Systems Causality, Assembly Theory, and the Discrete Accumulation of Negentropy

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Abstract. The Second Law of Thermodynamics states that entropy, or disorder, increases in closed systems. However, the observable universe has, over time, produced increasingly complex structured entities, from atoms and molecules to living organisms and civilisations. This paper explores the mechanisms behind this phenomenon, known as the accumulation of negentropy. That is, the growth of order despite the natural tendency toward disorder.

It is proposed that the accumulation of negentropy is not a separate force but rather a consequence of causal interactions whose structured complexity has increased over time. These interactions follow the principles of Systems Causality, where cause-and-effect relationships are shaped by the transfer of matter, energy, and information. Assembly Theory provides an explanation for the step-by-step emergence of ever more complex structured entities, including causal relationships, within the constraints of prior structures. It also explains the emergence of new laws and scientific disciplines as complexity increases.

Using this framework, the paper analyses how causality has driven the emergence of increasingly complex structured entities throughout Big History, from quantum fluctuations and chemical selection to biological evolution and human civilisation. It also examines the implications for humanity today.

1. Introduction

The Second Law of Thermodynamics states that entropy, or disorder, tends to increase over time (OpenStax, 2016). However, the universe has consistently produced ever more complex structured systems, from atoms and molecules to life and civilisations. At first glance, this seems contradictory: if disorder naturally increases, how do increasingly complex structured systems emerge and persist?

Physicist Erwin Schrödinger introduced the concept of negentropy (negative entropy) in his book "*What is Life?*" to explain how living systems counteract entropy (Schrödinger, 1944). To quote from this book: "*It is by avoiding the rapid decay into the inert state of 'equilibrium' that an organism appears so enigmatic. What an organism feeds upon is negative entropy. Or, to put it less paradoxically, the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive.*" Organisms do this by drawing in energy and order from their surroundings, maintaining structure and function over time. However, negentropy is not unique to life; it also appears in chemical, technological, and social systems.

An alternative way to describe order or structure within an entity is to refer to it as 'information at source.' The more ordered and structured a system is, the more information at source it holds. Therefore, the accumulation of negentropy in successive systems can also be described as "the accumulation of information at source".

This paper argues that the accumulation of negentropy or information at source over time is neither random nor a separate force. Rather, it is a natural result of the interaction of Systems

Causality and Assembly Theory. This interaction describes how cause-and-effect relationships are assembled over time, constrained by prior structures and selection pressures.

Systems Causality describes cause-and-effect relationships as the transfer of matter, energy or information from one system (the cause) to another (the effect). In other words, it involves the transfer of one or more systems from the cause to the effect. Assembly Theory explains how complex structured systems emerge through a sequence of ordered steps. Such systems arise only when their components interact in a way that forms a functional process.

The application of these ideas can explain how complex structured entities and the causal relationships between them have developed throughout Big History, from prebiotic chemistry and biological evolution to intelligence and technological civilisations.

Finally, the implications for humanity today are examined.

2. Systems and Levels of Complexity

a. Systems

A system is a set of elements that interact to form a coherent whole. Every system also interacts with other systems in its environment. Importantly, systems are nested. Each system is made up of smaller subsystems, which themselves contain even smaller interacting parts. This hierarchical structure reflects the organisation of reality.

For example, atoms combine to form molecules, molecules interact to form cells, and cells assemble into organisms. Similarly, organisms form ecosystems, and human societies function as complex networks of interacting individuals and technologies.

At its core, every system consists of three main components:

- Inputs. What enters the system (such as energy, matter, or information).
- Processes. How the system transforms its inputs.
- Outputs. What the system produces or releases.

Interaction between systems occurs when the output of one system becomes the input for another. This is how complexity grows, by linking different systems together into larger, interconnected structures.

b. Measuring Complexity

The complexity of a system can be measured in different ways. One simple approach is to count the number of fundamental particles it contains. However, a more useful measure considers how those components interact. A system with many interconnected parts performing structured functions is more complex than a system with the same number of parts acting randomly.

