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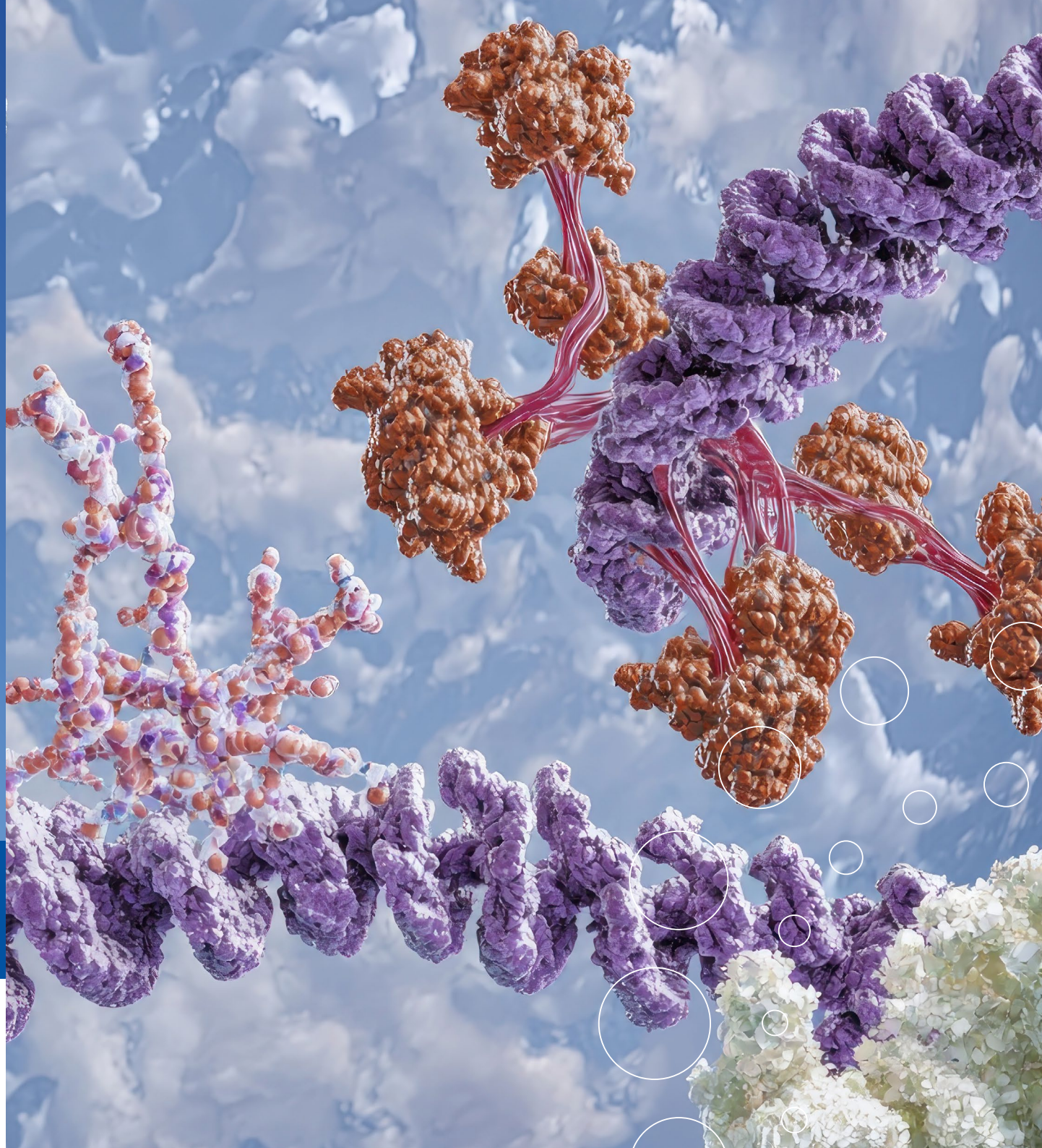
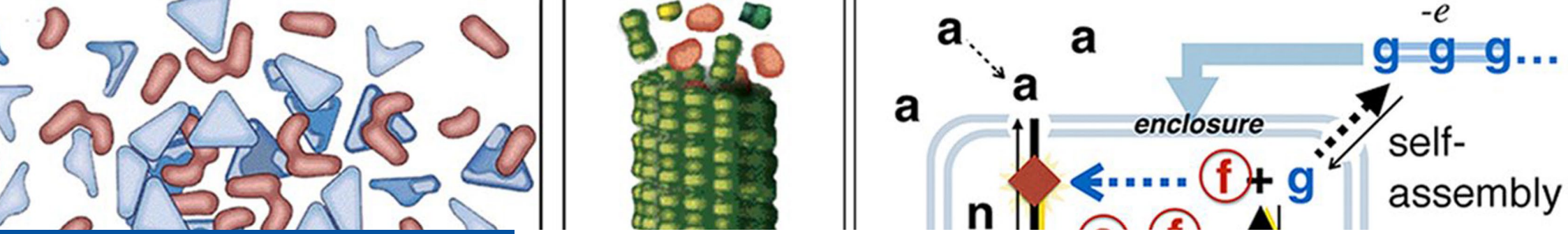




