Information and Agency: A Thermodynamic and Cognitive-Physicalist Perspective

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Abstract

Information and agency are often discussed in the language of computation or communication, as if they were abstract entities. Yet every bit of information and every act of agency are physically embodied. This paper presents a cognitive-physicalist framework that restores the thermodynamic grounding of information and shows how agency arises from the coupling between energetic substrates and informational constraints. The analysis links the work of Schrödinger, Brillouin, Landauer, and Prigogine with contemporary systems theory, offering a unified dimensional treatment applicable from physics to society.

1. Cognitive Physicalism: The Physical Basis of Information

Cognitive physicalism begins with a simple observation: all information is carried on a physical substrate of matter or energy. Whether it is the conformation of a DNA molecule, the firing of neurons, or the electromagnetic state of a microchip, information exists only as patterns within energy and matter.

This position rejects the Cartesian idea of "information in the void." Instead, cognition and communication are forms of thermodynamic organisation. The substrate supplies energy, while informational form constrains its flow, either within that substrate or, in more complex systems, across other substrates. Following physical convention:

$$[E] = ML^2T^{-2}, [I] = ML^2T^{-2}\Theta^{-1}.$$

where In dimensional notation, Θ denotes absolute temperature.

Energy is the capacity for work; information (negative entropy) is the structure that channels that capacity.

2. Information at Source as Negentropy

Léon Brillouin (1956) defined information as negentropy: the complement of entropy. Entropy measures randomness in a system's energy distribution; information measures the reduction of that randomness. The relationship is reciprocal:

$$I = S_{max} - S_{actual}.$$

Both share the same dimensional form $ML^2T^{-2}\Theta^{-1}$.

Erwin Schrödinger (1944) had already suggested that life maintains itself by "feeding on negative entropy." Brillouin quantified this idea, showing that information has measurable physical value. Information is therefore not an abstract number but an energetically maintained state of order.

3. Dimensional Analysis of Substrate and Information

Aspect	Meaning	Base Dimensions
Energetic substrate	capacity for work; material or energetic carrier	ML^2T^{-2}
Informational form	order or constraint (negative entropy)	$ML^2T^{-2}\Theta^{-1}$

Information exists as a pattern of constraints acting upon physical energy flows. In simple cases, the informational pattern constrains the energy within its own substrate, as when a transistor's state directs its own current. In more complex systems, including biology, cognition, and society, the informational pattern in one substrate can organise energy in another. For example, neural states in the brain shape muscular forces, and social meanings in one mind alter behavioural energies in others. Information is therefore best understood as a cross-substrate constraint on the flow and transformation of physical energy.

4. From Physical Order to Life and Agency

In purely physical systems energy and entropy interact without internal regulation: there is no mechanism for shaping, directing, or stabilising these flows. With the emergence of life, this changes. Biological systems evolve informational structures that regulate energy use, maintain internal order, and channel energetic processes toward survival-relevant ends. A cell uses metabolic energy to sustain molecular organisation; its genes encode the constraints that specify how these energetic processes unfold.

Biological information processing begins when patterns in one physical substrate impose constraints on energy flows in another. Neural firing patterns, for example, not only organise their own electrical activity but also regulate muscular contractions, glandular secretion, and sensory gating. Informational constraint does not need to act on the same energy that embodies it. Instead, it routinely acts *across substrates*, forming a network of causal relations that enables perception, action, and adaptive behaviour. This cross-substrate organisation marks the first true emergence of cognition.

As informational organisation becomes more complex, systems gain the capacity not merely to survive but to *select* among alternative possible actions: the hallmark of agency. Agency arises whenever informational form exerts causal control over energetic processes. In primitive life, this takes the form of metabolic agency, where informational constraints regulate the cell's own internal energy flows. In advanced life, it develops into cognitive agency, in which informational patterns in one substrate, typically the nervous system, can reliably organise energy in another, enabling flexible behaviour, communication, learning, and coordinated action.

5. Boltzmann's Constant and the Masking of Physicality

In statistical mechanics, Boltzmann's constant k_B links microscopic probability to macroscopic entropy:

$$S = k_B \ln W.$$

Information theory inherits this relation, but by dividing entropy by k_B it removes the physical units, making information appear dimensionless. This is mathematically convenient for

communication theory, but it obscures the thermodynamic fact, emphasised by Landauer (1961),that information is physical.

Landauer's principle states that the minimum energy required to erase one bit of information is:

$$E_{\min} \geq k_B T \ln\ 2,$$

where $k_B$is Boltzmann's constant and $T$is the absolute temperature (Kelvin). This is the physically correct, dimensionally balanced form. It makes explicit that every informational operation carries an energetic cost.

When $k_B$is suppressed, as is common in information theory, the dimensional signature of entropy disappears from the equations, and so too does our recognition that learning, computation, decision-making, and communication are irreducibly thermodynamic acts, grounded in the physical properties of the substrates that carry information.