For example, a pile of sand and a living organism may contain a similar number of particles, but the organism is vastly more complex because its components interact in highly organised ways to sustain life.

3. Emergence

a. Introduction

In the real world, the components of a system have a limited range of interactions. They can only exchange matter, energy, or information in specific ways. For example, in the nervous system, each neuron receives inputs as electrical or chemical signals and sends outputs in the form of electrical impulses to other neurons, muscles, or glands.

At first, if we combine just a few neurons, they behave in the same way as they do individually. However, as we increase the number of neurons and the connections between them, something new happens: the system as a whole begins to exhibit interactions that were not present in smaller groups. These new system-wide interactions mark the phenomenon of emergence.

b. What is Emergence?

Emergence occurs when a system reaches a level of complexity that allows it to exhibit new interactions and properties that do not exist at lower levels. These emergent properties are not found in individual components but arise from their structured interactions (Corning, 2002).

For emergence to occur, a system must reach a critical threshold where its components interact in a way that forms a functioning process. Below this threshold, the system remains just a collection of independent parts. But once a structured process forms, the system can interact with its environment as a unified whole.

Emergence manifests in two ways:

- New Inputs. The system can now handle inputs that individual components could not process alone.
- New Outputs. The system produces effects that no single component could generate on its own.

For example, while individual iron atoms have magnetic moments, they do not exhibit large-scale magnetism on their own. However, when a vast number of these atoms align their magnetic moments in the same direction, the system as a whole exhibits the emergent property of a permanent magnet. This collective alignment leads to behaviours such as attraction and repulsion, which do not exist at the level of a single atom.

c. Emergence is Not Just More Components

It is important to note that emergence is not just about adding more components. Simply increasing the number of elements in a system does not guarantee new properties. Instead, emergence requires that the components be structured in a way that allows for new forms of interaction.

Thus, the way a system interacts with other systems, and how we perceive it, is defined by its inputs and outputs. When a system gains new interactions due to an underlying structured process, these interactions represent emergent properties.

d. Discrete Emergence

Because a functioning process must be established before emergent properties can exist, new properties do not gradually emerge as complexity increases. Instead, they appear in distinct steps.

Between these steps, complexity may increase, but a system remains bound by the interactions that emerged at a lower level. The system appears chaotic or unpredictable during this phase, as human cognition struggles to track all the interactions. However, once a new level of emergence is reached, the system stabilises, and new properties become apparent. This process then repeats at each stage of increasing complexity.

e. Emergent Properties Exist Only at and Above Their Level

A key feature of emergence is that new properties only exist at the level at which they emerge and at higher levels. They do not exist at lower levels because there is not enough complexity to sustain the required processes. For example, individual water molecules do not have the property of "wetness," but a collection of them does.

f. Why This Matters for Human Understanding

Because emergent properties appear in discrete steps, human knowledge is divided into specialised disciplines. Each discipline studies the interactions at and immediately above a particular level of emergence. Physics studies atoms, biology studies cells, psychology studies minds, and so on.

Theoretically, the relationships between systems at one level of emergence can be explained by those of the levels below. However, due to our cognitive limits and the apparent chaos between levels of emergence two difficulties arise. Firstly, we cannot predict what systems will develop in this chaos and thus we cannot predict what will emerge. Secondly, when we observe a higher level of emergence, we can only fully explain the process that leads to it if that process is relatively simple. Highly complex processes may exceed our cognitive abilities. Thus, the only way to understand the relationships between levels of emergence is to analyse the processes that lead to them.

4. Entropy in Systems

a. Introduction

The concept of entropy was introduced by Rudolf Clausius in 1865 to describe how energy spreads out in a system. In the context of the Second Law of Thermodynamics, entropy is a measure of disorder. It describes how systems naturally tend toward states where energy is less available for useful work (OpenStax, 2016).

