Bridging the Gap: How Goals Emerge from a Purposeless Universe

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Abstract

There is an enduring puzzle: fundamental physics describes dynamics without ends, yet biology and cognition teem with goal-directed talk. This paper surveys conceptual resources from nonequilibrium thermodynamics, autopoiesis, teleonomy, control theory, and evolutionary biology, and proposes a synthesis: *goals* are emergent, graded organisational phenomena arising when far-from-equilibrium systems acquire reliable, history-dependent information about their environment and couple that information to control architectures that maintain their own viability. I propose operational markers for goal-like organisation, sketch causal pathways from chemistry to agency, and discuss implications for origin-of-life research, cognitive science, and normative discourse.

1 Introduction

Physics gives us strikingly accurate descriptions of how matter evolves under laws that are indifferent to ends. Yet the living world is replete with purposive-sounding phenomena: cells "seek" nutrients, organisms "repair" damage, populations "adapt". Reconciling the "purposeless" microphysics with the "goal-filled" macrodynamics of life is both a scientific and philosophical challenge.

Two central questions guide this paper. First, what minimal organizational features distinguish genuine goal-directedness from metaphor? Second, how do such features arise by natural processes from nonliving matter? I argue that *goal-directedness*, understood as information-directed control aimed at preserving a system's viability, emerges naturally via (i) self-maintaining organisation, (ii) information-viability coupling, and (iii) selection-like stabilization.

2 Background: conceptual building blocks

Below I summarise relevant conceptual strands; the synthesis in §3 integrates them.

2.1 Thermodynamics and self-organization

Schrödinger emphasized that living systems maintain low entropy locally by exporting entropy to their surroundings [8]. Non-equilibrium thermodynamics shows that sustained gradients can produce dissipative structures: organized, persistent patterns (e.g., Bénard cells, chemical oscillators). These energetic and material constraints make persistent organization possible, but they do not by themselves yield goal-directed control.

2.2 Autonomy and autopoiesis

Maturana and Varela's autopoiesis frames living systems as self-producing networks that maintain their own boundaries and internal organization [6]. Autonomy provides a privileged locus for normativity: a system that needs to maintain certain relations has something at stake (a viability domain).

2.3 Teleonomy and teleosemantics

Philosophers of biology have long argued that teleological language can be naturalized: features have *functions* because of selection histories (teleonomy); teleosemantics grounds content claims in biological history [7, 3]. This approach ties normative-seeming claims to causal, historical processes.

Teleonomy refers to the naturalistic project of explaining the apparent purposiveness of biological traits by their selection histories, while teleosemantics extends this etiological logic to representations, holding that the semantic content of internal states is grounded in evolutionary histories that linked those states to adaptive success.

2.4 Control theory and predictive processing

Control theory supplies a formal language for goals as maintained by feedback. More recent frameworks (optimal control, active inference) unify perception, action, and homeostasis as inference-like processes that minimize prediction error or variational free energy [2]. These frameworks show how compact architectures can enact robust, flexible "goal-directed" behaviour.

3 Emergent Goal Systems (EGS)

I propose the label *Emergent Goal System* (EGS) for any physical system that jointly satisfies three conditions:

1. **Autonomy / self-maintenance.** The system maintains a bounded set of internal relations and processes that constitute its identity over relevant timescales (a viability domain).
2. **Information-bearing coupling.** The system acquires and stores regularities about its environment that causally inform its continued persistence.
3. **Control/use of information.** The system uses that information in feedback loops to reduce the probability of transitions out of its viability set.

EGSs are graded (Figure 1): minimal autocatalytic chemical networks may qualify at a proto-level, bacteria at a higher one, and complex animals with hierarchical control architectures at still higher grades. The term *goal* refers to the stable pattern of information-directed control that preserves the system's organization: nothing metaphysical is added.

4 From nonliving matter to EGS: causal pathways

How do EGSs arise? I sketch four complementary pathways.

4.1 Self-organization under constraints

Chemical and physical gradients drive spontaneous pattern formation; structures that persist in given environments can serve as substrates for more complex organization (e.g., concentrated

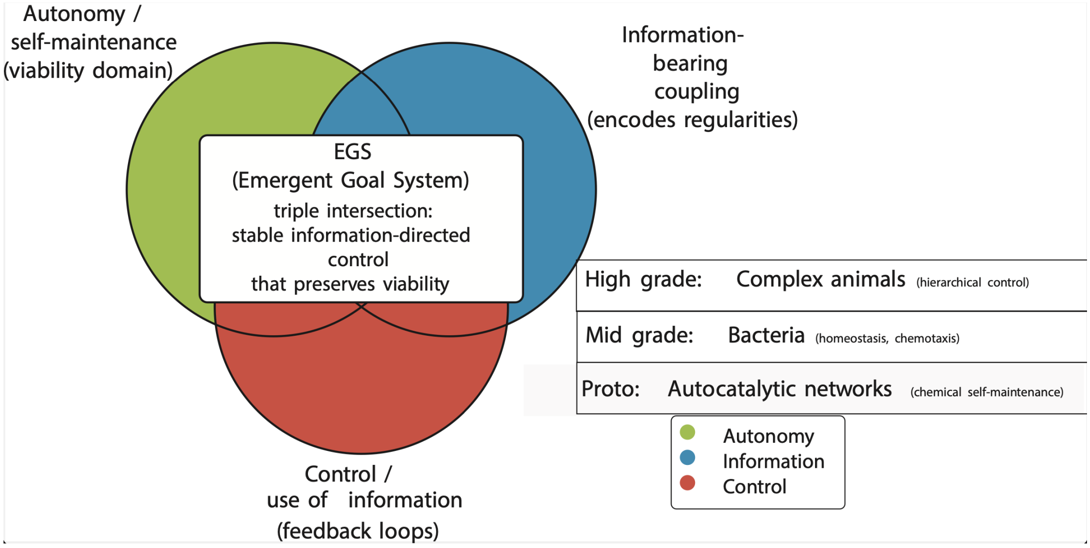

Figure 1: The EGS Venn Diagram: an Emergent Goal System is present where Autonomy (a viability domain), Information-bearing coupling (regularities about the environment), and Control (feedback that uses that information) all overlap. The graded stack at right indicates that different substrate/complexity levels (proto chemical networks → bacteria → complex animals) that can instantiate EGSs with increasing control complexity.

reaction networks that maintain gradients).

