# The Universal Information Optimization Principle

*Information Finiteness, Holographic Encoding, Least Action, and the Energetic Cost of Information as One Economy of Information*

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**Scope and Intellectual-Property Notice**

The established physical bounds invoked here — the Bekenstein bound, the holographic and covariant entropy bounds, the principle of least action, and the Landauer limit — are prior art and are cited as such. The original contribution of this work is the unifying constrained-optimization statement over them. The operational core of that contribution — the explicit cost functional, the closed-form optimization problem and its full proof, the optimal multipliers and shadow-price relations, the detailed saturation theorem, and the information-weighted action functional — is the subject of an intellectual-property filing (WIPO) and is deliberately withheld. The structural relations shown here are presented only at the level of named roles and qualitative results; they are insufficient, by design, to reconstruct, re-derive, or reverse-engineer the protected formulation by analytical, numerical, or automated (including AI-assisted) means. Requests for evaluation under appropriate confidentiality arrangements may be directed to the author.

***Companion note.*** *This principle is offered as a fourth foundational pillar in the author's program, autonomous in formulation and complementary in scope to the Unified Variational Principle (dynamics and equilibrium), the deterministic quantum-informational hash descriptor (informational identity), and the unified wave-confinement model (empirical observation). Where those supply dynamics, identity, and measurement, the present principle supplies the missing economic layer: how much information the universe displays, where it is encoded, how it evolves, and what it costs.*

## Abstract

The Universal Information Optimization Principle (UIOP) proposes a single organizing idea: the universe does not display information without limit — in any region it displays the least information that is both descriptively sufficient and physically admissible. Four independently established results — the finiteness of information in a finite region (the Bekenstein bound)[1][2], the holographic / covariant encoding of volumes onto boundaries[4][5][6], the extremization of an action functional, and the strictly positive energetic cost of irreversible information change (the Landauer limit)[7] — are reframed as four faces of one economy of information. The principle states that displayed information is fixed by a constrained optimization: minimize the energetic cost of information subject to a lower descriptive-sufficiency floor and an upper physical ceiling, with the ceiling given by the tighter of the Bekenstein and holographic limits. The maximal-information state of a region coincides with a black hole, recovering Bekenstein–Hawking entropy as the saturation case. The UIOP is offered as a fourth foundational pillar, formulated to be empirically falsifiable rather than merely interpretive. This document states the architecture and its qualitative results, while withholding the operational core of the optimization under intellectual-property protection.

## 1. Introduction

Modern physics has independently established four deep facts about information in the physical world. First, the information contained in a finite region with finite energy is bounded above. Second, that information can be encoded on the lower-dimensional boundary of the region rather than throughout its volume. Third, the dynamical evolution of physical systems extremizes an action functional. Fourth, erasing or irreversibly transforming information carries a minimum energetic cost. Each fact is well established in its own domain, yet they are usually presented as separate principles.

The UIOP unifies them under a single organizing statement: **the universe optimizes the information it displays**. This reframes finiteness, holography, least action, and information cost as four faces of one economy of information. Crucially, the contribution is not the bounds themselves — which are prior art — but the *unifying constrained-optimization statement* over them, together with its consequences for equilibrium, saturation, and falsifiability.

## 2. The Core Idea: A Global Optimization Condition

For any physical region with a boundary, an enclosed energy, and an enclosing radius, the information the universe displays is fixed by a **constrained optimization** bounded both from above and from below. Conceptually:

$$\textit{displayed information} \quad = \quad \textit{the least information that is both sufficient and admissible}$$

The optimization minimizes the energetic cost of maintaining and irreversibly transforming information, subject to two constraints: a **descriptive-sufficiency floor** (the minimum information needed to specify the region's state to the required resolution) and a **physical ceiling** (the maximum the region can hold). The lower bound is essential: without it, the cost-minimizing solution would be the trivial "display nothing," which is unphysical. With it, the optimum is the smallest description that is both physically sufficient and admissible. The explicit cost functional, the formal optimization problem, and its full solution are part of the protected core and are withheld.

$$\textit{minimize cost(information)} \quad \textit{subject to} \quad \textit{sufficiency floor} \leq \textit{information} \leq \textit{physical ceiling}$$

Two qualitative results follow and can be evaluated independently of the protected internals. When displayed information lies strictly below the ceiling, the region is in *informational equilibrium* and ordinary physics holds. As the requirement meets the ceiling, the region must shed information to its boundary (holographic encoding) or undergo gravitational collapse. The dynamical evolution of the displayed information is governed separately by least action (Component 3).

The physical ceiling is the tighter of two established bounds: the *Bekenstein bound*[1], which dominates for weakly self-gravitating systems, and the *holographic / covariant bound*[5][6], which dominates as the region approaches gravitational saturation. Both are prior art and are stated as external results, not as contributions of this work.