At its core, entropy reflects the number of possible ways a system's components can be arranged. The more possible arrangements, the higher the entropy. In physical terms, heat naturally flows from a hot object to a cold one, spreading energy more evenly. This process increases entropy because the system moves from an ordered state, i.e., energy concentrated in one place, to a more disordered state, i.e., energy dispersed.

b. Entropy in Functional vs. Dysfunctional Systems

Entropy can be better understood by comparing two otherwise identical systems:

- A functional system whose components are arranged to support a process.
- A dysfunctional system whose components are arranged in a way that prevents the process from working.

Since there are far more ways for a system's components to be arranged in a dysfunctional way than in a functional one, a dysfunctional system has higher entropy. This is why random changes are more likely to cause disorder than to maintain or restore order. For example, if you take apart a watch and shake the pieces in a box, they will not randomly reassemble into a working watch. This is because the number of non-functional arrangements far outweighs the number of functional ones. A broken watch has higher entropy than a working one because its parts can be arranged in many ways that do not perform a function.

c. Entropy Increases Unless Energy is Applied

The Second Law of Thermodynamics states that, in a closed system, without an external input of energy, the system will naturally move over time from a low-entropy, ordered state to a high-entropy, disordered one (OpenStax, 2016). This happens because random changes are overwhelmingly more likely to disrupt structure than to maintain it. For example, a sandcastle left on the beach will eventually collapse as wind and waves erode its structure. A hot cup of coffee left on a table will cool down, losing its concentrated heat energy to the environment.

However, the universe is an open system rather than a closed one and entropy can be counteracted, but only by applying energy in a way that maintains or restores structure. Living organisms, machines, and even human civilisations resist entropy by using energy to maintain function. Without continuous energy input, all structured systems will eventually degrade.

5. Negentropy

a. Introduction

In 1944, physicist Erwin Schrödinger introduced the concept of negentropy to explain how living systems resist the natural tendency toward disorder. Organisms maintain their structure and function by importing energy and order from their surroundings, preventing decay and sustaining life.

Negentropy does not just apply to living things. Any system that maintains structure and function over time is negentropic. This includes self-sustaining chemical reactions, technological systems, and even civilisations. However, maintaining negentropy requires a continuous input of energy. Without it, systems will eventually degrade.

b. What is Negentropy?

Negentropy refers to the order, structure, and organisation within a system. While entropy describes the number of possible arrangements of a system's components, most of which lead to disorder, negentropy refers to the subset of arrangements that sustain function. For example, a living cell maintains structure by using energy to repair damage and sustain biochemical processes. That is, the system actively counteracts entropy by organising energy and materials in a structured way.

c. Negentropy Does Not Violate the Second Law of Thermodynamics

While a system can locally resist entropy, it does so at the cost of increasing overall entropy. This is because energy is never perfectly transferred or stored. Some of it is always lost as waste heat or dispersed into the environment. For example, a plant absorbs sunlight to grow, reducing its internal entropy. However, in doing so, it releases heat into the environment, increasing overall entropy. A refrigerator keeps food cold by using electricity, but the cooling system expels heat into the surrounding air, increasing overall entropy. Thus, negentropy allows local order to persist, but always within the broader framework of the Second Law of Thermodynamics.

d. The Significance of Negentropy

Negentropy explains why all complex structures persist over time. Systems that fail to maintain negentropy will eventually break down, as random disorder overtakes structured function. For example, a forest maintains negentropy by recycling nutrients, energy, and water efficiently. A city resists entropy by using infrastructure, governance, and energy to maintain order. Topically, a civilisation must balance energy use, resource management, and social structures to sustain itself in the long-term.

In short, negentropy is the key to maintaining complex organised processes, whether in life, technology, or society. Whilst negentropy explains the persistence of complex organised processes, their growth in complexity, over time, will now be discussed using the frameworks of Assembly Theory and Systems Causality.

