What are the basic ingredients of natural selection?

Your suggestions

- Natural selection/filter
- Environmental change
- Resources
- Competition
- DNA
- Inheritance
- Mutations
- Variability

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What are the basic ingredients of natural selection?

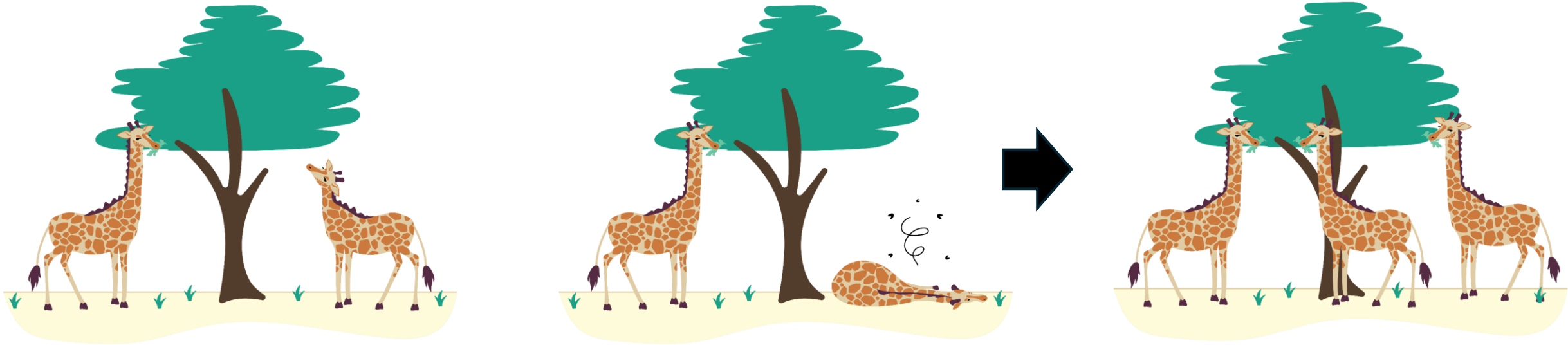
Your suggestions

- **Natural selection/filter**
- Environmental change
- Resources
- Competition
- DNA (not only)
- **Inheritance**
- Mutations
- **Variability**

What are the basic ingredients of natural selection?

In other words, what do we need to make it work?

- **Variability** among individuals
- Differential contribution to successive generations (**Natural selection**)
- Mechanism of **inheritance**



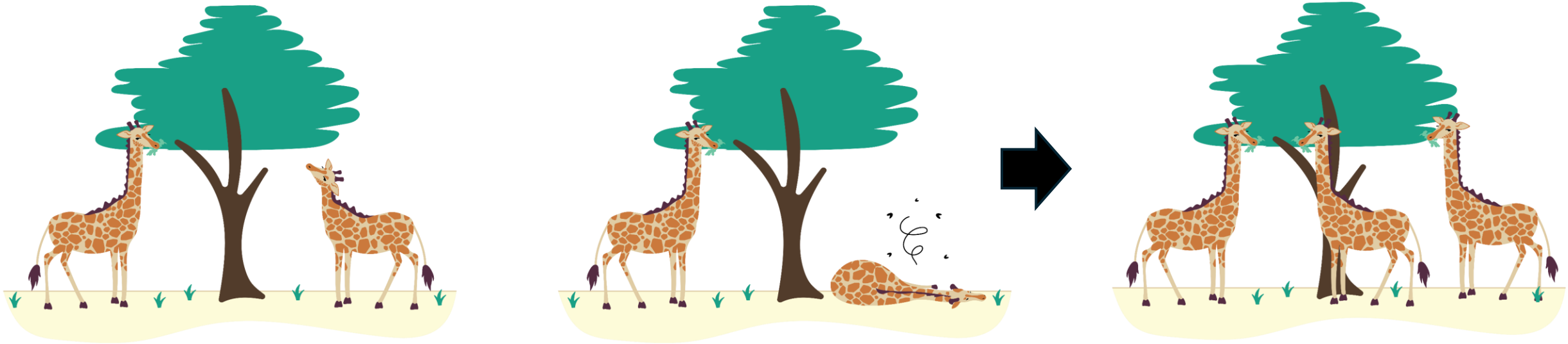
We would like to ask:

*Are **variability, genetic inheritance** and **differential contribution** all the ingredients for evolution?*

Are they sufficient?

Are they strictly necessary?

What are their implications?



Was Darwin's theory correct?

What are its predictions?

When does it work and when not?

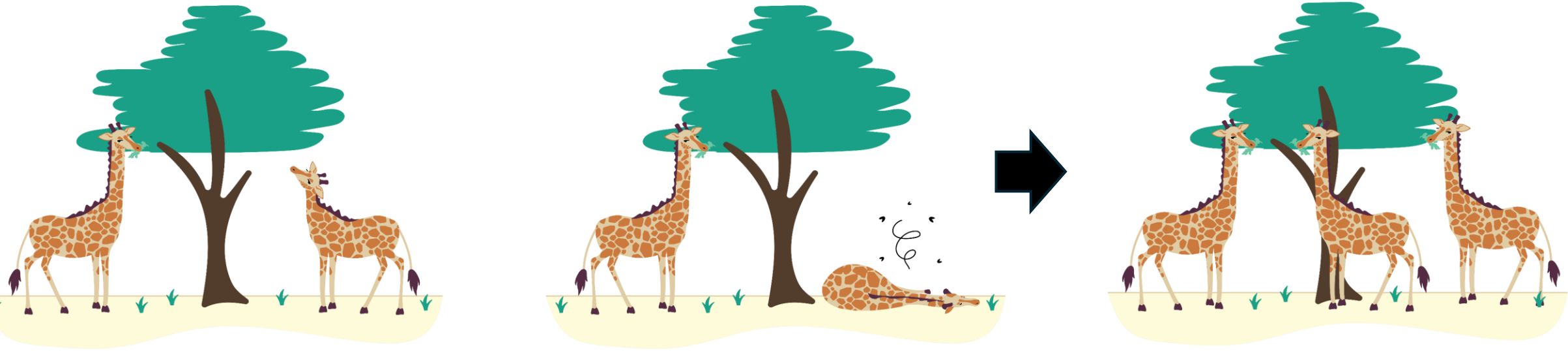
How to explore the predictions and implications of a theory?

Variability among individuals

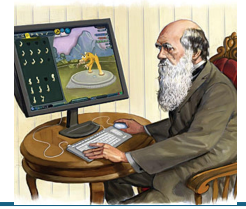
Selection on individuals

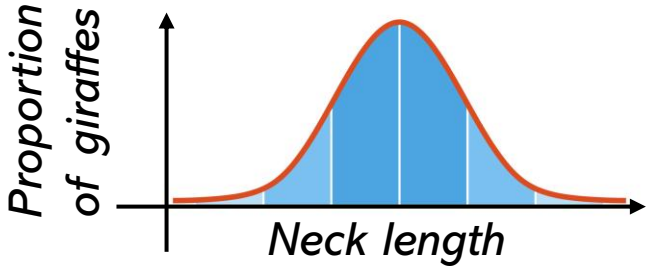
Inheritance

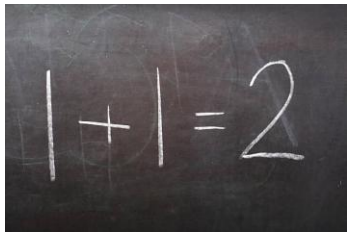
Biological model



Computational model/simulations

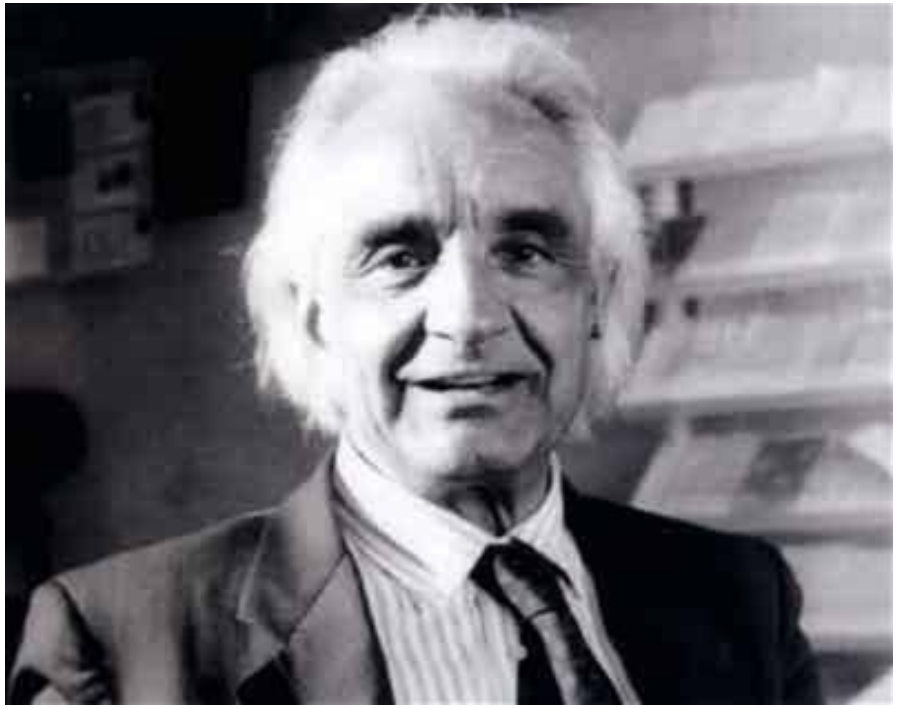




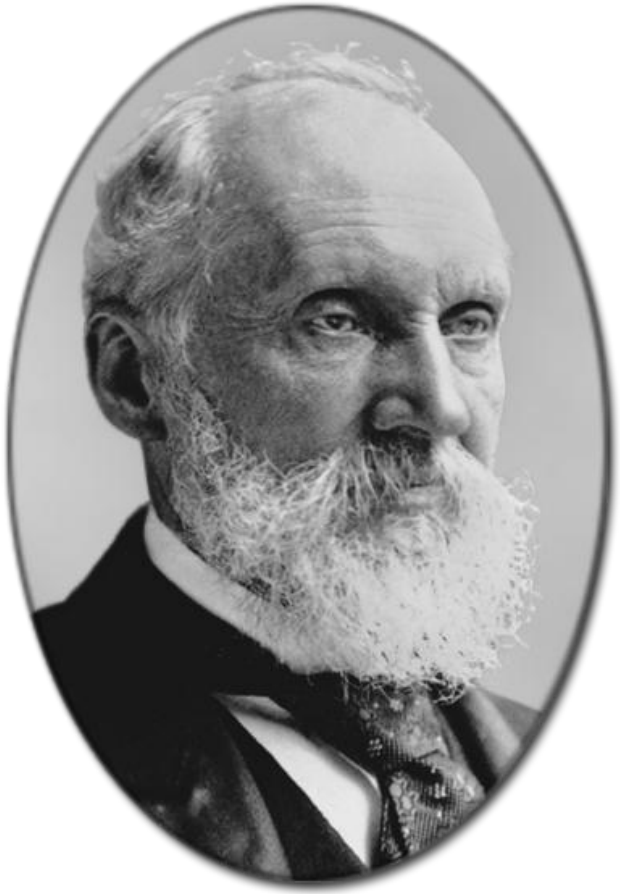


Mathematical/graphical model

Evolutionary theory has no mathematical foundation and makes wrong predictions



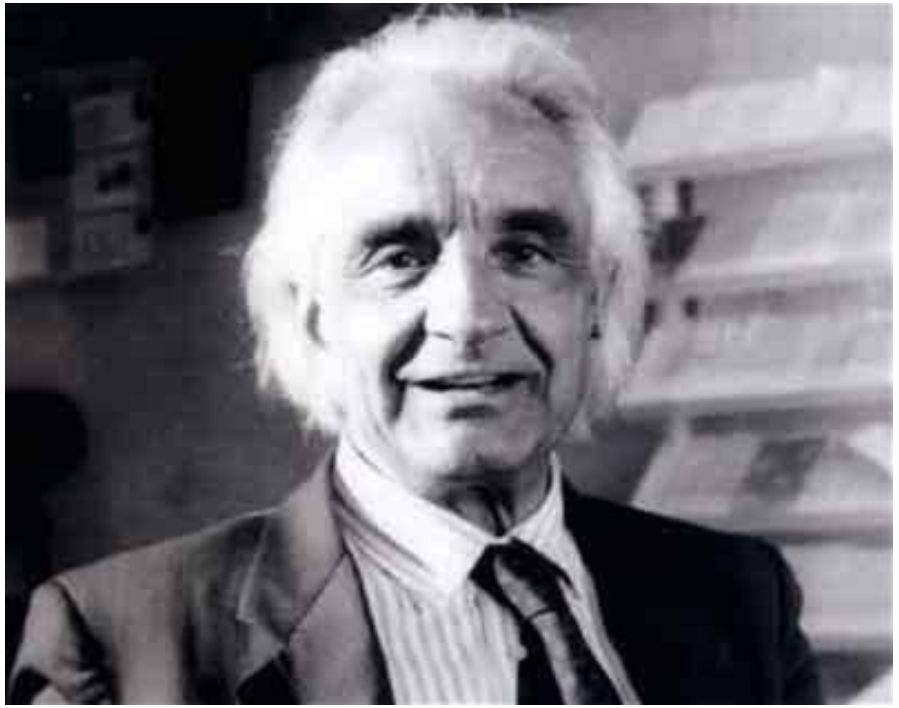
Antonio Zichichi 1929-2026



Lord Kelvin (1824-1907)

L’evoluzionismo non è una scienza - di Antonino Zichichi | Corrispondenza romana

Evolutionary theory has no mathematical foundation and makes wrong predictions



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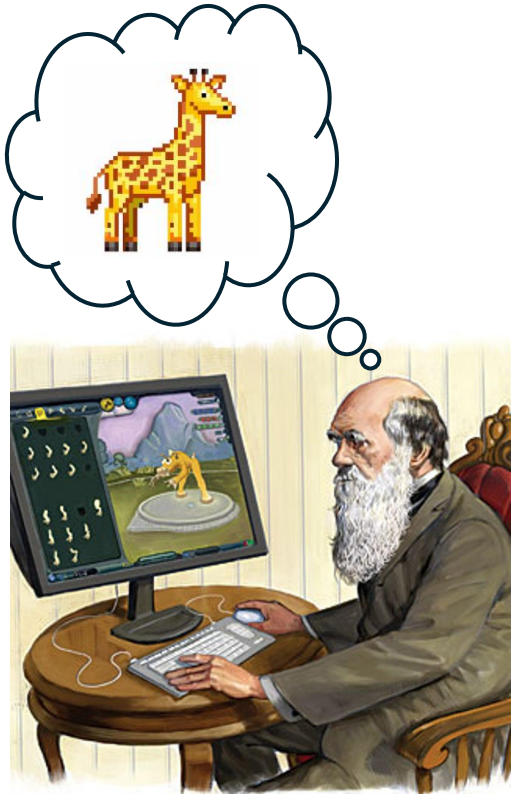
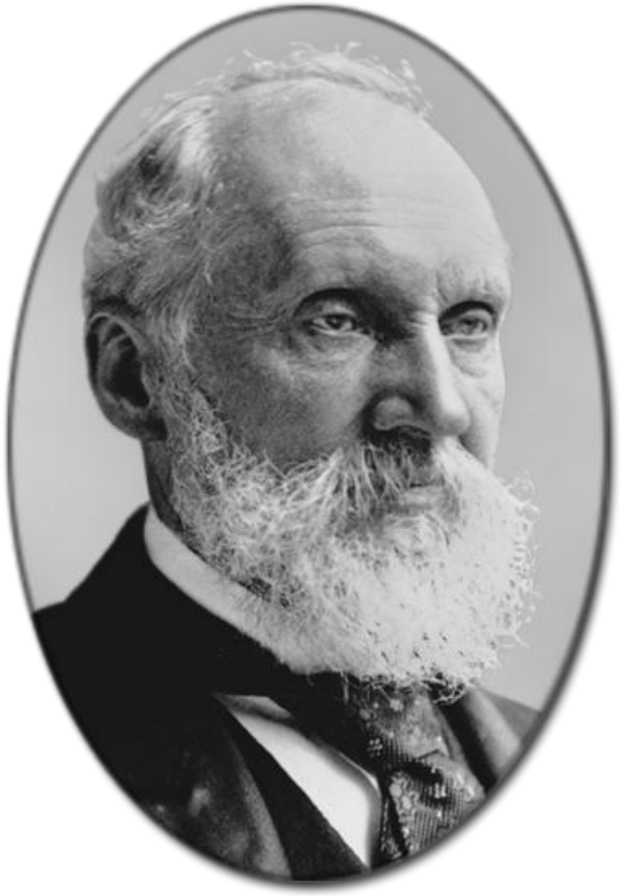
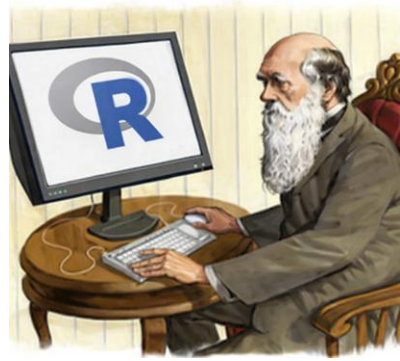




Lord Kelvin (1824-1907)

L’evoluzionismo non è una scienza - di Antonino Zichichi | Corrispondenza romana

A Primer in R

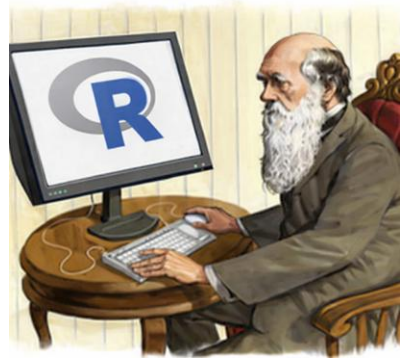



```
x=1
print(x)
```

Assign a value to a *variable* and print

```
1
x
1
```

A Primer in R



Assign a *value* to a *variable* and print

```
x=1
print(x)
```

```
1
```

```
x
```

```
1
```

```
y=2
y
```

```
2
```

Operations with variables

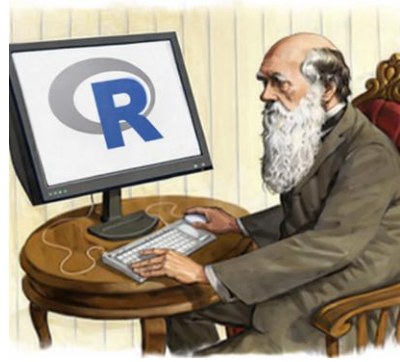
```
x+y
```

```
3
```

```
y=x
y
```

```
1
```

A Primer in R

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Operations with variables

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3
```

```
y=x
y
```

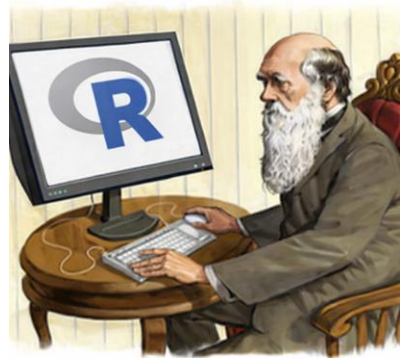
```
1
```

```
y=rep(1,4)
```

Variables can take the values of *vectors*

```
1 1 1 1
```

A Primer in R

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x+y
```

Operations with variables

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3
y=x
y
1
y=rep(1,4)
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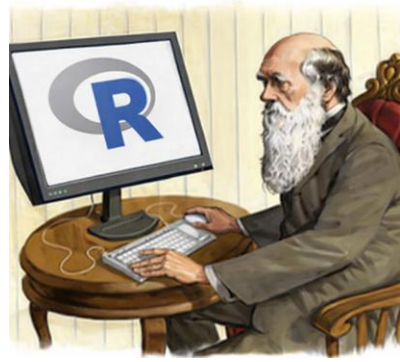
Variables can take the values of *vectors*

```
1 1 1 1
x=c(1,2,3,4)
```

c(..) concatenate values in a vector

```
x
1 2 3 4
```

A Primer in R

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```
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```

```
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```

Operations with variables

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y
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```

```
1 2 3 4
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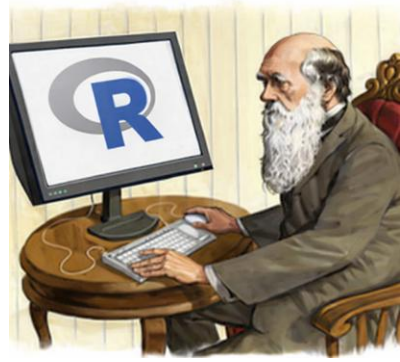
```
x[x>2]
```

Square brackets select specific values from a vector

```
3 4
```

A Primer in R

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x
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```
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Operations with variables
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```
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```
```
1 2 3 4
```
```
x[x>2]
```
Square brackets select specific values from a vector
```
3 4
```
```
1:4
```
```
1 2 3 4
```

A Primer in R

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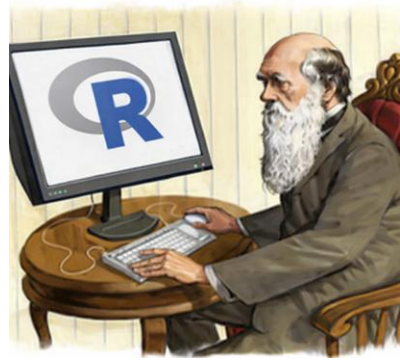
y=2
y
2
x+y
3
y=x
y
1
y=rep(1,4)
1 1 1 1
x=c(1,2,3,4)
x
1 2 3 4
x[x>2]
3 4
1:4
1 2 3 4
```

```
for ( x in 1:4 )
{
print(x)
}
```



For-loops iterate for all values of x in 1:4, repeating the operations within { .. } for each value

A Primer in R

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1
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y
2
x+y
3
y=x
y
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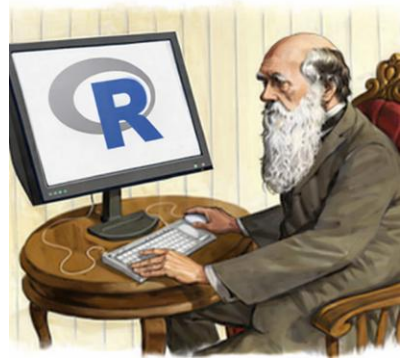
1 1 1 1
x=c(1,2,3,4)
x
1 2 3 4
x[x>2]
3 4
1:4
1 2 3 4
```

```
for ( x in 1:4 )
{
print(x)
}
1
2
3
4
```



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A Primer in R

```
x=1
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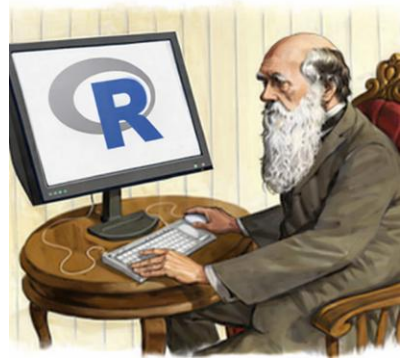
1
x
1
y=2
y
2
x+y
3
y=x
y
1
y=rep(1,4)
1 1 1 1
x=c(1,2,3,4)
x
1 2 3 4
x[x>2]
3 4
1:4
1 2 3 4
```

```
for ( x in 1:4 )
{
print(x)
}
1
2
3
4
```

```
x=0
for (y in 1:4)
{
x=x+1
}
x
```



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A Primer in R

```
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1
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2
x+y
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1
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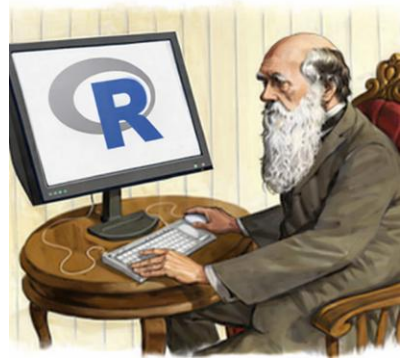
4
```



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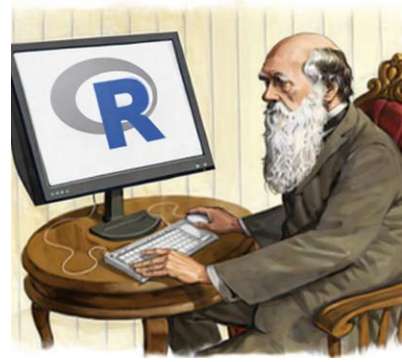
Probability in R




```
mean(0:10)
```

```
5
```

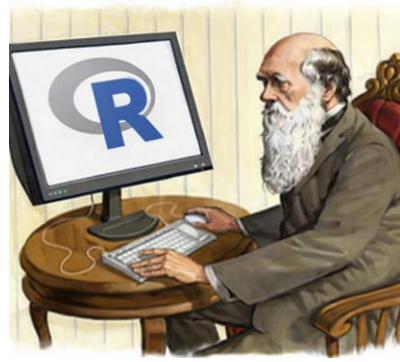
```
median(0:10)
```

```
5
```

```
1:10
```

```
1  2  3  4  5  6  7  8  9  10
```

Probability in R




```
mean(0:10)
```

```
5
```

```
median(0:10)
```

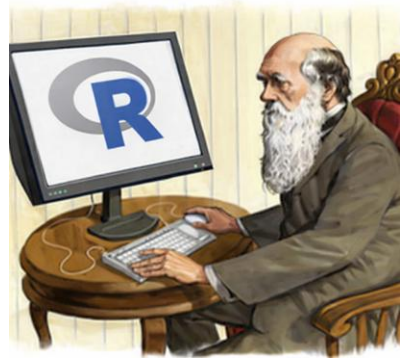
```
5
```

```
rnorm(n=100,mean=0,sd=1)
```

```
0.59162486  0.54468991  0.93817635 ...
```

Generate 100 values sampled from a Gaussian/Normal distribution

Probability in R

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0.59162486  0.54468991  0.93817635 ...
```

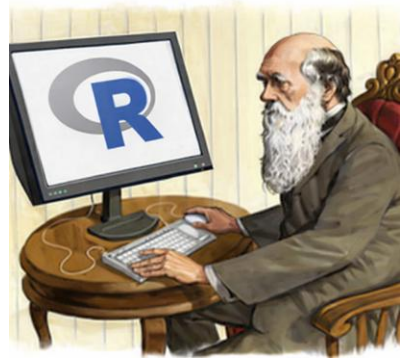
```
x=rnorm(100)
sd(x)
```

```
1.011
```

Generate 100 values sampled from a Gaussian/Normal distribution

If one does not specify mean and sd, rnorm assumes a standard normal distribution (mean=0,sd=1)

Probability in R

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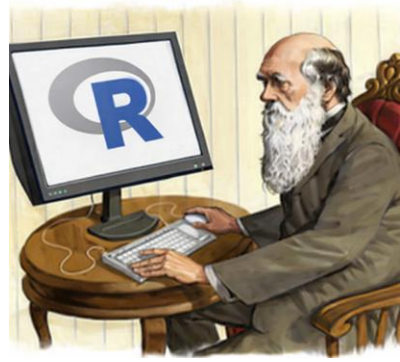
```
```
x=rnorm(100)
sd(x)
```
```
1.011
```
```
rbinom(n=5,size=10,prob=0.1)
```
```
1  1  2  0  1
```

Generate 100 values sampled from a Gaussian/Normal distribution

If one does not specify mean and sd, rnorm assumes a standard normal distribution (mean=0,sd=1)

The same can be done for any distribution (e.g. Binomial distribution with `rbinom`, `rexp` for exponential, etc.)

Probability in R

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```
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```

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5
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```
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sd(x)
```

```
1.011
```

```
rbinom(n=5,size=10,prob=0.1)
```

```
1   1   2   0   1
```

```
1:10
```

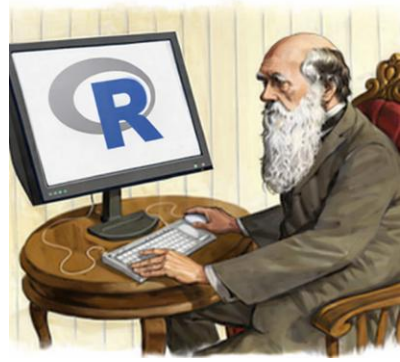
```
1  2  3  4  5  6  7  8  9  10
```

```
sample(1:10)
```

```
1  4  3  7  5  10  9  8  6  2
```

Shuffle/sample without replacement the vector 1:10

Probability in R

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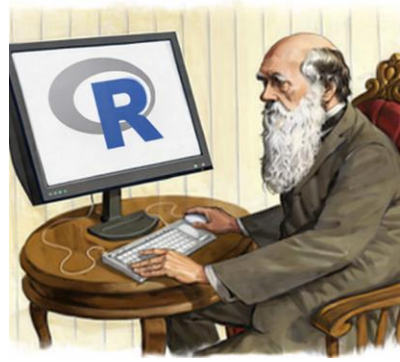
```
```
1  1  2  0  1
```

```
1:10
```
```
1  2  3  4  5  6  7  8  9  10
```
```
sample(1:10)
```
```
1  4  3  7  5  10  9  8  6  2
```
```
sample(1:10,replace=TRUE)
```
```
1  4  8  5  4  1  5  9  1  4
```

Sample WITH replacement

Probability in R

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1:10
```
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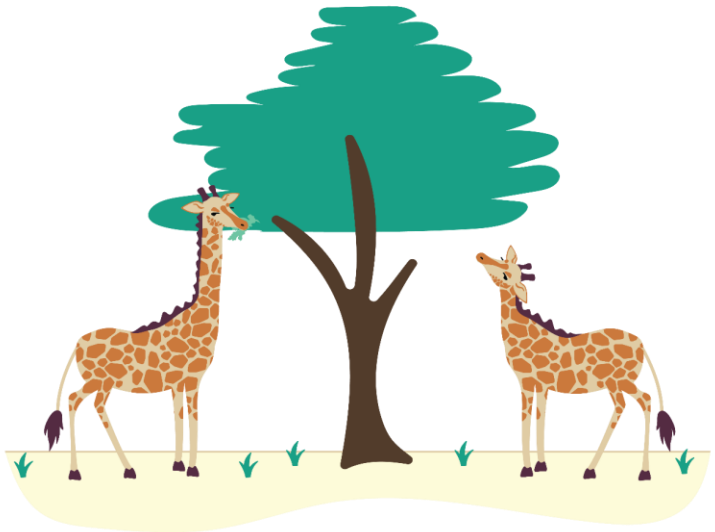
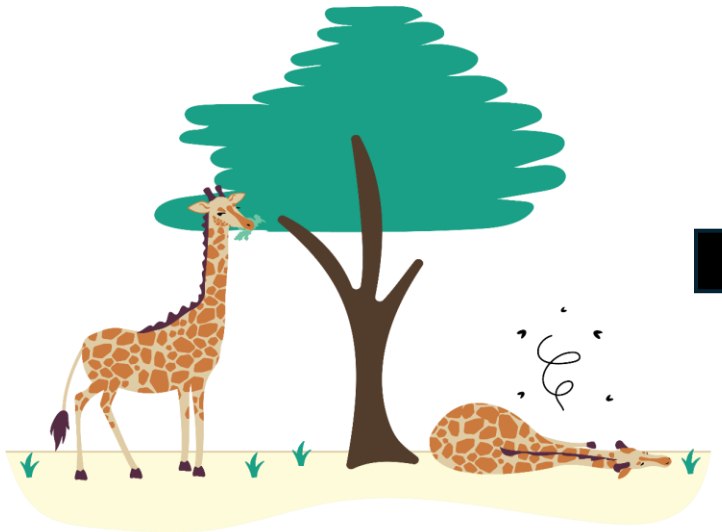
```
```
sample(1:10)
```
```
1  4  3  7  5  10  9  8  6  2
```
```
sample(1:10,replace=TRUE)
```
```
1  4  8  5  4  1  5  9  1  4
```
```
sort(sample(1:10,replace=TRUE))
```
```
1  3  3  5  6  7  8  9  9  9
```

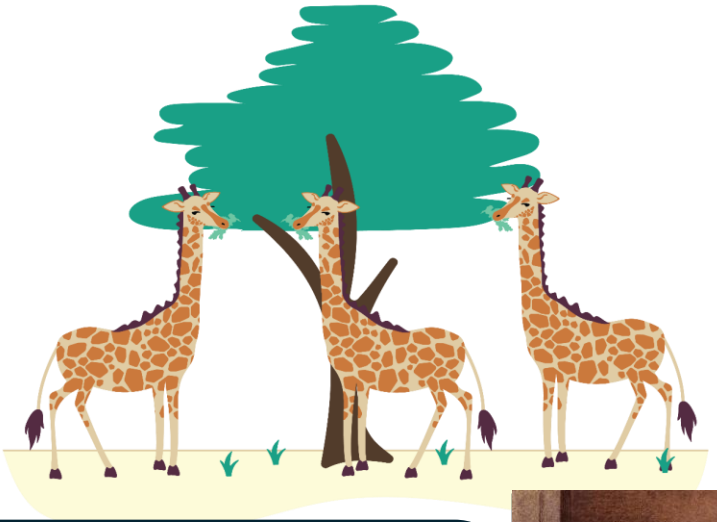
We now sorted the resampled values in ascending order

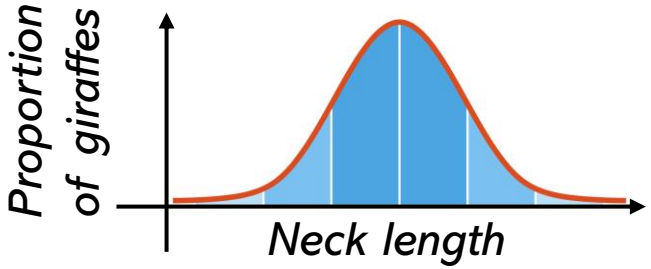
Our first basic “evolutionary model”

- **Variability among individuals**
- Differential contribution to successive generations
- Mechanism of inheritance







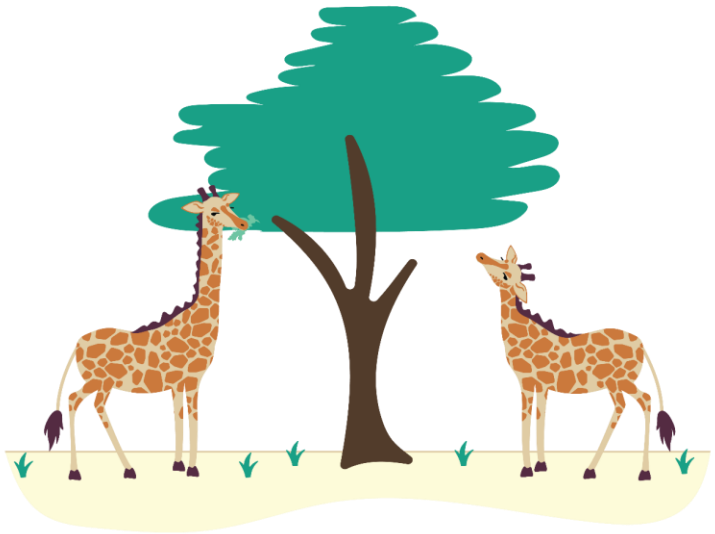


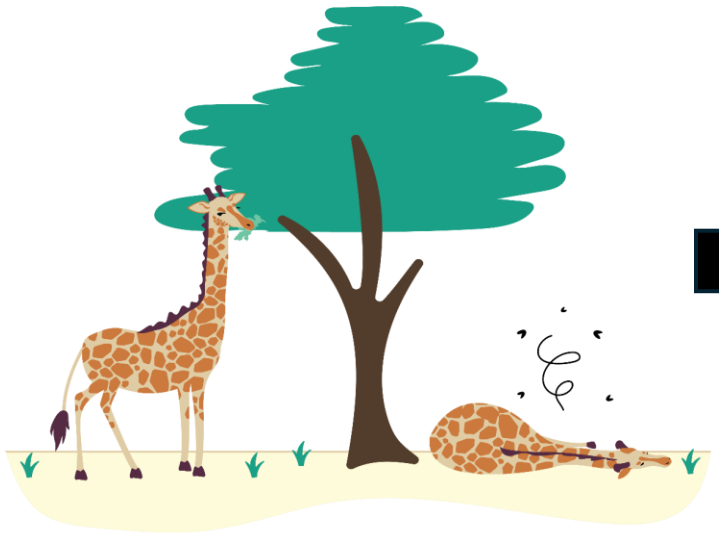
Normal distribution

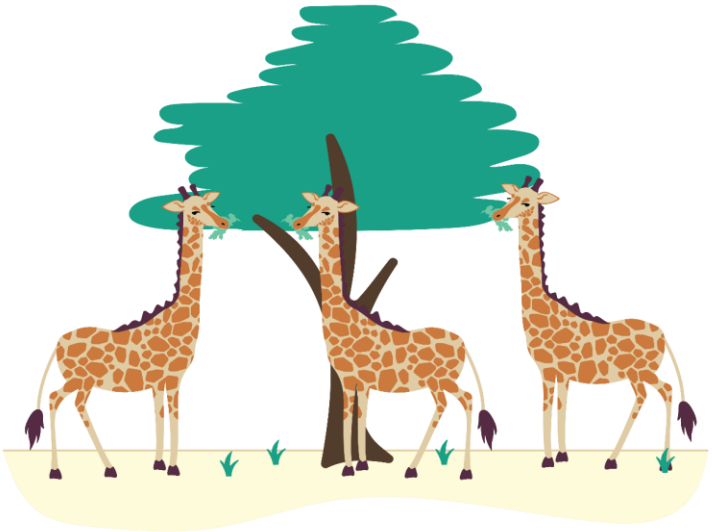
You could have chosen any other distribution. But it is not just because I am his cousin!
Francis Galton, 1822-1911

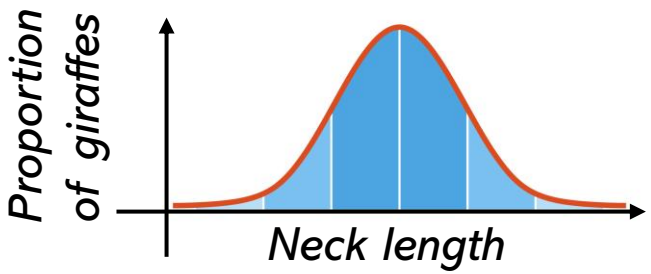
Our first basic “evolutionary model”

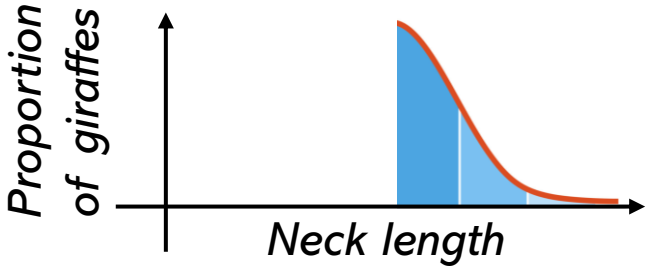
- Variability among individuals
- **Differential contribution to successive generations**
- Mechanism of inheritance





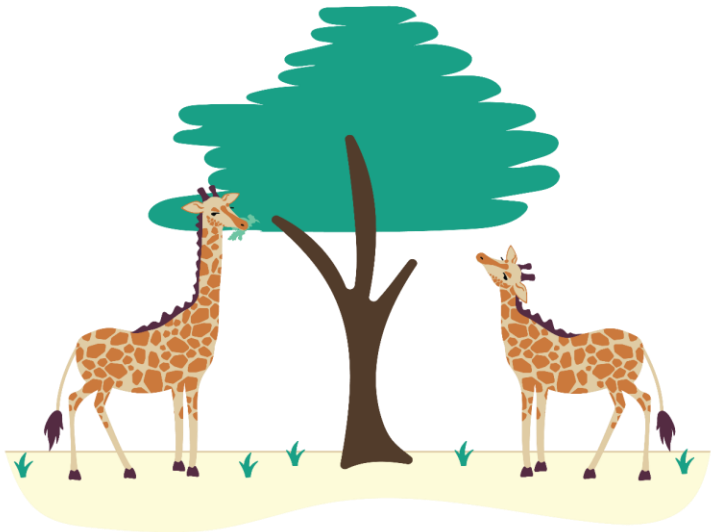


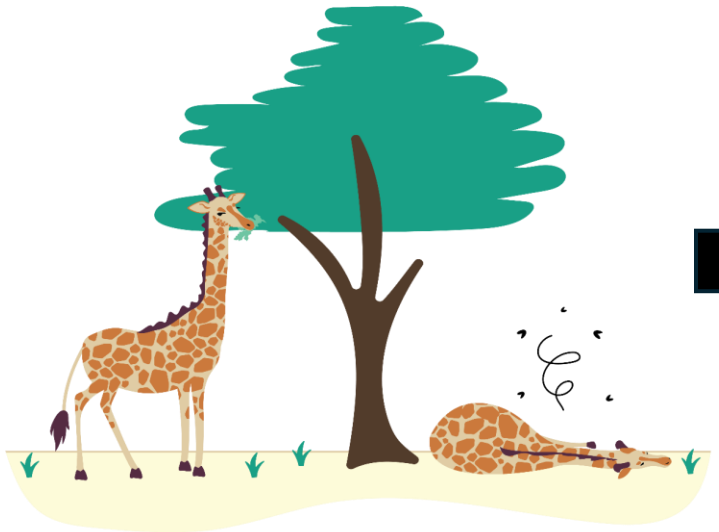


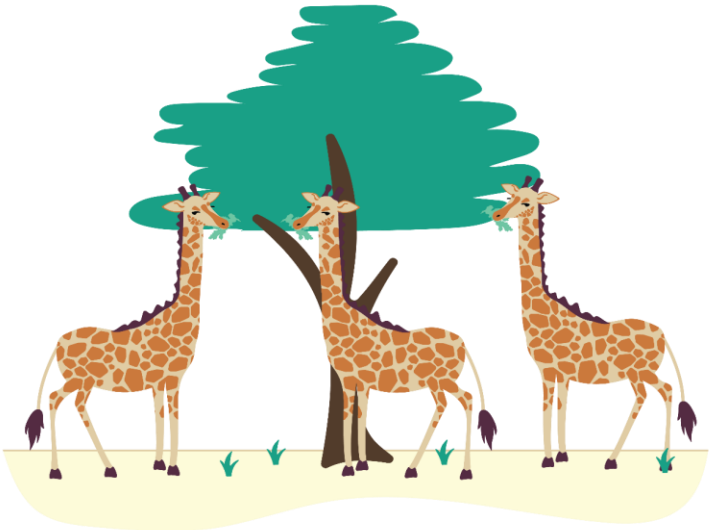


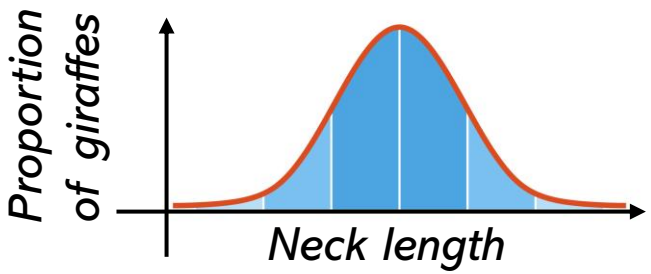
Our first basic “evolutionary model”

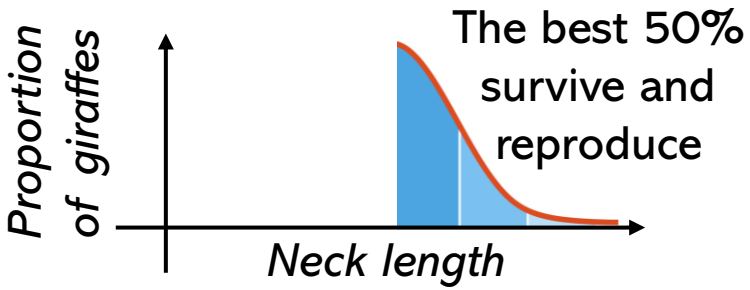
- Variability among individuals
- **Differential contribution to successive generations**
- Mechanism of inheritance







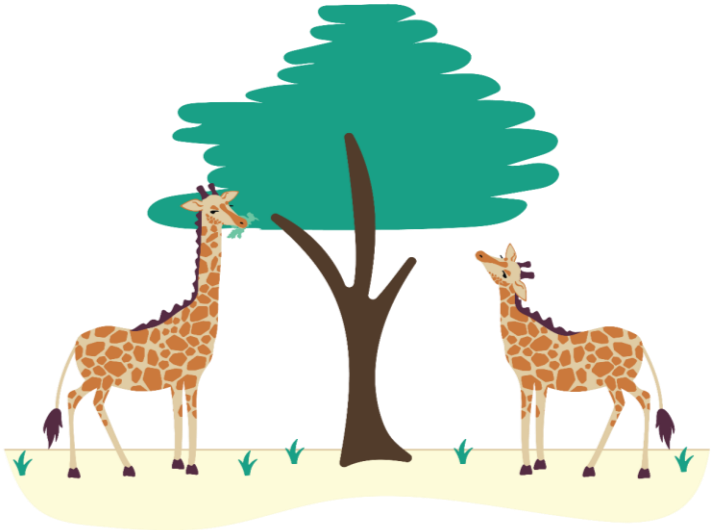


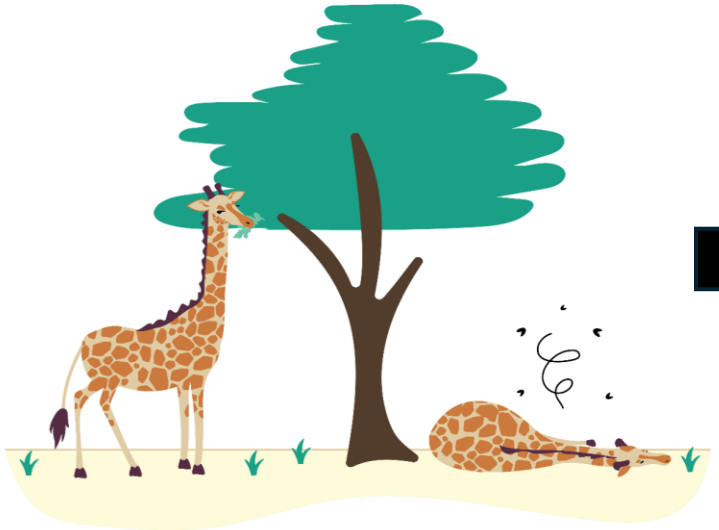


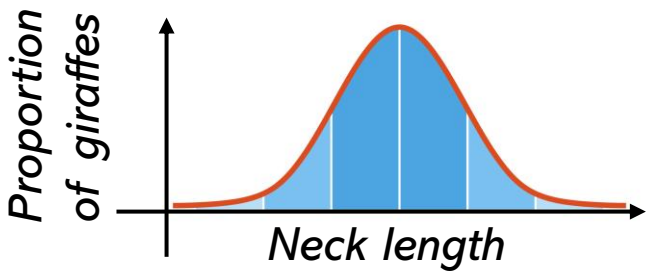
Our first basic “evolutionary model”

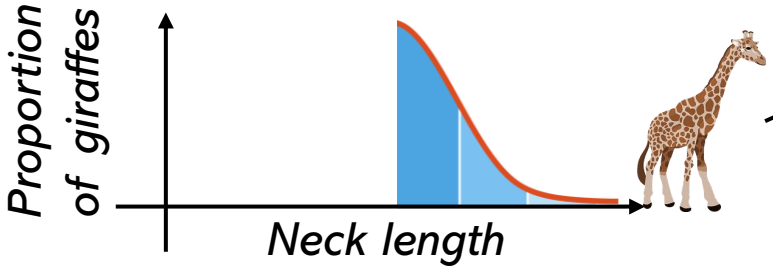
- Variability among individuals
- Differential contribution to successive generations
- **Mechanism of inheritance**

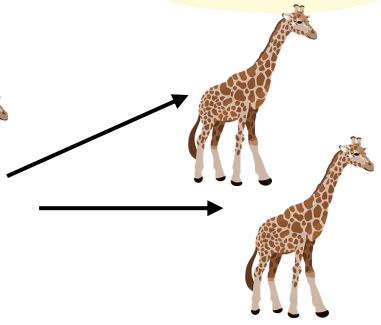
We want giraffes giving birth to «resembling» baby-giraffes









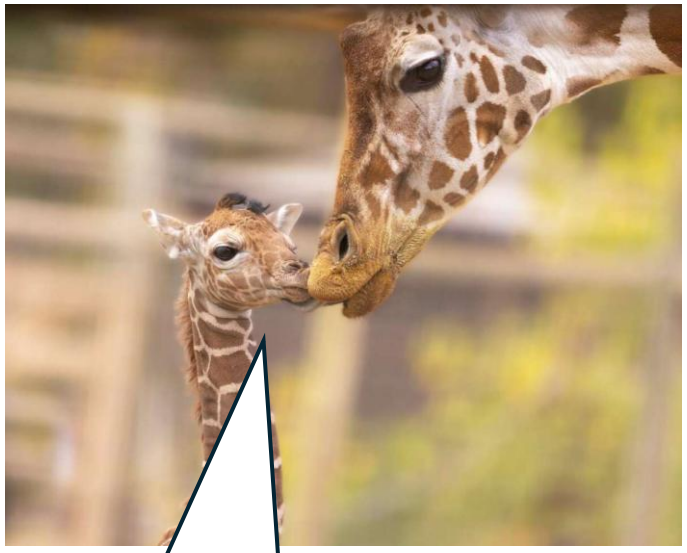


Next generation

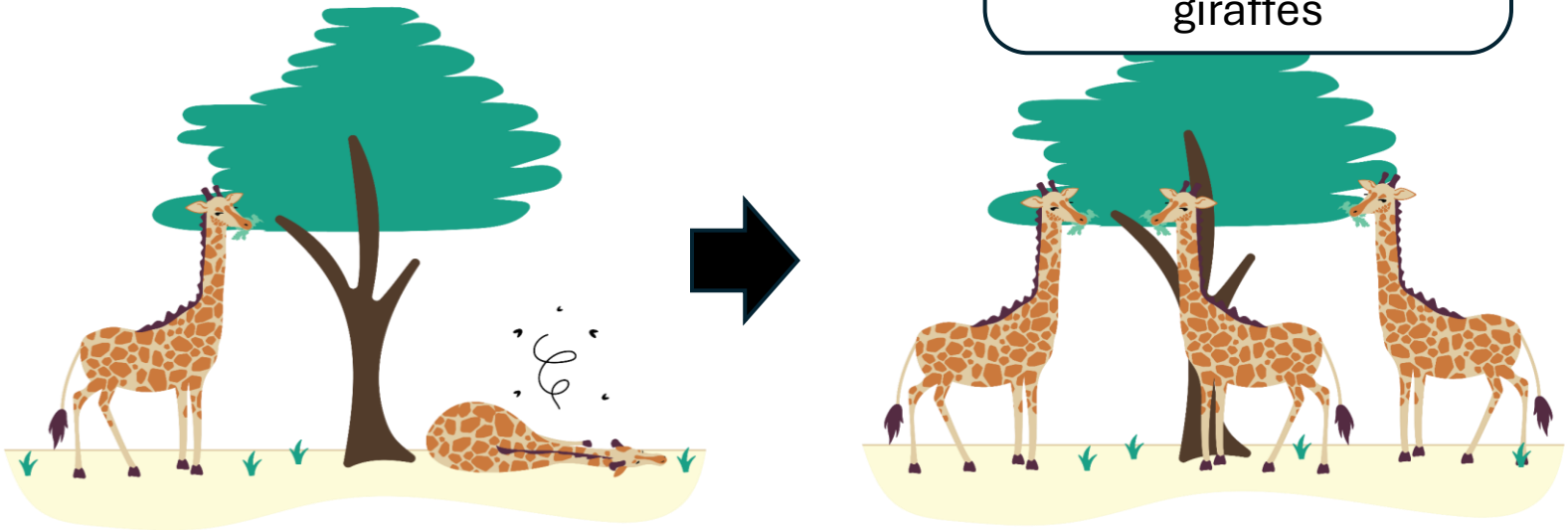
Our first basic “evolutionary model”

- Variability among individuals
- Differential contribution to successive generations
- **Mechanism of inheritance**

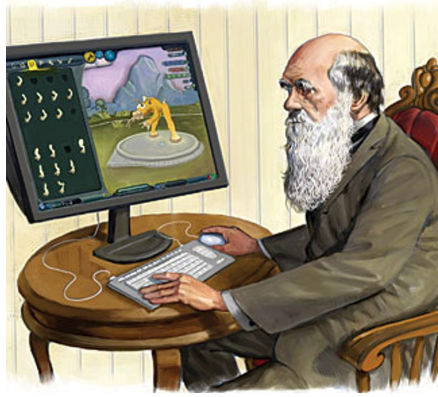
We want giraffes giving birth to «resembling» baby-giraffes



Precocial or *atricial* babies?



