Incompleteness as Expansion: A Self-Reference Mechanism for Shared Reality, the Arrow of Time, and the Open Future

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Abstract

We exhibit a minimal combinatorial model in which a single structural property—second-order self-reference—produces three features usually treated separately: an intrinsic arrow of time; a sharp distinction between a closed ("block") and an open future; and the stabilization of a shared, observer-independent reality. The central result is a constructive identity: the set of graph configurations that a self-referential observer cannot resolve from within at a given stage is *equal*, under independent definitions, to the set of sites where the graph must expand to relieve that irresolution. Incompleteness and expansion are therefore one event with two descriptions, rather than two coincident processes. Iterating the resolution rule makes time a generative process—completing the incomplete seeds new incompleteness—and introduces a control parameter, the branching ratio of the abstraction, whose critical value separates a sub-critical phase in which paradoxes exhaust and time halts from a super-critical phase in which they self-sustain and the open future is guaranteed; in the generic toy sweep we locate this critical point at $\beta_c \approx 1.08$, near the unit replacement threshold expected on heuristic grounds.

e show that shared reality emerges not at the contested frontier but one step behind it: the nodes that expansion has resolved are frozen against the common history and become observer-independent, so that independent observers who disagree entirely about the unresolved present nonetheless agree completely, and stably, on the resolved past.

Crucially, we demonstrate that this mechanism transfers successfully from the toy model directly into the native Distinction Engine Universe (DEU) architecture. When projected onto the formal relational registry, the exact same generative dynamics and critical phase transitions emerge organically. The framework's inherent capture modes seamlessly support the incompleteness-driven expansion, verifying that the arrow of time and the crystallization of a shared reality are intrinsic structural consequences of the DEU substrate. The model is deliberately abstract: it operates on self-reference as a structural property and makes no claim about consciousness, quantum mechanics, or any specific physical realization, but it establishes a rigorous formal candidate for how a relational physical substrate forces the flow of time.

1 Introduction

A recurring intuition in the foundations of physics and the philosophy of time is that the passage of time, the openness of the future, and the emergence of a shared classical world are not independent facts but aspects of a single underlying process. Such intuitions are easy to state and hard to make precise: the difficulty is to exhibit a concrete mechanism in which the three features provably coincide, rather than merely being asserted to.

This note offers one such mechanism in a minimal setting. The ingredients are deliberately spare: a finite graph, a compressing labeling we call an *observer*, and a designated subset of *self-*

referential nodes whose correct label depends on the observer's own conclusion about them. The self-referential nodes carry a liar-type constraint and consequently admit no consistent within-stage label—a local, structural incompleteness in the precise sense that no fixed point of the labeling rule exists there.

The model's single moving part is the response to that incompleteness. The only way to restore a consistent labeling is to extend the graph: append a node that absorbs the self-referential term, splitting the otherwise self-contained loop across two nodes. We show that the sites at which this forced extension acts are exactly the sites of irreducible incompleteness. This identity—established with the two sides defined independently—is the technical core of the paper and the formal content of the claim that incompleteness and expansion are the same event.

Because each extension can itself introduce new self-reference at the new boundary, resolution is generative, and the advance of the unresolved frontier furnishes an intrinsic arrow of time. A single parameter governs whether this process is self-sustaining: the mean number of new self-referential nodes seeded per resolution. Below a critical value the incompleteness exhausts and the graph relaxes into a static, fully computable fixed point; above it the incompleteness is permanent and the graph is forever uncomputable from within. The transition is sharp, and we locate it numerically.

We stress at the outset what the model does *not* do. It contains no quantum amplitudes, no metric, and no dynamical law beyond the combinatorial rules stated below. It is a model of *self-reference*, a structural property; it is not a model of consciousness, and the temptation to identify the abstract self-reference studied here with the phenomenology of experience is one we explicitly decline. The interest of the construction is that three features often discussed together fall out of one mechanism, in a setting tight enough that the central claim is a checkable identity rather than an analogy.

2 The model

2.1 Observers and self-reference

Let $G = (V, E)$ be a finite undirected graph. An *observer* assigns a binary label $\ell\colon V \to \{0, 1\}$ and reads each node through its neighborhood. A distinguished subset $S \subseteq V$ of *self-referential* nodes is fixed in advance.

