Origin of life: A Darwinian machine for non-living objects

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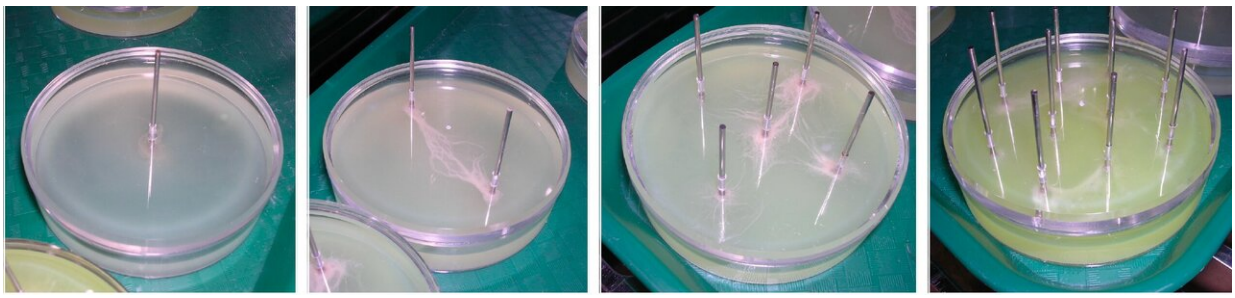

Experimental exploration of the evolution of multicellularity Credit: Paul Rainey

Life is usefully defined on the basis of process: Any set of entities that participates in the process of evolution by natural selection is alive. But how does evolution by natural selection—and thus life—get started? The answer is far from obvious. Lack of insight haunts origins of life research and plagues understanding of the major evolutionary transitions, including the transition from cells to multicellular life.

In a new paper published in *Nature Ecology & Evolution*, a team led by Paul Rainey at ESPCI Paris and the Max Planck Institute for Evolutionary Biology provides a solution. Adopting a theoretical approach inspired from earlier and on-going experiments, Rainey and his team show how ecological circumstances can kick-start life, both from the get-go, and also at each of the major evolutionary transitions.

For entities to participate in the process of evolution by natural selection, entities need to be discreet and vary one to another, entities must replicate and offspring must resemble parental types. These basic Darwinian properties (variation, reproduction and heredity) are such fundamental features of life that it is easy to take their existence for granted. But as Black et al point out, Darwinian properties are derived and require evolutionary explanation. In the absence of any manifestation of heritable variance in fitness evolution is governed by chance alone and the road out of randomness difficult to conceive.

Black et al argue that previous work has underappreciated the role of ecology. When more fully embraced, it becomes apparent that certain ecological circumstances can act to exogenously impose Darwinian properties on otherwise non-Darwinian entities. The team refers to this as "ecological scaffolding." Rainey says the necessary conditions are minimal: nothing more than patchily distributed resources and a means of between patch dispersal.

He points out that team members have previously explored the idea using bacterial populations to watch evolutionary change in real time. Starting with free-living cells the researchers exogenously imposed Darwinian properties on groups of cells resulting in the groups evolving as if members of multicellular organisms. According to Rainey, the result was striking: "Not only did groups become more successful, but they even evolved traits that underpinned a developmental program fueling a multicellular life cycle."

"In this current paper, we have taken what we learned from our earlier empirical work, removed all experimental details and built a theoretical model that is simple and generally applicable. In essence, we have produced an ecological recipe that, if followed, will result in the affected entities participating in the process of evolution by natural selection, with the outcome being some kind of Darwinian machine."

The work has exciting implications for the design of experiments looking for the emergence of life from non-living material and for understanding evolutionary transitions, but Rainey also draws attention to predictions that arise from looking for evidence of ecological scaffolding in nature. "For pathogens, such as HIV, the human host is a patch of resource. Transmission of the virus to new hosts via a single cell is akin to a group-level reproductive event."

"When this occurs," argues Rainey, "the virus will experience selective conditions as if it were part of a multicellular organism. Our theory thus predicts that HIV populations should be composed of cells that perform different functions—some soma-like and others germ line-like." Rainey points to recent evidence that this is, in fact, the case.

Ecological scaffolding, says Rainey, brings a new perspective to an old problem. Instead of appealing to focal chemistries or organisms for pre-existing solutions, scaffolding recognizes the continuity between nascent evolving systems and their environment. This view has implications for solving some of life's most fundamental problems, but also for top-down engineering new life forms.

More information: Andrew J. Black et al. Ecological scaffolding and the evolution of individuality, *Nature Ecology & Evolution* (2020). DOI: 10.1038/s41559-019-1086-9

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