Lab 1: exponential growth

NRES 470/670

Spring 2023

In this lab we will have an opportunity to do population modeling using three different software packages: MS Excel, R, and InsightMaker. I encourage you to work in groups- but just remember you must submit your answers individually on WebCampus!

Nomenclature for Population Ecology

First of all, we need a symbol to represent population size. This is N!

ΔN represents the change in population size, $N_{t+1} - N_t$

The famous "BIDE" equation is a way to break down ΔN into components.

$\Delta N = B + I - D - E \qquad \text{(Eq. 1)}$

where B represents the number of births, I represents the number of immigrants, D represents the number of deaths, and E represents the number of emigrants.

If we ignore immigration and emigration, then the BIDE equation simplifies to:

$\Delta N = B - D$

Now let's focus on B and D. The important thing to recognize is that the total number of births and deaths should get larger as the population size gets larger. That is, B and D are not *constant* over time- they change as the population size N gets bigger or smaller.

How can we re-express this statement in terms of *constant* properties of the population?

What about the *percent of the population that dies each year (percent mortality)*? Or... the *number of births per female (per-capita birth rate)*?

We will often call these quantities **population vital rates**. These quantities do not necessarily change as the population size N gets bigger or smaller.

Examples of population vital rates:

- "*for every female in the population*, we expect 1.1 offspring will be born this year"
- "*for every individual in the population today*, we expect 0.8 new one-year-olds to enter the population next year"
- "we expect 3% of the current population to be harvested this year"
- "we expect 10% of the current population to die in the coming year"

The population vital rates (per-capita demographic rates) are often expressed as lower case letters. So b represents per-capita birth rate, and d represents fractional death rate (fraction of the population dying each year).

To compute the per-capita **population vital rate** b, for example, you can just divide the total number of births (B) by the population size N:

$b = \frac{B_t}{N_t}$ (Eq. 2)

–or, re-factored in terms of B–

$B_t = b \cdot N_t$ (Eq. 3)

The letter t represents time (usually in years). So the above equation could be described as follows: "the number of births in a given year is equal to the per-capita birth rate times the total population size that year"

Similarly,

$D_t = d \cdot N_t$ (Eq. 4)

Okay, we're almost there.

If $\Delta N = B - D$ (Eq. 5)

then

$\Delta N = b \cdot N_t - d \cdot N_t$ (Eq. 6)

which is equal to:

$\Delta N = (b - d) \cdot N_t$ (Eq. 7)

which could also be written:

$\Delta N = r \cdot N_t$ (Eq. 8)

Where r represents the difference between the per-capita birth and death and death rates.

If r is positive, then births are greater than deaths and the population grows. If r is negative then deaths exceed births and the population declines.

This is probably the most fundamental equation of population ecology.

Continuous population growth

A continuously growing population is always growing over time- no matter how small the time step, there is always some population growth over that time.

We can use *calculus notation* to consider the change in population size for a continuously growing population:

$\frac{\partial N}{\partial t} = r \cdot N$ (Eq. 9)

If you *integrate* this equation over time from the initial time (t=0) to time t, you get an equation that describes the population size at any given time t:

$N_t = N_0 e^{rt}$ (Eq. 10)

That is, population size at time t is equal to the population size at time zero (initial abundance, N_0) multiplied by the base of the natural logarithm (e) to the rt power.

There you have it! Now you can compute population growth and population size over time for any population that is growing *continuously*!

Doubling time One of the most intuitive ways to think about continuous exponential growth is in terms of the *doubling time*- the time (usually in years) it takes for a population to double in size. Let's compute the doubling time for a population with 7% annual growth:

