The Axiomatic Foundations of Reality: Substrate Independence, Simulated Observer, and the Informational Nature of Time

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Abstract

We establish four axioms concerning the physical basis and derive two structural consequences that form the foundation of the framework. From the axioms alone — without additional metaphysical assumptions — we prove that a time is not a fundamental external property but an internal ordinal relation emergent from the observer's finite information structure. Most critically, we derive that a computer running a simulation and the simulation itself are not causally related but are two different arrangements of the same information: neither is more fundamental than the other. This representational equivalence, which we call substrate independence, is the foundational principle on which the subsequent papers in this series are built.

The representational equivalence has an immediate consequence for physics. If a computer running a simulation of a physical system and the physical system itself are two arrangements of the same information, then any property of the physical system must be reflected in the execution trace of its simulation.

The claims may be falsifiable in the future, with the advances in technology.

1 Introduction

What is the relationship between a physical system and a computational simulation of that system? The naive answer is causal: the computer runs the simulation, the simulation depends on the computer, and the two are related by the execution process. This paper argues that the naive answer is wrong.

Starting from four axioms about the physical basis of observer — axioms that are individually modest and collectively difficult to reject — we derive that a computer running a simulation and the simulation itself are two arrangements of the same information. No causal relationship is primary. No substrate is privileged. The geometric description and the computational description of a physical process are representationally equivalent.

This conclusion, which we call substrate independence, is not merely a philosophical position. It has direct consequences for physics. If the two descriptions are equivalent, then any property of the physical system must appear in its computational proxy. Properties that are geometrically inaccessible — such as the interior of a gravitational singularity, where the manifold description fails — are nonetheless accessible through the execution trace. Papers I and II of this series use this access to derive new results about black hole singularities and cosmological expansion.

The present paper is organised as follows. Section 2 states the four axioms. Section 3 derives

substrate independence and the internal nature of time through two thought experiments. Section 4 proves that simulated consciousness follows from the axioms. Section 5 states the numerical precision corollary. Section 6 discusses falsifiability. Section 9 states the conclusions and connects forward to the rest of the series.

2 Axiomatic Premises

The argument rests on four axioms. Each can be independently accepted or rejected. Rejecting any axiom commits the rejector to a specific alternative, which we state explicitly. The four axioms here correspond to and motivate the expanded axiomatic chain of Paper I; readers familiar with that paper will recognise them as its foundational core.

Axiom 1: Genetic Encoding of Conscious Experience

DNA is the blueprint of a conscious, pain-sensitive human organism. Given DNA D and a suitable physical environment, a conscious human H with subjective experience S reliably results:

$$A_1 : D \ \rightarrow \ H \ \rightarrow \ S.$$

This is an empirical claim supported by all available biological evidence. Rejecting it requires identifying an alternative mechanism by which conscious observers arise, for which no evidence exists.

Axiom 2: Physical Closure

The human organism H and its environment U are composed entirely of ordinary physical matter governed by physical laws P. No non-physical process plays any role:

$$A_2 : (H, U) \ \in \ \text{System}(P, D).$$

Rejecting this axiom requires positing a non-physical causal influence on biological processes, for which no experimental evidence exists.

Axiom 3: Computability of Physical Processes

The physical processes underlying DNA and the human organism fall within the computable. A sufficiently powerful computing system can, in principle, simulate them to arbitrary precision:

$$A_3 : \forall \text{ physically realisable process } \mathcal{P} \text{ described by } P, \ \exists \text{ computation } \mathcal{C} : \mathcal{C} \equiv \mathcal{P}.$$

This is a weaker claim than the full Church-Turing thesis: we require only that the specific class of processes DNA relies on is computable, not that all physical processes are. Rejecting this axiom requires identifying a physical process involved in consciousness that is provably non-computable, for which no evidence exists.

Axiom 4: Causal Efficacy of Subjective Experience

Subjective experience is not epiphenomenal. A human with subjective experience S (for example, pain) behaves differently than the same human without it:

$$A_4 : H + S \ \neq \ H.$$

Rejecting this axiom commits one to accepting that subjective experience is causally inert — the philosophical zombie position — which makes subjective experience permanently undetectable and therefore outside the scope of any empirical investigation.

