Hierarchies exist in the brain because of lower connection costs, research shows

Findings may also improve artificial intelligence and robotics systems

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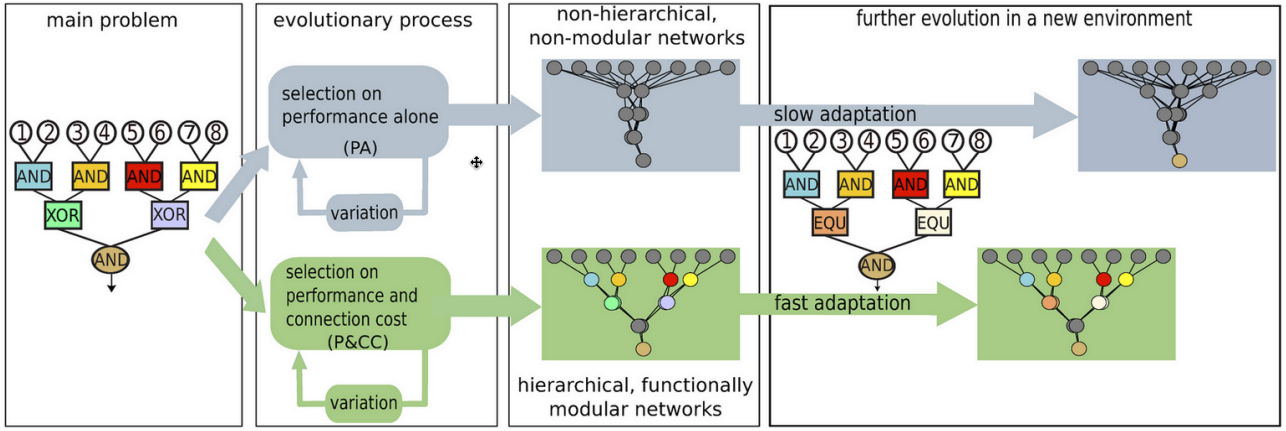

The Evolutionary Origins of Hierarchy: Evolution with performance-only selection results in non-hierarchical and non-modular networks, which take longer to adapt to new environments. However, evolving networks with a connection cost creates hierarchical and functionally modular networks that can solve the overall problem by recursively solving its sub-problems. These networks also adapt to new environments faster. (credit: Henok Mengistu et al./PLOS Comp. Bio)

New research suggests why the human brain and other biological networks exhibit a hierarchical structure, and the study may improve attempts to create artificial intelligence.

The study, by researchers from the University of Wyoming and the French Institute for Research in Computer Science and Automation (INRIA, in France), demonstrates that the evolution of hierarchy — a simple system of ranking — in biological networks may arise because of the costs associated with network connections.

This study also supports Ray Kurzweil's theory of the hierarchical structure of the neocortex, presented in his 2012 book, *How to Create a Mind*.

The human brain has separate areas for vision, motor control, and tactile processing, for example, and each of these areas consist of sub-regions that govern different parts of the body.

Evolutionary pressure to reduce the number and cost of connections

The research findings suggest that hierarchy evolves not because it produces more efficient networks, but instead because hierarchically wired networks have fewer connections. That's because connections in biological networks are expensive — they have to be built, maintained, etc. — so there's an evolutionary pressure to reduce the number of connections.

In addition to shedding light on the emergence of hierarchy across the many domains in which it appears, these findings may also accelerate future research into evolving more complex, intelligent computational brains in the fields of artificial intelligence and robotics.

The research, led by Henok S. Mengistu, is described in an open-access paper in *PLOS Computational Biology.* The researchers also simulated the evolution of computational brain models, known as artificial neural networks, both with and without a cost for network connections. They found that hierarchical structures emerge much more frequently when a cost for connections is present.

Aside from explaining why biological networks are hierarchical, the research might also explain why many man-made systems such as the Internet and road systems are also hierarchical. "The next step is to harness and combine this knowledge to evolve large-scale, structurally organized networks in the hopes of creating better artificial intelligence and increasing our understanding of the evolution of animal intelligence, including our own," according to the researchers.

Abstract of *The Evolutionary Origins of Hierarchy*

Hierarchical organization—the recursive composition of sub-modules—is ubiquitous in biological networks, including neural, metabolic, ecological, and genetic regulatory networks, and in human-made systems, such as large organizations and the Internet. To date, most research on hierarchy in networks has been limited to quantifying this property. However, an open, important question in evolutionary biology is why hierarchical organization evolves in the first place. It has recently been shown that modularity evolves because of the presence of a cost for network connections. Here we investigate whether such connection costs also tend to cause a hierarchical organization of such modules. In computational simulations, we find that networks without a connection cost do not evolve to be hierarchical, even when the task has a hierarchical structure. However, with a connection cost, networks evolve to be both modular and hierarchical, and these networks exhibit higher overall performance and evolvability (i.e. faster adaptation to new environments). Additional analyses confirm that hierarchy independently improves adaptability after controlling for modularity. Overall, our results suggest that the same force–the cost of connections–promotes the evolution of both hierarchy and modularity, and that these properties are important drivers of network performance and adaptability. In addition to shedding light on the emergence of hierarchy across the many domains in which it appears, these findings will also accelerate future research into evolving more complex, intelligent computational brains in the fields of artificial intelligence and robotics.

References:

- Henok Mengistu, Joost Huizinga, Jean-Baptiste Mouret, Jeff Clune. The Evolutionary Origins of Hierarchy. PLOS Computational Biology 2016 DOI: 10.1371/journal.pcbi.1004829 (open access)