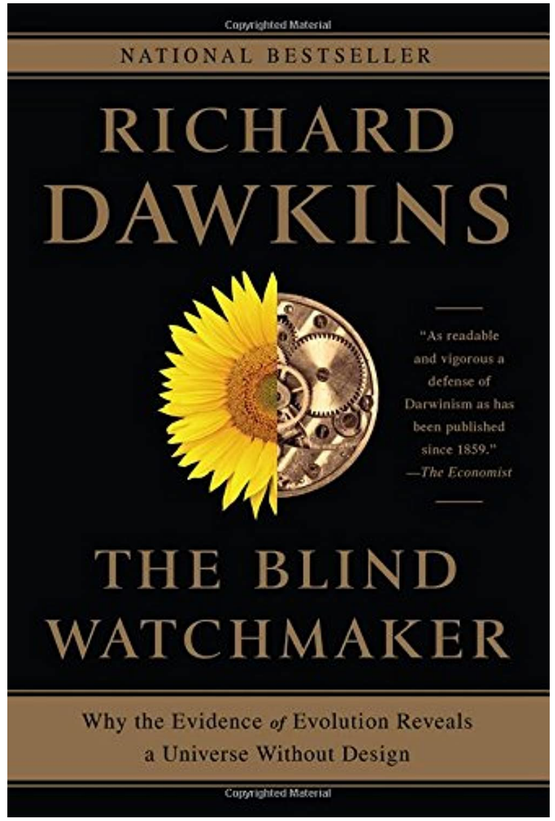
How does evolution produce complex machines?



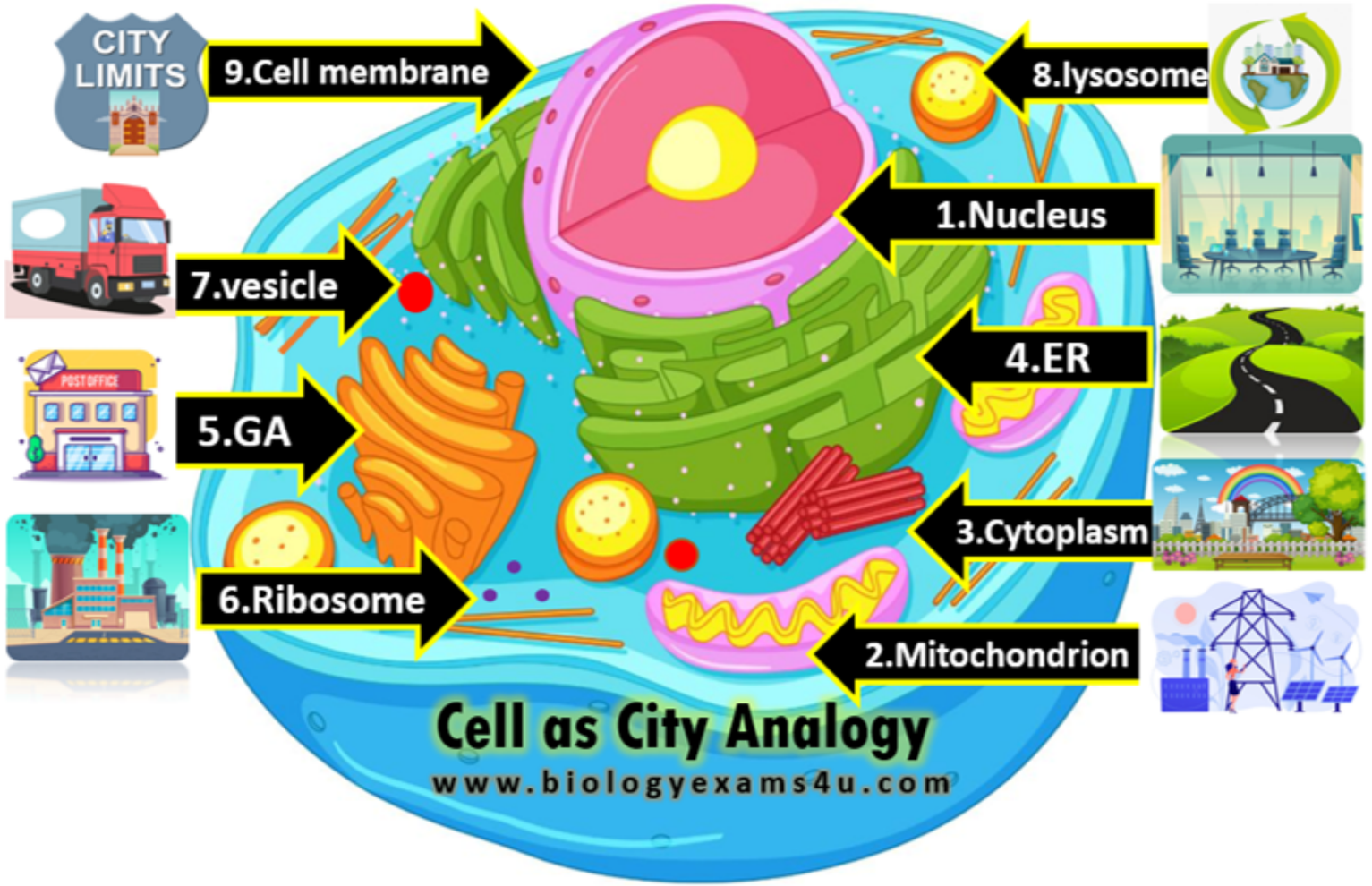
Is it like a blind watchmaker?

Can a randomly typing monkey produce Kalidasa's poems?