4.2 Embedding of information

Repeated interactions with structured environments create correlations between internal states and external variables. Chemical or structural memory (concentration regimes, patterning) can encode information useful for repair or replication.

4.3 Selection and stabilization

Variants of self-maintaining structures that more reliably resist perturbation persist and replicate, either chemically (autocatalytic sets) or biologically. Selection amplifies mechanisms that improve viability, thereby teleonomically biasing systems toward "behaviour" that preserves organization.

4.4 Control architecture elaboration

Over time hierarchical feedback, modulatory gates, and state-dependent switching can arise—first as simple thermostatic loops, then as networks enabling anticipatory behaviour. These elaborations increase adaptability and the repertoire of responses that maintain viability.

5 Operational markers for goal-directedness

To avoid mere metaphor we can test for goal-like organization with practical markers:

- **Viability set identification.** Can we define a set of internal/external conditions whose maintenance corresponds to persistence?
- **Information-viability coupling.** Is there measurable mutual information between internal states and environmental variables predictive of viability loss?

- **Control efficacy.** Do interventions on putative control loops modulate the probability of exiting the viability set?
- Heritability **/ evolution** Do the structures that realise maintenance show variation and differential persistence under selection [1]?

If the answer to these questions is yes, treating the system as goal-directed yields explanatory and predictive benefits.

6 Illustrative examples

6.1 Autocatalytic chemical networks

Autocatalytic sets can persist and reproduce under suitable fluxes [4]. When such sets encode environmental regularities (e.g., concentration gradients), they effectively "respond" to perturbations in ways that sustain themselves: *proto-goals*.

6.2 Single-celled organisms

Bacteria maintain internal homeostasis, sense gradients, and enact chemotaxis. They satisfy autonomy, information coupling, and control, illustrating a clear EGS at a modest level of complexity.

6.3 Animal nervous systems

Animals implement hierarchically organized control architectures (homeostasis, appetitive circuits, planning modules) and thus instantiate high-grade EGSs capable of flexible, predictive action.

7 Implications

7.1 Origins of life

EGS markers suggest empirical programs: seek chemical networks that both self-maintain and encode environmental regularities [1]; demonstrate control efficacy and selection-driven stabilization.

7.2 Cognitive science

Cognition may be re-cast as a graded phenomenon: the architecture and depth of information-control coupling determine the level of "goalness." Active inference offers a unifying mathematical language for many EGS phenomena [2].

7.3 Ethics and responsibility

Understanding goals as emergent and graded clarifies when moral language is appropriate. It also helps locate responsibility: when human action instruments or amplifies EGS dynamics (e.g., engineered pathogens, runaway socio-technical systems), moral and legal responsibility rests with the agents who design and deploy them.

8 Open questions

- What is the minimal information content required to sustain a given viability domain?
- How do implicit control-based goals become explicit representational states?
- How should moral and legal frameworks apportion responsibility across levels (cells, organisms, collectives, institutions) when harms arise from EGS dynamics?

9 Moral considerations

Moral consideration should follow the graded, functional account of goalness developed here, but it must not reduce to a simple equation of “has goals deserves moral standing". Hybrots (robots materially integrated with living tissue) and the deeper phenomenon of *synthbiosis* (tight, co-dependent couplings between engineered artefacts and biological systems) [5] will tend to embody heterogeneous goal-systems: designed, task-oriented objectives encoded by engineers; homeostatic, viability-preserving goals rooted in any embedded living components; and potentially emergent, history-dependent goals that arise as the hybrid system learns or is stabilized by selection-like processes.

These different goal-types have distinct ethical import. Instrumental, externally imposed goals (e.g. “navigate this course") do not by themselves ground claims of moral standing, whereas goal-structures that instantiate a genuine viability domain, robust information–viability coupling, and control loops capable of producing valenced (welfare-relevant) states do begin to look ethically significant. Put bluntly: goal-directedness is a relevant marker, but moral considerability is more plausibly tied to capacities for welfare, vulnerability, and morally salient interests (for which high-grade EGSs are prima facie candidates).

Practically, this suggests a graded ethics: as hybrid systems acquire deeper autonomy, richer information–control coupling, and signs of affect-like states, they should attract stronger protections and regulatory oversight. Independently of their intrinsic status, designers and deployers bear clear moral and legal responsibility for harms that such systems can cause or suffer; therefore, precautionary design, transparency about embedded biological components, and protocols for assessment of autonomy, valence, and dependence must accompany any pathway toward hybrot-driven synthbiosis.

10 Conclusion

The gulf between a purposeless microphysics and a goal-filled biosphere is not a metaphysical abyss but an explanatory bridge: far-from-equilibrium physics permits persistent organization; autopoietic autonomy provides stakes; information-viability coupling and feedback control realize action for those stakes; and selection stabilizes and amplifies these capacities. Goals are thus naturalistic phenomena: emergent products of history and organisation rather than injections of purpose into nature.

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