Evolution shapes the pace of aging: New software brings aging simulations to researchers' laptops

Why do some species live for only weeks while others survive for centuries? Researchers at the Leibniz Institute on Aging – Fritz Lipmann Institute (FLI) in Jena have developed AEGIS, a freely available software tool that enables scientists to simulate evolution on a standard computer and investigate how lifespan and aging evolve under different ecological pressures and genetic constraints. Described in a new study published in *PLoS Computational Biology*, the platform represents years of development and marks an important milestone in the evolutionary biology of aging.

Jena. Aging is not a fixed property of life. Across the tree of life, species differ dramatically when they start to age, how fast they age, and how long they live. Understanding what evolutionary forces produced this diversity is one of the deepest open questions in biology.

The challenge of studying evolution in real time

Experiments in the wild are slow and difficult to replicate; laboratory evolution takes years. But evolution can now be run *in silico*, at scale, and at the pace of a laptop processor.

AEGIS (**A**ging of **E**volving **G**enomes **I**n **S**ilico) is a cross-platform, individual-based modeling framework developed by researchers in the Valenzano laboratory at the Leibniz Institute on Aging – Fritz Lipmann Institute (FLI). It simulates populations of virtual individuals, each carrying a heritable genome that determines their age-specific probability of survival and reproduction. Rather than imposing fixed equations from the outside, AEGIS allows aging, lifespan, and demographic patterns to emerge from the bottom up as a result of evolution under user-defined conditions. Extrinsic mortality from predators, parasites, starvation, and seasonal abiotic stress can all be configured individually. Sexual and asexual reproduction, overlapping and non-overlapping generations, and varying germline mutation rates are all modifiable parameters. The tool comes with a graphical user interface, a web server for users who prefer not to install software locally, built-in visualization and analysis routines, and full documentation designed to make it accessible to researchers from diverse technical backgrounds.

Running evolution i*n silico*

"AEGIS is designed to run *in silico* experiments, where researchers allow virtual populations of organisms, but also cells, to evolve genetically under different selective pressures and environmental and niche constraints," says Prof. Dario Riccardo Valenzano, Scientific Director at the FLI and senior author of the publication.

The simple rules behind the complexity of aging

The central message of the paper is as striking as it is simple: given a population of individuals that replicate, mutate, and carry heritable gene modules affecting their age-specific chances of surviving and reproducing, aging emerges on its own after the onset of sexual maturation. No dedicated aging program is required. No special molecular mechanism needs to be invoked. Aging is not a biological puzzle awaiting a novel explanation — it is a corollary of the most basic rules of hereditary variation under age-structured selection, a result that Hamilton

predicted mathematically in 1966 and that AEGIS now makes directly observable and experimentally manipulable.

"AEGIS shows that with a few simple ingredients — replication, mutation, and evolvable gene modules affecting survival and reproduction at discrete ages — aging emerges inevitably after sexual maturation," says Prof. Valenzano. "No big mystery. Just a consequence of basic evolutionary foundations."

Reproducing and extending classic experiments

One of the key demonstrations presented in the paper is a computational replication of Rose's classic 1984 fruit fly *(Drosophila melanogaster)* experiment, in which populations of flies selected to reproduce only late in life evolved longer lifespans over successive generations. AEGIS recapitulates this result and extends it: when the evolved populations are subsequently placed in a simulated wild-like environment with high extrinsic mortality, the lifespan advantage largely disappears — consistent with theoretical predictions that delayed senescence is unlikely to evolve under high natural hazard. This illustrates how AEGIS can be used not just to reproduce known results, but to probe their boundary conditions and generalize findings that would be difficult or impossible to test experimentally.

A tool for accessible and scalable research

Beyond specific experiments, AEGIS generates comprehensive demographic, phenotypic, and genotypic outputs that support population genetic analyses, including site frequency spectra and allele frequency dynamics, and allows users to disentangle intrinsic genetic mortality from extrinsic environmental causes of death. Emergent phenomena such as late-life mortality plateaus and the rectangularization of survivorship curves arise naturally from the simulations without being imposed as model assumptions.

"With AEGIS you can run experiments on your laptop and accumulate large amounts of data," says Valenzano. "AEGIS comes at a time when systems biology and data science are becoming a commonly spoken language in biology of aging curricula. We are thrilled AEGIS is finally out, and I look forward to seeing this tool adopted by an increasing number of researchers interested in how evolution molds lifespan and aging."

The publication is the result of years of teamwork across multiple generations of lab members. The first seed of the project was planted by Arian Šajina, who joined the laboratory as a high-school intern and made foundational conceptual and software contributions. The project was then carried forward through critical methodological and computational work by Will Bradshaw, a former PhD student in the group. The paper's lead author, Martin Bagic, also a former PhD student in the Valenzano laboratory, brought the project to completion, driving the formal analysis, validation, visualization, and writing that resulted in the published manuscript.

AEGIS is freely available at https://github.com/valenzano-lab/aegis.

Publication

AEGIS: Individual-based modeling of life history evolution. Bagic M, Šajina A, Bradshaw WJ, Valenzano DR. PLoS Comput Biol. 2026, 22(3), e1014109.

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https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1014109

Software AEGIS GitHub repository: https://github.com/valenzano-lab/aegis

Picture

Researchers at the FLI have developed AEGIS, a freely available software tool that enables scientists to simulate evolution on a standard computer and investigate how lifespan and aging evolve under different ecological pressures and genetic constraints. The platform represents years of development and marks an important milestone in the evolutionary biology of aging. (Picture: FLI / Kerstin Wagner; partly AI-generated with ChatGPT)

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Background

The Leibniz Institute on Aging - Fritz Lipmann Institute (FLI) in Jena is a federal and state government-funded research institute and member of the Leibniz Association (Leibniz-Gemeinschaft). FLI conducts internationally recognized, high-impact research on the biology of aging at the molecular, cellular, and systems levels. Scientists from around 40 countries investigate the mechanisms of aging to uncover its root causes and pave the way for strategies that promote healthy aging. Further information: www.leibniz-fli.de.

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The Leibniz Association identifies focus areas for knowledge transfer to policy-makers, academia, business and the public. Leibniz institutions collaborate intensively with universities – in the form of “Leibniz ScienceCampi” (thematic partnerships between university and non-university research institutes), for example – as well as with industry and other partners at home and abroad.

They are subject to an independent evaluation procedure that is unparalleled in its transparency. Due to the importance of the institutions for the country as a whole, they are funded jointly by the Federation and the Länder, employing some 21,400 individuals, including 12,170 researchers. The entire budget of all the institutes is approximately 2,3 billion Euros. For more information: www.leibniz-gemeinschaft.de/en/.