Power of Natural selection

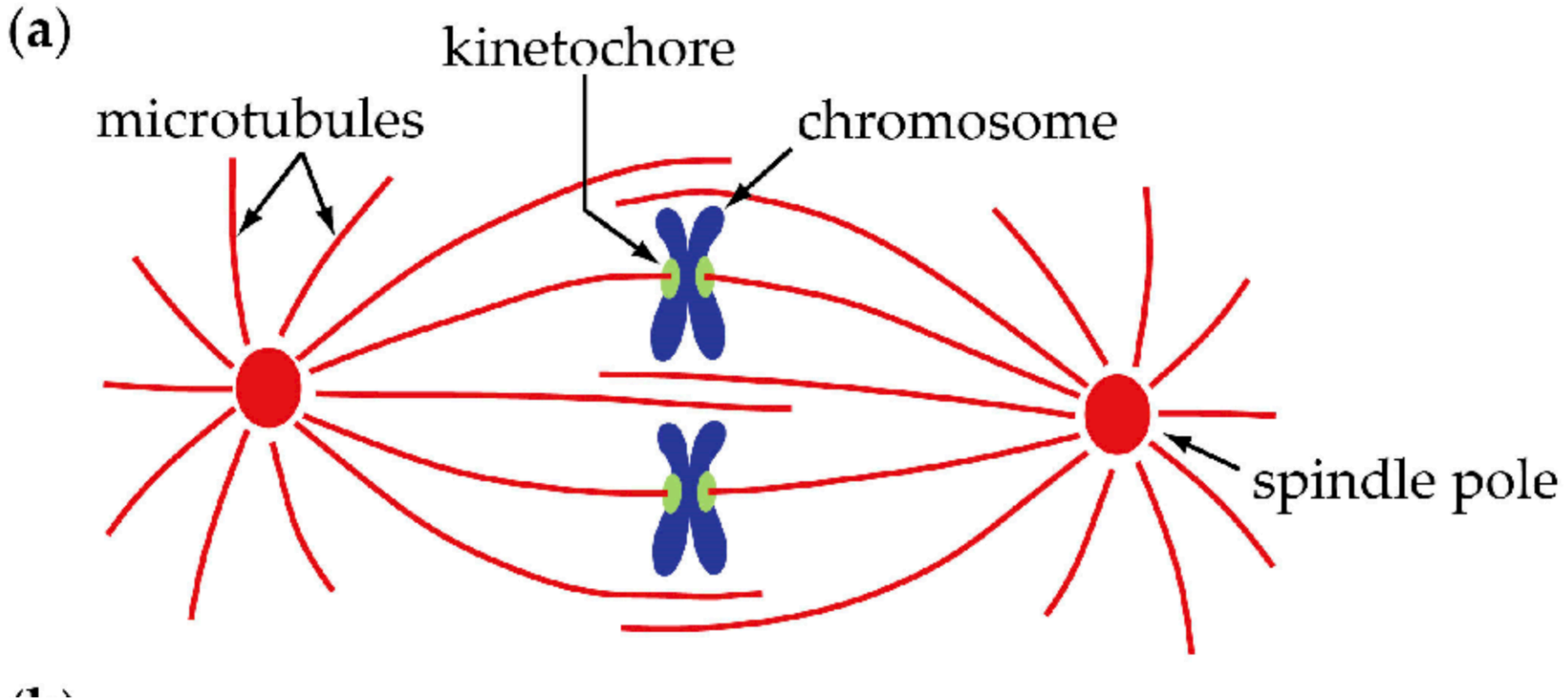
Inspires Genetic Algorithm in Computer Science!

Machinery for a whole "city"

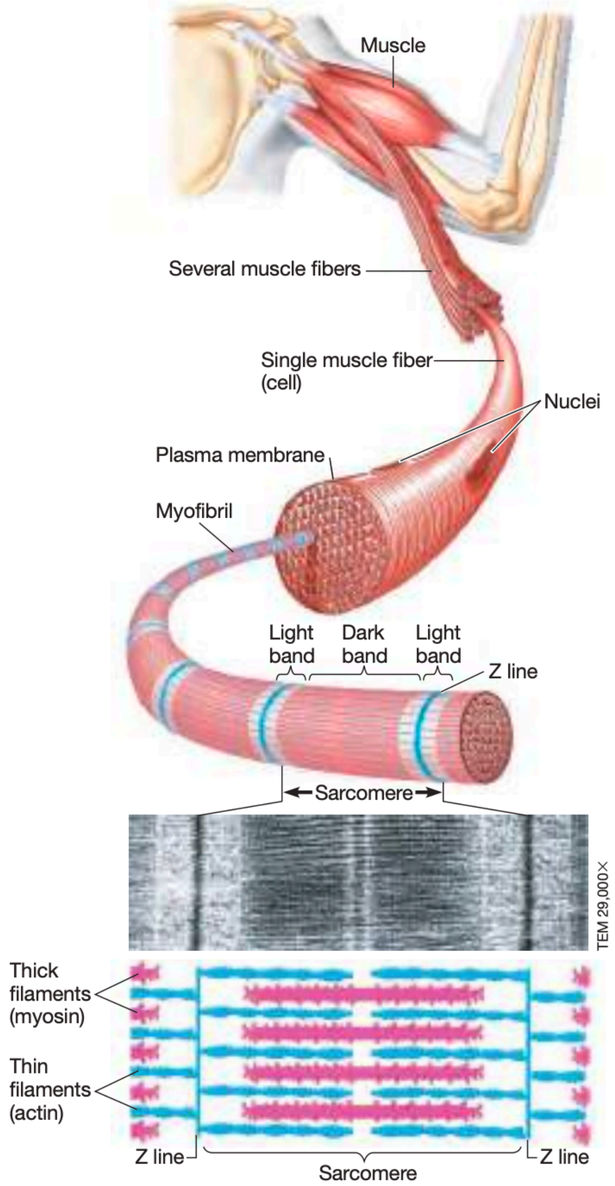


Imagine different types of machines and tools that you would need to make a city function!

