# How Did Complex Living Cells Evolve?

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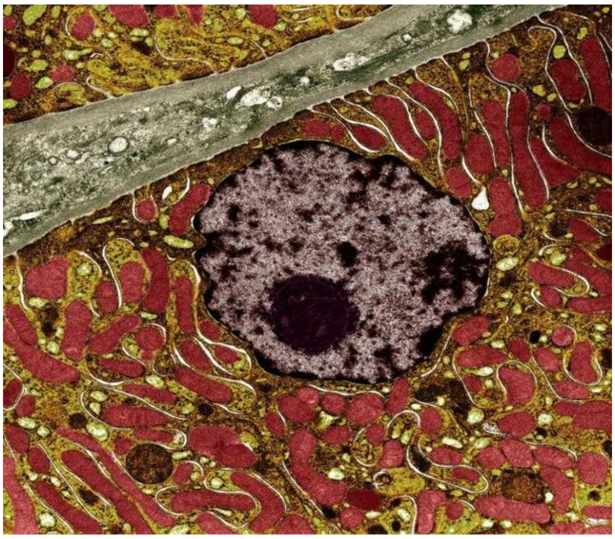
The unicellular protozoan *Phacus gigas* packed with endosymbiont algae cells living inside *P. gigas*'s cytoplasm (630x).



Mitochondria (false-coloured red) in a cell from a tubule in the kidney cortex. The nucleus of the cell has a prominent nucleolus (false-coloured dark brown).

In asking the question,[1] [2] "How Did Complex Living Cells Evolve?", do we default to answers such as, "Our gods did it, so complexity did not evolve at all"? Or, "So what, why should we care?". Or do we dig a little deeper? Let's dig a little deeper…

All—well, almost all—plant and animal cells have mitochondria. Mitochondria are important little organelles because they manufacture certain highly energetic molecules which cells need to get things done. So given the importance of mitochondria, where did they come from?

I find it fascinating that a deep ancestral connection might exist between mitochondria and certain types of bacteria. In fact, it is most likely that mitochondria were once free-swimming bacteria. The key to this mitochondrial/bacterial connection is something called *endosymbosis*.

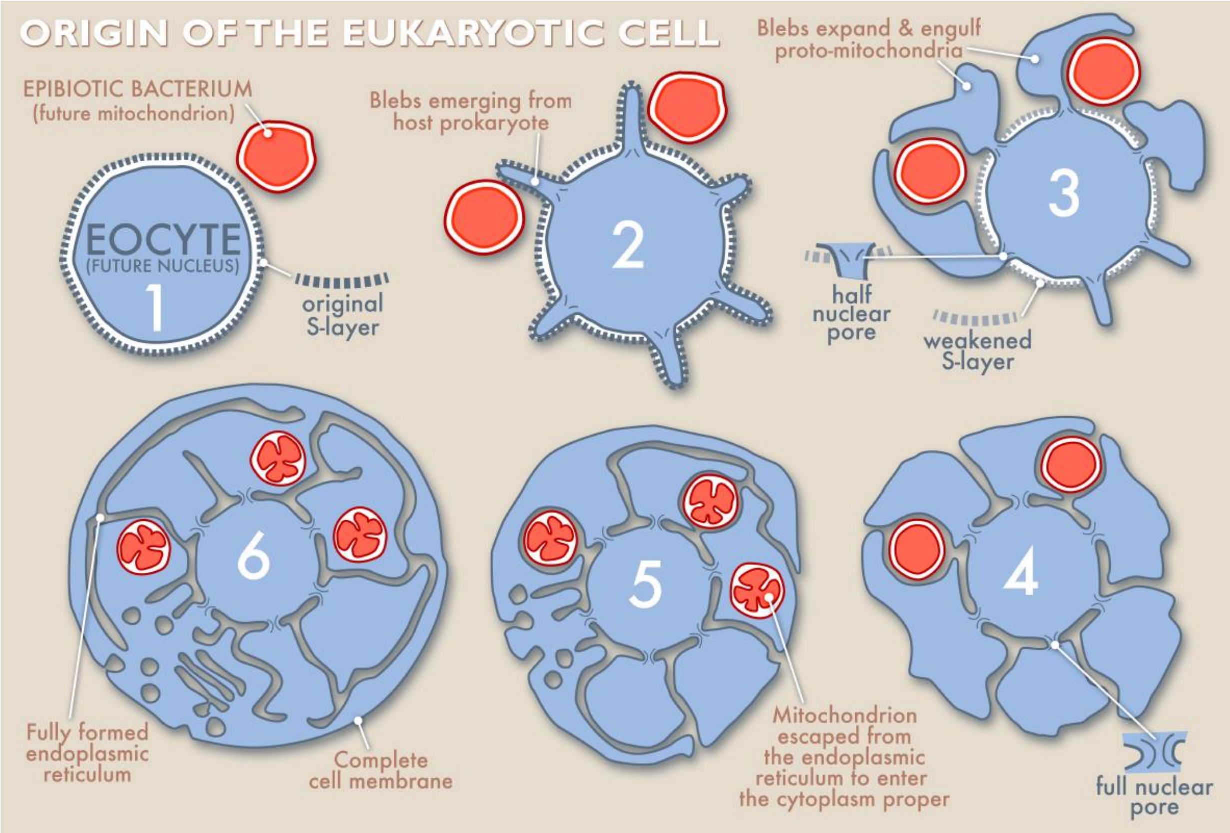
The coming about of endosymbosis on Earth is considered a major evolutionary transition. Some organisms evolved an ability to live inside the cells of other organisms without being digested, and such that both themselves and their hosts cells benefit. Indeed, endosymbiotic relationships between organisms are widely observed today.

