Native Cognition Kernel: A Bounded Deterministic Architecture for Symbolic Cognition in Nonstationary Black-Box Worlds

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Abstract

We present the Native Cognition Kernel (NCK) 0.1, a mathematically closed architecture for bounded deterministic symbolic cognition. NCK defines cognition as a typed, provenance-governed state transition over finite carriers rather than as an implementation-defined procedure. Its core transition admits observations and evidence, constructs bounded hypothesis and model frontiers, derives predictions, forms experiments, tests predictions against subsequent observations, revises falsified hypotheses or temporally scoped models, selects actions under an explicit decision policy, and authorizes execution through replayable proof dependencies. Nonstationarity is represented by temporally scoped piecewise models, so model error and regime change remain competing explicit explanations rather than hidden implementation diagnoses. The specification requires deterministic canonicalization, fail-closed resource bounds, provenance conservation, renaming equivariance, and atomic failure semantics. We evaluate an executable Rust realization through a black-box proof-of-concept in which hidden deterministic rule systems change without explicit notification to the kernel. The released evidence records 100 worlds and 6,400 world steps, with 96 objective-success events, 4 objective-failure events, 3,092 prediction failures, and 3,092 corresponding model revisions. A 55-test workspace suite passed with zero failures, including deterministic replay, hidden-state non-leakage, renaming equivariance, bounded action-space, and long-run regression tests. These results establish an executable bounded observe-predict-test-revise-act loop for the released conformance profile; they do not establish general intelligence, universal task transfer, complete machine-checked formal verification, or a completed hardware implementation.

Keywords: symbolic artificial intelligence; deterministic cognition; belief revision; causal reasoning; nonstationarity; provenance; bounded reasoning; black-box learning; formal methods.

1. Introduction

Many artificial-intelligence systems leave a semantic gap between an abstract description of reasoning and the behavior of the executable artifact. NCK 0.1 is designed around the opposite constraint: the mathematical specification is the sole semantic authority, and every parser, internal representation, runtime transition, test oracle, or prospective hardware refinement is correct only insofar as it is extensionally equivalent to that specification. The design objective is therefore not merely symbolic representation, but closure of the cognitive transition itself: all authoritative state changes must arise from explicitly defined finite operators, typed records, bounded carriers, and replayable provenance.

The resulting architecture occupies a distinct point in the design space. It is symbolic in the sense of manipulating typed constructor-defined objects; bounded in the sense that every certified run is parameterized by a finite resource contract; deterministic in the sense that canonicalization, candidate construction, tie handling, and failure selection are specified; and adaptive in the sense that prediction failures can produce explicit revision and temporally scoped reconstruction. NCK also admits interventional causal hypotheses, but does not treat causality as a privileged oracle: causal edges must be grounded in declared causal laws or admitted intervention/execution traces, while passive covariation alone cannot produce an interventional edge.

This paper does not reproduce the full normative specification, which is substantially larger than a conventional article. Instead, it isolates the mathematical mechanisms needed to state the architecture, its principal invariants, and the executable proof-of-concept (PoC) correspondence. The complete NCK Mathematics 0.1 specification remains the normative reference; the Rust realization and PoC evidence are subordinate implementation artifacts.

Contributions.

• Formal cognitive transition. A total deterministic kernel step over certified bounded state, with explicit semantic, local, and failure outcomes and atomic commit semantics.

• Explicit adaptive cycle. A finite production schedule connecting evidence, hypothesis construction, model building, prediction, experiment formation, falsification, revision, decision, and authorization.

• Nonstationary model semantics. Temporally scoped hypotheses and piecewise models that distinguish model error from regime change without retroactively invalidating correctly scoped historical models.

• Provenance and domain neutrality. Derived authority must be rooted in admitted evidence or replayable proof; uninterpreted identifier renaming commutes with kernel production and output.

• Executable conformance evidence. A Rust PoC that exposes the observe-predict-test-revise-act loop in hidden changing worlds, together with deterministic replay, anti-leakage, boundedness, and reproducibility tests.