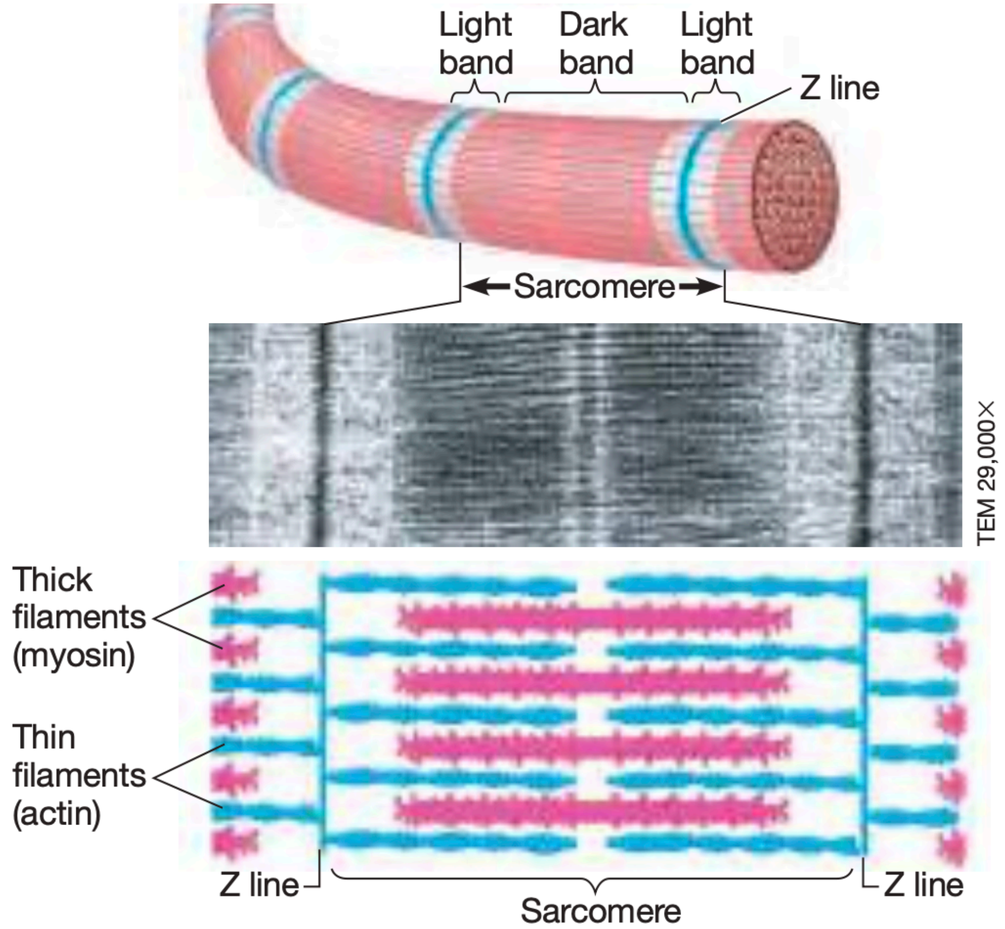
Machinery that segregate chromosomes



Muscle

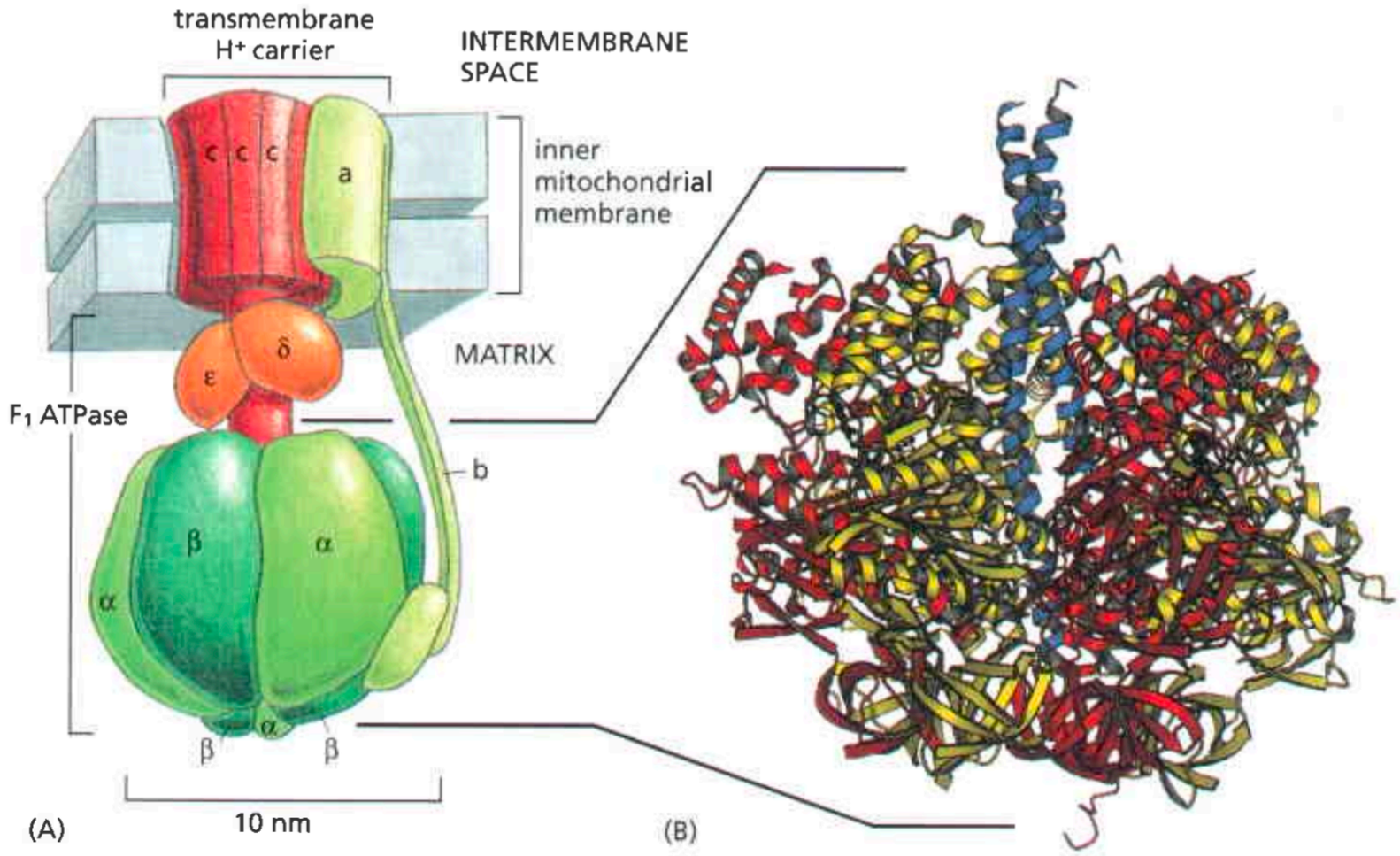


▲ **Figure 30.8** The contractile apparatus of skeletal muscle

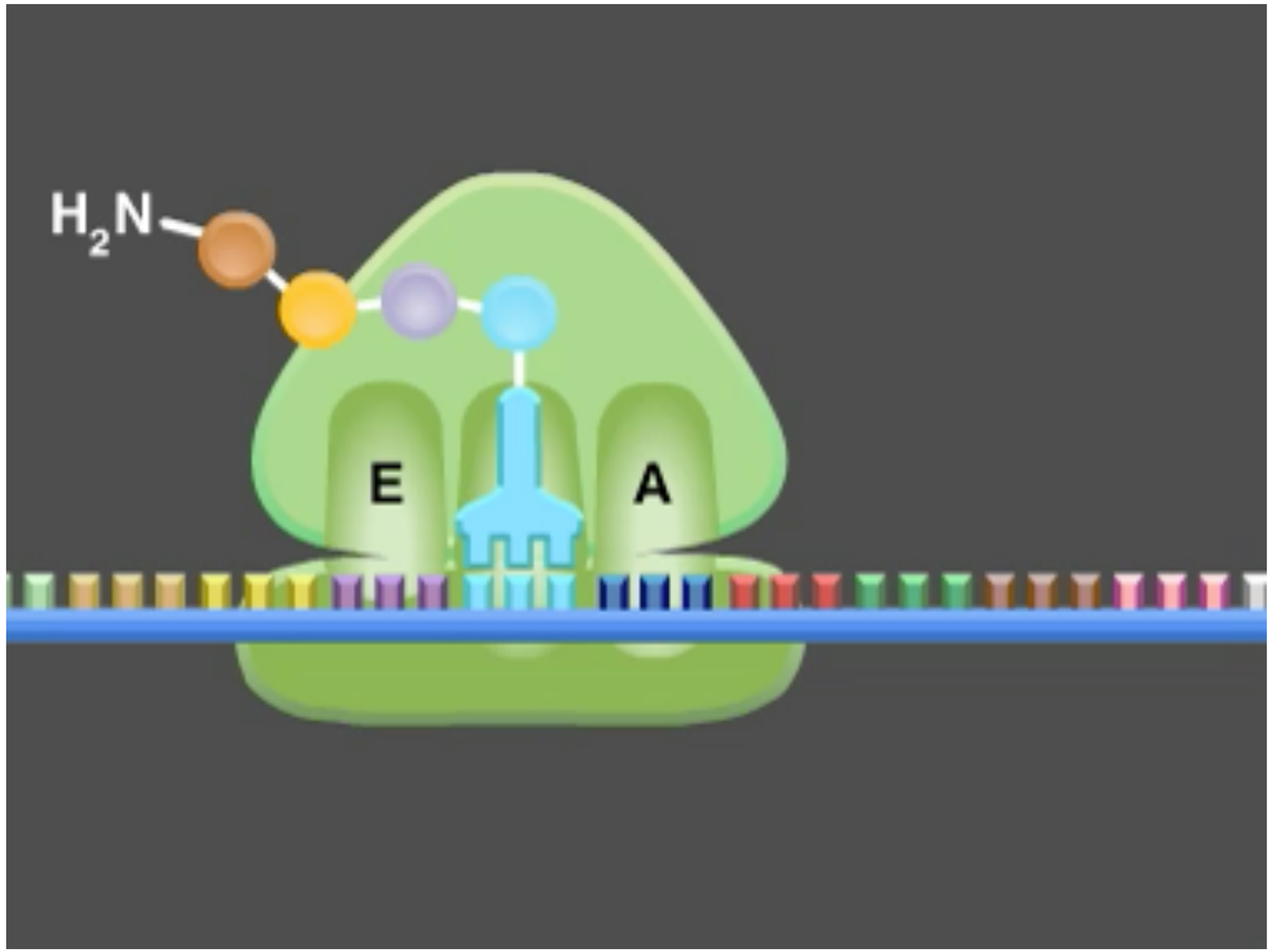


