Autopoiesis, causal poiesis, causal collapse

From life to consciousness

Introduction

Where does consciousness come from? Despite numerous theories – from neuronal correlates to information processing to quantum physical hypotheses – this question remains unanswered if it is considered only within narrow disciplinary boundaries. This essay proposes an alternative approach: consciousness is not understood here as an emergent phenomenon or product of neuronal activity, but as the result of a multi-stage, systemic-thermodynamic process. The key concepts are: **autopoiesis**, **causal poiesis** and **causal collapse**. They mark three fundamental stages on which living systems emerge, center, and finally, under certain conditions, develop consciousness.
The aim of this essay is to systematically reconstruct this path from life to consciousness on the basis of the concepts mentioned above – not in the sense of a goal-oriented development, but as a consequence of certain structural and exchange relations in open systems.
This approach deliberately differs from established information-theoretical models such as Integrated Information Theory (IIT) or Global Neuronal Workspace Theory (GNWT). While these try to explain consciousness through functional information integration, the approach proposed here is based on **structural-thermodynamic processes** as they occur in the self-organization of living systems. Terms such as "causal core" or "causal collapse" are conceptual proposals that are based on concretely describable systemic properties – even if they have so far only been formalized and operationalized in initial theoretical work (cf. Stegemann, 2025a, 2025b). The present text is therefore not intended as a complete theory, but as a theoretical framework for the development of an interdisciplinary model of understanding.

1. Autopoiesis – The framework of autocatalysis

Living systems differ from non-living matter in their capacity for **self-preservation through internal organization**. This is captured by the term *autopoiesis,* which was introduced by Maturana and Varela. Autopoiesis describes a system that produces its own components and at the same time forms a boundary to its environment – typically a membrane at first.

The physical basis of this organization is **autocatalysis**: chemical reactions that reinforce themselves, are cyclically maintained and are protected from

dissolution by spatial demarcation. An autopoietic system is in an open exchange with its environment, but organizes it internally in such a way that its structure is preserved.

This can be exemplified by simple protocells whose membrane has selective permeability. This makes it possible to absorb certain molecules and catalyze reactions within the cell, which in turn ensure the structure of the membrane and the catalytic units themselves.

Autopoiesis is thus not simply a property, but a dynamic-stable configuration that generates local structural stability under conditions of energetic imbalances.

2. Causal Poiesis – The Frame of the Causal Core

With increasing complexity of biological systems, local centers with increased reaction density emerge within open structures. This development is referred to here as **causal poiesis**: a process in which a causal core emerges **from energetic and functional asymmetries** (Stegemann 2025a).

The causal nucleus is not only a functional configuration, but in many cases it can also be **determined materially**. Examples are the nucleus in eukaryotic cells or central neuronal structures in the brain. Such centers bundle causal interactions and enable coordinated system dynamics.

From a thermodynamic point of view, this centering results from non-equilibriums, where certain local configurations are more stable or reactive than others. The formation of a core means an increase in internal control capacity. It is a functional center in which systemically relevant processes converge, stabilize and mutually regulate.

The transition from autopoiesis to causal poiesis can be described mechanistically: local gradients and unstable flows form structural condensations that create internally coupled reaction spaces. This development is visible in biological evolution, e.g. in the formation of eukaryotic cell nuclei or central nervous systems.

3. Causal Collapse – The Framework of Integration

Causal **collapse** refers to a transition in which segmented causal pathways transition into an integrated system state that correlates with the experience of consciousness (Stegemann 2025b,c).

In complex systems – such as the human brain – numerous sub-processes are active at the same time. Under certain structural and dynamic conditions, these processes are **recursively coupled**, resulting in a temporary integration.

It is a qualitative change in the system constellation: a coherent state is created in which previously separate functional areas are coupled within the system. This configuration results from the interplay of dynamic properties such as plasticity, depth of interconnection and energetic exchange.

One example is conscious perception: various sensory, motor, emotional and cognitive processes take place simultaneously, often independently. Only in certain moments does a coordinating connection occur, which is subjectively experienced as consciousness. This linkage is not synonymous with simultaneity, but with systemic coherence: a state in which recursive references produce relative integration.