Our first basic “evolutionary model”



- Variability among individuals
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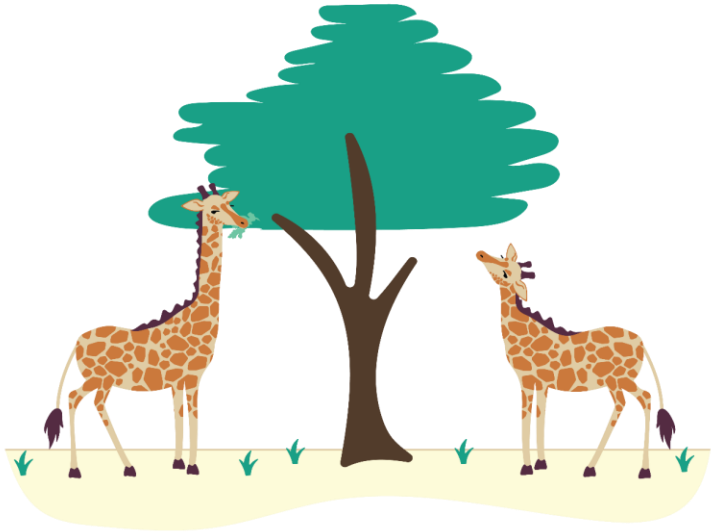
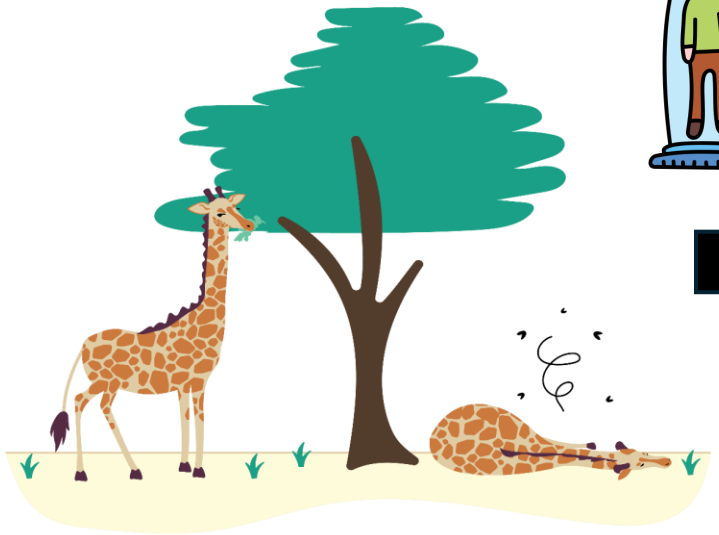
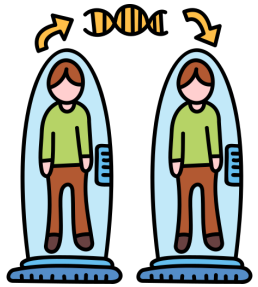
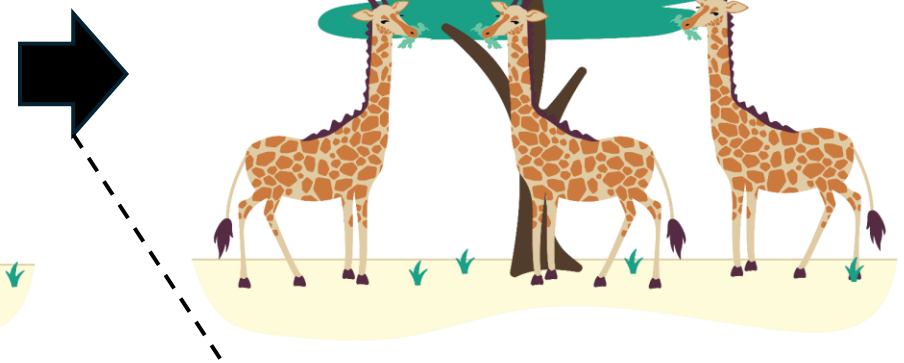
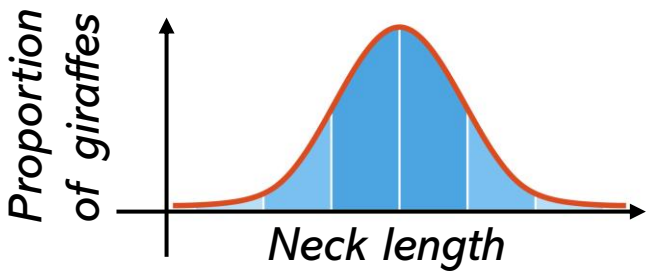
- **Mechanism of inheritance**

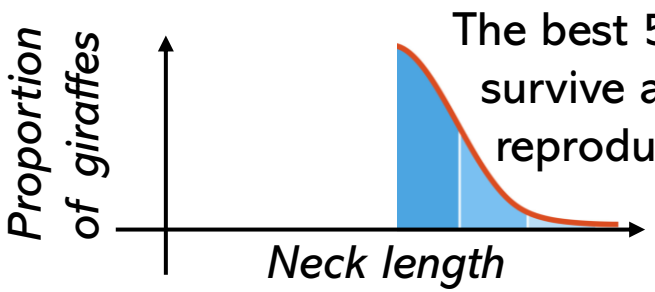










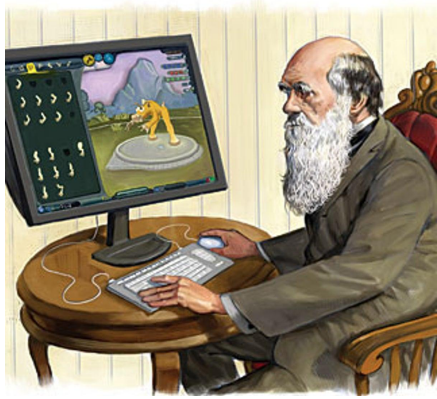


The best 50% survive and reproduce

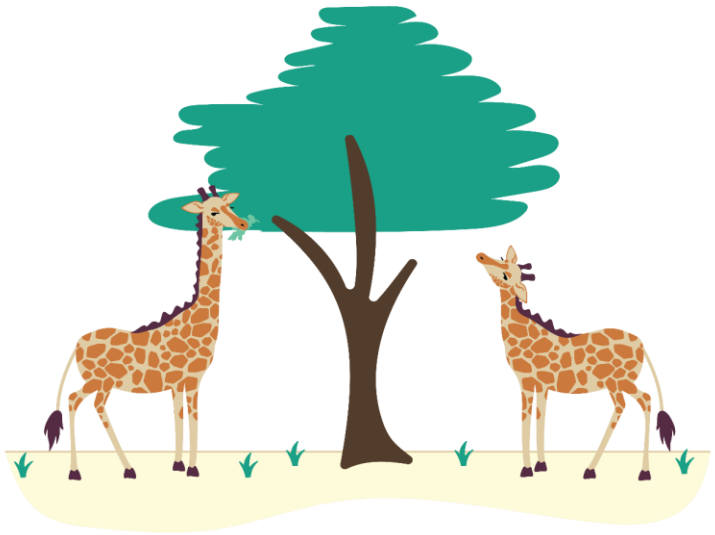
Perfect cloning of parents (same neck length as parents)

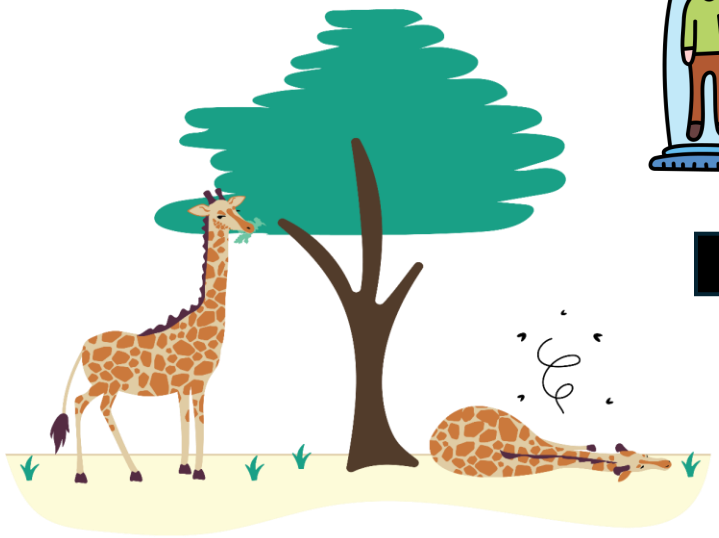
Our first ~~basic~~ very basic "evolutionary model"

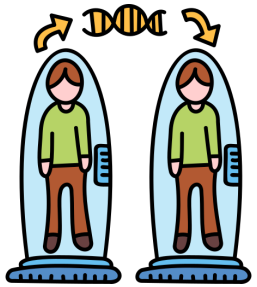
Dolly the sheep

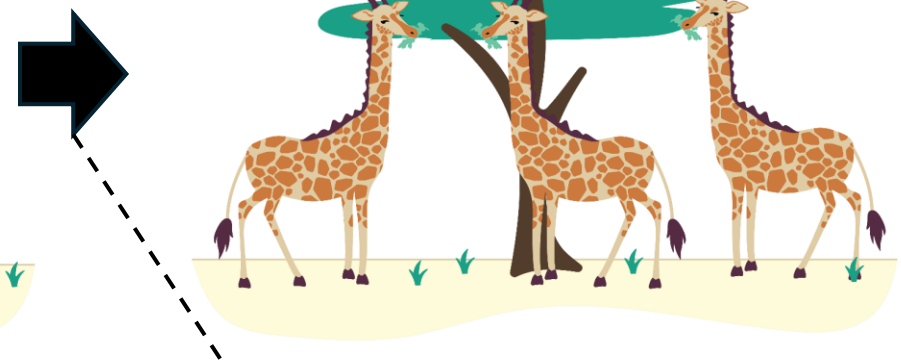


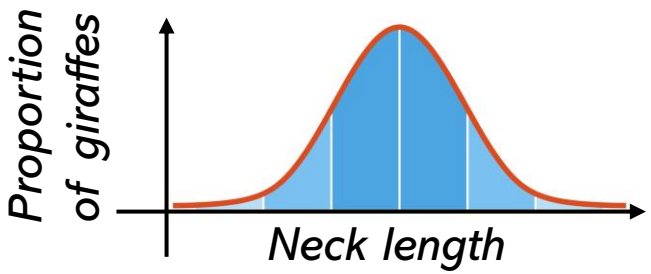
Simplifying assumption

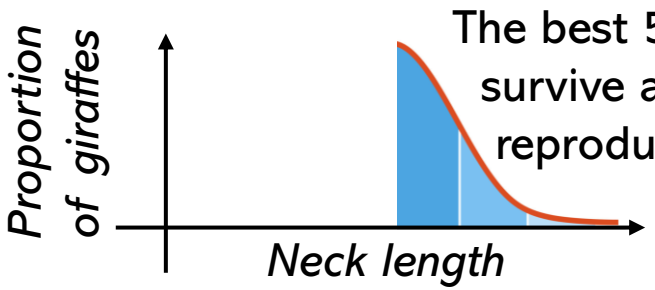








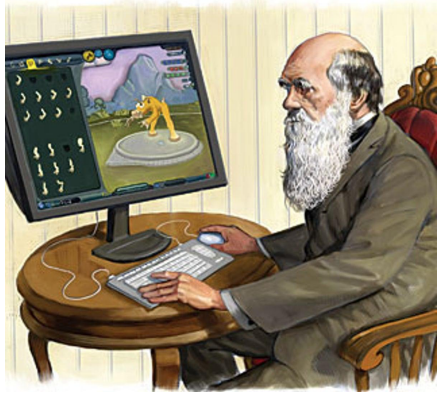


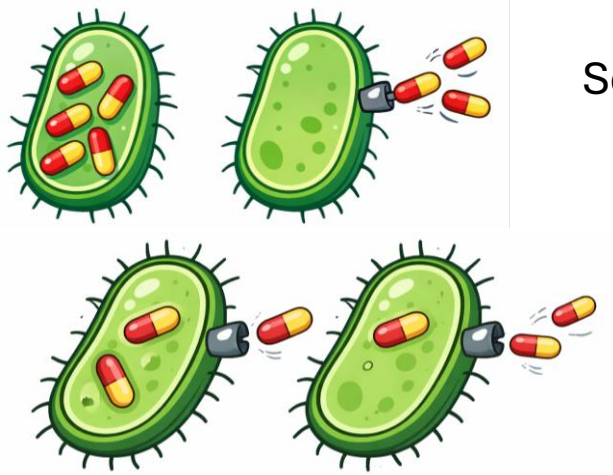


The best 50% survive and reproduce

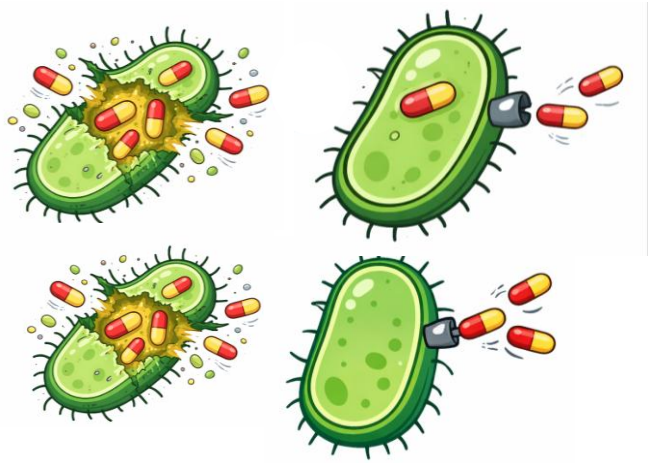
Perfect cloning of parents (same neck length as parents)

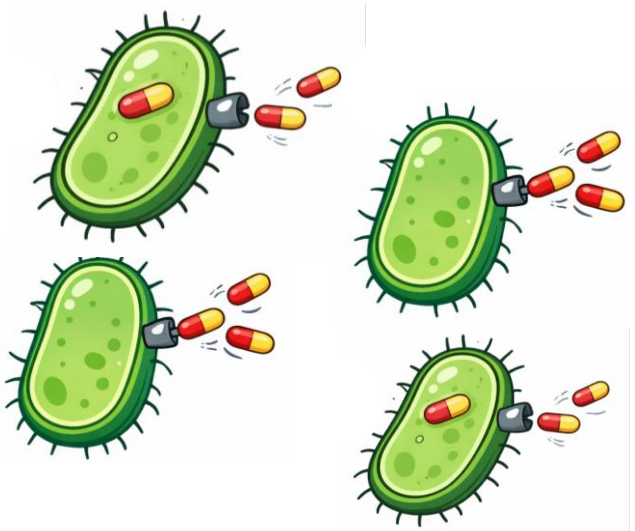
Haploid giraffes (or bacteria)





Selection





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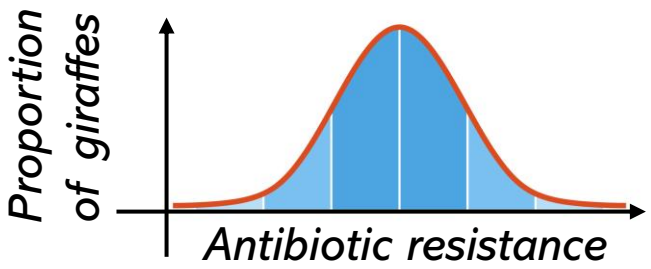

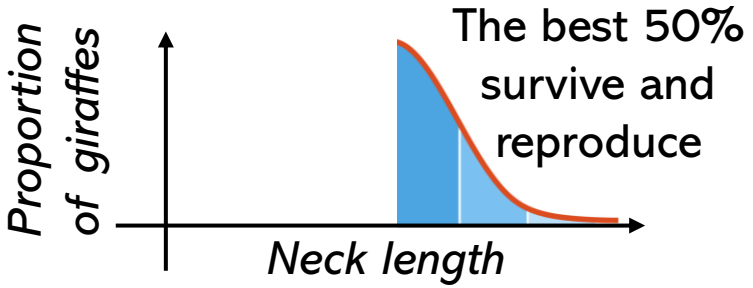

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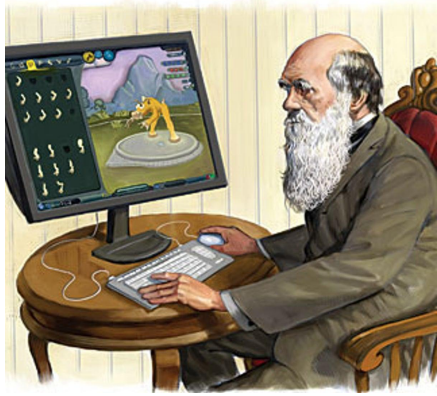
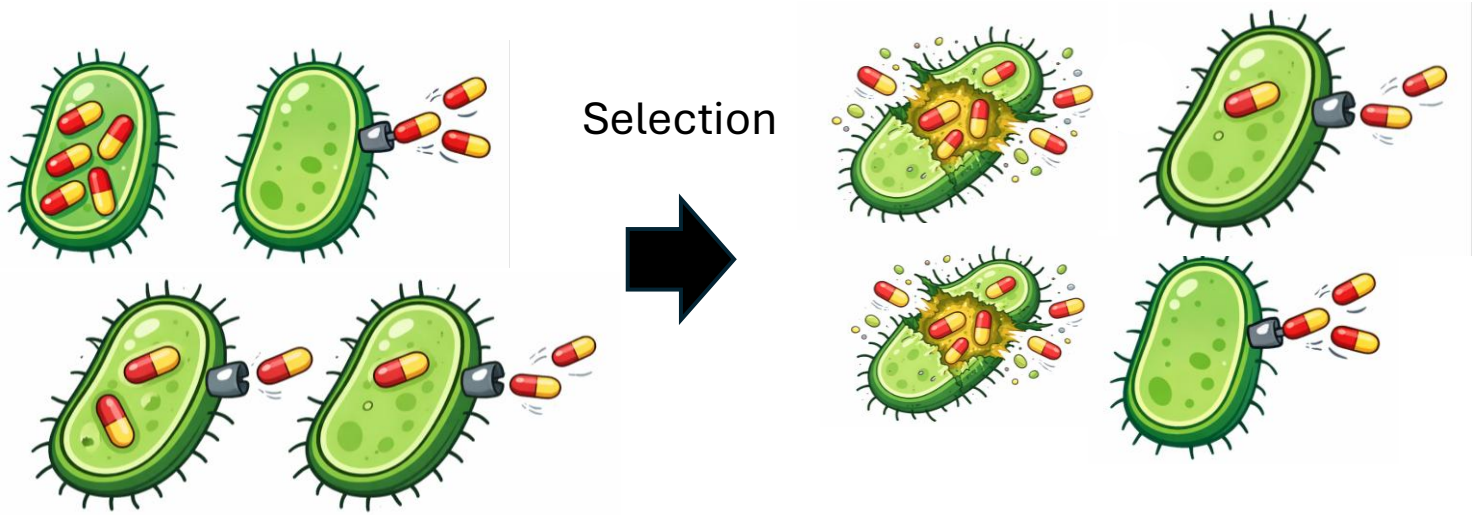
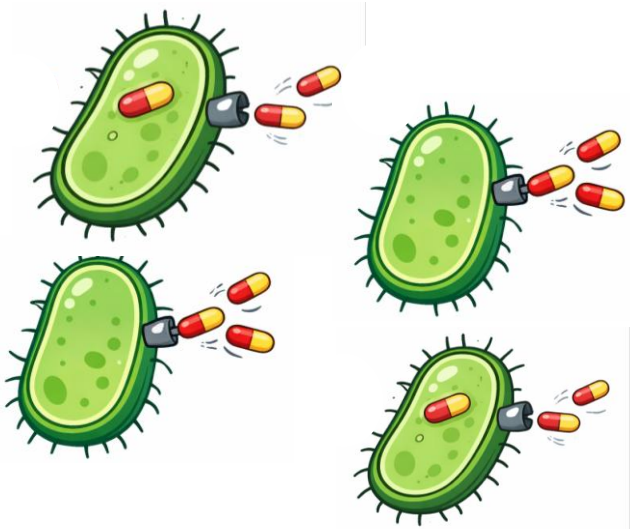
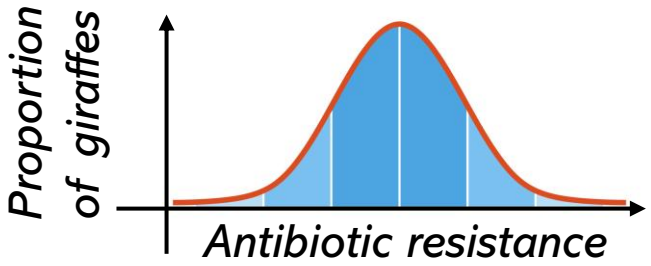
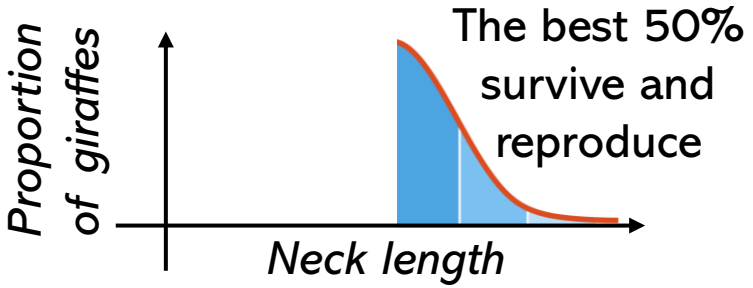






Examples:
Efflux pumps for Tetracyclines in *E.coli* and *Pseudomonas;*
For fluoroquinolones like ciprofloxacin in *S.aureus* and *Pseudomonas*





Perfect cloning of parents
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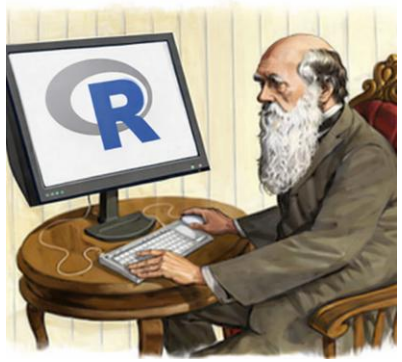
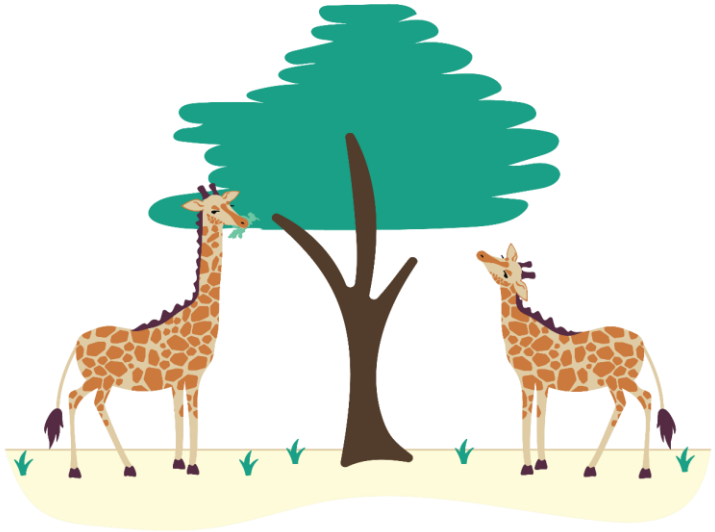
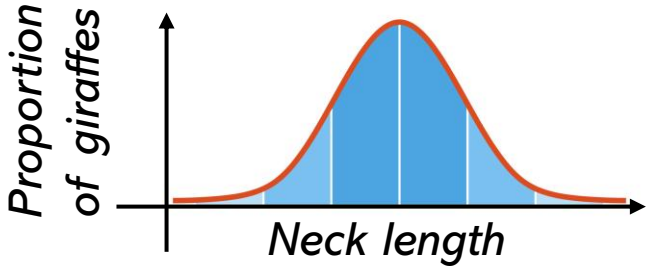
Our first basic “evolutionary model”



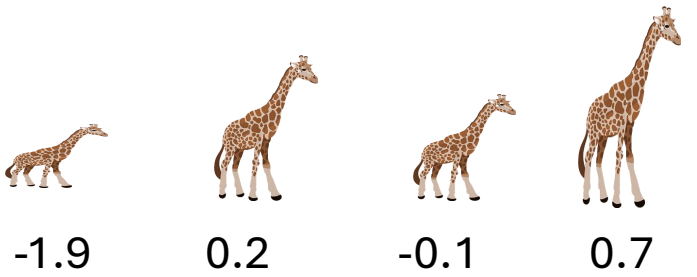
- **Variability among individuals**
- Differential contribution to successive generations
- Mechanism of inheritance





Sample 100 individuals from a Normal/Gaussian distribution

```
rnorm(100)
```



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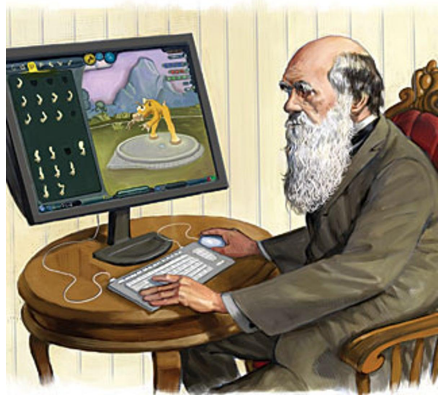

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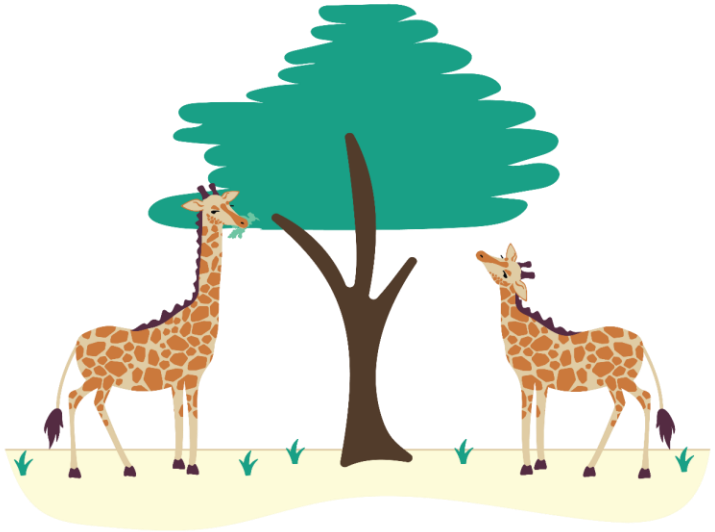
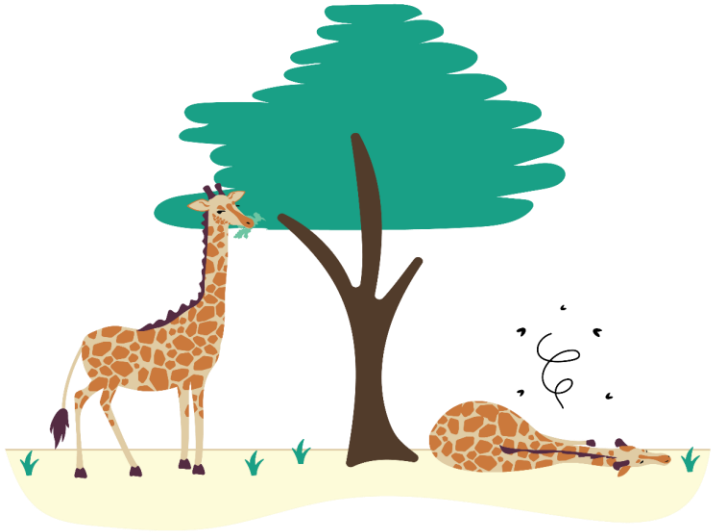
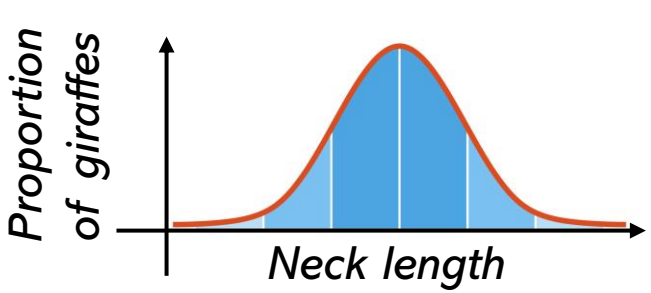
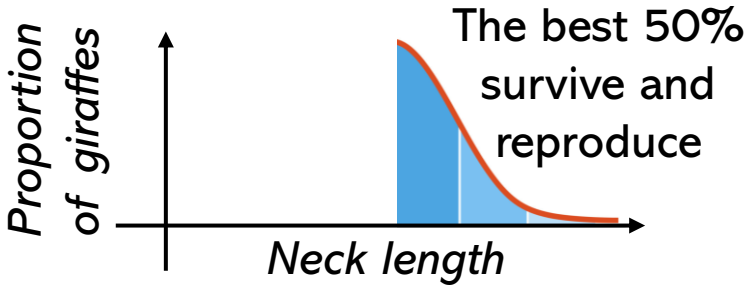


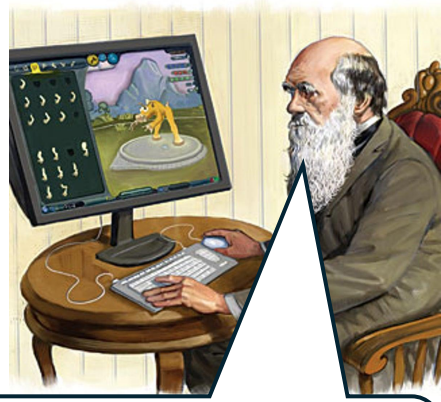




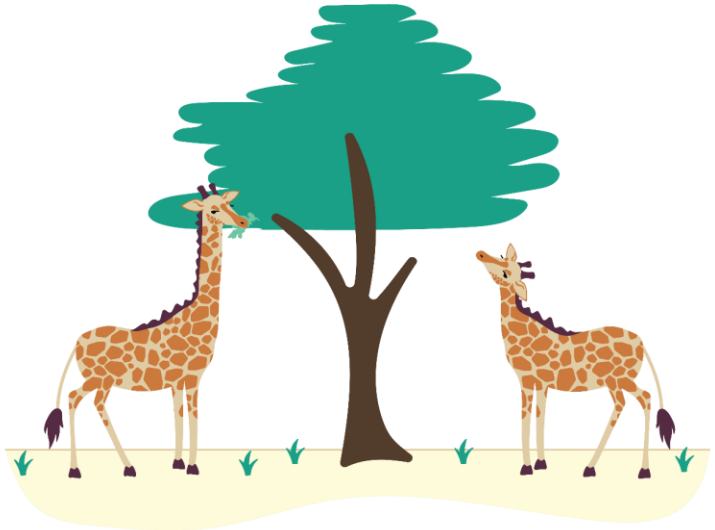


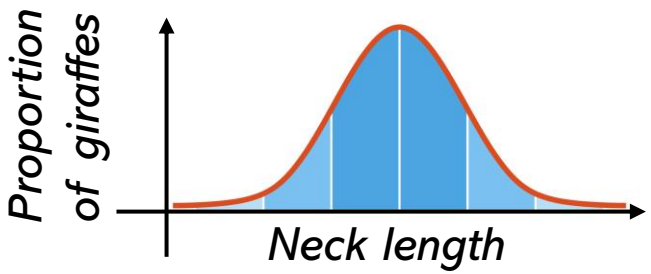
Our first basic “evolutionary model”

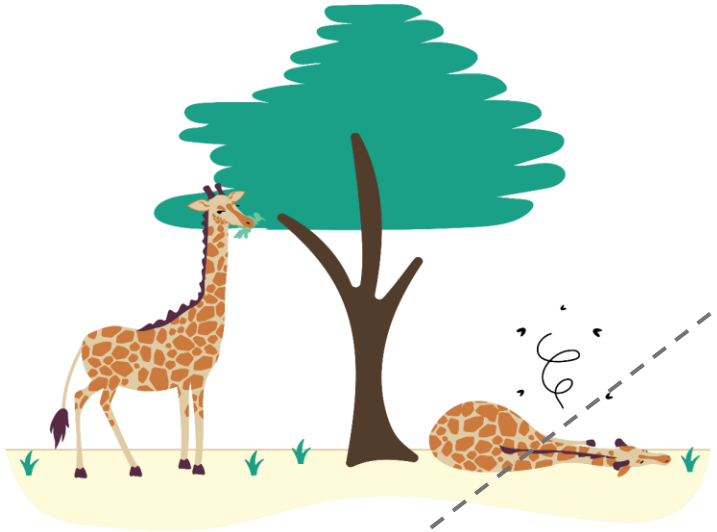
- Variability among individuals
- **Differential contribution to successive generations**
- Mechanism of inheritance

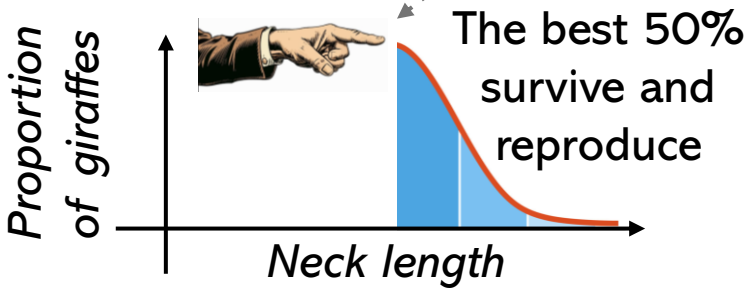


How do you call this?









Our first basic “evolutionary model”

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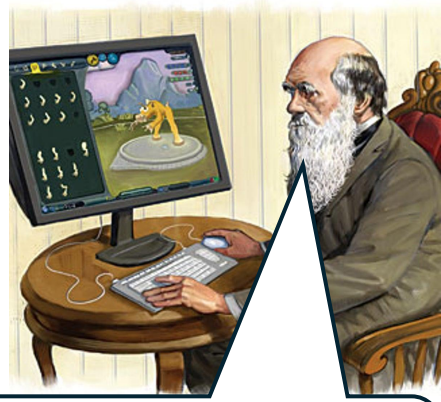
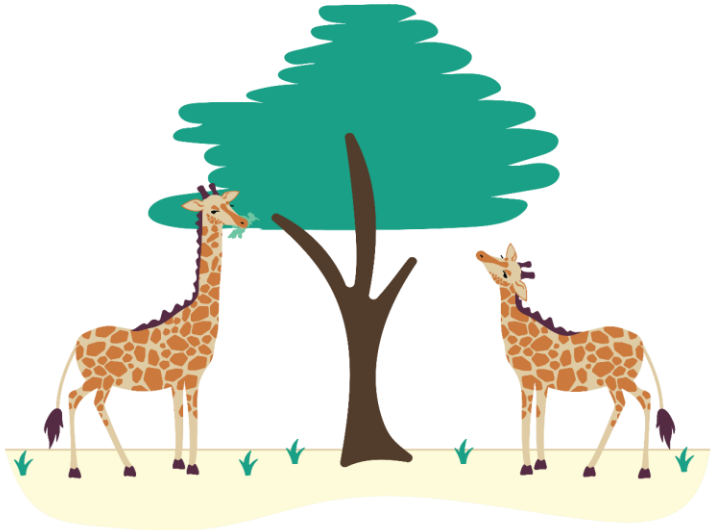
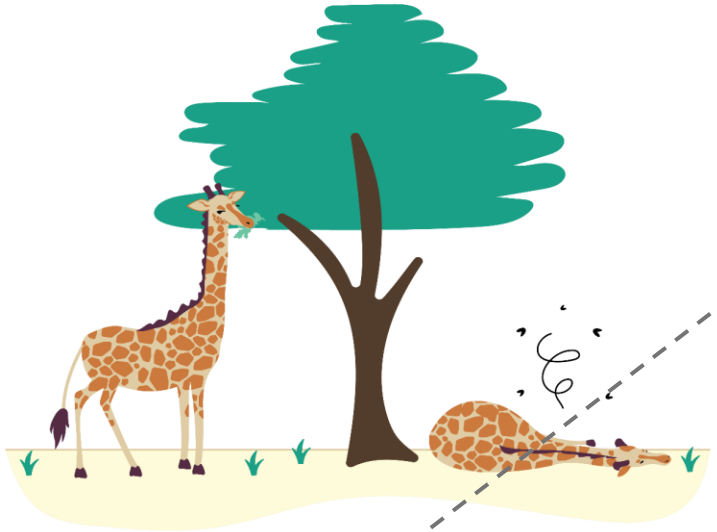
- Mechanism of inheritance

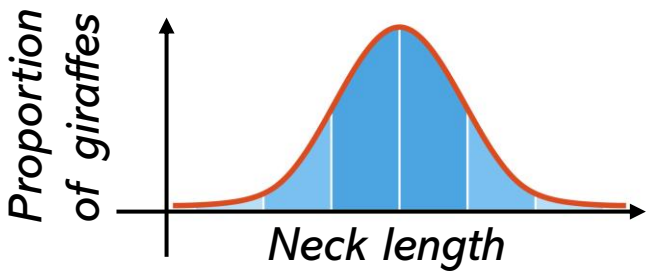


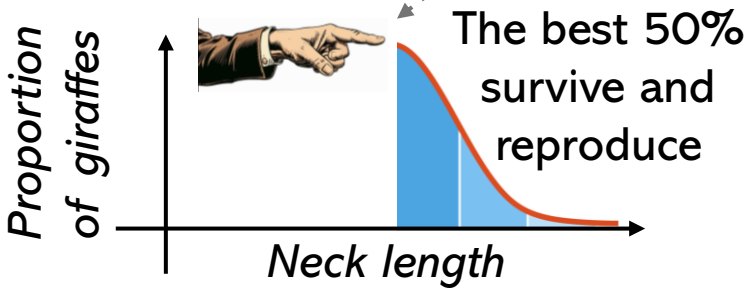
How do you call this?

`median(z)`

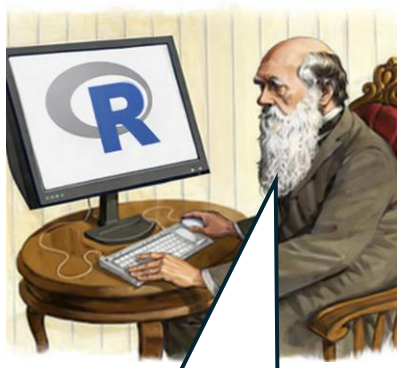




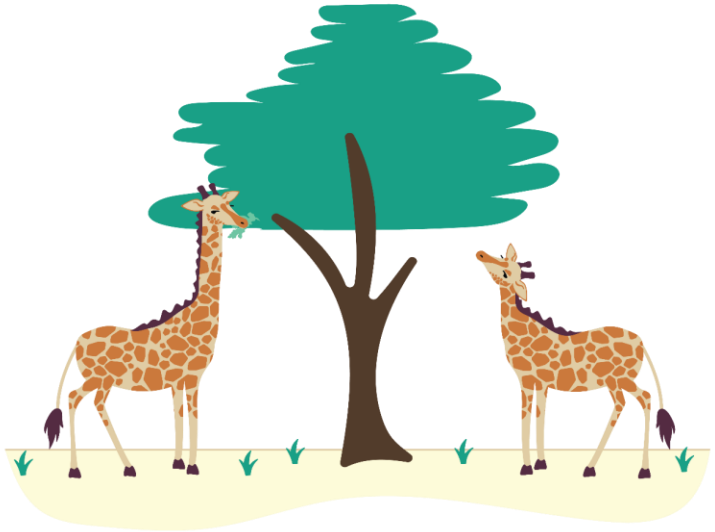


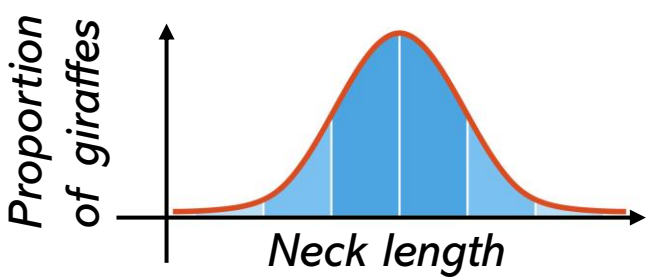


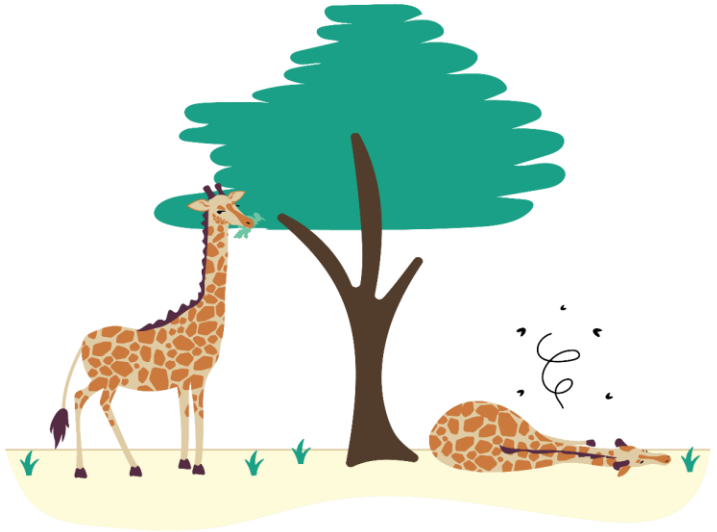
Our first basic “evolutionary model”

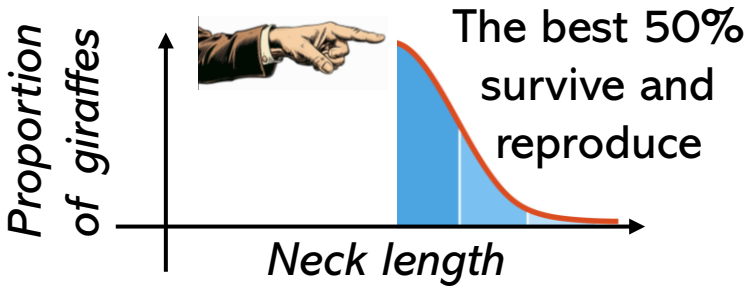


- Variability among individuals
- **Differential contribution to successive generations**
- Mechanism of inheritance



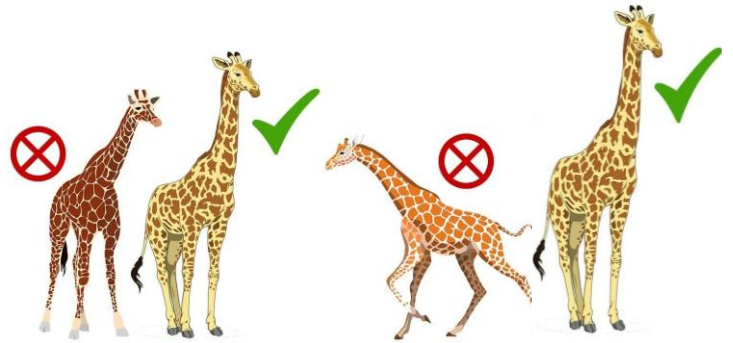






Let’s now «select» only the giraffes with neck longer than the median.

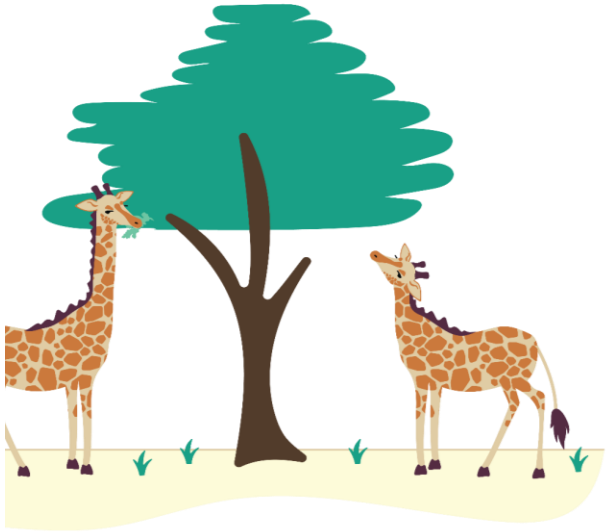
```
parents=z[z>median(z)]
```

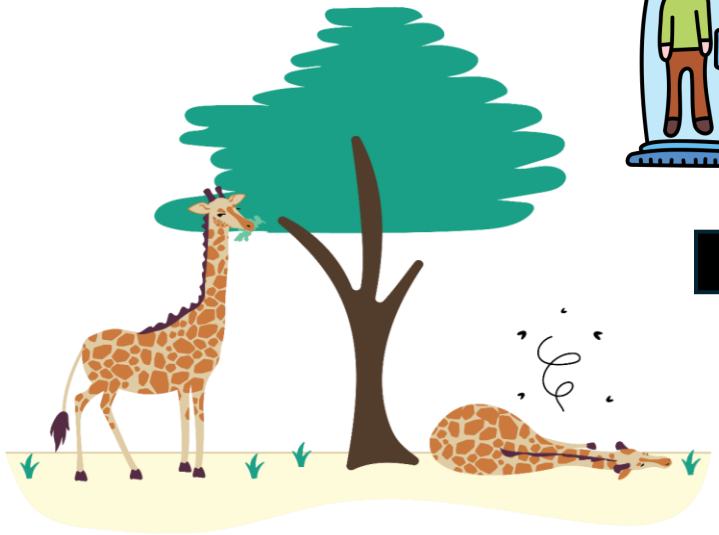


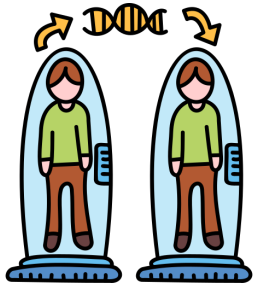
Our first basic “evolutionary model”

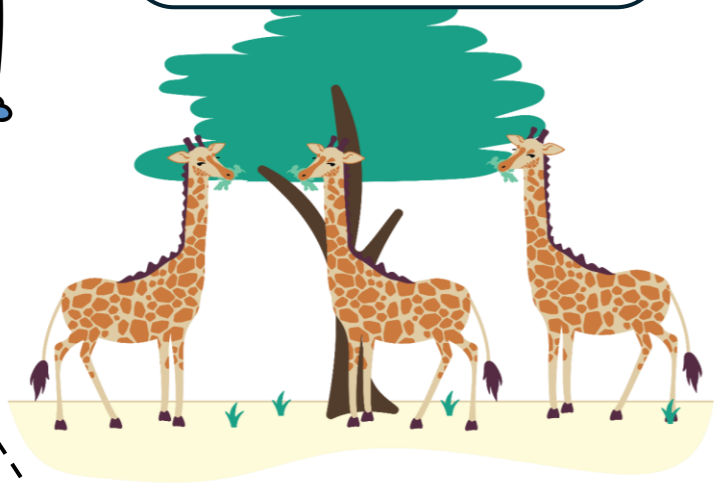
- Variability among individuals
- Differential contribution to successive generations
- **Mechanism of inheritance**

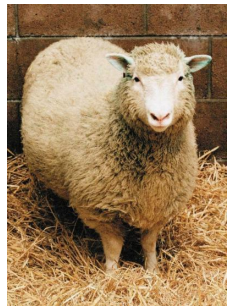
We want giraffes giving birth to «resembling» baby-giraffes









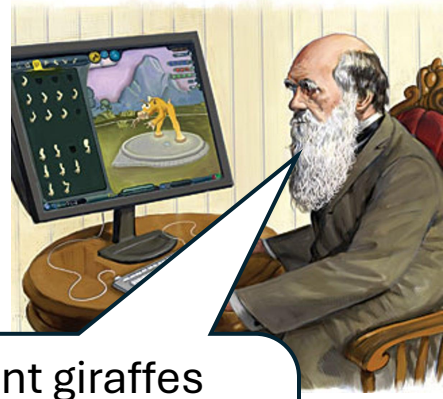


Perfect cloning of their parents (same neck length as parents)

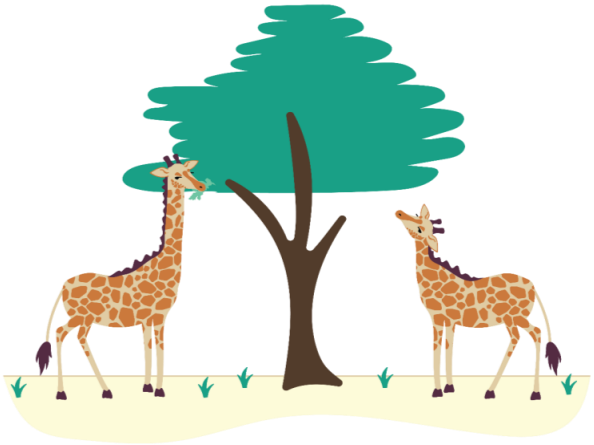
`z=parents`

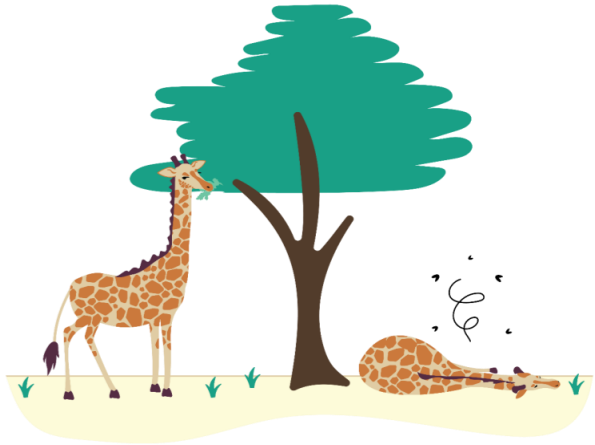
Would this be enough for evolution?

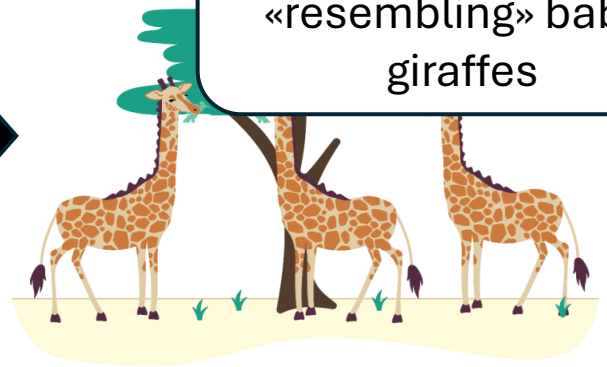
- Variability among individuals
- Differential contribution to successive generations
- Mechanism of inheritance

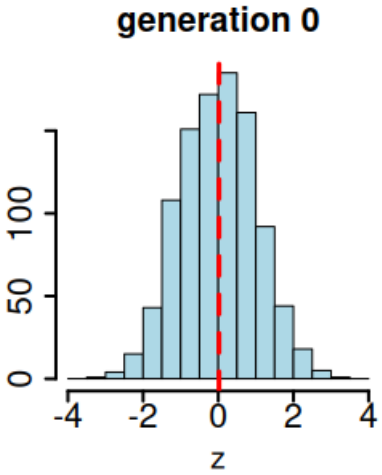


We want giraffes giving birth to «resembling» baby-giraffes

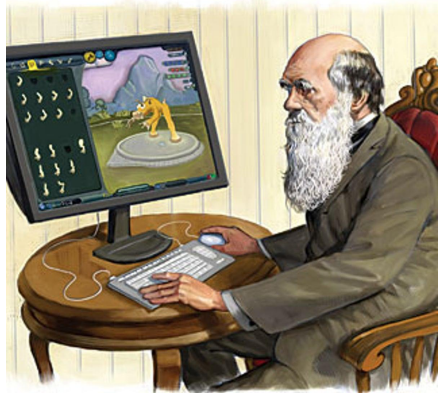




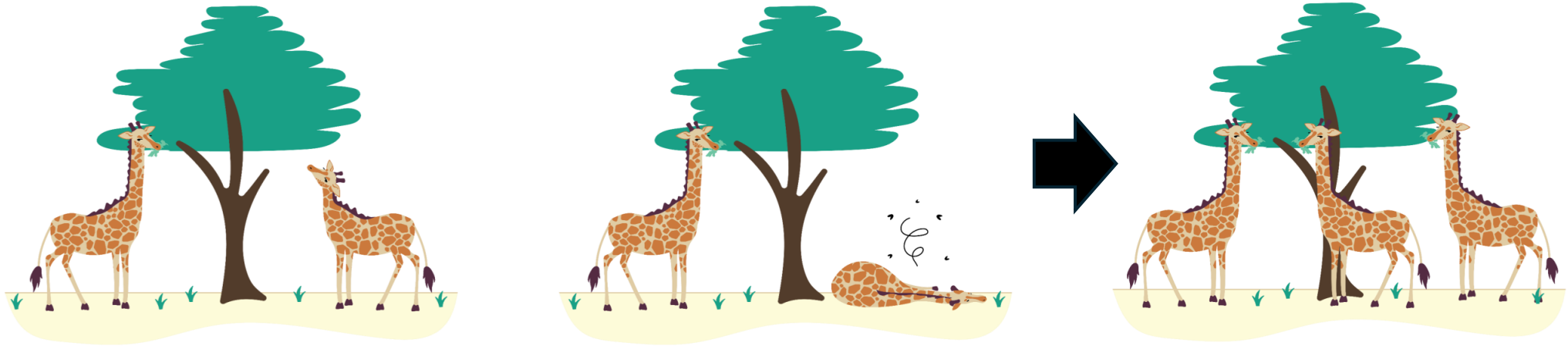


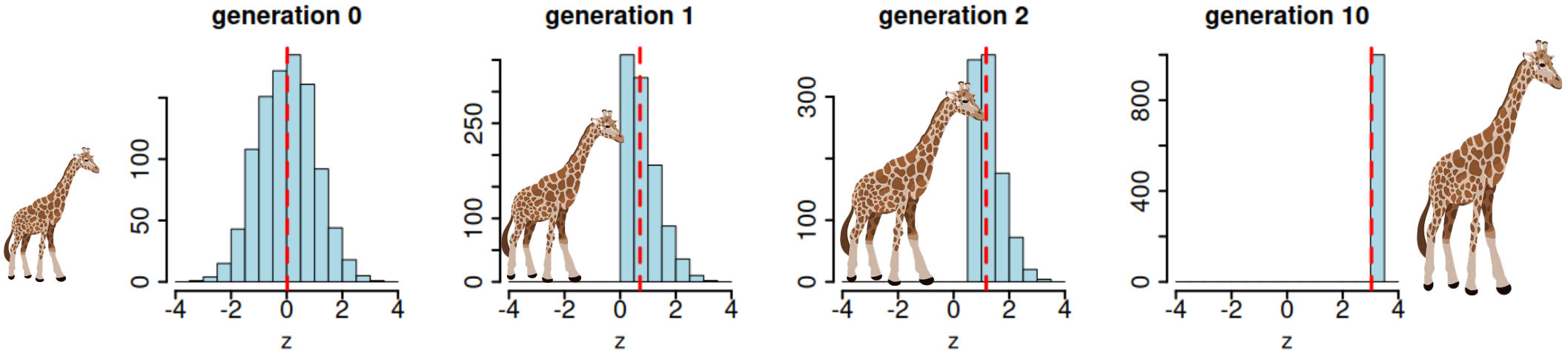


Our giraffes evolved a longer neck!

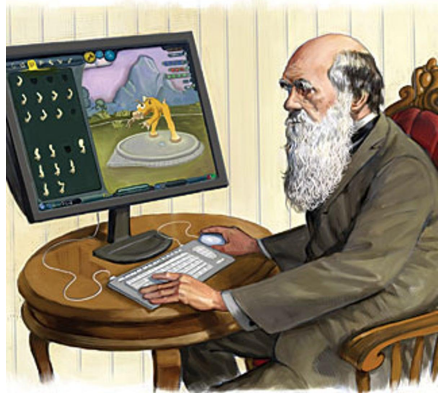


- Variability among individuals
- Differential contribution to successive generations
- Mechanism of inheritance





Our bacteria became more antibiotic resistant



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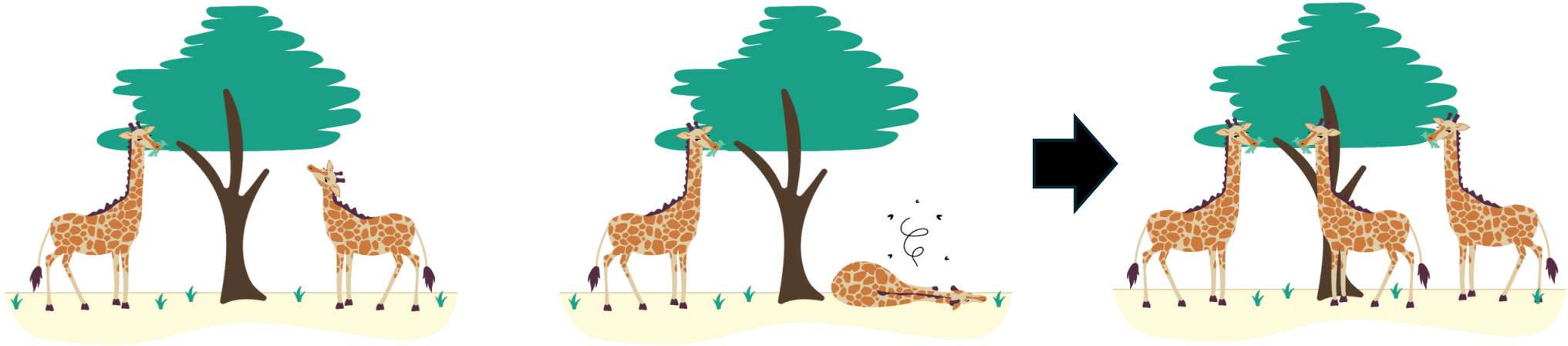
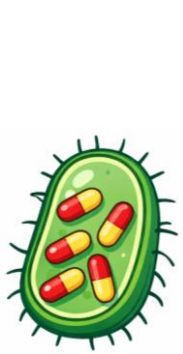
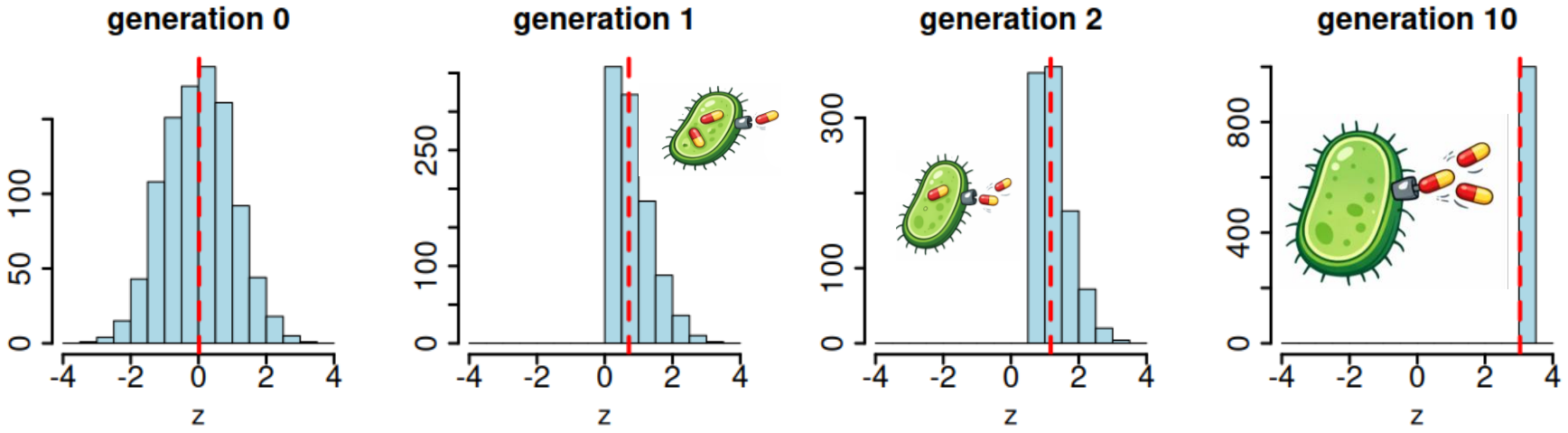
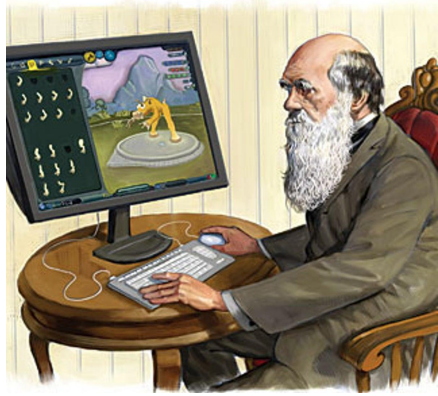






Our three ingredients are sufficient!



- Variability among individuals
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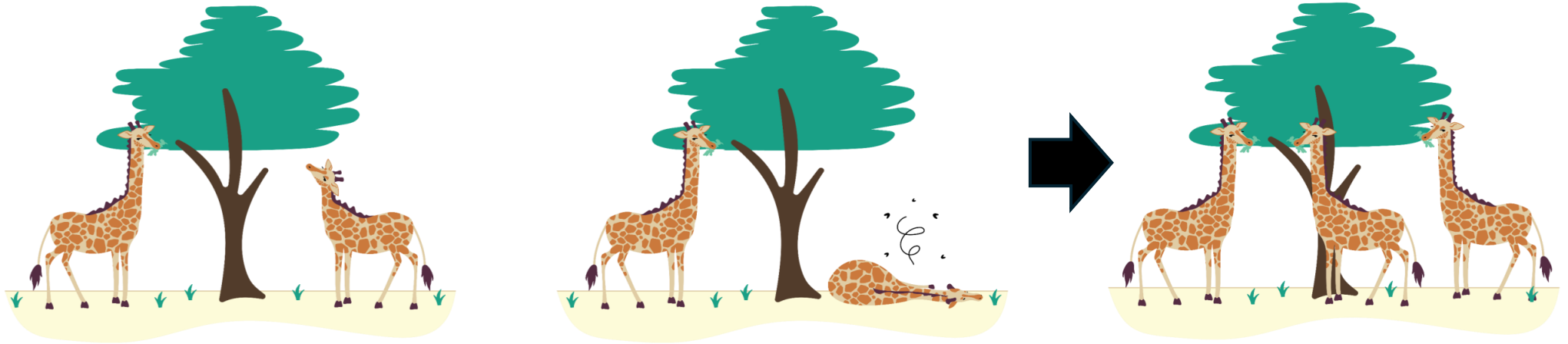
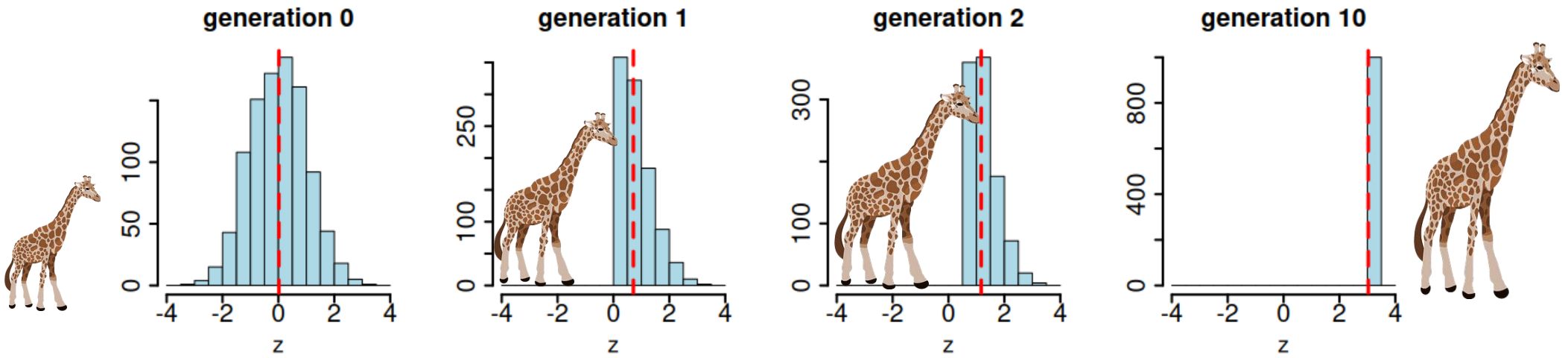
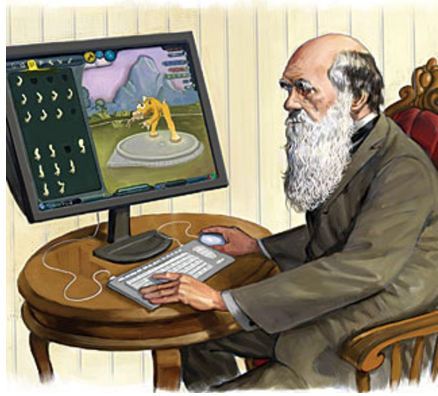




But are they also all necessary?