▲ **Figure 30.8** The contractile apparatus of skeletal muscle

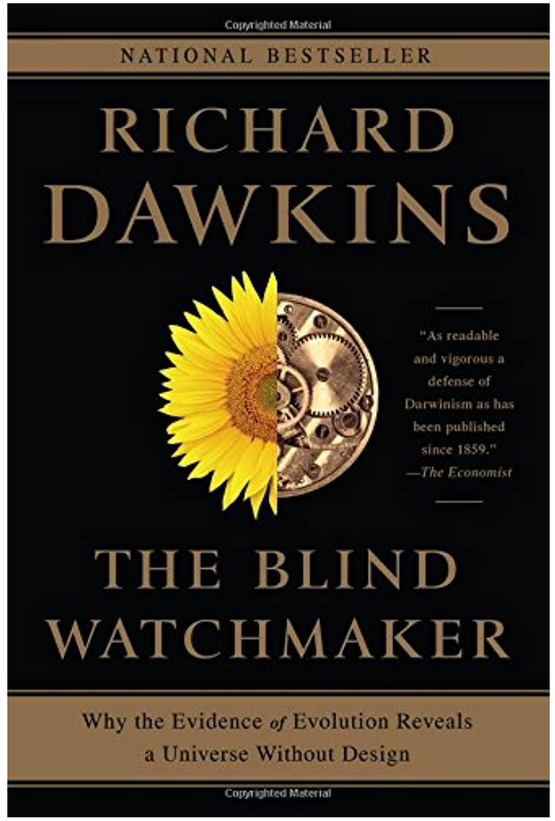
The amazing F0-F1 motor that makes ATP



Translation: ribosome making protein from mRNA



How does evolution produce complex machines?