Credit. Terrence W Deacon.

Challenging the RNA-World: Deacon's Semiotic Approach to the Origin of Life

Challenging the established RNA-World Model, Dr Terrence Deacon of the University of California, Berkeley, provides an exciting new approach to understanding biological processes and the emergence of information in biological systems.

Understanding the Origins of Life

The RNA-World hypothesis has long dominated the scientific understanding of life's origins, suggesting that molecular replication, particularly RNA's ability to self-replicate, provides a sufficient explanation for the emergence of life. This model assumes that molecules like RNA and DNA inherently carry information, driving biological processes and passing on life's organisational structure across generations.

Dr Terrence Deacon of the University of California, Berkeley, challenges this view, arguing that replication alone cannot account for the semiotic properties necessary for life – properties that involve interpretive processes, not mere replication. In his paper titled 'How Molecules Became Signs', Dr Deacon proposes that, while replication is important, it does not explain how molecules come to represent information meaningfully within biological systems. Instead, Dr Deacon introduces the concept of autogenic viruses – self-reproducing, non-parasitic systems capable of semiotic behaviour – as a model for how molecular systems might evolve to interpret their environment, thus forming the basis for life's semiotic processes.

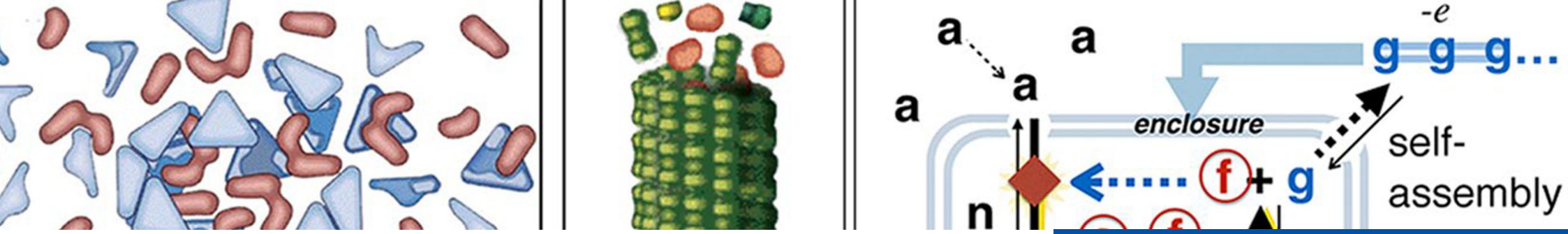
A New Perspective on Life's Origins

Dr Deacon critiques the assumption that molecular replication is the critical first step toward life. Rather than life beginning with molecular replication, Dr Deacon argues that RNA and DNA molecules did not initially evolve for informational functions but rather acquired this function secondarily. Instead, he hypothesises that life began as non-parasitic virus-like molecular structures – autogenic viruses – that are capable of self-repair and self-reproduction. Though no autogenic viruses are currently known, Dr Deacon contends that their potential existence and properties are empirically testable.