- Variability among individuals
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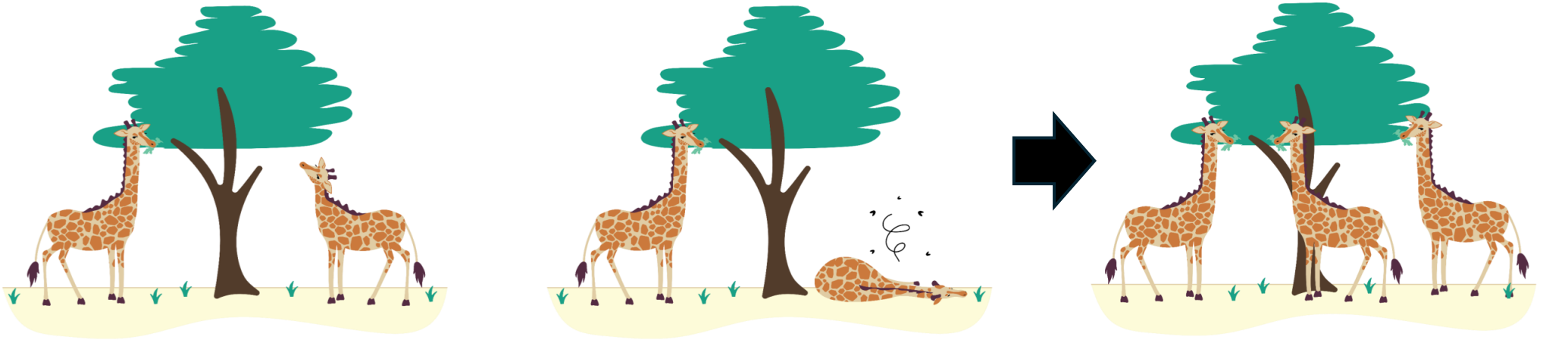
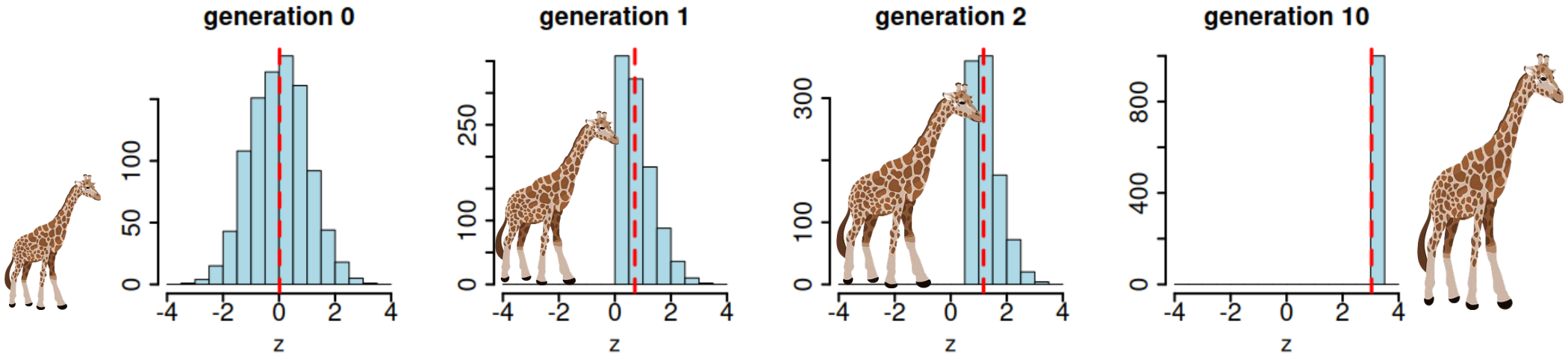
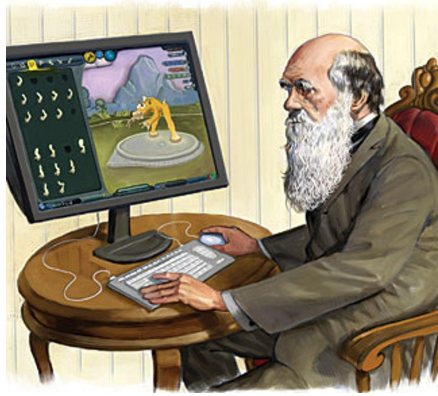




Let’s remove them in turn: no variability



- ~~**Variability among individuals**~~
- Differential contribution to successive generations
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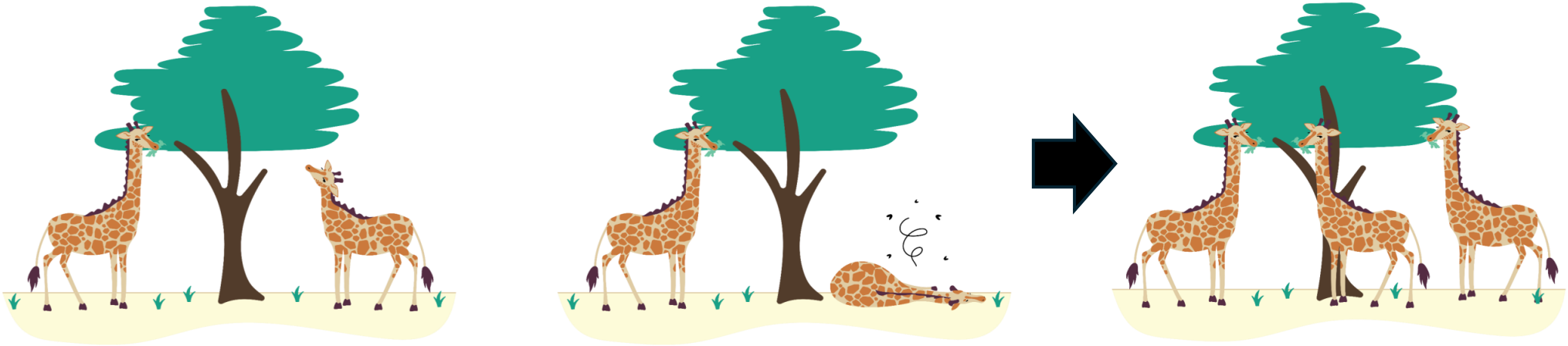

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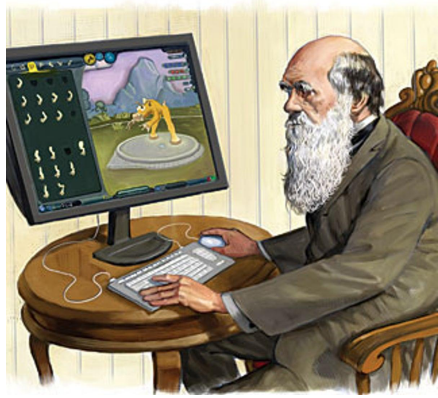

- ~~**Variability among individuals**~~
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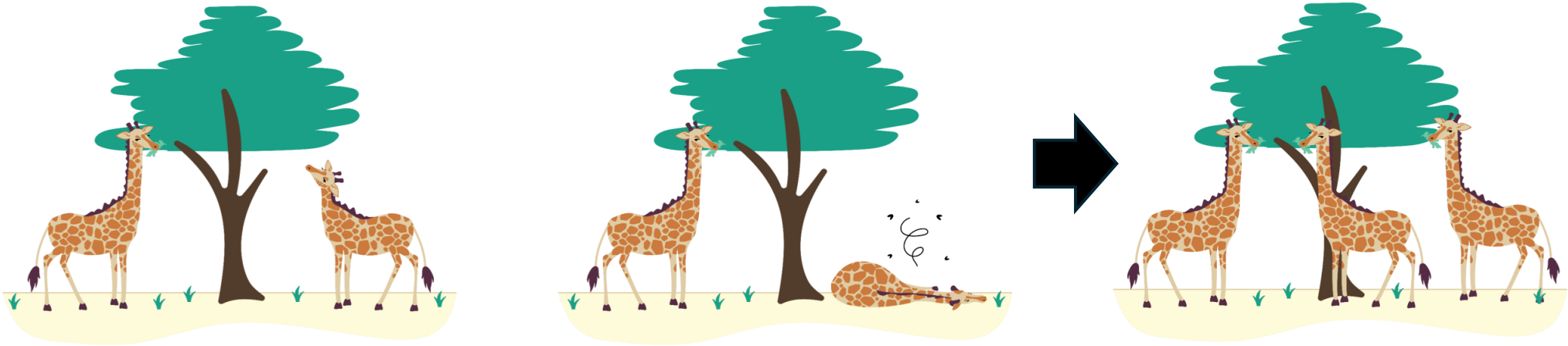
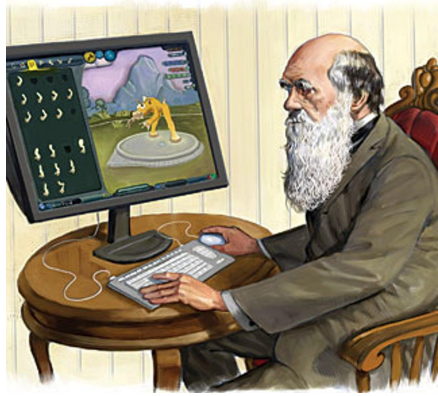


`rep(1,1000)` → 1 1 1 1 1

or

`rnorm(1000,sd=0.001)`

No variability → No evolution!



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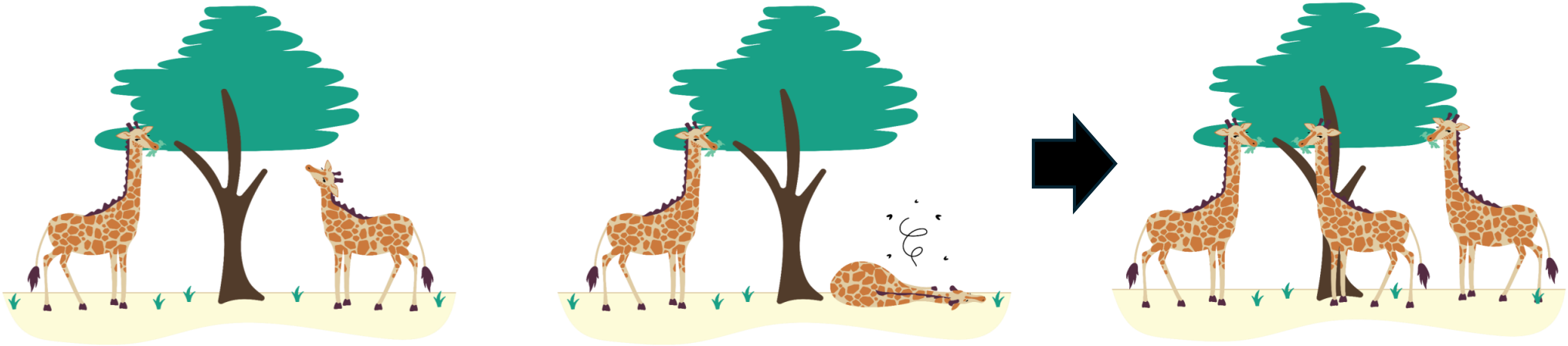
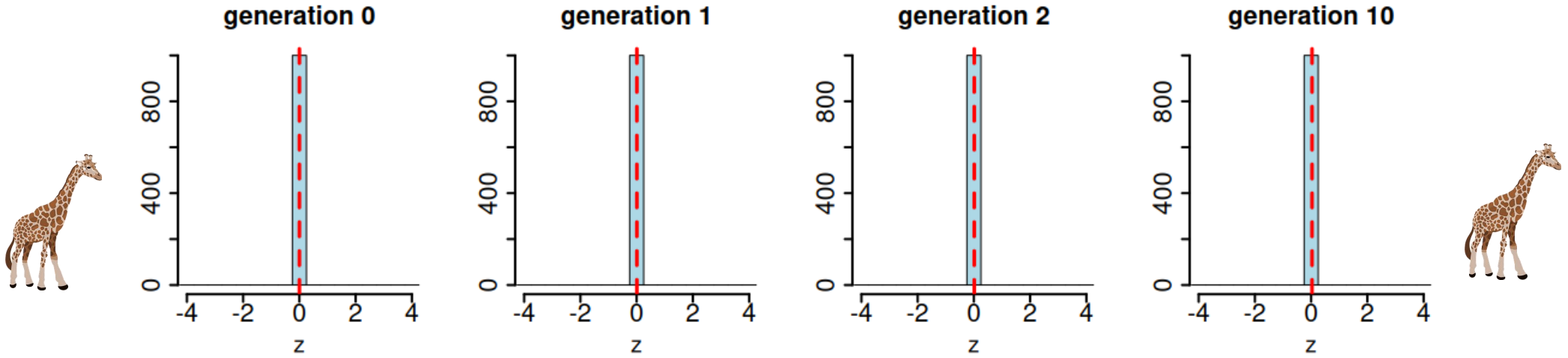
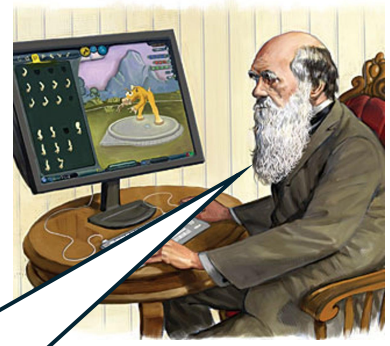




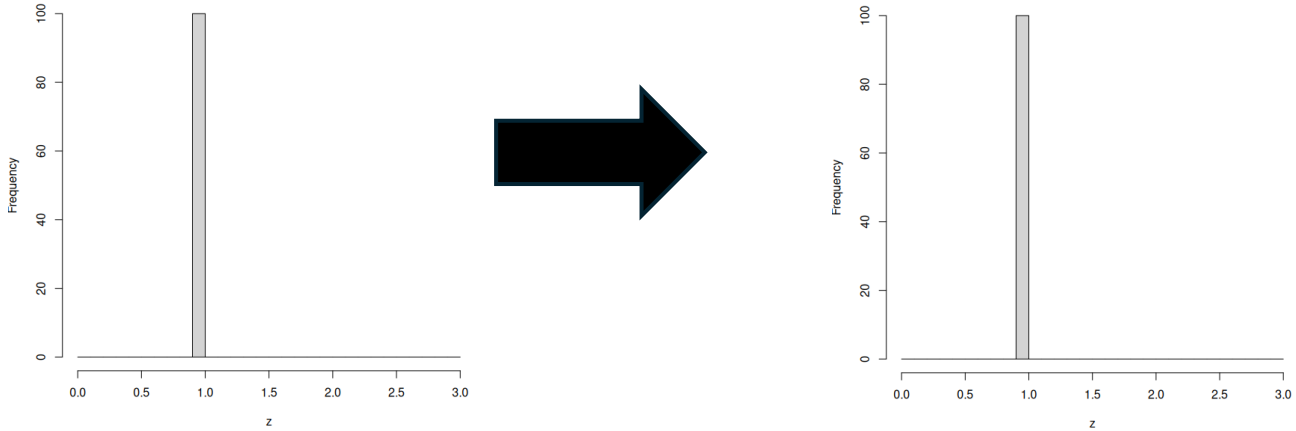
No variability → No evolution!

~~Variability among individuals~~
Differential contribution to successive generations
Mechanism of inheritance



What does it remind you in real life?

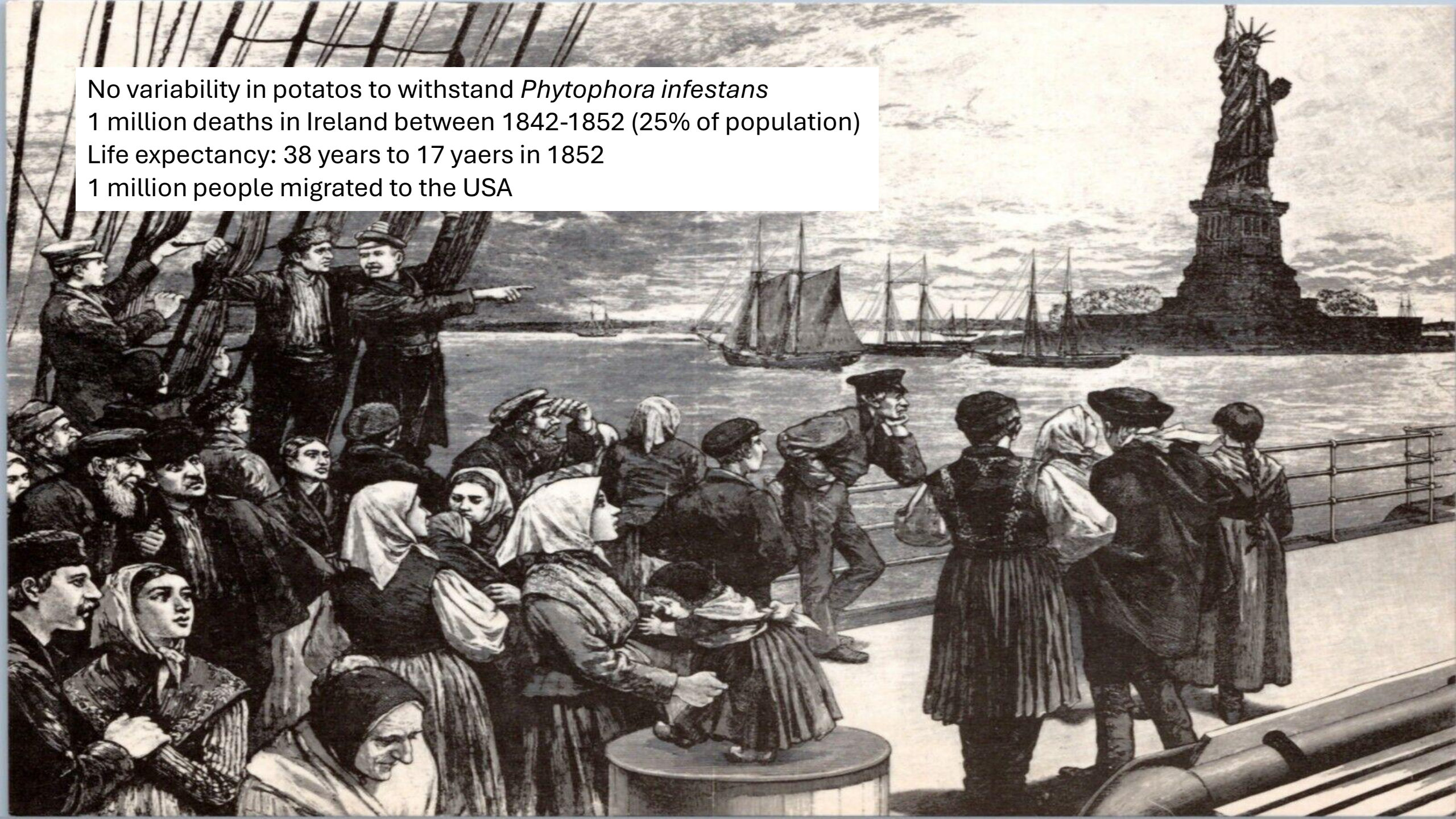
Phytophora infestans



Crops with low variability

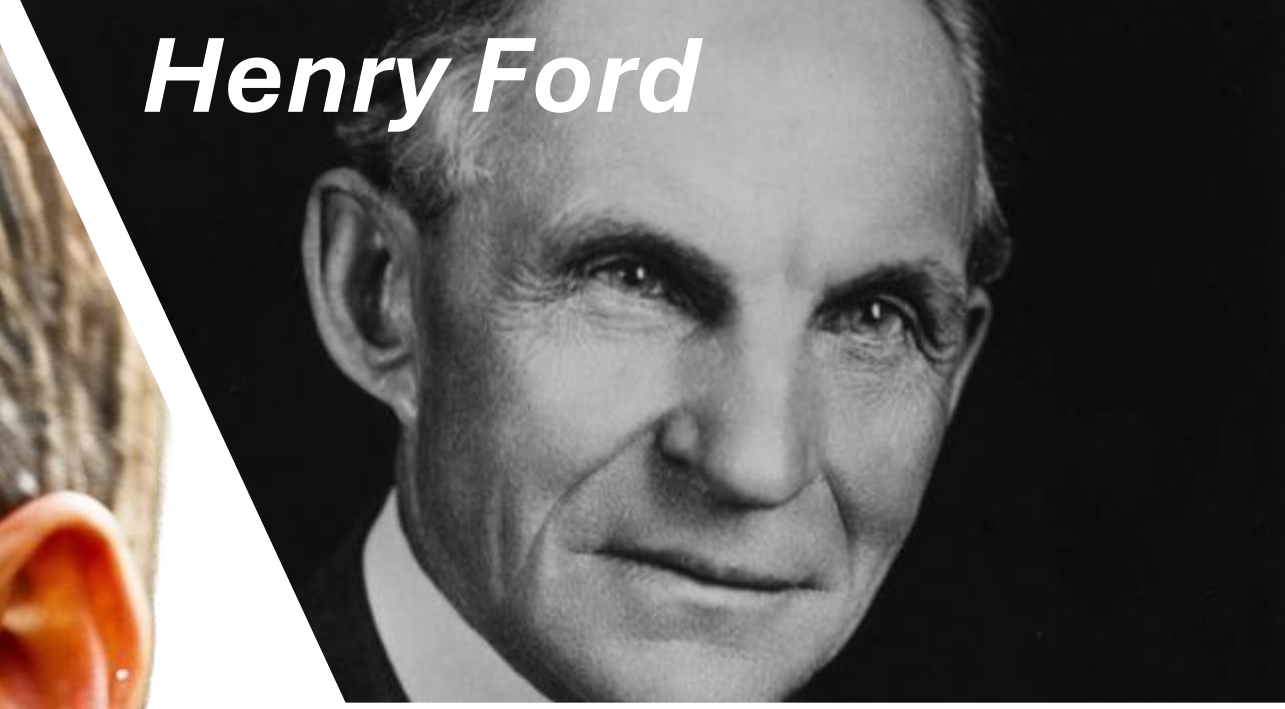
Ireland 1842-1852

No variability in potatos to withstand *Phytophora infestans*
1 million deaths in Ireland between 1842-1852 (25% of population)
Life expectancy: 38 years to 17 yaers in 1852
Ireland 1847 - The Great Hunger.



No variability in potatos to withstand *Phytophora infestans*
1 million deaths in Ireland between 1842-1852 (25% of population)
Life expectancy: 38 years to 17 yaers in 1852
1 million people migrated to the USA

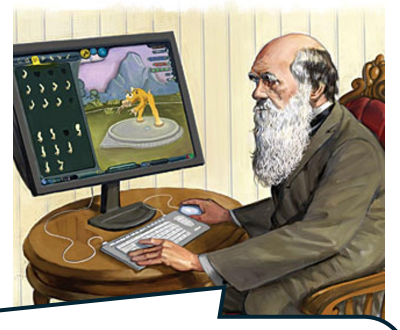
JFK



Henry Ford

Ronald Reagan

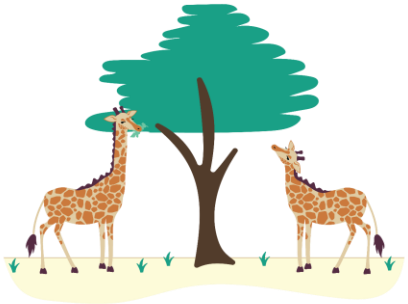
What happens with no “selection”?

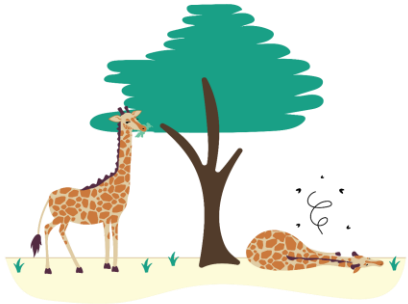


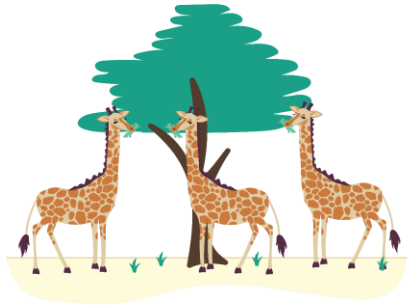
Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance

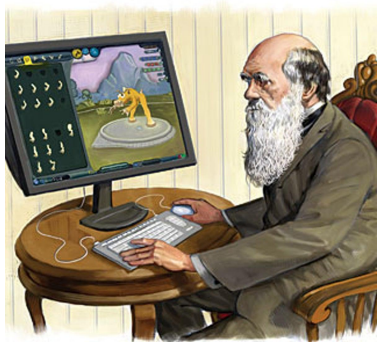






How would you model that?

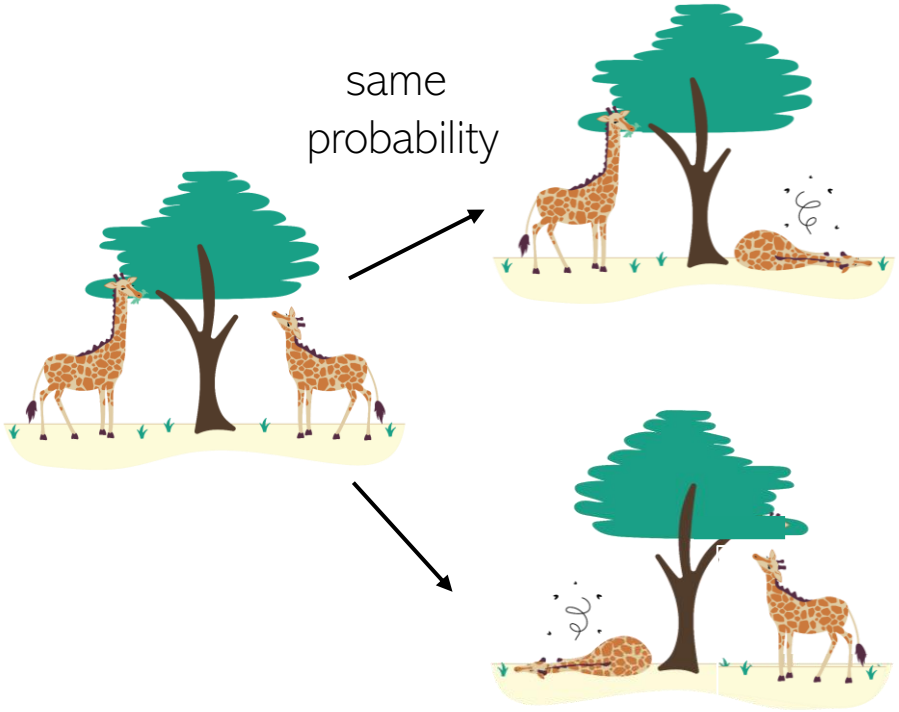
What happens with no “selection”?



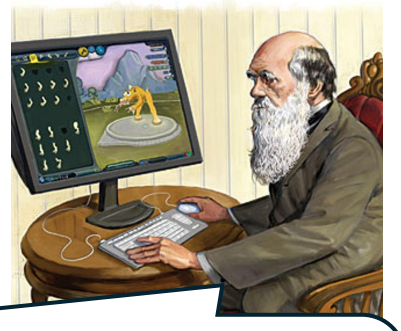
Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance



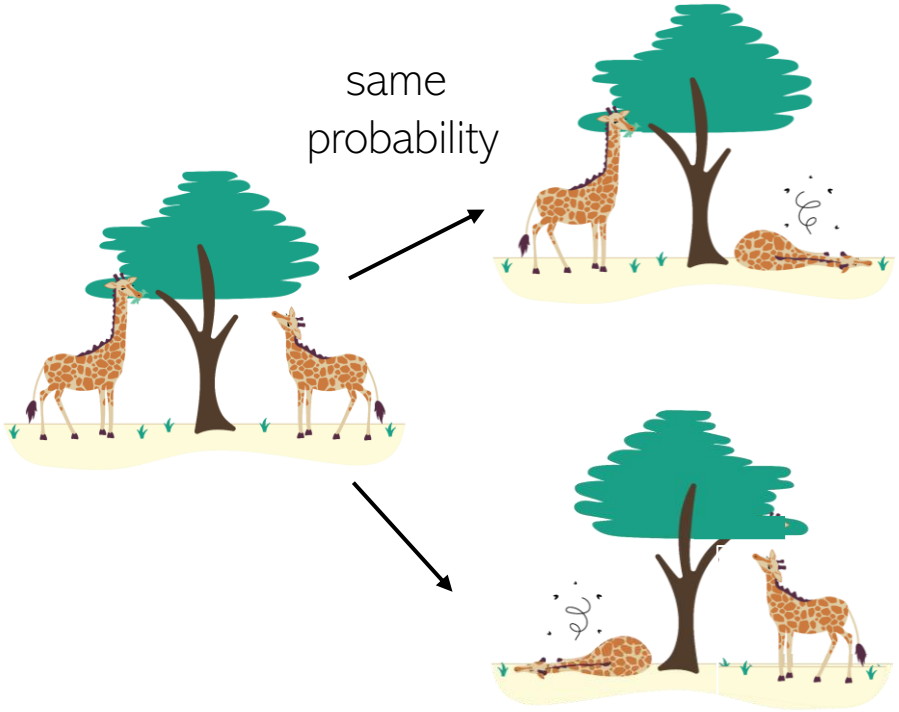
What happens with no “selection”?



Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance



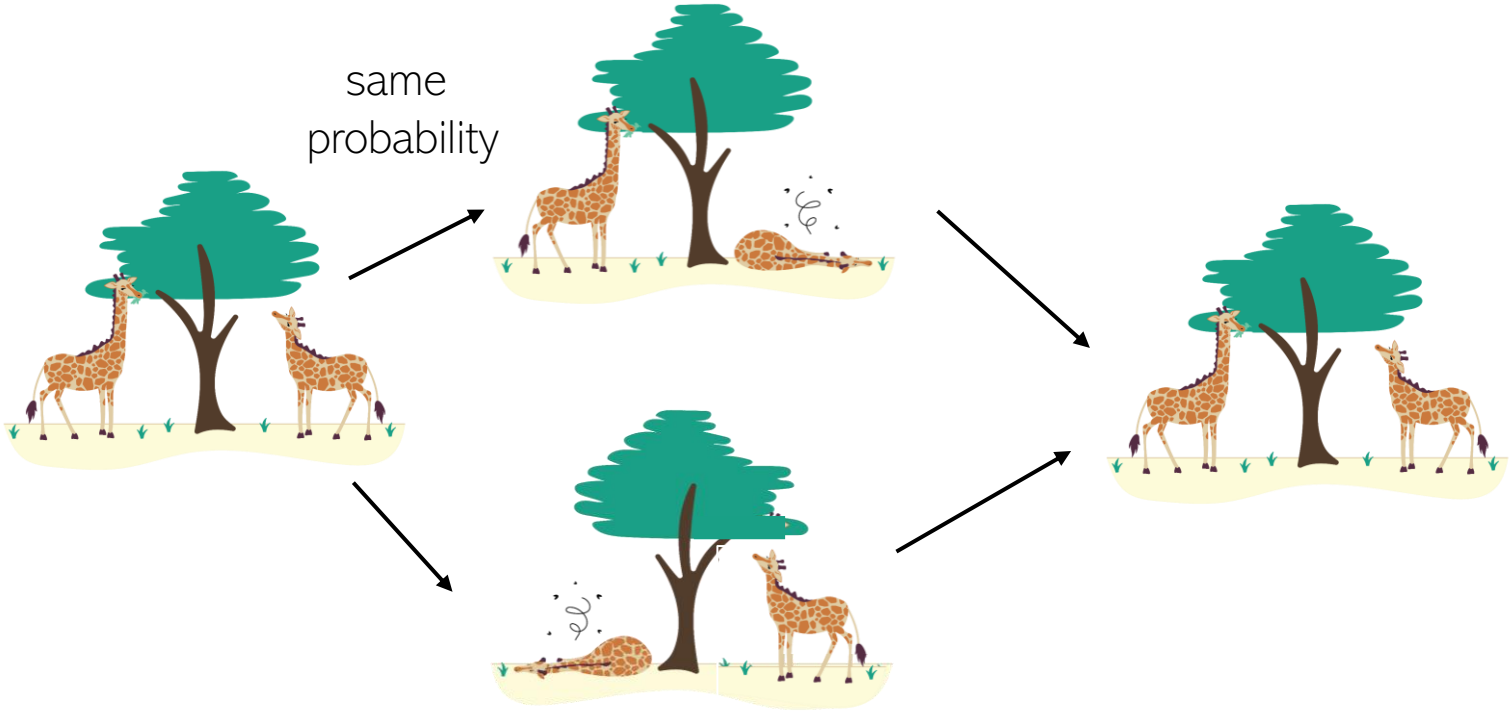
What happens?

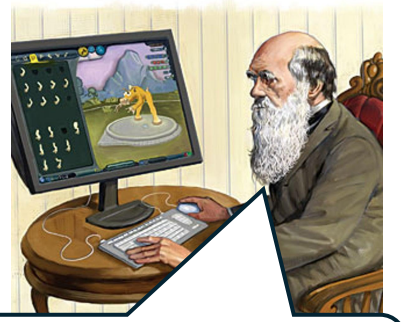
No selection → No evolution?

Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance





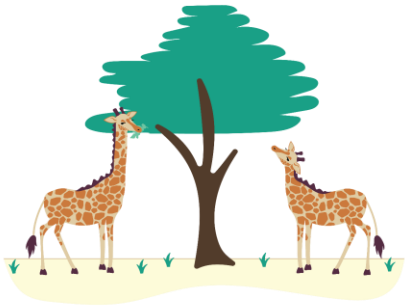
Well, no «biased» change..

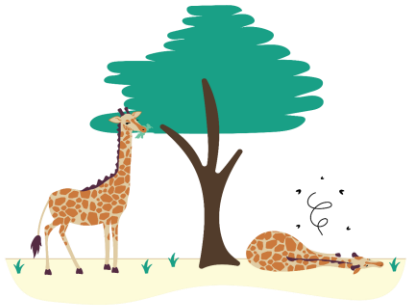
No selection → No evolution?

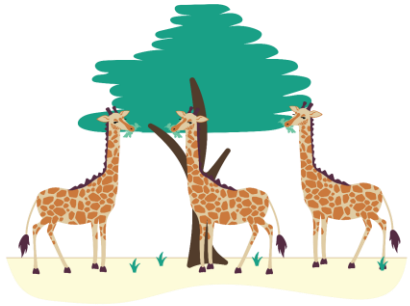
Variability among individuals

~~Differential contribution to successive generations~~

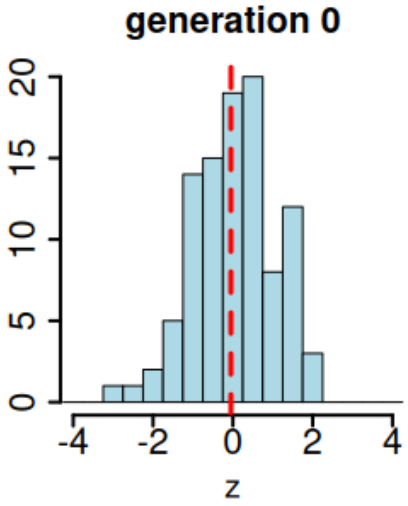
Mechanism of inheritance

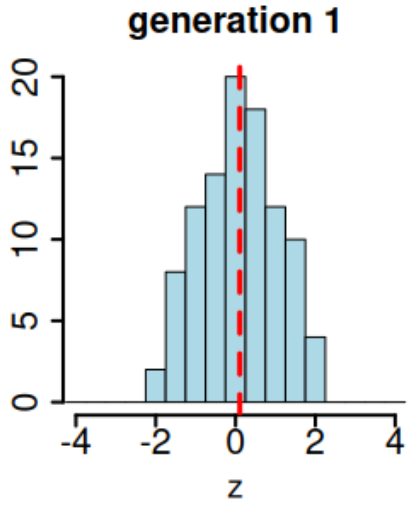


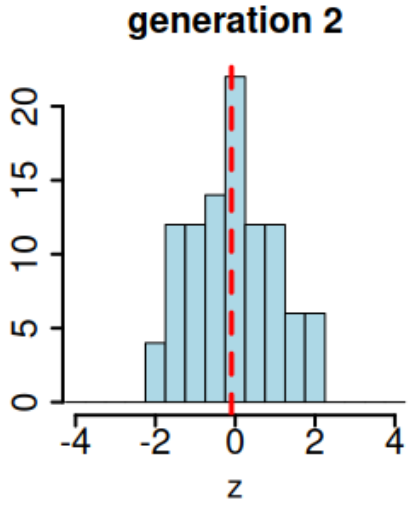


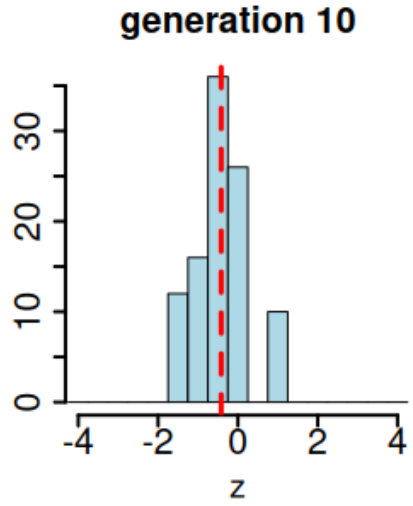


There is some small change/evolution!







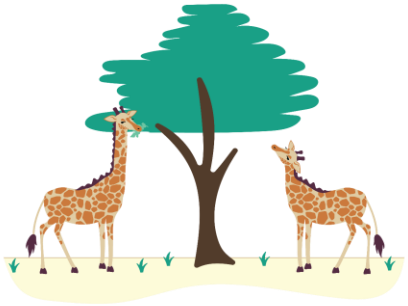


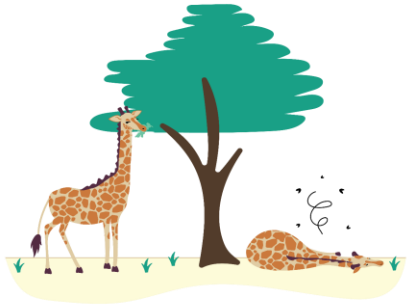
No selection → No evolution?

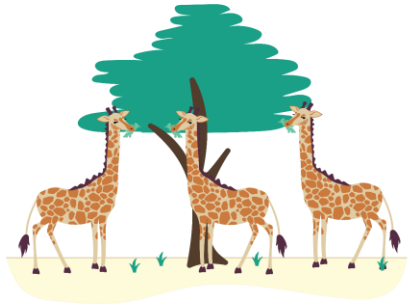
Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance







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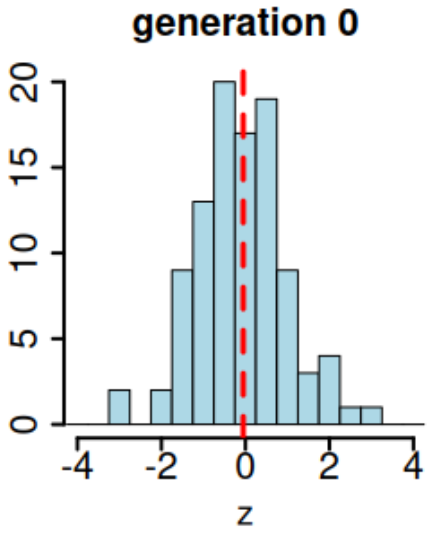
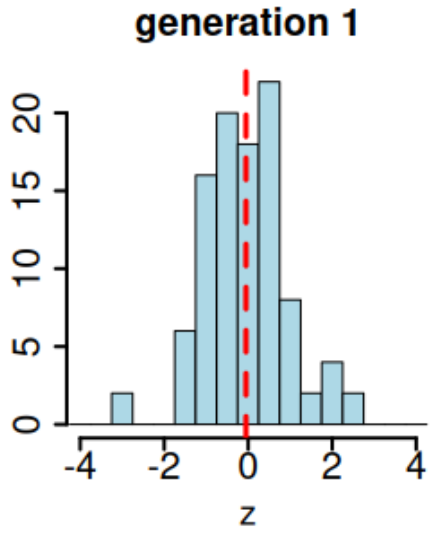
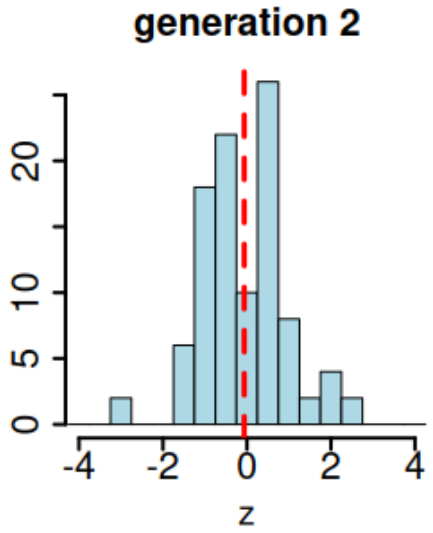
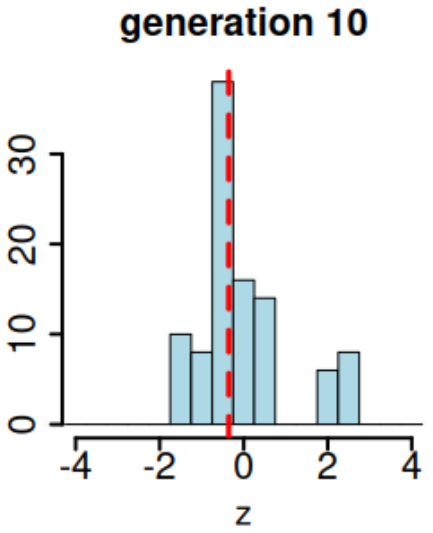






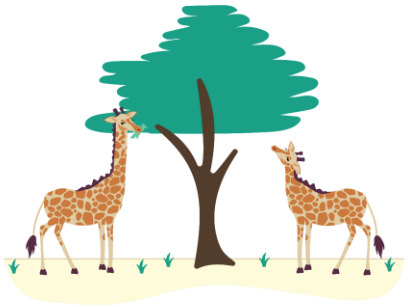


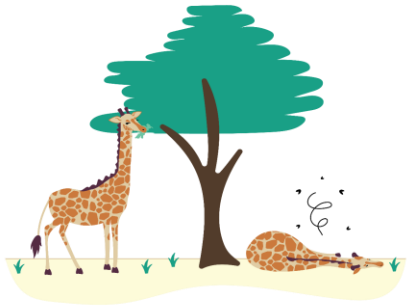
No selection → No evolution?

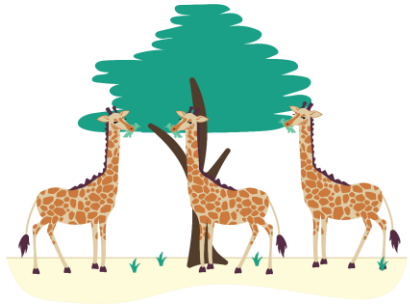
Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance







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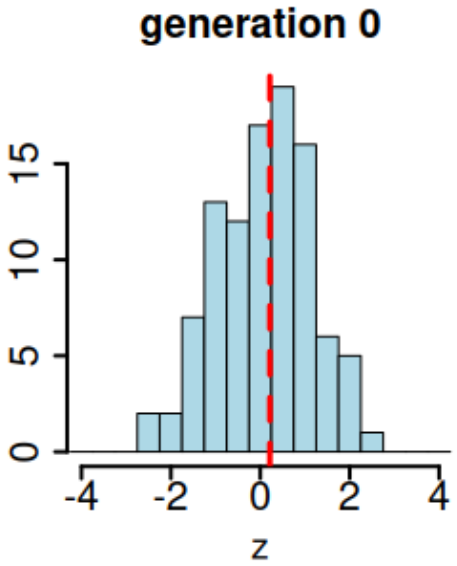
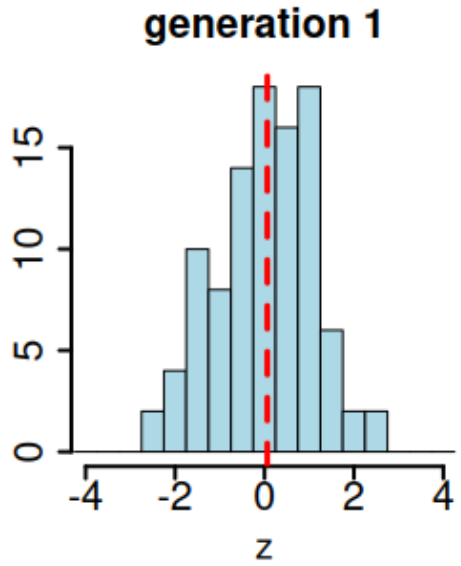
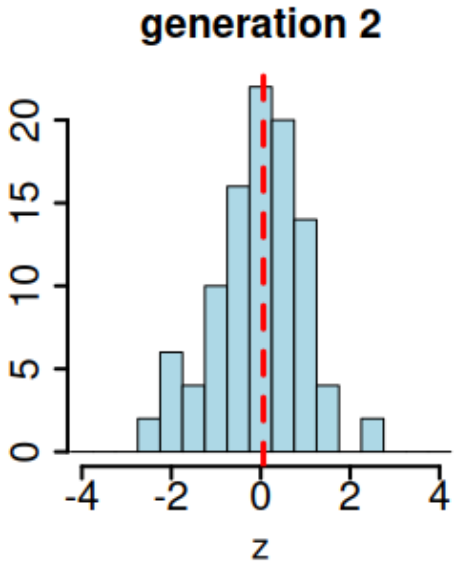
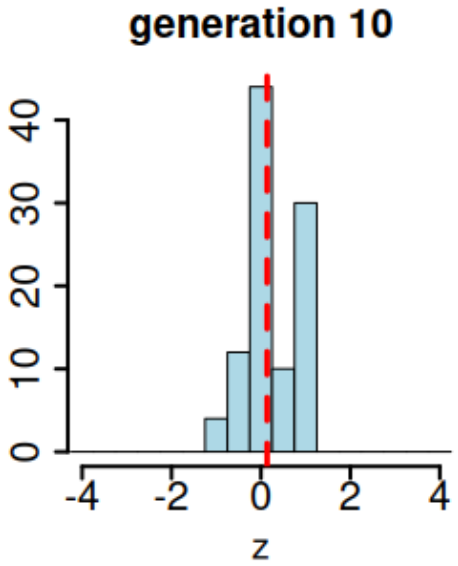






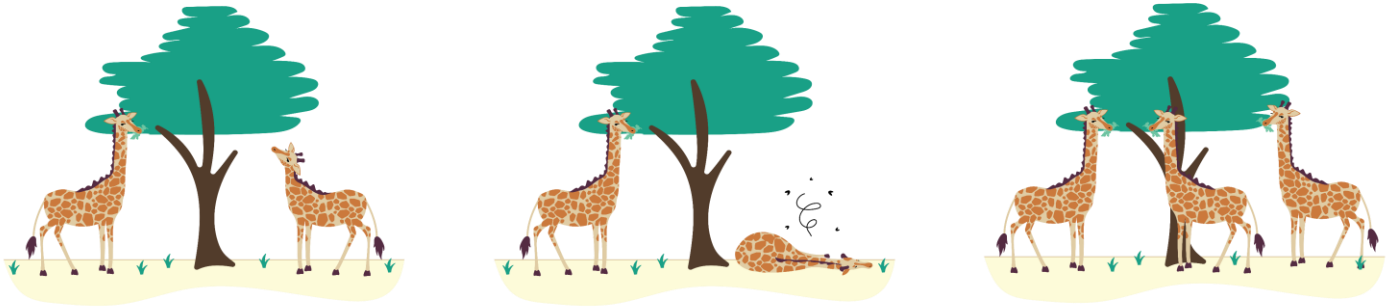


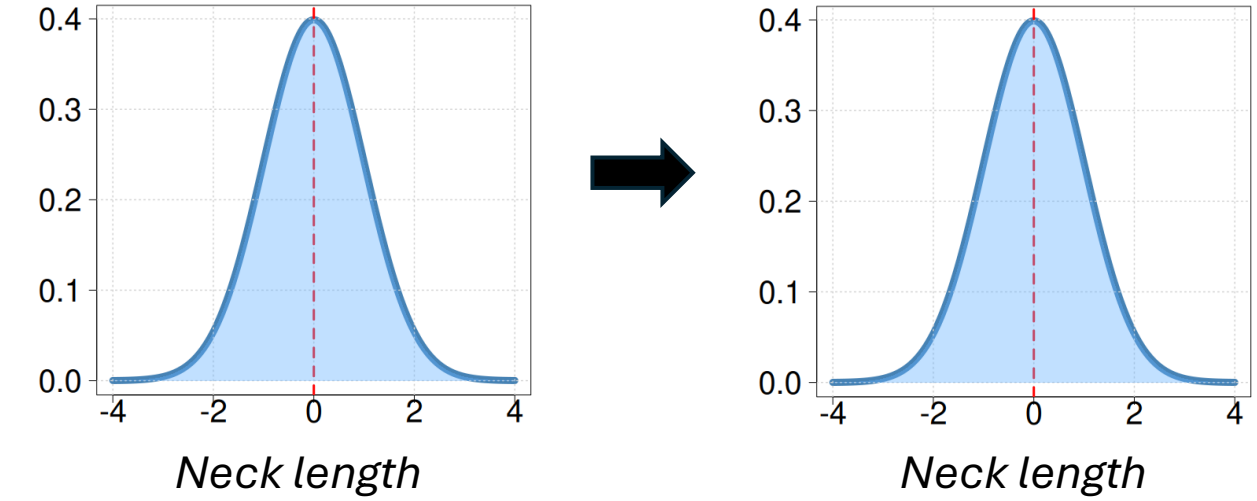
No selection → No directional evolution (on average)

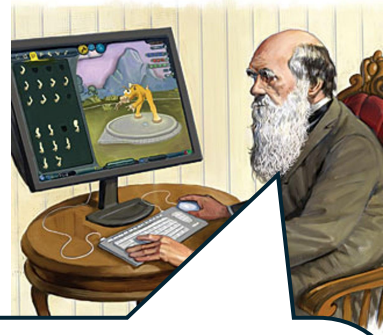
Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance





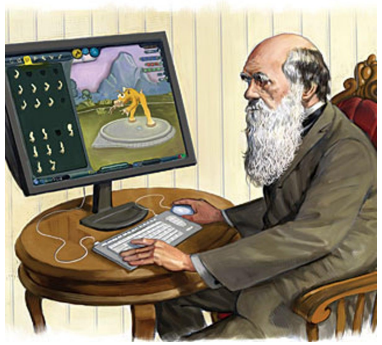


If we do it many times, on average populations keep the same neck length.

But each population still evolves in random directions!

This is **random genetic drift** and we will study it in population genetics

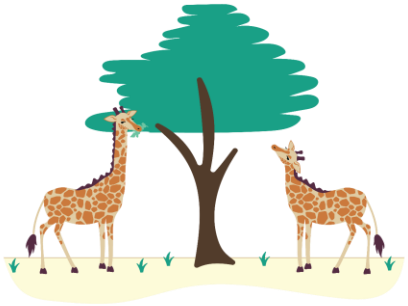
What happens with no inheritance?

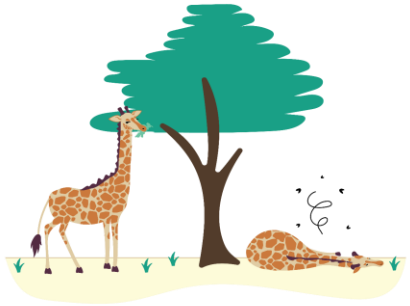


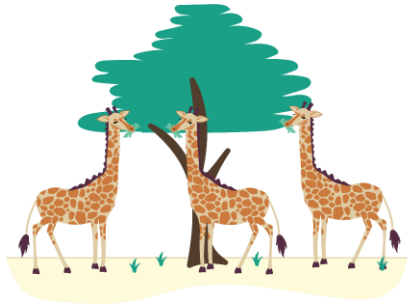
Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance







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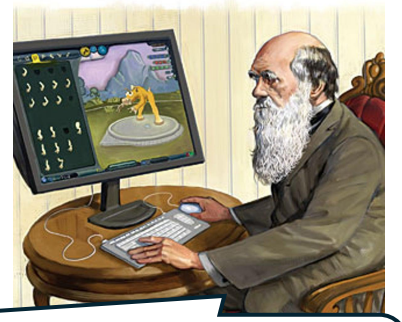
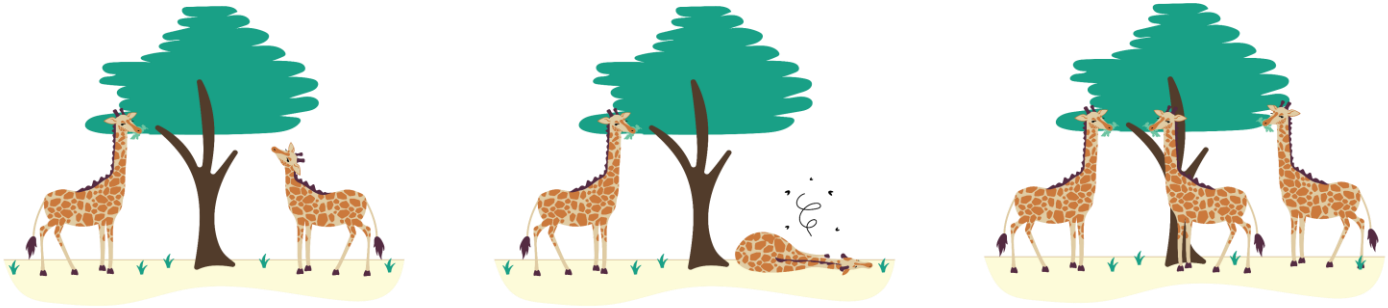


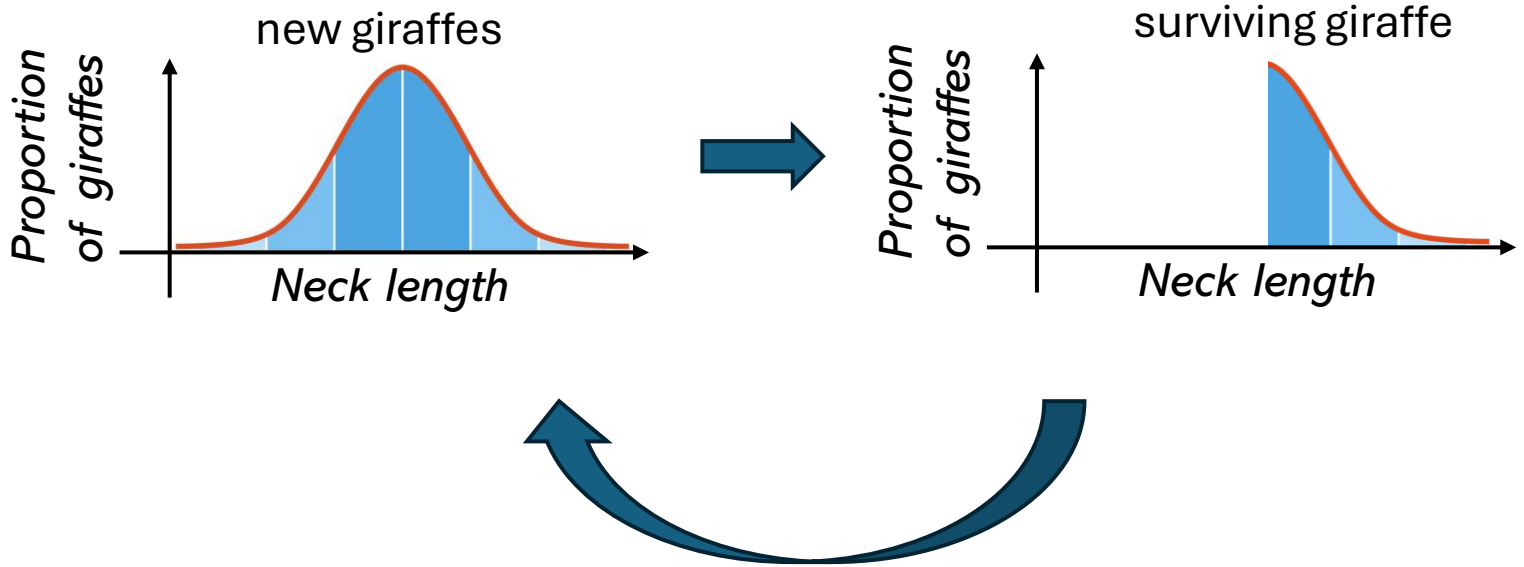
Variability among individuals

~~Differential contribution to successive generations~~

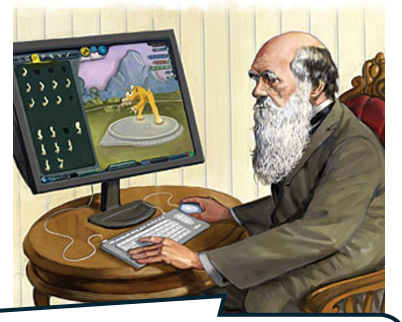
Mechanism of inheritance

All variability in neck length is just random





No inheritance → No evolution!



Variability among individuals

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Mechanism of inheritance

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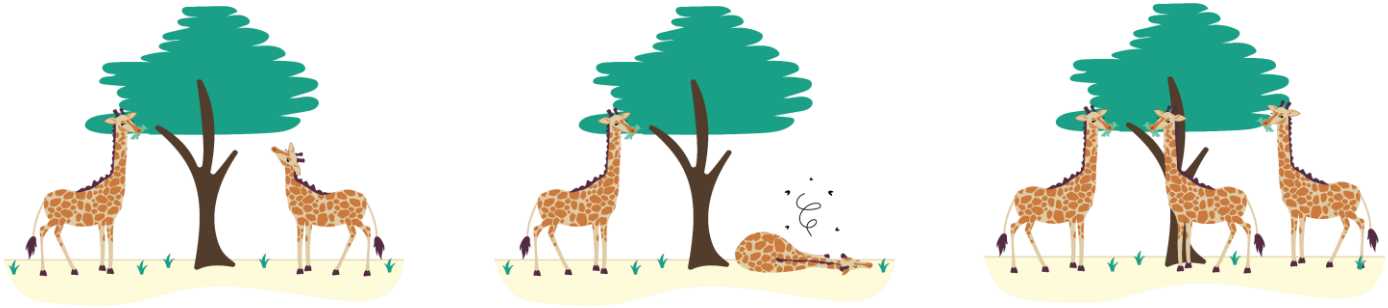

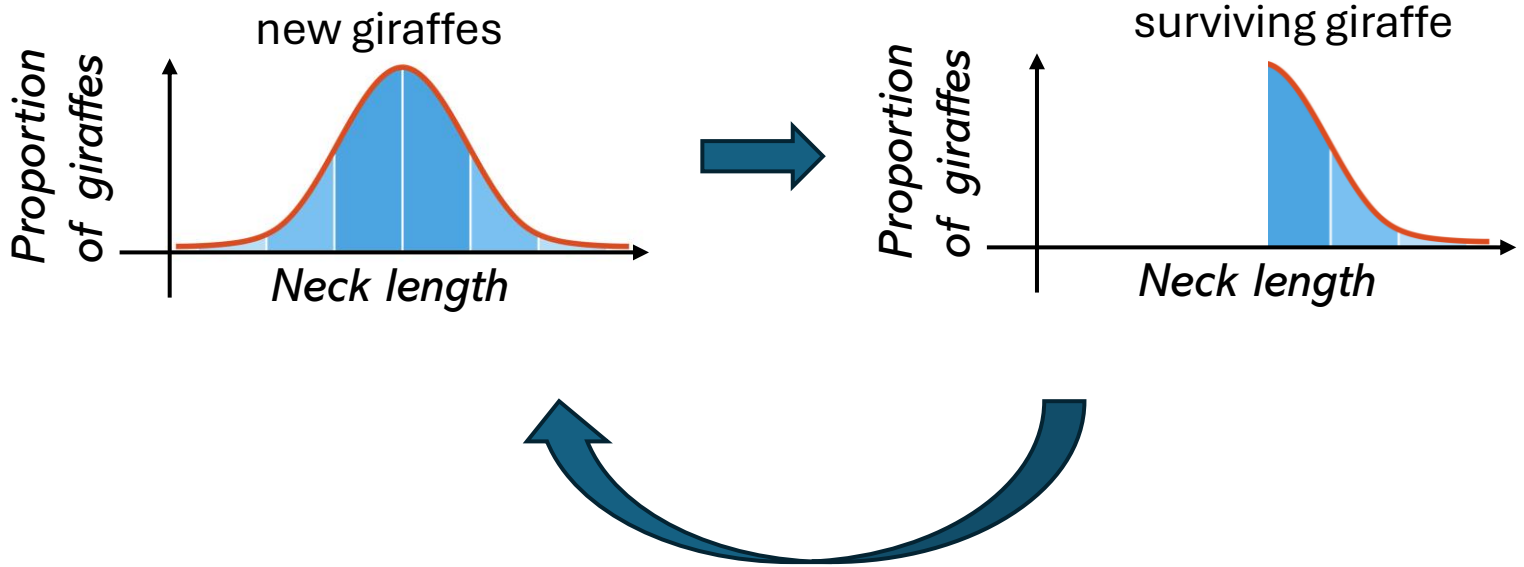

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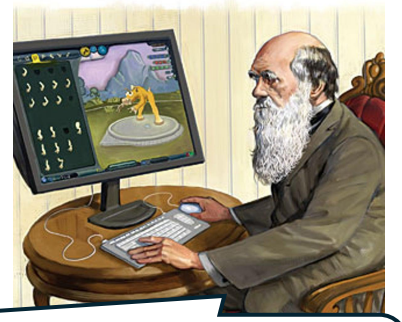

Variability among individuals

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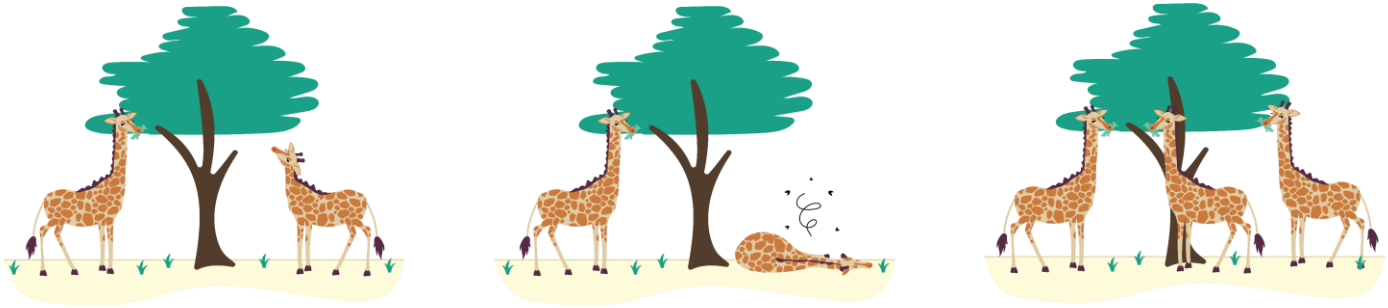

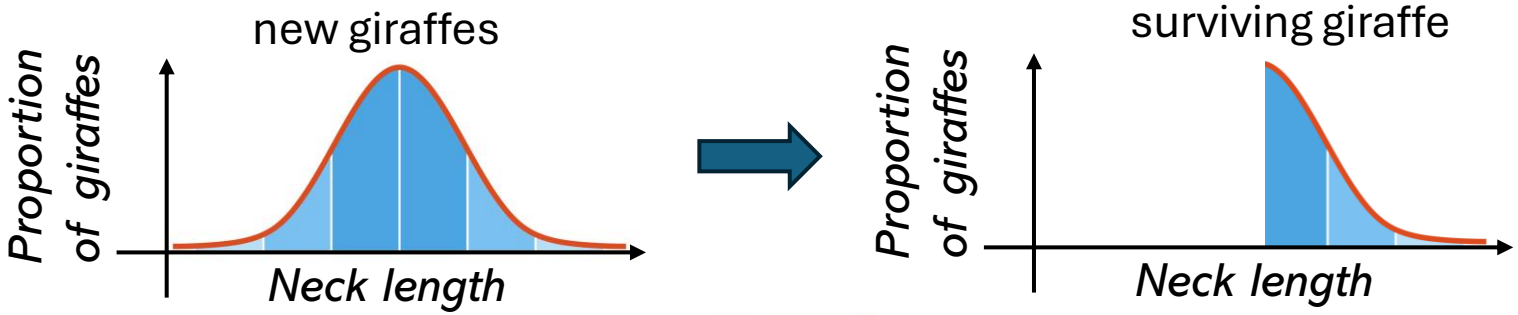

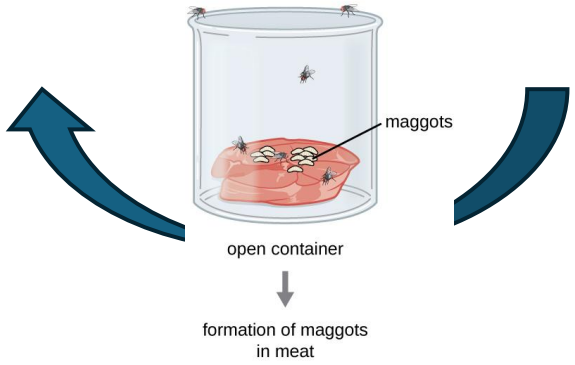

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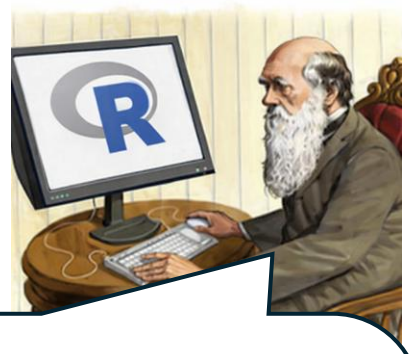

Variability among individuals

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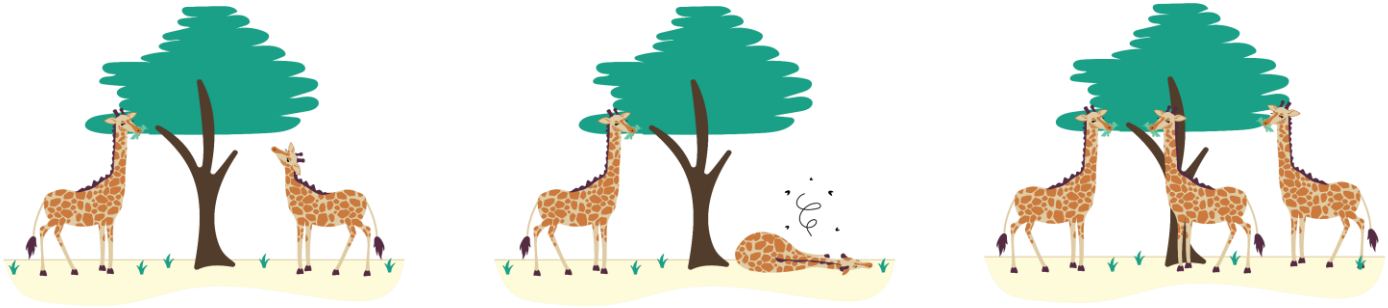
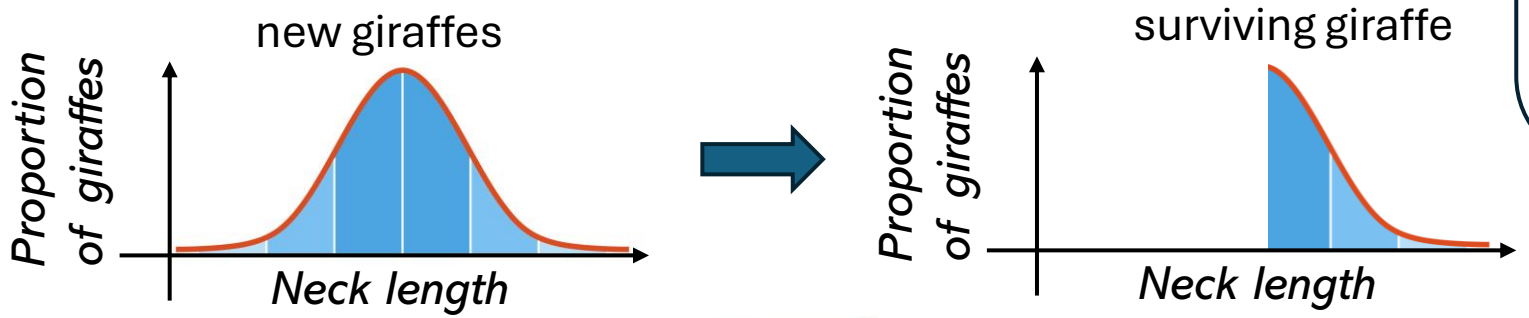
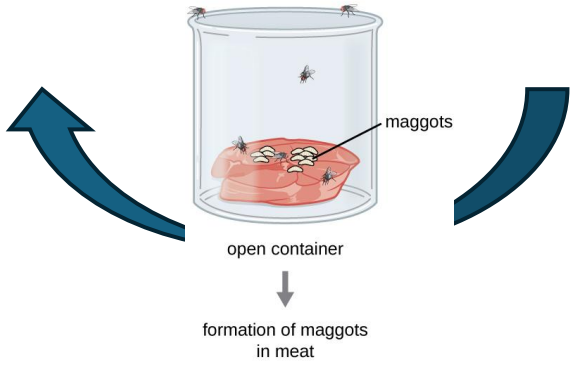
Mechanism of inheritance



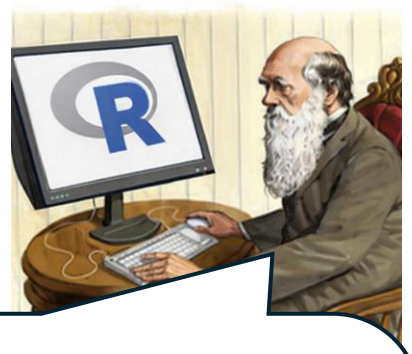




No «inheritance»

```
for (i in 1:1000)
{z= rnorm(N)}
```

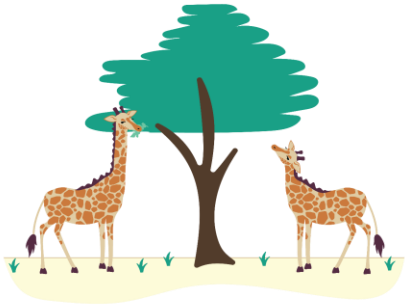
No inheritance → No evolution!