Is it like a blind watchmaker?

Can a randomly typing monkey produce Kalidasa's or Tagore's poems?

Power of Natural selection

Inspires Genetic Algorithm in Computer Science!

Let us simplify: How long does it take to generate a “useful” sentence using a computer program that types random letters:

YOU MUST BECOME THE CHANGE YOU WANT TO SEE

(A famous quote from Mahatma Gandhi’s work, just as an example sentence to demonstrate the idea)

Randomly typing: 42 characters (including space) with a keyboard having 26 alphabets and a spacebar (=27 keys)

YOU MUST BECOME THE CHANGE YOU WANT TO SEE

If hit all keys with equal probability, the number possible sentences: $27^{42} \approx 10^{60}$

Only one out of this 10 power 60 is the correct sentence!

Huge amount of time to produce the correct sentence! More than the age of the universe!

Randomly typing, possibilities: $27^{42} \approx 10^{60}$

Huge amount of time to produce correct sentence! More than the age of the universe!

We can generate it quicker if we follow an algorithm similar to evolution!

Evolution-like algorithm step 1: Start with a random sequence of the same length

YOU MUST BECOME THE CHANGE YOU WANT TO SEE

SUJOSL DJRUAPSH JSHDOU VNBHUS WUDHQVB HLA

(If we start with the black sentence, can “evolution”-like rules take it to the red sentence quickly?)

Evolution-like algorithm step 2: Duplicate the sentence with a probability to make a random error (mutation).

YOU MUST BECOME THE CHANGE YOU WANT TO SEE

SUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB HLA

SUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB SLA

Evolution-like algorithm step 2: Duplicate the sentence with a probability to make a random error (mutation).

Evolution-like algorithm step 3: Note the change; compare it with the target sentence (“useful sentence”)

YOU MUST BECOME THE CHANGE YOU WANT TO SEE

SUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB HLA

SUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB SLA

Evolution-like algorithm step 4: If there is a comparable character, keep it; and do not allow t to change in the next duplication; change any other character = natural selectio = “survival of the fittest”

Duplicate it with random error (mutation); note the change; compare it with the target sentence (“useful sentence”)

YOU MUST BECOME THE CHANGE YOU WANT TO SEE

SUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB HLA

SUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB SLA

YUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB SLA

Natural selection = keep only the “useful” character; the not so useful character will be “killed”

Duplicate it with random error (mutation); note the change; compare it with the target sentence (“useful sentence”); do many iterations

YOU MUST BECOME THE CHANGE YOU WANT TO SEE
SUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB HLA
SUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB SLA
YUJOSL DJRUAPSH JSHDOU VNB HUS WUDHQVB SLA
…… ……. ….. …… …….. …..
…… ……. ….. …… …….. …..
YOU SL DJBECPSH THEDOU VNB HUS WUDHQVB SEE
…… ……. ….. …… …….. …..
…… ……. ….. …… …….. …..
YOU SL DJBECPSH THE CHAVNE YOU WUDHQVB SEE
…… ……. ….. …… …….. …..
…… ……. ….. …… …….. …..
YOU MUST BECPME THE CHANGE YOU WANT TB SEE

Natural selection = keep only the “useful” character; harmful character will be “killed”

This will converge and reach the “useful” sentence quickly

This basic idea, led to the “Genetic Algorithm” in computer science, widely used today

Evolutionary change DNA is also due to events like “recombination” etc that you will learn later

How does the evolution generate diversity?

So much of diversity we see around

- If you just take fungi (yeast-like organism): there are millions of fungal species
- Half a million plant species
- Western ghats area (the mountains near Mumbai, and all the way upto Kanya Kumari parallel to the western coast of India) is world's one of the hottest biodiversity hotspots. So many different plants, bird species, reptile species, fish, insect species. Many of them globally threatened

How does the evolution generate diversity?

