

# **Converge Ledger**

## **The Memory of the System**

**A Distributed, Append-Only Runtime Substrate**

*For Distributed Systems Engineers & Architects*

# The Problem

## Large-Scale Agentic Systems Need Memory

### Context:

- AI agents execute complex, multi-step workflows
- Reasoning is expensive (LLM calls = seconds, not milliseconds)
- Human-in-the-loop gates create unpredictable pauses

### Constraints:

- Agents crash. Workflows pause. Progress must survive.
- Multiple observers need real-time visibility
- Recovery must be fast (not recompute-from-scratch)

# The Naive Solution

"Just use Postgres"

Why It Fails:

Problem	Impact
Polling	Latency and load
Centralized	Single point of failure
No native clustering	Complex HA setup
No real-time streaming	More polling
Relational model	Fighting append-only semantics

# The Architecture Principle

## "Functional Core, Imperative Shell"



# The Key Invariant

*"The Ledger never decides. It only remembers."*

- The engine can run **without** the ledger
- The ledger is **meaningless** without the engine
- Losing ledger data must **not** break correctness
- The ledger **never** rewrites history

All semantic authority lives in Converge Core (Rust).

# The Single-Writer Model

## Why No Coordination?

For any given Root Intent:

Property	Guarantee
Single Writer	Exactly one Converge engine appends
Multiple Readers	Any number of observers
Append-Only	No updates, deletes, or overwrites

### What This Eliminates:

- No conflicts
- No merge logic
- No consensus protocols (Raft, Paxos)
- No distributed transactions

# Why Elixir/OTP?

## The Right Tool for the Job

OTP Feature	How We Use It
<b>Mnesia</b>	Distributed, in-memory, soft-real-time storage
<b>GenServer</b>	Isolated failure domains
<b>Supervisors</b>	Automatic restart, self-healing
<b>:net_kernel</b>	Native clustering (no sidecars)
<b>:pg</b>	Zero-config service discovery

### What We Explicitly Avoid in Elixir:

- Semantic validation → Rust
- Domain logic → Rust
- Invariant enforcement → Rust

# The API

## Five Operations. That's It.

Operation	Purpose
Append(context_id, entry)	Add an immutable entry
Get(context_id)	Retrieve entries
Snapshot(context_id)	Serialize full context
Load(context_id, blob)	Restore from snapshot
Watch(context_id)	Stream new entries

**Deliberately Missing:** Updates, Deletes, Transactions, Branching, Conditional writes, Queries

# Trust but Verify

## Merkle Trees for Cryptographic Integrity

```
defmodule ConvergeLedger.Integrity.MerkleTree do
  def hash(content), do: :crypto.hash(:sha256, content)

  def combine(left, right), do: hash(left <> right)

  def compute_root([single]), do: combine(single, single)
  def compute_root(hashes), do: build_tree_level(hashes)
end
```

### Use Cases:

- Snapshot verification (tamper detection)
- $O(\log n)$  sync/diff between replicas
- Audit proofs without revealing all entries

# Merkle Tree Performance

Operation	Complexity	10K entries
compute_root	$O(n)$	~500ms
generate_proof	$O(n)$	~100ms
verify_proof	$O(\log n)$	~0.01ms

## Properties:

- Deterministic: Same inputs → same root
- Collision-resistant: Different inputs → different root
- Bitcoin-style: Single element duplicated

# Causal Ordering

## Lamport Clocks — "Who Did What When"

**The Problem:** Wall clocks lie. Machine clocks drift.

**The Solution:** Logical time.

```
defmodule ConvergeLedger.Integrity.LamportClock do
  defstruct time: 0

  def tick(%{time: t} = clock) do
    new_time = t + 1
    %{clock | time: new_time}, new_time
  end

  def update(%{time: local} = clock, received) do
    new_time = max(local, received) + 1
    %{clock | time: new_time}, new_time
  end
end
```