Dr Deacon argues that the simplest form of autogenic virus can be comprised of two linked self-organising chemical processes: reciprocal catalysis and self-assembly. These two classes of chemical processes are commonly found both in the living and nonliving worlds. Reciprocal catalytic interactions occur when catalyst A produces catalyst B, and catalyst B, in turn, produces catalyst A. As a result, the local concentrations of the two catalysts can rapidly grow. Self-assembly is a molecular variant of crystallisation in which molecules spontaneously stick together because of their geometric and chemical symmetries to form sheets, tubes, or polyhedrons. The molecular shells that enclose viruses – called capsids – self-assemble, as do many components of living cells like membranes and microtubules.

Together these two chemical processes provide each other's critical boundary conditions and so can restabilise each other should the whole become damaged. They can become inseparably linked if a reciprocal catalytic process produces side products that can self-assemble into a capsid, thereby containing the catalysts that produce it. This constitutes an autogenic (self-generating) virus-like structure because if damaged, it will 'spill' its catalytic contents, which will then produce more catalysts and capsid molecules and reassemble the whole. For Dr Deacon, this self-reconstructive capacity becomes the model for minimal semiotic behaviour because it effectively re-presents itself.

An autogenic virus can also reproduce itself if its components become dispersed so widely that separate regions reconstitute in isolation, provided the necessary substrates are present in the environment. This non-parasitic capacity for self-repair and reproduction makes the autogenic virus a unique candidate for exploring the minimal conditions required for life-like behaviour.



Credit. Terrence W Deacon.

Limitations of the RNA-World Hypothesis

The RNA-World hypothesis is rooted in the discovery that RNA can serve both as a template for replication and as a catalyst for chemical reactions. However, while the hypothesis successfully accounts for how molecules like RNA could replicate themselves, it faces significant theoretical and empirical limitations. This view assumes that the sequence of nucleotides in an RNA molecule is inherently informative – a blueprint for life processes. Nucleotides are treated as representations of molecular structures, and replication is seen as a transmission of this information across generations. This assumption is captured in what Francis Crick famously termed the 'central dogma' of molecular biology, in which information flows from nucleic acids (DNA/RNA) to proteins, but not in reverse.

Dr Deacon challenges this paradigm by pointing out that replication alone cannot account for the semiotic nature of information in biological systems. He argues that this view reduces information to a passive property of molecular structures, ignoring the critical question of 'aboutness' – the capacity of molecules to be interpreted as representing something beyond themselves. In the RNA-World model, there is no mechanism by which molecular sequences acquire meaning or significance within a biological system other than their ability to replicate.

This reductionist approach, Dr Deacon contends, obscures a crucial distinction, namely, 'information is not simply a pattern'. While a nucleotide sequence may carry a regular structure, the role of that sequence as information requires an interpretive process beyond mere replication. For a sequence of RNA to be about something and to represent a function or a process, there must be an interpretive system that interacts with the molecule, interpreting its structure in relation to other molecules and the environment.

The RNA-World hypothesis also struggles with the issues of error correction and functional relevance. While replication might explain how molecules can persist across generations, it does not explain how errors in replication are recognised and corrected, nor how these molecular structures come to have functional relevance in a biological system. As Dr Deacon points out, replication on its own lacks any intrinsic mechanism for distinguishing between a 'meaningful' copy and an 'error'.

