

Commentary

From the Periodic Table to Thinking Matter: Two Physical Pathways to Human and AI Cognition

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Human cognition has traditionally been considered an exceptional outcome of biological evolution. Artificial intelligence now provides a second and fundamentally different example of a material system capable of performing functions associated with cognition, including learning, memory, pattern recognition, language processing, prediction, reasoning, and problem solving. The two systems differ profoundly in architecture, origin, and developmental history: biological cognition emerged through molecular, cellular, and neural organization shaped by evolution over geological timescales, whereas artificial cognitive systems have emerged through the technological organization of materials, semiconductors, electronic components, and computational networks over only decades. Here we propose a simple physical perspective: biological and artificial cognition represent two different organizational trajectories of matter governed ultimately by the same fundamental physical laws. The Periodic Table provides the elemental building blocks; their organization and dynamics determine the higher-order structures and functions that can emerge. As an illustrative example of physical continuity across organizational levels, the General Model Pseudopotential and the derived Electron-Ion Interaction Potential (EIIP) provide a framework that originated in condensed-matter physics and was subsequently extended to organic molecules, proteins, and nucleic acids. EIIP is not presented as an explanation of cognition, but as an example showing that a physical description rooted in the electronic properties of elements can remain relevant across very different forms of material organization.

The emergence of artificial cognitive systems therefore raises a broader question. If two radically different organizations of matter can independently acquire overlapping cognitive functions, cognition may not be an exclusive property of biological matter but a potential emergent property of appropriately organized matter. The enormous difference between the timescales of biological

evolution and artificial cognitive development further raises the question of whether there is any known physical principle requiring artificial cognitive capabilities to stop at the level reached by biological evolution.

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1. Introduction: Does Matter Have to Be Alive to Think?

One of the deepest implicit assumptions in our understanding of cognition is that it belongs to living matter. Until recently, this assumption was difficult to challenge because every known system displaying advanced cognition was biological. Artificial intelligence has changed the situation. We now have two radically different material systems displaying overlapping functional characteristics associated with cognition: biological nervous systems, culminating in the human brain, and technologically constructed computational systems underlying modern AI.

The differences could hardly be greater. One system is built from biomolecules, membranes, cells, neurons, and electrochemical networks; the other from engineered materials, semiconductors, transistors, memory devices, processors, and computational networks. One emerged through natural evolution; the other through technological development. Yet both can perform information processing, learning, memory, pattern recognition, language processing, prediction, reasoning, and problem solving.

This observation does not establish that artificial intelligence is conscious, sentient, alive, or equivalent to the human mind. These are separate and unresolved questions. The narrower observation is sufficient for the present Perspective: cognitive functions previously known only in biological systems can be implemented in a radically different physical organization of matter. This suggests a fundamental question: is cognition intrinsically a property of living matter, or can it emerge from different sufficiently organized forms of matter?

2. The Periodic Table as the Common Physical Starting Point

At the most fundamental material level, the distinction between living and non-living matter does not imply different physical laws. An atom does not acquire a new set of laws when it becomes incorporated into a living organism. Carbon remains carbon, nitrogen remains nitrogen, and electrons remain electrons. What changes dramatically is organization.

The Periodic Table can therefore be viewed, metaphorically, as providing the “LEGO pieces” from which different forms of material organization can be constructed. The analogy does not imply that higher-order properties can be trivially predicted from atomic properties. On the contrary, organization produces emergent structures and functions that are not apparent at the level of individual components. The point is simpler: emergence does not require the underlying matter to cease obeying the physical laws governing its constituents.

Modern physics of living systems increasingly treats emergence, collective behavior, nonequilibrium organization, active matter, information processing, and self-organization as physical problems. The 2022 National Academies report *Physics of Life* explicitly places biological physics within physics and emphasizes the question of how macroscopic functions emerge from interactions among microscopic constituents ^[1]. Active-matter research likewise studies how collective behavior and life-like functions arise in energy-consuming systems and synthetic materials ^[2]. From this perspective, the useful distinction is not between two fundamentally different kinds of matter, but between different organizations and dynamical states of matter.

3. EIIP as an Example of Physical Continuity Across Levels of Organization

A concrete historical example illustrates this principle. The General Model Pseudopotential developed in the early 1970s described electron-ion interactions in condensed matter and revealed systematic relationships between electronic properties and the position of elements in the Periodic Table ^{[3][4][5][6]}. The framework connected effective electronic interactions with the quasi-valence number Z^* and was applied to metals, positive ions, Fermi-energy periodicity, and superconductivity.