## 3. The Four Components

The information economy of every region is shaped by the interaction of four components. Each rests on an established result (prior art); the UIOP's role is to bind them into a single optimization.

| Component | Role in the economy of information | Established basis (prior art) |
|---|---|---|
| **1. Finiteness (the bound)** | No region can contain unlimited information; exceeding the ceiling forces gravitational collapse | Bekenstein bound [1][2] |
| **2. Holography (the surface)** | Admissible information is encoded on the boundary, not the volume; volumetric description is redundant | 't Hooft; Susskind; Bousso [4][5][6] |
| **3. Least action (the dynamics)** | Among admissible trajectories, the realized one extremizes an action functional | Principle of least action; Jacobson [8] |

| Component | Role in the economy of information | Established basis (prior art) |
|---|---|---|
| **4. Cost (the price)** | Irreversible information change carries a strictly positive minimum energetic cost | Landauer limit [7] |

Components 1, 2, and 4 fix *how much* information is displayed at a given instant; Component 3 fixes *how that information evolves*. The static content optimization and the dynamical trajectory selection are logically distinct: one selects the magnitude of displayed information, the other selects the path. The precise way these are combined — in particular the information-weighted action functional — is part of the protected core.

## 4. Saturation and the Black-Hole Limit

A central qualitative result of the principle is that the **maximal-information state of a region is a black hole**. As the descriptive requirement approaches the holographic ceiling, the optimum saturates the covariant bound, and the corresponding entropy equals one quarter of the horizon area — precisely the Bekenstein–Hawking entropy[2][3]. Black-hole thermodynamics thus emerges not as a separate postulate but as the boundary case of informational optimization: the region where displayed information exactly meets its ceiling. The detailed saturation theorem and its proof are withheld; only the result is stated here.

$$\text{requirement} \to \text{holographic ceiling} \quad \Longrightarrow \quad \text{maximal-information state} \;=\; \text{black hole}$$

## 5. Problems the Principle Addresses

1. **Why information is finite, not infinite.** Finiteness becomes an optimization constraint: a region can display only as much information as fits its boundary, and exceeding that ceiling triggers collapse.
2. **Why the world looks volumetric but is surface-limited.** The holographic component explains why maximum information scales with area, not volume — the universe displays boundary-encoded, non-redundant information.
3. **Why dynamics follows least action.** Least action is reframed as the dynamical signature of an optimizing universe rather than an unexplained variational accident.
4. **Why information has a price.** The Landauer component grounds the economy: irreversible change costs energy, so an optimal universe is biased toward reversible, information-preserving evolution.
5. **A unified reading of black-hole thermodynamics.** Black holes become the saturation case — the boundary state of informational optimization.

## 6. Falsifiability Conditions

The principle is constructed to be refutable. It is invalid or incomplete if any of the following are demonstrated:

- A finite region with finite energy contains information exceeding the Bekenstein / holographic ceiling without collapsing.
- The maximum information of a region scales with its volume rather than its boundary area in any regime where the covariant bound should apply.
- A physical system evolves along trajectories that do not extremize any action functional.
- Irreversible erasure of information is achieved below the Landauer energetic cost.

- The saturation state fails to coincide with black-hole entropy ($S = A / 4$ in natural units).
- Information density in nature is found to be unbounded in any finite-energy region.

Each condition maps to a measured or measurable quantity, so the principle is refutable rather than purely interpretive.

## 7. Limiting and Extreme-Case Behaviour

- **Empty region.** With nothing to describe, the optimum is zero displayed information at zero cost — the informational vacuum.
- **Sub-saturated region.** The region is informationally relaxed; displayed information equals the descriptive requirement, evolution follows least action, and ordinary physics is recovered.
- **Saturating region.** The requirement approaches the ceiling; information must be shed to the boundary or the region collapses into a black hole, the maximal-entropy state.
- **Zero-temperature limit.** The Landauer cost per bit vanishes, so reversible processing becomes free; only the bound and dynamical faces remain active.
- **Cosmological scale.** Displayed information is bounded by the area of the cosmic horizon, consistent with the universe not being a black hole and with entropy scaling as area rather than volume.

## 8. Relation to the Foundational Program

The UIOP is presented as a fourth foundational pillar, autonomous in formulation and complementary in scope. Where one foundation unifies physical dynamics and equilibrium, another encodes informational identity, and another governs the confinement of waves, the UIOP supplies the missing economic layer: it states how much information the universe displays, where it is encoded, how it evolves, and what it costs. Applied and dynamical models in the program inherit this layer as their physical substrate — in particular, any framework that treats information, memory, or perception as physical can rest on the UIOP's guarantee that information is finite, surface-encoded, least-action-driven, and energetically priced.

**Notational independence.** The optimization functionals and the displayed-information quantity introduced by this principle are self-contained and are not equated with, derived from, or dependent on the variables of any other model in the program. The principle relies only on established physical results, cited as external prior art, and introduces a unifying optimization statement over them. No formulation here reproduces the protected equations of any other framework.

## 9. Conclusion

On the basis of four independently confirmed physical results, the Universal Information Optimization Principle establishes that the universe optimizes the information it displays. By unifying information finiteness, holographic encoding, least-action evolution, and the energetic cost of information into a single constrained-optimization condition, it reframes a set of separate physical facts as one economy of information. It explains why information is finite, why volumetric description is redundant, why dynamics follows least action, and why information carries a price, and it identifies black-hole thermodynamics as the saturation case. Each of its claims is tied to a measurable quantity, so the principle can be tested and, if wrong, refuted. As a foundational pillar it provides the physical substrate of information economy on which the broader program can build.

## Intellectual-Property Statement



## References (Prior Art)

*The physical bounds invoked by the UIOP are established results in the literature; the contribution of this work is the unifying constrained-optimization statement over them, not the bounds themselves.*

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