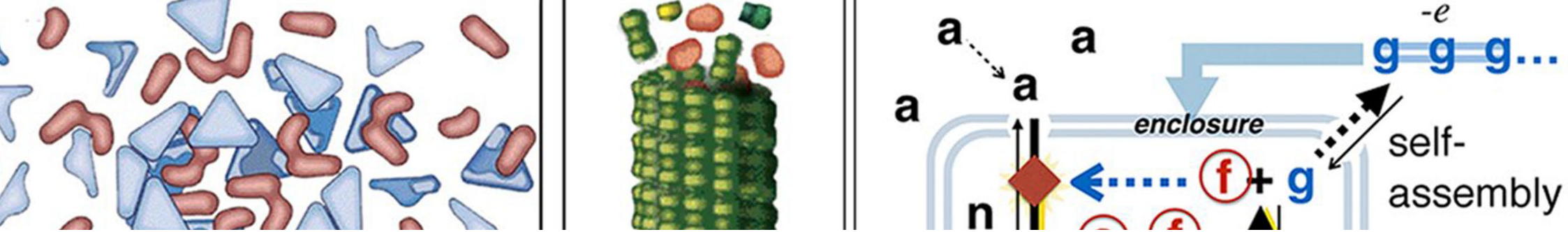
Furthermore, Dr Deacon criticises the RNA-World model for its external perspective on biological information. From an external human observer's point of view, we can describe nucleotide sequences as information that codes for proteins or other biological functions. However, within the molecular system itself, there is no such intrinsic representation unless there is a process that treats the sequence as meaningful in the context of the organism's survival and reproduction.

Semiotic Scaffolding

Autogenic dynamics helps to answer a central question: 'What is necessary and sufficient for a molecule to function as a sign?'. A sign is something that stands for something else to an interpreter. Anything can serve as a sign for something else, given an appropriate interpretive process. So, explaining what constitutes an interpreter at this simplest molecular level becomes the goal.

To help explain how a molecule like RNA can initially become endowed with the capacity to record and organise the relationships between other molecules of a primitive life-like system, Dr Deacon outlines a logic of 'semiotic scaffolding'. Semiotic scaffolding is a process by which simple semiotic relationships become the foundation upon which progressively more complex semiotic relationships can be built.

> By outlining the minimal conditions required for semiosis, the autogenic virus offers a clearer, more testable alternative than other origin-of-life models, and avoids the even more questionable assumption that RNA replication is intrinsically informational.



Credit. Terrence W Deacon.

Using a 'scaffolding logic', Dr Deacon argues that there are three progressively more complex levels of semiotic relationships that emerge from molecular interactions. Following Charles Peirce's semiotic categories of icon (correspondence of form), index (physical correspondence), and symbol (indirect correspondence), he argues that there are molecular analogues to these relationships that are effectively 'interpreted' by the processes of autogenic self-repair and reproduction.

Dr Deacon contends that this provides a proof-of-principle that semiotic processes can emerge from basic molecular interactions. To link this with molecular genetics, he then shows how some of the self-reconstituting constraints of autogenesis can be progressively off-loaded onto the structure of a molecule, like RNA.

Examining the Relationships between Molecules

The distinct properties of different molecules can become affordances that the autogenic process can interpret with respect to its successful self-preservation. At the most basic level, if two different molecules are incorporated into the autogenic process in a way that makes no difference, they are interpreted as iconic of one another. At a slightly more complex level, molecules that are consistently associated with each other by physical connection or correlated interactions can be interpreted indexically. With respect to autogenic persistence, the presence of one predicts the other and anticipates the effect that their interaction produces. Combining iconic and indexical interpretive properties can further provide an interpretive bridge linking otherwise unrelated molecules to one another with respect to their contribution to the autogenic process. So, although these semiotic terms originally referred to mental concepts, they have analogues at the bio-molecular level. This conceptual correspondence constitutes the basis for the field of biosemiotics.