A simple model to understand the diversity generation is the Wright Fisher Model

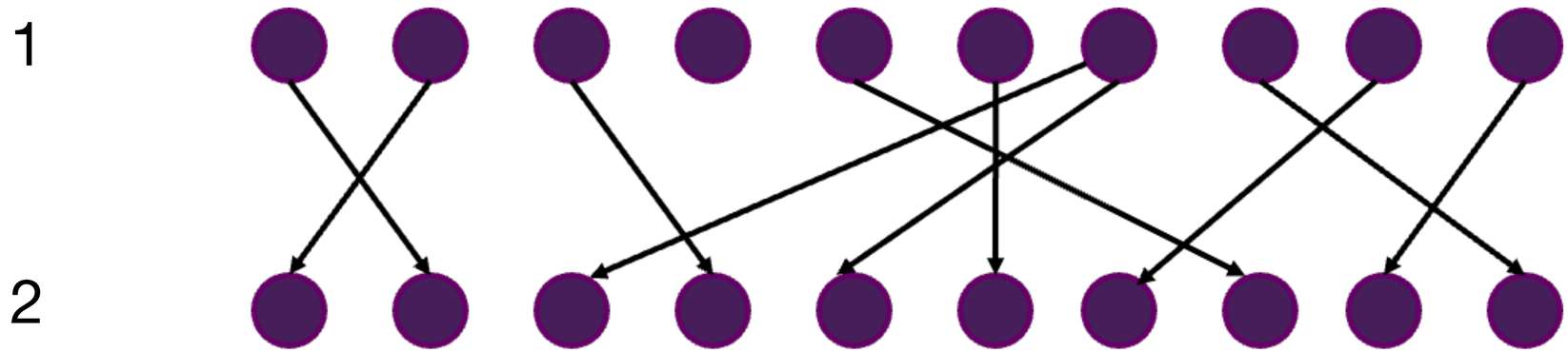
Wright-Fisher model

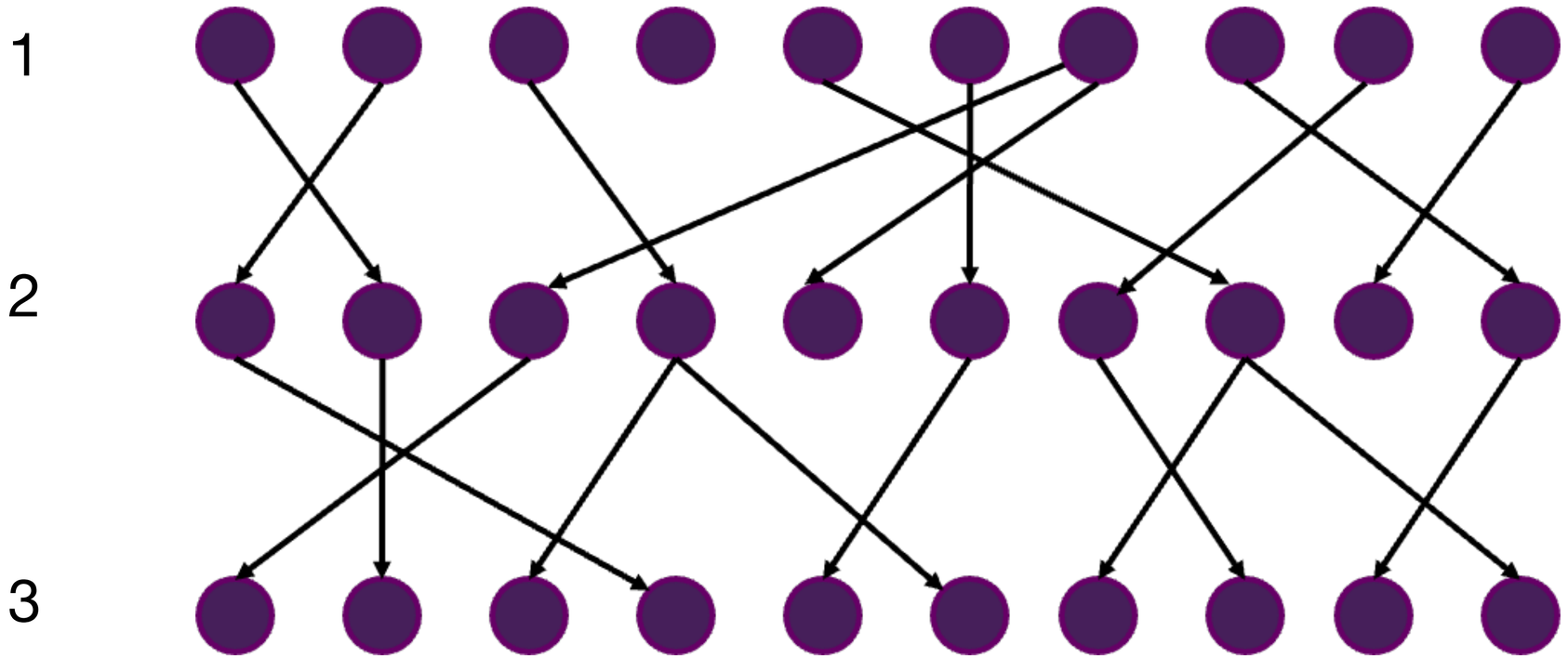
- Named after Sewall Wright and Ronald Fisher
- Simplest because: No mutation. It computes the diversity that is generated by simply distributing chromosomes differently

Wright-Fisher Model

- Imagine a haploid population of n individuals
- Assume constant population – that is, n offspring individuals
- Each offspring individual picks up parent randomly from the previous generation
- Each offspring inherits chromosome of the parent (no mutation, no change)

The model:Each offspring individual picks up parent randomly from the previous generation and inherits chromosomes




1
2
3

If ‘p’ is the probability of finding allele ‘a’ in the current generation, what is the probability of finding the same allele in the next generation ?

There are 10 individuals; out of it 4 have allele ‘a’.

$p=0.4$

In the next generation, what is the probability that 7 of them have allele ‘a’ ?

Binomial distribution

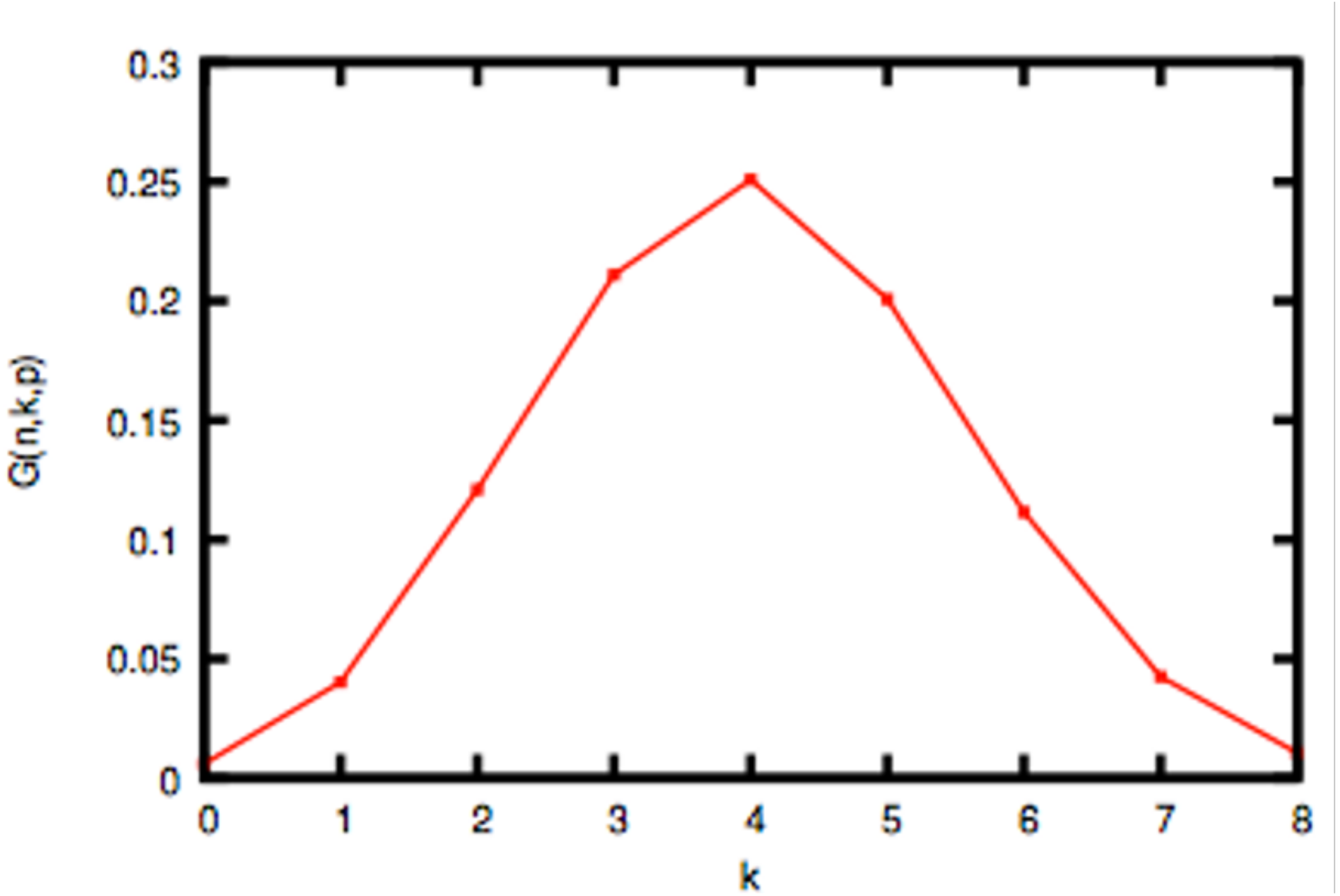
(that you learned in class 11 or 12 mathematics)