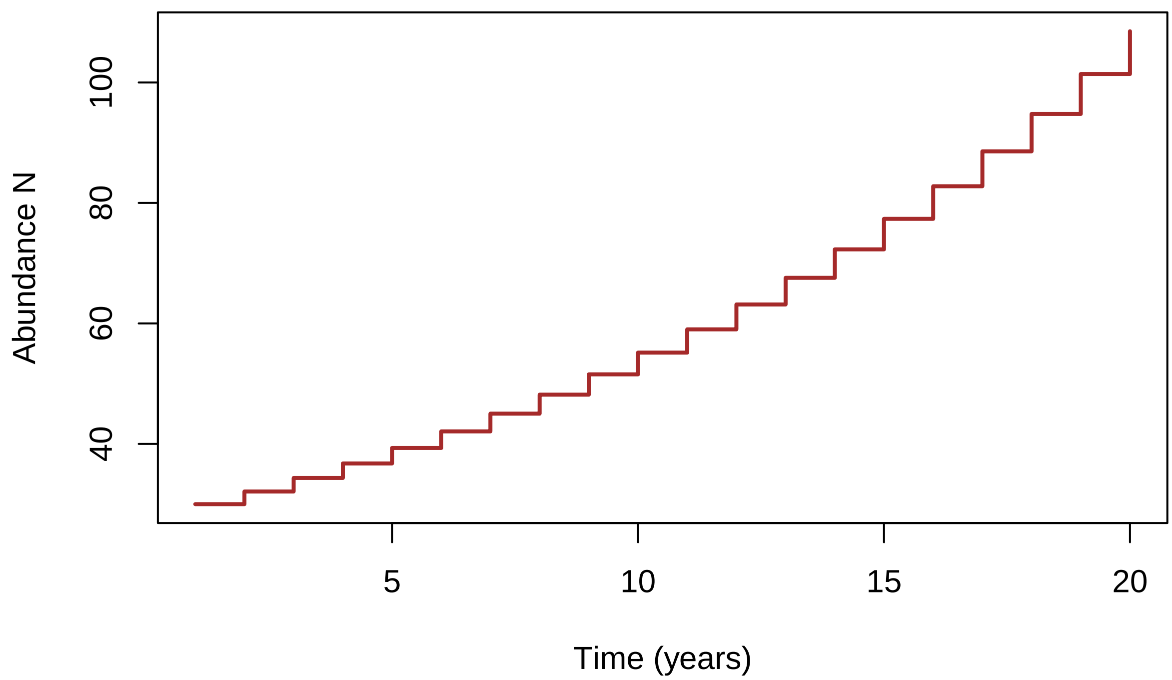
If you replace N_t in the above equation (eq. 10) with $2 * N_0$ (representing a doubling of population size), replace r with 0.07 (representing 7% annual growth), then you can solve for t. The result is that you get the equation: $t = \frac{ln(2)}{0.07}$. Since the natural logarithm of 2 is 0.69, we can substitute 0.7 as a close approximation.

Since we tend to think best in percentages, we can multiply by 100 (converting to percent) and we get $t = \frac{70}{7}$, which means this population will double approximately every 10 years!

In general, if you want to compute the approximate doubling time of a population, you can simply take the number 70 and divide by the annual growth percentage: so if you have 7% annual growth per year, then to compute doubling time just take the number 70, divide by the percent rate of growth (here, 7%), and there you have it- the population will double approximately every 10 years!

Discrete population growth

In a population with discrete growth, the population grows in spurts- periods of relative lack of growth are interspersed with periods of rapid population growth. Effectively, this results in a "stair-step" model, looking something like this:



You've probably seen the term "Lambda" (greek symbol λ) before to represent population growth rate. Lambda is the "multiplicative growth rate", also known as the *finite rate of growth.*

Lambda is what you multiply current abundance by to compute abundance in the next time step. It itself can be computed using the formula $\frac{N_{t+1}}{N_t}$

Since Lambda is what we use to "bump" population size up from what it is this year to what it will be next year, Lambda is a representation of *discrete population growth* (it implicitly represents a "stair-step" model of population growth.

We can derive Lambda using the following logic:

$N_{t+1} = N_t + B - D \qquad \text{(Eq. 11)}$

$N_{t+1} = N_t + b_d \cdot N_t - d_d \cdot N_t \qquad \text{(Eq. 12)}$

I am using the d subscript to indicate that the per-capita birth and death rates now represent **discrete growth** (births and deaths only occur once in each time step)

$N_{t+1} = N_t + (b_d - d_d) \cdot N_t$ (Eq. 13)

$N_{t+1} = N_t + r_d \cdot N_t$ (Eq. 14)

$N_{t+1} = N_t \cdot (1 + r_d)$ (Eq. 15)

$N_{t+1} = \lambda \cdot N_t$ (Eq. 16)

Finally, if you want to compute the population size after t time-steps of discrete population growth (analogous to eq. 10) you can use the following equation:

$N_t = N_0 * \lambda^t$ (Eq. 17)

Difference between discrete and continuous growth

It can be difficult to differentiate between discrete and continuous growth.