A long time ago, life on Earth was much simpler than it is today. That's because only simple organisms existed. These were the bacteria, cyanobacteria and archaea. Each would consume each other. But the cyanobacteria also evolved an ability to convert carbon dioxide into food using sunlight. Some of the bacteria which were engulfed by the archaea were not digested. Instead, they acquired an ability to live happily inside the archaeal cells. In turn, the archaeal cells became accustomed to the bacterial cells being there.

Over time, both the bacteria and the archaea grew to depend on each other more and more. Until eventually, neither could survive without the other. And so the engulfed bacterial cells eventually lost their bacterial character and evolved into mitochondria. Correspondingly, the host archaeal cells lost their archaeal character and evolved into plant and animal cells. This remarkable story is similar for how some cyanobacteria evolved to become the photosynthetic chloroplasts in plants.

[1] Thanks to Leslie Viljoen whose Facebook post on 25Aug23 inspired this essay.

[2] See: NB Düz and P Dincer,[1] T Gabaldón[2] and T Devitt.[3]




Schematic of the *inside-outside autogenous model* of eukaryogenesis. In the model, an archaeon engulfs free-swimming proteobacteria by the outward expansion of its endosplasm (**1**, **2** & **3**). The expansion begins as blebs which form at the archaeon's outer cell wall and plasma membrane (**2**). This outward expansion offers the proto-eukaryote cell a foraging advantage (**3**) because the increased surface area of its plasma membrane increases the likelihood of engulfment by phagocytosis of nearby organisms, whilst protecting its nuclear DNA material in its central nucleoid (**4**). Some engulfed aerobic proteobacteria resist digestion (**4**) and evolve into the familiar mitochondria organelles (**5**). Over time, the nucleoid evolves into the eurkaryotic nucleus (**5** & **6**). The endoplasmic reticulum, the double-layered phospholipid enveloping membrane surrounding the nucleus, and the protein complexes located at the nuclear pores are all structural and functional remnants of the process (**6**).

*Endosymbosis*! Endosymbosis thus offered life an important cellular pathway for a ratcheting up of cellular complexity on Earth.

So as I write this short essay, I wish to honour those early bacteria, cyanobacteria and archaea. And I thank them for their struggles to survive and thrive, and to learn how to co-exist and cooperate. But I also lament that as we inevitably dwell on our human-centric issues of today and tomorrow, we often seem ignorant of the role that these and a myriad other creatures played—and do play—across the aeons in making us us.

"Bacteria, cyanobacteria and archaea, with your endosymbosis, please take a bow!"

## References


[1] NB Düz, P Dincer. A review on theories on the origin of the nucleus in modern eukaryotes. *Gene Technology*, 10(5), 2021. Retrieved from `https://www.walshmedicalmedia.com/open-access/a-review-on-theories-on-the-origin-of-the-nucleus-in-modern-eukaryotes-88171.html`. Accessed 7 April 2023.

[2] T Gabaldón. Origin and early evolution of the eukaryotic cell. *Annual Review of Microbiology*, 75(1):631–647, October 2021. Retrieved from `https://doi.org/10.1146/annurev-micro-090817-062213` Accessed 7 April 2023.

[3] Terry Devitt. New theory suggests alternate path led to rise of the eukaryotic cell. Retrieved from https://news.wisc.edu/new-theory-suggests-alternate-path-led-to-rise-of-the-eukaryotic-cell/. Accessed 3 September 2023.