6. Assembly Theory

a. Introduction

Assembly Theory was developed by Lee Cronin and Sara Imari Walker to explain how complex structures arise over time (Cronin & Walker, 2016). The key idea is that complexity does not appear randomly or instantly. It is built step by step through a sequence of assembly events.

Whilst Cronin & Walker's Assembly Theory is focused on molecular complexity and selection processes, it is reasonable to extend it to higher-order systems (e.g., intelligence, civilization), although this is not yet widely accepted.

Their theory provides a way to measure complexity by counting the number of non-random, causally linked steps required to construct a given structure. It helps us to understand how complex things, from proteins to machines, and even human beings are assembled.

b. Building Complexity Step by Step

In a functioning system, every component is itself the result of a functioning process that emerged at a lower level of complexity. For example, a protein functions within a cell, but it is built from amino acids, which themselves are assembled from simpler chemical building blocks. A microprocessor functions within a computer, but it is built from semiconductors, which, in turn, are refined from raw materials.

Functioning processes at each level of complexity are only possible because of the structured interactions or processes that emerged at a previous lower level.

c. The Rules of Assembly Theory

Complex structures must be built up step by step. A highly complex object cannot appear in a single step. It must be assembled through a series of intermediate forms.

Each step depends on what came before. Complexity can only grow based on previously assembled structures. A system cannot transfer complexity beyond what it has already assembled.

History matters. The final structure of a system is shaped by the constraints and interactions that occurred during its formation. For example, in biological evolution simple molecules assembled into self-replicating systems. These systems then evolved into cells, then multicellular organisms, then intelligent beings. At each stage, the previous complexity constrained and enabled what could come next.

The same pattern applies in technology and culture. Every innovation builds upon prior knowledge and materials.

d. Assembly Theory and Emergence

Assembly Theory helps explain why emergence happens in steps rather than as a smooth progression. A new property can only emerge once a structured process has been assembled. This is why certain levels of complexity, like life, intelligence, or technology, appear suddenly in history rather than gradually. For example, scattered technological advancements do not change civilisation, but once key infrastructure is in place, an industrial revolution occurs.

Thus, Assembly Theory provides a framework for understanding how complexity builds over time and why emergent properties appear in discrete steps.

7. Systems Causality

a. Causality as a transfer process

Systems Causality was formalised by the author in a paper "*Unifying the Universal Disciplines towards a General System Theory*", (Challoner, 2025). Traditional views of causality often treat events as simple, direct interactions without explaining the process involved.

However, Systems Causality unifies systems theory and causality by describing cause-and-effect relationships as due to the transfer of matter, energy or information between systems processes.

b. Types of Systems Causality

In Systems Causality an output from one process (P) that acts as an input to another is known as a transfer (T). Systems Causality is complex. However, within it we can identify chains as follows:

... process (P) – transfer (T) - process (P) -transfer (T) - process (P) - transfer (T) ...

A cause and an effect must have the same structure and must share a common element to be contiguous in space-time. Thus, there are just two types of Systems Causality: one in which PTP is a cause or effect and a process (P) is shared. Another in which TPT is a cause or effect and a transfer (T) is shared.

In Process-Transfer-Process (PTP) causality, causes and effects are events in which one process directly alters another by transferring some energy, information or material that we can identify to it. For example, in an electrical circuit, the cause may be turning on a switch to transfer energy to a lightbulb. The effect may then be the light bulb illuminating a room due to the transfer of photons. The feature common to both cause and effect is the light bulb.