The transition from causal poiesis to causal collapse can be described as a structural threshold event: When recursive interconnections, plastic coupling and energetic dynamics exceed a certain degree of internal reconnection, a stable state of activity arises that can be experienced as a subjective presence. The concept of collapse refers to the simultaneity of integration and reduction – many paths condense into a state that can be experienced.

4. Comparative structure

Process	System Type	Dynamics	Result
Autopoiesis	Closed cell	Autocatalysis, membrane formation	Stabilization of life
Causal poiesis	Complex cell system	Reaction compression, centering	Formation of functional nuclei
Causal collapse	Recursive Network	Integration of segmented paths	Consciousness

5. Philosophical and empirical implications

A current empirical reference emerges from the study by Luppi et al. (2023) published in 2023. There, functional MRI data and the Integrated Information Decomposition (ΦID) method were used to investigate how information integration in the brain changes under conditions of altered consciousness (e.g. due to anesthesia or impaired consciousness). Particularly striking is the reduction of synergistic information integration in the default mode network (DMN) in the event of loss of consciousness – as well as its restoration when returning to the waking state.

These findings can be interpreted as empirical support for the structural relationships proposed in the present model:

- In this study, the DMN assumes a gateway function for global integration – corresponding to the **causal core described here** in the context of **causal poiesis**.
- The alternation between integrated and disintegrated states corresponds to the transition to **causal collapse** – a state of recursive coupling identified in the model with consciousness emergence.
- The measures used, such as ΦR (revised integrated information) and PCI (Perturbational Complexity Index), represent dynamic correlates for the structural integration described here.

Thus, concrete conceptual connections between the systemic-thermodynamic model of this essay and empirical measurement methods of modern consciousness research are revealed.

This theory avoids reductionist interpretations by focusing not on individual causes or substrates, but on systemic configurations. It replaces vague assumptions of emergence with comprehensible transitions between different system states. Consciousness does not appear as a separate entity, but as the result of structural conditions within complex, open systems.

At the same time, current empirical findings offer possible starting points for testing this model. For example, studies on neuronal **avalanche criticality** (Beggs, J. M., & Plenz, D. (2003) and **chaotic edge dynamics** (Shew, W. L., & Plenz, D. 2013) show that conscious states typically arise in a dynamic region between order and chaos. This corresponds to the threshold structure of causal collapse described here.

In addition, the **Perturbational Complexity Index (PCI)** (Schartner, M. et al. 2015; Casali, A. G. et al. 2013) provides a measurable correlate for the extent of conscious integration. PCI quantifies the complexity of the brain response to

external stimulation and has been shown to be a robust indicator of different levels of consciousness – e.g., in anesthesia, sleep, or impaired consciousness. The theory presented here suggests that high PCI values are related to the state of maximally integrated recursive coupling (causal collapse).

Concepts such as the synergistic workspace – which couples gateway regions such as the default mode network with executive networks – can also be interpreted as functional manifestations of a structural core, as described by the concept of causal poiesis.

These empirical indications do not replace theory, but make it compatible for interdisciplinary validation.

6. Mathematical sketch of the model

The model presented here can be structured mathematically in parts, but without claiming to make subjective experience completely formally comprehensible. Rather, the aim is to correlate the transitions between the system states – autopoiesis, causal poiesis and causal collapse – with dynamic and structural variables.

6.1 Autopoiesis

Autopoietic systems can be described as open, nonlinear flow systems whose stability is based on feedback and boundary formation. Formally, system dynamics can be modeled by a set of coupled differential equations:

$$\frac{dC_i}{dt} = f_i(C_1, C_2, \dots, C_n) - \gamma_i C_i + I_i(t)$$

Here, C_i is the concentration of a system component, f_i describes autocatalytic interactions, γ_i stands for decay constants, and I_i(t) for external inputs. The condition of structural coupling is shown by the fact that the system maintains its organization despite exchange with the environment.