To exemplify this semiotic scaffolding, Dr Deacon describes two more complex variants of the autogenic process: one with a selectively sensitive capsid surface and another containing a molecular template. In the first case, if surrounding substrate molecules for catalysis tend to stick to the capsid surface and weaken it depending on their numbers, it will bias breakage in contexts favourable to reproduction. Substrate binding will be interpreted by this action as indicating likely reproduction. In the second case, if another side product of reciprocal catalysis is a molecule onto which catalysts bind in an order appropriate to their optimal interaction probabilities, it will enable a more complex pattern of reciprocal catalysis to evolve by off-loading interaction probabilities onto this molecular structure. In this case, the structure of that molecule will become information about the structure of this catalytic process. Because this relationship is neither iconic nor indexical to the catalytic organisation it influences it is analogous to a symbolic relation, as are DNA sequences to the cellular processes they regulate.

The semiotic scaffolding that supports this process is built up from the more fundamental levels of iconic and indexical interpretation, creating a system capable of using the structure of a molecule like DNA to store and reproduce information about the molecular relationships it helps maintain and propagate. This demonstrates how molecular constraints can provide the basis for molecular semiosis.

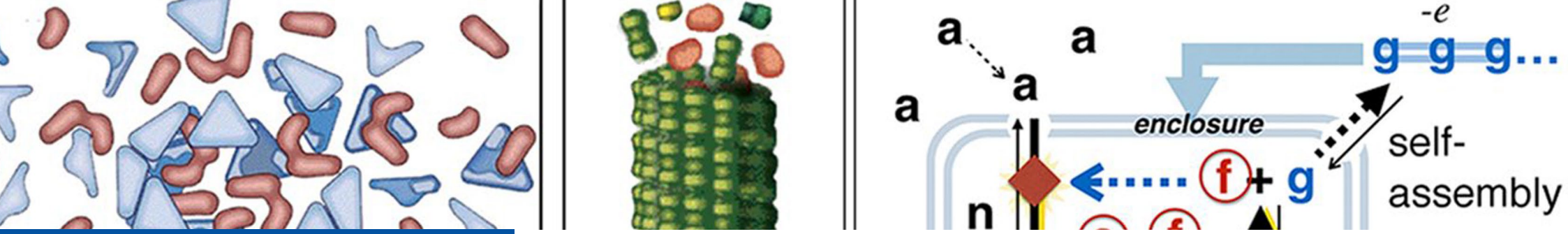
Recognising how molecular constraints can provide biological information enables Dr Deacon to identify a broader principle: the interdependence of semiosis and thermodynamics.

Drawing on the work of Stuart Kauffman, Dr Deacon explains that thermodynamic work requires both a source of energy and constraints that channel that energy into productive activities. For living systems, the source of energy is often external, but the constraints that direct this energy are internal to the system. The autogenic virus exemplifies this principle by using external energy sources – such as available substrates – to fuel internal processes of self-repair and reproduction, all while maintaining the internal semiotic constraints that define its structure and function.

The Role of Nucleotides

Following a suggestion originally made by the physicist Freeman Dyson, Dr Deacon argues that the original function of nucleotides (the basic building blocks of RNA and DNA) was to capture and transfer energy to aid catalytic chemistry (as nucleotides still do). But in quiescent periods, energetic molecules can be problematic. But when nucleotides are polymerised into an RNA string this free energy is neutralised, leaving the form of the nucleotide sequence available to be recruited for other purposes, such as information storage.

Dr Deacon suggests that such polymerised nucleotides would provide an ideal template molecule onto which catalysts could bind. This is because the specific sequence of nucleotides in the polymer determines its shape. Template shape determines the pattern of catalyst binding, and catalyst binding order determines the pattern of reciprocal catalysis that supports autogenesis. As a result, the nucleotide sequence will be subject to natural selection for its contribution to survival and reproduction. Re-presenting the dynamical constraints of autogenic chemistry as the structural constraints of a linear molecule like RNA creates a primitive form of genetic information.