There are *n* individuals; out of it *p* fraction have allele ‘a’.

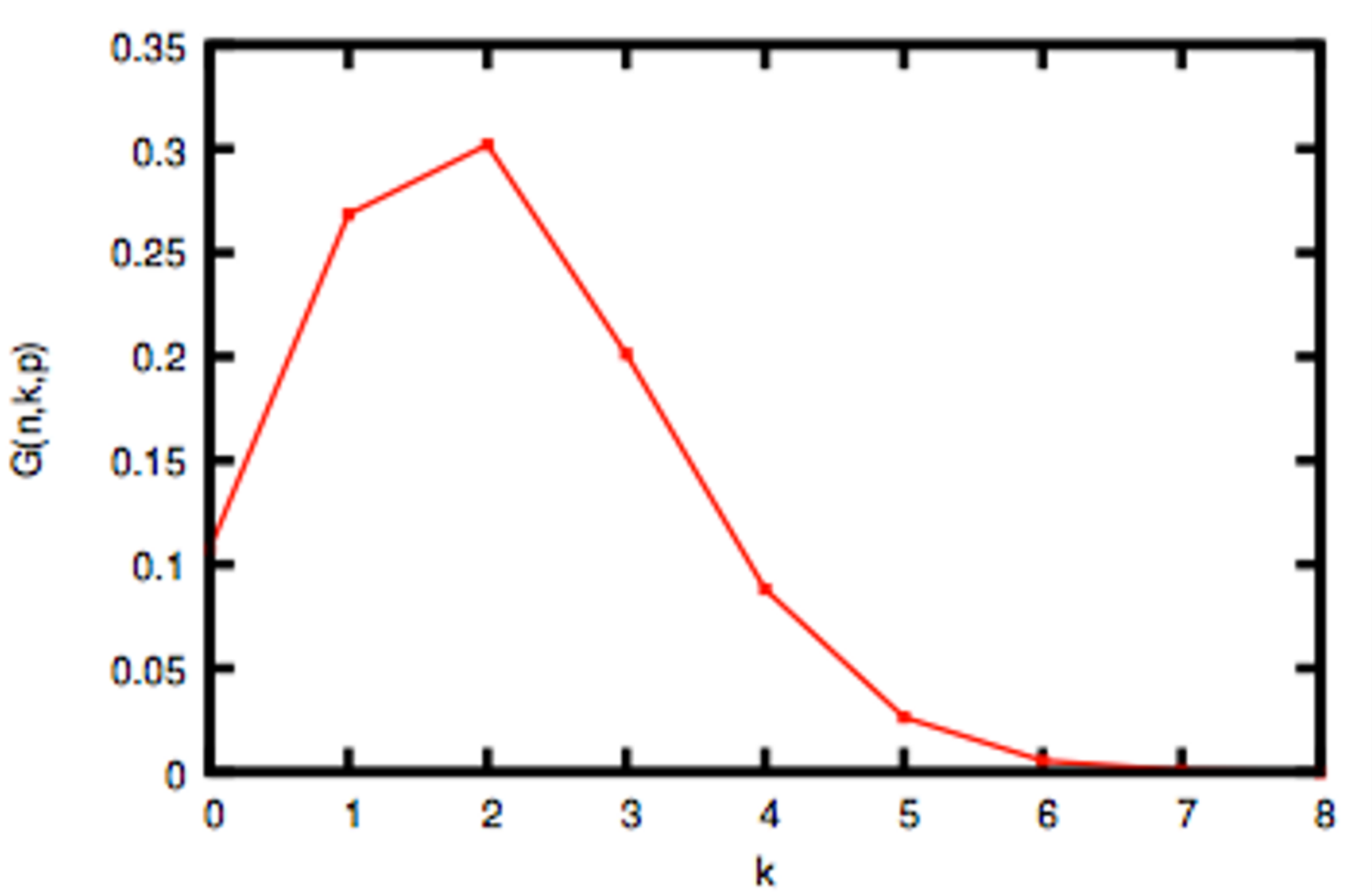
In the next generation, what is the probability that *k* of them have allele ‘a’ ?

