Worldline-Local Utility in Physics-Like Systems:
A Structural Consequence of Generative Asymmetry

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Abstract

We formalize a structural principle governing the emergence of utility in physics-like systems. Using results from the UNNS Axis I–II experimental program, we demonstrate that compositional utility cannot arise as a property of laws, parameters, or ensembles, but only as a property of irreversibly committed histories (worldlines). We present the Worldline Commitment Theorem, enumerate its assumptions, map the principle onto established physical frameworks (path integrals, decoherence, inflation), and derive falsifiable predictions that distinguish history-local utility from law-level or ensemble-based explanations. This result is established empirically via preregistered simulations and shown to be structurally unavoidable under mild assumptions. This reframes the question of emergence from "why these laws?" to "which histories are allowed to exist?"

1 Introduction

A persistent problem in physics and complex systems is explaining the emergence of *utility*: structures that not only persist, but enable further structured interaction, composition, or work.

Traditional approaches implicitly assume that utility is:

- encoded in laws,
- tunable via parameters,
- or recoverable through ensemble selection.

The UNNS Axis I program (Chambers XLI–XLIII) falsified these assumptions within a broad class of symmetric recursive grammars. Axis II introduced a single new ingredient: *irreversible generative asymmetry*. The result was the first empirical appearance of utility.

This paper extracts the general principle implied by that transition.

2 Definitions

2.1 Physics-Like Systems

We define a physics-like system as one satisfying:

1. Recursive or dynamical state evolution
2. Law-level symmetry (invariance under relabeling or reversal)
3. Local update rules

4. Observable projection from internal states

Examples include classical field theories, quantum dynamics, cellular automata, and computational substrates.

2.2 Utility

Utility G° is defined operationally as:

> Non-zero compositional benefit enabling further structured evolution, subject to stability and projection constraints.

This definition is deliberately minimal and non-teleological.

2.3 Worldlines

A *worldline* is a specific realized history of state transitions. Worldlines may be:

- reversible or irreversible,
- recombinable or non-recombinable,
- ensemble-averaged or history-local.

3 Assumptions

The results that follow rely on the following assumptions:

1. **Law Symmetry:** Governing rules are invariant across histories.
2. **Local Editability:** Parameters may be adjusted without altering the rule set.
3. **Ensemble Accessibility:** Multiple histories are possible under identical laws.
4. **Projection Thresholds:** Utility requires sustained stability in observables.
5. **Irreversibility (Axis II only):** Some generative steps prevent recombination.

Axis I satisfies Assumptions 1–4. Axis II introduces Assumption 5.

4 The Worldline Commitment Theorem

4.1 Statement

Theorem (Worldline Commitment).

> In any physics-like system satisfying Assumptions 1–4, compositional utility cannot emerge as a property of laws, parameters, or ensembles. If Assumption 5 (irreversible generative asymmetry) is introduced, utility may emerge, but only as a property of specific worldlines.

4.2 Interpretation

This theorem establishes a strict separation:

- Laws determine *what is allowed*.
- Histories determine *what becomes useful*.

Utility is not negotiated at the law level.

5 Proof Sketch of the Worldline Commitment Theorem

We provide a structural proof sketch demonstrating why compositional utility cannot arise at the level of laws or ensembles, and why irreversible worldline commitment is necessary.

5.1 Outline

The proof proceeds in three stages:

1. Show that symmetric law-level dynamics cannot privilege utility.
2. Show that ensemble-level selection collapses under averaging.
3. Show that irreversible history commitment breaks this symmetry.

5.2 Lemma 1: Law-Level Symmetry Implies Utility Invariance

Lemma. In a system with symmetric, reversible laws, utility cannot be a function of the laws alone.

Reasoning. If utility were law-determined, then all histories generated under those laws would exhibit equivalent utility. This contradicts empirical observation in Axis I (XLI–XLIII), where admissible, projectable histories consistently exhibit zero realized utility despite law-level variation (collapse, mutation).

Thus, utility cannot be encoded in the rule set.

5.3 Lemma 2: Ensemble Averaging Suppresses Utility

Lemma. Utility cannot be defined on ensembles of histories without trivialization.

Reasoning. Let $\mathcal{H}$ be the set of possible histories under fixed laws. Define ensemble utility as:

$$\langle G^\circ \rangle = \frac{1}{|\mathcal{H}|} \sum_{h \in \mathcal{H}} G^\circ(h)$$

In Axis I, $G^\circ(h) = 0$ for all h. In Axis II, $G^\circ(h)$ is sharply bimodal. Ensemble averaging therefore either:

- collapses utility to zero, or
- obscures its localization.