6.2 Causal poiesis

The transition to causal poiesis can be understood as the formation of an attractor center. A causal density function describes the local concentration of action pathways:$\rho(x, t)$

$$\rho(x,t) = \sum_j \delta(x - x_j(t))$$

A causal nucleus is formed when the density ρ forms a local maximum within a region Ω:

$$\nabla\rho(x,t) = 0, \nabla^2\rho(x,t) < 0$$

This corresponds to the emergence of a structural center of increased causal intensity.

6.3 Causal collapse

Causal collapse is described as a transition to a highly integrated recursive state. This can be modeled as a critical threshold process:

$$K(t) = \int_{t_0}^{t} R(\tau) \cdot \lambda(\tau)\, d\tau$$

$R(\tau)$ describes the density of recursive loops, λ(t) the instantaneous coupling strength. If , a stable state of integration is created:$K(t) > K_c$

$$K(t) > K_c \Rightarrow \text{bewusster Zustand}$$

This state can be correlated in some ways with high values of the Perturbational Complexity Index (PCI), even if the model is not based on measured values, but on structural configurations.

7. Discussion and outlook

The present theory on the emergence of consciousness via the three stages **of autopoiesis**, **causal poiesis** and **causal collapse** combines structural self-organization with dynamic integration. Methodologically, it differs from classical emergence theories in its systemic-thermodynamic approach and gains plausibility through current empirical studies.

7.1 Empirical connectivity

This connectivity becomes particularly clear in the light of the study by Luppi et al. (2023), which shows the connection between consciousness and **synergistic information integration** . The *gateway regions* (e.g. default mode network) and *broadcaster regions* (e.g. executive control network) identified there correspond structurally to the concept of the **causal core** introduced here in

the context of causal poiesis. The restoration of global synergies in the transition from the unconscious to the conscious state is also in line with the dynamics of **causal collapse**.

Likewise, studies on the **Perturbational Complexity Index (PCI)** (e.g., Casali et al., 2013) confirm the dynamics described in the model: high PCI values stand for integrated, conscious states, while low values are associated with disintegration and unconsciousness. These threshold transitions can be interpreted as quantifiable manifestations of the collapse scheme.

7.2 Open Challenges

Despite these similarities, several questions remain unanswered that should be the subject of future research:

- **Mathematical precision**: The equation for the causal coupling value as the threshold value for the causal collapse requires a more precise connection with experimentally accessible parameters such as PCI or network density. The aim would be to calibrate the theoretical threshold with empirical complexity values.
- **Falsifiability**: The model should formulate specific predictions, e.g., on the dynamics of conscious transitional states (e.g., when falling asleep, during absences, or psychedelic experience) that go beyond existing models.
- **Step dynamics**: The transitions between autopoiesis, causal poiesis and collapse could be interpreted as **phase transitions** and quantitatively modelled – for example by gradients in energy flows, network configuration or entropy.

7.3 Perspective: Testability via TMS-EEG

A promising next step would be to try to test the model assumptions **experimentally within the framework of existing TMS-EEG protocols** . The following hypotheses could be operationalized:

1. The causal nucleus (e.g. DMN) shows a particularly high degree of re-integration (high-frequency synergies) under TMS excitation during waking states.
2. Causal collapse is associated with a sudden increase in global complexity (PCI > 0.3), which occurs specifically in deliberate transitions.
3. When returning from unconsciousness, the gateway cores (DMN) reconfigure first before broadcaster networks (ECN) generate full integration – which harmonizes with the phase model proposed here.

8. Conclusion

Autopoiesis, causal poiesis, and causal collapse describe three successive processes by which structurally centered, functionally integrated systems emerge from physical, open systems – up to the emergence of what we call consciousness. The strength of this model lies in its interdisciplinary connectivity: it combines thermodynamics, systems theory, biology and philosophy of mind – without falling into metaphysical speculation or reductionist short-circuits.

The thesis is: With this perspective, consciousness as the result of coherent system states under conditions of nonlinear, open dynamics can be understood – within scientific explainability and without recourse to teleological or dualistic assumptions.

9. Literature

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