Agency, Causal Leverage, and Social Power: A Thermodynamic Perspective

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Abstract

Agency is one of the most fundamental but least understood features of living and social systems. Traditional accounts describe agency in terms of intention, motivation, or symbolic meaning, but they rarely explain *how agency works physically*. This paper offers a thermodynamic and informational account of agency grounded in the concept of *causal leverage:* a process by which a small, informationally guided energetic act triggers, redirects, or inhibits a much larger energetic flow in another system. This framework unifies insights from thermodynamics, information theory, cognitive science, cybernetics, and social systems theory. It explains why agency is both informational and energetic, why control components in engineered systems use small signals to manage large energy flows, and why social power emerges as the capacity to mobilise collective energy through informational influence. The result is a physically grounded understanding of meaning, action, and social coordination that illuminates the deep continuity between physics, life, cognition, and society.

1. Introduction

Agency is everywhere in living and social systems. A neuron fires and a limb moves. A political leader speaks and thousands of people change their behaviour. A single instruction in an organisation directs the labour of many. These phenomena appear obvious, even intuitive, yet the underlying mechanisms remain poorly understood.

Historically, explanations of agency have relied on metaphor, psychology, or narrative reasoning. But agency is also a *physical* process. It requires energy, it involves information, and it produces large-scale effects that disproportionally exceed the energy invested in the initiating act. The challenge is to explain this relationship clearly, rigorously, and in a way that unifies physical, biological, cognitive, and social domains.

This paper develops such an account by introducing the concept of *causal leverage*; the amplification mechanism by which informational structures in one substrate control or redirect larger energetic flows in another. This framework builds on and extends ideas in causality (Challoner, 2025), thermodynamics (Landauer, 1961), constraint-based causation (Juarrero, 1999; Deacon, 2012), top-down influence (Ellis, 2012), and multiscale cybernetics (Holland, 2012). It offers a unified explanation of agency and social power grounded not in metaphor but in physics.

2. Information, Energy, and the Foundations of Agency

At its core, agency requires two ingredients: *Information* determines *what* action is taken, and *energy* determines *that* the action occurs at all.

Although we often speak of information as if it were abstract, information in the physical world is always a *pattern of order*, i.e., structure, carried on some energetic or material substrate. In thermodynamic terms, such structure is a form of *negentropy*: local order that stands against

the tendency toward disorder. DNA sequences, neural firing patterns, muscle coordination routines, spoken language, written symbols, and organisational rules all qualify as informational structures because they introduce pattern, constraint, and regularity into the systems that carry them.

Energy, by contrast, is the capacity to do work. It makes physical change possible, but energy without structure is *blind*; it does not know which direction to go or which outcome to favour. Information provides that direction. Thus: *information is form; energy is force*.

Agency arises when *informational form constrains energetic flow*, shaping it toward a specific, organised end (Deacon, 2012; Juarrero, 1999). This is why both ingredients are required: information alone is inert, and energy alone is undirected.

Even the simplest agentic acts, such as moving a muscle, speaking a word, pressing a button, require a small amount of *activation energy*. This energy comes from the agent's own physical substrate (metabolic processes, neural electrochemistry). Importantly, this tiny energetic trigger does *not* produce the large-scale effects by itself. Instead, it selects, releases, or redirects much larger flows of energy downstream.

This is the key to understanding agency: *it works through amplification*. A small, information-guided act alters the causal landscape so that much larger amounts of energy follow the path that the informational pattern has selected.

3. Causal Leverage: Small Causes with Large Effects

Causal leverage is the mechanism by which informationally guided actions produce disproportionally large outcomes. Although we often speak of causation as a logical or conceptual relation, in physical systems causality always has a concrete substrate. For one event to affect another, some transfer of energy or matter must cross the boundary between them. No such transfer, no causal influence. Crucially, this transferred energy or matter may also carry information, i.e., patterns or constraints that shape the subsequent behaviour of the receiving system. Neural spikes, sound waves, chemical signals, mechanical forces, and symbolic marks on paper all illustrate this dual role: they transmit energy, and that energy is organised so as to convey information. Causation is therefore not merely a connection between events in time; it is a physically mediated flow in which energetic transfer is shaped by informational structure. This physicality of causation is essential for understanding agency, because agency depends on the ability of informational patterns to make energetic flows take one path rather than another.

Formally, causal leverage is: *a small, low-energy act guided by information unlocks, redirects, or inhibits a much larger energetic flow in another system*.