In Transfer-Process-Transfer (TPT) causality, causes and effects are changes in system states in which one change appears to result in another. If the change is causal, then this is due to an underlying transfer. However, that transfer may not be known or observable. For example, in economics, an increase in demand leads to higher prices, even though the transfer of information connecting them is complex and indirect. So, what may seem to be a TPT causal relationship may merely be a correlation unless what is transferred can be identified. TPT causality should not be dismissed, however, because it provides us with insights that can later be verified or refuted using PTP causality.

c. Transfers Cannot be More Complex than Their Cause

A fundamental feature of Systems Causality is that what is transferred from one system to another is itself a system or collection of systems that originally existed within the cause. However, because this transfer originated in the cause, it cannot be more complex than is origin, and so, cannot possess properties that emerged at a higher level of complexity than the cause.

For example, in chemistry, a reaction can only transfer molecular fragments or energy that were generated through prior chemical processes. It cannot suddenly create molecules more complex than what has been assembled so far. In technology, an early mechanical device could not suddenly transfer the knowledge to build a microprocessor. That complexity had to be assembled gradually through advancements in engineering.

d. Integration of Causal Transfers into the Effect

Causal interactions do not simply transfer entities unaltered. The receiving system may transform them before integration. Once something is transferred, it becomes part of the effect, either as a whole or by being broken down and reassembled. This means effects are not just passive outcomes. They are shaped by both what is transferred and how the receiving system integrates it. For example, when an organism consumes food, it does not absorb nutrients in their original form. Instead, it breaks them down into smaller molecules before reassembling them into useful biological components. In communication networks, a signal is received, processed, and restructured before being transmitted further. To cite a further example, when raw ore is extracted from the earth, it is not used in its original form. Instead, it is broken down through refining processes to separate useful metals from unwanted materials. These purified components are then reassembled into new structures, such as tools, machinery, or electronics, that could not be assembled from the raw ore.

e. Causality and Properties

Some of the properties of a system are its interactions. Thus, the interaction between a cause and an effect is a property of both the cause and the effect. For example, a predator hunts its prey but the property of being a predator is defined by the fact that it hunts. Similarly, the property of being prey is defined by the fact that it is hunted.

This implies that causal relationships are also subject to emergence, and thus, the accumulation of negentropy or information at source. This idea is central to the emergence of new laws as new disciplines address ever more complex structured entities.

f. Causality is Assembled

Systems Causality involves the transfer of systems. Those systems too are subject to Assembly Theory and have been assembled over time. Every transferred system comprises components with functioning processes that have previously emerged. The transferred system cannot comprise processes that require a higher level of complexity than has already been built. For example, a cell can transfer genetic material (DNA) to another cell, but it cannot transfer an entire organism. This is because that level of complexity does not exist at the cellular level. A computer program can send data to another system, but it cannot suddenly generate an entire operating system unless all necessary components have been assembled first.

This aligns with Assembly Theory, reinforcing the idea that causal interactions, and thus the laws governing a discipline, do not happen randomly but emerge through structured, stepwise processes.

Together, Systems Causality and Assembly Theory provide a powerful framework for understanding the emergence of complexity in everything from biology to technology to civilisation itself. That is, they can explain Big History.

8. The Assembly of Causality and Negentropy in the Context of Big History

a. Introduction

Big History is an interdisciplinary framework that traces the history of the universe, Earth, life, and human civilisation as a single, unified narrative. First formalised by David Christian in the late 20th century, Big History examines how complex structured systems have emerged over time, from cosmic evolution to biological life and technological civilisation (Christian, 2004).

The emergence of complex structured systems in Big History can be understood through Systems Causality and Assembly Theory, which explain how negentropy or information at source has accumulated over time.

Crucially, the nature of causality itself has changed in discrete steps as its level of complexity increased. In the early universe, only probabilistic causality existed, governed by quantum fluctuations and thermodynamic constraints. As complexity increased, causality came to include structure that was constrained by prior assembly steps and emergent system properties. At higher levels, such as biological evolution and technological development, causality came to include processes that allowed systems to actively engineer their own persistence against entropy.