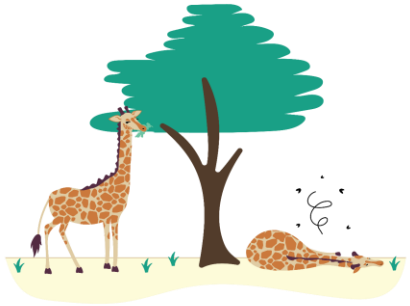


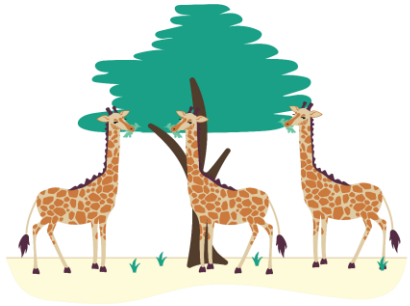
Variability among individuals

~~Differential contribution to successive generations~~

Mechanism of inheritance

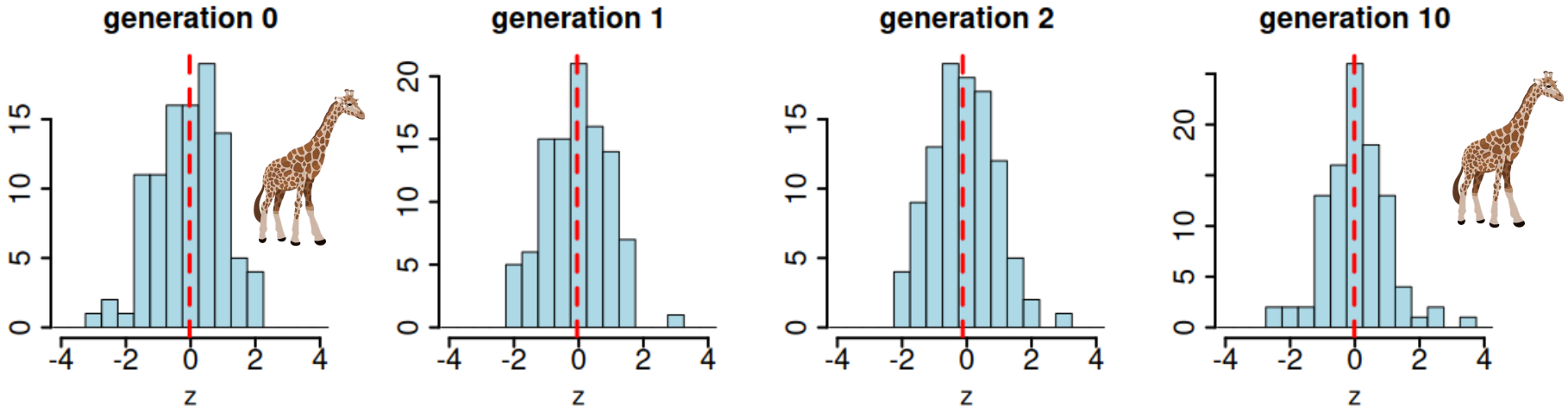






No «inheritance»

```
for (i in 1:1000)
{z= rnorm(N)}
```



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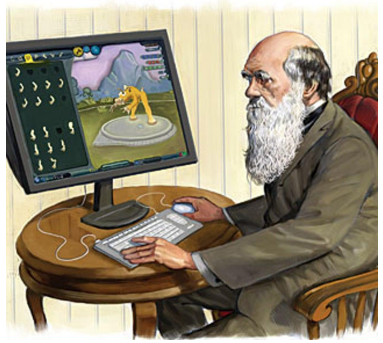
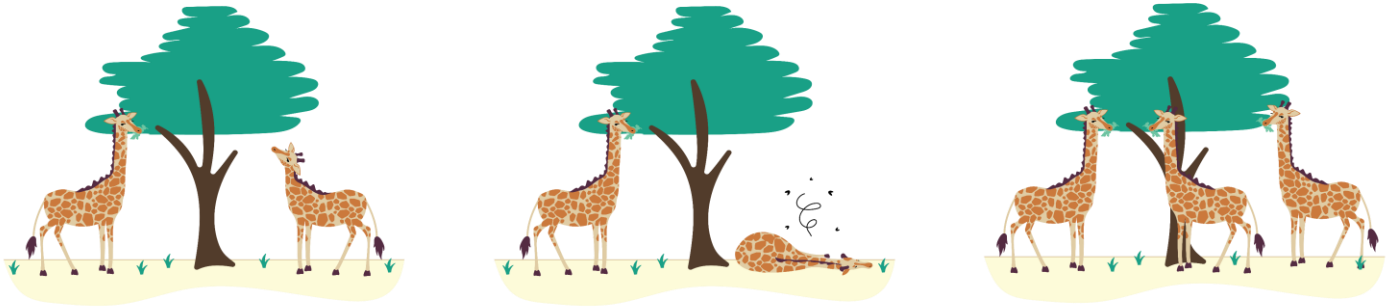
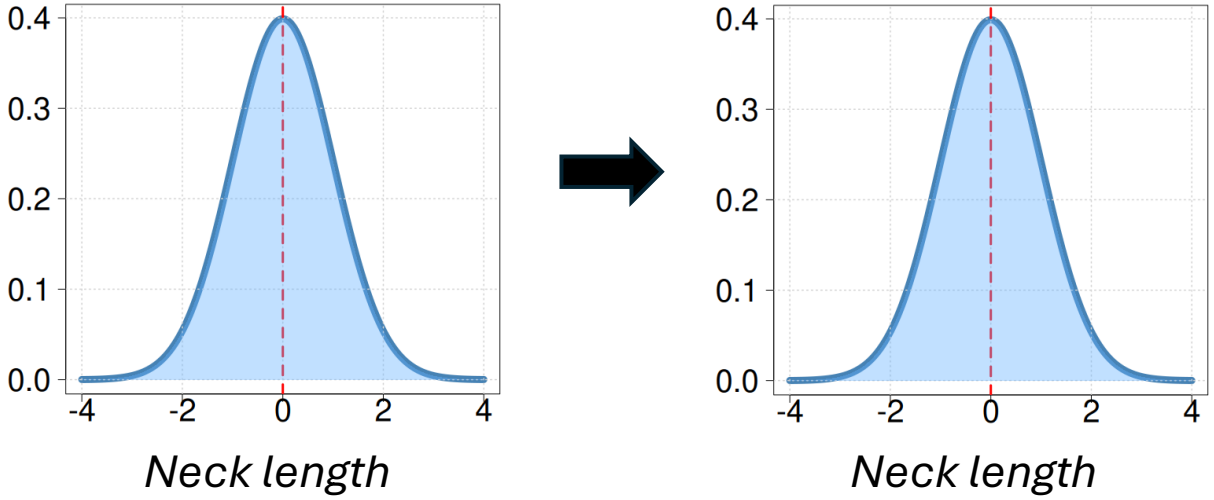


Variability among individuals
Differential contribution to successive generations
~~Mechanism of inheritance~~

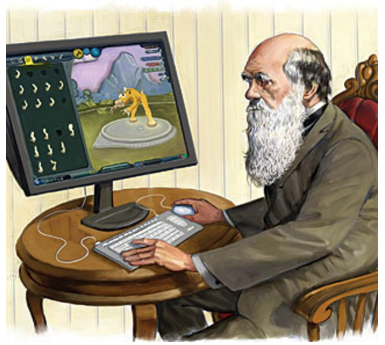


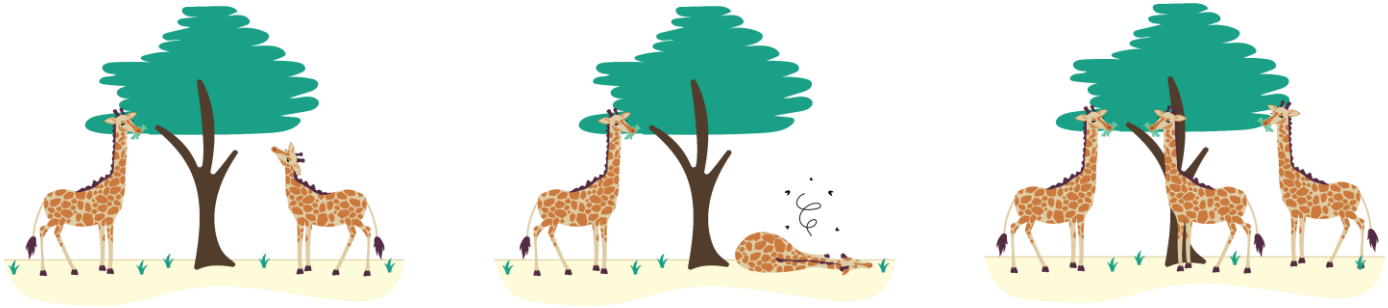


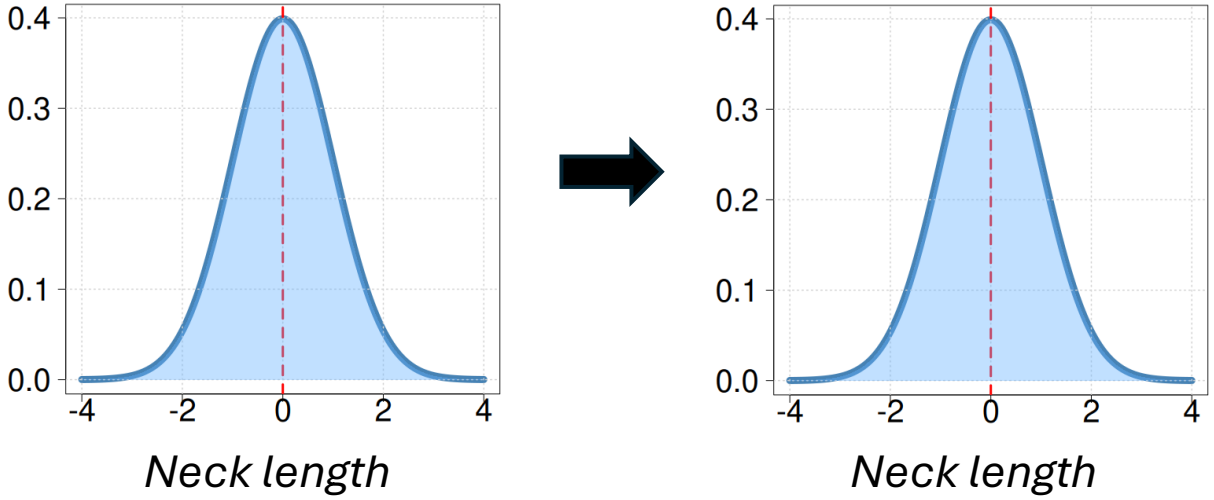
All three ingredients are necessary and sufficient

Variability among individuals
Differential contribution to successive generations
Mechanism of inheritance

in silico







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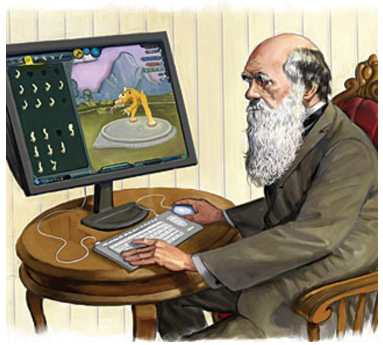
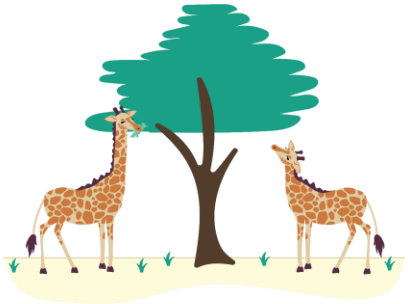
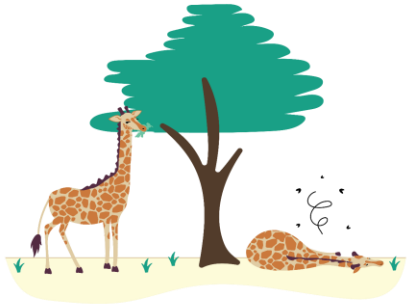
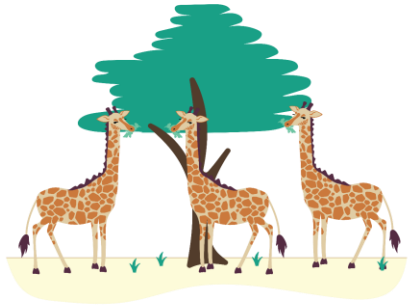


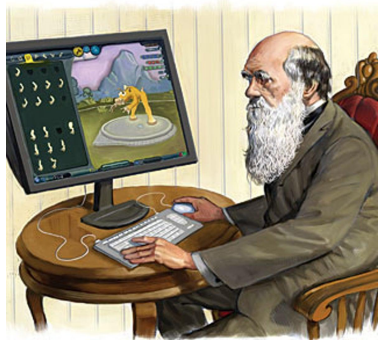


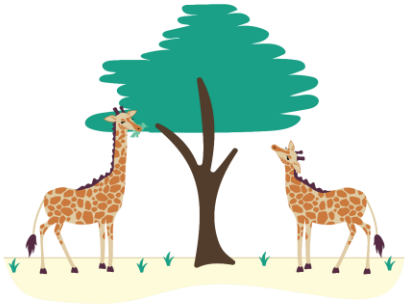


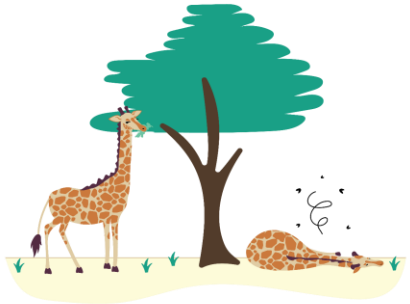


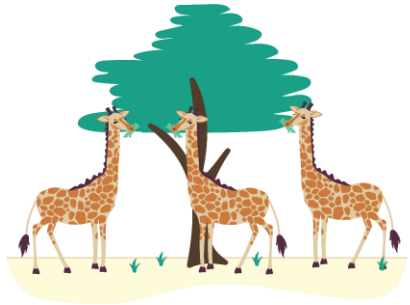
..and in our **toy** model

Limitations of our toy model?









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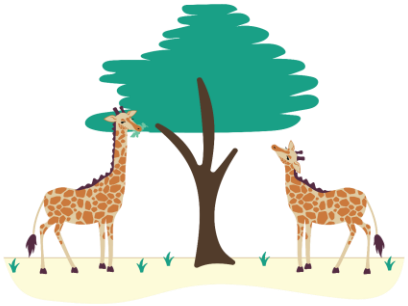
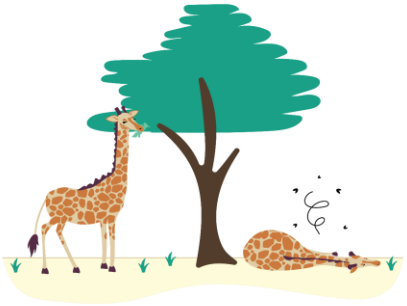
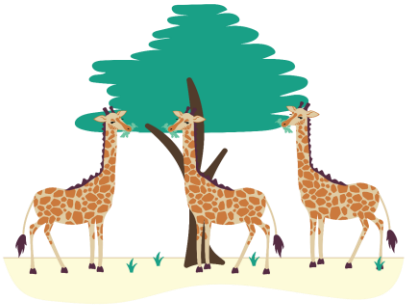
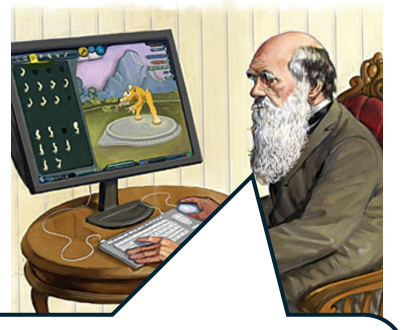


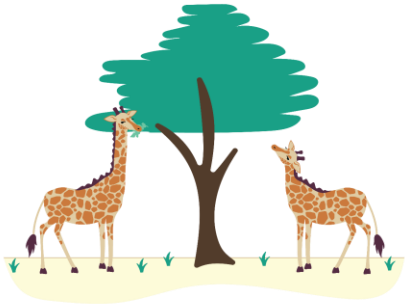


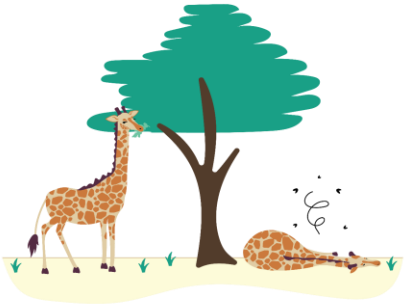


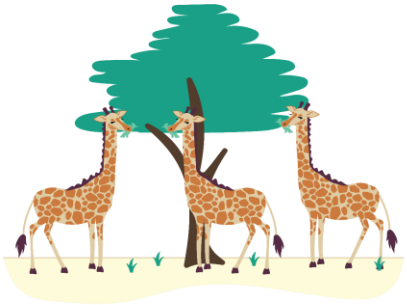


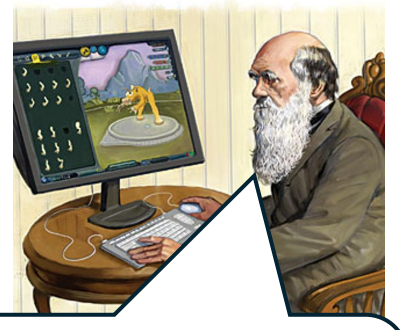
So far we used an extremely simplistic inheritance model. What is missing?

Limitations of our toy model









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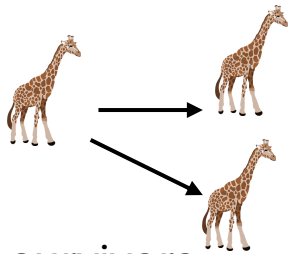

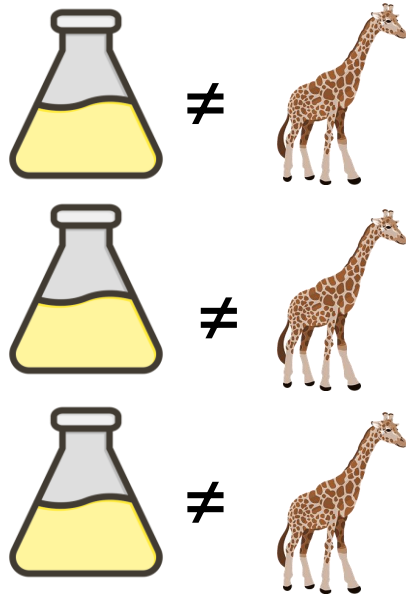

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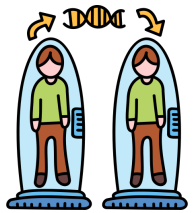
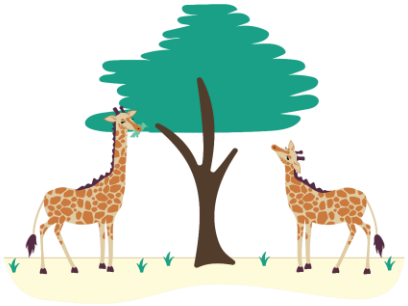
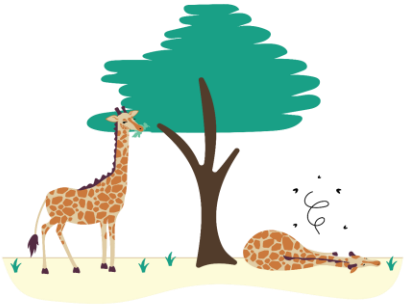
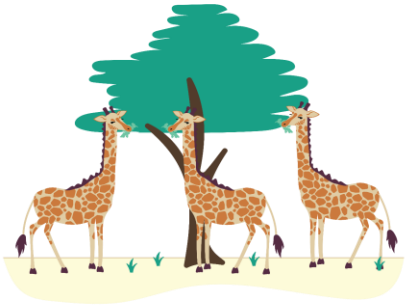
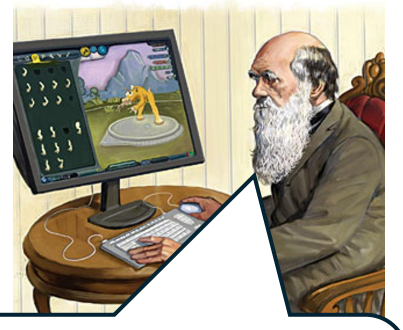


Limitations of our toy model

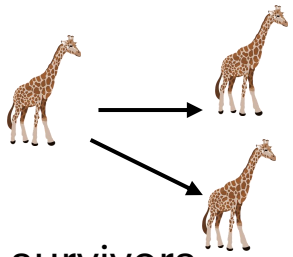








Actually not even bacteria in flask



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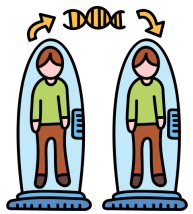
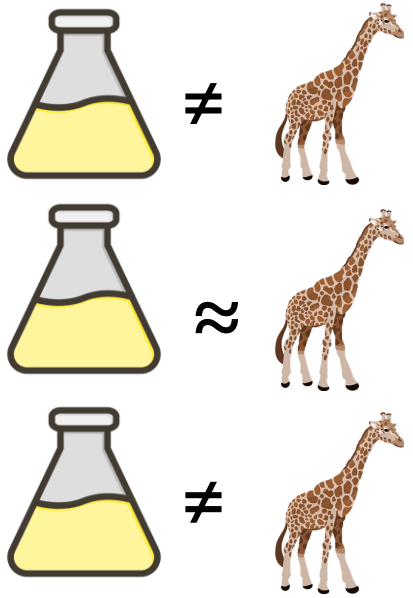
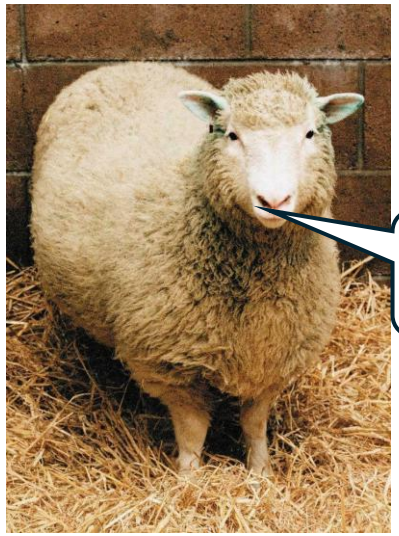
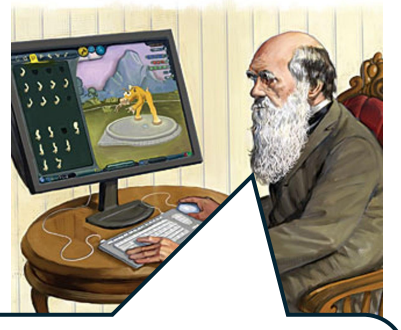




Limitations of our toy model



Not even me



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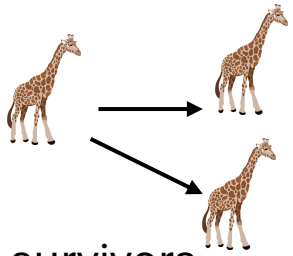

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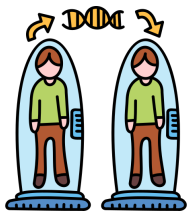
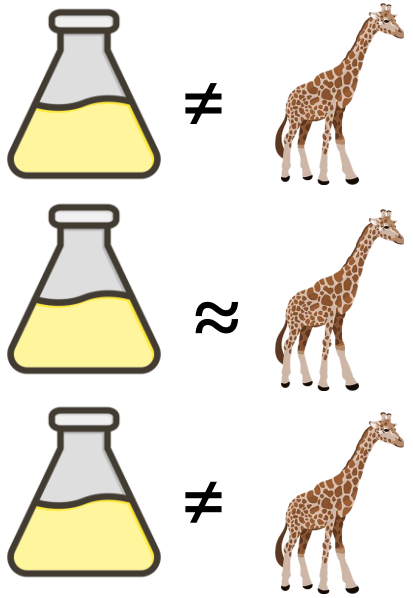
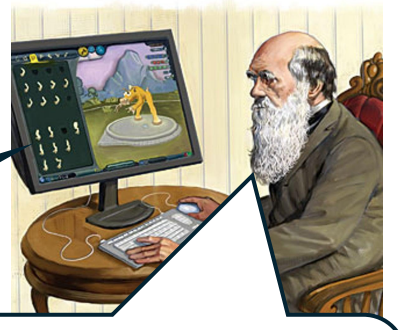




Limitations of our toy model

Not even me

And I know, many other things are missing: mutation, recombination, culture, changes in the environment..but let's start simple



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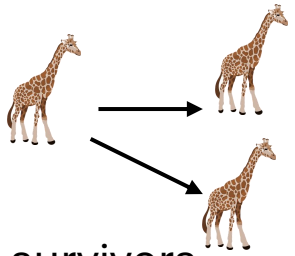

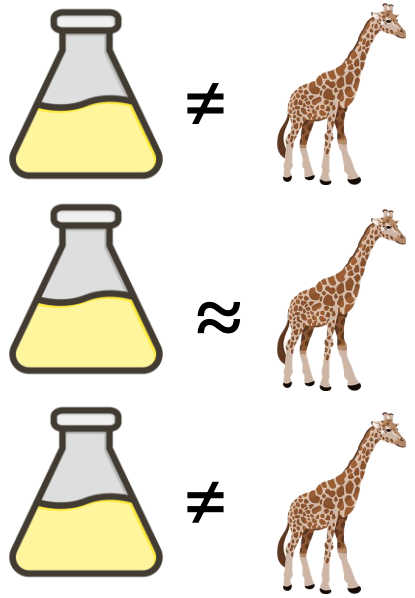

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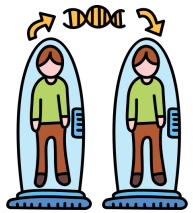
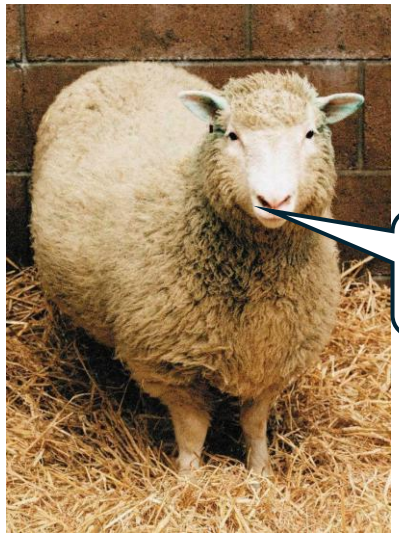


Let’s address these limitations



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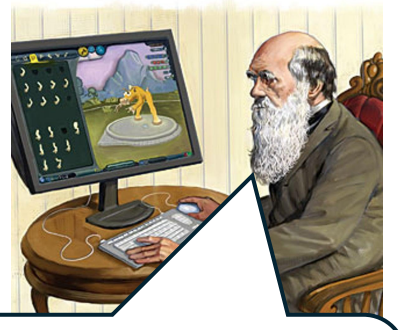

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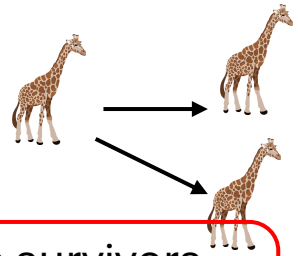

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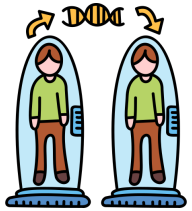
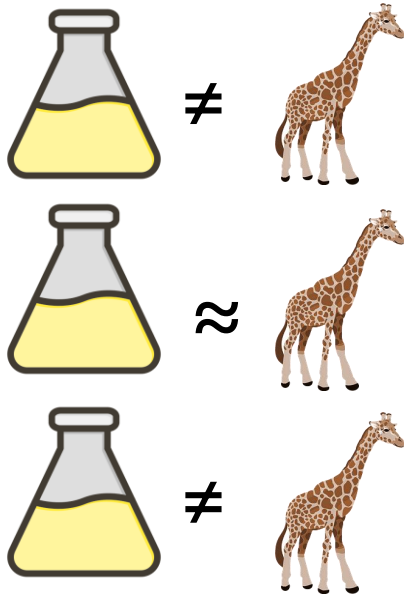
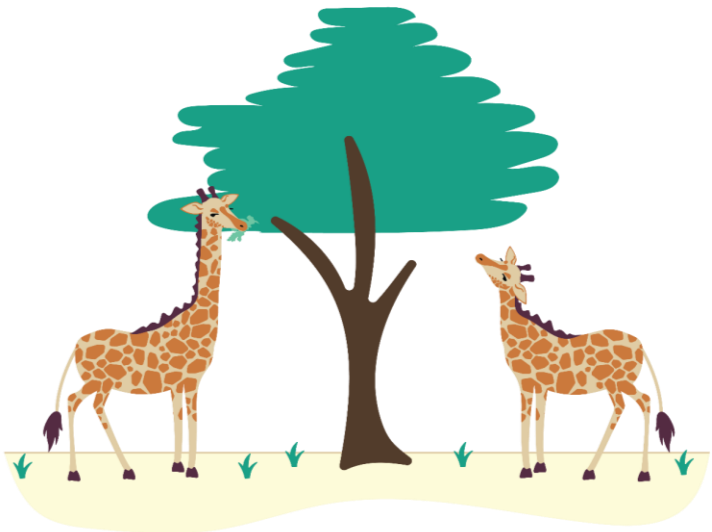
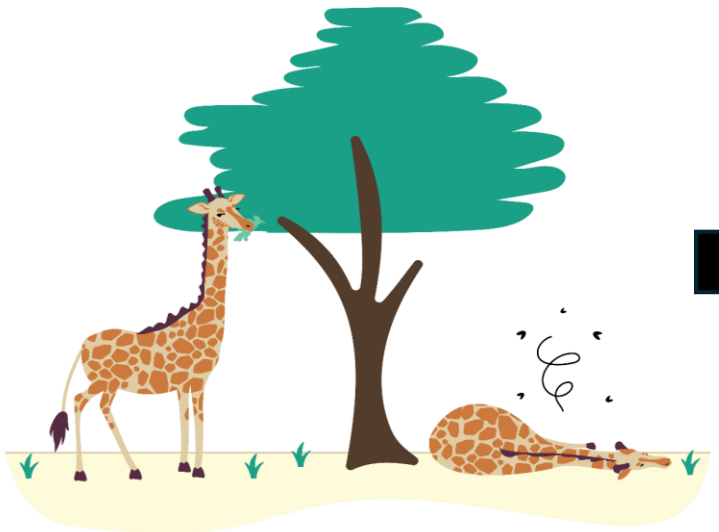
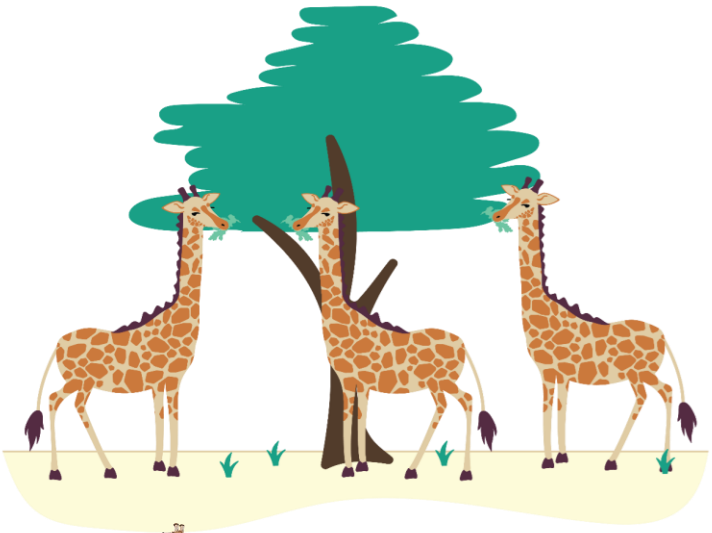


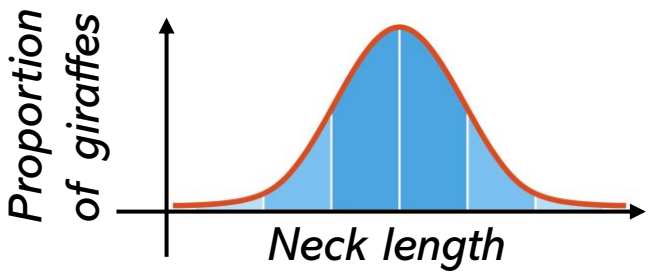


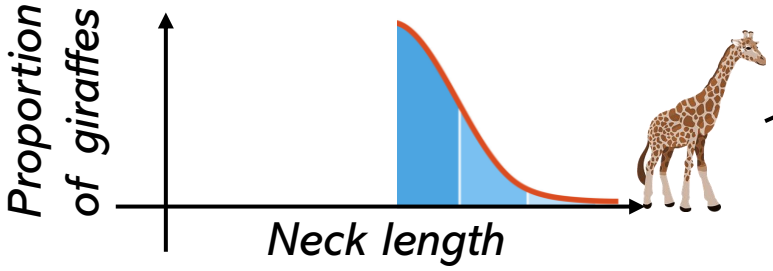
Randomness in reproduction

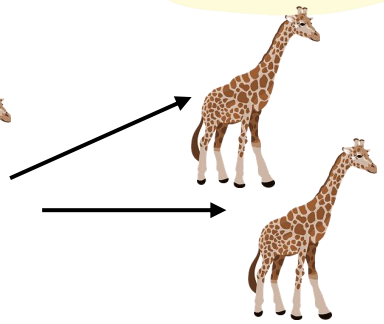










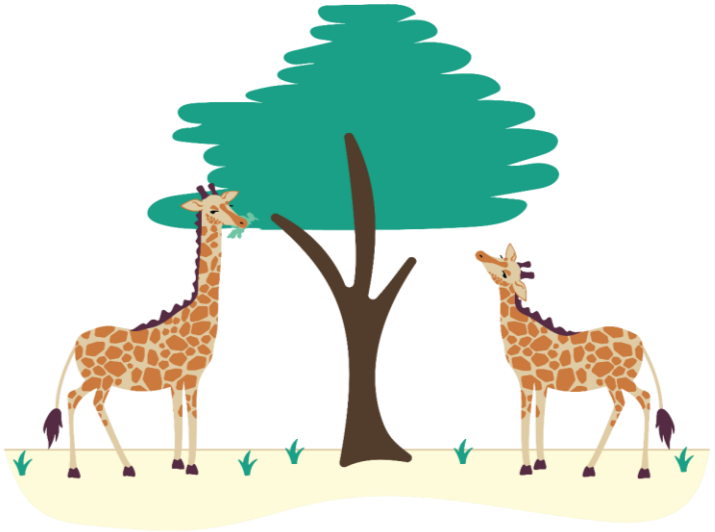


Next generation

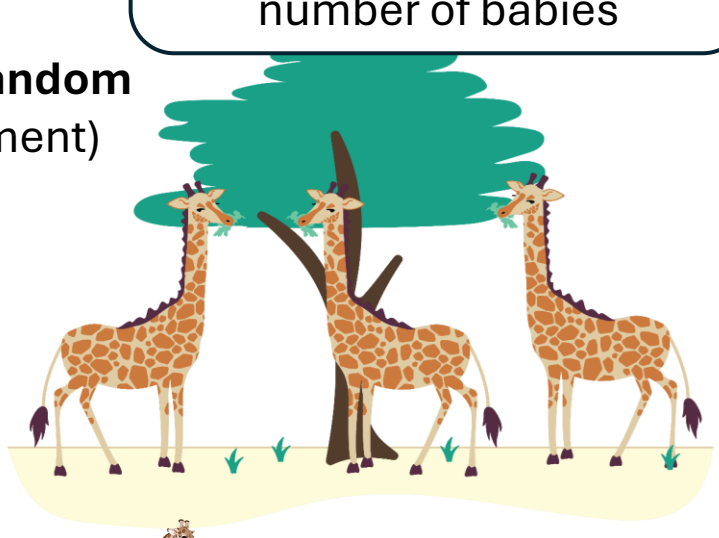
Randomness in reproduction

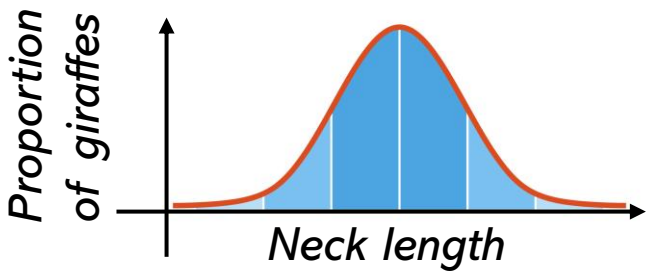
«Same as before», but now we do not force each giraffe to have the same number of babies

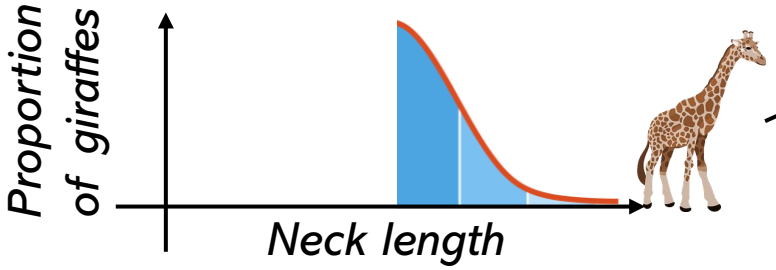
Assume that each surviving individual has the same chance of reproducing

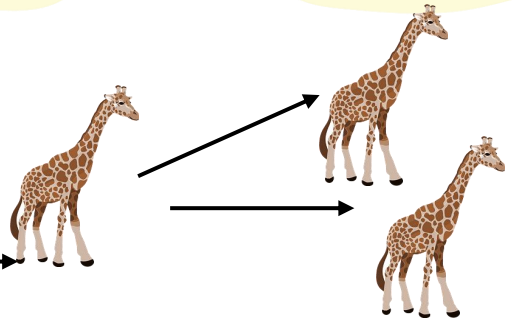


sampling **at random** (with replacement)









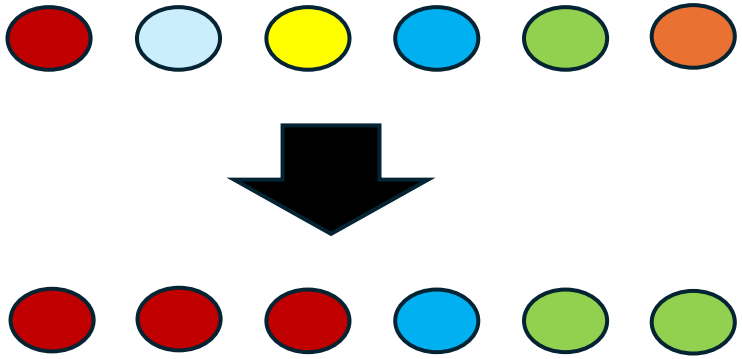
Next generation

Randomness in reproduction

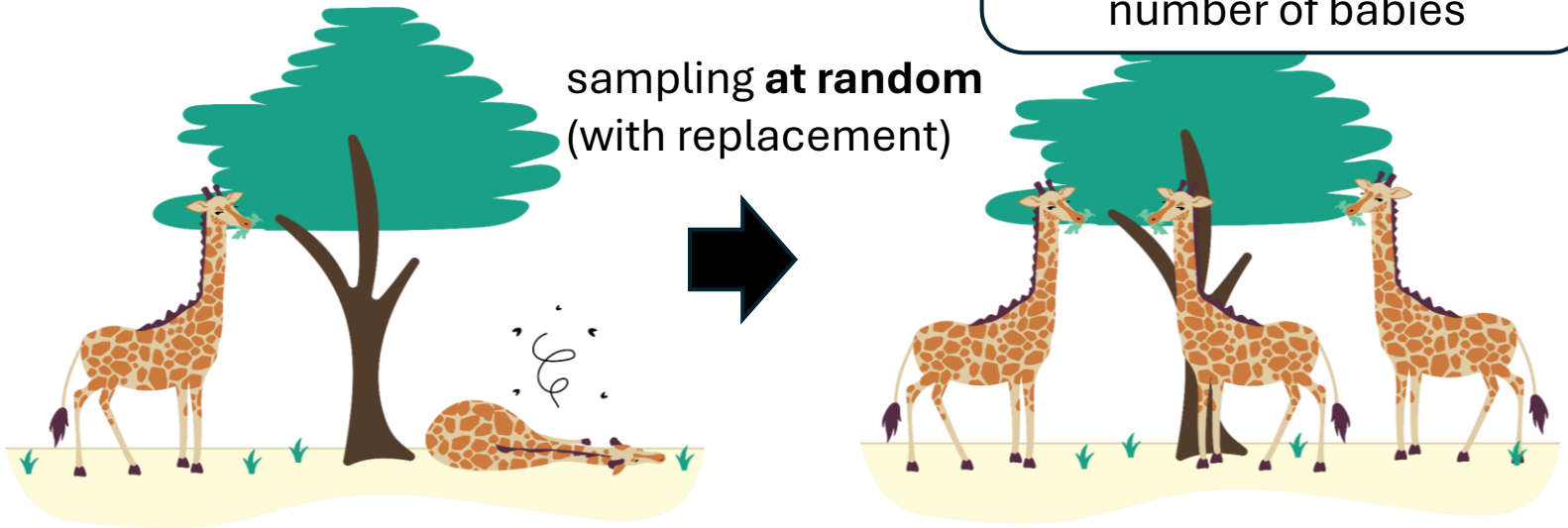
Assume that each surviving individual has the same chance of reproducing

«Same as before», but now we do not force each giraffe to have the same number of babies

sampling at random
(with replacement)

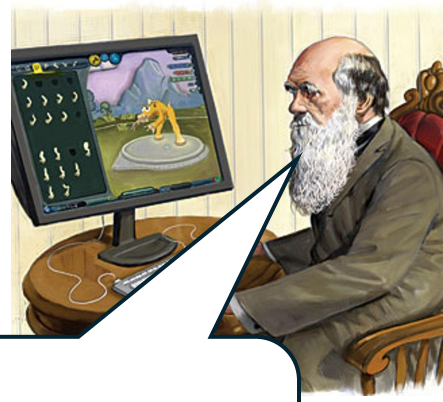


sampling **at random**
(with replacement)



```
sample(survivors, N, replace = TRUE)
```

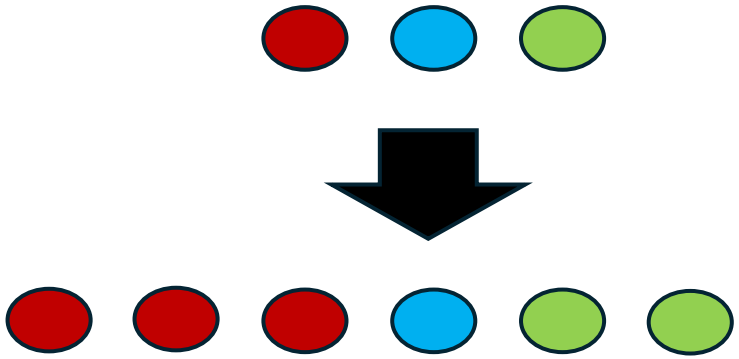
Randomness in reproduction

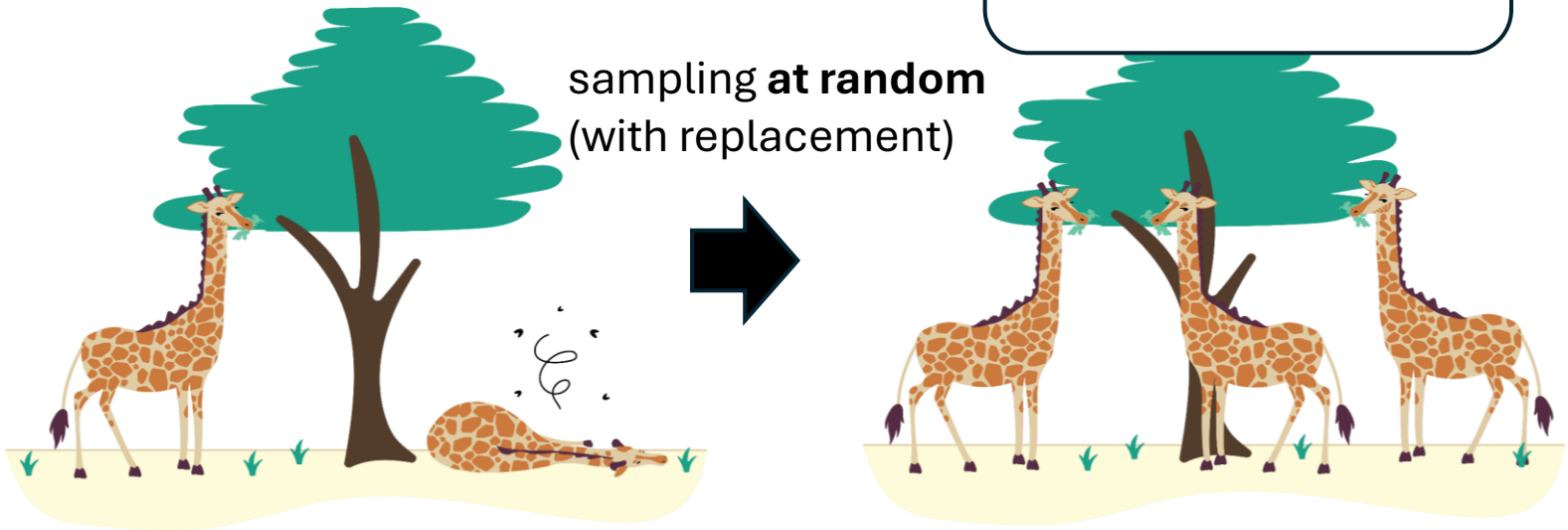


In our model only half giraffes were surviving

Assume that each surviving individual has the same chance of reproducing

sampling at random
(with replacement)

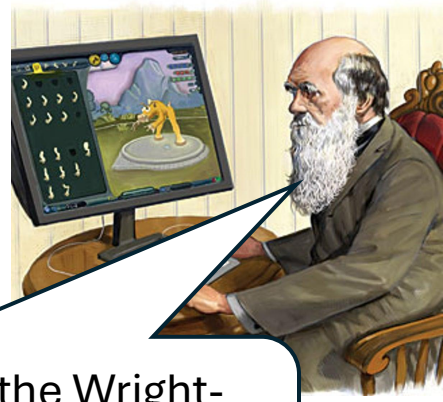




sampling **at random**
(with replacement)

```
sample(survivors, N, replace = TRUE)
```

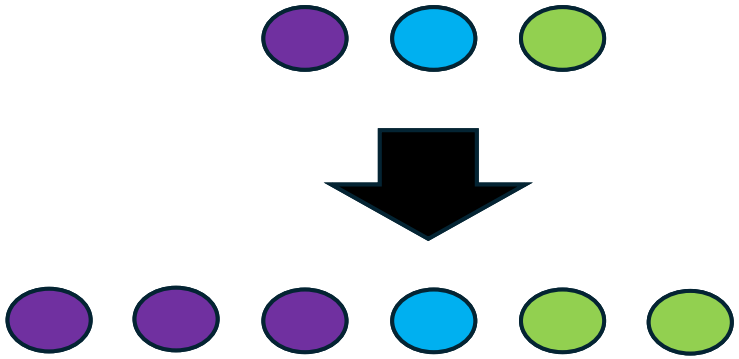
Our first basic “evolutionary model”

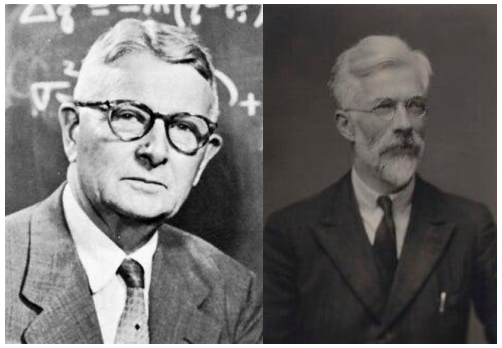


- Variability among individuals
- Differential contribution to successive generations
- **Mechanism of inheritance**

This will be the basis for the Wright-Fisher model, which is at the cornerstone of all population genetics!

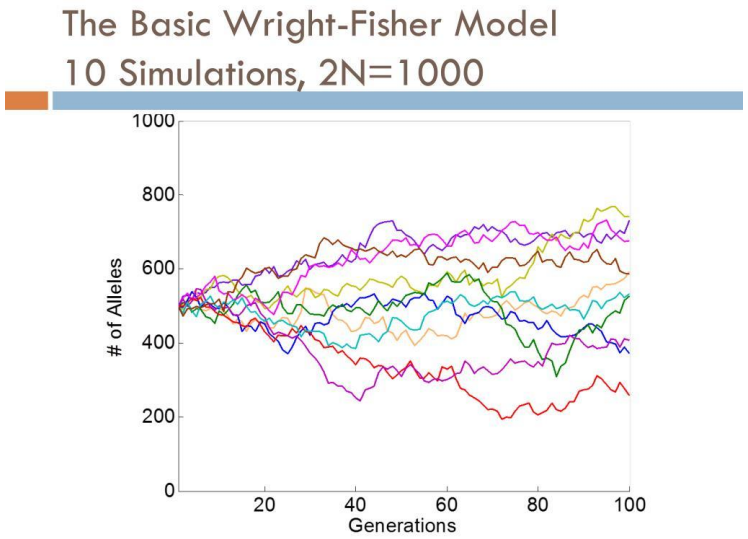
sampling at random
(with replacement)



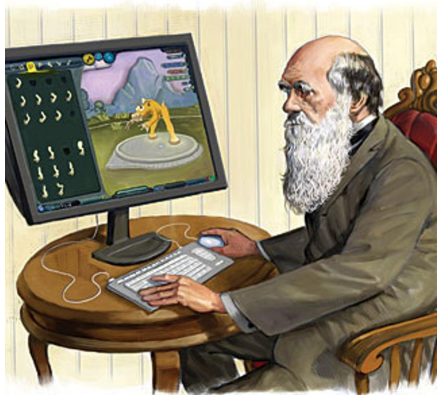


Sir Ronald-Fisher (1889-1988)

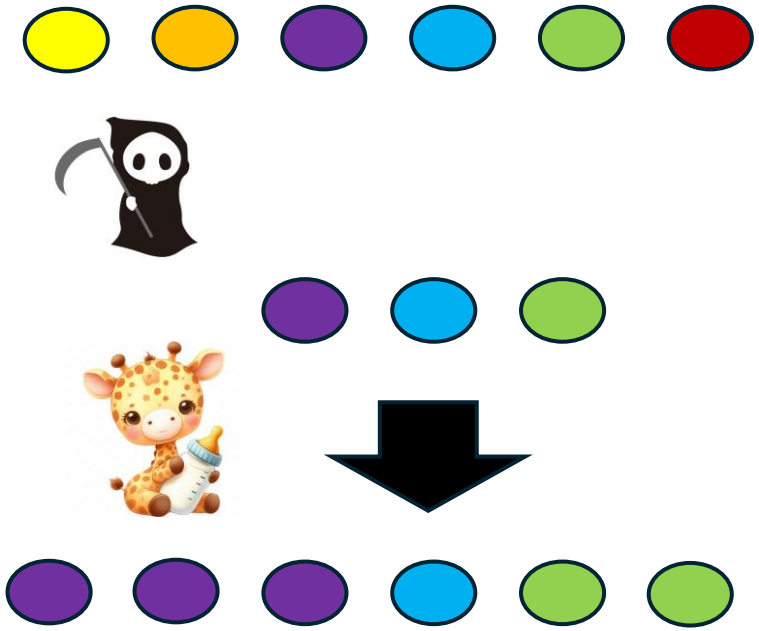
Sir Ronald-Fisher (1890-1962)



Our first basic “evolutionary model”

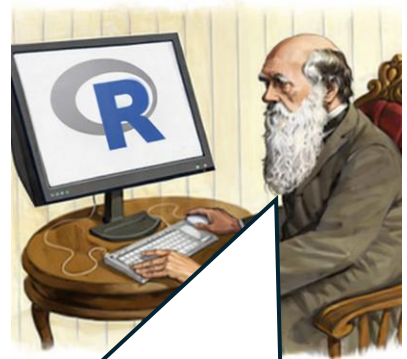


- Variability among individuals
- Differential contribution to successive generations
- Mechanism of inheritance



Our **toy** model

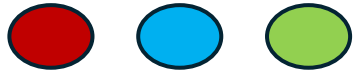
Our first basic “evolutionary model”



- Variability among individuals
- Differential contribution to successive generations
- Mechanism of inheritance

Let’s put together our toy model

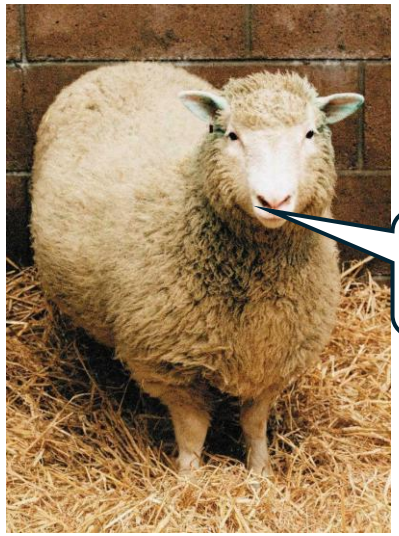
```
N=100
z=rnorm(N)
```



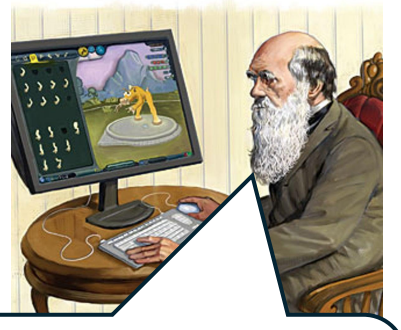
```
survivors=z[z>median(z)]
```

```
z=sample(survivors, N, replace = TRUE)
```

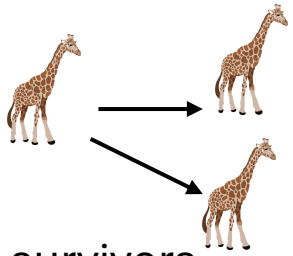
Let’s address these limitations



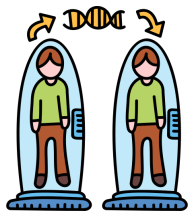
Not even me

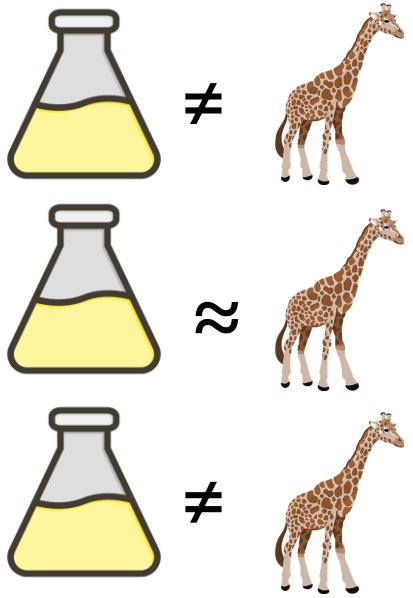


Actually not even bacteria in flask

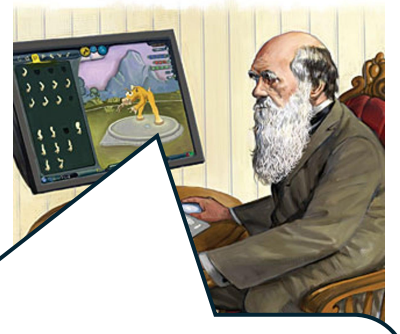


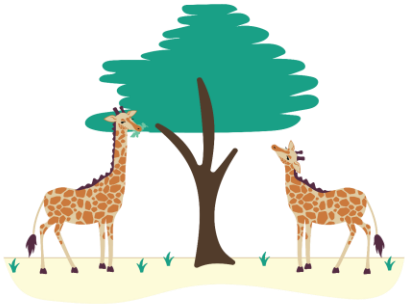
- **Randomness in reproduction**: not exactly two offsprings for one survivors – giraffes are not bacteria!
- There is **variation in the environment** – giraffes are not bacteria in a flask!
- **Diploidy** and sexual reproduction – giraffes are not bacteria!

