The origin of the very first species and the start of Darwinian evolution

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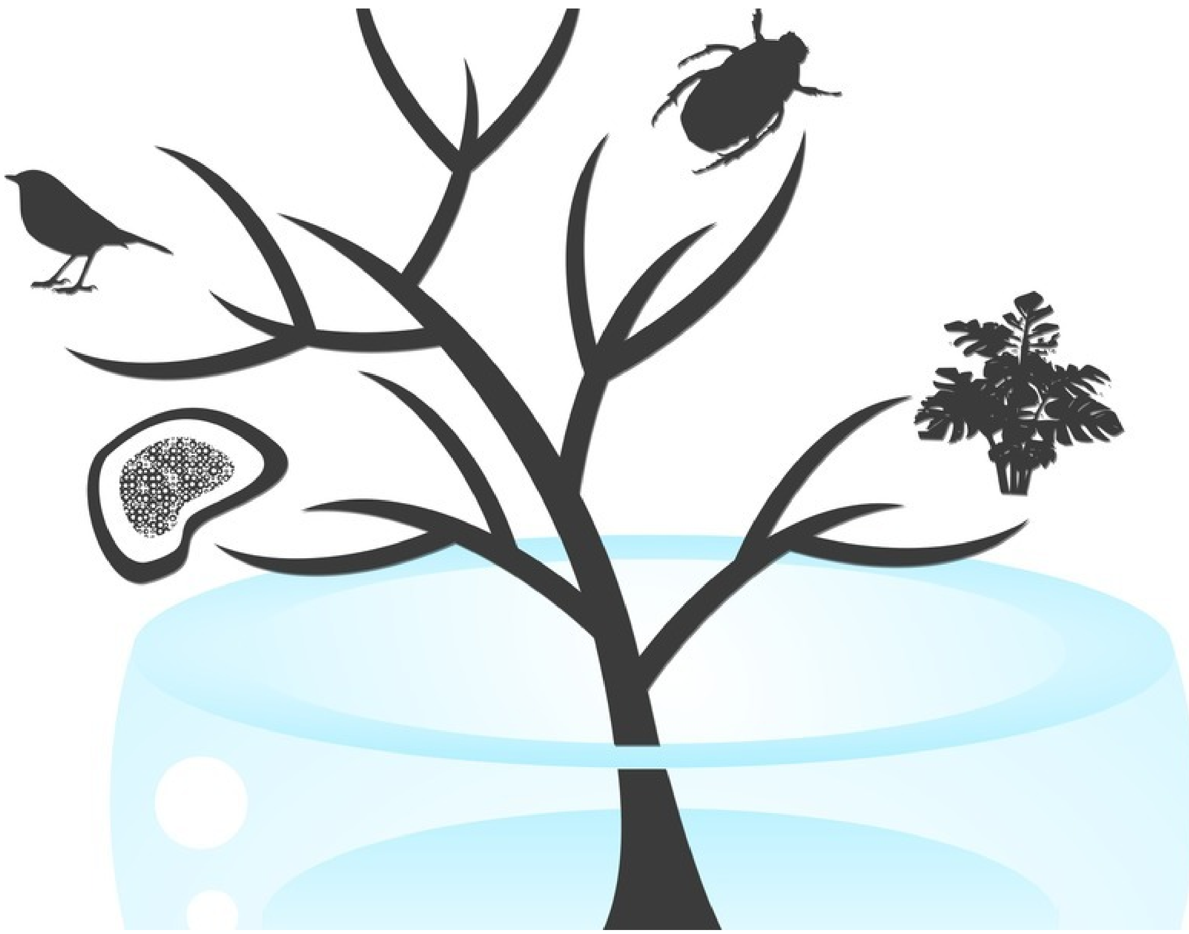

At the root of the tree of life: The first biological species, which initiated Darwinian evolution, presumably originated in a collective state of mixed genomes lacking well-defined species. Credit: Jose Casadiego, Carolin Hoffrogge and Marc Timme

During the earliest evolution on earth, life probably resembled one big genetic jumble. At some time, presumably around 3.8 to 3.5 billion years before today, the very first biological species appeared – the ancestor of all life forms that developed via Darwinian evolution. Researchers at the Max Planck Institute for Dynamics and Self-Organization in Göttingen and at Cornell University in the USA have now conceived and modelled a possible scenario by which the first defined species could have emerged from this genetic mix. The researchers proposed that before the dawn of Darwinian evolution, life fluctuated back and forth between a genetically highly mixed and a partially unmixed state. Over time, the less mixed state exhibiting a more clearly defined genetic profile became increasingly stable and eventually generated the very first species.