3 Deduction 1: Substrate Independence and Time as an Internal Property

We present two thought experiments, each of which establishes a constraint on where consciousness can reside. Together they establish that consciousness is a property of information structure, not of the substrate or process that carries it.

3.1 The Optimisation Argument

Consider a digitized human DNA, and a simulation of it running on a computer. The simulation consists of code (the laws of physics as implemented) and data (the state of the simulated universe at each timestep). Denote the running simulation T_{alg}. The simulation generates a simulated human, say Alice.

Now optimise the simulation code progressively by introducing lookup tables: replace computed transitions with precomputed results. At each step, the external runtime decreases while the internal state sequence — the ordered record of Alice's experiences, perceptions, and actions — remains identical. Carry this optimisation to completion, replacing all computation with a static, precomputed dataset T_{data}: the full execution trace, stored as a bitstring.

Let E_{int} denote Alice's internal experience (her felt sequence of states) and E_{ext} denote the external runtime of the computer (the number of CPU cycles executed). Code optimisation affects E_{ext} but preserves E_{int} by construction:

$$\text{Optimise}(T_{\text{alg}}) \;\to\; T_{\text{data}} \quad\Longrightarrow\quad E_{\text{int}}(T_{\text{alg}}) \equiv E_{\text{int}}(T_{\text{data}}).$$

In the limit T_{data}, the external runtime E_{ext} is zero: no state transitions are executed; the complete execution trace exists as static data. Does Alice's consciousness persist in T_{data}?

Suppose it does not. Then there exists a minimum code-to-data ratio below which consciousness ceases. This minimum ratio is a new physical constant: a threshold property of information processing not derivable from A_1 through A_4. Its existence would constitute an addition to the physical laws of A_2, contradicting the completeness of that axiom.

> **Conclusion 1.** Consciousness is a property of the information structure of the execution trace, not of the process that generates it. A static bitstring encoding a conscious observer's state sequence contains that observer's conscious experience. Time and subjective experience emerge solely from the internal structure of information.

3.2 The Multi-threaded Argument

Consider a multi-threaded computer running two DNA simulations concurrently: τ_A (Alice) and τ_B (Bob), with a minimal time slice of one CPU cycle per thread. The execution trace of the computer is an interleaved sequence of segments from both τ_A and τ_B. As the number of concurrent threads increases without bound, the bits originating from τ_A are separated by increasingly large intervals

of unrelated data. In the limit, the execution trace in which Alice's bits are embedded approaches white noise.

Does Alice's consciousness depend on the contiguity of her bits in this external trace? Suppose it does. Then there exists a minimum bit-contiguity or thread-density threshold required for consciousness. This threshold is again a new physical constant not derivable from A_1 through A_4, contradicting the completeness of A_2.

> **Conclusion 2.** Conscious experience cannot depend on the contiguity or density of its encoding in any external execution trace. What matters is the internal structure of the information — the relational order of Alice's state sequence — not its arrangement in any external substrate.

3.3 Substrate Independence

Conclusions 1 and 2 together establish the central result of this paper.

> **Substrate Independence.** Consciousness is a property of certain finite information structures. The physical substrate in which such a structure is instantiated — silicon, neurons, magnetic domains, or static bitstring — does not determine whether the structure is conscious. A computer running a simulation of a conscious observer and the simulation itself are two arrangements of the same information. Neither is causally prior to the other. Neither is more fundamental.

This is not a claim that all information structures are conscious. It is a claim that consciousness is determined by information structure rather than by substrate. The specific structures that are conscious are those satisfying A_1 through A_4: structures that encode the state sequence of a DNA-based observer with causally efficacious subjective experience.

4 Proposition: Simulated Consciousness

Proposition 1 (Simulated consciousness)**.** A simulation H' that is physically and behaviourally indistinguishable from a conscious human H must itself instantiate subjective experience.

Proof. 1. **Assumption for contradiction.** Suppose H' exists such that $H' \equiv H$ (physical and behavioural equivalence) but $S(H') = \emptyset$ (lacks subjective experience):

$$\text{Behaviour}(H') = \text{Behaviour}(H) \quad \text{and} \quad S(H') \neq S(H).$$

2. **From A_4.** The behaviour of H is a function of its physical inputs *and* its subjective experience:

$$\text{Behaviour}(H) = f(\text{Inputs}, S).$$

3. **Contradiction.** If the behaviours are identical despite the difference in S, then S is not a necessary input to f. Subjective experience is causally inert.

