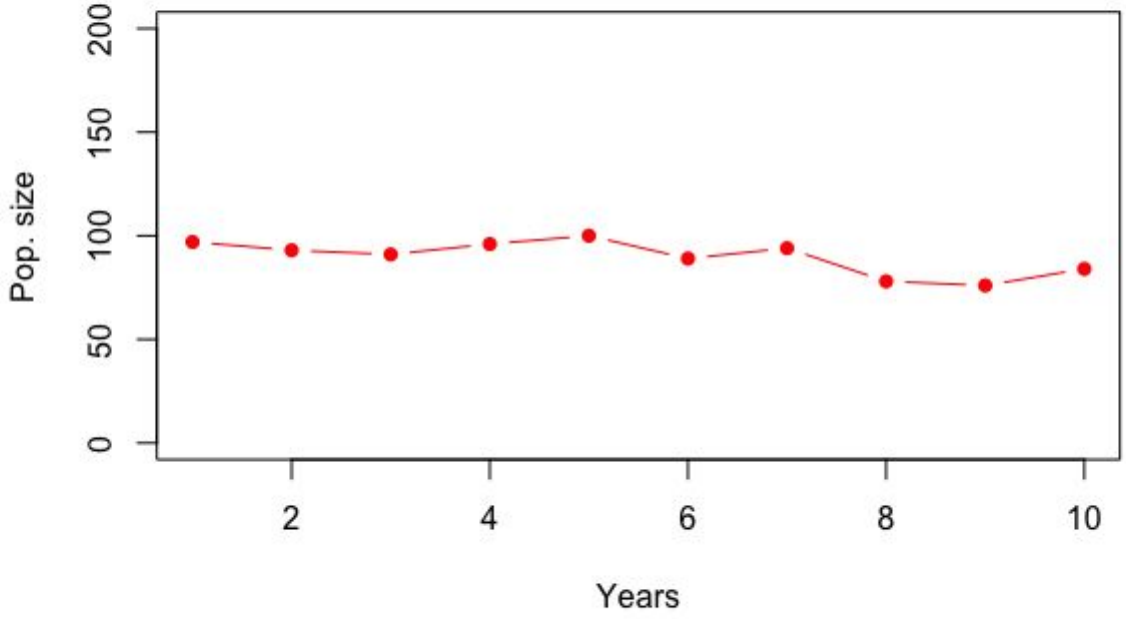
```r
> table(NextPopulation)
NextPopulation
 1  2
50 51
```

```
> NextPopulation
  [1]  2 NA  1  2  1  2  2  2  1 NA  1  1 NA  1  2  2  2  2  1 NA  2 NA  1 NA  2  2  2  1 NA  1 NA NA NA NA  1  2 NA NA
 [39]  1 NA  1  1  2  2 NA  2 NA  1 NA  2 NA  2  1  1  1  2  2  1  1  1 NA NA  1  2  1 NA  1 NA  2 NA NA  1 NA  2  2  2
 [77] NA  1  1  2  1  1 NA NA NA  1 NA  1 NA  1  1  2 NA  2 NA  1 NA  1  2  1  2  2  2  1 NA NA  2  1  2  1  1 NA  1  2
[115]  2  1 NA NA  1 NA NA  2  2 NA  2 NA  2  2  2  2  2  2 NA  2  1 NA  2 NA  1 NA  1  1  2  2  1 NA  1  2  1 NA
> is.na(NextPopulation)
  [1] FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
 [20]  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE
 [39] FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
 [58] FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE
 [77]  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE  TRUE
 [96] FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE
[115] FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE
[134] FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE
> !is.na(NextPopulation)
  [1]  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
 [20] FALSE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE
 [39]  TRUE FALSE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
 [58]  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE  TRUE  TRUE  TRUE
 [77] FALSE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE FALSE  TRUE FALSE
 [96]  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE
[115]  TRUE  TRUE FALSE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE
[134]  TRUE  TRUE FALSE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE FALSE
> NextPopulation[!is.na(NextPopulation)]
  [1] 2 1 2 1 2 2 2 1 1 1 1 2 2 2 2 1 2 1 2 2 2 1 1 1 2 1 1 1 2 2 2 1 2 2 1 1 1 2 2 1 1 1 1 2 1 1 2 1 2 2 2 1 1 2 1 1 1 1
 [59] 1 1 2 2 1 1 2 1 2 2 2 1 2 1 2 1 1 1 2 2 1 1 2 2 2 2 2 2 2 2 2 2 1 2 1 1 1 2 2 1 1 2 1
```

```r
# This is a comment...

IND_ACT = function(age, fec, psuv){…} # CTRL+Enter

### Initialization
Population = rep(1, 100) # CTRL+Enter
FinalYear = 10

for (year in 1:FinalYear){
  NextPopulation = c()

  for(i in 1:length(Population)){
    # Append to NextPopulation all "families"
    NextPopulation = c(NextPopulation, IND_ACT(age = Population[i], fec = 1.0, psuv = 0.5))
  }

  Population = NextPopulation[!is.na(NextPopulation)]
}
```

```r
# This is a comment...

IND_ACT = function(age, fec, psuv){...} # CTRL+Enter

### Initialization
Population = rep(1, 100) # CTRL+Enter
FinalYear = 10
PopulationSize = rep(0, FinalYear)

for (year in 1:FinalYear){
  NextPopulation = c()

  for(i in 1:length(Population)){
    # Append to NextPopulation all "families"
    NextPopulation = c(NextPopulation, IND_ACT(age = Population[i], fec = 1.0, psuv = 0.5))
  }

  Population = NextPopulation[!is.na(NextPopulation)]
  PopulationSize[year] = length(Population)
}
```