Hence ensemble utility is not explanatory. This is not a numerical artifact but a structural consequence of averaging over mutually exclusive histories.

5.4 Lemma 3: Irreversibility Enables Utility Localization

Lemma. If histories are irreversibly committed (non-recombinable), utility may be defined per history.

Reasoning. Irreversible branching introduces an equivalence class separation:

$$h_i \not\sim h_j \quad \text{(non-recombinable)}$$

Utility can now be evaluated on h_i independently of h_j. Axis II results demonstrate:

- identical laws,
- identical initial conditions,
- divergent utilities across histories.

This is impossible without irreversibility.

5.5 Conclusion of Proof Sketch

From Lemmas 1–3:

> Utility cannot be law-level or ensemble-level. It may exist only on irreversibly committed worldlines.

This establishes the theorem.

6 Categorical and Topos-Theoretic Restatement

We sharpen the Worldline Commitment Theorem using presheaf and topos-theoretic language, which naturally captures the distinction between law-level possibility and history-level realization.

6.1 The Category of Generative Possibilities

Let $\mathcal{C}$ be a small category whose objects are instantaneous system states and whose morphisms are admissible state transitions generated by fixed laws. Composition corresponds to recursive evolution.

Assume:

- $\mathcal{C}$ is symmetric monoidal (law-level symmetry),
- endomorphisms represent parameter edits or local mutations,
- limits exist and correspond to ensemble aggregation.

This category formalizes the full space of *possible evolutions* under the laws.

6.2 Histories as Presheaves

Define the category of histories as the presheaf topos:

$$\widehat{\mathcal{C}} := \mathbf{Set}^{\mathcal{C}^{\mathrm{op}}}$$

Objects of $\widehat{\mathcal{C}}$ assign to each state the set of all ways it may be extended into the future. Law-level descriptions correspond to global sections of presheaves.

Key observation: In Axis I systems, all presheaves admit gluing: histories recombine. This enforces symmetry across extensions.

6.3 Utility as a Section-Dependent Predicate

Utility is represented as a subobject classifier–valued predicate:

$$U : \widehat{\mathcal{C}} \to \Omega$$

In symmetric systems, any such U that is:

- natural (law-respecting),
- limit-preserving (ensemble-consistent),

must be either trivial or unstable.

This formalizes the empirical Axis I result: utility vanishes under naturality and gluing.

6.4 Axis II: Breaking the Sheaf Condition

Generative asymmetry introduces histories that are *non-gluable.* Formally, this replaces $\widehat{\mathcal{C}}$ with a subcategory $\widehat{\mathcal{W}} \subset \widehat{\mathcal{C}}$ where:

- presheaves fail the sheaf condition,
- pullbacks do not exist between divergent branches,
- no global section reconstructs the ensemble.

These are irreversibly committed worldlines.

6.5 Topos-Level Obstruction

Categorical Form of the Theorem:

> There exists no nontrivial, natural, limit-preserving utility predicate $U : \widehat{\mathcal{C}} \to \Omega$. However, such predicates exist on $\widehat{\mathcal{W}}$, where the sheaf condition is broken by generative asymmetry.

Thus, utility is obstructed at the topos level by gluing. Removing gluing enables worldline-local utility.

6.6 Interpretation

- Laws define the site.
- Ensembles correspond to sheaves.
- Utility requires presheaves that cannot be sheafified.

This precisely explains why ensemble reasoning erases utility and why irreversible history commitment restores it.

7 Relation to Known Physics Frameworks

7.1 Path Integrals

In path-integral formulations, dynamics are described as sums over histories.

Mapping:

- Axis I corresponds to full path summation.
- Axis II corresponds to post-selection on non-recombinable paths.

Implication: Utility cannot be defined on the full path integral. It exists only after effective history selection.

7.2 Decoherence

Decoherence explains the suppression of interference between branches.

Mapping:

- Decoherence selects stable pointer states.
- Axis II selects stable *histories*.

Decoherence is necessary but not sufficient: it explains classicality, not utility. Axis II adds commitment beyond decoherence.

7.3 Inflationary Cosmology

Inflation produces vast ensembles of possible universes.