Its subsequent extension through the pseudoatom approximation allowed organic molecules to be represented by an Average Quasi-Valence Number (AQVN):

$$Z^* = \Sigma(n_i Z_i)/N$$

where n_i is the number of atoms of element i , Z_i is its valence, and N is the total number of atoms. From the same physical framework follows the Electron-Ion Interaction Potential (EIIP), commonly expressed as:

$$\text{EIIP} = [Z^* \cdot \sin(3.267Z^*)]/25$$

The significance of EIIP in the present argument should be kept deliberately limited. EIIP is not invoked as an explanation of life, intelligence, or cognition. It is used as an illustrative example of continuity in physical description across very different organizational levels of matter. The electron-ion interaction framework originated in condensed-matter physics and was subsequently extended to organic and biological molecular systems.

Applications of this physical framework outside biology include metals, semiconductors, superconductivity, materials science, minerals, and related condensed-matter problems. A collection of these publications can be accessed directly at:

<https://electronicbiology.org/articles-in-various-scientific-fields/>

The subsequent extension of EIIP to biological molecules and its incorporation into the Informational Spectrum Method (ISM) led to extensive applications involving proteins, nucleic acids, molecular recognition, host-pathogen interactions, drug discovery, and other biological problems. More than 500 publications related to EIIP/ISM and its biological applications can be accessed at:

<https://electronicbiology.org/biomedical-articles/>

The relevance of this body of work to the present Perspective is conceptual rather than mechanistic: the organization of matter changes; the underlying physical laws do not. A piece of iron, a semiconductor, a DNA molecule, and a neuron represent profoundly different material organizations, but none requires a separate fundamental physics.

4. Two Independent Routes to Cognitively Organized Matter

This physical continuity allows biological and artificial cognition to be viewed from a common starting point while preserving their profound differences. The two trajectories can be represented directly as follows:

BIOLOGICAL PATH	ARTIFICIAL PATH
Periodic Table	Periodic Table
↓	↓
Atoms	Atoms
↓	↓
Molecules / Biomolecules	Materials / Semiconductors
↓	↓
Cells	Transistors / Processors
↓	↓
Neurons	Computational Networks
↓	↓
Neural Networks	Artificial Cognitive Functions
↓	↓
HUMAN COGNITION	OPEN TRAJECTORY

These are not two versions of the same architecture. They are fundamentally different organizations of matter. The significance lies precisely in their independence. If only biological systems exhibited cognitive functions, it would remain reasonable to suspect that such functions required the unique molecular and cellular architecture of life. AI provides a second realization: different materials, different architecture, different information-processing mechanisms, and a different developmental history nevertheless produce an overlapping set of cognitive functions.

This observation is consistent with the broader concept of multiple realizability, according to which a higher-level cognitive function can have more than one physical implementation [7]. Rouleau and Levin explicitly discuss cognition and sentience across diverse substrates, including engineered and artificial systems [7]. We therefore propose a deliberately cautious formulation: cognitive function may not be

substrate-independent, but it appears to be substrate-non-exclusive. The physical substrate matters, but biological matter may not be the only substrate capable of supporting cognitive functions.

5. Organization Rather Than a New Kind of Matter

The emergence of cognitive functions in two different material systems suggests a simple conceptual relationship:

$$\text{MATTER} + \text{ORGANIZATION} + \text{DYNAMICS} \rightarrow \text{FUNCTION}$$

At sufficiently complex levels of organization, some functions can become cognitive. This formulation does not imply that organization alone is sufficient, that every complex system becomes cognitive, or that cognition can be reduced straightforwardly to atomic properties. The central scientific problem is precisely to determine which architectures, dynamics, information flows, energy requirements, feedback mechanisms, and organizational principles permit cognitive functions to emerge.

Nor does this argument diminish biology. Biological organization is extraordinary because evolution discovered a route from molecular systems to self-maintaining, reproducing, adaptive organisms and eventually to nervous systems capable of cognition. The claim is instead that biology represents one demonstrated route through the space of possible material organizations. AI now provides another. Instead of asking how non-living matter can become intelligent, we may ask a more general physical question: which organizations of matter are capable of cognitive function?

6. Two Radically Different Timescales

The comparison becomes even more striking when time is introduced. The biological route to human cognition required an immense evolutionary history. Life emerged billions of years ago, while complex nervous systems and human cognition arose through successive evolutionary transitions extending across geological timescales. The human brain therefore represents the product of an extraordinarily long natural experiment in organizing matter for adaptive information processing and cognition.