Negentropy is not an external force, therefore, but a consequence of structured causal interactions that sustain function. The accumulation, over time, of negentropy or information at source, and thus, ever more complex structured systems, occurred in a step-by-step manner, constrained by physical laws and selection pressures.

b. Step 1: Particles and Atoms – Selection via Physical Laws & Stability.

At the earliest stage, quantum fluctuations produced a range of possible particle states, but only the most stable ones persisted. Particles then combined but again only the most stable structures, i.e., atoms, persisted. In the cosmic environment, these stable forms underwent atomic selection, where stars fused lighter elements into more complex atomic structures. Again, only certain chemical elements proved stable enough to persist. Throughout these processes, causality was probabilistic rather than deterministic, but the foundation for structured interactions had been laid.

c. Step 2: Molecules – Selection via Physical Laws & Stability

With the emergence of chemically stable elements, molecular selection began to shape the emergence of complex structured entities. Physical laws dictated that certain molecular configurations were more stable than others, leading to the formation of fundamental biological precursors such as amino acids and lipids. While these molecules were relatively rare, sufficient existed and persisted long enough for the next stage in the assembly process to occur.

d. Step 3: Autocatalysis – Selection via Physical Laws, Stability & Self-sustaining Interactions

A major transition occurred when some molecules developed autocatalytic properties, meaning they catalysed their own formation (Kauffman, 1986). This introduced feedback mechanisms, where certain chemical reactions sustained themselves, persisting longer than non-replicating structures. This stage represented the emergence of assembled causal relationships, where molecular interactions were no longer governed solely by external conditions but began to exhibit self-sustaining properties. Although even more rare, this was countered by replication and sufficient examples existed for the assembly process to proceed to the next stage.

e. Step 4: Self-Maintenance – Selection via Physical Laws, Stability & Early Replication

Over time, some autocatalytic networks developed protective barriers, enhancing survival rates. This marked the onset of homeostasis, where primitive systems began to regulate internal conditions to resist entropy. Such systems actively resist entropy through self-regulation and selective interaction with their environment, a characteristic described as autopoiesis: the process by which living systems sustain themselves by continuously regenerating their components (Maturana & Varela, 1973). Selection favoured self-maintaining structures due to their persistence (Camazine et al., 2001). Again, although even more rare, this was countered by replication and self-maintenance for sufficient examples existed for the assembly process to proceed to the next stage.

f. Step 5: Evolution – Selection via Physical Laws, Stability & Competitive Replication

With the emergence of replication, causal selection shifted to biological evolution, where variation, competition, and selection drove adaptive complexity. Organisms developed increasingly sophisticated self-maintenance strategies, such as metabolism, cellular repair, and reproduction, ensuring that complexity was not only preserved across generations but also extended (Darwin, 1859). The accumulation of negentropy became self-reinforcing, as systems actively preserved and refined their structure over time.

g. Step 6: Cybernetic Regulation & Predictive Control – Selection via Stability, Homeostasis & Anticipation

As life became more complex, organisms and ecosystems developed ways to regulate themselves through feedback loops. This means they could sense environmental changes and respond to keep conditions stable, like sweating when it’s hot or adjusting predator-prey populations. Over time, some organisms evolved a degree of predictive control, meaning they could anticipate changes and act before they happened, like storing food for winter or hunting strategically. Due to complexity in causal interactions, precise prediction is not possible. Nevertheless, his shift gave life a new level of control over negentropy, allowing systems to actively shape their survival conditions rather than just reacting to them.

h. Step 7: Intelligence & Technology – Selection via Learning, Cultural Transmission & Environmental Engineering

At this stage, intelligence emerged, allowing organisms not just to adapt to their environment but actively shape it. Unlike previous stages, where negentropy was maintained by biological and ecological processes, intelligence enabled deliberate control over complexity.

The key breakthrough was cultural inheritance, instead of relying solely on biological evolution, intelligence allowed knowledge, skills, and strategies to be stored and passed down across generations. This meant that advances in complexity no longer depended solely on genetic mutations and natural selection but could be directed through learning and technological innovation.