Mapping:

- Inflation generates diversity.
- Worldline commitment selects realized structure.

Anthropic reasoning corresponds to ensemble averaging, which this theorem shows cannot explain utility.

8 Falsifiable Predictions

The Worldline Commitment Principle implies concrete predictions:

8.1 Prediction 1: Ensemble Suppression

Averaging over histories will systematically reduce or erase utility signals, even when individual histories exhibit high utility.

8.2 Prediction 2: Branch-Local Variance

Utility distributions should be highly bimodal across histories, with sharp separation between productive and sterile worldlines.

8.3 Prediction 3: Irreversibility Threshold

There exists a minimum irreversibility scale below which utility does not emerge, and above which it appears abruptly rather than continuously.

8.4 Prediction 4: Law Insensitivity

Moderate perturbations of laws or parameters should not create utility unless they alter history commitment structure.

Each prediction is empirically testable in simulations or physical analogues.

9 Relation to Renormalization

The Worldline Commitment Principle has a direct analogue in renormalization theory.

9.1 Coarse-Graining as Ensemble Averaging

Renormalization group (RG) flow integrates out microscopic degrees of freedom, producing effective laws at larger scales. This procedure is inherently ensemble-based.

Analogously:

- Axis I corresponds to repeated coarse-graining.
- Utility behaves as an RG-irrelevant quantity.

Indeed, in Axis I, utility flows to zero under aggregation.

9.2 History Dependence vs Fixed Points

RG fixed points describe universal behavior independent of microscopic detail. Utility, however, is *non-universal*:

- it does not survive coarse-graining,
- it depends on specific trajectories through state space,
- it is destroyed by averaging.

This mirrors Axis II: utility appears only along specific histories, not at fixed points.

9.3 Implication

Utility is not a property of effective field theories. It is a property of realized trajectories *before* coarse-graining.

This explains why utility is absent from fundamental Lagrangians yet ubiquitous in historical systems (chemistry, biology, observers).

9.4 Summary

Renormalization explains why laws simplify. Worldline commitment explains why usefulness does not.

10 Implications

10.1 Against Anthropic Explanations

If utility is worldline-local, ensemble reasoning is structurally invalid as an explanatory tool for observed usefulness.

10.2 On Fine-Tuning

Constants need not be tuned for utility. They only need to permit irreversible histories.

10.3 On Emergence

Emergence is historical, not mechanical. The question shifts from:

> "Why these laws?"

to

> "Which histories are allowed to persist?"

11 Implications for Cosmology and Quantum Foundations

The Worldline Commitment Principle has direct consequences for foundational questions in cosmology and quantum mechanics.

11.1 Cosmology: Inflation and the Measure Problem

Inflationary cosmology produces vast ensembles of causally disconnected regions. Standard anthropic reasoning treats utility (e.g., structure, observers) as an ensemble property.

The present results imply:

- Ensemble measures cannot explain utility.
- Typicality arguments are structurally ill-posed.
- Selection must operate at the level of realized worldlines.

This reframes the measure problem: the relevant question is not "which universes exist?" but "which histories are committed?"

11.2 Quantum Mechanics: Decoherence and Many Worlds

In Everettian interpretations, all branches exist. Decoherence explains classicality but not preference or usefulness.

The Worldline Commitment Theorem implies:

- Utility cannot be assigned across branches.
- Branch-local structure matters more than global wavefunction structure.
- Any account of emergence must privilege irreversibility beyond decoherence.

This does not refute many-worlds, but constrains where explanation must occur.

12 Relation to Causal Sets and Consistent Histories

The Worldline Commitment Principle bears structural resemblance to existing history-centered approaches in quantum foundations and quantum gravity. Here we clarify similarities and differences without asserting equivalence.

12.1 Causal Set Theory

Causal set theory models spacetime as a partially ordered set of events, with fundamental emphasis on causal precedence rather than metric structure.

Points of Contact:

- Both frameworks treat histories (ordered events) as primary.
- Both reject smooth, law-level descriptions as fundamental.
- Irreversibility is built into the structure (no closed causal loops).

Key Difference: Causal set theory focuses on *spacetime reconstruction* from order, whereas the Worldline Commitment Principle focuses on *utility emergence* from irreversibility.

In particular, causal set dynamics does not distinguish between useful and non-useful histories; UNNS explicitly does.

12.2 Consistent Histories

The consistent histories formalism assigns probabilities to decoherent sets of quantum histories without invoking measurement collapse.