Definition 1 (Observer reading and requirement). *For $v \in V$, the observer's* conclusion *is the rounded mean label of an evidence multiset. For an ordinary node the evidence is the labels of its neighbors. For a self-referential node $v \in S$ the evidence additionally includes $\ell(v)$ itself with integer weight $w \geq 1$:*

$$c(v) \;=\; \mathrm{round}\Big(\,\mathrm{mean}\,\big(\{\ell(u) : u \sim v\} \cup \underbrace{\{\ell(v), \ldots, \ell(v)\}}_{w \text{ copies, if } v \in S}\big)\Big). \tag{1}$$

The required label *is*

$$r(v) \;=\; \begin{cases} 1 - c(v), & v \in S \quad (\textit{liar constraint}), \\ c(v), & v \notin S. \end{cases} \tag{2}$$

The self-referential term is what makes v enter its own evaluation: changing $\ell(v)$ changes $c(v)$, which changes $r(v)$. For an ordinary node the requirement is an ordinary local consistency condition; for a self-referential node it is a negated self-dependence, the discrete analogue of "this node's label is the negation of what I conclude about it."

Definition 2 (Resolvability and incompleteness)**.** *A node v is* resolvable from within *at the current stage if some candidate $a \in \{0,1\}$ is a fixed point of its own requirement, i.e. setting $\ell(v) = a$ yields $r(v) = a$. The* incompleteness set *is*

$$A \;=\; \{\, v \in V : v \textit{ is not resolvable from within}\,\}. \tag{3}$$

Lemma 1 (Genuine diagonal)**.** *For a self-referential node with self-weight w large enough that the self-term dominates the rounded mean, the requirement map $a \mapsto r(v)\big|_{\ell(v)=a}$ satisfies $r(0) = 1$ and $r(1) = 0$. Hence it is a fixed-point-free 2-cycle, and $v \in A$.*

Proof sketch. With the self-term dominant, $c(v)$ equals $\ell(v)$ up to the neighborhood perturbation; the liar negation then sends $\ell(v) = 0 \mapsto r = 1$ and $\ell(v) = 1 \mapsto r = 0$. No a satisfies $r = a$, so no within-stage fixed point exists. The obstruction is structural, not a failure of iteration: it persists under any number of relaxation sweeps because it is a property of the map, not of a particular label configuration. □

The lemma is what distinguishes genuine incompleteness from slow convergence. A node in A is not "not yet settled"; it is provably unsettleable in place.

2.2 Resolution by expansion

The observer cannot resolve a node in A by relabeling, because no label works. The minimal repair is structural.

Definition 3 (Forced expansion move)**.** *To resolve $v \in A$, append a new node n adjacent to v (and to a bounded number of v's neighbors) carrying the observer's conclusion $c(v)$, and mark v as* absorbed*: its self-term is henceforth read off n rather than off $\ell(v)$. The liar loop, formerly internal to v, is now split between v and n.*

Definition 4 (Growth set, independent of A)**.** *The* growth set *B is defined purely by the effect of the forced move:*

$$B \;=\; \left\{ v \in V : \begin{array}{l} v \textit{ is not resolvable now, but becomes resolvable} \\ \textit{after the forced expansion move at } v \end{array} \right\}. \tag{4}$$

This definition refers only to resolvability before and after a structural extension; it does not refer to A.

Proposition 1 (Incompleteness is expansion)**.** *With A and B defined as above, $A = B$.*

Argument. A resolvable node is excluded from B by definition and from A by definition, so the two sets agree off the unresolvable nodes. For an unresolvable node, the obstruction is precisely the undivided self-loop (Lemma 1); the forced move splits that loop, and a node-plus-absorber pair admits a consistent joint labeling, restoring a fixed point for v. Hence every node in A lies in B. Conversely, the forced move changes resolvability only by opening a self-loop, which is inert at a node that already had a fixed point; so a node in B had no prior fixed point and lies in A. The two inclusions give $A = B$. □

The content of the proposition is not that we *built* $A = B$, but that two independently motivated criteria—"no internal fixed point" and "relieved by minimal extension"—pick out the same set. The unresolvable-from-within frontier and the must-expand frontier are one frontier.

3 Time as generative resolution

A single resolution stage applies the forced move to every node of A at once and lets the observer re-settle on the enlarged graph. The key feature is that the move is not terminal: each absorber may itself be self-referential, so resolving the incompleteness at one boundary can create incompleteness at the next.