Already in 1937, the tree of life sketched by Darwin illustrated his hypothesis of how existing species continually gave rise to new ones while other species die out. The resulting family tree since then became the guiding principle of evolutionary research in general, highlights the common origin of all life forms as well as how they are related. The root of this genealogical tree is composed of one specific species of primordial unicellular organisms, which are the progenitors of all living beings that exist on earth today. Yet even before the emergence of this very first species, which passed on its genome from generation to generation, there was probably already life evolving on earth. "We were fascinated by the question how this first species originated and what triggered the transition to Darwinian evolution," says Marc Timme, Head of the research group on Network Dynamics at the Max Planck Institute for Dynamics and Self-Organization.

Today, some evolutionary researchers believe that the first biological species should already have possessed a relatively functional biochemical apparatus, and were relatively fit - in the Darwinian sense. Yet the components of life probably did not go together so well right from the start. Initially, life presumably existed in the form of a genetically highly mixed collective state in which the biochemistry of individuals functioned in a very rough-and-ready fashion. It seems likely that even unrelated specimens of these early life forms promiscuously exchanged genetic material via horizontal gene transfer during their lifetimes. In Darwinian evolution, however, the dominant form of inheritance from one generation to the next is vertical gene transfer, between generations.

The population's fitness increased sporadically

Thanks to this rampant exchange of genes in early evolution, it might have been possible that at different places within this strongly mixed state, individual biochemical instruments developed – instruments that were also useful for the unicellular organisms that made up the first defined species. It is conceivable that in some places even two or more of such instruments incidentally coincided. This would have increased the fitness of certain individuals, which then multiplied more rapidly and potentially also survived longer than the rest, causing their genetic code to aggregate and stand out from the otherwise randomly mixed collective of genes. It was in these organisms that the first signs of the emergence of a species sporadically began to appear.

Teaming up with Hinrich Arnoldt, who conducted research at the Max Planck Institute for Dynamics and Self-Organization, and Steven Strogatz, a scientist at Cornell University, Marc Timme has now presented a simple mathematical model showing that the collective state with highly mixed genetic material could have coexisted with the second, far less mixed state. Even at the beginning when the highly mixed state was predominant, the evolutionary dynamics repeatedly reverted into the less mixed state in which many cells shared similar genomes.

In the genetically unmixed state of greater biological fitness, the competence of unicellular organisms to engage in horizontal gene exchange with other individuals would have decreased. That is because, due to their slightly more developed biochemical apparatus, it would have been more difficult for these cells to randomly incorporate the components imposed on them during the horizontal gene exchange. It is more likely that in genetically unmixed phases, the life forms instead passed on more or less unchanged versions of their genomes to daughter cells to following generations.

Increasing fitness: from a collective state to a distinct species

Initially, however, the genetically unmixed episodes did not last very long. Time and again the advantage for survival was lost in what was still a very undefined genetic blur. Horizontal gene transfer once again took over the reins – but no longer to the same extent. A trace of the superior biological fitness remained in some individuals within the collective state. This also meant that, on average, the collective state was hampered in its efforts to exchange genes horizontally and became a bit more biologically fit.

The model proposed by the German-American research team shows that over time the declining average ability to exchange genes horizontally caused the population to remain less frequently in the highly mixed state, and more often in the less mixed state. This could have gradually accelerated the development of evolution, which ultimately led to the emergence of the first biological species: As the population's fitness increased, its ability to transfer genes horizontally decreased, causing the collective to switch into less mixed states more frequently and for longer periods of time, which in turn further raised the fitness levels of a part of the population, and thus also the average population.

The researchers' most significant finding indicates a qualitative transition that put an end to the back and forth between highly mixed and unmixed states: Once the life forms were limited in their ability to exchange genes horizontally, the less mixed state not only became more common; it was adopted permanently, as the highly mixed state no longer existed. "Strongly related cells with similar genomes would then have persisted," says Steven Strogatz. That means: A primordial species could have formed because the combined biochemical configuration of a part of the population potentially functioned so well that these cells became more viable than the rest; their genomes were transferred to new generations via vertical gene transfer. As a result, the genetic blueprint of these cells permanently stood out from the rest of the collective: The first defined species had emerged and paved the way for Darwinian evolution.

More information: Hinrich Arnoldt et al. Toward the Darwinian transition: Switching between distributed and speciated states in a simple model of early life, *Physical Review E* (2015). DOI: 10.1103/PhysRevE.92.052909

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