Here are some expressions to illustrate the difference between discrete and continuous population vital rates:

$b = 0.9$: "New individuals enter into the population at a rate of 0.9 per female per year, and these new individuals are born continuously throughout the year"
$b_d = 0.9$: "Babies enter the population at a per-capita rate of 0.9 per female per year, but individuals only give birth once each spring"
$d = 0.23$: "Approximately 23% of the population dies each year, but the deaths occur evenly throughout the year"
$d_d = 0.23$: "Approximately 23% of the population dies each year, but nearly all the deaths are assumed to occur near the end of winter hibernation"
$r = 0.15$: "The population is growing constantly (continuously) at a rate of exactly 15% per year" NOTE: you will not have exactly 15% more individuals in the population one year later, but in fact you will have 16.2% more individuals due to the process of *compounding* (because the population keeps growing even within each time step- the population doesn't just remain at it's initial size)! This should be more clear by the end of this lab.
$r_d = 0.15$: "The population size one year from now will be exactly 15% higher than it is today"

Just so you know, you can convert between the discrete-time rate of growth Lambda (λ) and the continuous rate of growth (r) easily: all you need to do is use the natural logarithm:

$e^r = \lambda$
$r = ln(\lambda)$

Q What is lambda for a population that growing at a *discrete* rate of 7% per year?

Q What is lambda for a population that growing *continuously* at a rate of 7% per year? [this is harder!]

Okay let's start the lab! The first software we will use is our old friend, MS **Excel**!

Exponential growth in Excel

We will start with an in-class demonstration:

1. Open the Excel spreadsheet ExpGrowthExcel.xlsx. To download this file, right click on the link and select "*Save link as..*". In the first column, we have a time step of 1 year for 30 years. In the second column, we have an initial population size (N_0) of 100 individuals. We also have a per-capita rate of increase (r) that is currently set at 0.1 (10%) per year. Assume for now that r represents r_d, or the *discrete rate of increase*. That is: the population size next year will be exactly 10% larger than the population this year.

2. To generate N_t for the remaining time steps, we need to apply our knowledge of population ecology. Specifically we need to apply equation 16, above for modeling discrete population growth in a single time step. You will first want to convert r_d to λ using the formula $\lambda = 1 + r_d$. Do this by clicking in a cell (e.g., cell D5), typing '=' in the cell (indicating that you are about to enter a **formula**), clicking on cell D3 (indicating that you will use this cell's value in the formula) and adding 1. As you do this, you should see the equation you are creating appear in the equation editor. The formula should look like "=D3+1". Next, you can apply equation 16 directly by clicking in the empty N_1 cell (position B3), typing '=' in the cell (indicating that you are about to enter a **formula**), clicking on the N_0 cell (position B2– indicating that you will use this cell's value in the formula), and completing the equation (e.g., "=B2*D5", where cell D5 stores λ). Hit enter.

3. You can fill the remainder of the cells using the same equation for the other time steps by clicking and dragging (or double clicking) the small square at the bottom of the N(2) cell, which appears when the cell is selected.

4. What happened? We are not seeing a growing population here- actually it seems quite flat! this is surely not what we want! Click on the N(3) cell to see what equation is being used to calculate the cell value. The equation is =B3*D6. The B3 part is correct - we want to calculate the N(3) population size using the N from the previous timestep - but the D6 part is incorrect. We always want to use the same λ - which is always in the same cell (cell D5). You can see that when you drag down an equation as we have done, Excel adds 1 for each row so that the equation references the same relative positions in the spreadsheet for each new cell you want to calculate. We like that Excel did that for N, but not for r or λ, so we can tell Excel to keep this value in the same row (row 3) for r (or λ) by inserting a dollar sign in our equation (in Excel terminology, this is a 'fixed reference').

5. In the N(2) cell, edit the equation in the equation editor (or 'function bar') above the spreadsheet so that there is a dollar sign in D3 (i.e., 'D$3' instead of 'D3') (or just use the F4 shortcut).

6. Now drag the equation down again, and you should have a population size in row 32 of 1745 (representing the population size at year 30!).

NOTE: you can format the cells in column B to be whole numbers using the context menu (select column B » Format Cells » Number » Decimal places = 0)

7. Now we will plot our population against time. Select both columns of data, and select the *scatter plot* (or "line plot") option under the 'Insert' menu. A plot of N by Time will automatically appear. You can change the r value, the data and chart will automatically adjust.