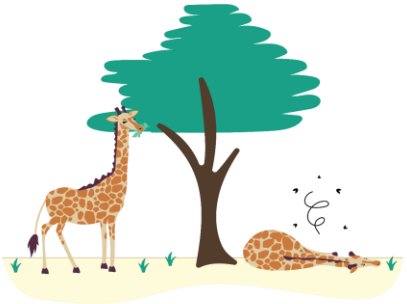


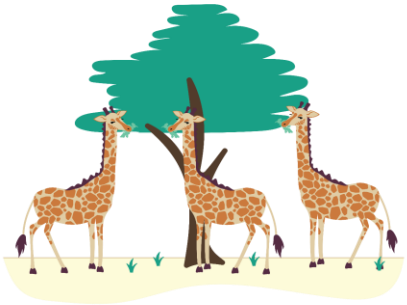


A more realistic inheritance model

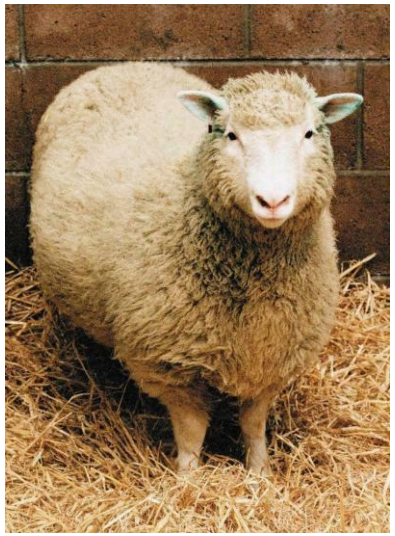




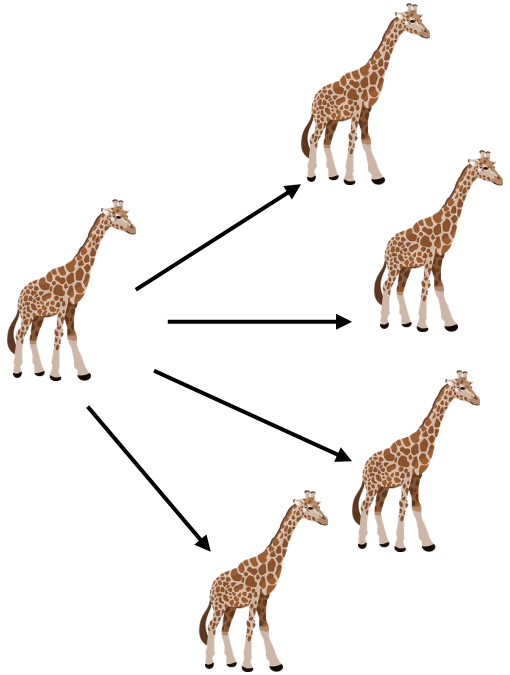


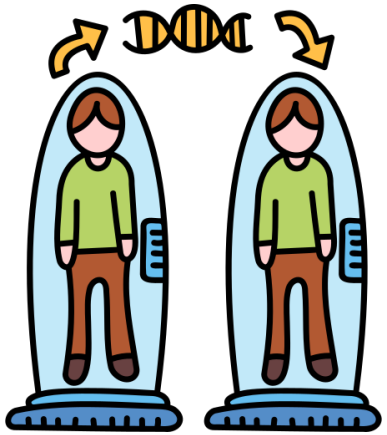


Perfect cloning/asexual reproduction + Environmental variability

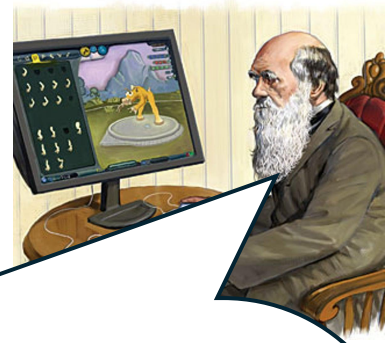


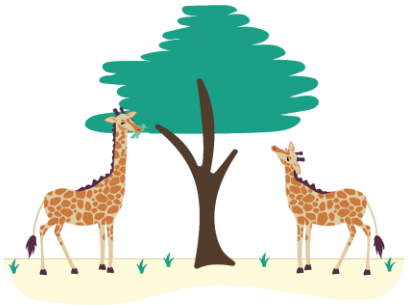
Dolly the sheep

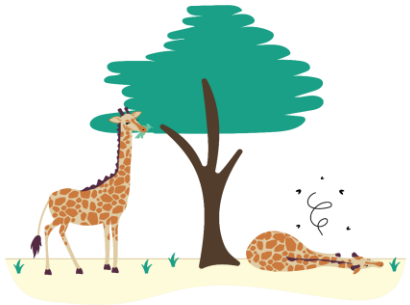


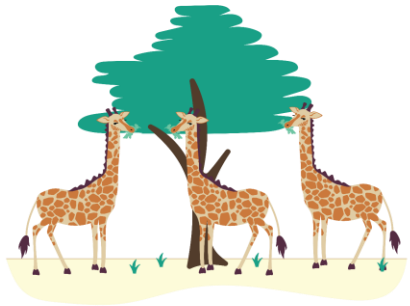


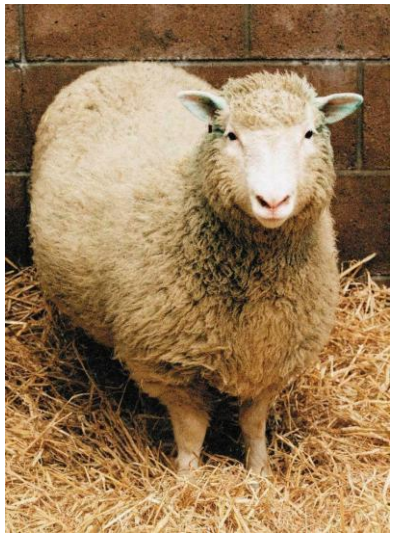
A more realistic inheritance model





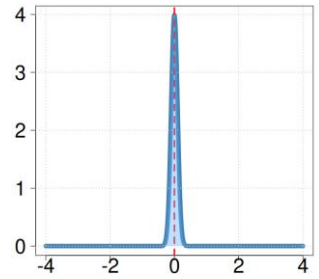




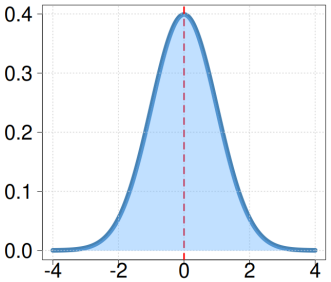


Environmental variability

A trait with low environmental variability?



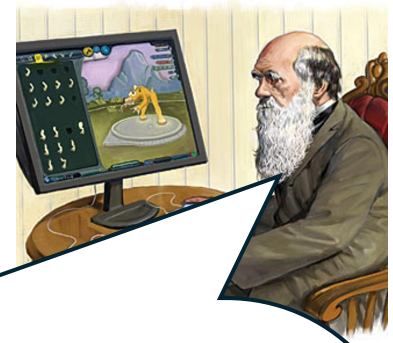
Low

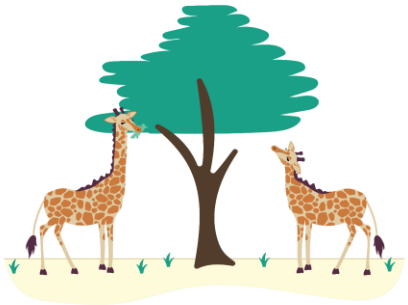


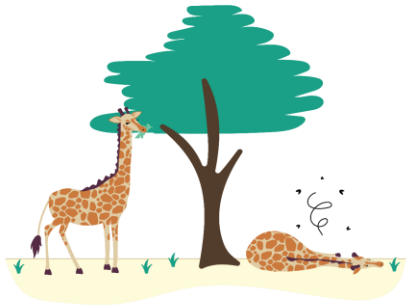
High

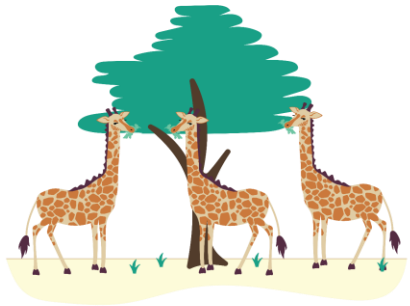
Standard deviation / environmental variability

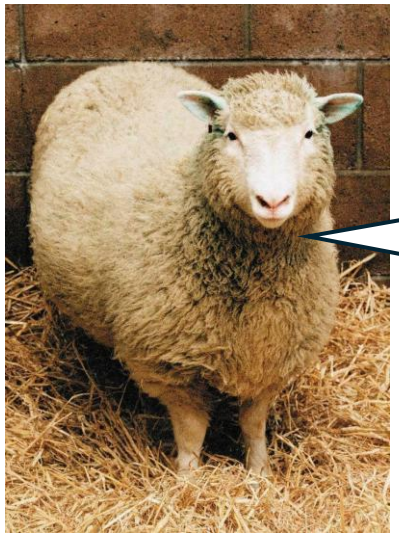
A more realistic inheritance model





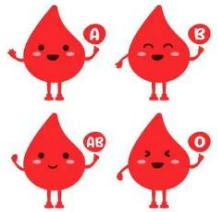


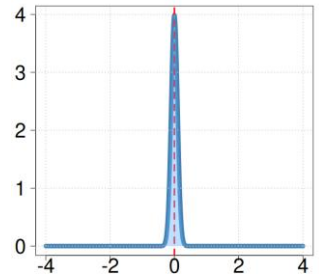




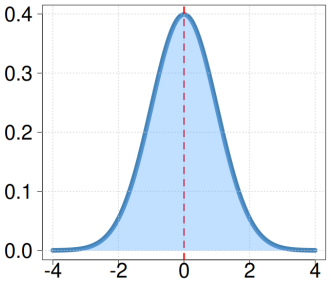
In the cloning model it was as if we had standard deviation `sd=0`

Environmental variability





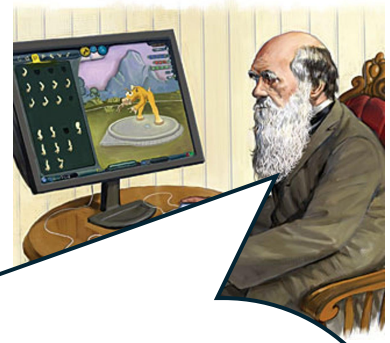
Low

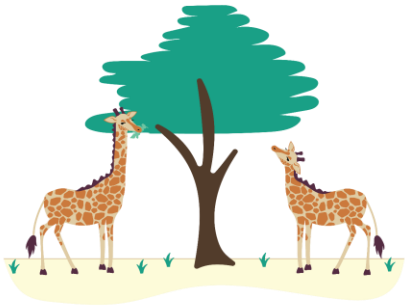


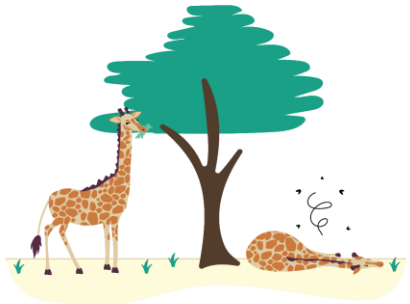
High

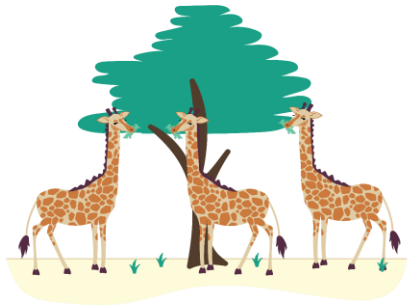
Standard deviation / environmental variability

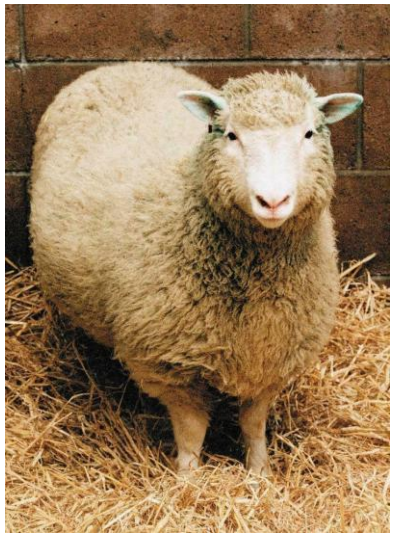
A more realistic inheritance model

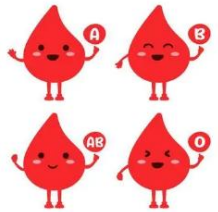






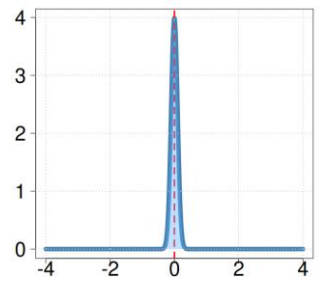




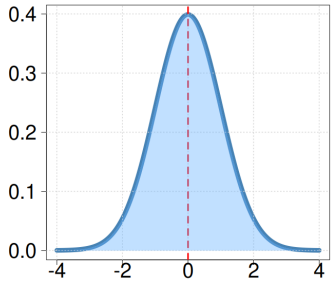


Environmental variability

?



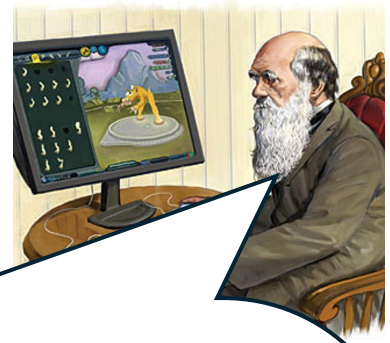
Low

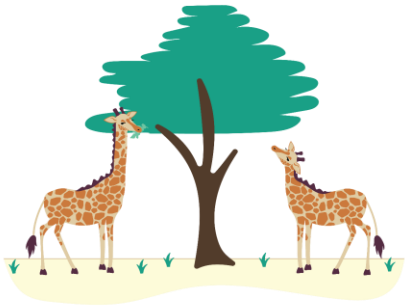


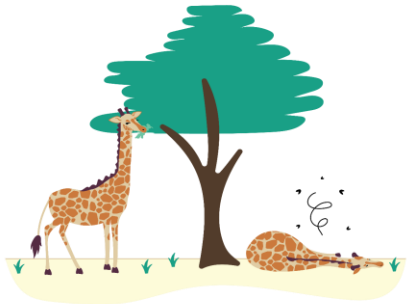
High

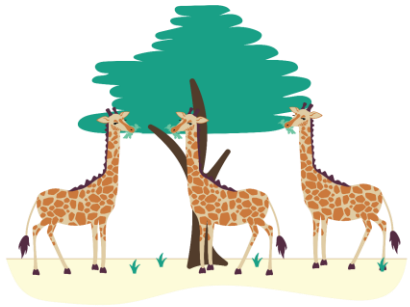
Standard deviation / environmental variability

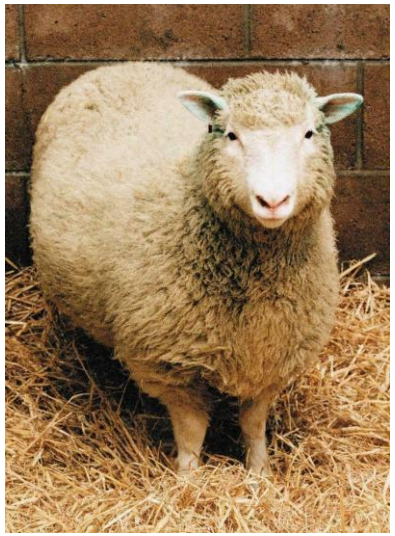
A more realistic inheritance model

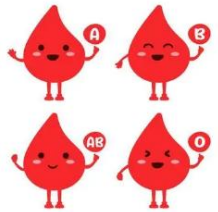




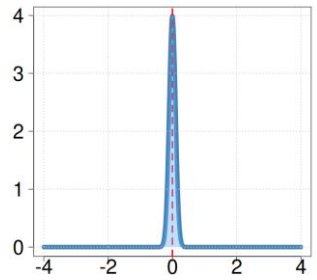








Environmental variability



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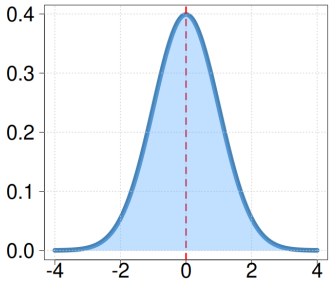
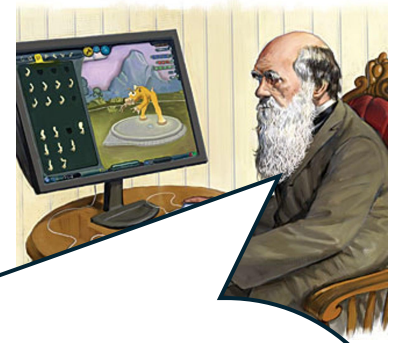
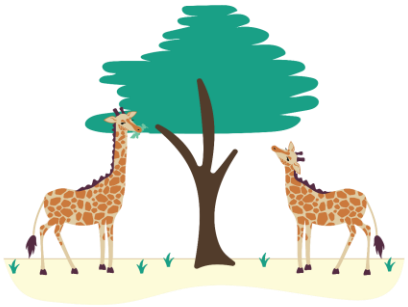


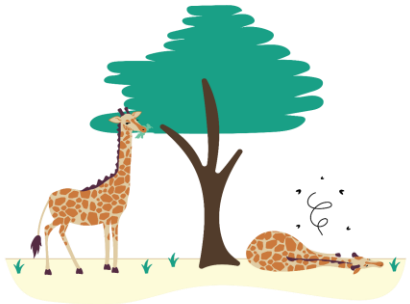
High

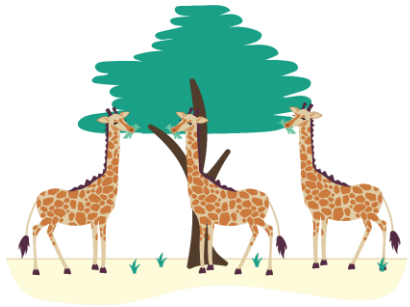
Standard deviation / environmental variability

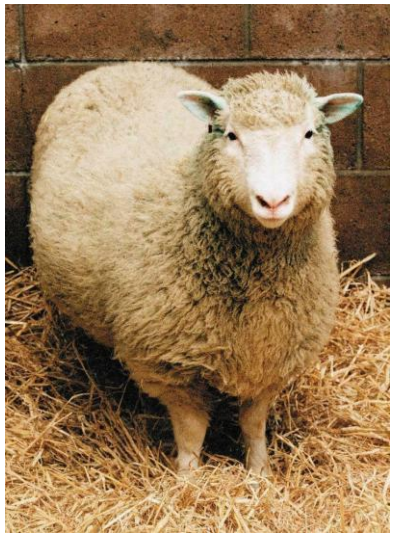
A more realistic inheritance model



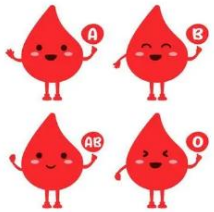




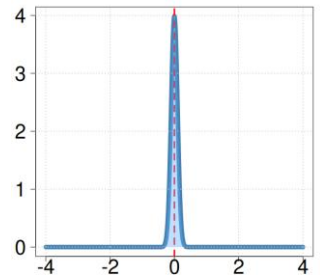




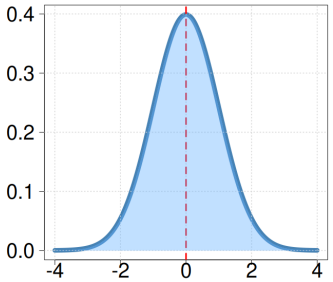
Height is 70-80% heritable



Environmental variability



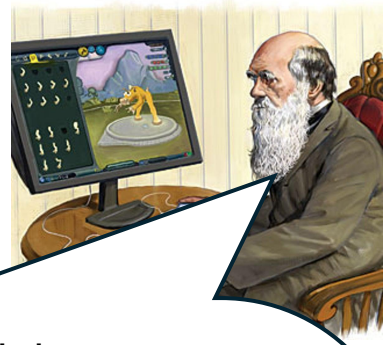
Low

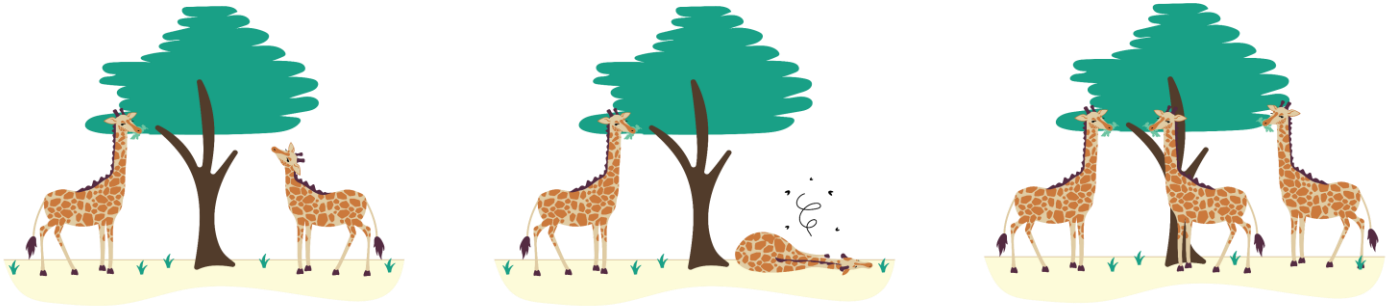


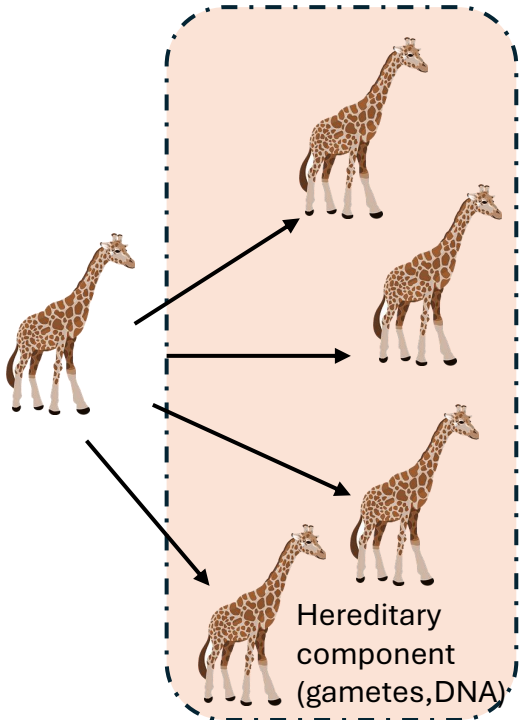
High

Standard deviation / environmental variability

A more realistic inheritance model







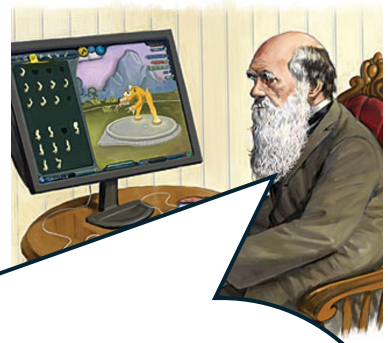
More realistic model

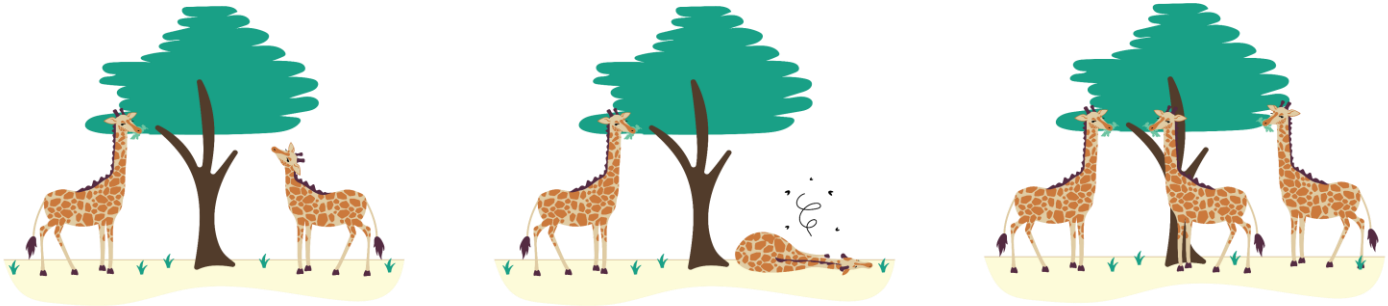
Perfect cloning/asexual reproduction

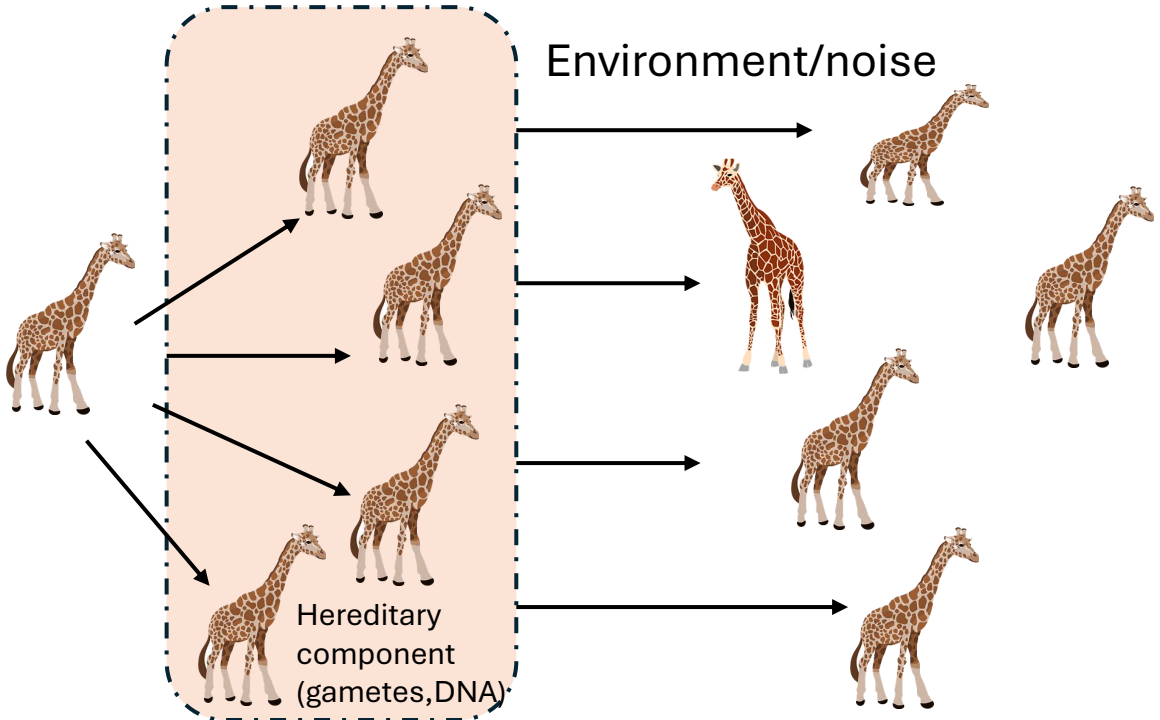
+

Environmental variability

A more realistic inheritance model



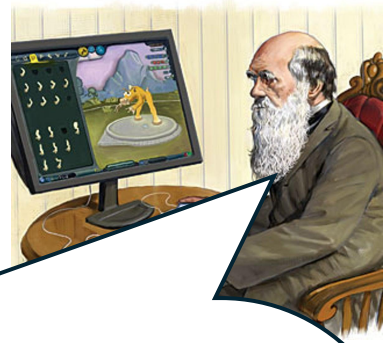


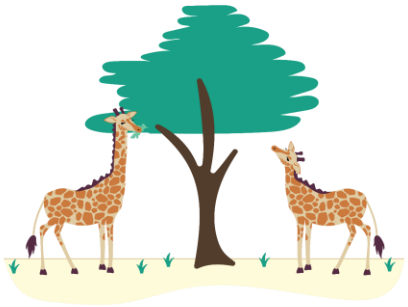


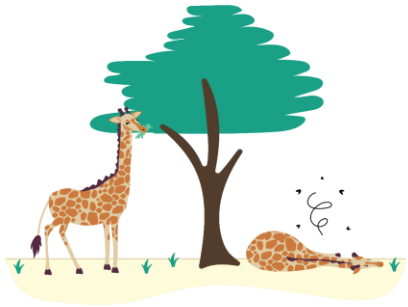
More realistic model

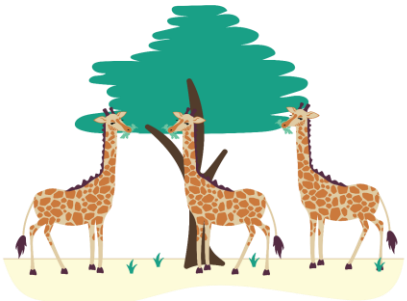
Perfect cloning/asexual reproduction + Environmental variability

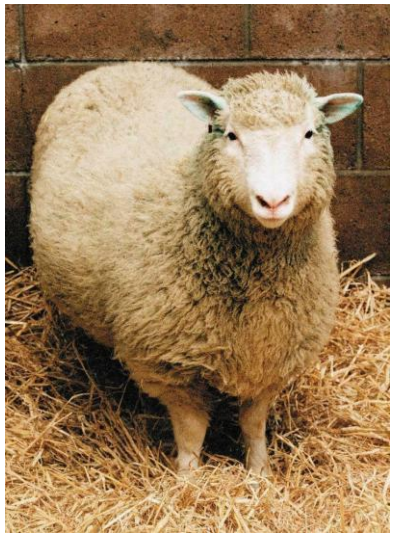
Cloning vs realistic model

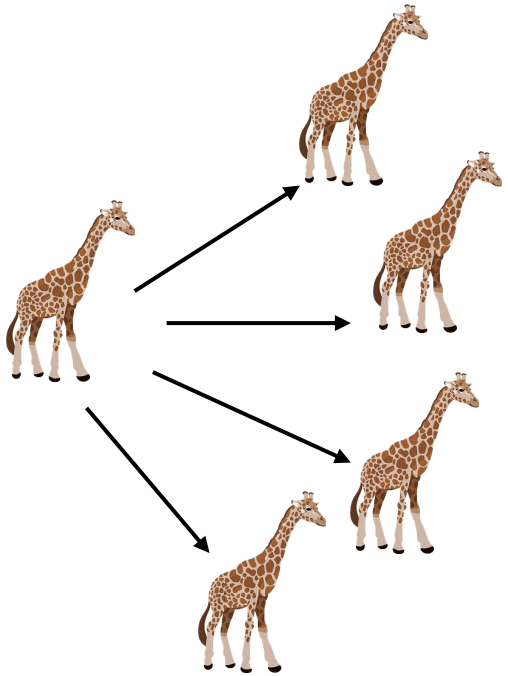












VS

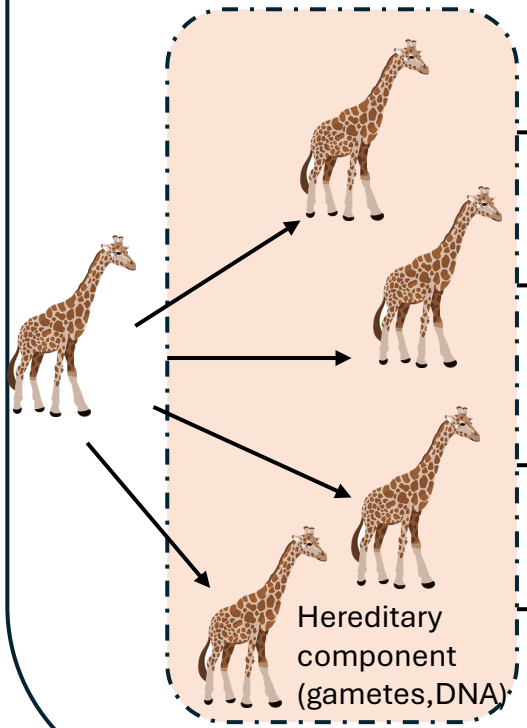
More realistic model

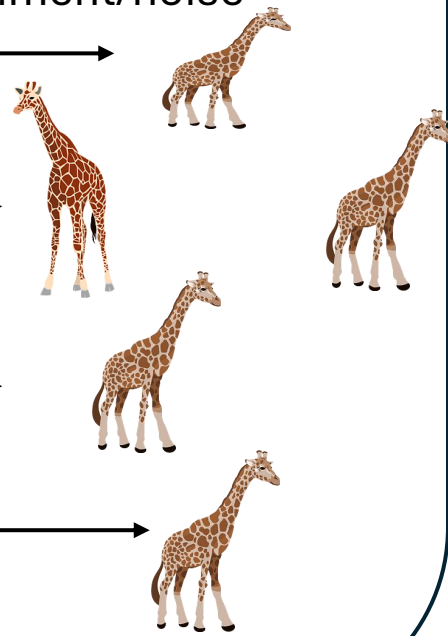
Perfect cloning/asexual reproduction

+

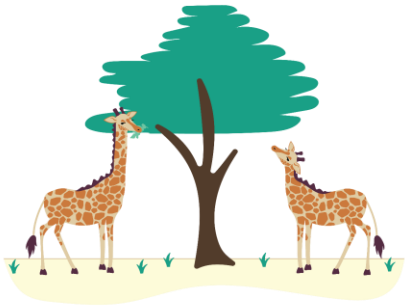
Environmental variability

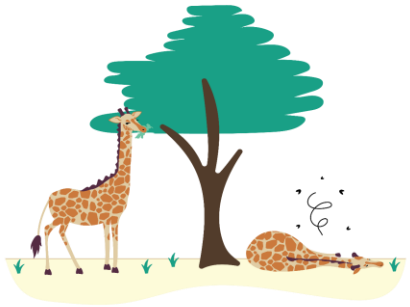
Environment/noise

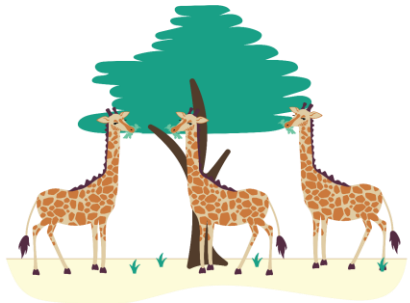


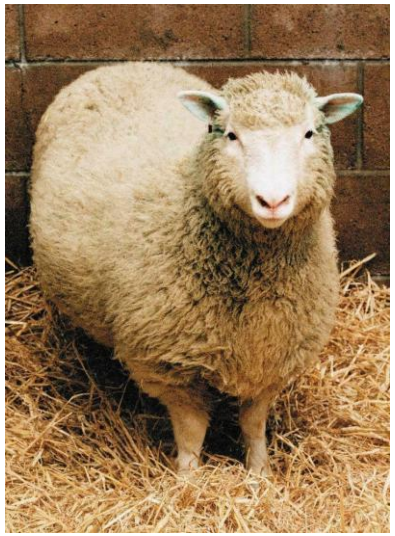


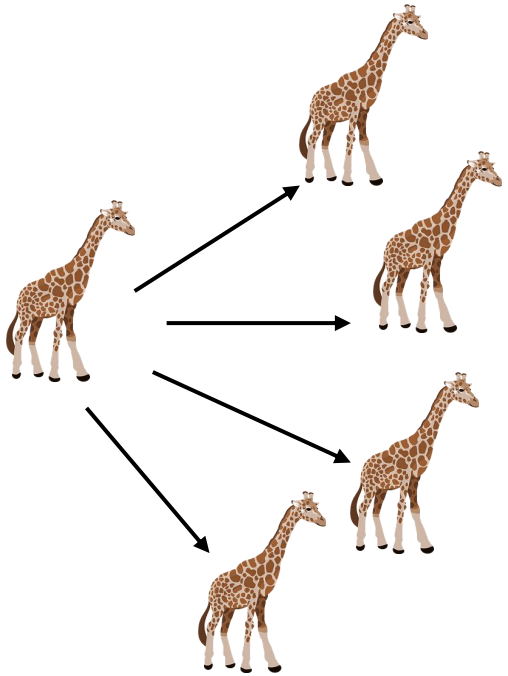
A more realistic inheritance model (code)







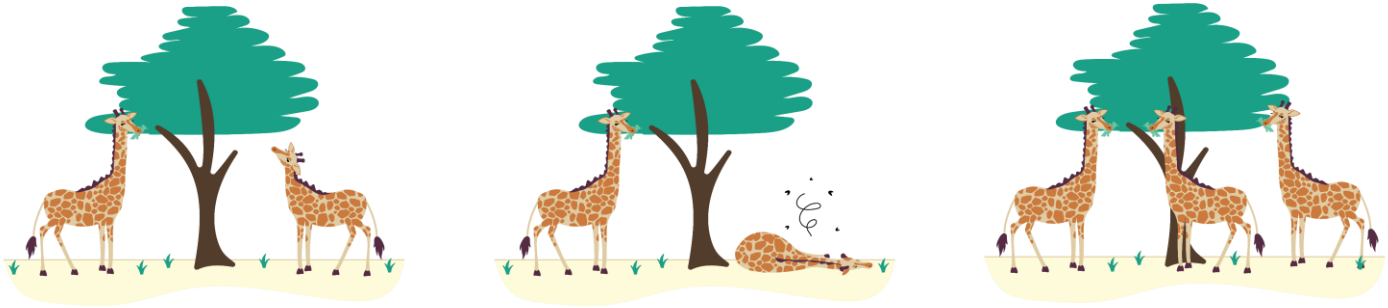


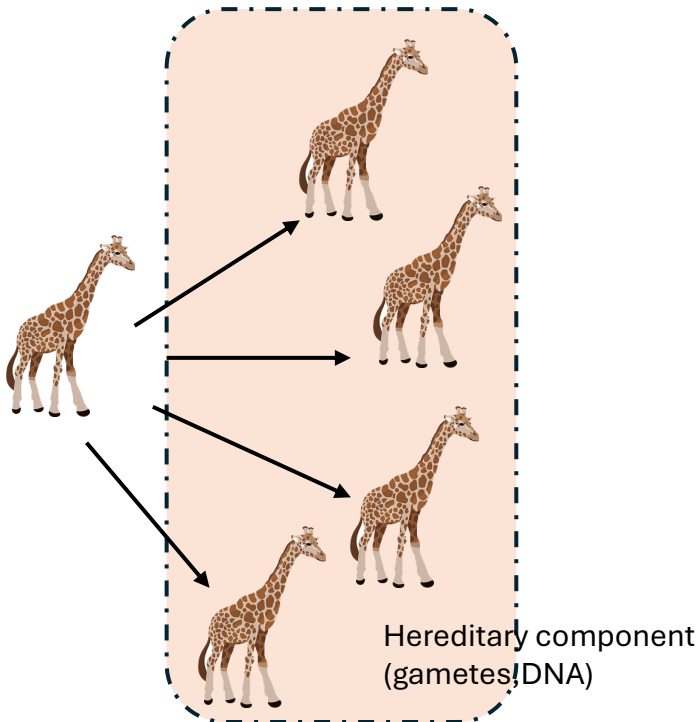


First basic model with cloning

```
z=rnorm(N)
survivors=z[z>median(z)]
parents=survivors
z=sample(parents,N,replace=TRUE)
```

A more realistic inheritance model (code)





More realistic model

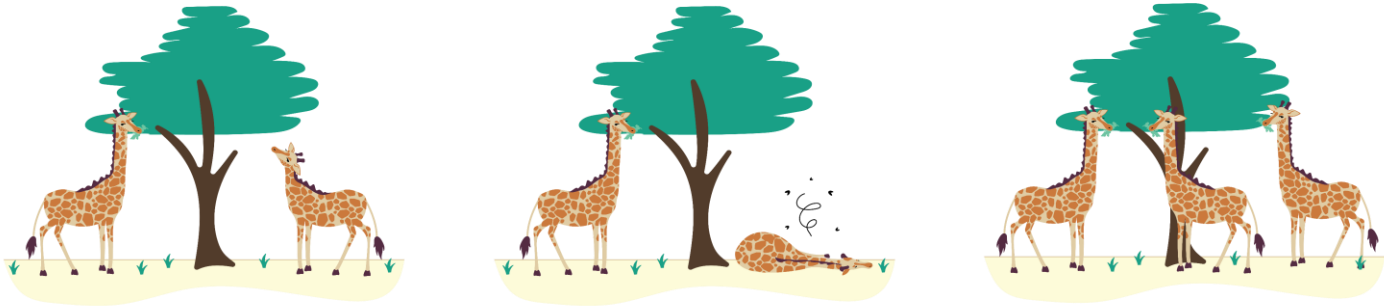
Perfect cloning/asexual reproduction + Environmental variability

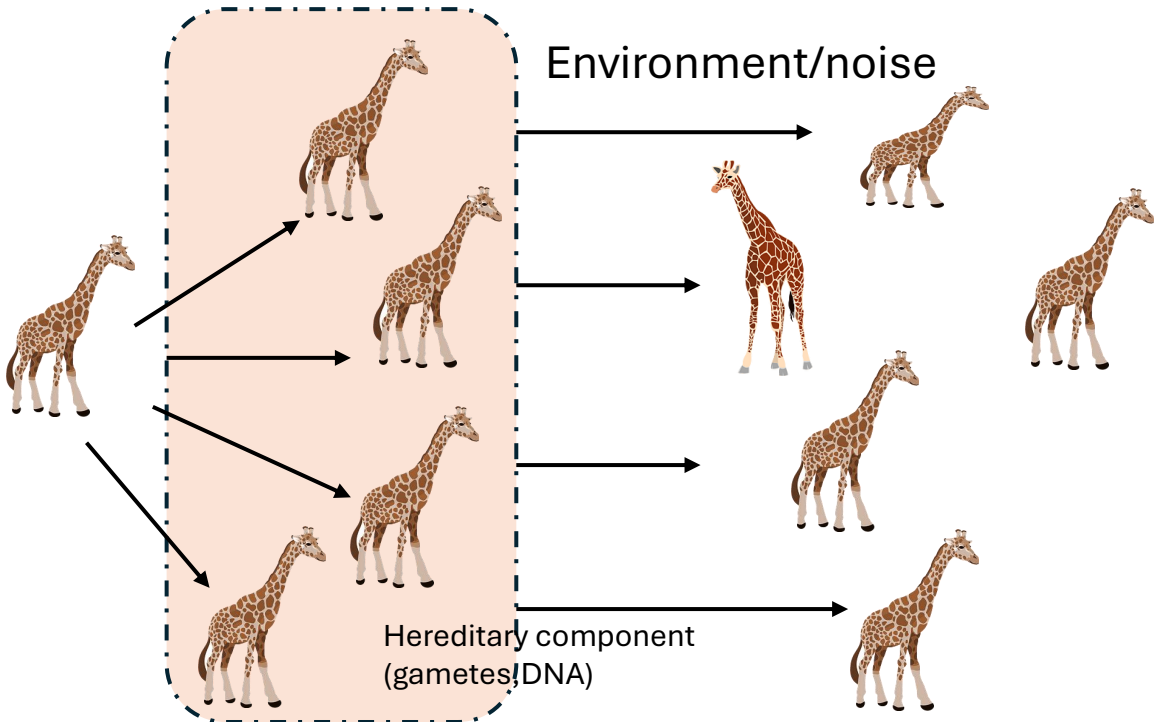
```
parents=survivors
gametes=sample(parents,N,replace=TRUE)
```

First basic model with cloning

```
z=rnorm(N)
survivors=z[z>median(z)]
parents=survivors
z=sample(parents,N,replace=TRUE)
```

A more realistic inheritance model (code)





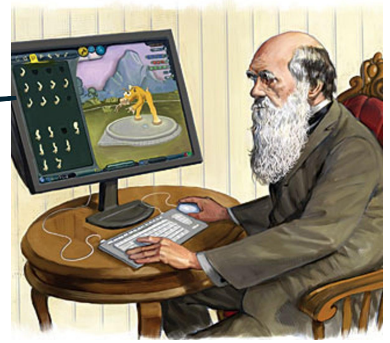
Perfect cloning/asexual reproduction + Environmental variability

```
parents=survivors
gametes=sample(parents,N,replace=TRUE)
z=gametes + rnorm(sd=0.1)
```

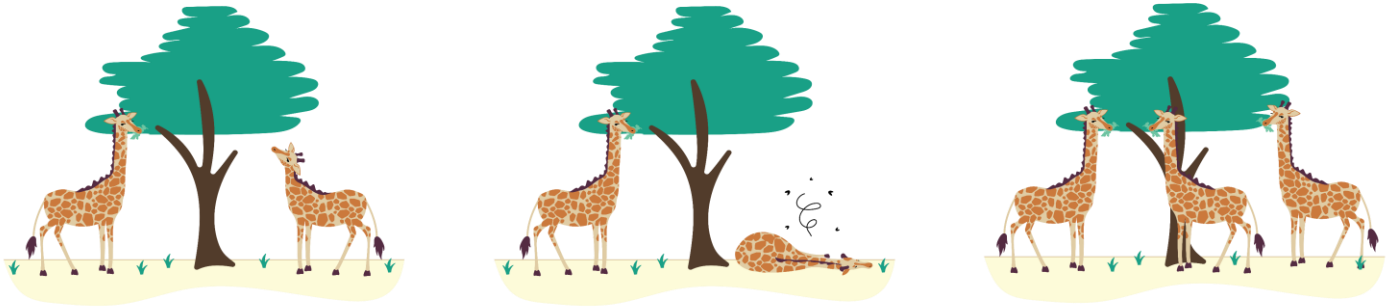
First basic model with cloning

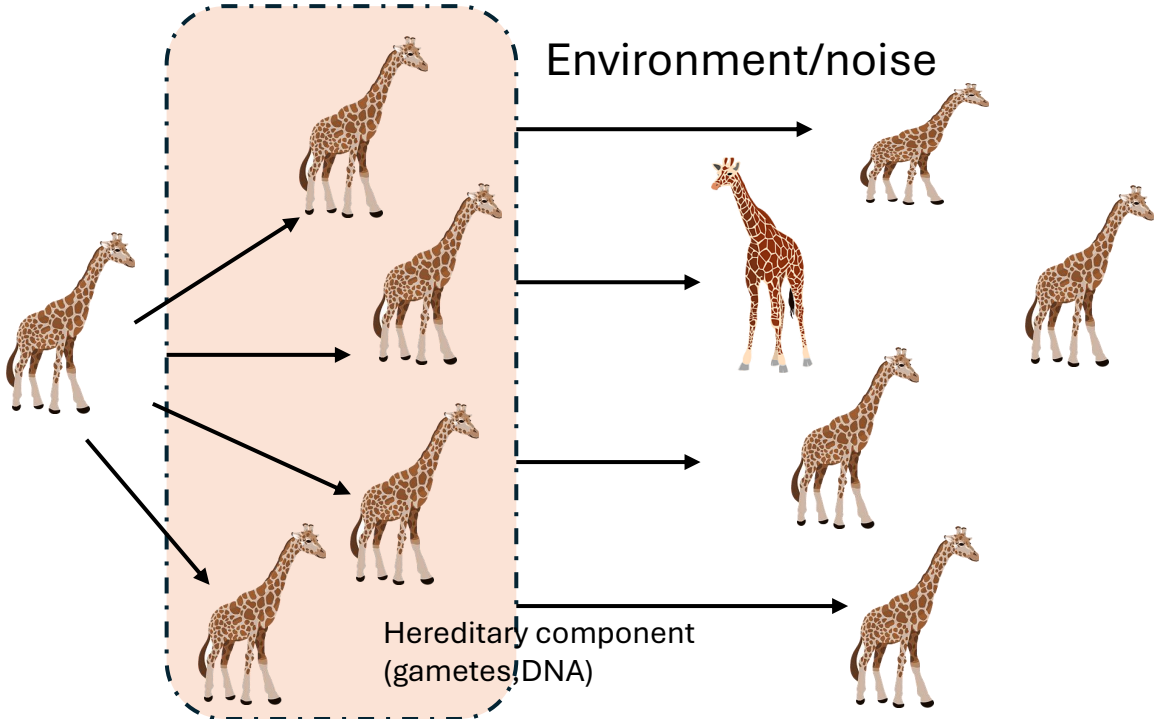
```
z=rnorm(N)
survivors=z[z>median(z)]
parents=survivors
z=sample(parents,N,replace=TRUE)
```

A more realistic inheritance model

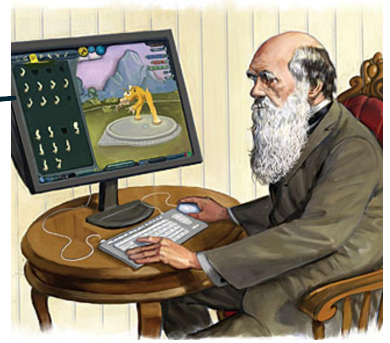


Does my theory work even with environmental variability and a more realistic inheritance model? What happens?

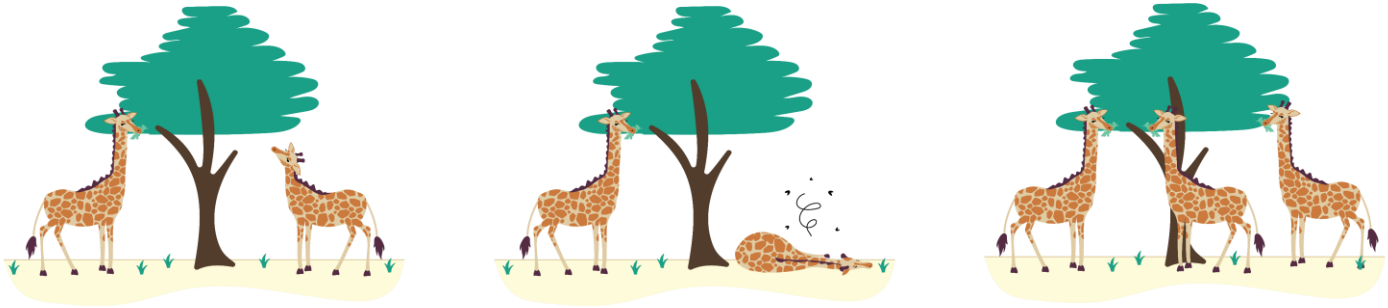


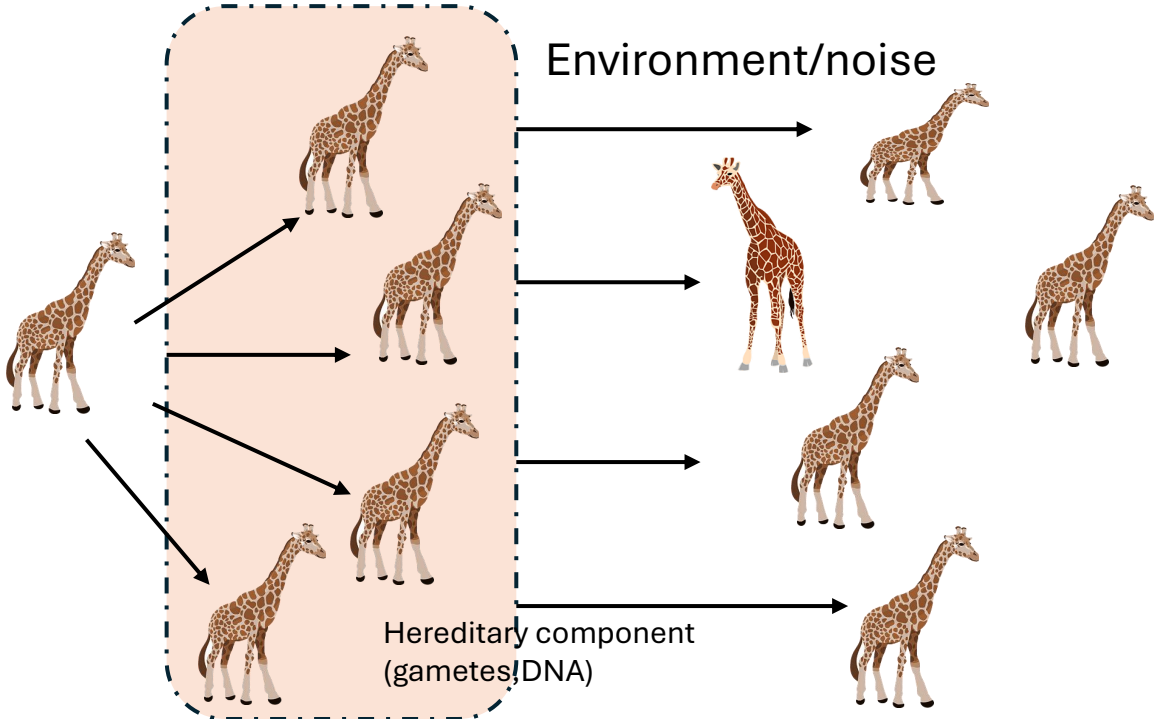


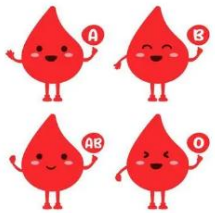
A more realistic inheritance model

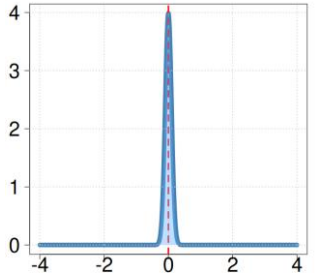


Does my theory work even with environmental variability and a more realistic inheritance model? What happens?

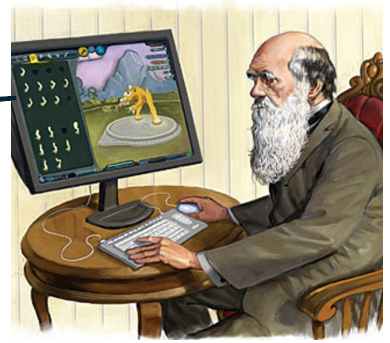




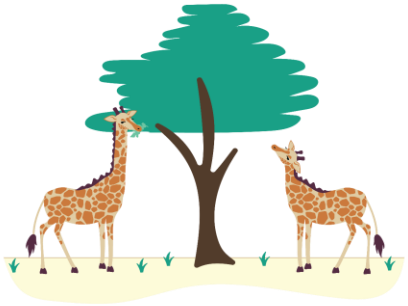


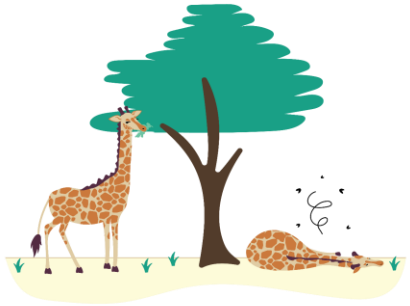


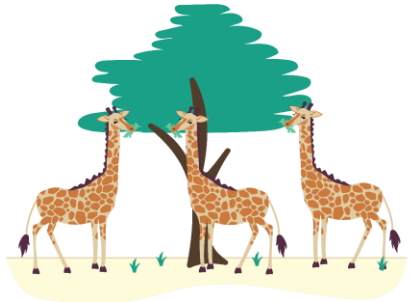
A more realistic inheritance model

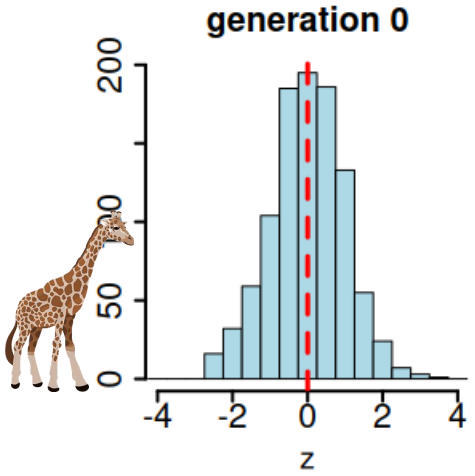


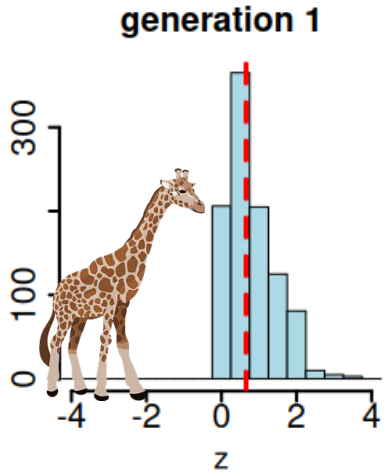
Does my theory work even with environmental variability and a more realistic inheritance model? What happens?