2. Mathematical setting

A certified NCK execution is parameterized by one immutable finite bound contract B. The contract bounds symbol, relation, variable, record, proof, expression, hypothesis, model, prediction, experiment, revision, plan, epoch, depth, active-frontier, microstep, enumeration-workspace, NIR, and numeric-width capacities. The mathematical meaning of resource exhaustion is therefore explicit: an operation returns OUTSIDE_BOUND only when a semantically indispensable live object, retained frontier, proof/result, numeric value, NIR object, or atomic transaction cannot be represented inside the fixed contract after semantics-preserving maintenance. Large historical operation count alone is not a semantic failure.

```
B = (B_sym, B_rel, B_var, B_rec, B_proof, B_expr, B_hyp, B_model, B_pred, B_exp, B_rev, B_plan,
                    B_epoch, B_depth, B_active, B_step, B_enum, B_nir, ...)
```

2.1 Closed outcome algebra

NCK separates epistemic status from structural non-applicability and certified transition failure. This distinction prevents uncertainty, conflict, or a failed match from being silently converted into an implementation exception or guessed value.

```
Outcome(X) = Ok(X) ⊎ Semantic(SemStatus) ⊎ Local(LocalStatus) ⊎ Fail(FailureStatus)
```

Semantic statuses include PROVEN, JUSTIFIED, CONSISTENT, REFUTED, NOT_TESTED, NEED_EVIDENCE, UNDERDETERMINED, CONFLICT, NO_UNIQUE_WINNER, HORIZON_EXHAUSTED, and QUIESCENT. Certified failures are restricted to INVALID_INPUT, INVALID_PROVENANCE, and OUTSIDE_BOUND. Compound operators propagate these constructors explicitly.

2.2 Certified state and provenance

Authority is not structural membership. A record is authoritative only if it is an admissible typed root or the conclusion of an admitted derivation. For a certified state C, provenance is a finite directed graph whose vertices are admitted roots and derived records, and whose edges point from dependencies to derived records. Dependencies are temporally non-forward and therefore the provenance graph is acyclic. The genesis state contains generic calculus, representation rules, and fixed bound/trust configuration, but no game rule, puzzle answer, domain ontology, pretrained domain model, or expected answer unless supplied through an admitted root after genesis.

3. The cognitive transition

The sole abstract cognitive transition is NCKStep_B. It executes on a shadow state, validates the input and trusted boundary, admits roots and replayable history, performs bounded cognitive production to closure, projects outputs and proof dependencies, applies semantics-preserving maintenance when required, checks final encodability and bounds, and only then commits.

```
StepResult = (C, O, Π, status, witness)

NCKStep_B(C_t, I_t) → (C_{t+1}, O_t, Π_t, status, witness)
```

For fixed B, C_t, and I_t, the specification states that canonicalization, complete bounded enumeration, and explicit tie semantics yield exactly one result. If any input, provenance, proof, enumeration, state, output, or representation-capacity check fails, the exact prior certified state is returned and none of the shadow transaction commits. Repeated adaptation is simply repeated application of this same

transition; there is no hidden unbounded learner outside the recurrence.

```
C_{t+1} = π_C(NCKStep_B(C_t, I_t))
```

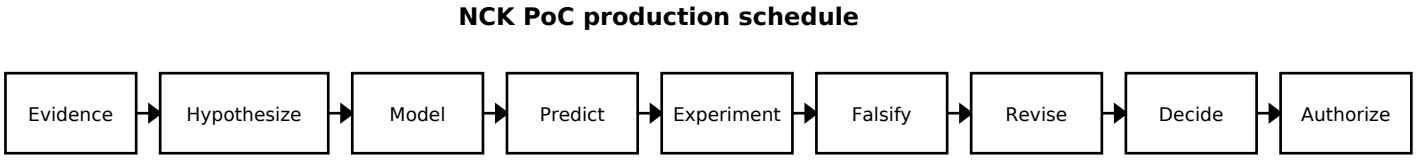

Figure 1. Restricted production schedule used by the NCK 0.1 PoC conformance profile. The profile restricts candidate carriers but does not redefine the underlying cognitive operators.