Exercise 1

Please provide short answers to the following questions on WebCampus (you will be asked to **provide your Excel spreadsheet**).

- ***Short answer (1a.)*** Change the per-capita growth rate to 0.09 in cell D3. Based on what we did together in the demo, this should change the value of abundance in year 30 (cell B32) automatically. *What is the new final abundance at year 30?*

- ***Short answer (1b.)*** Assuming that the per-capita rate of growth represents *continuous* and not *discrete* growth, apply equation 10 (continuous-growth model- see above) to compute the expected population size in year 30. *What is the new final abundance at year 30, assuming continuous growth?*. Is this value different from your answer in question 1a? If so, in what way are the two values different (i.e., which one is larger/smaller than the other)?

HINT: computing abundance at time t in the continuous-time model is a *single calculation*- don't over-think this one. You may use a scientific calculator instead of Excel if you want!

HINT: use the EXP function in Excel to raise e (the base of the natural logarithm) to any power: for example, to compute $e^{1.7}$ you type "=EXP(1.7)" in Excel.

In general, if you don't know the syntax for a function in Excel, click on the button labeled "fx" and you can search for functions using search terms!

- ***Short answer (1c.)*** What are the *units* of the per-capita population growth rate (also known as "intrinsic rate of growth"), r?

HINT: The answer is in the Gotelli book. Note that abundance N is in units of *individuals*. Time is generally represented in units of *years* in wildlife population models.

For the following problem (1d.) we will again assume discrete population growth (i.e., the "stair-step" model where the population grows in spurts), but this time we will assume the growth occurs in half-years instead of whole years (semi-annual growth). To do this, you will first need to divide the annual per-capita growth rate in half: so, if the annual growth rate is 0.9, the semi-annual growth rate would be 0.045 (4.5% percent growth each 6 months). Also, you need to change your number of time steps to 60 (60 half-years is equal to 30 whole-years). Try it in Excel!

- ***Short answer (1d.)*** What is the final abundance after 30 years (60 half-years) assuming a semi-annual growth rate of 4.5% (see more detailed instructions above)? Is this value different from your answer in question 1a? If so, in what way are the two values different (i.e., which one is larger/smaller than the other)?
- ***Short answer (1e.)*** Assuming that the semi-annual rate of growth (0.045) represents *continuous* and not *discrete* growth, apply equation 10 (continuous-growth model- see above) to compute the expected population size at time step 60 (60 half-years). *What is the new final abundance at time step 60, assuming continuous growth?*. Is this value different from your answer in question 1a? If so, in what way are the two values different (i.e., which one is larger/smaller than the other)? Of the two discrete-growth models (annual vs semiannual), which one yields a final abundance estimate that is closest to the continuous growth estimate (your answer to 1b.)?
- ***Short answer (1f.)*** Imagine you modeled this population using a discrete growth model in which the population grows once per month instead of once every 6 months. Based on your above results (q1a-e), do you think the resulting estimate of population size after 30 years (360 months, using a growth rate of 0.09/12) would be closer to your continuous-time estimate (answer to 1b) than your answer from 1d (semi-annual discrete growth)? [you could test this using Excel, but it is not necessary for answering this question]?
- ***Short answer (1g.)*** Can you think of at least one real-world example where continuous growth (eq. 10) would be a more biologically realistic model than discrete growth (eq. 16)? Justify your answer.
- ***Short answer (1h.)*** Can you think of at least one real-world example where discrete-time population growth would be a more biologically realistic model than continuous growth? Justify your answer.
- ***Excel submission (1i.)*** Please submit your final Excel workbook. If you used Google Sheets, please export as ".xslx" file.

Exponential growth in R

R is the most common software used by ecologists and conservation biologists for data analysis and simulation. R is incredibly powerful and useful, but there is a little bit of a learning curve with R! I will try to integrate R into this class as much as I can. We will do more with R when we get into data analysis! And you will do a LOT more with R in NRES 488!

SET UP

Open the R software from the program menu or desktop.

PROCEDURE

STEP I: Set up R and RStudio!

Go to website http://cran.r-project.org/. This is the source for the free, public-domain R software and where you can access R packages, find help, access the user community, etc.