9. Implications For Humanity

Many psychologists regard meaning and purpose as essential human needs. It is for this reason that we form religions and search for a General System Theory. That is, to provide a sense of meaning and purpose to our lives. However, existential psychologists often argue that meaning and purpose do not inherently exist in the universe, and that we must come to terms with this. But are they correct? The processes described above suggest otherwise. In this section, we will summarise the processes, associate them with human cognition and examine their implications.

In summary, negentropy is a measure of the organisation or structure within an entity. As time passes entities that display increased amounts of organisation or structure are assembled. This phenomenon can be described as the “accumulation of negentropy”. As time progresses, negentropy, or information at source, locally accumulates in some entities.

This accumulation occurs because functional processes are assembled from components that were previously assembled and already possess their own functional processes. This recursive nature of assembly leads to increasing complexity over time.

Human beings recognise entities with negentropy or information at source. In contrast, we do not intuitively recognise chaotic collections of entities that lack a functioning process. We then translate information at source into cognitive information which we then encode into language for communication.

We also have the ability to reason with this cognitive information. Unconsciously, we recognise patterns and correlations within this cognitive information through TPT causal reasoning as described in “*Unifying Universal Disciplines Towards a General System Theory*” (Challoner, 2025). We also consciously test these correlations for strict causality using PTP causal reasoning, as described in the same paper.

Through this process, we can model, design and fabricate new functional processes with greater negentropy or information at source than those we have previously observed. This makes us agents of increasing negentropy, meaning that through human cognition and action, the accumulation of negentropy, or information at source, has become self-sustaining.

Human beings appear to be unique in this role, at least on Earth. This uniqueness suggests that our existence carries an intrinsic meaning and purpose: to drive the accumulation of negentropy or information at source.

This raises an important ethical question: What ethical principles would best facilitate this meaning and purpose? Suggestions include frameworks that encourage innovation, respect for the truth, cooperation, and sustainability.

10. Summary and Conclusions

This paper has explored the paradox of increasing complexity in the universe despite the Second Law of Thermodynamics, which dictates that entropy tends to increase over time. The phenomenon of accumulating negentropy (negative entropy) was examined as a natural consequence of Systems Causality and Assembly Theory, rather than as a separate force.

a. Key Findings:

- Systems Causality and Assembly Theory:
    - Systems Causality describes how structured interactions transfer matter, energy, and information across systems, leading to the emergence of increasingly complex structured entities.
    - Assembly Theory explains how complexity is built step by step, constrained by prior structures and selection pressures.
- Emergence of Complexity:
    - Complexity arises in discrete steps, with each new level of organisation dependent on previous structures.
    - This process has governed the development of systems from subatomic particles to life and human civilisation.
- Causality and Negentropy:
    - Causal relationships themselves emerge and evolve, contributing to the accumulation of negentropy (or information at source) over time.
    - Biological, technological, and social systems maintain negentropy by sustaining structured interactions that counteract disorder.
- Big History and the Growth of Complexity:
    - The paper traces the stepwise increase in complexity, from quantum fluctuations and atomic formation to the emergence of life, intelligence, and technological civilisation.
    - Each stage represents a new threshold of structured causality, shaping future possibilities while constrained by past developments.
- Implications for Humanity:
    - Human cognition and innovation play a unique role in driving the self-sustaining accumulation of negentropy.
    - This process provides a potential intrinsic meaning and purpose to human existence: to advance structured complexity and knowledge.

b. Conclusion:

The emergence and persistence of complexity in the universe follow a structured, stepwise process governed by causal interactions and assembly constraints. Negentropy is not an external force but a product of structured causality, explaining why complex systems endure despite entropy. Humanity, as an agent of increasing complexity, holds a key role in shaping the future of intelligence, technology, and sustainability. Understanding these principles can help guide ethical and strategic decisions for long-term stability and advancement.

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