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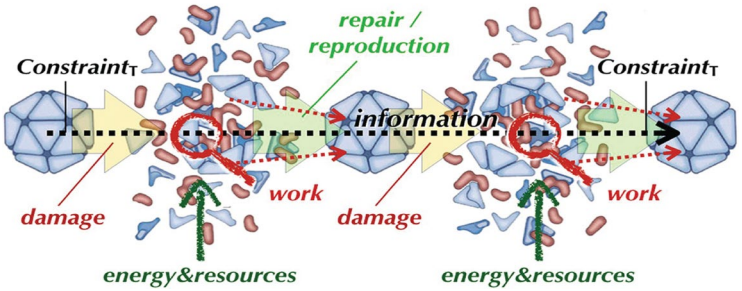


This diagram depicts two cycles of damage and self-repair in which integrity is temporarily lost but the intrinsic constraints distributed in co-localised molecules enables the recruitment of energy and new substrates from the environment to reconstitute autogenic integrity. As a result, the constraints embodied in the first inert autogen are maintained throughout. They remain continuously present despite old molecular substrates being replaced by newly synthesised ones. In this way, information in the form of these constraints is inherited by future materially independent replicas and "instructs" their formation

Credit. Terrence W Deacon.

From Molecules to Minds

Dr Deacon suggests that the semiotic processes seen in these molecular systems have analogues in other more complex forms of interpretation, such as those produced by nervous systems and, ultimately, in cognition. The triadic scaffolding of iconic, indexical, and symbolic relations is generic, irrespective of whether it is embodied in molecules, neural signals, or words. As life evolves, this scaffolding is recursively expanded, allowing organisms to interpret not only chemical signals but also sensory data, social interactions, and abstract concepts.

Dr Deacon maintains that these higher-order semiotic processes evolved from basic beginnings to form a nested hierarchy of semiotic complexity. It suggests that the ability to interpret signs is a fundamental feature of living systems, extending from simple molecules to complex thought.

Criticisms and Responses

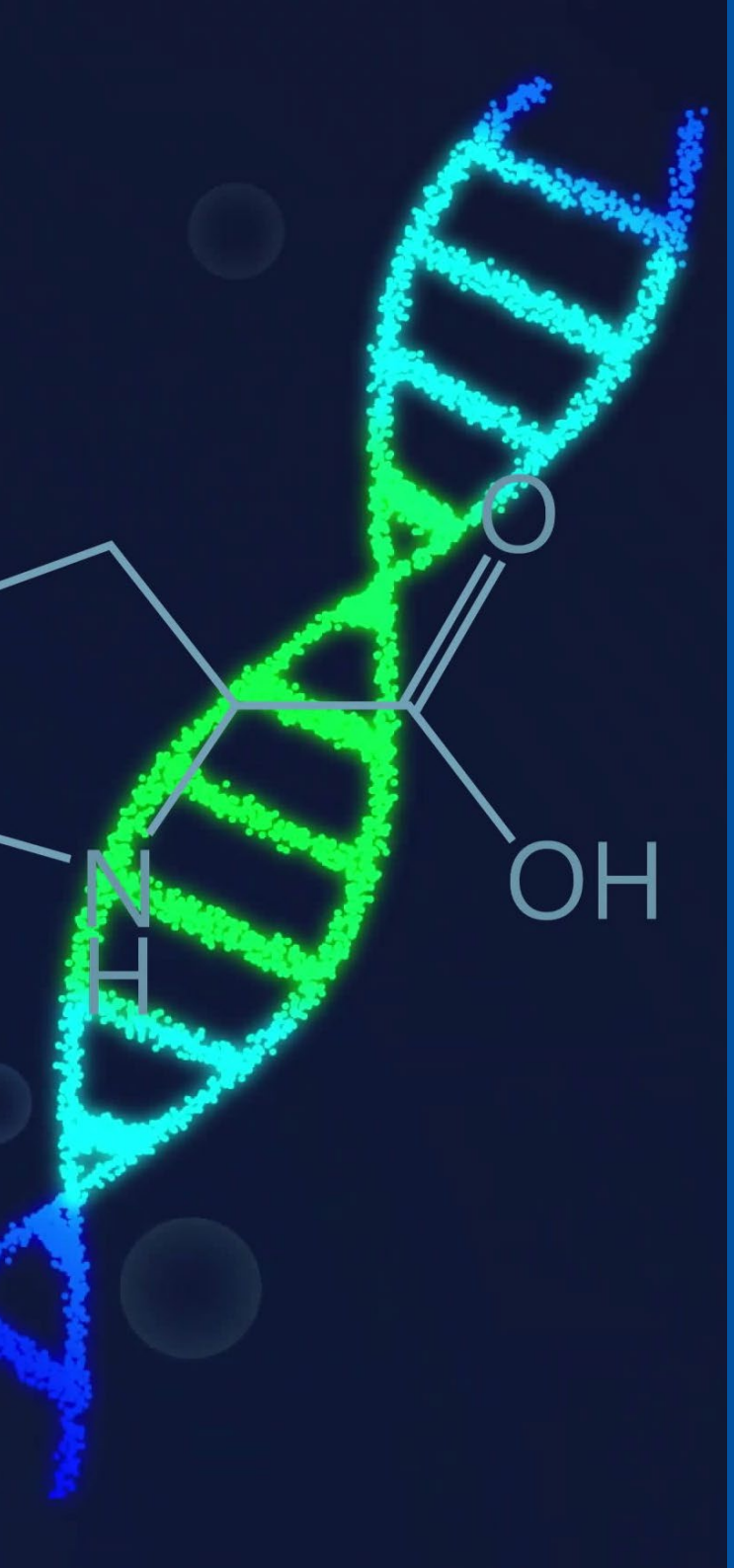
One major criticism of the autogenic virus model concerns its reliance on external stimuli to initiate self-repair and replication. Tom Froese, for example, argues that this reliance limits the system's semiotic competence because it lacks internalised activity – an essential feature of most living organisms. Dr Deacon responds by emphasising that semiotic competence does not require constant internal activity. He points to biological examples, such as seeds and spores, which can remain dormant for extended periods yet retain their potential for life. The autogenic virus functions similarly, remaining inactive until triggered by external conditions.

