Finding the roots and early branches of the tree of life

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A study published in *PLoS Computational Biology* maps the development of life-sustaining chemistry to the history of early life. Researchers Rogier Braakman and Eric Smith of the Santa Fe Institute traced the six methods of carbon fixation seen in modern life back to a single ancestral form.

Carbon fixation – life's mechanism for making carbon dioxide biologically useful – forms the biggest bridge between Earth's non-living chemistry and its biosphere. All organisms that fix carbon do so in one of six ways. These six mechanisms have overlaps, but it was previously unclear which of the six types came first, and how their development interweaved with environmental and biological changes.

The authors used a method that creates "trees" of evolutionary relatedness based on genetic sequences and metabolic traits. From this, they were able to reconstruct the complete early evolutionary history of biological carbon–fixation, relating all ways in which life today performs this function.

The earliest form of carbon fixation identified achieved a special kind of built-in robustness – not seen in modern cells – by layering multiple carbon-fixing mechanisms. This redundancy allowed early life to compensate for a lack of refined control over its internal chemistry, and formed a template for the later splits that created the earliest major branches in the tree of life. For example, the first major life-form split came with the earliest appearance of oxygen on Earth, causing the ancestors of blue–green algae and most other bacteria to separate from the branch that includes Archaea, which are outside of bacteria the other major early group of single-celled microorganisms.

"It seems likely that the earliest cells were rickety assemblies whose parts were constantly malfunctioning and breaking down," explains Smith. "How can any metabolism be sustained with such shaky support? The key is concurrent and constant redundancy."

Once early cells had more refined enzymes and membranes, giving greater control over metabolic chemistry, minimization of energy (ATP) used to create biomass, changes in oxygen levels and alkalinity directed life's unfolding. In other words, the environment drove major divergences in predictable ways, in contrast to the common belief that chance dominated evolutionary innovation – and that rewinding and replaying the evolutionary tape would lead to an irreconcilably different tree of life.

"Mapping cell function onto genetic history gives us a clear picture of the physiology that led to the major foundational divergences of evolution," explains Braakman. "This highlights the central role of basic chemistry and physics in driving early evolution."

With the ancestral form uncovered, and evolutionary drivers pinned to branching points in the tree, the researchers now want to make the study more mathematically formal and further analyze the early evolution of metabolism.

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