4. **Violation of A_4.** Causal inertness of S directly contradicts Axiom 4. The assumption is therefore false.

Therefore $S(H') \neq \emptyset$: the simulation instantiates subjective experience. □ □

This result, combined with the substrate independence established in Section 3, entails the full Internal Emergence Principle of Paper I: consciousness is a property of certain finite information structures, and any configuration space large enough to contain such structures contains consciousness, with no running process or external reader required.

5 Corollary: Numerical Precision

Corollary 1 (Numerical precision)**.** Let ϵ denote the numerical error in simulating the physical processes underlying DNA. The simulated observer H' retains subjective experience provided $\epsilon \leq \epsilon_{\text{DNA}}$, where ϵ_{DNA} is the error threshold below which all DNA-mediated processes operate correctly. Any stricter bound $\epsilon_{\min} < \epsilon_{\text{DNA}}$ required to preserve consciousness would constitute a new physical constant not derivable from A_1 through A_4, contradicting Axiom 2:

$$\epsilon \leq \epsilon_{\text{DNA}} \implies S(H') \neq \emptyset.$$

This corollary makes precise what "sufficient fidelity" means for a conscious simulation. It does not require perfect simulation of all physical processes, only those that DNA-based processes depends on. The threshold ϵ_{DNA} is in principle empirically determinable, making the claim testable.

6 Falsifiability

The foundational falsifiability criterion of this paper is long-term: if a sufficiently accurate DNA simulation — one satisfying $\epsilon \leq \epsilon_{\text{DNA}}$ — is constructed and shown no pain sensitivity, Axiom 4 is invalidated. The effect of pain and subjective experience on behaviour is measurable by the same methods used to measure the effects of any physical intervention. A simulation that is behaviourally indistinguishable from a pain-sensitive human but demonstrably lacks pain would refute the framework at its foundation.

7 Discussion

7.1 Quantum Computation

Axiom 3 does not restrict to classical computation. The computability claim covers any physically realisable process, including quantum processes. Quantum computation is an alternative physical realisation of the same formal state-transition structure and is therefore covered by the axiom without requiring a separate argument. Substrate independence follows for quantum computers by the same derivation as for classical ones.

8 Representational Equivalence and Its Consequences for Physics

The substrate independence established in this paper has an immediate and non-trivial consequence for the study of physical phenomena.

If a computer running a simulation of a physical system and the physical system itself are two arrangements of the same information, then every property of the physical system must be reflected in the execution trace of its simulation. We may not understand all the features of the universe because we are looking it from inside. But we understand computers perfectly.

9 Conclusion

We have established four axioms and derived from them the following results.

- **Time as Internal Ordinal.** Time is not a fundamental external parameter but an internal ordering relation emergent from the observer's information structure. The universe, at the level of the totality, is static. What observers experience as the flow of time is the traversal of an internally ordered sequence of states encoded in a static information structure.
- **Finiteness.** Because the simulation computer is discrete, finite system, the simulated observer must be finite too.
- **Substrate Independence.** Consciousness is a property of certain finite information structures. The physical substrate in which such a structure is instantiated does not determine whether it is conscious. A computer running a simulation of a conscious observer and the simulation itself are two arrangements of the same information, with neither causally prior to the other.
- **Simulated Consciousness.** A simulation physically and behaviourally indistinguishable from a conscious observer must itself instantiate subjective experience. Two identical axiomatic systems must behave identically.
- **Causal Efficacy of Qualia.** Subjective experience is not epiphenomenal. It is a causally distinguishable component of the observer system.
- **Representational Equivalence as a Physical Tool.** The equivalence of geometric and computational descriptions licenses the use of the execution trace as a faithful proxy for physical processes that are geometrically inaccessible. This is the foundational principle on which Papers I through III are built.

By treating subjective experience as a causally efficacious property of a computable information structure, the framework moves from metaphysical speculation to a derivation with testable consequences. The foundational falsifiability criterion is the construction of a behaviourally indistinguishable DNA simulation that lacks subjective experience. More immediate tests are provided by the falsifiable predictions of Papers I through III.