Install Rstudio. This is a program that makes R easier to use!

STEP II. Take some time to get familiar with R

If you already have some R expertise, this is your opportunity to help your peers develop the level of comfort and familiarity with R that they will need to perform data analysis and programming tasks in this course.

Depending on whether you are already familiar with R, you may also find the remainder of this document useful as you work your way through the course (and there are many other good introductory R resources available online… let me know if there is one you particularly like and I will add it to the course website (Links page)). As you work your way through this tutorial on your own pace, please ask the instructor or your peers if you are uncertain about anything.

For a more detailed tutorial, see my "R Bootcamp" website: https://kevintshoemaker.github.io/R-Bootcamp/!

Set up the workspace/environment

The first thing we usually do when we start an R session is we:

1. Open an new or existing RStudio Project
2. Open a new or existing **script**
3. In the script, define key variables and functions, and load any additional **packages** (extensions) into our environment (or workspace). When you write code, always type in the "script" window in Rstudio. You can execute commands using command-enter or control-enter in Rstudio.

In this lab, setting up the workspace is easy. We don't need to load any packages or define any new functions. We just need to define our parameter of interest - r -, and set up a **storage vector** to store population abundance over time.

We can store data in memory by assigning it to an "object" using the assignment operator **<-**. For example, this would assign the object "x" the value of 5.

```
x <- 5      # define the variable 'x' as representing the value 5
x           # Print the value stored in the object "x"
```

Note that any text after a pound sign (#) is not evaluated by R. These are *comments* and are intended to help you follow the code. You should always include comments in any code that you write- we humans tend to read and understand written language better than computer code!

Let's assign our per-capita population growth rate, r (but this could be called anything), and our initial population size to an object called **N0** (that is, population size at time 0), and the number of years to simulate.

```r
r <- 0.1     #Assign the value of 0.1 to the object "r", or per-capita growth rate (discrete)
lambda <- 1 + r           # (1 + r) is equal to lambda, the finite rate of growth.  This stores the res
N0 <- 100    #Assign the value of 100 to the object "N0", or initial population size
nyears <- 30 #Assign the value of 30 to the object "nyears", or the number of time steps to simulate
```

If we want to know what the population size is at the next time step, we can simply multiply N0 by lambda.

```r
N0 * lambda   #Multiplies the value stored in the object "N0" by lambda. As soon as you run this line o
```

```
## [1] 110
```

How can we find the population size for the next 30 years? Let's first make an object that is a vector of years using the **seq()** or "sequence" function.

```r
year <- seq(from=0, to=nyears, by=1)   #Creates a sequence of numbers from 0 to the value stored in the

year                                   #Print the value of the object "years" that you just created.
```

```
##  [1]  0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
```

Now, let's build a storage structure to store simulated population size over this time period

```r
N <- numeric(nyears+1)    #Make an empty storage vector. The numeric() function takes the contents with

names(N) <- year

N                         #Prints the contents of the object "N".
```

```
##  0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
##  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

Run the simulation!

Then we can use a **for loop** (a very powerful computer programming trick) to automatically generate the population size for each of those years (note the similarity in the equation inside the for loop to Expression 1.15 in Gotelli).

```r
N[1] <- N0                # The brackets [] are used to indicate the position of an element within a ve

for (i in 2:(nyears+1)){  # This for-loop will run through the line of code between the curly brackets
  N[i] <- N[i-1] * lambda  # This takes the [i - 1] element of "N", multiplies that element by the valu
}                         # This ends the for-loop.