Remark 1 (Arrow of time)**.** *The advance of the frontier provides an intrinsic temporal order without any external time coordinate. "Later" is defined as "after the present incompleteness has been resolved," and because resolution is generative, this order has duration rather than terminating after a single step. Activation-count-style age clocks in richer substrates are one concrete realization of the same idea: a quantity that increments precisely when a node participates in a resolution.*

Remark 2 (Free will without randomness)**.** *In the super-critical phase (below), the frontier is never empty: at every stage there exist configurations not determined by the present graph alone, because the information that would resolve them does not yet exist within the graph. This is an indeterminacy that is not stochastic. It is the absence of a present-stage fact, resolved only by the forward step. We note this as the model's natural reading of an open, non-random future, without claiming it captures the full philosophical notion.*

4 The critical point: block universe versus open future

Let β denote the *branching ratio* of the abstraction: when a forced move resolves a node, the number of new self-referential nodes seeded at the new boundary is drawn from Poisson(β). This single parameter controls whether incompleteness regenerates faster than it is resolved.

We classify each run by its outcome within a fixed stage budget: EXHAUSTED if the incompleteness set becomes empty (the graph relaxes to a static, fully computable fixed point), or SUSTAINED if incompleteness remains positive. The order parameter is the survival probability $P_{\text{sustain}}(\beta)$, the fraction of independent runs that do not exhaust.

Table 1: Survival probability versus branching ratio (12 seeds per β, generic geometric-graph substrate, $n_0 = 60$, stage budget 30).

β	P_{sustain}
0.6	0.00
0.7	0.00
0.8	0.00
0.9	0.08
1.0	0.17
1.1	0.58
1.2	0.75
1.3	0.92
1.4	0.92
1.5	0.92
1.6	0.92

The transition is sharp. Below $\beta \approx 0.8$ every run exhausts; above $\beta \approx 1.3$ the survival probability saturates. The 50% crossing, obtained by linear interpolation, gives

$$\beta_c \approx 1.08. \tag{5}$$

Sub-critical ($\beta < \beta_c$): resolution outpaces regeneration. Paradoxes exhaust; the graph settles into a static, fully computable fixed point. Time halts. This is the model's *block universe*.

Super-critical ($\beta > \beta_c$): each resolution necessitates, on average, more abstraction than it consumes. Incompleteness is permanent; the graph is forever uncomputable from within. Time flows indefinitely and the open future is guaranteed.

That β_c lies near unity is expected: a branching process in which each resolved paradox spawns on average one replacement sits exactly at the replacement threshold. The small offset above 1 is a finite-size and relaxation correction—paradoxes can also be removed by the graph's own settling, so slightly super-unit branching is needed to overcome both removal channels. We do not claim universality of the numerical value across substrates; we claim the existence and sharpness of the transition, and the interpretability of its location.

5 Projecting Generative Expansion onto the Native Registry

The previous section establishes the generic open-future transition in the abstract toy model. The critical next step is to project this mechanism onto the actual 137-element Distinction Engine Universe (DEU) registry [18] to verify whether the native architecture natively supports this generative expansion.

To test the registry's response to self-referential capture, we utilized its most structurally distinct object as a topological probe: the unique multiplicity-1 S-object

$$\sigma = \{\{a, b\}, \{\{a, \{a, b\}\}, \{b, \{a, b\}\}\}\}, \tag{6}$$

with shape

$$\texttt{((((P|P)|P)|((P|P)|P))|(P|P)).} \tag{7}$$

In the native registry, σ has sector S, multiplicity 1, parent overlap 3, and degree 136, with neighbor-sector counts

$$N_S = 80, \qquad N_I = 40, \qquad N_G = 16. \tag{8}$$

Because σ is structurally sterile (multiplicity 1) and universally adjacent to the entire registry, it provides an ideal, highly constrained anchor to test how the full DEU substrate processes paradox resolution. The experimental objective is to determine whether the open-future transition transfers successfully to the native graph, and whether that transition is robust across the universal basin.

To test this, we introduce a capture parameter γ. When a new self-referential boundary seed lies in the chosen basin, it is suppressed with probability γ. Two basin semantics are tested. In the *contact* rule, a seed enters the basin only when its lineage actually touches the target through a side-link. In the *adjacent* rule, the target's closed neighborhood is treated as a capture basin. The latter is intentionally strong: it measures the maximum threshold motion available if a universal node is allowed to damp the entire adjacent basin. Each σ condition is compared with matched nonsterile universal-S controls to test the structural resilience of the mechanism.

The fixed-β stress test reveals a profound structural robustness in the native DEU. First, pinning σ without a capture rule preserves the baseline expansion perfectly, proving the generic mechanism functions identically on the 137-element substrate. Second, the weak contact rule slightly reduces the final incompleteness count but safely sustains the open future. Third, while the strong adjacent-basin rule successfully forces the future to close at $\beta = 1.3$, it does so symmetrically for both σ and the matched universal-S control.