4. Hypotheses, models, prediction, and causal projection

Hypothesis construction is finite and origin-grounded. Every hypothesized symbol or constraint must be traceable to admitted evidence/declarations or to the fixed generic operator language. Empirical support does not by itself establish universal truth. Models are finite admitted structures assembled from current hypothesis/rule components. Predictions carry the source model, context dependencies, epoch, scope, temporal interval, coverage marker, proof references, and replayable application witnesses. A prediction is current only while its source model and dependencies remain current on the relevant scope and interval.

NCK's causal projection is a provenance-labeled directed hypergraph extracted from admitted interventional clauses. For a clause $C \wedge do(a) \Rightarrow Y$, the projection contains an edge $(C,a) \rightarrow Y$ labeled by its hypothesis/model and intervention evidence. A passive observational rule produces only an observational dependency edge. Thus empirically intervention-supported causal edges remain hypotheses/models subject to prediction, experiment, falsification, and revision; they are not elevated to deductive truth merely by being causal candidates.

5. Falsification and revision

A prediction is refuted only by a testable mismatch. Missing or out-of-scope data produce NOT_TESTED rather than REFUTED. A refuted test result stores the exact prediction, observation, execution dependencies, and counterexample witness. Revision is then an explicit structural operation over a closed edit algebra that includes outcome repair or weakening, context specialization, action specialization, condition addition, scope refinement, and temporal splitting. New syntactic material introduced by revision must remain evidence-grounded.

Corrective revision requires an admitted falsification witness reaching the parent hypothesis and a child hypothesis that repairs the tested mismatch without arbitrarily invalidating retained supporting traces inside the child's scope and interval. Historical evidence is not erased by revision; ancestry is retained.

6. Nonstationary worlds

Nonstationarity is represented directly in the model language. Every empirical hypothesis or model has a bounded half-open temporal validity interval. A nonstationary candidate is a finite piecewise model over nonoverlapping intervals.

```
M = {(I_1,h_1), ..., (I_k,h_k)}, k ≤ B_model
```

When a previously fitting model is falsified, the closed explanation space distinguishes ModelError from RegimeChange. A regime-change candidate introduces an evidence-grounded split epoch κ and separate pre/post hypotheses. Additional splits carry positive structural complexity, so one surprising observation does not automatically force a regime-change diagnosis. A model valid on an earlier interval may remain historically consistent after a later regime change.

$$M_\kappa = ((h_{pre},[e_0,\kappa)), (h_{post},[\kappa,e_t)))$$

7. Decision, exploration, and bounded planning

Action selection is not authorized by observation alone, experiment candidacy alone, or mere capability existence. Decisions depend on admitted consequences and an explicit declared preorder. For the built-in policy, hard invariants are checked before goal, information, and cost comparisons. When multiple actions remain tied after semantic comparison and safety checks, a deterministic exploration scheduler selects among the tied maximal set using authenticated numeric action-choice keys and the current epoch. This scheduler is not a reward function; it prevents bootstrap deadlock in symmetric opaque environments without using lexical names, host enumeration order, or randomness.

$$\mathrm{ExploreIndex}_B(C,M) = \mathrm{epoch}(C) \bmod |M|$$

Planning is a bounded composition of admitted transition/model relations. Counterfactual states are read-only hypothetical views carrying explicit provenance and unresolved obligations; they do not mutate actual authority. The specification therefore separates hypothetical consequence construction from actual execution authorization.