N                         # Now print the contents of the object "N".
```

```
##         0         1         2         3         4         5         6         7         8         9
##  100.0000  110.0000  121.0000  133.1000  146.4100  161.0510  177.1561  194.8717  214.3589  235.7948
##        11        12        13        14        15        16        17        18        19        20
##  285.3117  313.8428  345.2271  379.7498  417.7248  459.4973  505.4470  555.9917  611.5909  672.7500
##        22        23        24        25        26        27        28        29        30
##  814.0275  895.4302  984.9733 1083.4706 1191.8177 1310.9994 1442.0994 1586.3093 1744.9402
```

If we just wanted to know the abundance at year 30, we could skip the FOR loop, and simply apply equation 17:

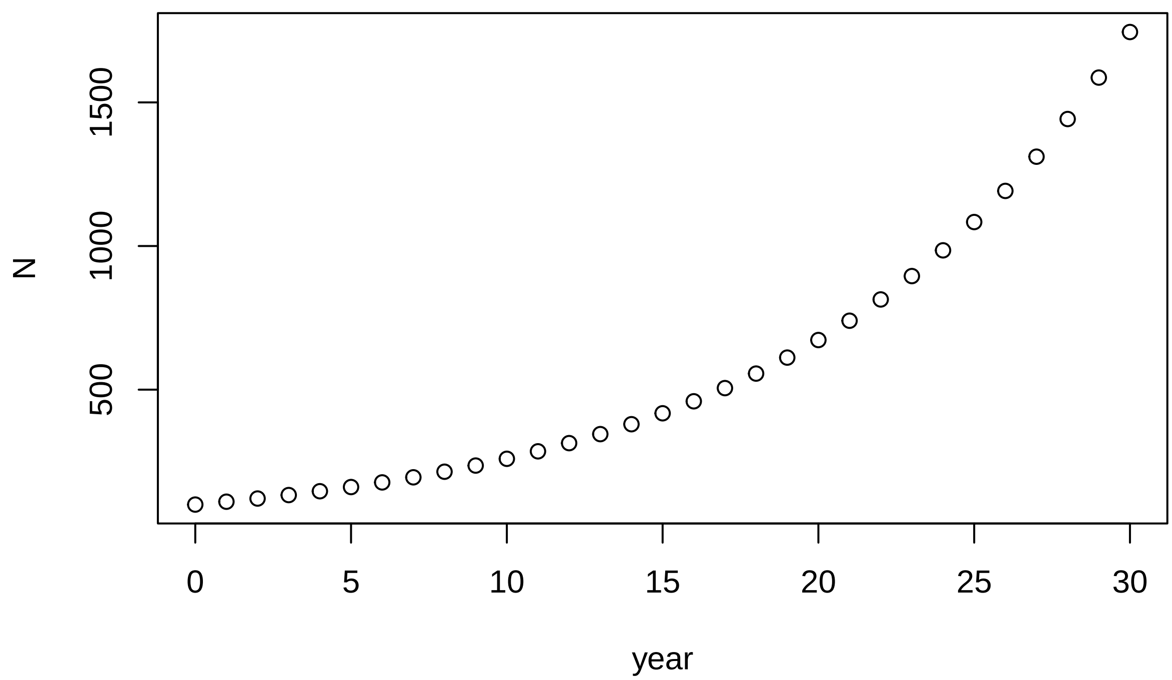
```
N30 = N0*lambda^nyears
N30
```

```
## [1] 1744.94
```

Plotting

Let's plot our population size against time.