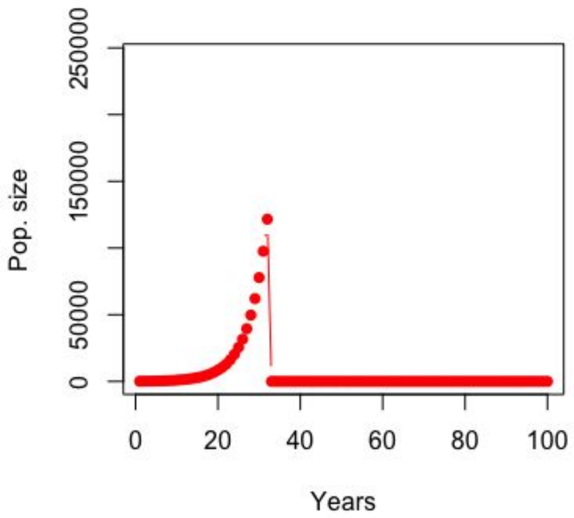
```r
plot(x = 1:FinalYear, y = PopulationSize,
     type = "b",
     col = "red", pch = 16,
     ylim = c(0, 2*max(PopulationSize)),
     xlab = "Years", ylab = "Pop. size")
```



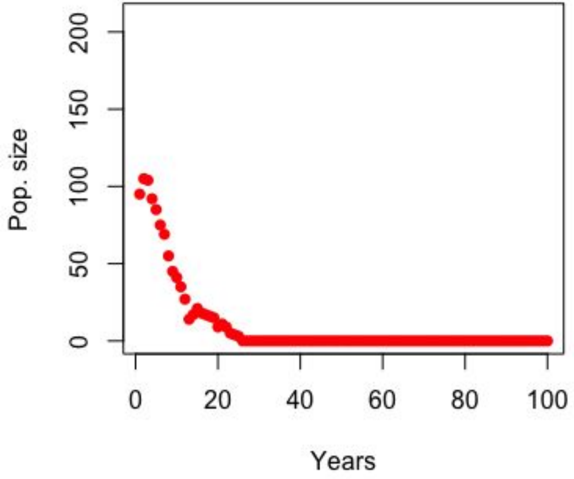
```
# This is a comment...

IND_ACT = function(age, fec, psuv){...} # CTRL+Enter

DYN = function(n0, FinalYear, fec, psuv){
  ### Initialization
  Population = rep(1, n0)
  PopulationSize = rep(0, FinalYear)

  for (year in 1:FinalYear){
    NextPopulation = c()

    for(i in 1:length(Population)){
      # Append to NextPopulation all "families"
      NextPopulation = c(NextPopulation, IND_ACT(age = Population[i], fec = fec, psuv = psuv))
    }

    Population = NextPopulation[!is.na(NextPopulation)]
    PopulationSize[year] = length(Population)
  }

  return(PopulationSize)
}

# Runs one simulation with a set of parameters
sim = DYN(n0 = 100, FinalYear = 100, fec = 1.0, psuv = 0.5)

# Plots the output of the simulation
plot(x = 1:100, y = sim,
     type = "b",
     col = "red", pch = 16,
     ylim = c(0, 2*max(sim)),
     xlab = "Years", ylab = "Pop. size")
```

```r
# This is a comment...

IND_ACT = function(age, fec, psuv){...} # CTRL+Enter

DYN = function(n0, FinalYear, fec, psuv){
  ### Initialization
  Population = rep(1, n0)
  PopulationSize = rep(0, FinalYear)

  for (year in 1:FinalYear){
    NextPopulation = c()

    for(i in 1:length(Population)){
      # Append to NextPopulation all "families"
      NextPopulation = c(NextPopulation, IND_ACT(age = Population[i], fec = fec, psuv = psuv))
    }

    Population = NextPopulation[!is.na(NextPopulation)]
    PopulationSize[year] = length(Population)

    if( length(Population) == 0 ){ break } # Population went extinct
    if( length(Population) > 100000 ){ break } # Population skyrocketed
  }

  return(PopulationSize)
}
```

```r
# This is a comment...

IND_ACT = function(age, fec, psuv){...} # CTRL+Enter

DYN = function(n0, FinalYear, fec, psuv){...}

# Runs one simulation with a set of parameters
sim = DYN(n0 = 100, FinalYear = 100, fec = 1.5, psuv = 0.5)

# Plots the output of the simulation
plot(x = 1:100, y = sim,
     type = "b",
     col = "red", pch = 16,
     ylim = c(0, 2*max(sim)),
     xlab = "Years", ylab = "Pop. size")
```




```r
# This is a comment...

IND_ACT = function(age, fec, psuv){...} # CTRL+Enter

DYN = function(n0, FinalYear, fec, psuv){...}

# Runs one simulation with a set of parameters
sim = DYN(n0 = 100, FinalYear = 100, fec = 0.8, psuv = 0.5)

# Plots the output of the simulation
plot(x = 1:100, y = sim,
     type = "b",
     col = "red", pch = 16,
     ylim = c(0, 2*max(sim)),
     xlab = "Years", ylab = "Pop. size")
```



Now, it's up to you:

We model the dynamics of a population, including **reproduction**, **aging** and **death**.

For simplicity, we assume individuals cannot live for more than six years, such that the population is structured into a newborn age-class (year 0) and six reproducing age-classes (from year 1 to year 6).

The **fecundity** and **survival probability** differ across ages.

Age a (in years)	Fecundity m_a	Survival probability p_a
0	-	0.8
1	0.57	0.52
2	2.10	0.60
3	4.25	0.71
4	4.25	0.71
5	4.25	0.71
6	4.25	-

Table 1: *Sus scrofa* life-table.