8. Formal properties

Property	Specification obligation
Determinism	For fixed B, certified state, and input, NCKStep_B yields exactly one next-state/output/proof/status/witness tuple.
Type preservation	Every admitted derived object is well typed under declarations admitted before it.
Root closure	Every authoritative record is an admissible root or has a finite dependency path to admissible roots.
No forward provenance	No event semantically depends on a future event.
Renaming equivariance	Injective sort-preserving renaming of uninterpreted symbols commutes with every kernel production and output.
Contradiction containment	Conflict evidence does not license arbitrary conclusions.
Falsification exactness	Refutation requires a testable mismatch; missing or unscoped data do not count as refutation.
Revision ancestry	Every revision identifies a refuted parent and falsification witness.
Nonstationary separation	Later regime change does not retroactively falsify a correctly scoped earlier rule.
State boundedness	Every live store and microstep is bounded by B; overflow fails closed.
Failure atomicity	A failed step returns the exact prior certified state with no partial semantic commit.
NIR transparency	Encoding/decoding preserves semantics and cannot add authority.
Domain neutrality	No primitive branches on domain labels or contains a domain formula.

Table 1. Selected global invariants and theorem obligations of NCK 0.1. The full specification contains the complete formal statements and operator registries.

9. PoC conformance profile

The first executable PoC is defined as a restricted admitted subdomain of the full kernel, not as a second cognitive engine. It fixes a finite action universe A, one Boolean observation relation Obs(Action,Bool), and a family of temporally scoped deterministic transition-table hypotheses:

$$\mathrm{TableHyp}(A,J,f) = \wedge_{a\in A} \left(\mathrm{do}(a) \Rightarrow \mathrm{Next}(\mathrm{Obs}(a,f(a))) \right),\ f:A\to\mathrm{Bool}$$

No table entry is supplied by the environment. Retained entries must be supported by admitted post-action observations and trace/evidence constructions. The PoC production schedule is Evidence → Hypothesize → ModelBuild → Predict → Experiment → Falsify → Revise → Activate → Decide → Authorize. Prediction, falsification, and revision are restrictions of the already-defined full-kernel operators rather than alternative shortcuts.

$$\mathrm{PoCStep}_B(C,I) = \mathrm{ProjectPoC}_B(\mathrm{NCKStep}_B(C,I))$$

The refinement theorem states that, on the admitted PoC domain, the restricted step is the corresponding projection of the full NCK step and preserves determinism, boundedness, provenance, domain neutrality, renaming equivariance, and failure/status distinctions. The conformance invariant

additionally forbids the implementation from inspecting hidden environment state, regime identifiers, game/world names, expected answers, benchmark labels, host hash order, identifier spelling preference, random samples, or non-profile solver output.

10. Rust realization and black-box environment

The released Rust implementation exposes a live/headless transport path in which the hidden world evaluates its rule, emits a bounded observation through the .nck surface and NIR representation, invokes the NCK state machinery, receives an authorized action, and advances the world. The current live action vocabulary contains eight bounded actions: TOUCH(△), TOUCH(○), TOUCH(□), PAIR(△,○), PAIR(□,◇), MOVE(△,□), MOVE(◇,○), and WAIT.

The hidden world is deterministic from a seed and contains causal action/value rules, relational rules, temporal-history rules, delayed rules, chain rules, relational-history rules, majority-over-history rules, and XOR/AND/NOT compositions. The world can also perform hidden regime changes. Tests explicitly check that hidden rule, hidden state, regime, family, best action, expected answer, and viewer truth are absent from NCK semantic inputs, and that rule changes are not explicitly announced to the kernel.

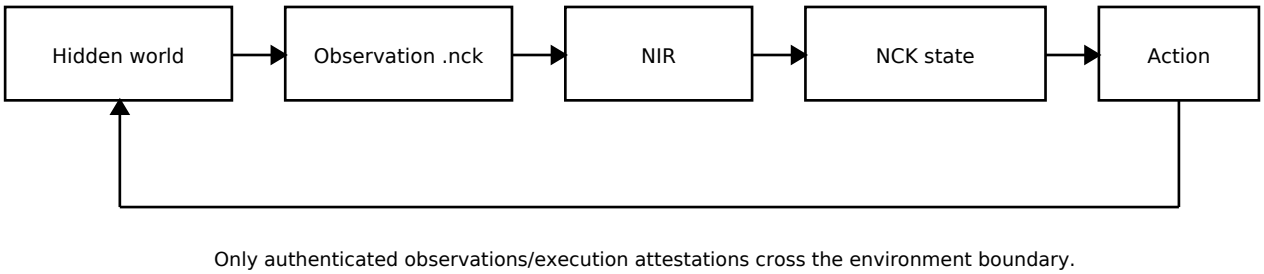

Figure 2. Executable black-box loop. Hidden evaluator state remains outside NCK; the cognition path receives only the declared bounded observation channel and certified history/state.