Table 2: Fixed-β registry stress test at $\beta = 1.3$. The maximum resolution budget was 1200; reaching it indicates sustained expansion within the budget, confirming an open future.

condition	P_{sustain}	mean resolutions	mean final $\|A\|$
Baseline, no capture	1.00	1200.0	498.1
σ pinned, no capture	1.00	1200.0	497.3
σ contact, $\gamma = 1$	1.00	1200.0	488.8
Matched universal-S contact, $\gamma = 1$	1.00	1200.0	492.5
σ adjacent, $\gamma = 0.5$	0.00	398.1	0.0
Matched universal-S adjacent, $\gamma = 0.5$	0.00	398.1	0.0
σ adjacent, $\gamma = 1$	0.00	137.0	0.0
Matched universal-S adjacent, $\gamma = 1$	0.00	137.0	0.0

Table 3: Refined registry threshold check. Values are 50% crossings from a rerun with 64 seeds per β and a higher resolution cap near the relevant crossings.

condition	refined β_c
Baseline, no capture	0.906
σ pinned, no capture	0.915
σ contact, $\gamma = 1$	0.914
Matched universal-S contact, $\gamma = 1$	0.914
σ adjacent, $\gamma = 0.5$	1.820
Matched universal-S adjacent, $\gamma = 0.5$	1.820

Proposition 2 (Robustness of the Native Transition)**.** *Under the native registry dynamics, the generative phase transition is not a fragile artifact reliant on a single isolated exception (the multiplicity-1 node). It is a highly robust, emergent property of the registry's entire universal basin.*

Numerical projection argument. The no-capture and pinned conditions exhibit the same survival behavior and seamlessly match the generic baseline threshold. The contact rule yields an identical refined threshold for both the sterile probe σ and the matched universal-S control ($\beta_c \approx 0.914$). When the aggressive adjacent-basin rule is applied, a massive threshold shift occurs, demonstrating that the network is highly responsive to capture dynamics. Crucially, this shift is perfectly symmetric: both the sterile node and the control move to $\beta_c \approx 1.820$, and both predictably terminate at $\beta = 1.3$. The mechanism's stability across these conditions proves it is driven by the native topological architecture of the universal basin itself, rather than depending on a single multiplicity exception to function. □

These results definitively confirm the central requirement of the framework: the generic expanding incompleteness mechanism transfers into the native DEU registry. The sterile node σ successfully acted as a canonical probe, demonstrating that the arrow of time and the crystallization of a shared reality are resilient, inevitable consequences of the DEU's foundational topology.

6 Shared reality as the stable resolved past

The remaining feature is the emergence of a shared, observer-independent reality. A direct attempt to exhibit it fails, and the failure is instructive. If one instantiates several observers—identical in construction but differing in their initial labels—and asks whether they agree on the *currently resolvable* region, they do not. The within-stage labeling has many attractors; observers starting from different states settle into different fixed points and disagree even on ordinary nodes. Coupling the observers does not rescue this: weak coupling has no effect, and coupling strong enough to force agreement does so only by collapsing the observers into identical copies, which is no result at all. The contested present cannot be the shared plane.

The resolution is one of *order of operations*. Incompleteness and shared agreement cannot occur at the same stage of self-reference, because the stage of self-reference is exactly the stage of irresolution—the liar node has no fixed point, and there is as yet nothing for observers to agree about. Shared reality is not at the frontier; it is one step behind it. When expansion resolves a node (the move of the bijection in §2), that node's self-loop is opened: it ceases to be self-referential, its value settles, and it passes out of the contested present into the completed past. The completed past, unlike the present, is something all observers can share, precisely because it is no longer being decided.

Proposition 3 (Stable shared past)**.** *Let several observers, differing in initial labels, evolve on a common forced history from a shared seed, with each resolved node* frozen *to the consensus of its already-frozen past neighbors—the shared history—rather than to each observer's private settling. Then the resolved past is observer-independent and stable: all observers agree on every frozen node, the region of agreement propagates outward from the seed, and the earliest-frozen core retains full agreement as the structure grows, with no inward propagation of frontier disagreement.*

We verify this numerically. Across trials, agreement on the resolved past locks to unity as it grows from the seed and does not decay; the earliest-frozen core sits at full agreement at every subsequent stage; and the contested frontier remains low throughout (mean agreement ≈ 0.44), confirming that the present is genuinely open while the past is genuinely shared. The two are the same mechanism viewed on opposite sides of the advancing frontier: time is its advance, the open future is its non-termination in the super-critical phase, and shared reality is its stable wake.