6. Restoring the Thermodynamic View

Ilya Prigogine's work on dissipative structures (1977) demonstrated that order can increase locally while total entropy still rises globally. Every living or cognitive system fits this description: internal order is maintained by exporting entropy to the environment.

Re-introducing the physical dimensions of information makes this relationship explicit:

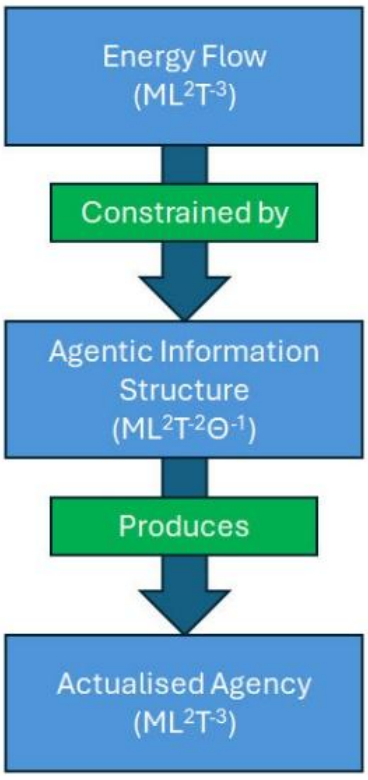

Figure 1. The effect of agency on energy flow

When energy is channelled by informational structure, the result is *directed work*. The maintenance of that structure always requires further energy throughput. Hence cognition and culture are never free.

7. Dimensional Structure of Agency

Agency manifests in three inter-linked dimensions:

Concept	Description	Dimensions
Agentic information structure	Encoded pattern or policy that directs energy	$ML^2T^{-2}\Theta^{-1}$
Agentic potential	Information-structured energy capacity	ML^2T^{-2}
Actualised agency	Directed energy flow through time	ML^2T^{-3}

The relationship can be summarised as:

$$\text{Agency} = \text{f}(\text{Energy Flow constrained by Information})$$

Energy provides means; information provides form; their coupling produces purposeful work.

This triad holds across levels, molecular, biological, cognitive, and social, demonstrating dimensional continuity from physics to behaviour.

To clarify how the dimensional structure of agency operates in real situations, consider two simple examples: one energetic, in which an agent acts upon the environment, and one informational, in which an agent acts upon another agent. Both obey the same thermodynamic–informational logic described above.

Example 1 — Switching on a Device (Energetic Agency)

Plain English description:
A person decides to switch on a lamp. The decision originates as an informational pattern within the brain; an organised neural configuration encoding the intention "I want light."
Muscular contraction applies mechanical work to the switch, closing an electrical circuit.
Electrical energy flows into the lamp's filament or diode, which emits light.
Chemical energy in the person's body has been transformed into mechanical energy, enabling the flow of electrical, and finally radiant energy.
The total entropy of the combined system (agent + device + environment) increases.

In EFGST idiom:

- Neural activation: **agentic information structure** or the negentropic blueprint of action $[I] = ML^2T^{-2}\Theta^{-1}$
- Metabolic readiness: **agentic potential** or the stored energetic capacity to enact that blueprint $[E] = ML^2T^{-2}$
- Motor action: **actualised agency** or the realised flow of energy through that structure over time. $[P] = ML^2T^{-3}$
- Environmental outcome: The agent's *actualised agency* $[P_{agentic}] = ML^2T^{-3}$produces a new **output state** in the environment with redistributed energy $[E_{env}] = ML^2T^{-2}$. Electrical and radiant energies are re-ordered under the constraints of the agent's

information structure $[I_{agentic}] = ML^2T^{-2}\Theta^{-1}$. Total energy is conserved, while global entropy increases as organised energy disperses into ambient heat and light.

Interpretation:
This act demonstrates **energetic agency**, i.e., information within the agent directs an external energy flow. Cognitive order (intention) is converted into physical order (illumination) through work on the environment. It illustrates the coupling of information (form) and energy (means) that defines all purposeful action.

Example 2 — Answering a Question (Informational Agency)

Plain English description:
One person asks another, "Is the meeting today?"
The responder replies, "Yes."
Although the energetic cost is small, information has moved from one mind to another.
The questioner's uncertainty (entropy) decreases; their internal model becomes more ordered.
Speech production and perception involve metabolic energy, sound propagation, and neural reorganisation; each a physical process.