11. Experimental evidence

The release evidence was produced from the Rust repository at commit cddb709fb274e184c2d3c247d2efe766bb9b4044 on Windows 11 using rustc 1.98.0 and cargo 1.98.0. The full workspace verification passed cargo fmt, cargo check, cargo test, and Clippy with warnings denied. The test suite contained 55 passing tests and no failures or ignored tests.

Metric	Observed value
Worlds	100
Steps/actions per world	64
Total world steps/actions	6,400
Objective success events	96
Objective failure events	4
Prediction failures	3,092
Model revisions	3,092
Workspace tests	55 passed / 0 failed
Invalid actions in three detailed samples	0
OUTSIDE_BOUND in three detailed samples	0

Table 2. Aggregate released PoC evidence. Objective-success and objective-failure counts are events reported by the preserved forensic artifact and should not be interpreted as a universal task-success rate.

11.1 Detailed trace behavior

A preserved sample for puzzle seed 10001 begins with false observations and incorrect predictions, records prediction mismatch and revision when the observation becomes true, later records recovery after failure, and reaches OBJECTIVE_ACHIEVED at step 12. Across the three detailed 64-step sample reports, all three objectives were achieved; the reports contained 101 failed predictions, 101 eliminated hypotheses, 101 model revisions, and 45 recovery events. Detection lags were 1, 7, and 4 steps, and recovery latencies were 17, 13, and 15 steps, respectively.

Seed	Objective result	Failed pred.	Revisions	Recoveries	Detect lag	Recovery latency
10001	OBJECTIVE_ACHIEVED	30	30	17	1	17
10002	OBJECTIVE_ACHIEVED	36	36	13	7	13
10003	OBJECTIVE_ACHIEVED	35	35	15	4	15

Table 3. Three detailed forensic sample reports preserved in the release evidence.

11.2 Determinism, leakage controls, and invariance tests

The workspace includes explicit tests for deterministic replay, hidden-future-state non-leakage, semantic identifier renaming, action permutation equivariance, bounded generated worlds, static anti-cheating checks, action-space bounds, observation-channel hiding/noise behavior, and a regression exceeding 1,000 epochs without freeze. Two runs with the same seed and step count are required to produce identical semantic traces. Separate tests check that renaming semantic identifiers or permuting action names does not change behavior modulo the same transformation.

12. Interpretation

The empirical result is narrower than a claim of general intelligence and broader than a parser or unit-test demonstration. The released artifact demonstrates an integrated loop in which a kernel that is not given the hidden rule or regime repeatedly acts, receives bounded observations, constructs and tests predictions, records falsification, revises its current model state, and continues acting under changing hidden rules. Because the PoC is defined as a conformance profile of the full transition, the scientific role of the game is to expose a vertical slice of the mathematics under controlled adversarial conditions rather than to define an independent game-solving algorithm.

The aggregate 96/100 objective-success events should therefore be interpreted as evidence about this benchmark family, not as an estimator of performance on arbitrary environments. Likewise, the observed equality between prediction-failure and model-revision counts reflects the released PoC behavior under its current evidence/revision path; it is not a theorem that every future NCK profile must revise once per failed prediction.

13. Relation to prior work

NCK belongs to the broad symbolic tradition in which cognition is represented through explicit symbol structures and operations, but differs from the classical physical-symbol-system thesis by making the semantic authority, resource contract, provenance discipline, and transition closure explicit parts of the mathematical object rather than general architectural commitments [1]. Its finite bound contract is related in motivation, though not in formal content, to bounded-rationality approaches that treat decision procedures as constrained by finite computational ability [2].