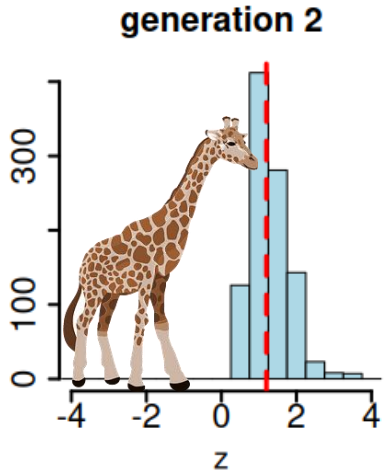


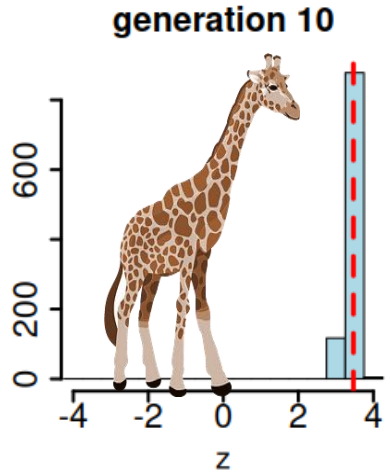


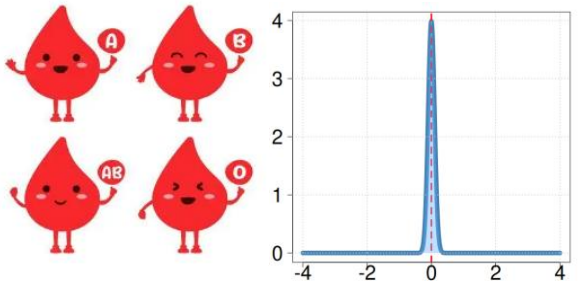






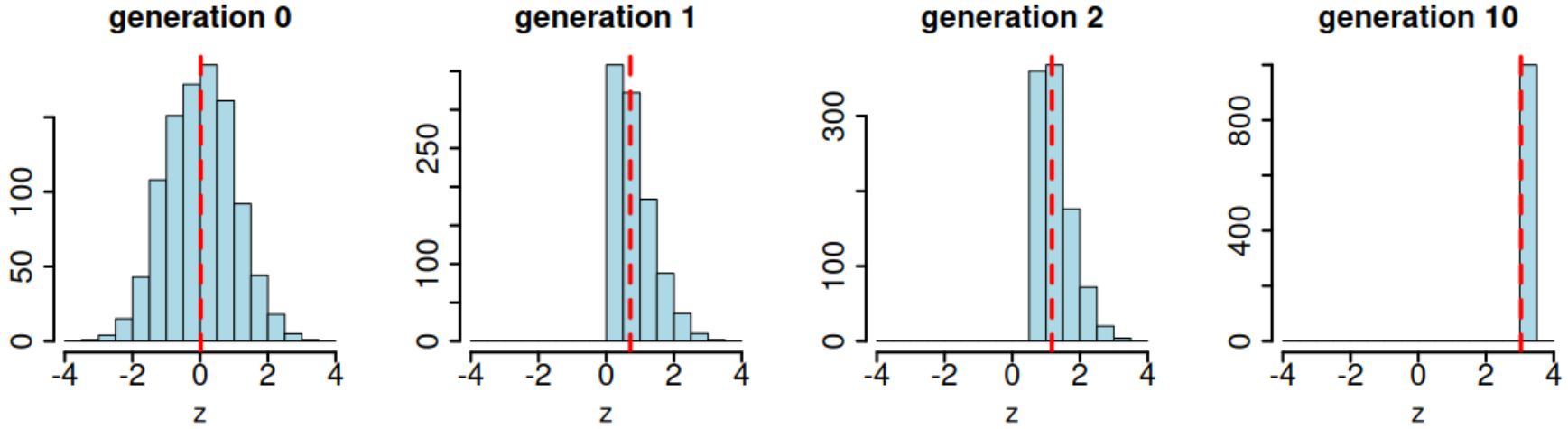




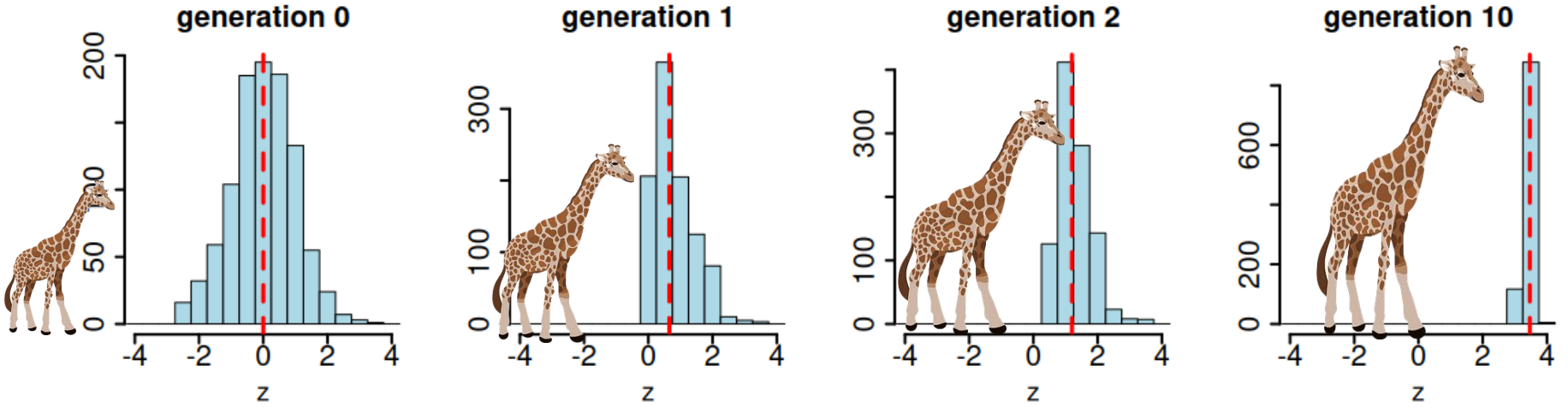


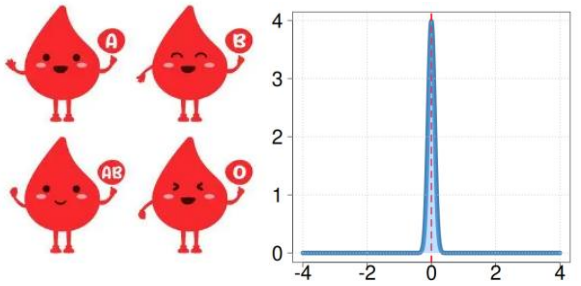
A more realistic inheritance model

Similar to what happened with no randomness or environment: fast evolution



Very basic model
(cloning, no environment)

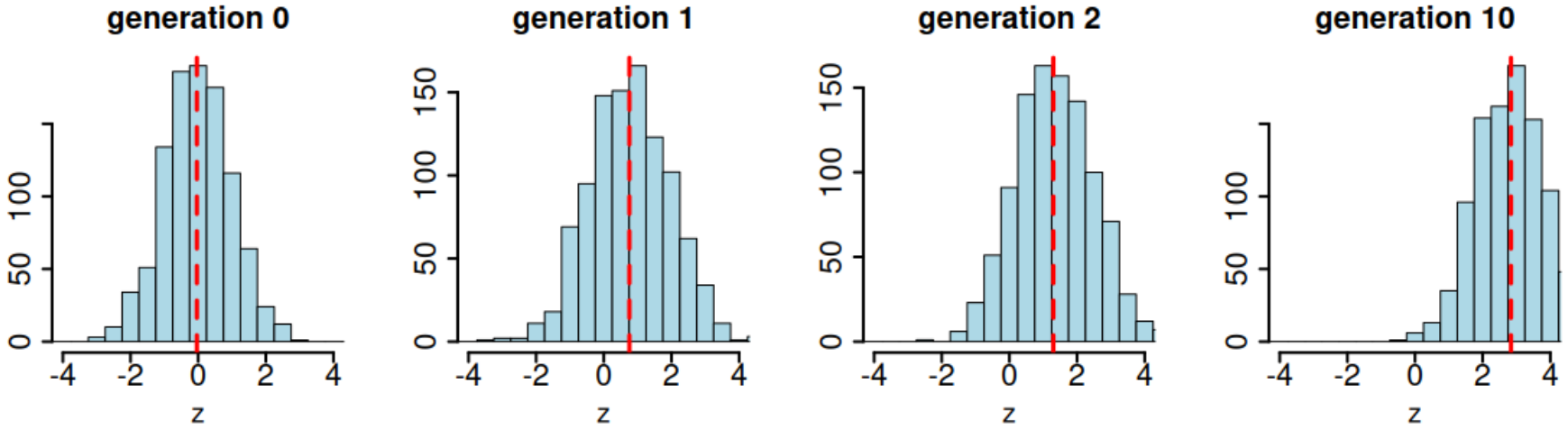




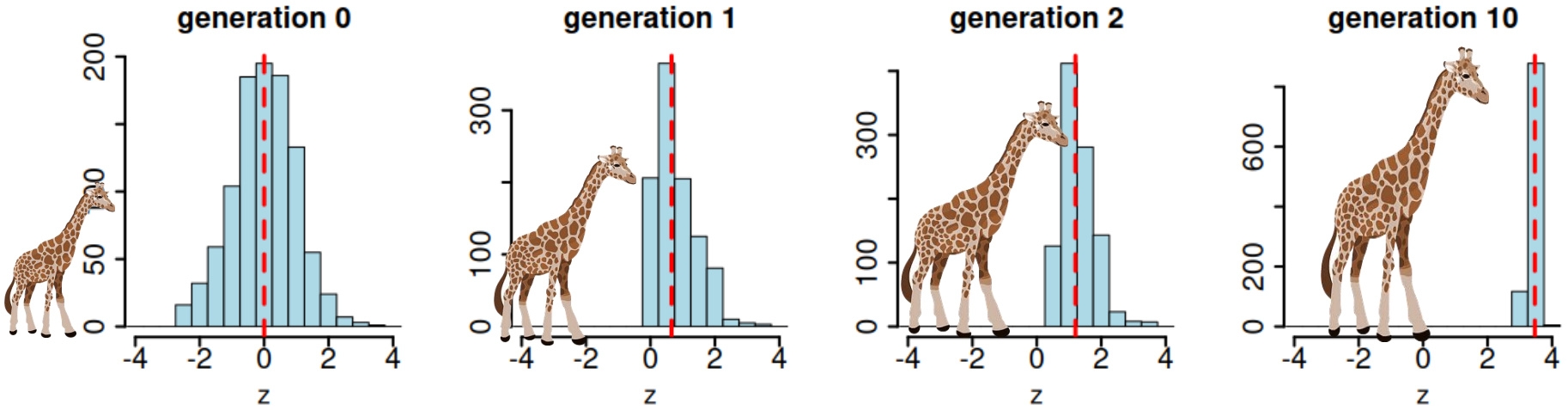
Low environmental variability

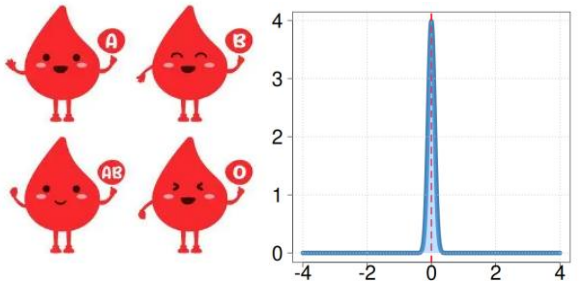
A more realistic inheritance model

Environmental variance slows down a bit (but does not impede) evolution!



High environmental variability (sd=0.9)





Low environmental variability (sd=0.1)

In future lectures we will see that..

$$R = h^2S$$

Breeder's equation (Lush,1937)

- **R**= the response to natural selection
- **h^2**= heritability (the proportion of "genetic variation" – variation that can be inherited
- **S**=Selection strength

The origin of species, 1859 (1st ed.)

Observations

- Husbandry and **artificial selection**
  - **Diverse** breeds are obtained from **common ancestors**

More people thinking of natural selection *before Darwin…*

(..and acknowledged by Darwin himself)

Patrick Matthew (Scottish agronomist)

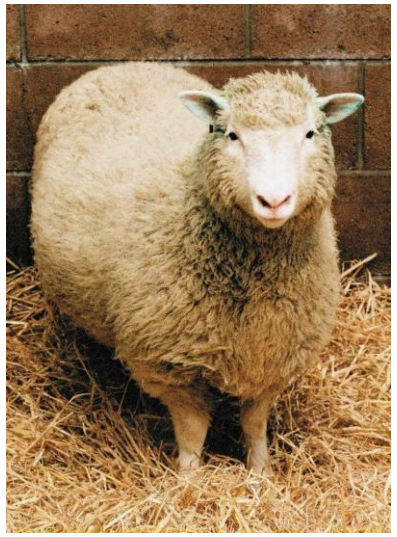
On Naval Timber and Arboriculture (1831)

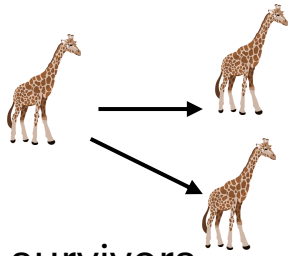
There is a law universal in nature, tending to render every reproductive being the best possibly suited to its condition that its kind [...]

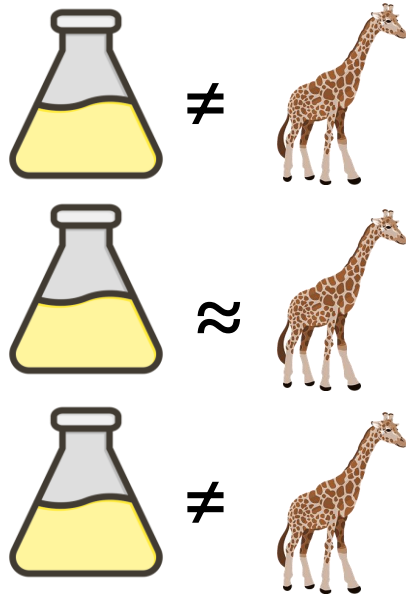
… those individuals who possess not the requisite strength, swiftness, hardihood, or cunning, fall prematurely without reproducing [...], their place being occupied by the more perfect of their own kind, who are pressing on the means of subsistence.

The law of entail, necessary to hereditary nobility, is an outrage on this law of nature which she will not pass unavenged ..

Finally, let's make our giraffe stop cloning and have….be diploid

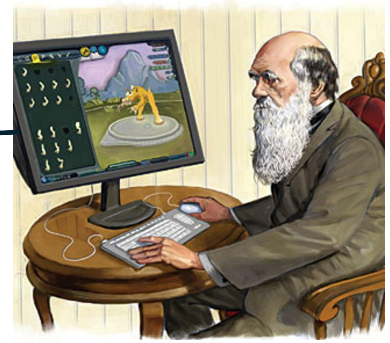




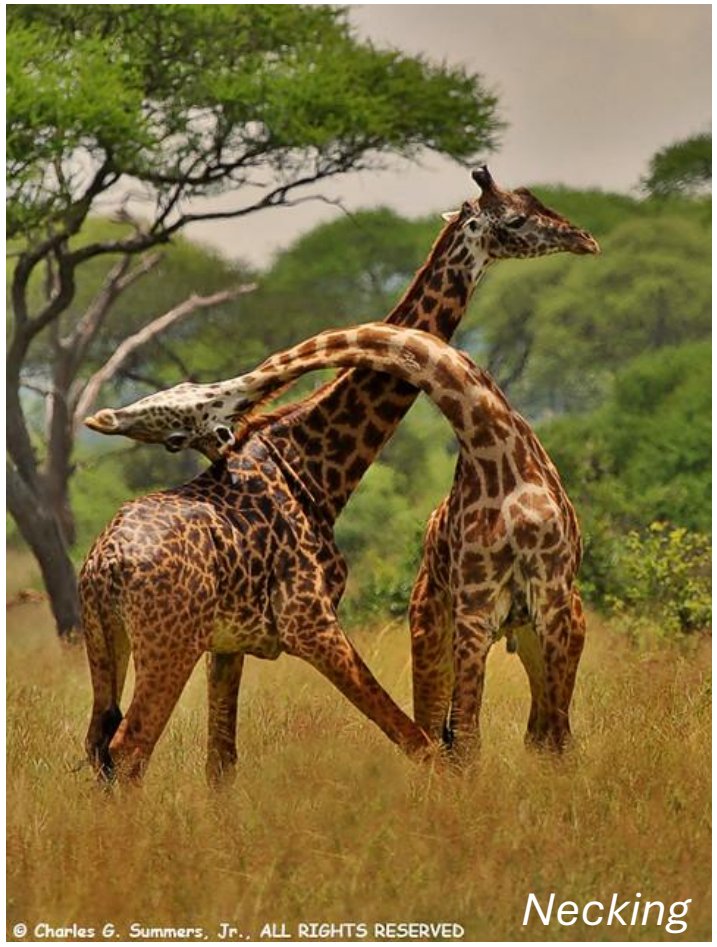


- **Randomness in reproduction**: not exactly two offsprings for one survivors – giraffes are not bacteria!
- There is **variation in the environment** – giraffes are not bacteria in a flask!
- **Diploidy** and sexual reproduction – giraffes are not bacteria!

Finally, let's make our giraffe stop cloning and have….be diploid



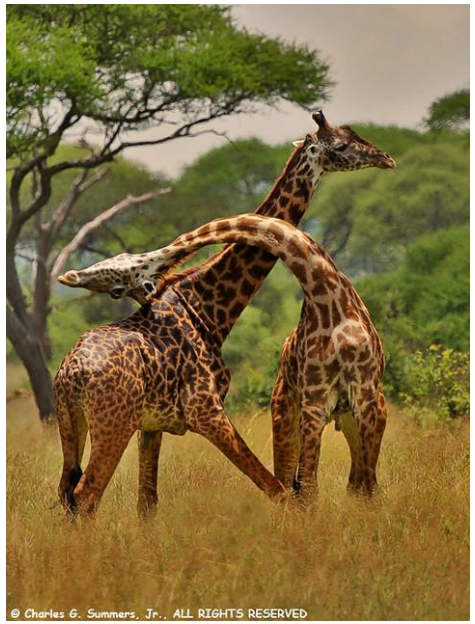
How would you model that?

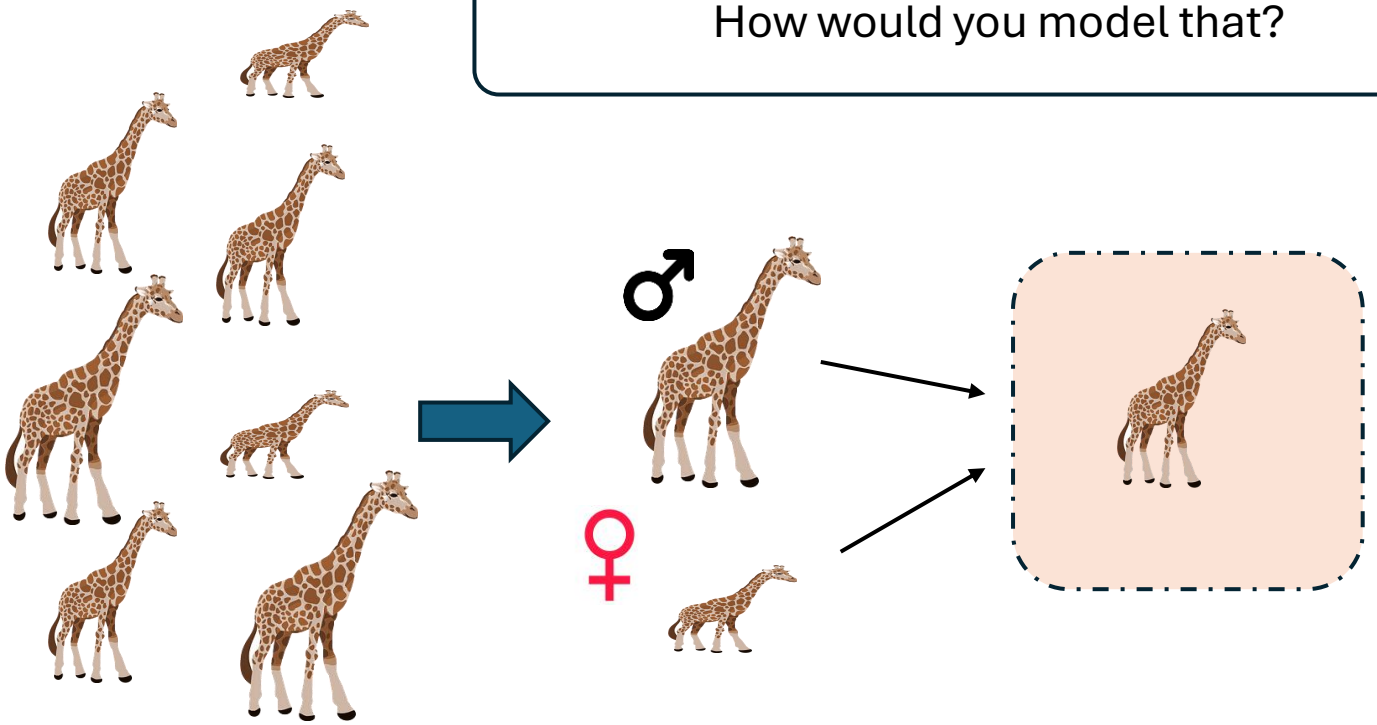


Necking

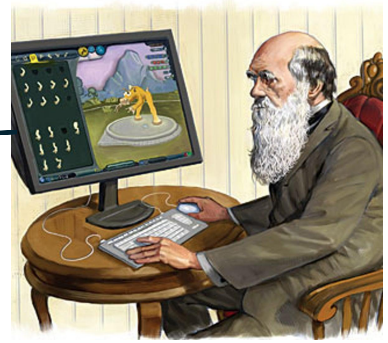
- **Diploidy** and sexual reproduction – giraffes are not bacteria!

Finally, let's make our giraffe stop cloning and have….be diploid



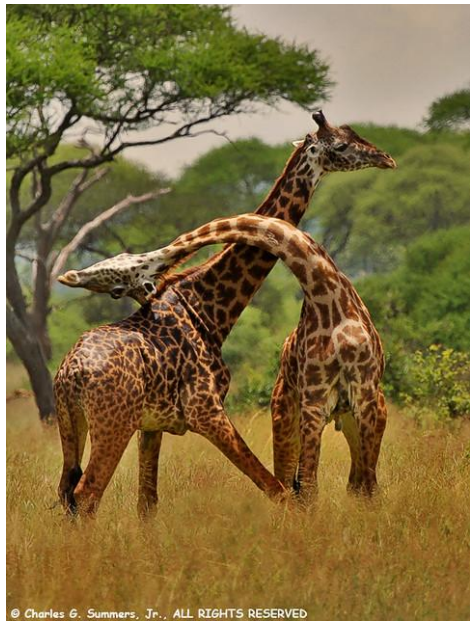


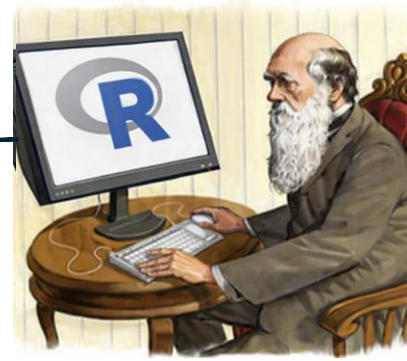
How would you model that?



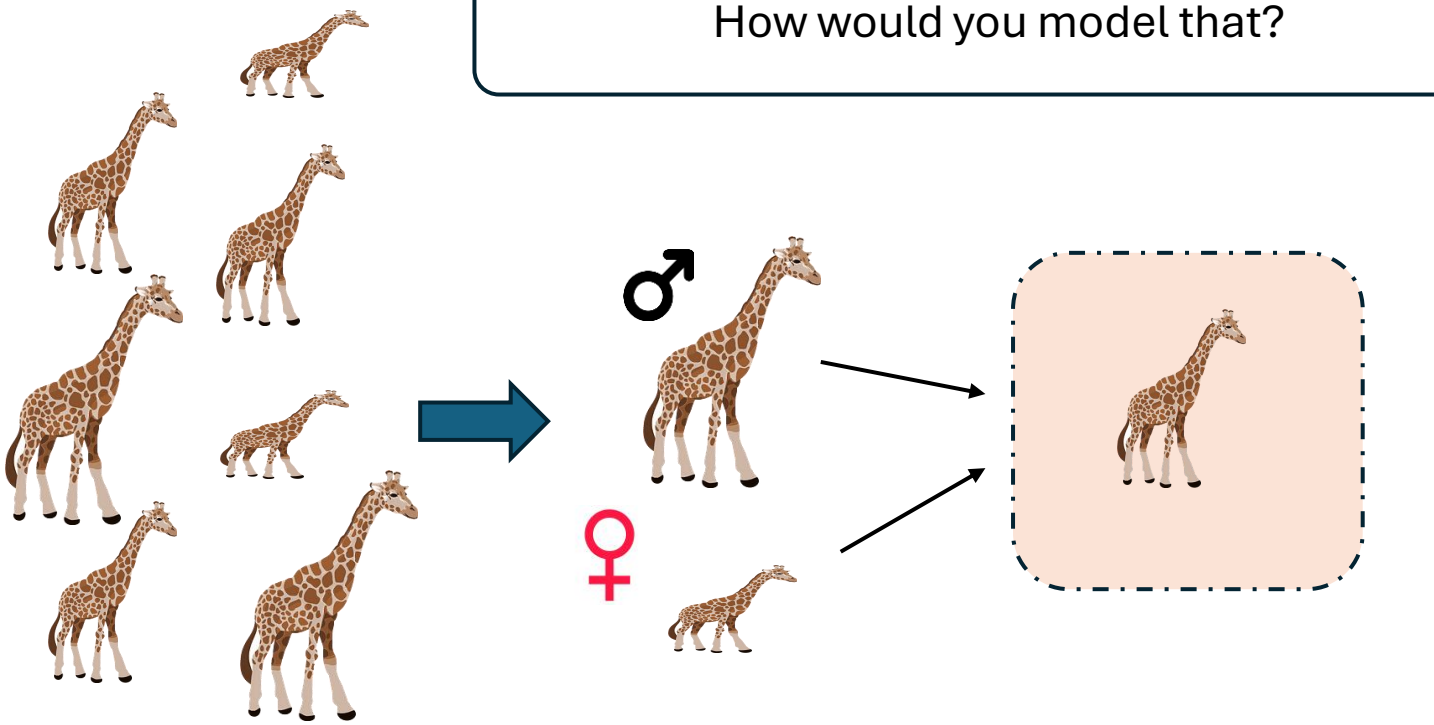
Offspring has neck that is average of mom and dad

Finally, let's make our giraffe stop cloning and have….be diploid





How would you model that?

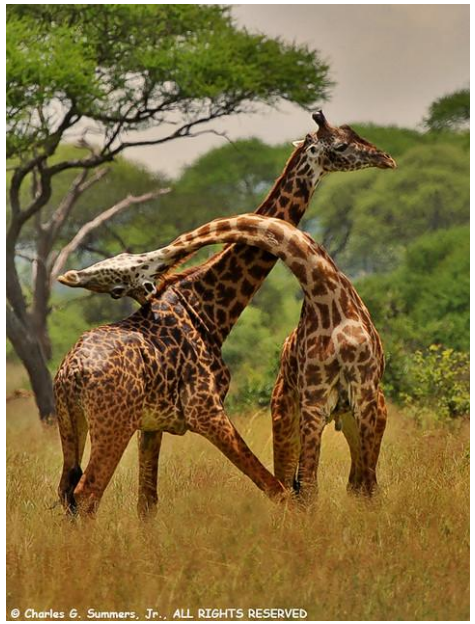


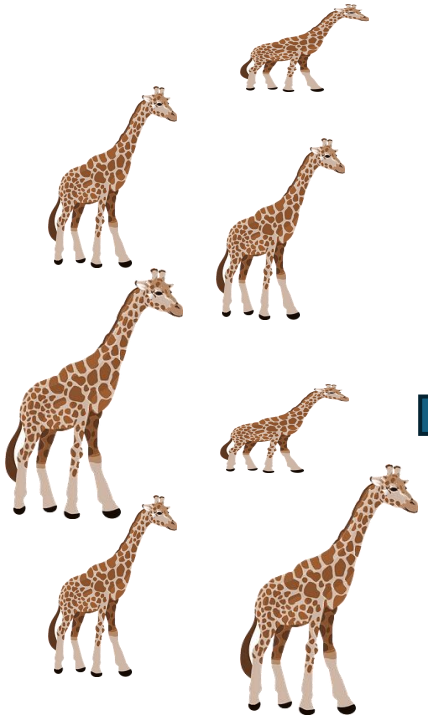
Offspring has neck that is average of mom and dad

```
fathers=survivors
mothers=sample(survivors)
```

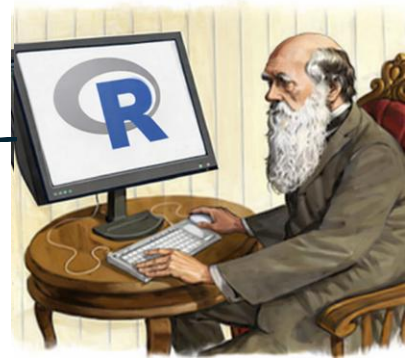
```
gametes=(fathers+mothers)/2
```

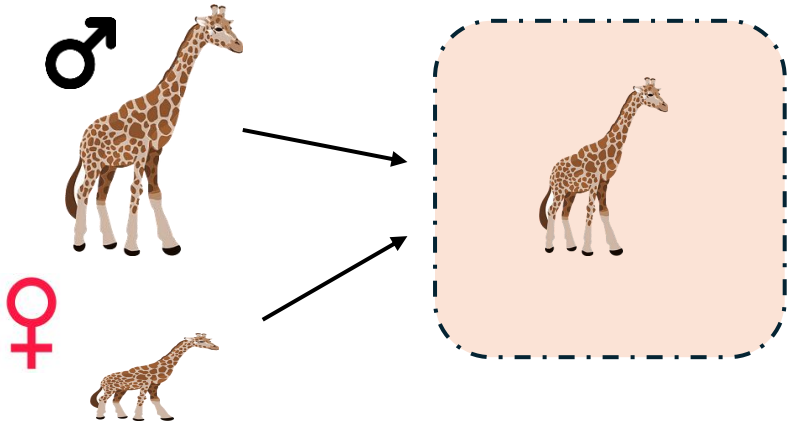
Finally, let's make our giraffe stop cloning and have….be diploid





How would you model that?



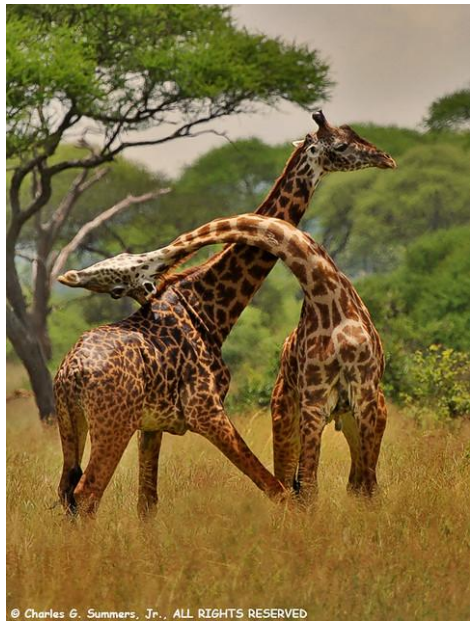


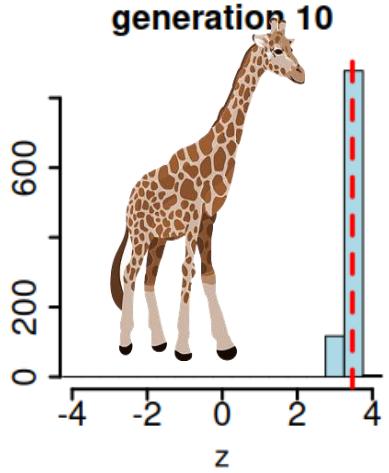
Offspring has neck that is average of mom and dad

```
N=100; i=0
z=rnorm(N); gametes=z
for (i in 1:10){
survivors=sort(gametes)[((N/2)+1):N]
survivors=c(survivors,survivors)
fathers=survivors
mothers=sample(survivors)
gametes=(fathers+mothers)/2
z=gametes + rnorm(N,sd=0.1)}
```

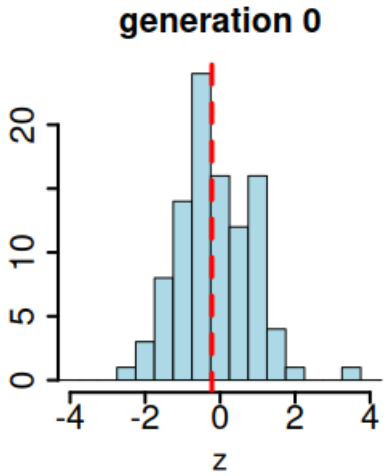
```
gametes=(fathers+mothers)/2
```

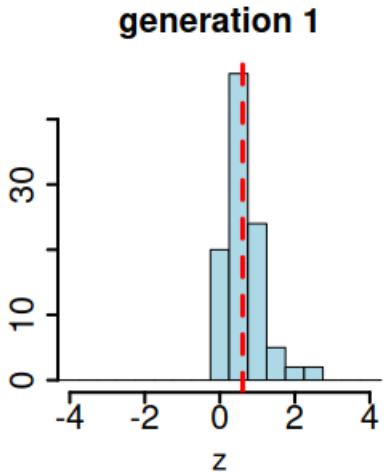
Evolution still happens, but apparently less than in haploids

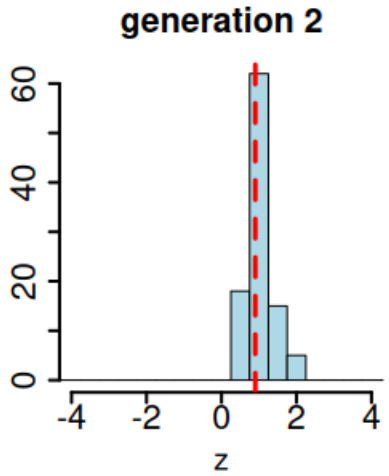


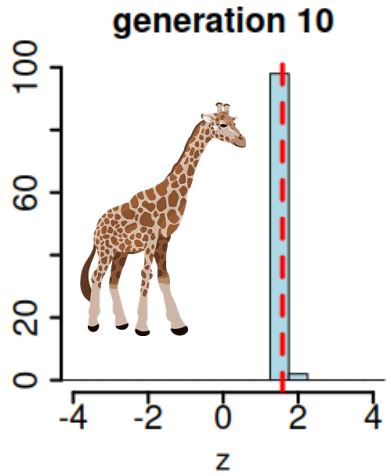


Haploid model

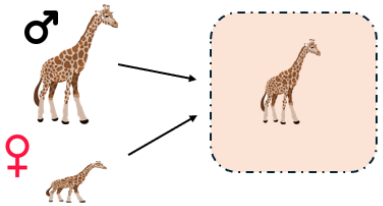




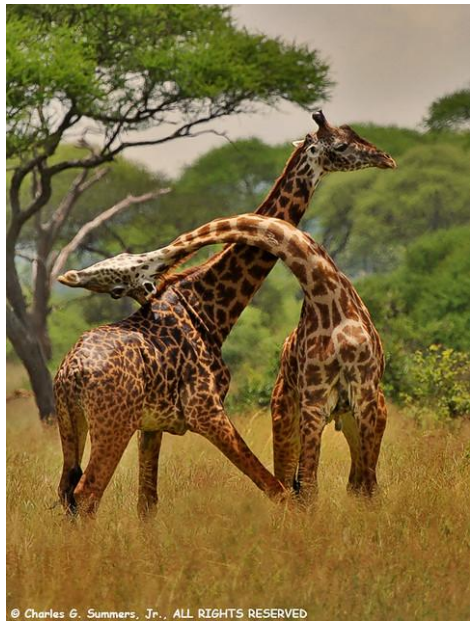




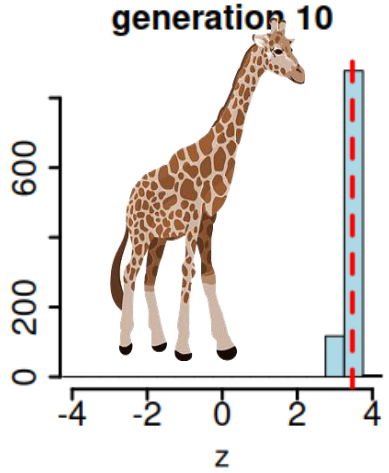
Diploid model.
Offspring average neck length



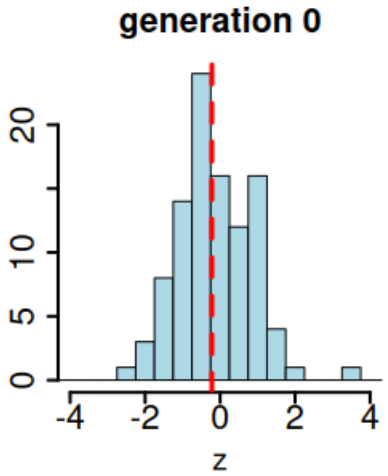
Evolution still happens, but apparently less than in haploids

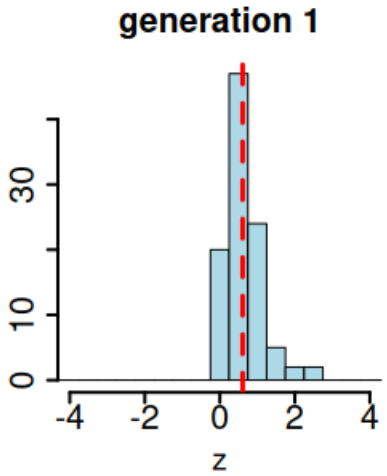


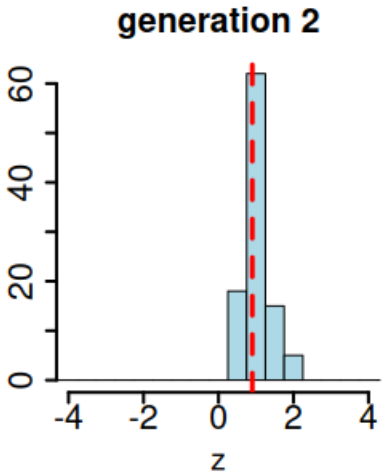
Why? Is this correct?

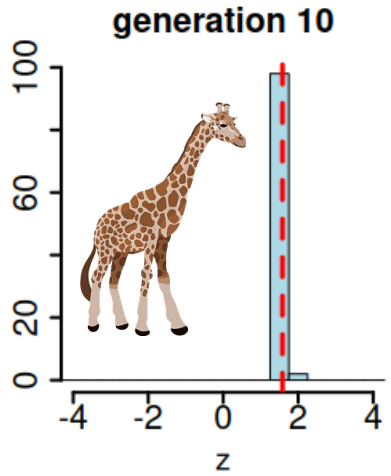


Haploid model

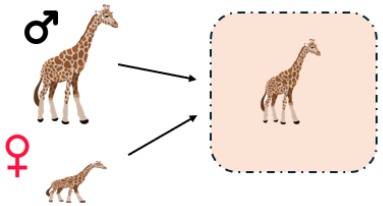




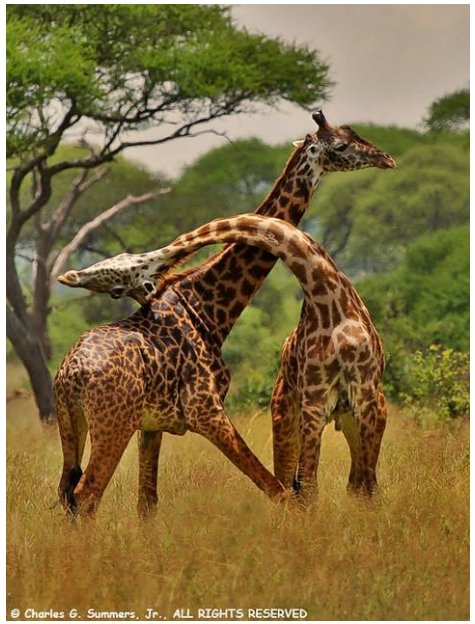


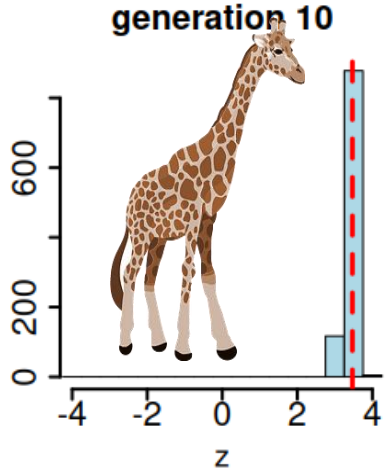


Diploid model.
Offspring average neck length

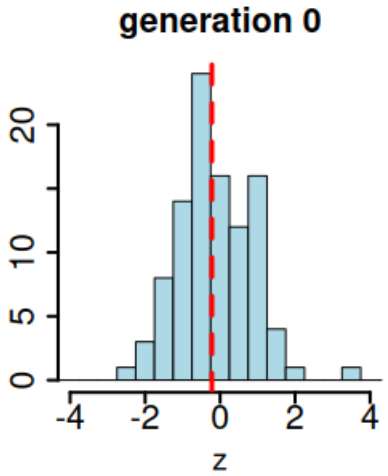


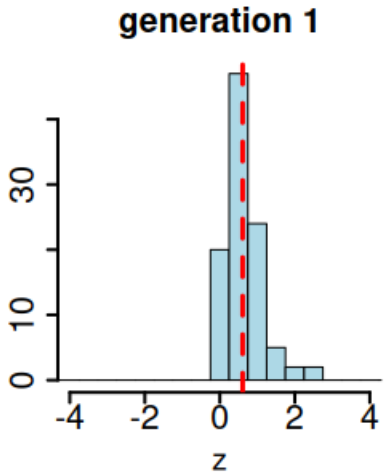
The «blending inheritance» problem

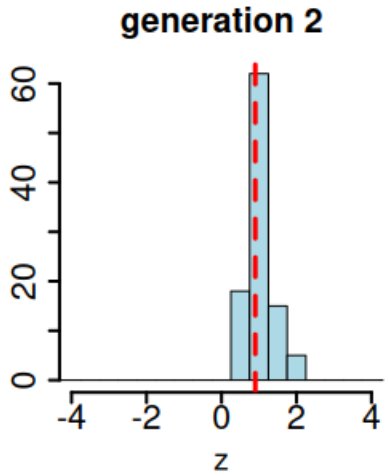


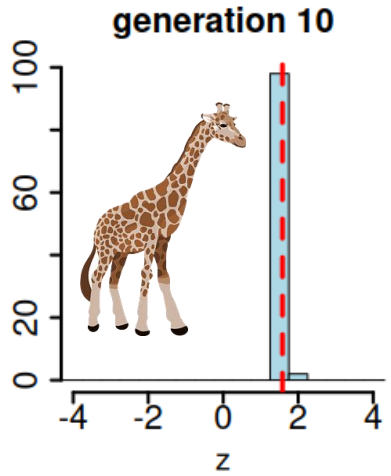


Haploid model

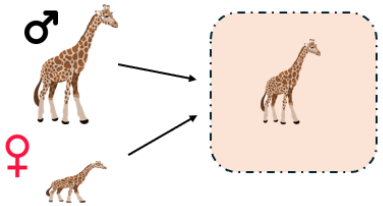




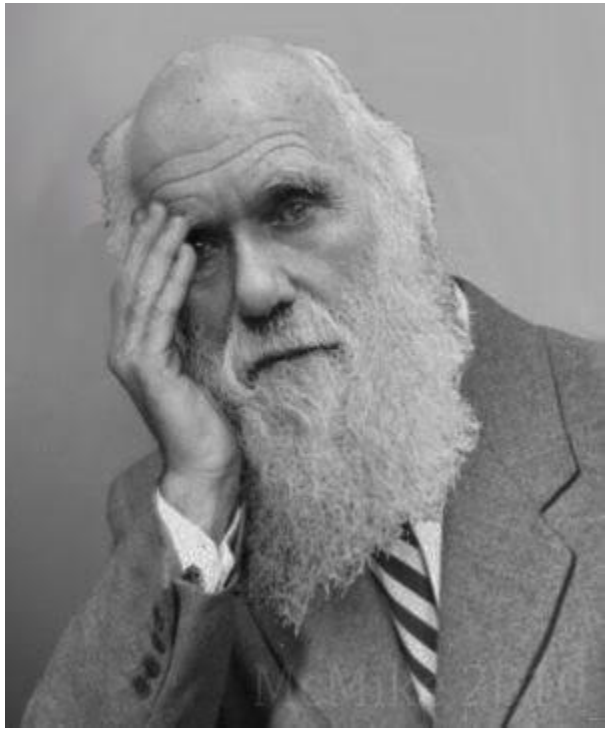


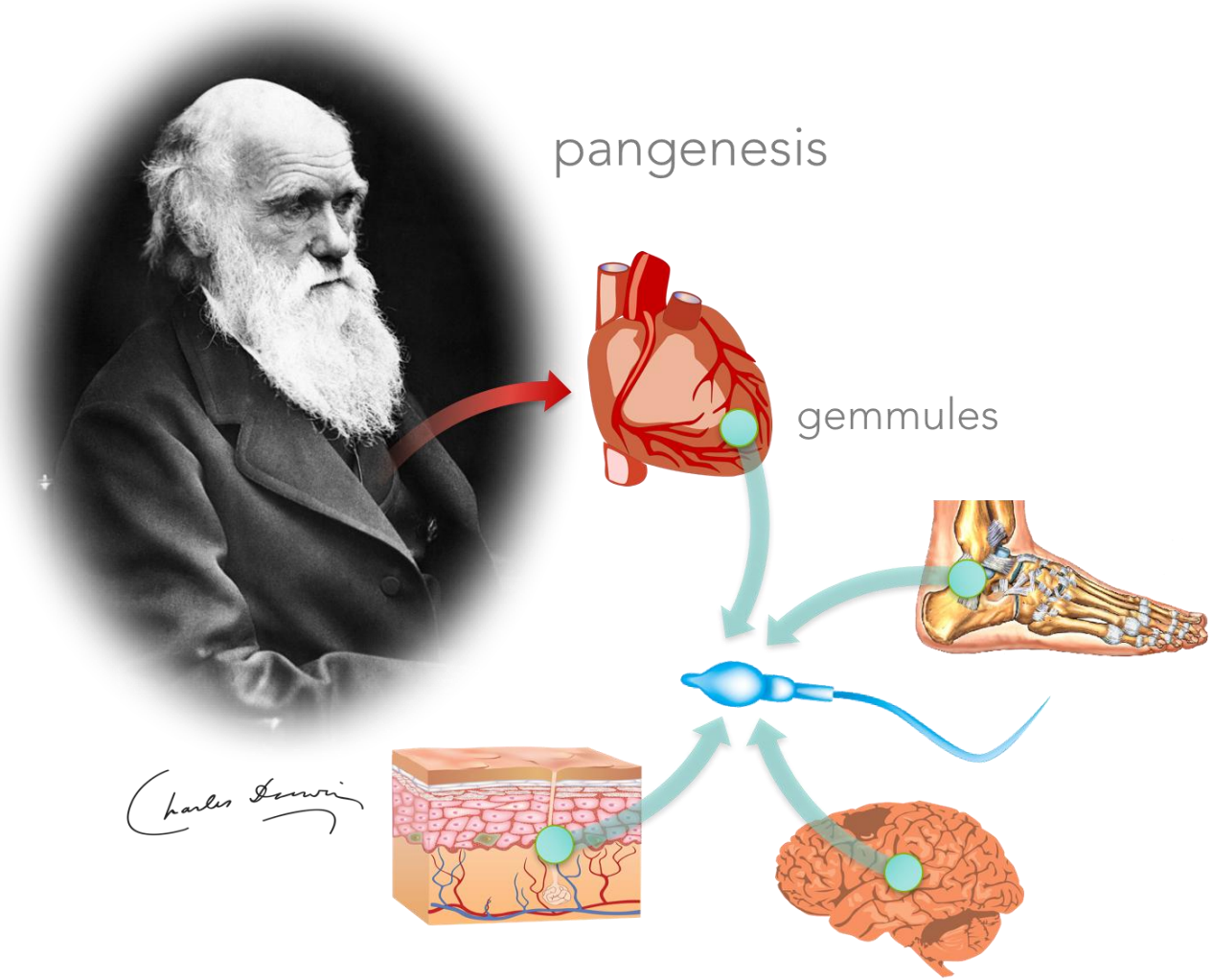


Diploid model.
Offspring average neck length



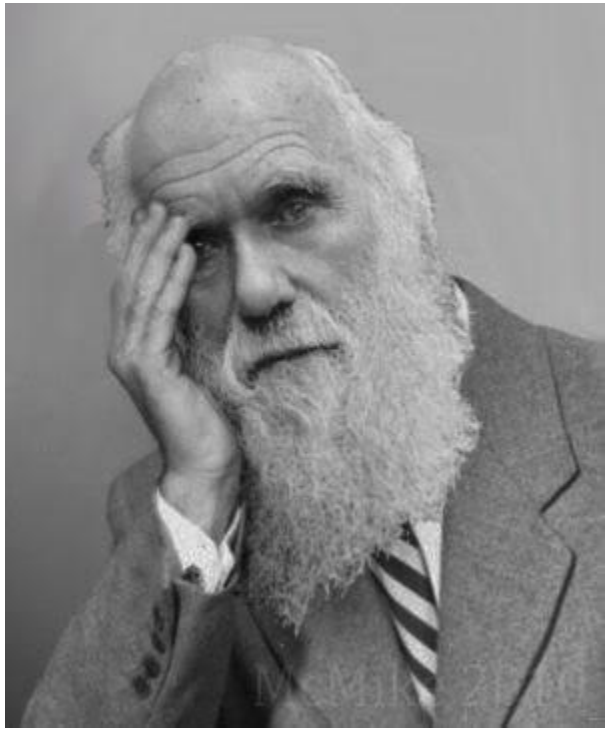
What did Darwin think about inheritance?

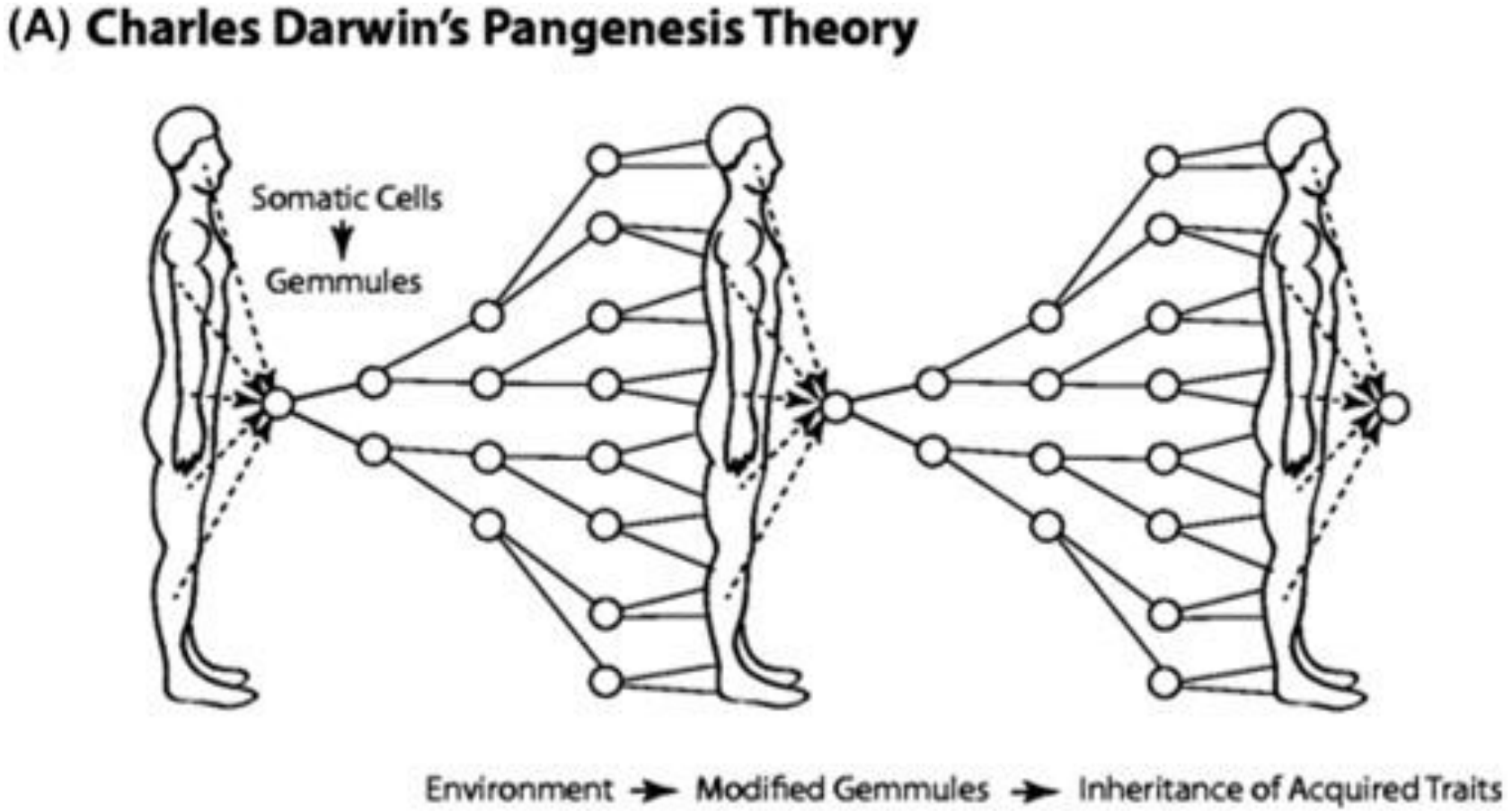




Darwin believed in ***pangenesis***!

What did Darwin think about inheritance?





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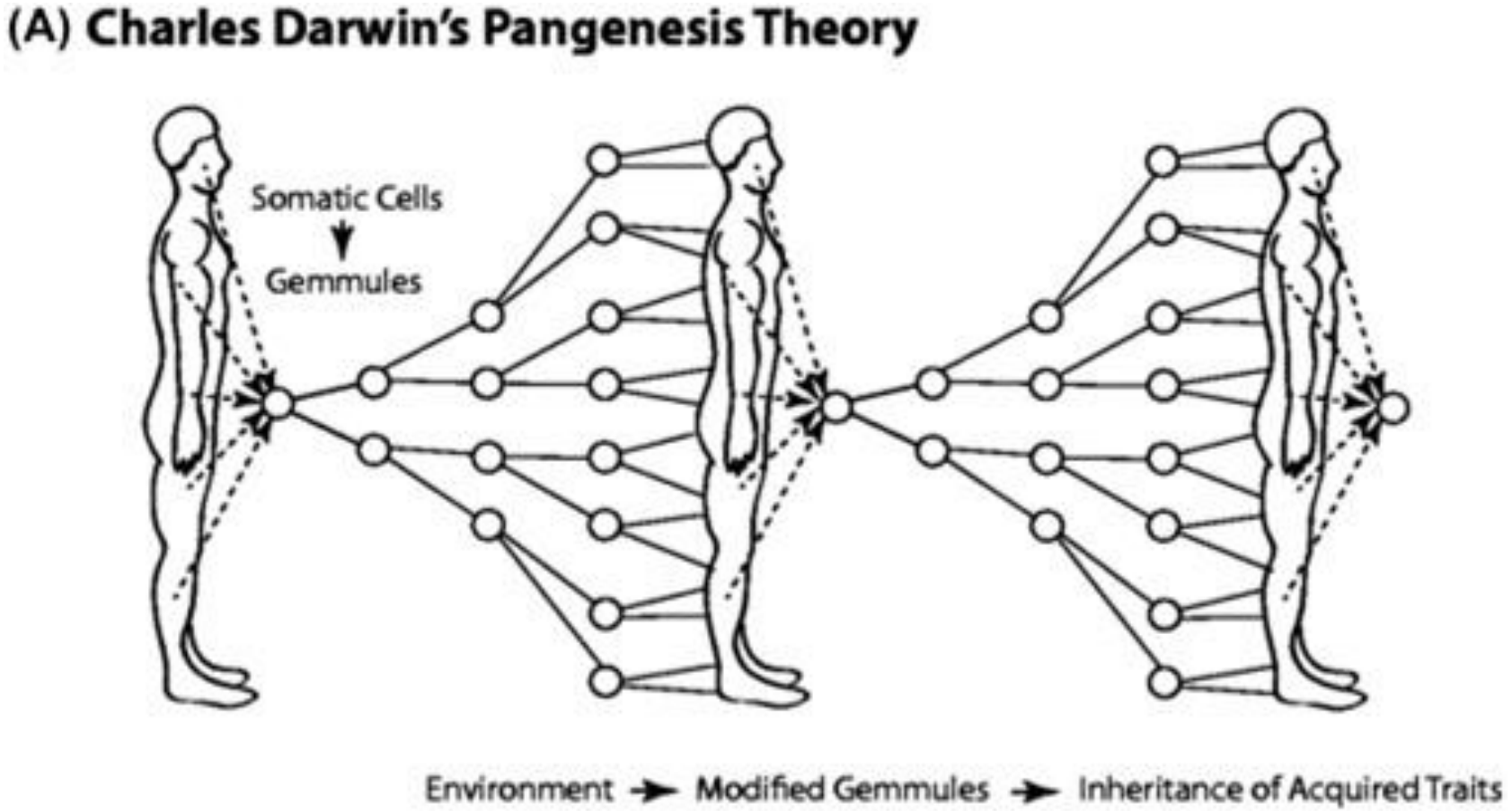
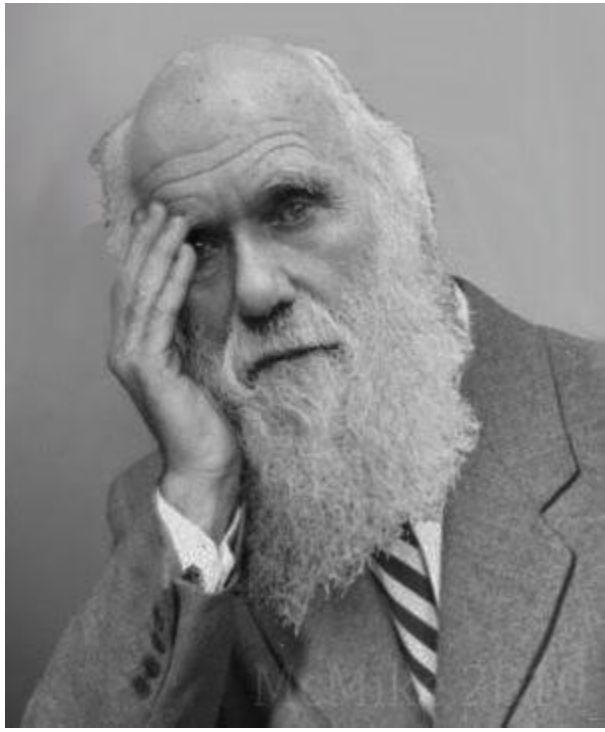
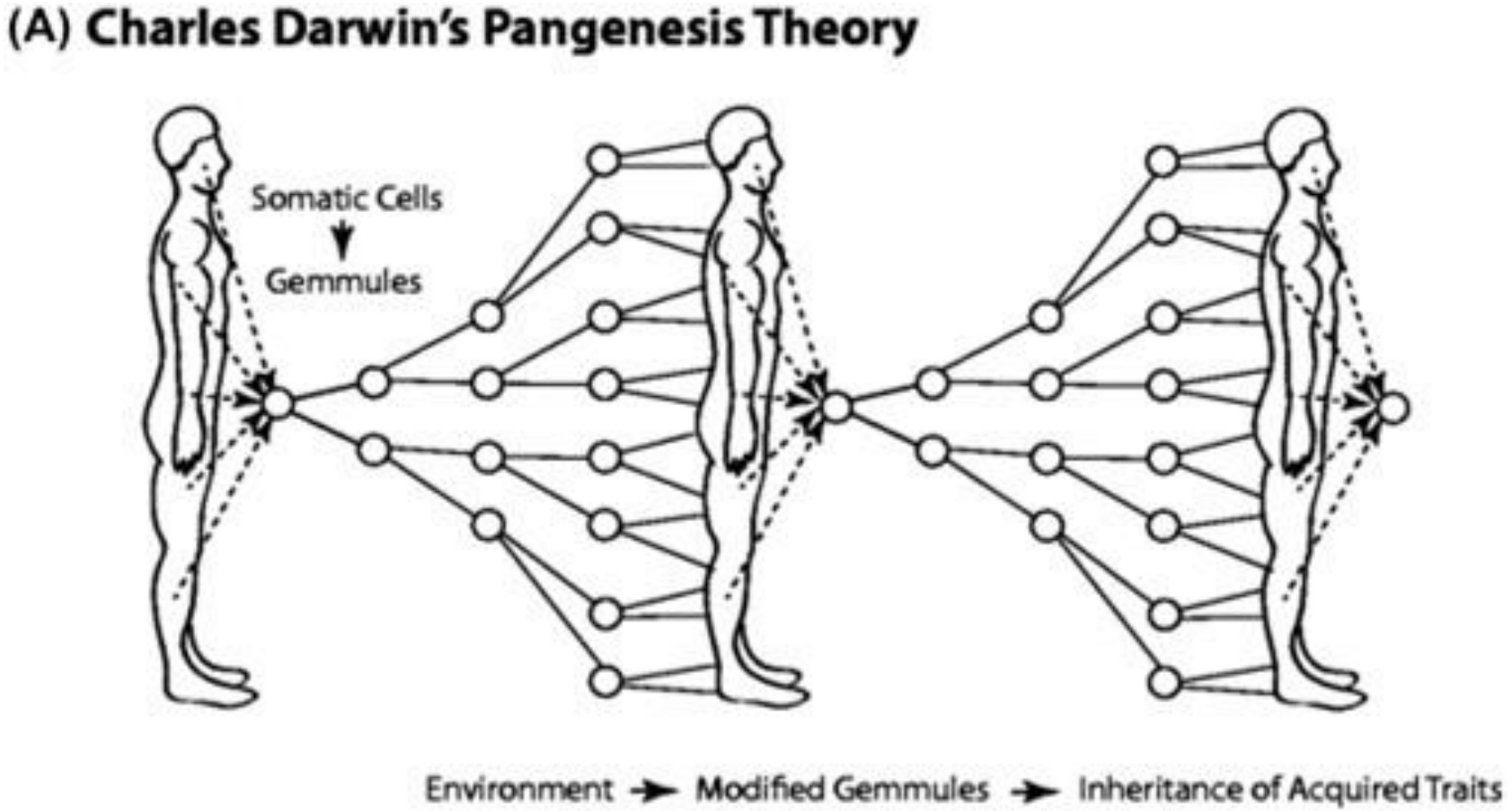
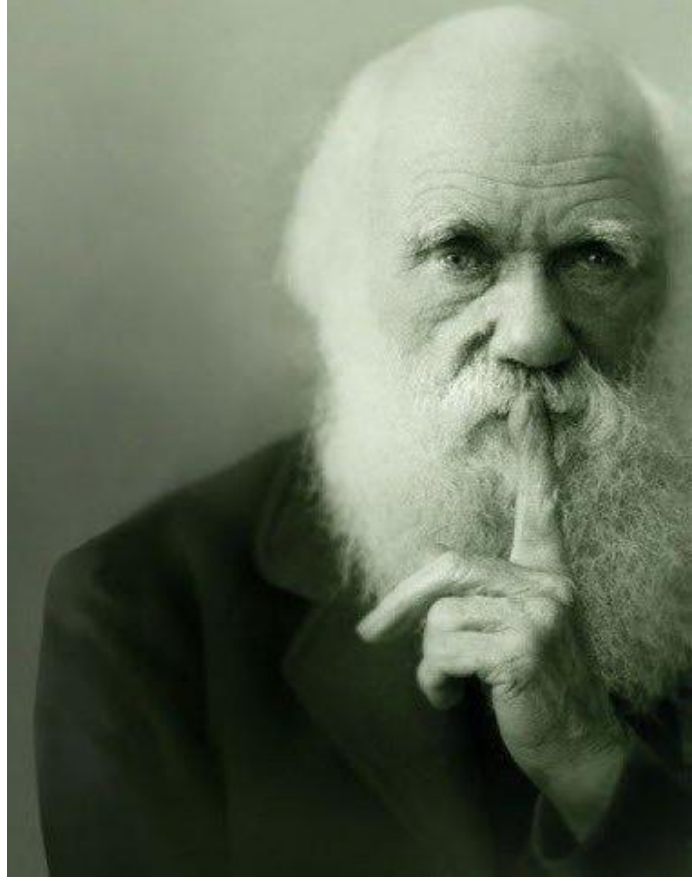




With pangenesis even Lamarckism would be plausible!