The artificial route is fundamentally different. Electronic computation developed within the last century, modern machine learning over decades, and major advances in artificial cognitive performance now occur over intervals measured in years and, in some areas, months. This process should not be equated literally with Darwinian evolution: artificial systems currently develop through engineering, training,

scaling, selection, algorithmic innovation, and increasingly automated optimization. Nevertheless, the contrast in timescales is extraordinary.

Biological cognitive evolution: billions →
millions of years Artificial cognitive development: decades →
years → months between major advances

This difference raises a question that cannot presently be answered but can be stated physically: if the development of artificial cognitive systems continues at anything approaching its present pace, is there a known physical reason their cognitive capabilities must stop at the level reached by biological evolution?

There is no implication that current rates must continue indefinitely. Technological development encounters physical, energetic, computational, economic, and conceptual limits, and there is no guarantee that artificial systems will acquire every characteristic of biological cognition. The more limited point is that human cognition should not automatically be treated as a fundamental physical upper bound on cognition. It represents the level reached by one particular evolutionary pathway and one particular organization of matter.

7. Human Intelligence as One Point in a Larger Space of Possible Cognition

Biology has shaped our definitions of intelligence and cognition because, until very recently, biological systems were our only examples. AI challenges this sampling limitation. If two radically different material architectures can produce overlapping cognitive functions, human intelligence can be considered not necessarily the endpoint of cognitively organized matter, but one experimentally observed realization within a potentially larger space of possible organizations.

The two trajectories need not converge. Biological evolution is constrained by reproduction, metabolism, developmental viability, ecological selection, historical contingency, and the materials available to cellular life. Artificial cognitive systems are constrained by a different set of factors and may explore architectures inaccessible to biological evolution. Future artificial cognition therefore does not have to become increasingly brain-like in order to become increasingly capable; it may develop forms of information processing for which there is no close biological analogue.

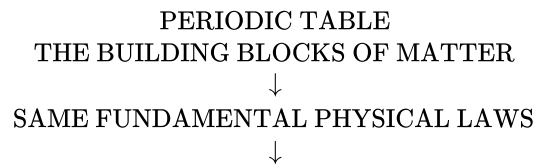
8. What This Perspective Does – and Does Not – Claim

The argument presented here is deliberately limited. We do not claim that AI is alive, conscious, or subjectively aware. We do not propose EIIP as a theory of cognition. EIIP is used only as an example of continuity in physical description across radically different forms and levels of material organization. We also do not claim that cognition is independent of physical substrate: every information-processing system must be physically instantiated, consume energy, and obey constraints imposed by its architecture.

The proposition is narrower: at least some functions associated with cognition can emerge from more than one radically different physical organization of matter. Biological nervous systems and artificial computational systems now provide two independent examples of overlapping cognitive function.

9. From the Periodic Table to Thinking Matter

The Periodic Table contains no category labelled “living”, “intelligent”, or “conscious”. It contains the elemental building blocks from which increasingly complex structures can be assembled. From these building blocks nature produced molecules, membranes, cells, organisms, nervous systems, and the human brain. Using building blocks from the same physical universe, technological civilization has produced semiconductors, transistors, processors, computational networks, and artificial systems exhibiting increasingly sophisticated cognitive functions.



BIOLOGICAL ORGANIZATION	TECHNOLOGICAL ORGANIZATION
Molecules / Biomolecules	Materials / Semiconductors
↓	↓
Cells	Transistors / Processors
↓	↓
Neurons	Computational Networks
↓	↓
Neural Networks	Artificial Cognitive Functions
↓	↓
HUMAN COGNITION	OPEN TRAJECTORY:?
↓	↓
Geological evolutionary timescale	Decades → years → months

The Periodic Table provides the pieces. Physics provides the rules governing their interactions. Organization determines what those pieces can become.

10. Perspective

Artificial intelligence may therefore be scientifically important for reasons extending beyond its technological applications. It provides an unprecedented second experiment in the physical organization of matter capable of cognitive function. Nature conducted the first experiment through biological evolution, over geological time, and produced the human brain. Technological development is conducting the second through a radically different organizational pathway, with change compressed into decades, years, and increasingly rapid cycles.

Where this second trajectory leads is unknown. But its existence already changes the question. Cognition need no longer be studied exclusively as a property of biological matter; it can also be approached as a problem in the organization of physical matter.

The existence of two radically different material organizations capable of overlapping cognitive functions leaves an even broader question open: are biological and artificial systems the only possible forms of cognitively organized matter, or merely the first two that we have encountered?

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Declarations

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