In EFGST idiom:

- Stored knowledge in the responder: **agentic information structure** or the negentropic blueprint of action $[I] = ML^2T^{-2}\Theta^{-1}$
- Metabolic energy driving speech: **agentic potential** or the stored energetic capacity to enact that blueprint $[E] = ML^2T^{-2}$
- Vocalisation: **actualised agency** or the realised flow of energy through that structure over time. $[P] = ML^2T^{-3}$transmitting structured energy (sound).
- **Receiver's neural update:** A local increase in agentic information structure $[I_{agentic}] = ML^2T^{-2}\Theta^{-1}$ occurs as cognitive entropy decreases in the listener's substrate, guided by informational form originating in the responder's substrate. This cross-substrate constraint is sustained by metabolic energy expenditure $[E_{agentic}] = ML^2T^{-2}$, while global entropy still rises through dissipated heat and acoustic losses, preserving thermodynamic balance.

Interpretation:
This case exemplifies **informational agency**, i.e., the transfer of negentropy between agents via energetic media. The responder's internal order is partially replicated in the questioner's cognition. Communication thus appears as physical energy flow shaped by informational form.

Summary

Type of Agency	Domain of Action	Principal Flow	Informational Effect
Energetic	Agent → Environment	Energy transformation (chemical → mechanical → radiant)	External re-organisation
Informational	Agent → Agent	Energy-encoded message (acoustic or symbolic)	Internal re-organisation

In both examples:

Information (negentropy) + Energy (capacity) ⇒ Agency (directed work or communication).

Agency therefore appears as a universal coupling of **form and flow**: energy provides the means, information provides the form, and the result is purposeful change in the physical or cognitive environment.

8. The Sun as the Source of Agency

All terrestrial agency ultimately derives from **solar energy**. The Sun supplies a continuous flux of electromagnetic radiation that drives photosynthesis, fuels atmospheric and oceanic circulation, and sustains all higher forms of metabolism. Through successive transformations, that energy becomes progressively more structured:

1. **Physical capture** — photons converted to chemical potential (ATP, sugars).
2. **Biological organisation** — molecules and cells use stored energy to maintain low entropy.
3. **Cognitive integration** — neural systems channel metabolic energy into perception and decision.
4. **Social amplification** — collective intelligence harnesses physical resources to direct global energy flows.

Every act of life and thought is therefore part of an unbroken energetic cascade from the Sun to the mind. The total agentic potential of Earth's biosphere is a solar derivative; culture and technology are its most complex expressions.

9. Thermodynamic Nature of Learning, Communication, and Social Change

The energetic cost of information transformation appears across scales.

Learning

Neural plasticity depends on metabolic work. Functional magnetic resonance imaging shows glucose and oxygen consumption rising sharply during focused learning. Each new memory corresponds to a local reduction in neural entropy, i.e., new synaptic order, balanced by heat dissipation and driven by metabolic energy. As with all cognition, informational form reorganises the substrate itself and also constrains downstream energetic behaviour. "Subjective "effort" thus reflects real energy expenditure.

Communication

Producing, transmitting, and interpreting messages all consume energy: muscle work, electronic power, cognitive attention. Shannon's idealised model treats communication as noise reduction, but thermodynamically it is entropy management; each bit of clarity purchased by energy use somewhere in the system.

Social and Cultural Change

Cultural transformation requires reorganising vast stores of information: languages, institutions, norms. Education systems, media infrastructures, and political movements convert energy into

lower societal entropy (greater informational order). When energy inputs fall or informational coherence decays, collective agency weakens, as seen in institutional collapse or loss of public trust.

Ecological Reorganisation

Ecosystems recovering from disturbance demonstrate the same principle: re-establishing ordered flows of energy and matter requires work. Pioneer species capture sunlight and rebuild trophic structures, lowering local entropy until stability returns.

10. Conclusion

Information and agency are not abstractions. They are thermodynamic phenomena that span the continuum from physics to mind and society. Information is negative entropy, i.e., an ordered configuration that constrains how energy can flow. Agency is the realised coupling of energy and information, producing directed work.

By re-introducing dimensional analysis, we recover the physical integrity of these concepts:

Level	Informational Form	Energetic Capacity	Directed Flow
Information structure	$ML^2T^{-2}\Theta^{-1}$	—	—
Agentic potential	—	ML^2T^{-2}	—
Actualised agency	—	—	ML^2T^{-3}

Treating information as dimensionless hides this link; recognising its entropy dimensions reconnects it with energy and temperature, revealing why all cognition, communication, and cooperation are costly in energetic terms.

From Brillouin's negentropy and Schrödinger's "order from disorder" to Landauer's and Prigogine's later insights, a consistent picture emerges:

- **Energy** is the means of persistence,
- **Information** is the organisation of that means,
- **Agency** is their coupling in time.

Seen through this lens, life and society are continuous extensions of physics, i.e., open systems that convert the Sun's free energy into informational order and directed work. Understanding this continuity allows us to describe biological and social coordination not as metaphor but as thermodynamic reality.

By grounding cognition and agency in thermodynamics, social coordination, communication, cooperation, and institutional behaviour can be analysed not metaphorically but physically. This opens the door to a quantitative social systems theory grounded in the same physical laws that govern biological and cognitive systems.

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