Why did life turn to multicellularity?

Individual cells are great, but with little perspectives

Cells are the basic units of life:

- ⇨ They are simple: a few organelles are needed for their metabolism
- ⇨ They are efficient: each individual cell responds to all their needs
- ⇨ They reproduce rapidly via mitosis: A cell cycle (From 1 cell to 2 identical daughter cells) lasts a few hours ($\sim 24\ h$ for a human cell, meaning the number of cells is multiplied by 2 every 24h)

However

- ⇨ Cells are small (Ø~ a few µm): Space is limited
  - Limited storage (constant need of "energy input")
  - Limited complexity (no possibility for "enhancements")
  - ⇨ High vulnerability to environmental changes

What about growing in size?

A higher volume allows more space, therefore possibilities of complexification and more storage.
However, with increased volume comes an increased need:

- ⇨ Energy input has to increase
- ⇨ O2 input has to increase
- ⇨ CO2 output has to increase
- ⇨ Waste output has to increase

From a mathematical view: If the radius of a cell (modelled as a sphere) is multiplied by a factor n,

- Volume V increases by a factor n^3 => needs increase by a factor n^3
- Surface area SA increases by a factor n^2 => exchange capacity increases by a factor n^2

- ⇨ $\frac{SA}{V}$ ratio changes by a factor $\frac{n^2}{n^3} = n^{-1}$: The needs grow faster than the exchange capacity, meaning the needs grow faster than the capacity to respond to them.
- ⇨ This solution is not viable

Viruses are microscopic unistructural organisms that can infect host cells.

Sometimes, errors are a great thing

DNA replication is not a perfect process, and "errors" randomly occur: the wrong nucleotide can be bonded to the opposed nucleotide (e.g. C – A). These errors are called mutations.

- Efficiency of DNA replication:
  1 "error" in the replication of 10^5 – 10^6 nucleotides

To reduce the probability of these mutations, control processes occur during replication:

- Proof-reading: DNA-polymerase correction, done systematically while adding the nucleotides
  1 "error" in the replication of 10^7 nucleotides
- Mismatch correction: via the MMR system, based on Mut-proteins
  1 "error" in the replication of 10^9 – 10^{10} nucleotides

The error rate is very low, showing a very efficient process.
However, the human genome is made of ~6x10^9 pairs of bases

- ⇨ 0.6 to 6 mutations per cell cycle (mitosis)

Statistically, most of these mutations occur in non-coding DNA, or lead to non-significant changes.

⇨ 25 to 350 mutations per cell life (mitosis occurs on average from 40 to 60 times in the life of a cell)

This number is not negligible, meaning that significant consequences can occur in the lifetime of a cell.

A change in the genetic information leads to a change in the structure of the proteins produced by the ribosomes, leading to a change in their function.

⇨ Cell differentiation: the heir of a cell does not necessarily have the same metabolism than the primary cell.

A long path from multicellular colonies to complex organisms

- The earliest evidence of colonies of cells goes to 2 billion years ago.
  - ⇨ Provides mutual protection against predators.
  - ⇨ Increases efficiency of nutrients intake

Ex: Thanks to chemotaxis (response of the cytoplasm to chemical stimuli), Slime Mold colonies move towards a food source as if they were a unique organism.

However, each of these organisms remains "basic".

- 1.5 billion years ago appear the first differentiated cells: the number of mutations has been important enough for the metabolism of these cells to be significantly different.
  - ⇨ The structure of the colonies depends on these differences:
    - Outer cells focus on protection of the colony.
    - Inner cells focus on absorption of nutrients, which will then be shared amongst all cells of the colony.
    - ...

Ex: Volvox are colonial algae in which peripherical cells have flagella which allow the whole colony to move.

These colonies were more efficient. Through an easier reproduction and transmission of these characters, evolution reinforced these changes (natural selection).

- Colonies aged 800 million years are the earliest evidence for cells with permanent specialization.
  - ⇨ Specialized cells lost the ability to revert into other types.
  - ⇨ Gene regulation mechanisms controlled which cell became what.
  - ⇨ The different specialized cells were not self-sufficient anymore: The cells of the colony became inter-dependent.

- The first traces of complex organisms have been found in sandstones aged 600 million years. A clear organization can be recognized, with distinct body parts and patterns of cell organization suggesting a higher level of complexity than earlier forms of life.

Note: The term "Ediacaran biota" is commonly used to describe these macroscopic fossils found all around the world, from Russia, South Australia and Namibia to Newfoundland, China or Spain.
The more than 200 members of this biota were soft-bodied, constructed by segments of quilts of soft tissue.

Almost 3.5 billion years after the first cells, life had started to take a more complex form... This is a LOOOOOONG time, especially compared to the only 600 millions years that then lead to the biodiversity we have now: A process other than mitosis has to be involved in that.