What did Darwin think about inheritance?

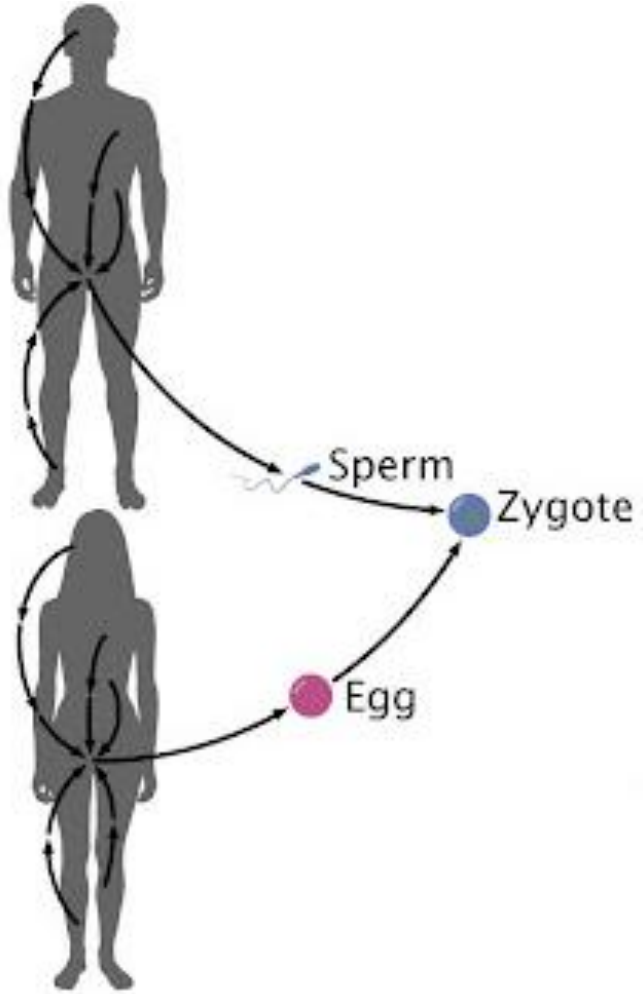


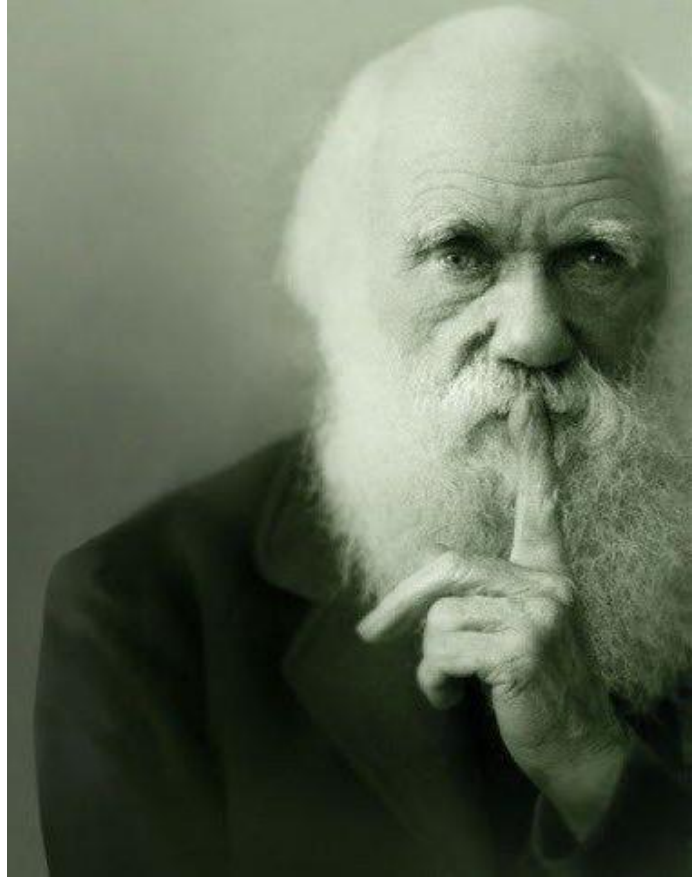


Do you see other problems?

If so, which one?

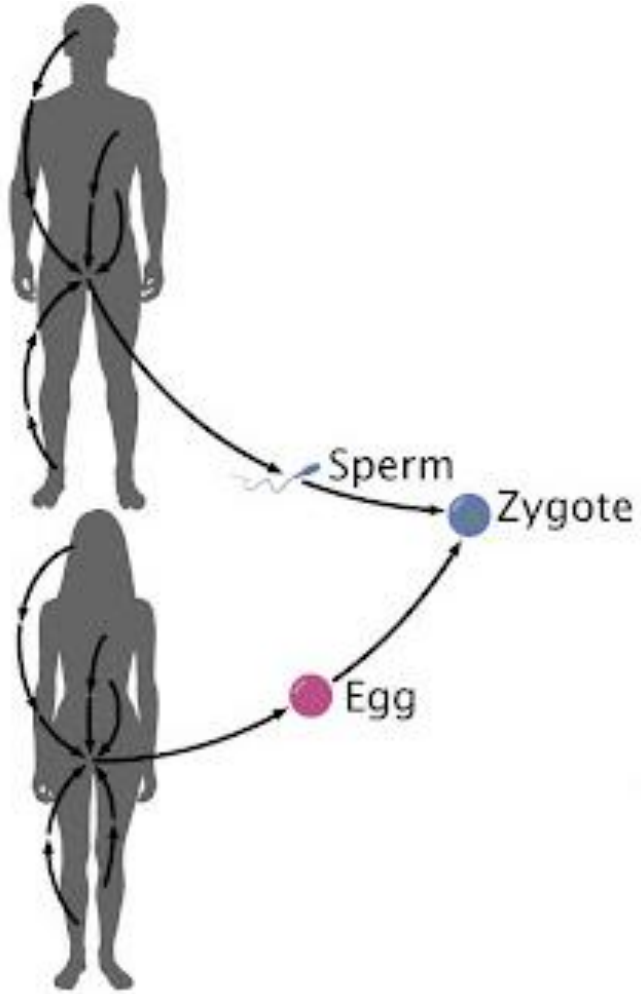
Another (even bigger!) problem

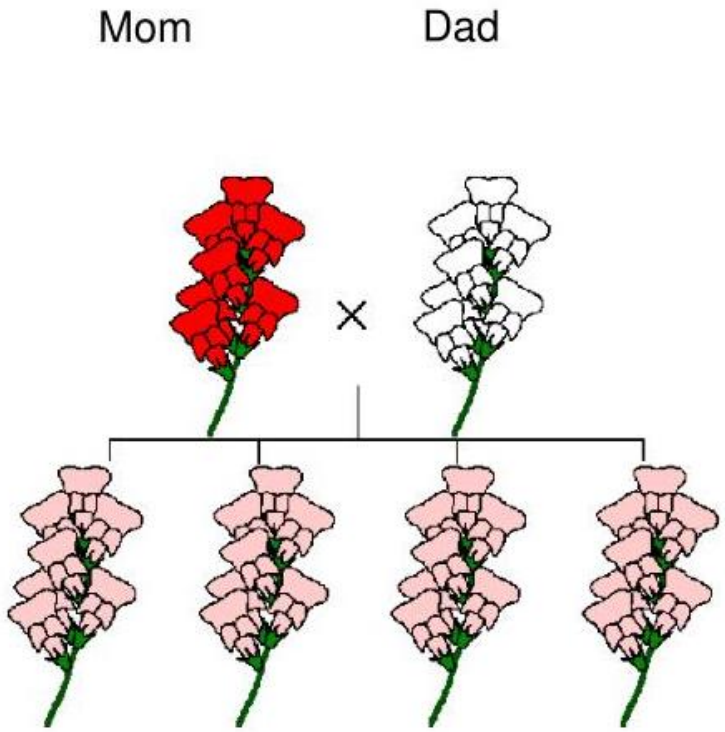


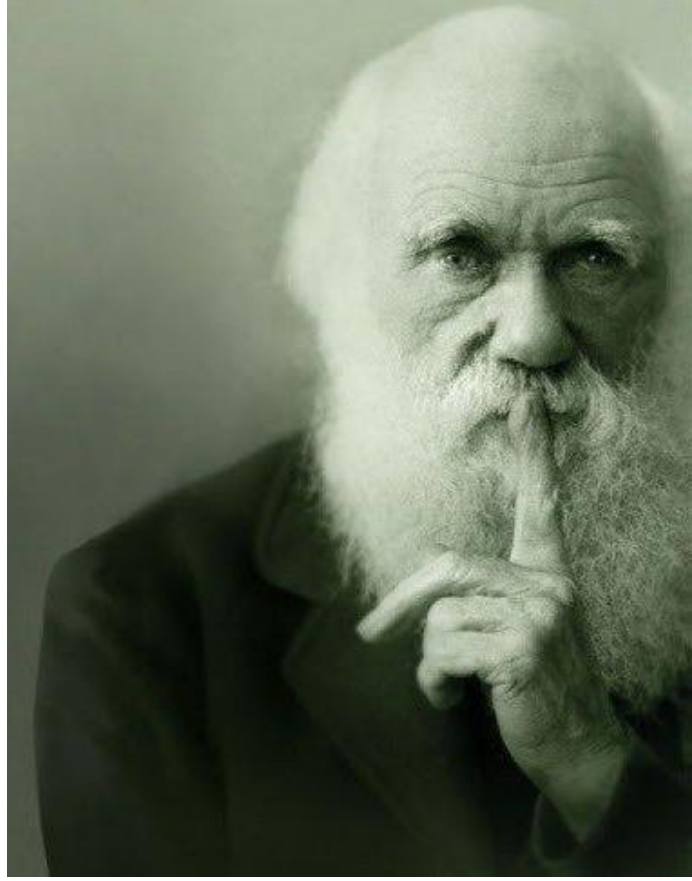


What does this imply?

Another (even bigger!) problem



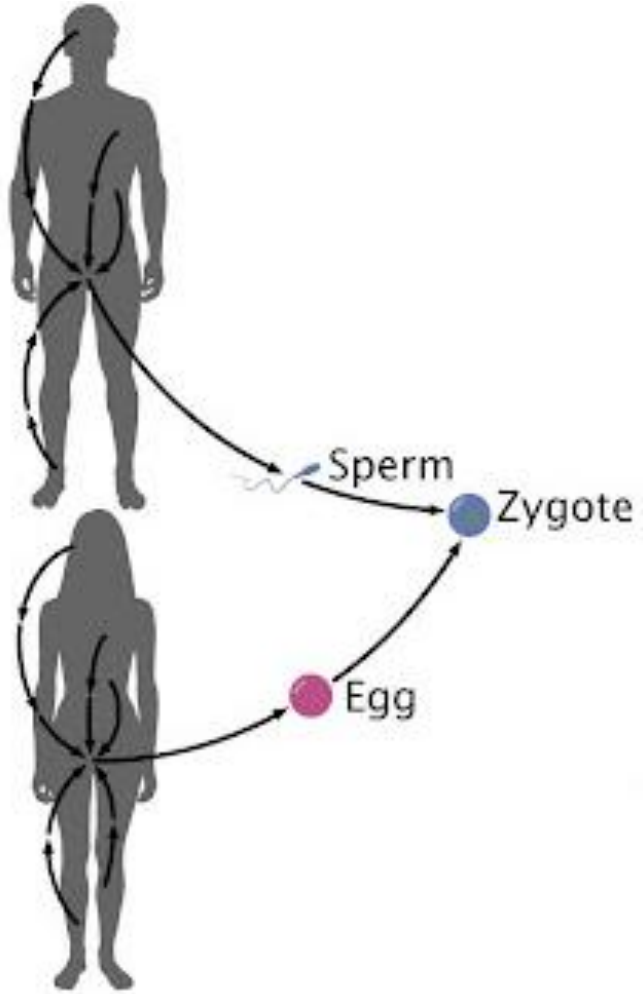


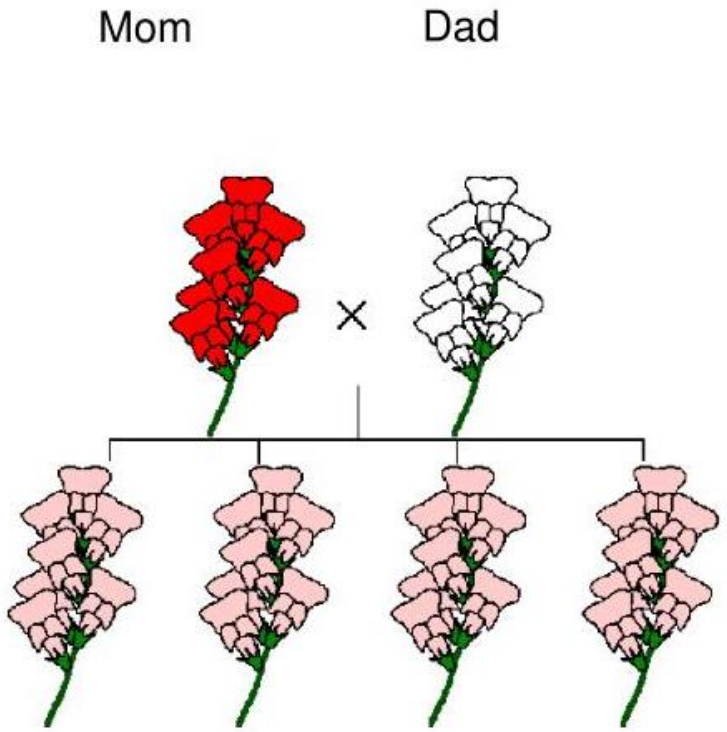


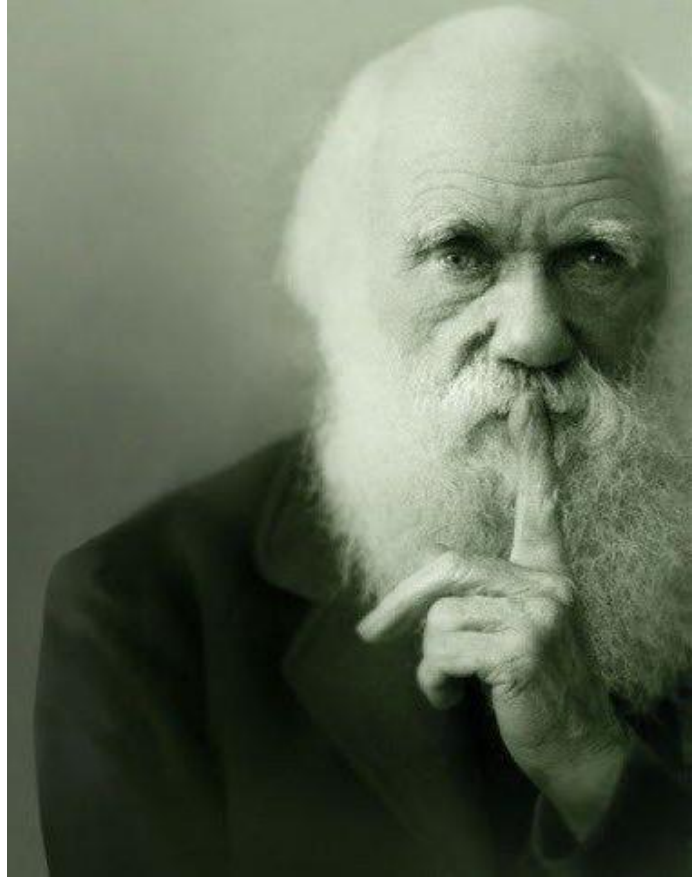
What does this imply?

Blending of inheritance!

What is the problem with «blending of inheritance»?



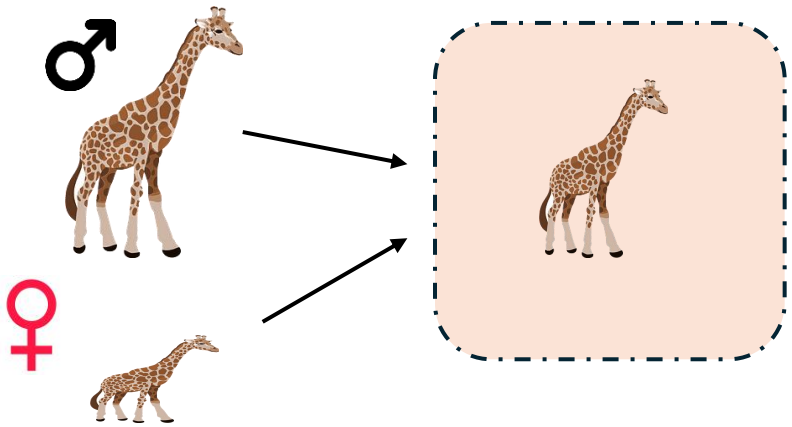




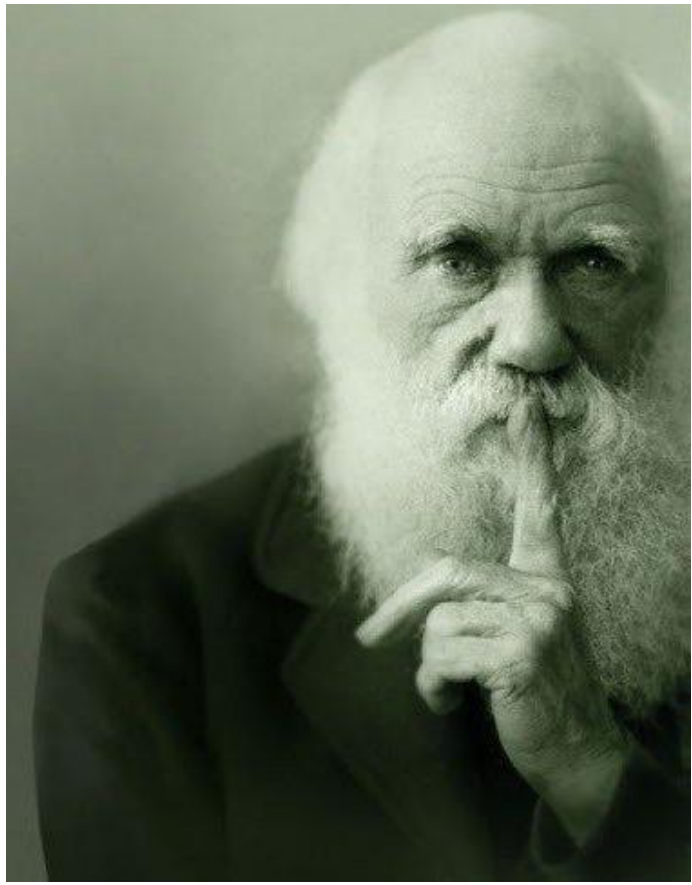
What does this imply?

Blending of inheritance!

Let’s use our toy mode (using Darwin’s inheritance)l!



Offspring has neck that is average of mom and dad



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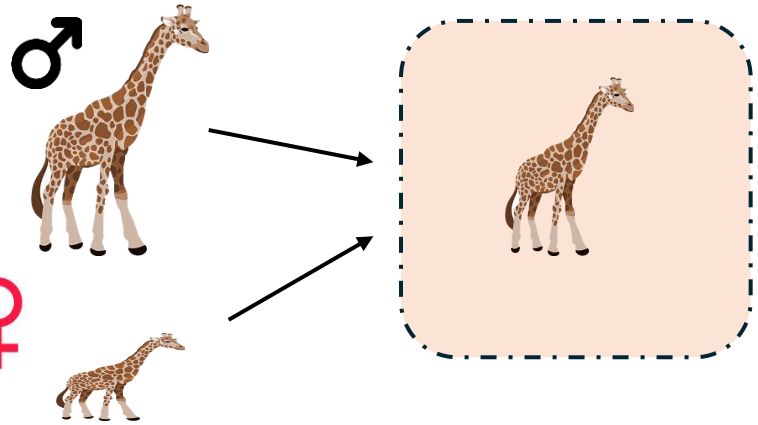

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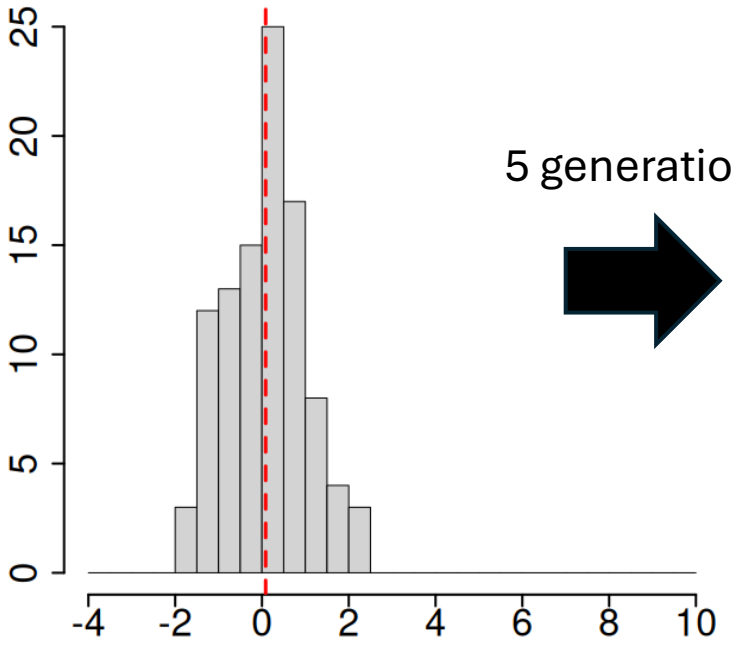
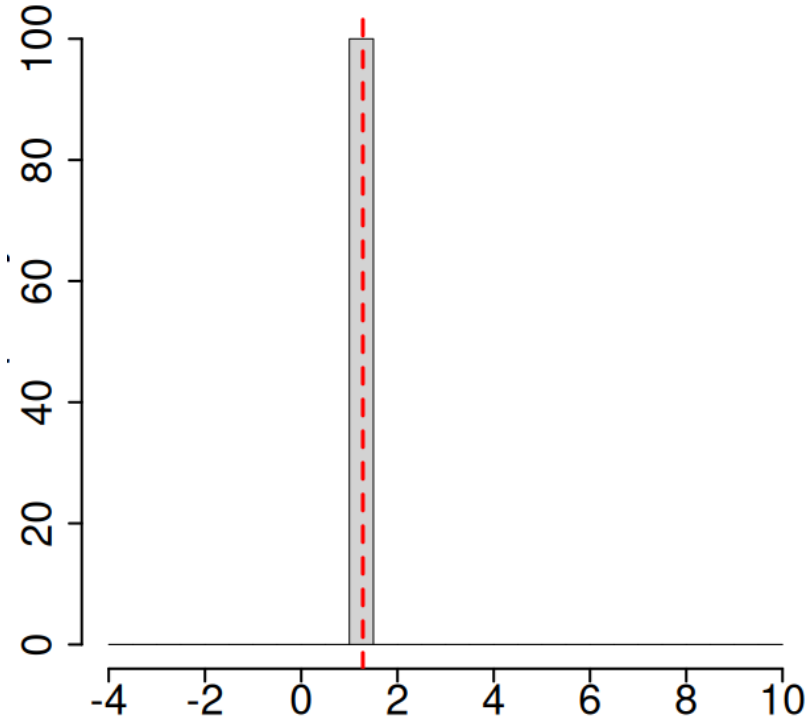
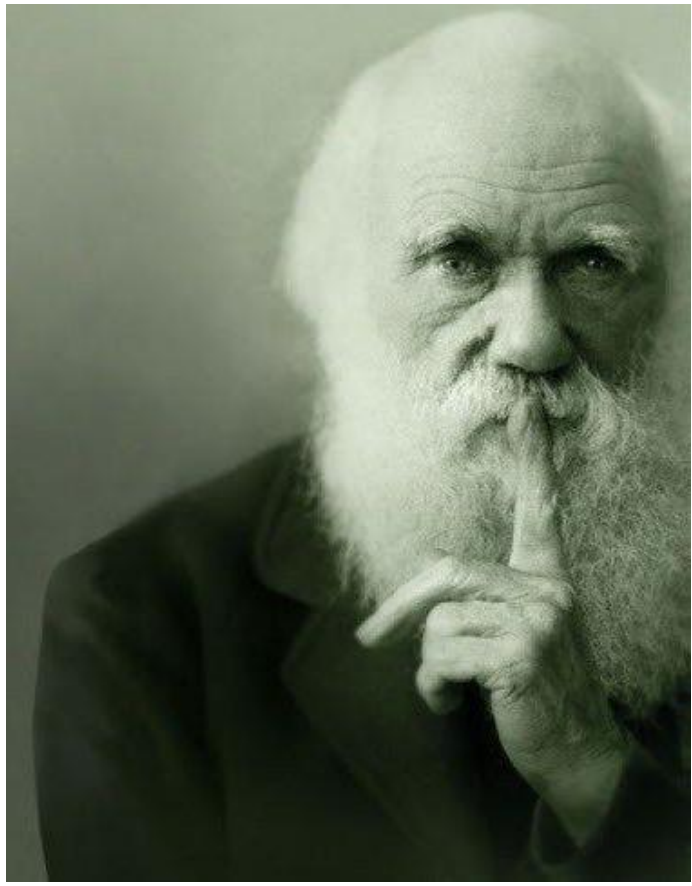


5 generations

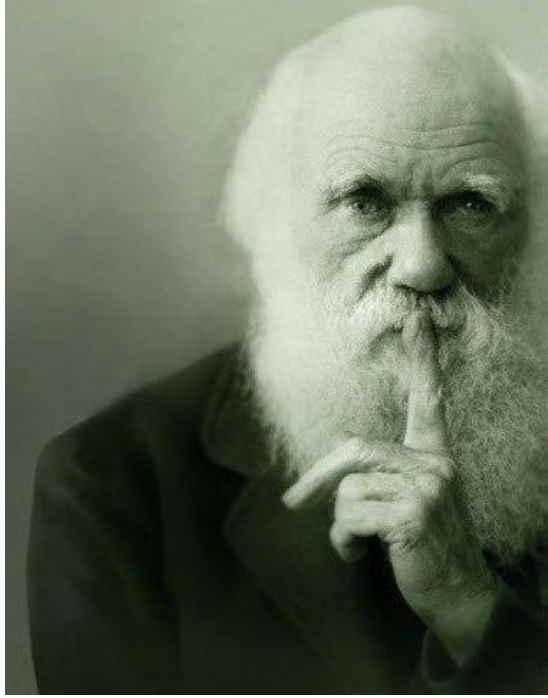


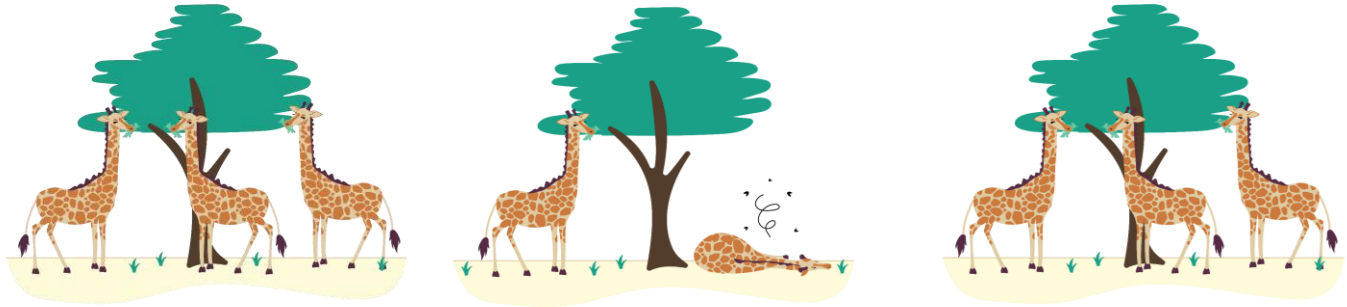


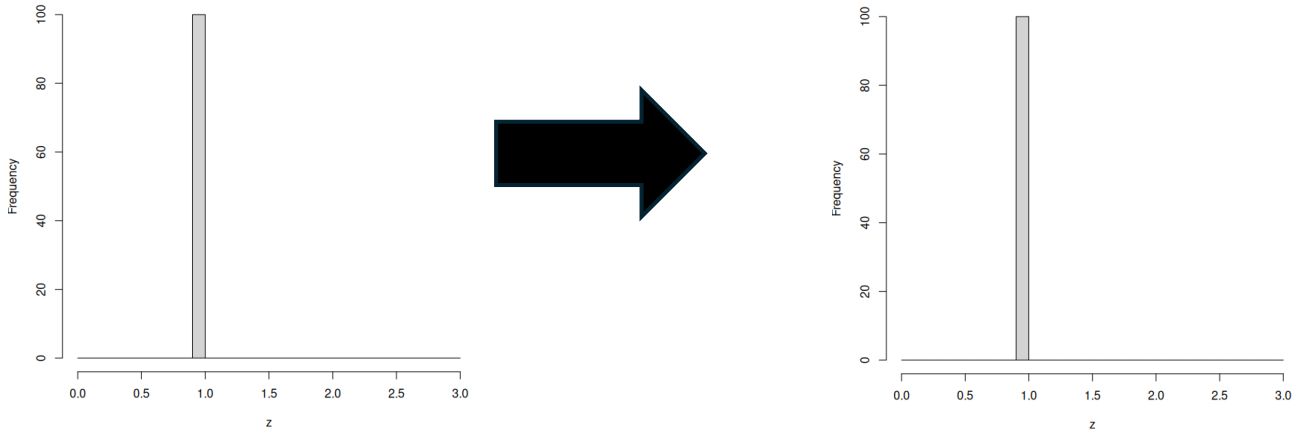
What do you notice?

No variability → No evolution!

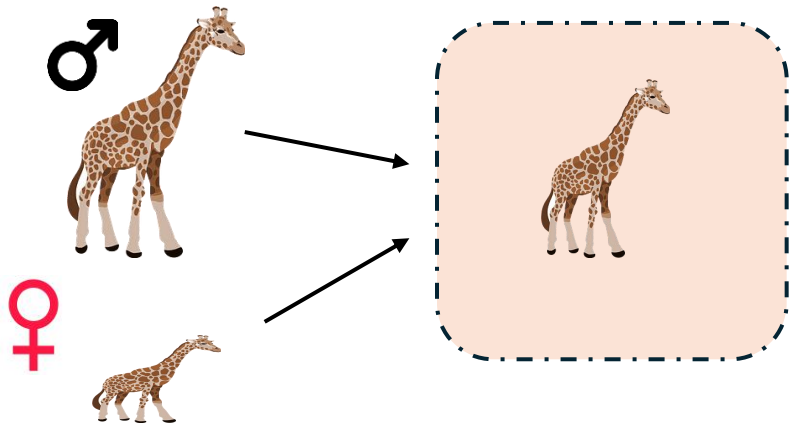
~~Variability among individuals~~
Differential contribution to successive generations
Mechanism of inheritance



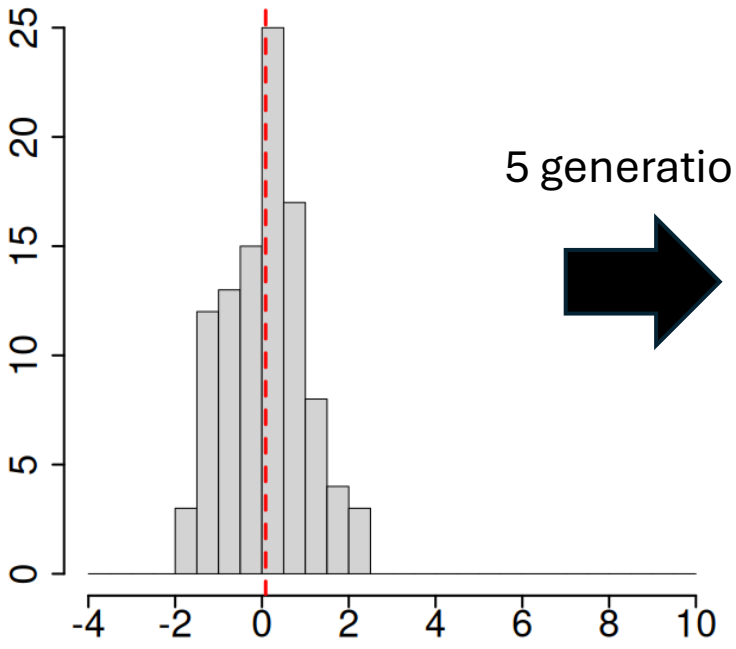




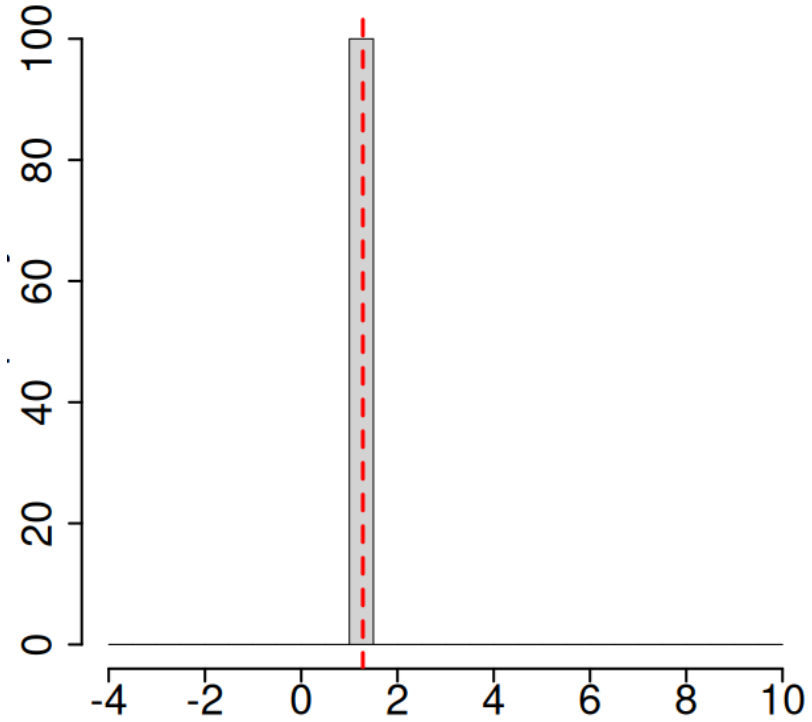
If inheritance «blends», all variability disappears very quickly in a population !

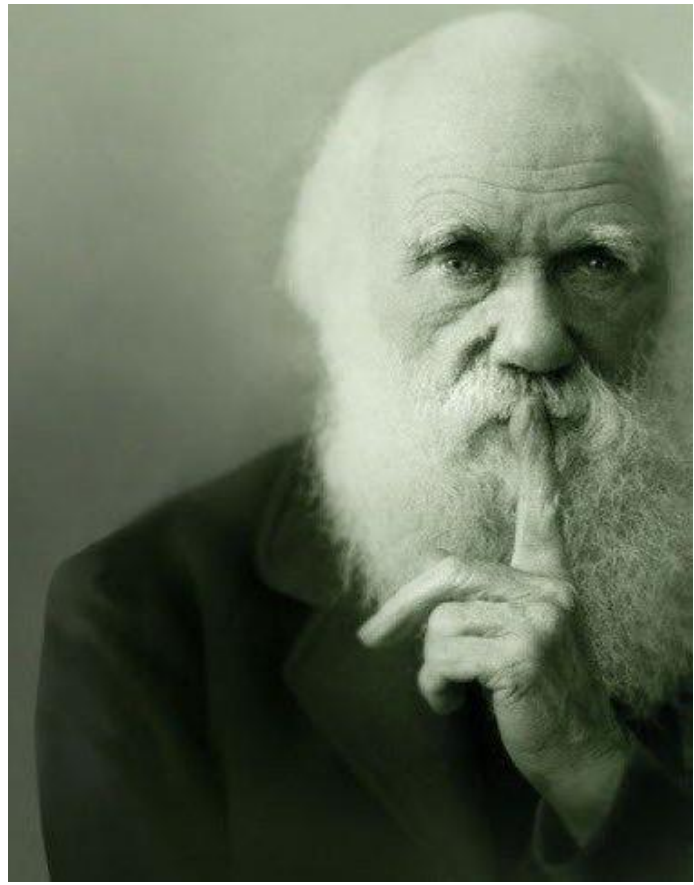


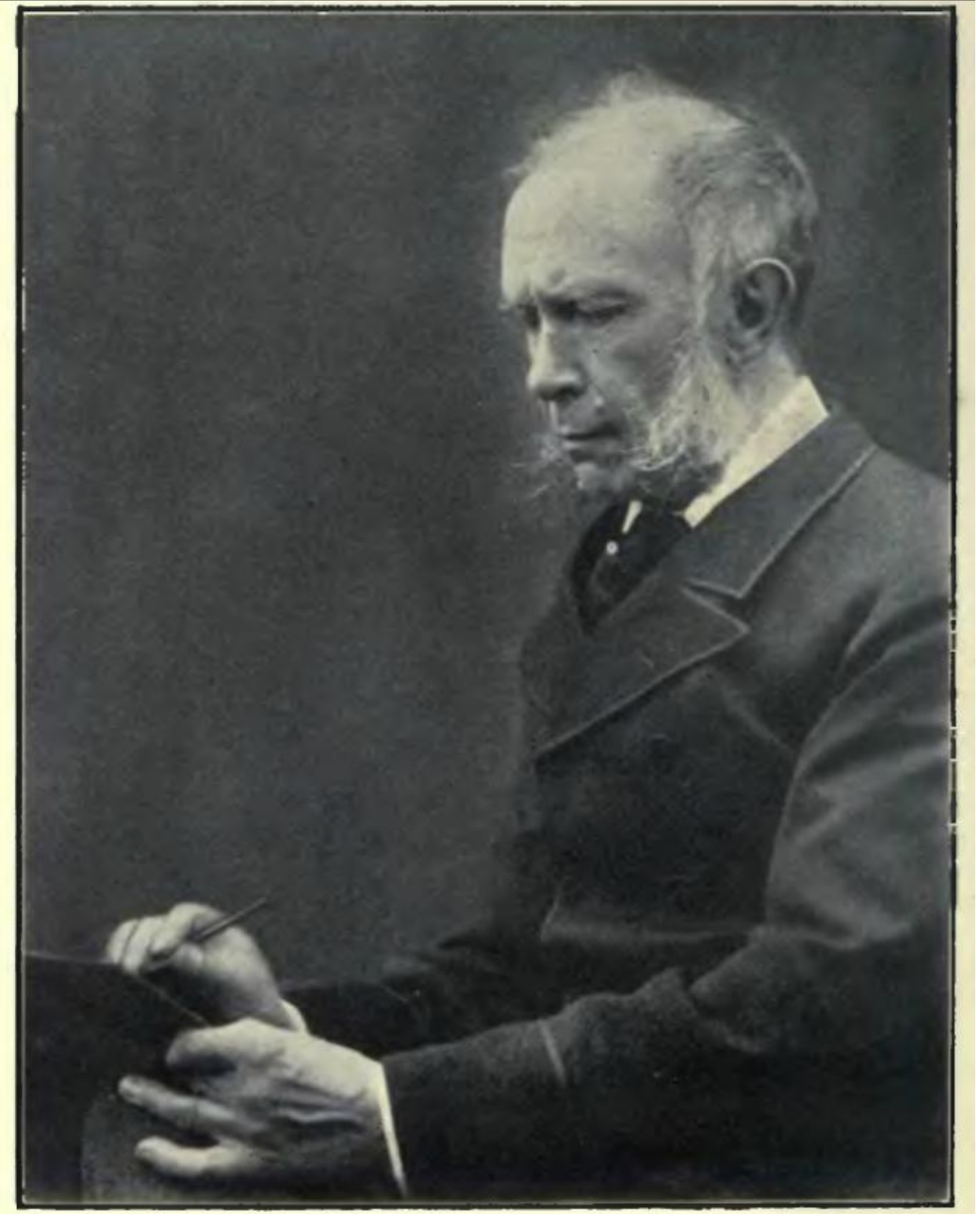
Offspring has neck that is average of mom and dad



5 generations







FLEEMING JENKIN, F.R.S., LL.D.

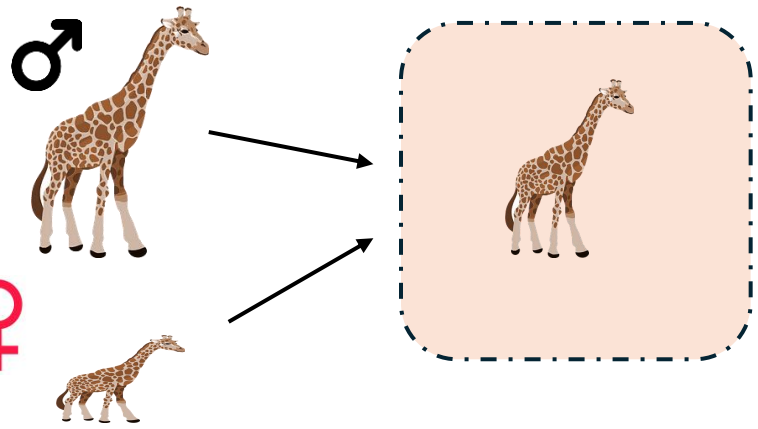
From a photograph kindly lent by Mrs. Dew Smith.

“Swaming Argument” of Fleeming Jenkin, 1867

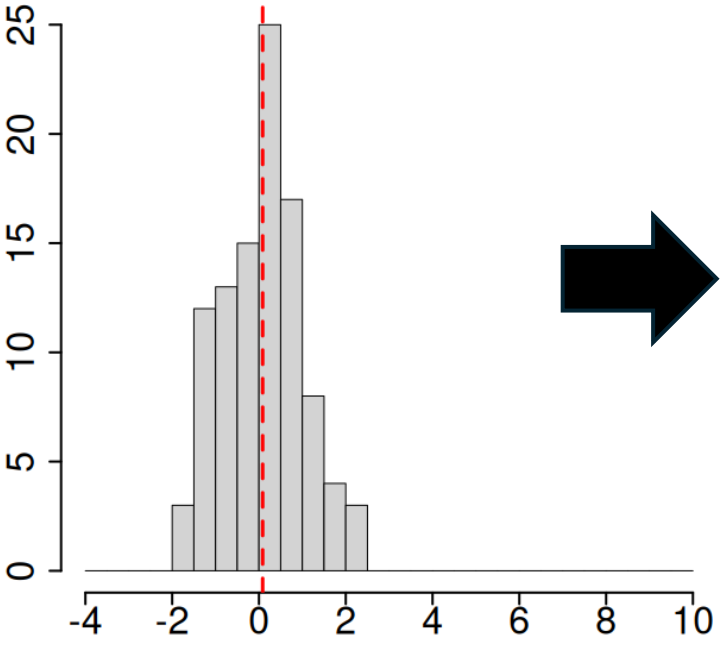
“Darwin's theory of the origin of species is not only without sufficient support from evidence, but is proved false by a cumulative proof.”

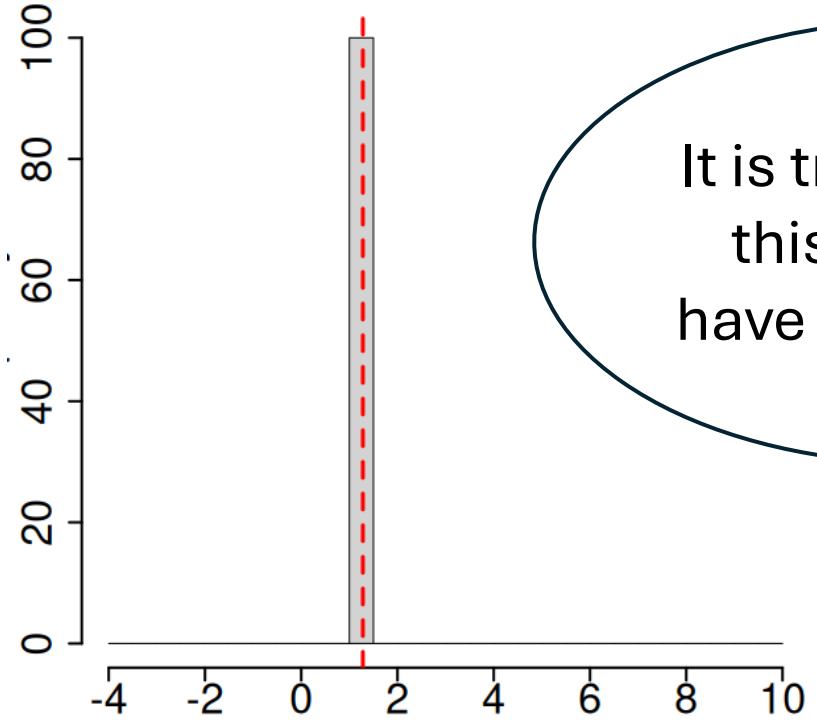
[Jenkin, Fleeming]. 1867. [Review of] The origin of species. The North British Review 46 (June): 277-318.

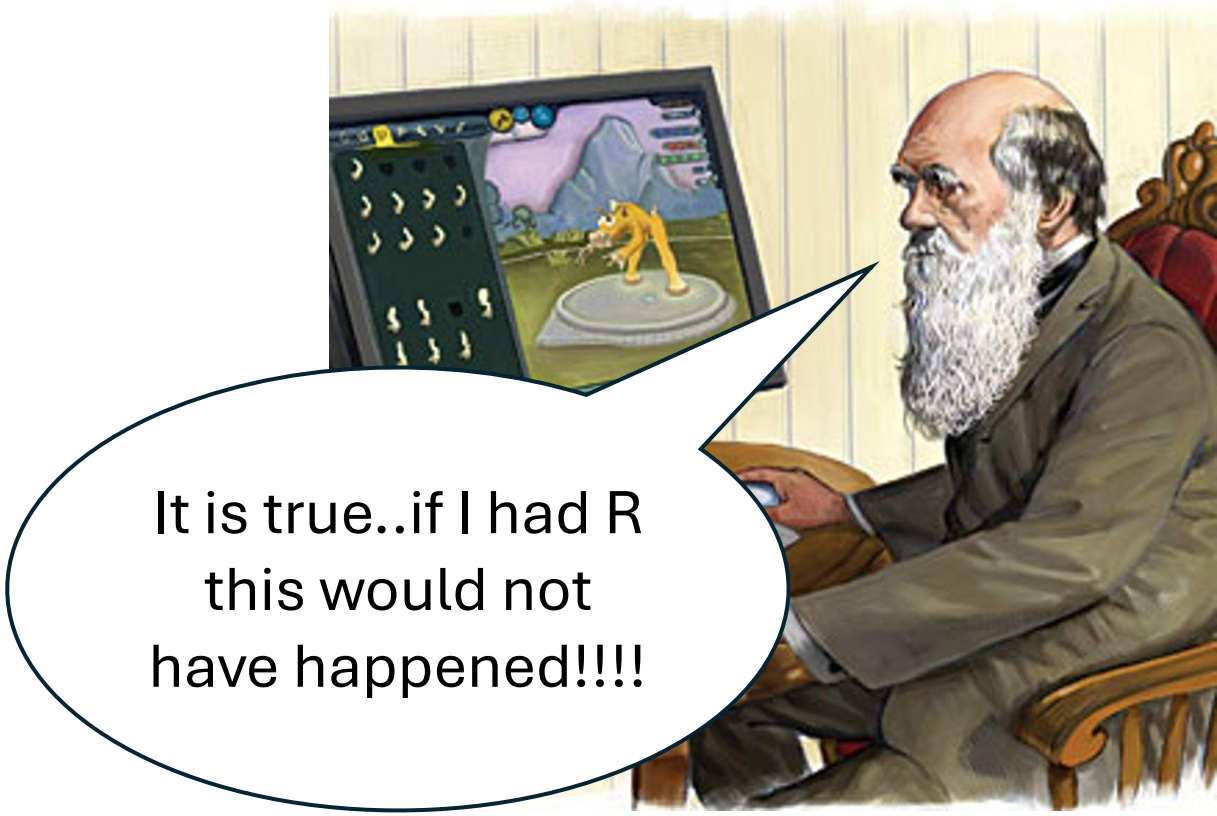
No variability → No evolution!



Offspring has neck that is average of mom and dad







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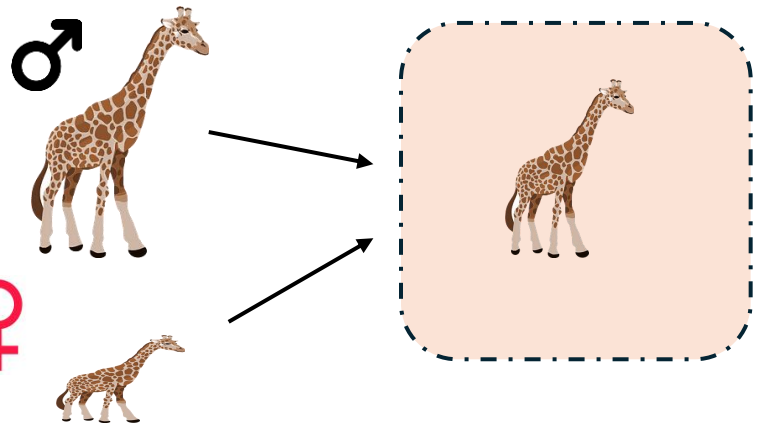

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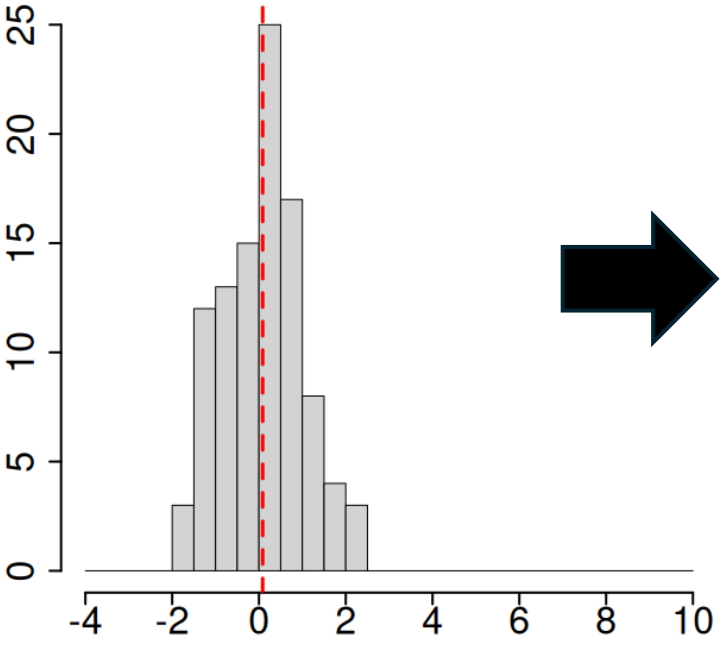
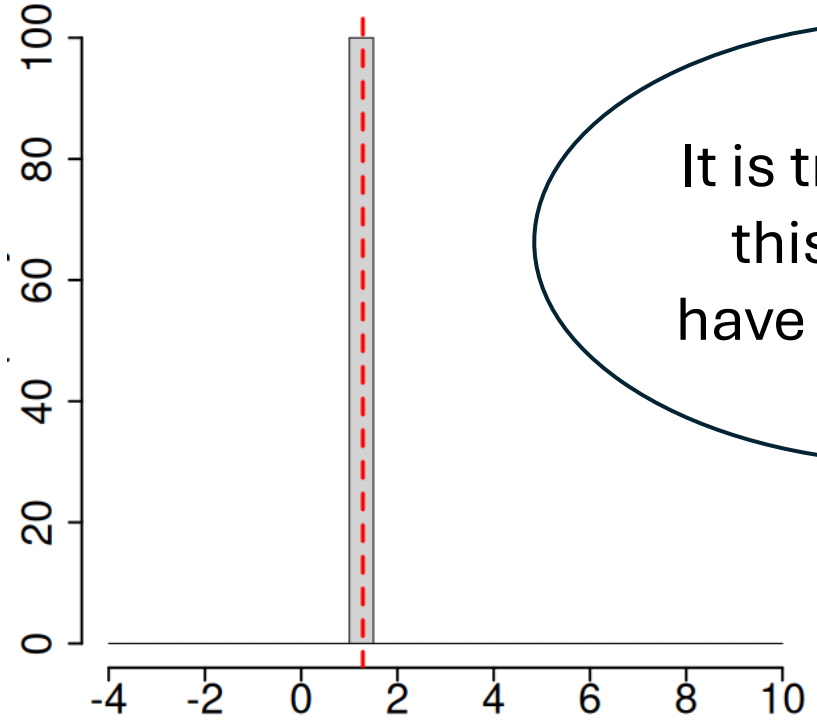
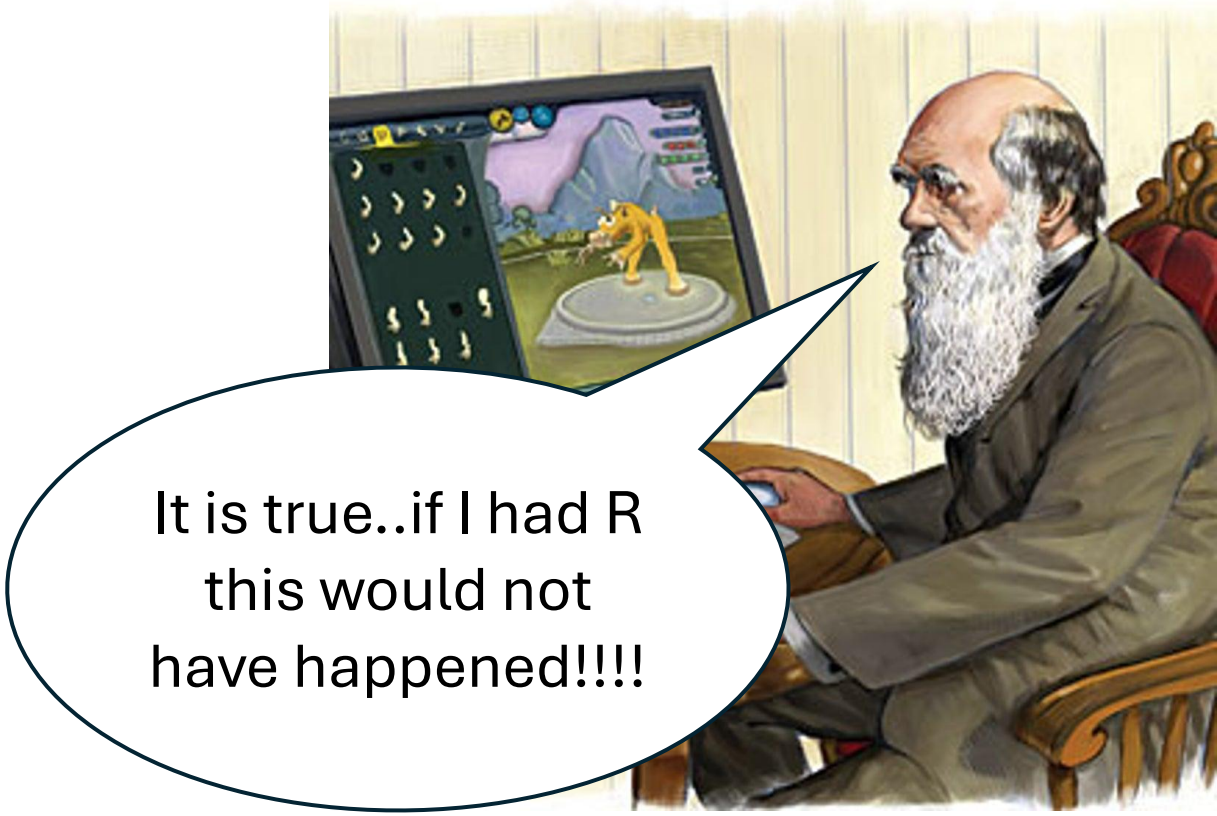
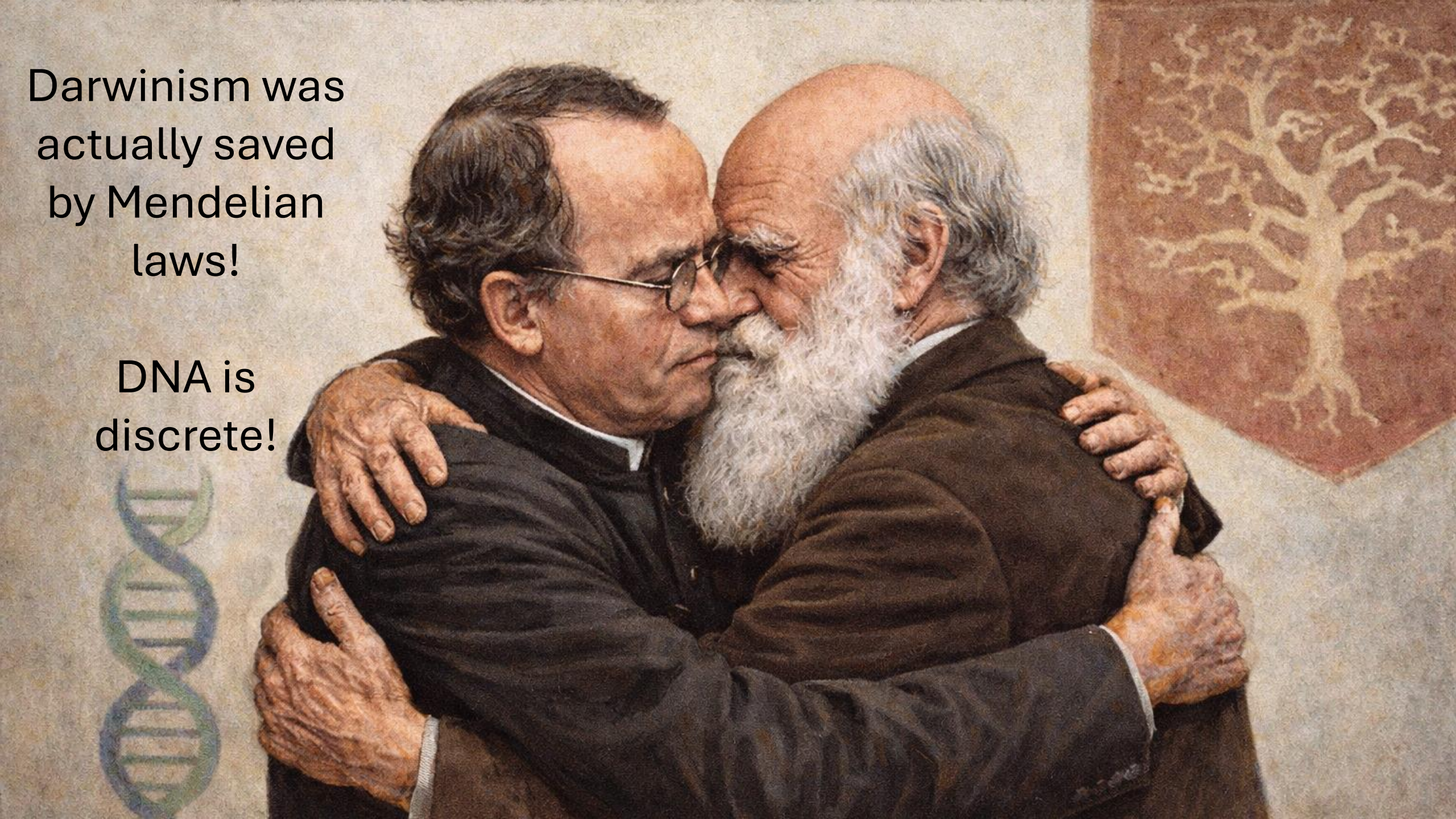
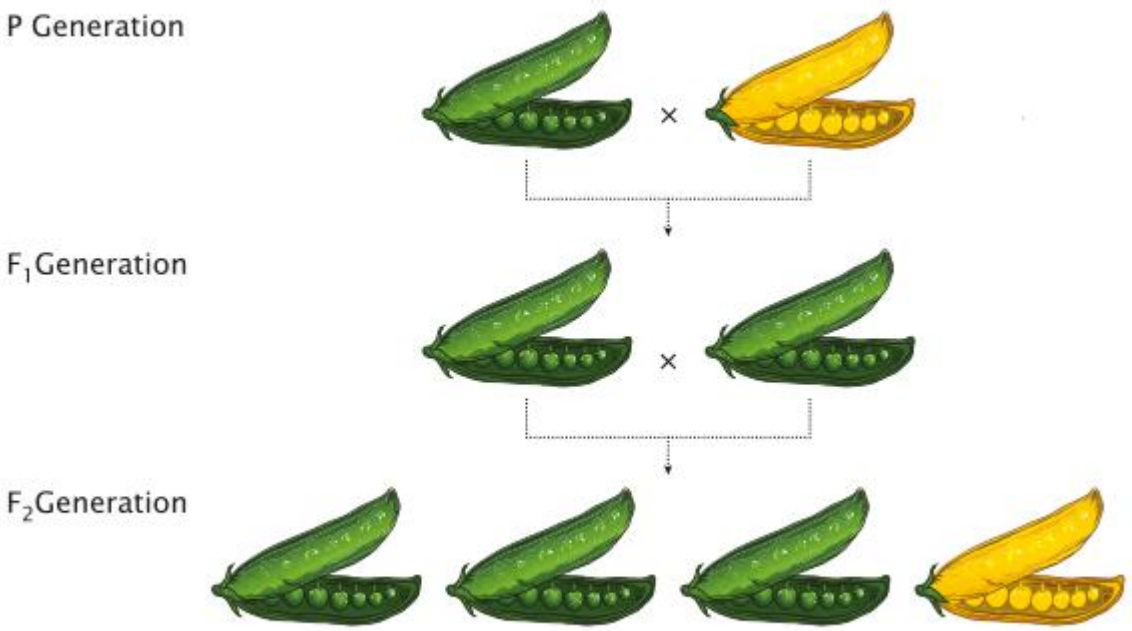


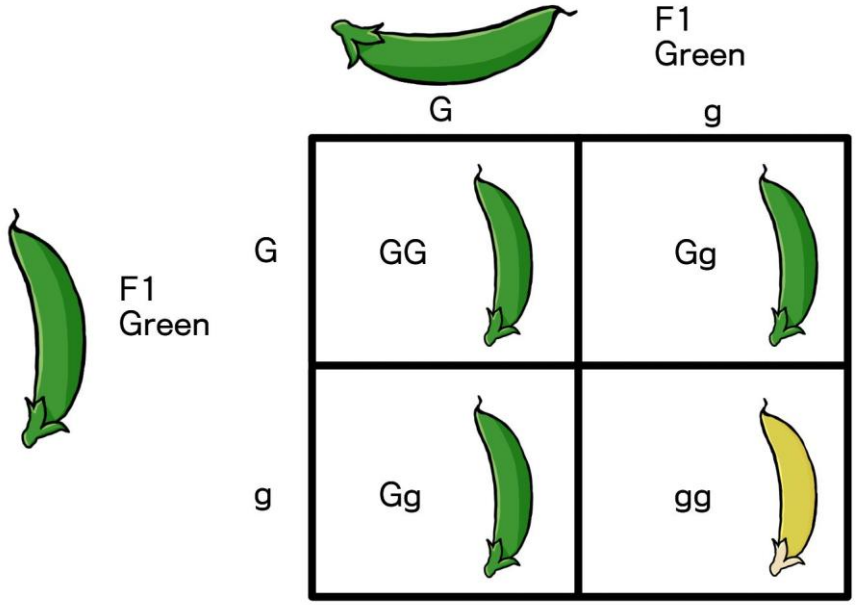





Darwinism was actually saved by Mendelian laws!
DNA is discrete!