Points of Contact:

- Both treat histories as the fundamental objects of analysis.
- Both impose consistency (non-interference) conditions on histories.
- Both reject privileged observers.

Key Difference: Consistent histories remains ensemble-based:

- Probabilities are assigned across sets of histories.
- No history is ontologically privileged.

By contrast, the Worldline Commitment Principle asserts that *utility cannot be ensemble-defined*. Only irreversibly committed histories may carry utility.

12.3 Structural Summary

	Laws	Histories	Utility
Causal Sets	Secondary	Primary	Not addressed
Consistent Histories	Primary	Primary	Ensemble-level
Worldline Commitment	Secondary	Primary	History-local

12.4 Interpretive Implication

These comparisons suggest that existing history-based frameworks successfully move beyond law-centric explanations, but stop short of addressing why some histories become *useful*.

The Worldline Commitment Principle fills this gap by identifying irreversible non-recombinability as the missing structural condition.

12.5 Collapse Theories

Objective collapse models introduce irreversibility, but often treat collapse as law-level.

Axis II results suggest:

- Collapse is necessary but not sufficient.
- What matters is historical non-recombinability, not stochasticity.
- Utility tracks commitment, not randomness.
- Stochastic collapse without commitment does not localize utility.

12.6 A Shift in Explanatory Strategy

Across frameworks, a common pattern emerges:

> Explanations that remain at the level of laws fail. Explanations that descend to committed histories succeed.

This suggests a unifying principle: physics explains possibilities; histories explain usefulness.

12.7 Summary

The implications are conservative but deep:

- No appeal to teleology is required.
- No fine-tuning is implied.
- No violation of known physics is assumed.

What changes is the explanatory target: from laws to worldlines.

13 Conclusion

The Axis I–II UNNS program establishes a structural result: utility does not live in laws, parameters, or ensembles.

It lives in committed histories.

This reframes emergence, selection, and explanation in physics-like systems as problems of worldline permission rather than rule optimization. The Worldline Commitment Theorem provides a falsifiable, non-teleological constraint on where usefulness can arise in nature.

Data Availability: All simulations, preregistrations, and results are available at `unns.tech/chambers`.

A Methods and Simulation Appendix

A.1 Overview

This appendix documents the simulation methodology used to validate the Worldline Commitment Theorem in UNNS Axis II (Chamber XLIV v1.0.1).

All experiments were preregistered prior to execution.

A.2 System Architecture

- Recursive operator algebra: $\{\tau, \sigma, \kappa, \rho\}$
- Fixed motif backbone: $M_2 \to M_1$
- Selection mechanism: S_3 (memory-based contraction)
- Resonance: ρ OFF
- Recursion depth: 400 steps
- Seeds: $N = 10$ (pilot), $N = 300$ (full runs)

A.3 Generative Asymmetry Operator (γ)

γ introduces irreversible branching at a fixed timestep $t = 60$.

For each seed:

- k branches are instantiated
- Each branch receives multiplicative bias b_i on motif parameters
- Bias vectors satisfy $\prod b_i \approx 1$ (geometric normalization)
- Branches do not recombine

A.4 Branch Independence Guarantees

Each branch maintains:

- independent state history,
- independent S_3 contraction memory,
- independent observables.

No cross-branch state or memory access is permitted.

A.5 Metrics

Per-branch metrics:

- Projection fraction
- Contraction count
- Utility potential
- Realized utility $G^{\circ} \in \{0, 1\}$

Aggregate metrics:

- Median contractions (all branches) — acceptance metric
- Median contractions (worst branch) — diagnostic only
- Mean Branch Differentiation Index (BDI)

A.6 Acceptance Criteria (Pilot Phase)

Pilot acceptance required:

1. γ activation $\geq 95\%$
2. Mean BDI ≥ 0.1
3. Median contractions $\in [50, 390]$
4. Zero-projection rate $= 0\%$
5. Complete logging

Violation of any criterion halted full runs, per preregistration.

A.7 Utility Definition

For each branch:

1. Projection $\geq 40\%$
2. Contractions > 0
3. Utility potential > 0

If all conditions hold, $G^{\circ} = 1$.

A.8 Reproducibility

All runs are deterministic given:

- random seed,
- preregistered parameters,
- code hash.

Execution artifacts, raw JSON outputs, and UI logs are archived at `unns.tech/chambers`.