```
plot(N~year)    #This plot() function tells R to plot the y variable by the x variable. "N" is the y var
```



Exercise 2 (R-related problems)

Please provide short answers to the following questions. You will also be asked to **provide your R code via WebCampus to back up your answers**.

Modify the above code to change r to 0.09 instead of 0.1, and run this model for 85 years instead of 30 years. Use this model to answer questions 2a and 2b:

- ***Short answer (2a.)*** What is the final population size at year 85 (with starting abundance of 100 and r=0.09)?

- ***Plot Upload (2b.)*** Upload your plot (produced using R) of abundance vs time, illustrating population growth across the entire 85 year time span.

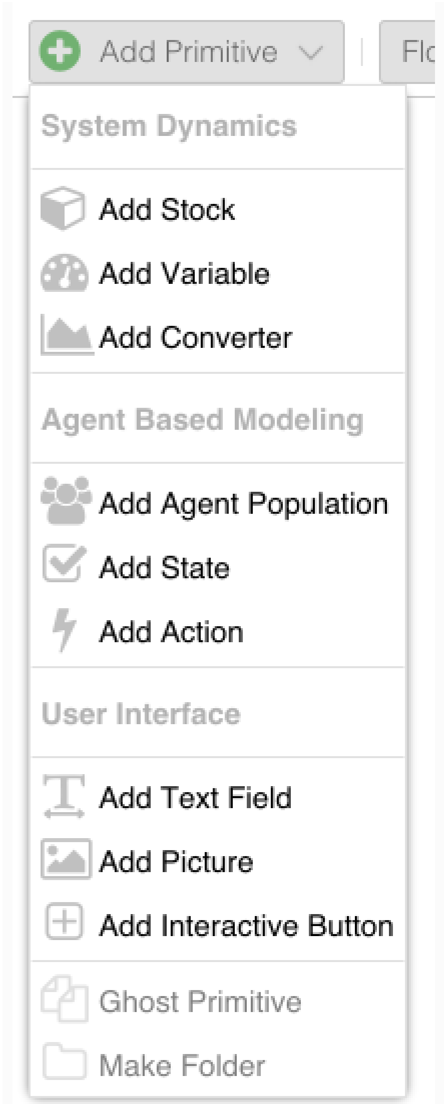
Modify the code again, this time change r to 0.3 instead of 0.09, and run this model again for 85 years. Use this model to answer questions 2c and 2d:

- ***Short answer (2c.)*** What is the final population size at year 85 (with starting abundance of 100 and r=0.3)?
- ***Plot Upload (2d.)*** Upload your plot (produced using R) of abundance vs time, illustrating population growth across the entire 85 year time span.
- ***Short answer (2e.)*** Use trial and error to modify the value of r such that the final population size after 85 years is as close as possible to 1000 (initial population is still 100). What is the value of r you identified by trial and error?
- ***Image upload (2f.)*** After you solve this problem by trial and error (2e), try to solve this problem analytically using Eq. 10. Use scratch paper (or virtual scratch pad) to make your calculations, take a photo (or screenshot) and upload the image in WebCampus.
- ***Short answer (2g.)*** Change the value of r to -0.08. How long until the population goes extinct? NOTE: we will define extinction in this exercise as <1 individual in the population- a fraction of an individual is not much of a population!
- ***Short answer (2h.)*** In 2g above, we defined extinction as <1 individual in the population. Propose one alternative definition of extinction and justify why your definition might make more sense than the definition used in 2g (feel free to use a real-world example).
- ***Text entry (2i.)*** Please copy and paste the R script you used to answer the above questions.

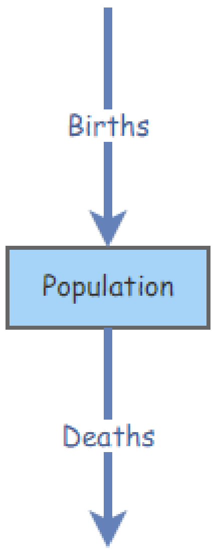
Exponential growth in InsightMaker

You should already have created a free account in insightmaker, and you should already know the basics about how to set up and run a model.

1. Click "Create New Insight" to start a new model (click "Clear this Demo" to clear the canvas and have an open workspace). Save the blank model by clicking the "Save" button.
2. Create a new [Stock] named *Population* using the "**Add Primitive**" button at top left ("Primitive" is just a computer-sciencey term referring to basic building blocks of a computer programming language). You can name the [Stock] and configure it in the properties tab at the right. Make sure you set the [Stock] so that negative values are NOT allowed.



3. Change the Initial Value of *Population* to 100.
4. Create a new [Flow] going from empty space to the primitive *Population* (make sure the **Flow/Transitions** button is activated instead of **Links** at the top, hover over *Population* until an arrow appears, click and drag to create the [Flow], use the **Reverse Connection Direction** button to change the flow direction). Name the flow *Births*.
5. Create a new [Flow] going from *Population* to empty space. Name the flow *Deaths*.
6. The model diagram should now look something like this:



7. Change the **Flow Rate** property of *Births* to $0.13 * [\text{Population}]$. This represents the total number of individuals entering the [Stock] (population) in each time step.

8. Change the **Flow Rate** property of *Deaths* to $0.10 * [\text{Population}]$. This represents the total number of individuals leaving the [Stock] (population) in each time step.

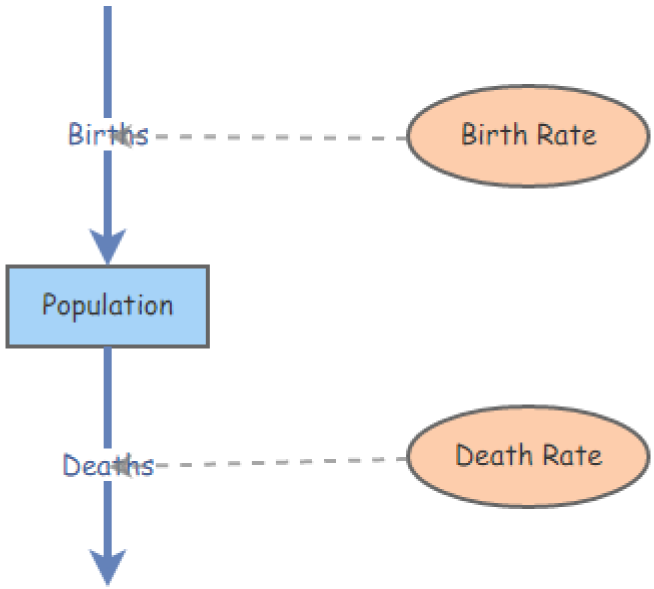