# Lamport Clock Guarantee

*If event A happened-before event B, then  $\text{clock}(A) < \text{clock}(B)$*

**Cross-Context Causality:**

```
# Context A creates entry
{:ok, a} = Store.append("ctx-a", "facts", "data")
# a.lamport_clock = 1

# Context B receives A's data and extends
{:ok, b} = Store.append_with_received_time(
  "ctx-b", "facts", "derived", 1
)
# b.lamport_clock = 2 (guaranteed > a)
```

# Zero-Config Discovery

## How Nodes Find Each Other

```
defmodule ConvergeLedger.Discovery do
  def join(context_id) do
    :pg.join({:context, context_id}, self())
  end

  def members(context_id) do
    :pg.get_members({:context, context_id})
  end

  def broadcast(context_id, message) do
    members(context_id)
    |> Enum.each(&send(&1, message))
  end
end
```

No sidecars. No service mesh. No configuration.

# Cluster Self-Healing

## Automatic Topology Management

```
defmodule ConvergeLedger.Cluster.MnesiaManager do
  use GenServer

  def init(_) do
    :net_kernel.monitor_nodes(true)
    {:ok, %{}}
  end

  def handle_info({:nodeup, node}, state) do
    :mnesia.change_config(:extra_db_nodes, [node])
    replicate_tables()
    {:noreply, state}
  end
end
```

**On join:** Connect Mnesia, replicate tables

**On leave:** Automatic failover

# The Data Model

## Context Entries

Context: growth-strategy-001		
seq=1	facts	market_size: 2.4B
seq=2	intents	objective: increase_demand
seq=3	traces	agent:analyst started
seq=4	proposals	strategy: partnership_model
seq=5	evals	confidence: 0.73

No updates. No deletes. No rewrites.

# Supervision Tree

## Fault Isolation

```
ConvergeLedger.Supervisor
├── StorageSupervisor
│   └── Mnesia initialization
├── WatchRegistry (GenServer)
│   └── Subscriber management
├── MnesiaManager (GenServer)
│   └── Cluster topology
└── GrpcServerSupervisor
    └── External API
```

Each component has an **isolated failure domain**.

## Q&A: Why Not Kafka?

Concern	Answer
Weight	Too heavy for our use case
Snapshotting	We need state recovery, not just events
Integrity	No built-in Merkle verification
Use case	Kafka is pub/sub; we need context memory

## Q&A: Why Not Redis?

Concern	Answer
Clustering	Complex native clustering
Integrity	No Merkle trees, no Lamport clocks
Persistence	Memory-only or complex setup
Model	Key-value, not append-only contexts

# Q&A: Why Not Postgres?

Concern	Answer
Streaming	Polling, not real-time
Clustering	No native clustering
Model	Relational fights append-only
Supervision	No process fault isolation

# Architecture Danger Signs

## When to Stop and Re-Read the Docs

If you want...	You need something else
Conditional writes	Coordination layer
Conflict resolution	Consensus protocol
Complex queries	A real database
Background jobs	Workflow engine
Event handlers	Pub/sub system

This is specialized memory, not a general-purpose system.

# Summary

## Key Takeaways

1. **Separation of concerns:** Rust decides, Elixir remembers
2. **Single-writer model:** No coordination needed
3. **Append-only:** No conflicts, no merges
4. **Cryptographic integrity:** Merkle trees + Lamport clocks
5. **OTP primitives:** Battle-tested infrastructure
6. **Minimal API:** Five operations, no more

# The Golden Rule

*Converge converges in Rust.*

*Anything distributed exists only to remember what already happened.*

# Resources

- **README.md** — Overview and philosophy
- **ARCHITECTURE.md** — Detailed design decisions
- **AGENTS.md** — Process architecture
- **docs/INTEGRITY.md** — Merkle trees and Lamport clocks

# Thank You

## Questions?

*Converge Ledger — Optional, Derivative, Replaceable*

[github.com/converge-zone/converge-ledger](https://github.com/converge-zone/converge-ledger)