Although individual effects can sometimes be traced to a single dominant cause, most arise from multiple causes acting together, all of which are necessary but only jointly sufficient for the effect. Each contributing cause transfers a certain amount of energy or matter across the system boundary, but these contributions need not be equal. Some causes are large-scale energetic drivers, the background forces without which the effect could not occur. Others are small-scale informational triggers that enable or inhibit those drivers. It is in this latter category that agency operates. Even when the bulk of the energy driving an outcome originates elsewhere, a small informational act can "tip" the system by selecting, enabling, or inhibiting one specific downstream flow. Causation in physical, biological, cognitive, and social systems

is therefore distributed, with both major energetic drivers and minor informational selectors contributing to the final effect. Causal leverage arises precisely when the smallest of these contributing causes, through its informational organisation, directs the largest energetic component of the process.

Examples occur across all scales of organisation. In physics and engineering: a spark plug releases the energy stored in petrol; a transistor gate (tiny energy) controls the current of an amplifier (large energy); and a valve stem regulates the flow of high-pressure steam. In biology: a single neurotransmitter molecule triggers waves of neuronal firing; a gene-regulatory switch activates a metabolic cascade; and a neural spike causes an arm or leg to move. In human cognition and communication: a spoken word alters another person's emotional, cognitive, or behavioural state; a decision in the prefrontal cortex reorganises behaviour throughout the body; and a symbolic cue (a sign, gesture, or instruction) mobilises coordinated action. In society: a leader's short message mobilises a population; a policy directive reorganises the labour of thousands; and a legal ruling restructures a nation's behaviour.

In all these examples the initiating energy is small, but the downstream energy is large, and the causal mechanism is informational constraint. This is causal leverage, and it is the physical engine of agency.

4. Cross-Substrate Causation

A central feature of true agency is that it is almost always cross-substrate. Information does not merely organise the energy within its own physical medium. Instead: neural information controls muscular energy; linguistic information controls cognitive energy in another brain; institutional information controls organisational energy; symbolic information controls collective social energy.

This cross-substrate constraint is what distinguishes agency from simple mechanical reaction (Ellis, 2012; Hoel, 2017). It is also why agency is embodied, energetic, and informational.

5. Cybernetics and Control Components

Causal leverage also provides a physical explanation for classical cybernetic architecture. Engineered systems, from thermostats to aircraft autopilots, use control components that consume little energy but regulate processes that consume much more. Cybernetic control is therefore fundamentally a form of causal leverage (Holland, 2012).

The low-energy control signals: select among system states; regulate high-energy flows; enable purposeful behaviour; reduce uncertainty; impose constraints on dynamics. What cyberneticians described abstractly, thermodynamics explains physically.

6. Social Power as Amplified Agency

Causal leverage also explains the physical basis of *social power*. In social systems, individuals rarely mobilise large amounts of energy themselves. Instead, their *informational acts*, i.e., their instructions, messages, narratives, or gestures, mobilise the energetic behaviour of others.

Thus: *Social power is the capacity to use small informational acts to mobilise large amounts of collective energy.*

A leader's speech, a symbolic action, a policy decision, a norm, or a social cue can shift the behaviour of thousands or millions. This is not metaphorical. It is *the same physical principle* as

a transistor, a gene switch, or a neural spike. Social power is therefore a thermodynamic phenomenon: a form of *high amplification* built on *informational constraint*.

7. Why Humans Seek Social Power

This framework explains the universal human drive toward influence, leadership, and institutional authority. Power: reduces the energetic cost of achieving desired outcomes; increases the amplification of one's actions; creates stability, control, and predictability; and increases the effectiveness of cooperation.

In thermodynamic terms: *To seek power is to seek an increase in one's agentic leverage.* This is not a moral claim; it is a physical one.

8. Implications for Social Systems Theory

By grounding agency in energy and information, this model:

- integrates physical, biological, cognitive, and social processes;
- provides a causal mechanism linking micro-acts to macro-scale behaviours;
- explains cooperation as shared and mutually amplifying agentic leverage;
- frames institutions as collective control components;
- establishes the basis of a thermodynamic social systems theory.

This approach unifies long-separated domains and offers a rigorous alternative to metaphorical descriptions of social power, intention, influence, and organisation.

9. Conclusion

Agency is not mysterious, metaphysical, or purely symbolic. It is a thermodynamic process in which informational structures in one substrate exert causal leverage over the energetic behaviour of another. This small-cause/large-effect relationship underlies biological action, cognition, communication, social power, and institutional dynamics.

Understanding agency as causal leverage allows us to integrate physics, cybernetics, and social systems theory into a coherent framework. It reveals that the mechanisms enabling an enzyme to trigger metabolism, a neuron to move a body, or a leader to mobilise a population are fundamentally the same.

This provides a powerful foundation for developing a physically grounded theory of social systems; one capable of explaining cooperation, coordination, meaning, and power in terms of constraint, energy, and amplification.

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