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Reliability theory explains human aging

Posted By: News-Medical in Medical Research News

Published: Monday, 4-Oct-2004

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The quest to understand and control aging has led University of Chicago biologists Leonid Gavrilov and Natalia Gavrilova to draw inspiration from what might seem an unlikely source: reliability engineering.

The reliability-engineering approach to understanding aging is based on ideas, methods, and models borrowed from reliability theory. Developed in the late 1950s to describe the failure and aging of complex electrical and electronic equipment, reliability theory has been greatly improved over the last several decades. It allows researchers to predict how a system with a specified architecture and level of reliability of the constituent parts will fail over time. But the theory is so general in scope that it can be applied to understanding aging in living organisms as well.

In the ways that we age and die, Gavrilov and Gavrilova find, we are not so different from the machines we build. "The difference is minimized if we think of ourselves in this unflattering way: we are like machines made up of redundant components, many of which are defective right from the start," the two write in the September issue of IEEE Spectrum.

In reliability theory, aging is defined through the increased risk of failure. More precisely, something ages if it is more likely to fall apart, or die, tomorrow than today. If the risk of failure does not increase as time passes, then there is no aging.

By looking closely at human aging data, the University of Chicago researchers noted striking similarities between how living organisms and technical devices age and fail. In both cases, the failure rate follows a curve shaped roughly like a bathtub. The curve consists of three stages, called infant mortality, normal working, and aging. Death rates are rather high during infant mortality, but then drop to a low constant rate during the normal-working period. In humans, "this period is all too short, just 10 to 15 years, starting at about age 5," write Gavrilov and Gavrilova, a husband and wife team. "If only we could maintain our body functions as they are at age 10, we could expect to live about 5000 years on average."

Machines and humans even share these strange characteristics at very old age. As humans approach the age of 100, the risk of death stops increasing exponentially and instead begins to plateau. "If you live to be 110, your chances of seeing your next birthday are not very good, but, paradoxically, they are not much worse than they were when you were 102," the authors write. "There have been a number of attempts to explain the biology behind this in terms of reproduction and evolution, but since the same phenomenon is found not only in humans, but also in such man-made stuff as steel, industrial relays, and the thermal insulation of motors, reliability theory may offer a better way."

An immediate consequence of the last observation is that there is no fixed upper limit to human longevity--there is no special number that separates possible from impossible values of a life span. This conclusion flies in the face of the common belief in the existence of a fixed maximal human life span and a biological limit to longevity.

The University of Chicago researchers were able to adapt reliability theory to biological aging by thinking of humans as a collection of redundant parts that do not, in themselves, age. But to get the model to work exactly, Gavrilov and Gavrilova had to make a radical assumption. Instead of humans starting life in pristine condition, the reliability equations suggest that we actually start with a great many defective parts. "If we accept the idea that we are born with a large amount of damage, it follows that even small improvements to the processes of early human development--ones that increase the numbers of initially functional elements--could result in a remarkable fall in mortality and a significant extension of human life," write Gavrilov and Gavrilova.

The authors are research associates at the Center for Aging at the University of Chicago's National Opinion Research Center. Their research was sponsored by the National Institute on Aging.

Full text of the published article "Why We Fall Apart" by Leonid Gavrilov and Natalia Gavrilova in the September 2004 issue of the IEEE Spectrum journal is available online at:
http://www.spectrum.ieee.org/WEBONLY/publicfeature/sep04/0904age.html

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