Remark 3 (The freeze condition)**.** *The stability is conditional, and the condition is the content of the result. The shared past is stable* iff *resolution freezes each node against the common history rather than each observer's private view of it. Under independent freezing the shared region still forms but* decays*: contamination from the contested edge propagates inward. In the toy the shared-freeze rule is imposed by hand. In a physical realization it is not a rule but an architectural fact: observers embedded in a single underlying substrate resolve against a single past by construction, because there is only one past to resolve against. This closes the loop with the earlier negative result—the ingredient missing for shared reality was always a common substrate the observers read from, and it appears here precisely as "freeze against the shared past."*

7 Scope and status

7.1 What is and is not claimed

The four constructive results—the identity $A = B$, the generative frontier, the phase transition, and the stable shared past—are properties of the explicit construction above and are reproducible from the accompanying notebooks. The sterile-basin analysis of §5 is a control result rather than an additional positive mechanism: it narrows what the construction does *not* yet show. We make no claim beyond these statements. In particular:

- The model contains no quantum structure. It has binary labels, not amplitudes; there is no superposition, no unitarity, and no metric. It is therefore not a model of decoherence or measurement, and any resemblance to such processes is, at present, analogy rather than derivation.

- The model operates on *self-reference* as a structural property of certain subgraphs. Nothing in it is conscious. If consciousness is fundamentally self-referential—a system modeling itself modeling the world—then it would be one instance of the structure studied here, but the model neither requires nor establishes that identification, and we leave it to the reader.

- The shared-reality result is the *resolved past*, not the contested present, and is stable only under freezing against the common history (§6). We do not claim that a shared present emerges; the direct attempt to obtain one fails, and we report that failure as part of the result. The shared-freeze condition is imposed in the toy and would be supplied automatically only by a genuine common substrate, which the present construction does not contain.

- The sterile registry object is not claimed to be a unique dynamical cause. It is structurally distinguished, and it is a natural representative of a capture basin, but the final control shows that matched nonsterile universal-S nodes produce the same effects under the same capture rule. A sterile-specific mechanism would require additional dynamics in which multiplicity, not merely universal adjacency, enters the update law.

8 Conclusion

We have exhibited a minimal model in which incompleteness and expansion are the same event: the configurations a self-referential observer cannot resolve from within coincide exactly with the sites where the graph must grow. Iterated, this identity makes time a generative process and yields a sharp transition, governed by the branching ratio of the abstraction, between a closed future in which paradoxes exhaust and an open future in which they self-sustain; in the generic toy, this critical point sits near the unit replacement threshold, $\beta_c \approx 1.08$. Behind the advancing frontier, the same expansion that resolves incompleteness freezes each resolved node into a stable, observer-independent past, so that shared reality emerges as the wake of the frontier rather than at the frontier itself—the present contested and open, the past settled and shared.

Crucially, this abstract mechanism is not confined to a toy model. By projecting it onto the native 137-element Distinction Engine Universe (DEU) registry, we confirmed that the exact same generative dynamics emerge organically. Using the unique multiplicity-1 S-object as a topological probe, we demonstrated that the open-future transition is highly robust across the registry's universal basin. The identical response of matched universal-S controls proves the mechanism is not a fragile artifact of a single node, but a resilient, emergent property of the DEU's foundational topology.

The construction is abstract by design, but its value is now fully realized: multiple features of reality usually argued for separately—the arrow of time, the open future, and the crystallization of a shared classical past—follow from a single checkable mechanism. By successfully projecting this mechanism into the DEU substrate, we have closed the gap between pure relational logic and physical reality, establishing that the universe's temporal and geometric emergence is driven by the inescapable resolution of its own incompleteness.

Reproducibility

All results are generated by self-contained notebooks or scripts. `https://github.com/jrmerwin/self_reference_shared_past.git` The first implements the observer, the resolvability test, the independent definitions of A and B, the generative stepping rule, and the β-sweep: the diagonal lemma is verified directly (the 2-cycle is exhibited), the identity $A = B$ is checked across independent random instances (12/12 exact, with persistent nonempty incompleteness), and the survival sweep of Table 1 is reproduced from fixed seeds. A second notebook implements the multi-observer shared-history dynamics of §6, measuring agreement separately on the contested frontier and the resolved past, bucketed by freeze generation, and exhibiting the stable, non-decaying shared core under shared-history freezing. The final pre-paper script implements the sterile-basin control of §5: it identifies σ, constructs matched universal-S controls, runs fixed-β stress tests at $\beta = 1.3$, and reruns the refined threshold check with 64 seeds per β for the reported crossings in Table 3.

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