Other criticisms focus on the model's reliance on generic chemical processes without fully specifying the specific molecules or chemical reactions involved in the virus's catalytic and self-assembly dynamics. While some argue that this makes the model too speculative, Dr Deacon maintains that the model's simplicity is its strength. By outlining the minimal conditions required for semiosis, the autogenic virus offers a clearer, more testable alternative than other origin-of-life models, and avoids the even more questionable assumption that RNA replication is intrinsically informational.

What Next?

Dr Deacon's semiotic framework offers a significant departure from traditional views on the origin of life, particularly the RNA-World hypothesis. He shifts the conversation from mere replication to semiotic work, where molecules act as signs within an emergent system of meaning. The autogenic virus model, with its capacity for self-repair, reproduction, and interpretive action, provides a minimal yet powerful example of how life's semiotic properties might have emerged from basic chemical processes.

Though faced with critiques, the autogenic virus model remains an innovative and empirically testable approach, offering a compelling new lens through which to explore the fundamental question of how molecules became signs, and how life itself began.



MEET THE RESEARCHER

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Dr Terrence Deacon obtained his PhD from Harvard University in 1984. After undertaking various academic appointments at the same institution, he moved to Boston University in 1992 as an Associate Professor in Biological Anthropology while also a Research Associate at McLean Hospital and Harvard Medical School. From 2001 to 2002, Dr Deacon was a Visiting Professor at the University of Washington, and from 2010 to 2013, he was a Chair in the Department of Anthropology at the University of California, Berkeley. Since 2002, Dr Deacon has been a Distinguished Professor in the Department of Anthropology at the University of California, Berkeley. Dr Deacon has published extensively throughout his career and received numerous awards for his fascinating work. These include the J. I. Staley Prize 2005, School of American Research (the 'Pulitzer Prize of Anthropology') for his text *The Symbolic Species*, and the Forbes Book of the Year 2012 for his text *Incomplete Nature*.

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FURTHER READING

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