$$G(n,k,p) = \binom{n}{k} p^k (1-p)^{n-k}$$

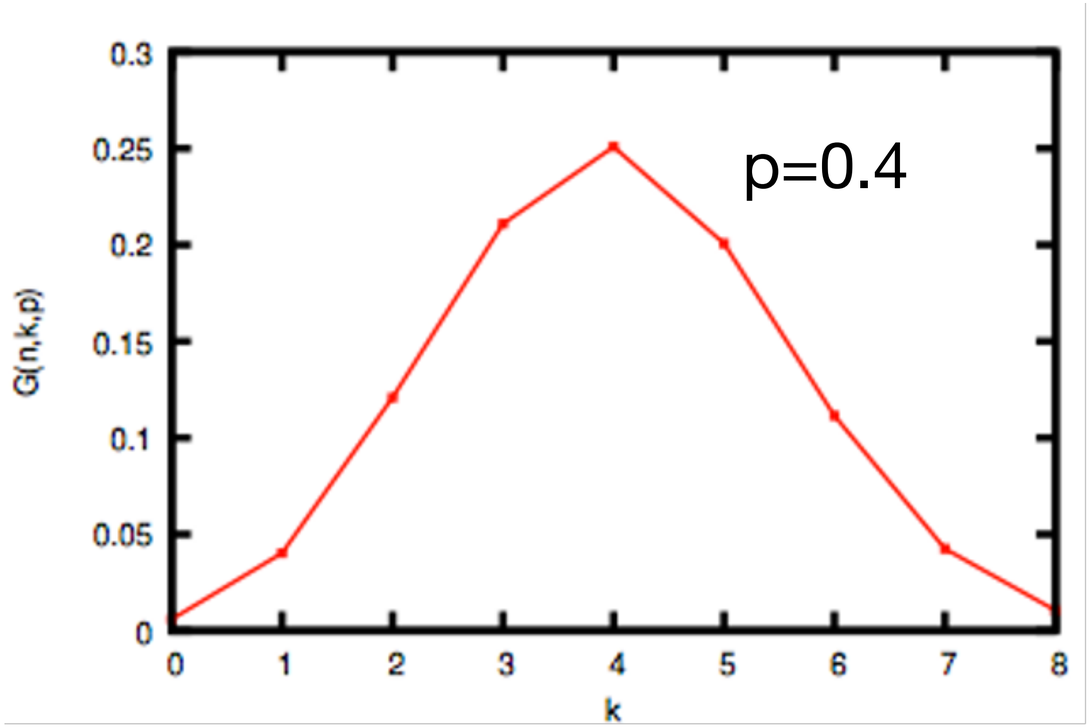
Probability that k individuals have allele ‘a’, when p=0.4

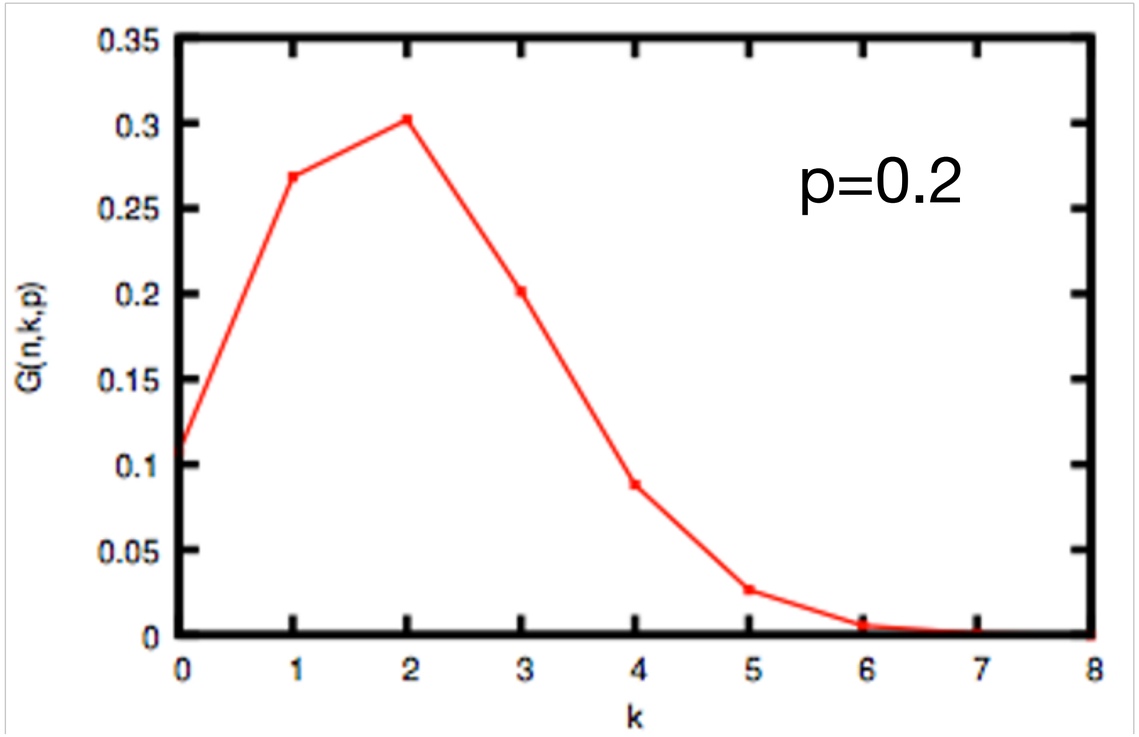


Probability that k individuals have allele ‘a’, when p=0.2



Probability of losing an allele= what is the probability that no individual in the next generation has that allele?





You can extend the model to introduce mutations with probability m

Each offspring inherits chromosome of the parent with a probability (1-m). With probability m, it will change the allele

This can answer many interesting questions:

For example: What is the probability that two Individuals had a common parent t generation ago ?

Statistics plays a very important role in biology

Summary

- How does evolution generate complex machines within a finite time?
- A simple algorithm that will demonstrate the key idea
- Diversity in a population
- Ideas from statistics are powerful to understand ideas in biology