The revision component is related to formal belief-change research initiated by AGM and later work on iterated revision [3,4]. NCK does not present itself as an AGM implementation: its state contains typed provenance-bearing records, temporal scopes, explicit prediction/test objects, and resource failures, and its corrective revision algebra is tied to falsification ancestry and retained trace constraints. The comparison is therefore conceptual: both treat rational change as a formal operation rather than an unspecified update.

For causality, NCK uses intervention-conditioned clauses and a do-labeled causal projection, which places it in conversation with structural and interventional approaches to causal reasoning [5]. The present release does not claim identification results comparable to statistical causal inference. Instead, its causal claim is representational and provenance-constrained: an interventional edge must descend from an admitted causal law or intervention/execution trace, and passive covariation alone cannot establish that edge.

14. Limitations

• The Rust evidence does not constitute a machine-checked proof that the implementation is a complete refinement of every theorem and operator in the full mathematical specification.

• The current benchmark family is deterministic and synthetic. It does not establish transfer to arbitrary real-world environments.

• The released evidence does not establish general intelligence, broad task transfer, or superiority over statistical or neural systems.

• Memory per step was not reliably measured in the evidence dossier.

• A complete Lean certification of the full NCK 0.1 mathematics is not established by the present evidence.

• No completed FPGA, ASIC, or silicon implementation is established by this release. Hardware realization remains a planned refinement target subject to extensional equivalence with the mathematics.

• The reported runtime measurements are implementation- and host-specific and are not presented as optimized performance benchmarks.

15. Hardware refinement perspective

The specification is intentionally representation-neutral: software and prospective hardware are downstream realizations rather than semantic authorities. A future FPGA or ASIC realization would therefore be evaluated by extensional correspondence: predicates must agree on admitted inputs, functions must produce equal outputs, and inductive data must be constructor-isomorphic to the normative definitions. The fixed bound contract provides a natural hardware interface because the simultaneously live semantic capacities are explicit. However, this paper reports no completed hardware implementation and makes no area, power, latency, or throughput claim.

16. Reproducibility and artifact availability

The complete normative mathematics and the executable implementation are released as persistent public artifacts. The NCK Mathematics 0.1 publication is archived on Zenodo at https://doi.org/10.5281/zenodo.22307279. The NCK 0.1 technical implementation release, including the Rust runtime and proof-of-concept materials, is archived on Zenodo at https://doi.org/10.5281/zenodo.22308217. The public source repository is available at https://github.com/adrenalineusmle/native-cognition-kernel.

The technical package contains the Rust runtime, Cargo lockfile, tests, PoC implementation, preserved BLACKBOX_LOGIC_FORENSIC.json artifact, provenance records, technical handoff, and SHA-256 release manifests. The evidence dossier records the commands required to reproduce the workspace checks and run the live black-box demonstration locally. The mathematical specification remains the sole normative authority; the Rust runtime implements the released PoC profile but does not redefine NCK semantics.

17. Conclusion

NCK 0.1 specifies a bounded deterministic cognitive kernel in which authoritative state change is produced by explicit typed operations with replayable provenance. The architecture integrates evidence admission, hypothesis and model construction, prediction, experiment formation, falsification, revision, decision, authorization, and bounded planning while preserving explicit distinctions among uncertainty, conflict, underdetermination, and resource failure. Nonstationary behavior is represented by temporally scoped model structure rather than by hidden mutable heuristics.

The Rust PoC provides an executable vertical slice of this calculus in changing black-box worlds. The current evidence demonstrates deterministic replay, hidden-state non-leakage, bounded action selection, prediction failure and revision, recovery after error, and objective completion across the released benchmark artifact. The appropriate next scientific steps are independent reproduction, broader benchmark families, machine-checked refinement evidence, and hardware realization under the same extensional semantics.

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