Even continuous traits are transmitted as discrete alleles





Darwin's "mistakes"

- **Environmental change** is necessary to generate variation

  One argument was that **variation is (apparently) more common in artificial conditions**

  - **Reproductive organs fail** due to changes from the "natural" conditions
  - **Development fails**

  (Apparently, Darwin went **deeper and deeper** into this "mistake" with time!)

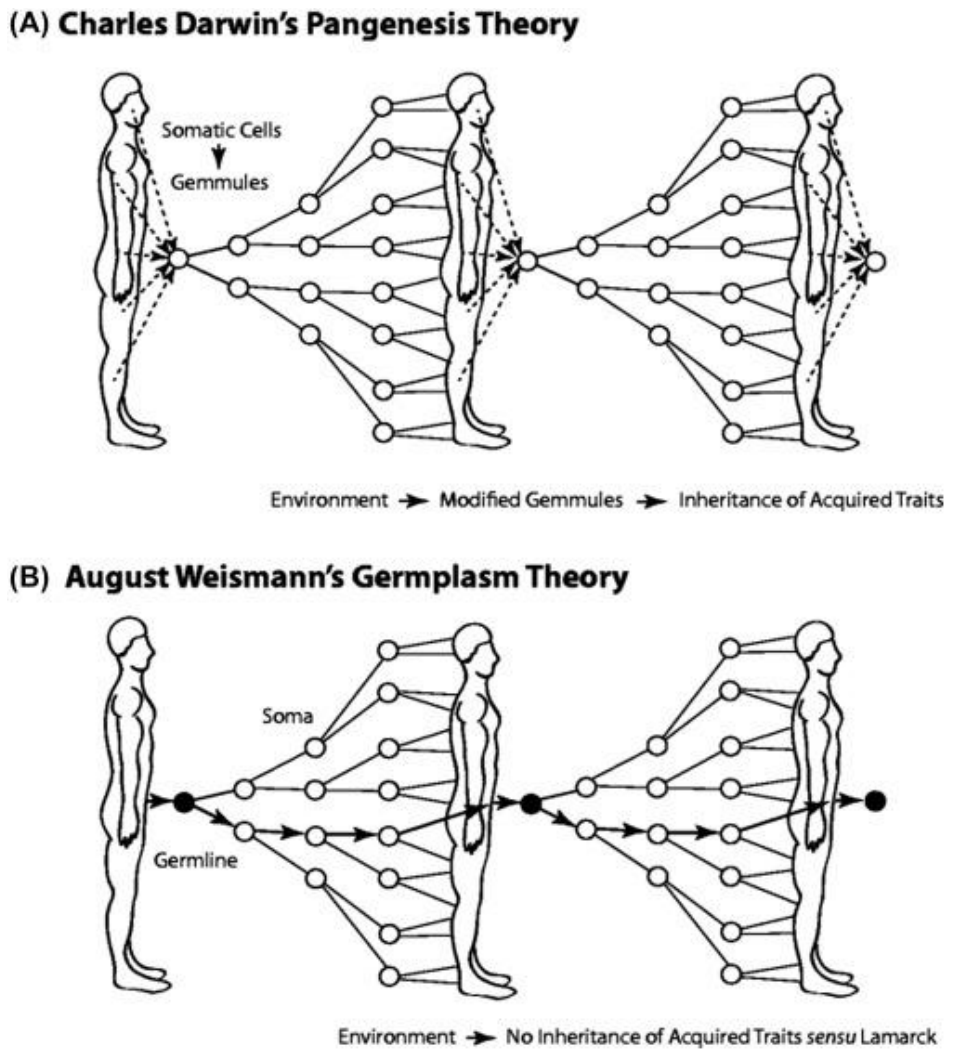
Kalds et al., 2022

Darwin's "mistakes"

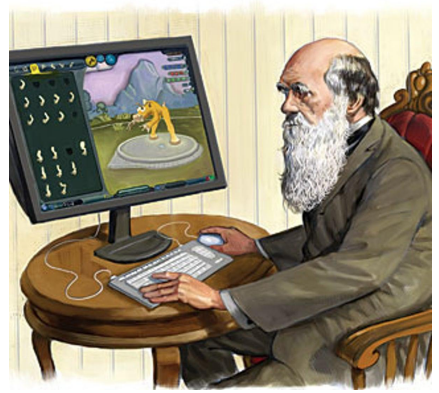
- Environmental change is necessary to generate variation
- **… Inheritance of acquired characters** (*Pangenesis*)

  Cells in an organism are capable of shedding minute particles he called gemmules, which are able to circulate throughout the body and finally congregate in the gonads

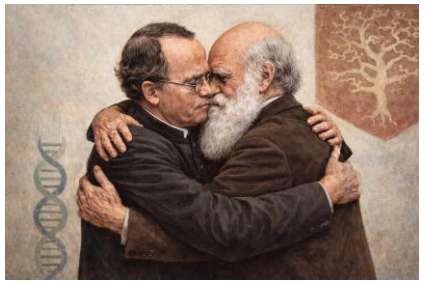
  I fully believe that ***each cell does actually throw off an atom or gemmule of its content***



Conclusions

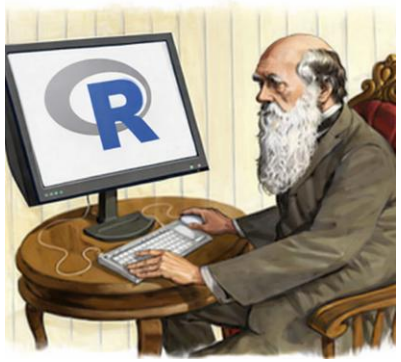


- Formal models can save your life
- Simulations are «less general», but they help a lot too
- We implemented our first evolutionary model



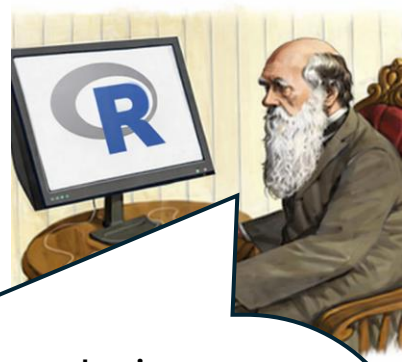
- We tested where Darwin was wrong
- But also why he was right: fundamental principles of «natural selection»:
  - Variability
  - Differential contribution
  - Inheritance

Appendix: some explanations on the code

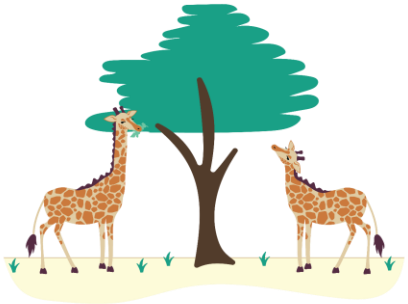


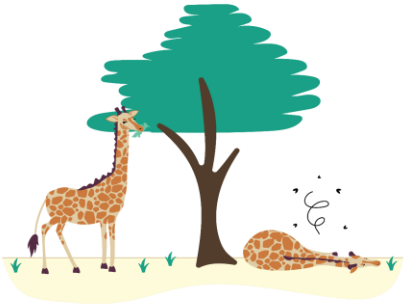
- This is optional and just for students interested in the code

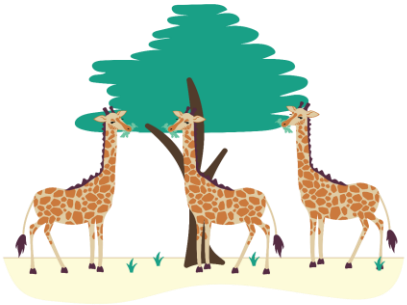
We can now test *in silico* “evolutionary theory”



Variability among individuals
Differential contribution to successive generations
Mechanism of inheritance







Out first basic model of evolution

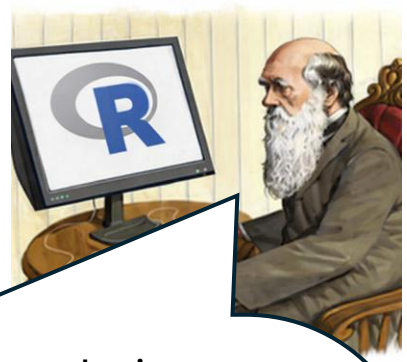
```
N=100
z=rnorm(N)
```

Initialize population

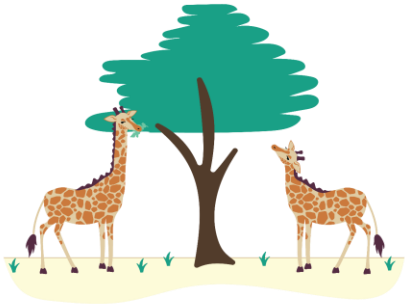
Life cycle

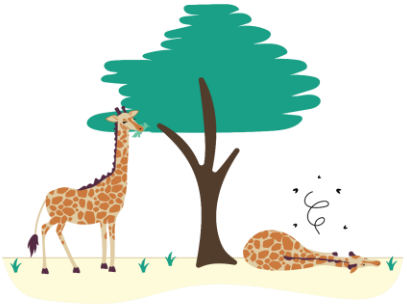
```
survivors=z[z>median(z)]
z=sample(survivors,N,replace=TRUE)
```

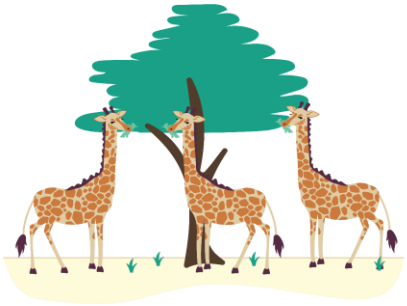
We can now test *in silico* “evolutionary theory”



Variability among individuals
Differential contribution to successive generations
Mechanism of inheritance







For many times (generations)

Out first basic model of evolution

```
N=100
z=rnorm(N)
```

Initialize population

Life cycle

```
survivors=z[z>median(z)]
z=sample(survivors,N,replace=TRUE)
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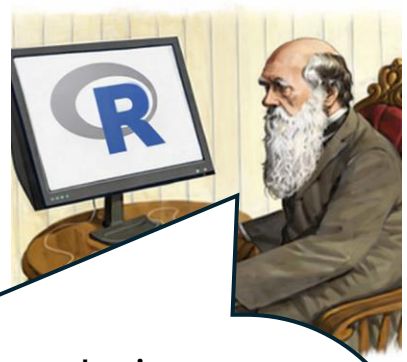
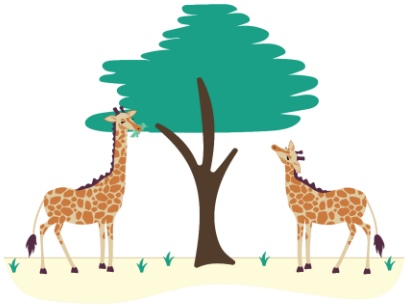
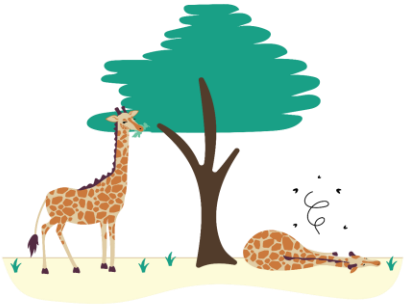
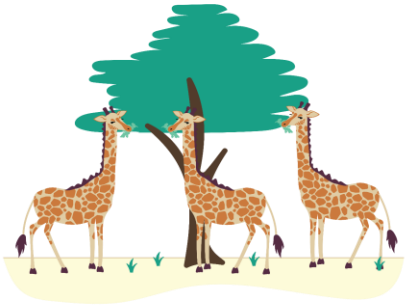
We can now test *in silico* "evolutionary theory"



Variability among individuals
Differential contribution to successive generations
Mechanism of inheritance







For many times
(generations)

Out first basic model of evolution

```
N=100
z=rnorm(N)
```
Initialize population

Life cycle

```
survivors=z[z>median(z)]
z=sample(survivors,N,replace=TRUE)
```

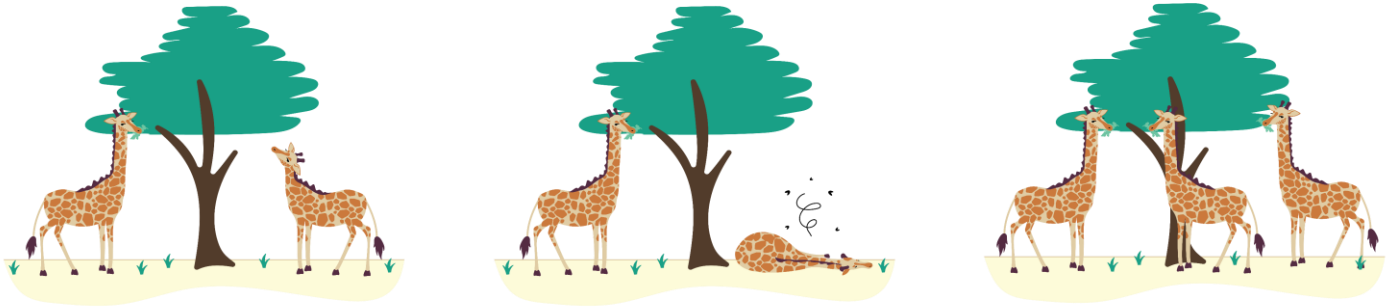
To examine results

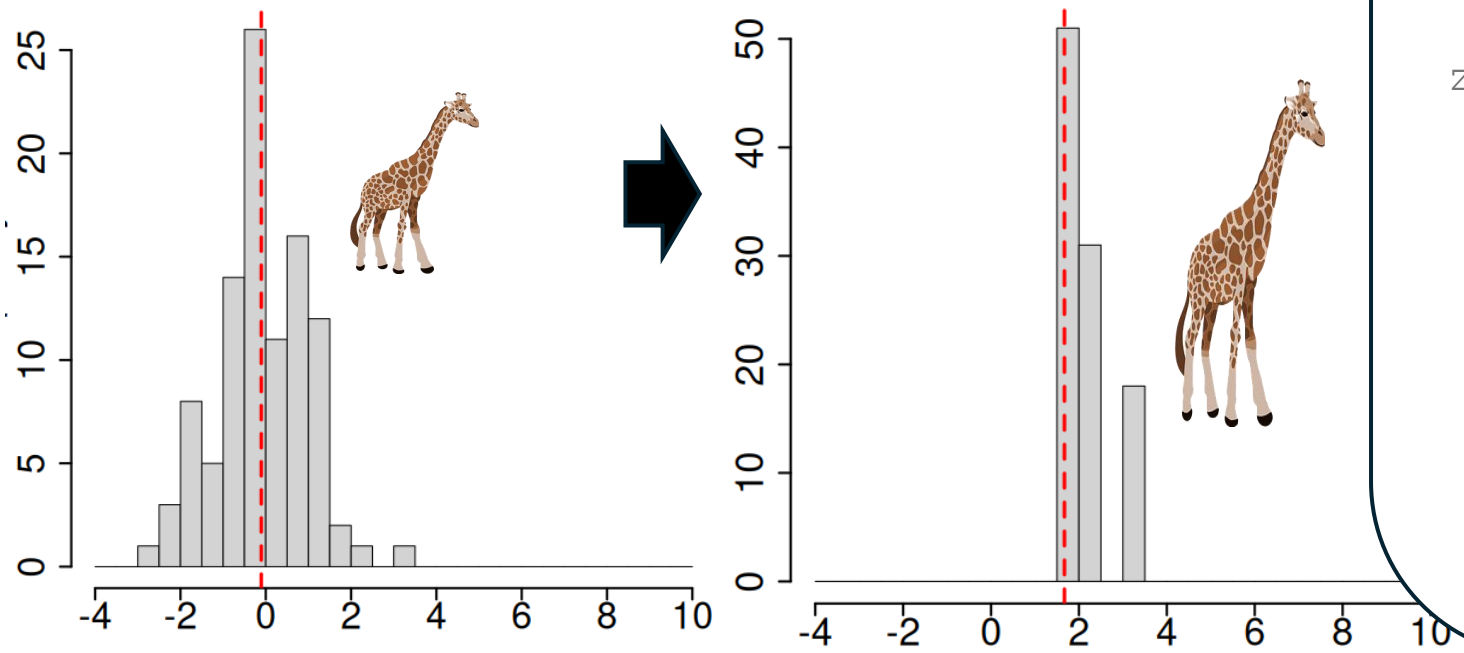
```
hist(z)
```
Histogram of neck lengths

```
median(z)
```
Median of neck lengths

They are sufficient to elongate the necks of our giraffes

Variability among individuals
Differential contribution to successive generations
Mechanism of inheritance





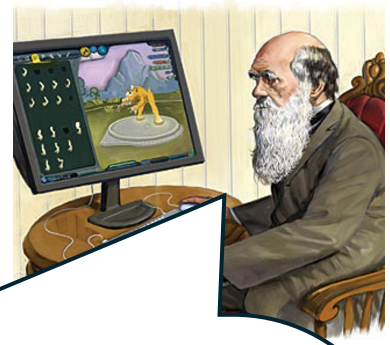
Out first basic model of evolution

```
N=100
z=rnorm(N)
hist(z)
```

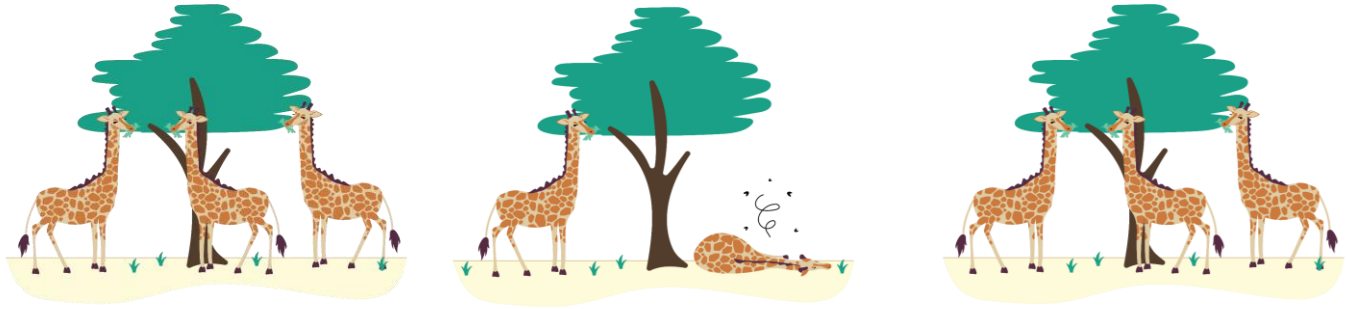
```
survivors=z[z>median(z)]
z=sample(survivors,N,replace=TRUE)
hist(z)
```

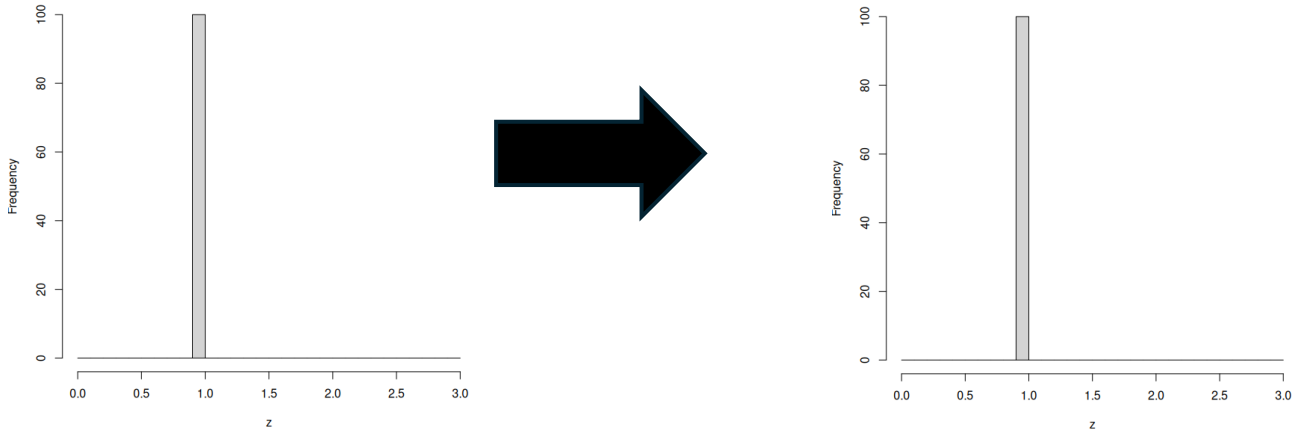
Our new giraffe population has a longer neck!

No variability → No evolution!



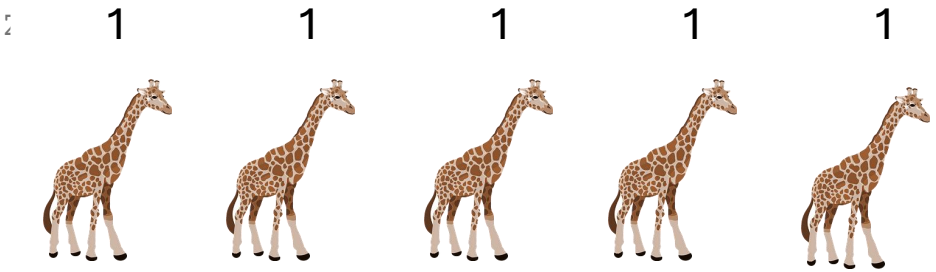
~~Variability among individuals~~
Differential contribution to successive generations
Mechanism of inheritance



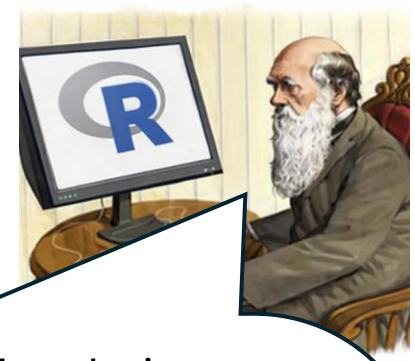


Let's give to all giraffes an initial neck long 1

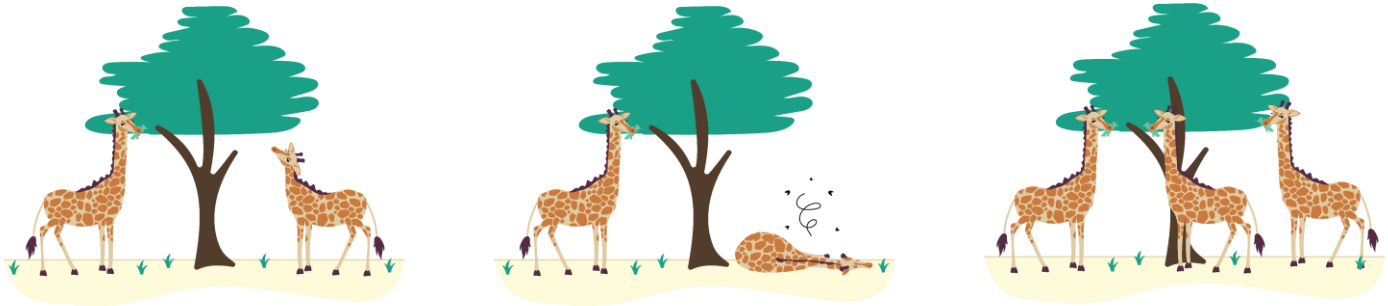
```
N=100
z=rep(1,N)
```

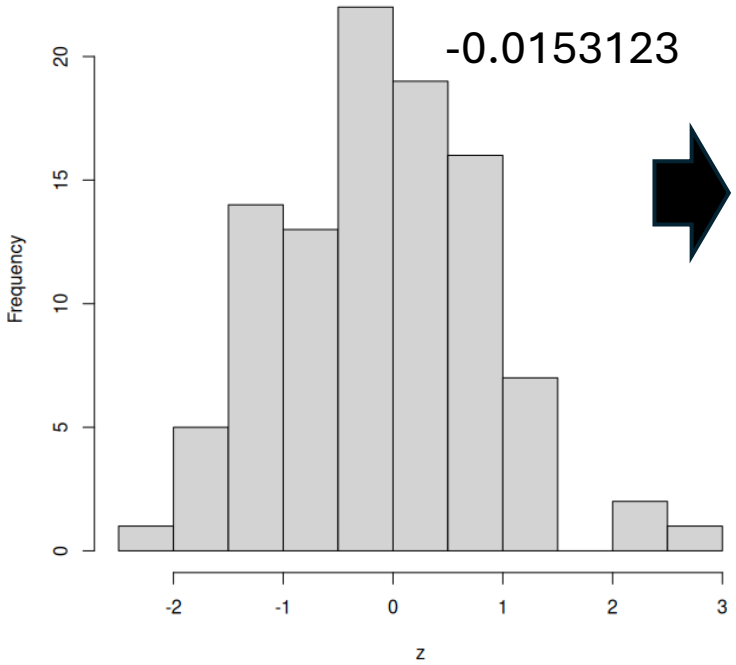


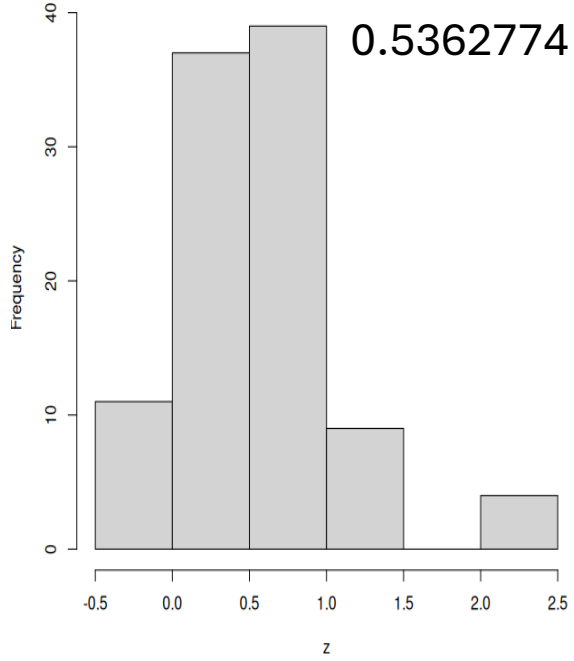
These mechanisms are sufficient to elongate the necks of our giraffes



Variability among individuals
Differential contribution to successive generations
Mechanism of inheritance







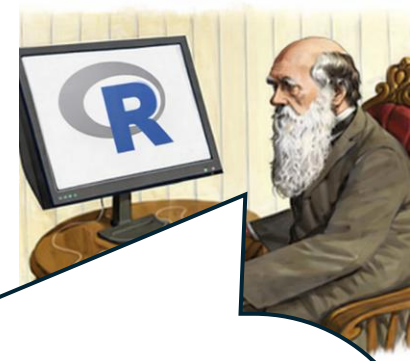
Out first basic model of evolution

```
N=100
z=rnorm(N)
hist(z)
median(z)
```
→ -0.0153123

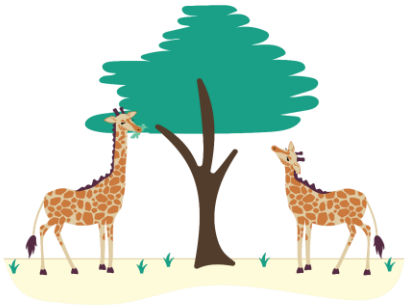
```
survivors=z[z>median(z)]
z=sample(survivors,N,replace=TRUE)
hist(z)
median(z)
```
→ 0.5362774

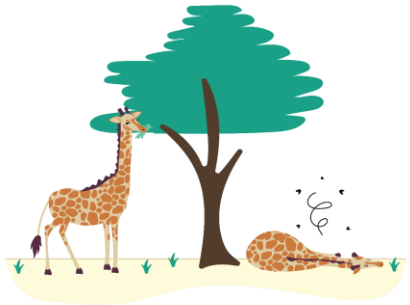
Our new giraffe population has a longer neck!

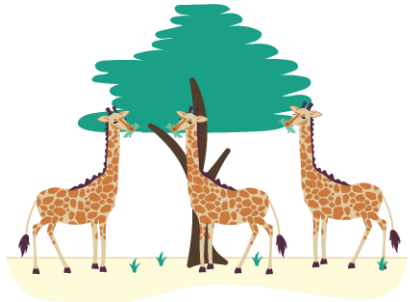
.. over generations

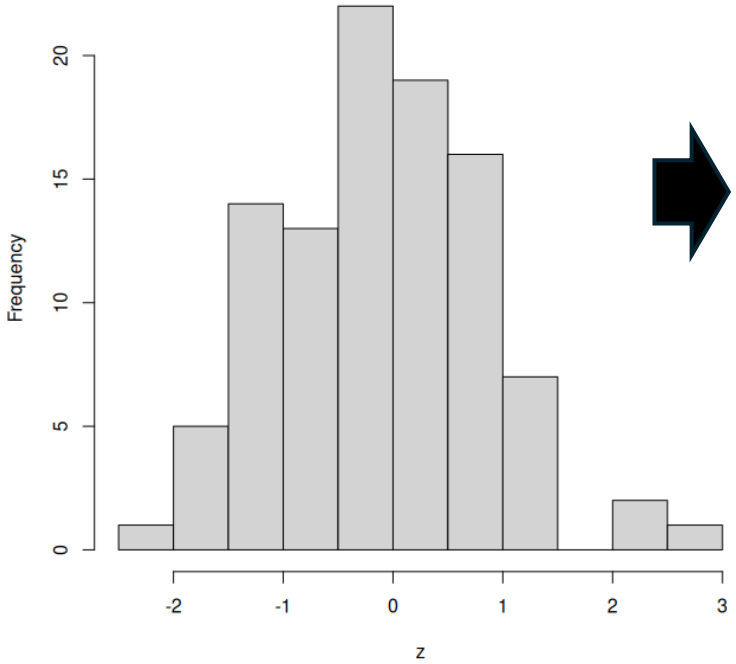


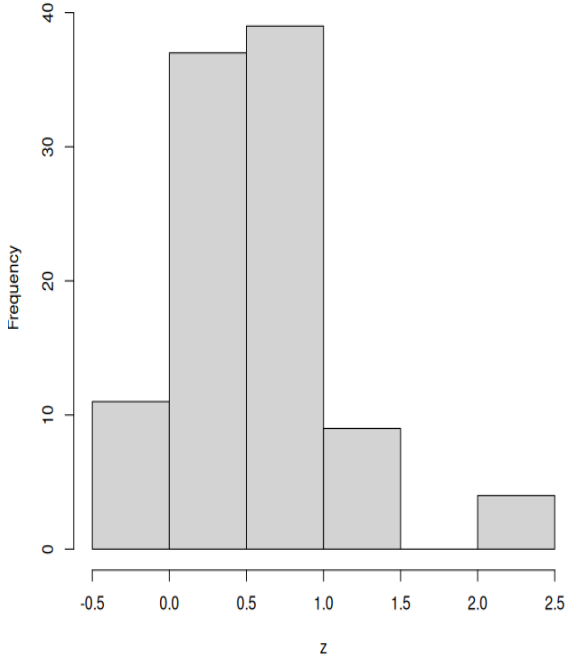
Variability among individuals
Differential contribution to successive generations
Mechanism of inheritance











We can iterate this over generations

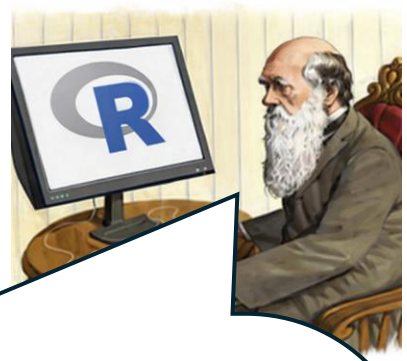
```
median(z)
for (i in 1:5)
{
survivors=z[z>=median(z)][1:50]
z=sample(survivors,N,replace=TRUE)
}
median(z)
```

→ 0.5362774

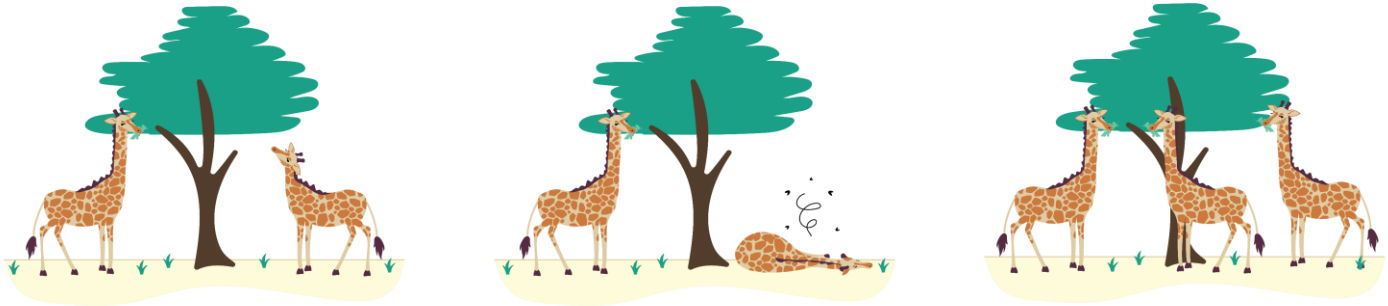
→ 1.513446

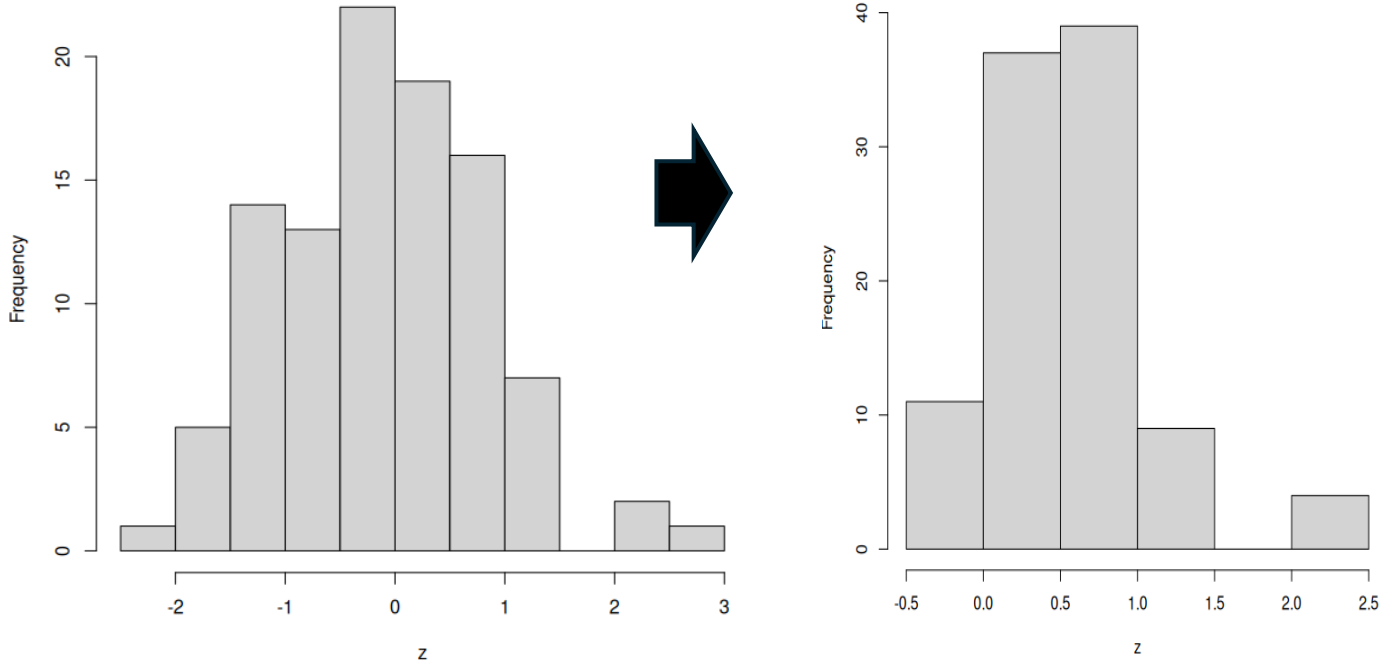
Our new giraffe population has an even longer neck!

Some details of the “code”



Variability among individuals
Differential contribution to successive generations
Mechanism of inheritance





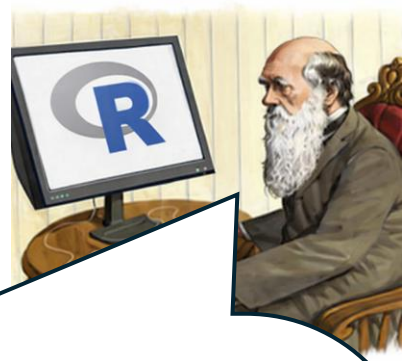
We can iterate this over generations

```
median(z)
```
→ 0.5362774

```
for (i in 1:5)
{
survivors=z[z>=median(z)][1:50]
z=sample(survivors,N,replace=TRUE)
}
median(z)
```
→ 1.513446

This is a «for loop». It only means that we repeat all the code within the curly brackets { } for five times.

Some details of the “code”



Variability among individuals
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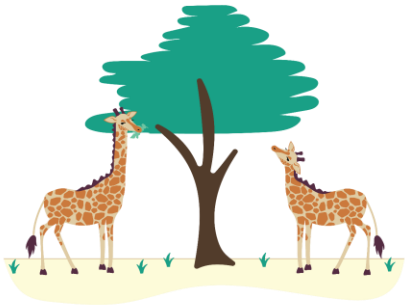
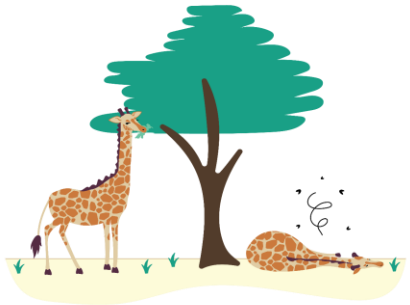
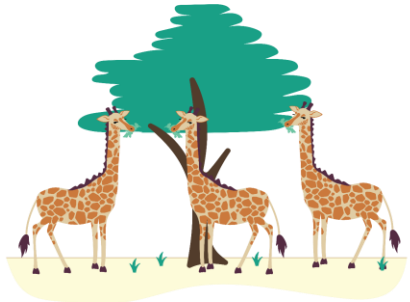
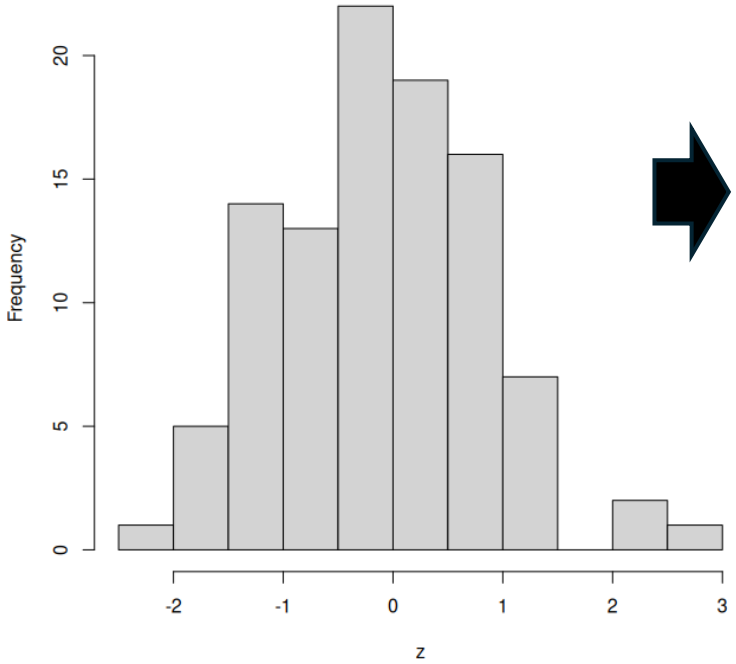
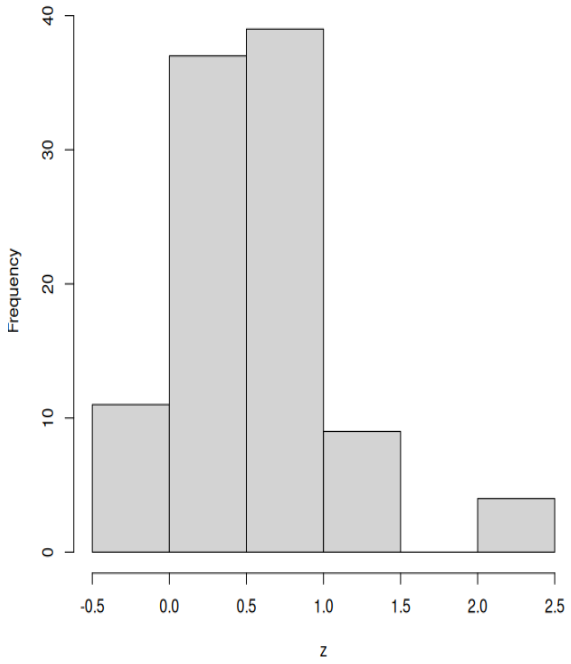










We can iterate this over generations

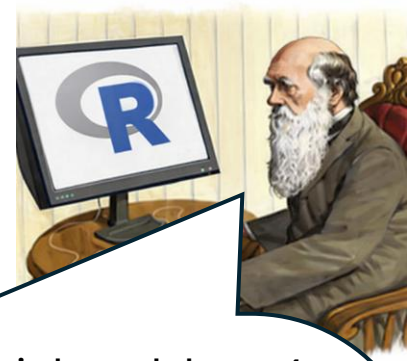
```
median(z)
for (i in 1:5)
{
survivors=z[z>=median(z)][1:50]
z=sample(survivors,N,replace=TRUE)
}
median(z)
```

→ 0.5362774

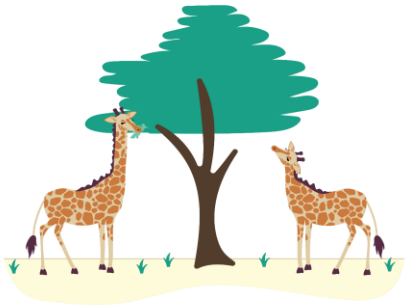
→ 1.513446

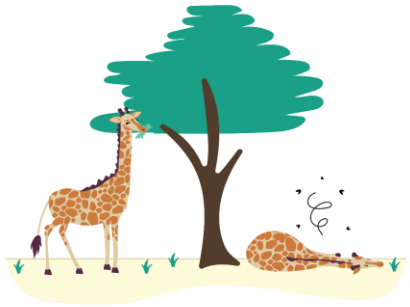
This is just to make sure that I sample half the individuals as at some point it might happen that individuals will have the same neck length

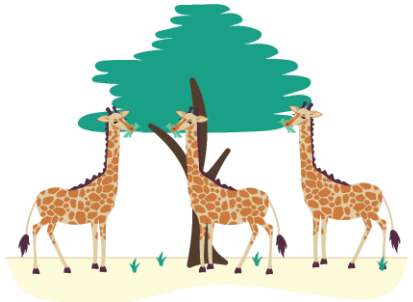
What happens with no variability among individuals?

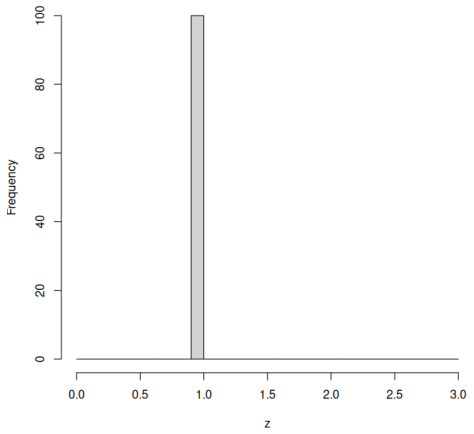


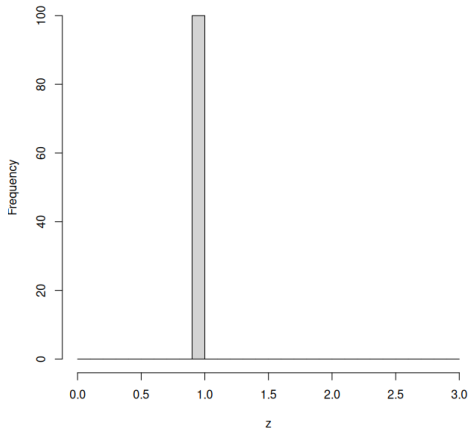
~~Variability among individuals~~
Differential contribution to successive generations
Mechanism of inheritance







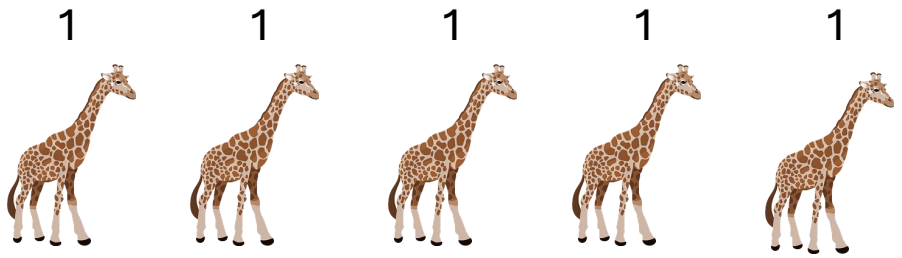




Let's give to all giraffes an initial neck long 1

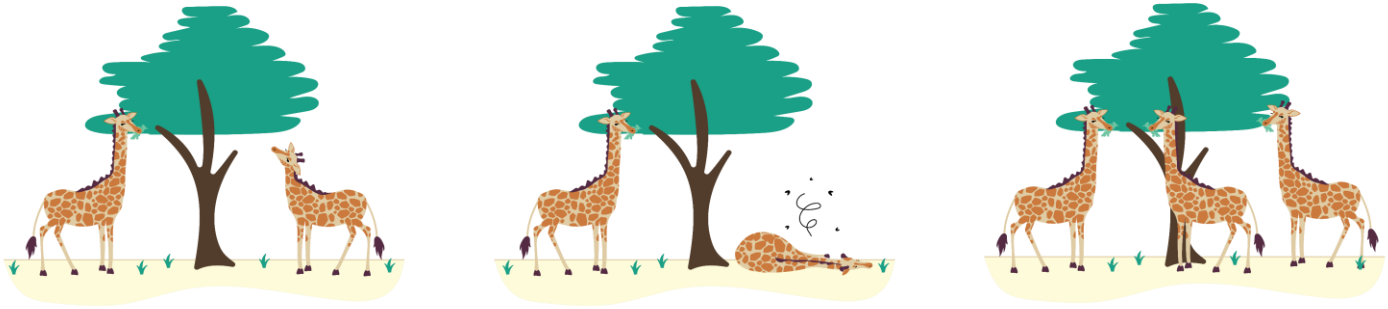
```
N=100
z=rep(1,N)
```

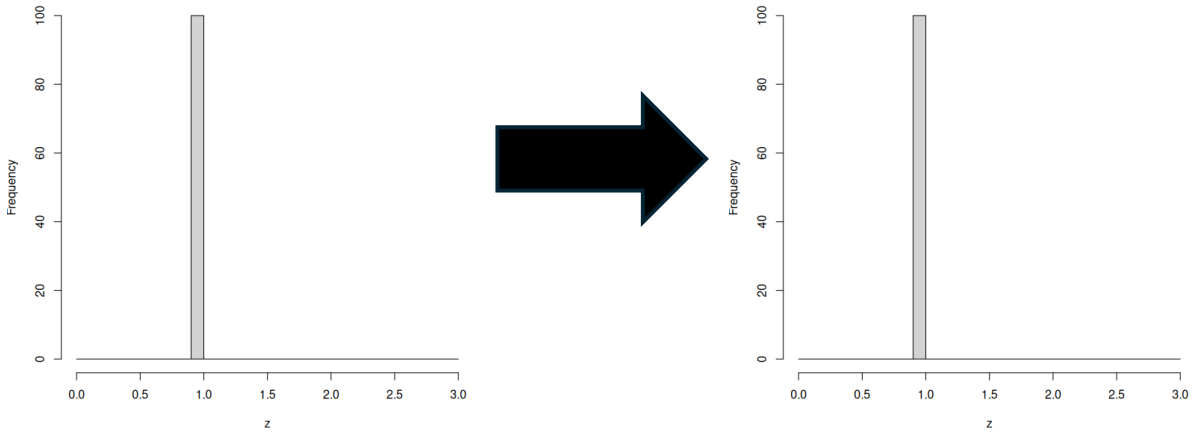
```
survivors=z[z>=median(z)][1:50]
z=sample(survivors,N,replace=TRUE)
```

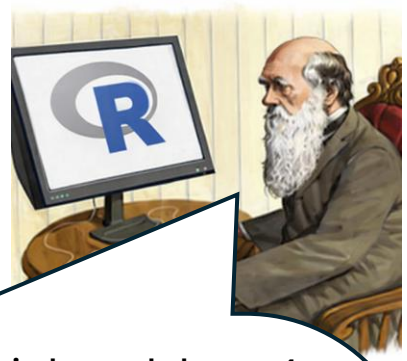


No variability → No evolution!

~~Variability among individuals~~
Differential contribution to successive generations
Mechanism of inheritance







Let's give to all giraffes an initial neck long 1

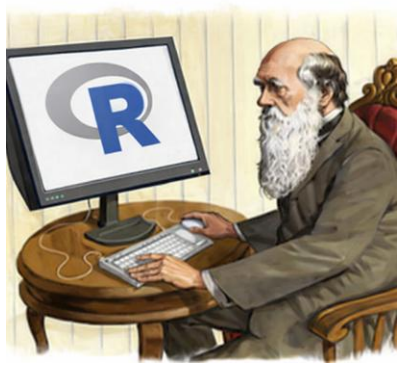
```
N=100
z=rep(1,N)
```

`median(z)` → 1

```
survivors=z[z>=median(z)][1:50]
z=sample(survivors,N,replace=TRUE)
```

`median(z)` → 1

Realistic inheritance model

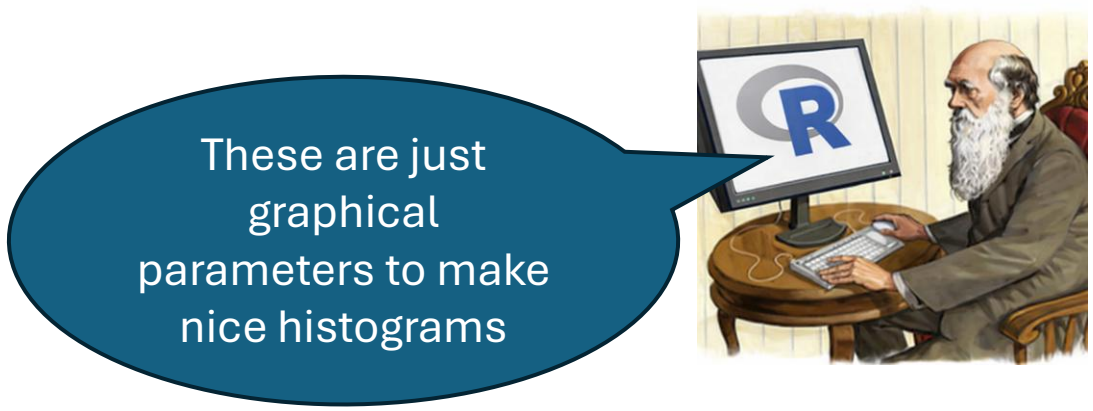



```
N=100
z=rnorm(N)



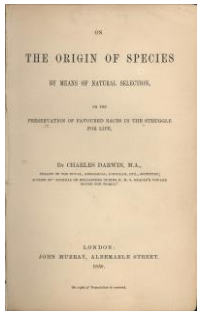
for (i in 1:5){
survivors=gametes[z>=median(z)][1:50]
parents=survivors
gametes=sample(parents,N,replace=TRUE)
z=gametes + rnorm(N,sd=0.9)
}
```

Realistic inheritance model




```
N=100
z=rnorm(N)
hist(z,breaks=seq(-4,10,0.5),xlim=c(-4,10),lwd = 2,cex.lab =
2,cex.axis = 2)
abline(v = median(z), col = "red", lwd = 3, lty = 2)
median(z)
for (i in 1:3){
survivors=gametes[z>=median(z)][1:50]
parents=survivors
gametes=sample(parents,N,replace=TRUE)
z=gametes + rnorm(N,sd=0.9)
}
hist(z,breaks=seq(-4,10,0.5),xlim=c(-4,10),lwd = 2,cex.lab =
2,cex.axis = 2)
abline(v = median(z), col = "red", lwd = 3, lty = 2)
```

Conclusions



- Modern historical origin of evolutionary thought
- Lamarck
- Darwin and the Origin of Species
  - Fundamental principles: variability, differential survival, inheritance
- What Darwin got wrong about inheritance

- Weismann barrier
- Lamarck vs Darwin
  - Empirical evidence
  - From first principles
- Learning vs Evolution
  - Similarities
  - Interactions:
    - When learning helps evolution: Waddington and Baldwin's effect
    - When learning prevents evolution

Next time

- Modern historical origin of evolutionary thought
- Lamarck
- Darwin and the Origin of Species
  - Fundamental principles
- What Darwin got wrong about inheritance
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- Lamarck vs Darwin
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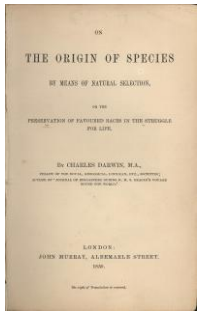

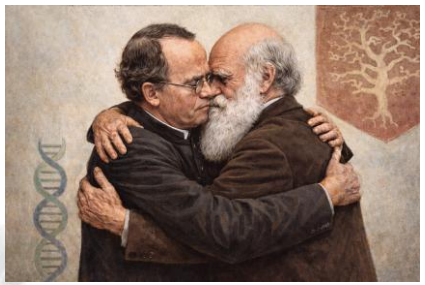

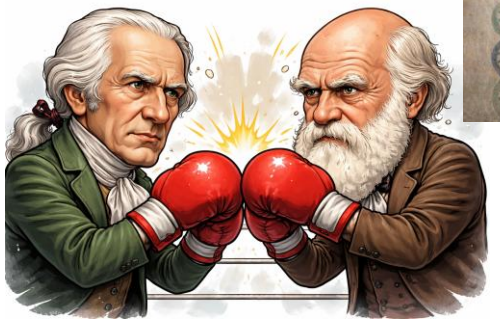
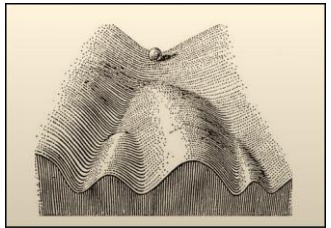
Geoffrey Hinton, Nobel in Physics 2024