Can you already tell whether this is a growing or declining population? (just a quick thought question, not part of the written lab!)

9. Run the model by clicking the **Simulate** button. We can change how the simulation is run by clicking the **Settings** button (left of Save). We can also change the settings of how the plot is created by clicking the **Configure** button within the simulation results window.

Exercise 3 (InsightMaker problems)

Please provide short answers to the following questions, and (when prompted) **provide your "Insights" to back up your answers**.

First, modify the above model so that per-capita (discrete) birth rate (b_d) and death rate (d_d) are separate elements of the model (using the "Variable" primitive). Your Insight should look something like this:



To enable easy manipulation of these variables, change the **Show Value Slider** options for *Birth Rate* and *Death Rate* (in the properties windows for these variables) to 'Yes'. For both of these two variables, change the **Slider Max value** to 1, the **Slider Min value** to 0, and the **Slider Step value** to 0.01. For *Population*, set the **Show Value Slider** option to 'Yes'; for this slider (which represents initial abundance N_0), set the maximum slider value to 1000 and set the slider step size to 1 so we don't have fractional individuals!

Now click on the white space of your model; you should now see the Birth Rate, Population and Death Rate sliders on the info tab. Change the slider values of the rates a few times, re-running the simulation each time. When you are confident that your model is working right, share it with your instructor and TA (save as a "public insight" and insert URL in the appropriate place in WebCampus).

Clone your previous Insight before you move on to the next problem (otherwise any changes you make will carry over to your answer to the previous problem!). The "Clone Insight" link is located in the upper right corner. In general, always clone your Insights after you have copied a link to an insight into your lab write-up. That way, you won't inadvertently change a model before your instructors have a chance to verify you did everything right!

- ***Short answer (3a.)*** Submit the link for your InsightMaker model here.
- ***Short answer (3b.)*** Starting with a growing population, can you come up with two different scenarios in which *Population* is neither growing nor declining, by only changing one of the sliders from the starting conditions (ie, starting with the version you just submitted in 3a)? Explain your answer.

Checklist for Lab 1 completion

- Please submit all files (Excel file as attachment in WebCampus and R script as text pasted into WebCampus) and responses via WebCampus. The InsightMaker models should be shared by saving your Insights as "public" and sharing the URL link with your instructors in Top Hat.

Due Feb. 10

- WebCampus short answers and file submissions
  - **Exercise 1**

    * *Short answer (1a.)*
    * *Short answer (1b.)*
    * *Short answer (1c.)*
    * *Short answer (1d.)*
    * *Short answer (1e.)*
    * *Short answer (1f.)*
    * *Short answer (1g.)*
    * *Short answer (1h.)*
    * *Submit Excel file (1i.)* Your Excel file should show that you were able to successfully use formulas to calculate N_t for each time step (year and half-year) and show a plot of N by Time.
  - **Exercise 2**
    * *Short answer(2a.)*
    * *Plot upload (2b.)*
    * *Short answer(2c.)*
    * *Plot upload (2d.)*
    * *Short answer (2e.)*
    * *Image upload (2f.)*
    * *Short answer (2g.)*
    * *Short answer (2h.)*
    * *Copy and paste R code (2i.)* Your R code should show that you were able to:
      a. adapt the given code to run for 85 years, and can display a plot of the results;
      b. change r to 0.35 and run for 85 years and plot the results;
      c. identify a value of r that gives a population size of 1000 after 85 years; and
      d. change r to -0.08 and run until the population goes extinct- and plot the results.
  - **Exercise 3**
    * *Submit InsightMaker link (3a.)*
    * *Short answer (3b.)*

–End of Lab 1–