Unified Payments Ledger v2

Engineering Design Document

Status: **In Review** Version: **2.4.0** Team: **Payments Infra** Squad: **Ledger Core**

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Context & Scope

Problem. The current single-ledger Postgres monolith cannot sustain the projected 40× write throughput required for the 2026 Stripe-level merchant-acquiring rollout. P99 write latency breached 800 ms during the Q3 Black Friday stress test. This document proposes replacing the hot-path write layer with a partitioned, event-sourced ledger backed by Apache Kafka and a TiDB-distributed storage tier.

Scope. Covers the `ledger-write-service`, `ledger-query-service`, Kafka topic schema, TiDB shard strategy, and the zero-downtime migration plan. Out of scope: fraud-scoring pipeline, merchant portal UI, settlement batch jobs.

Background. Stripe's public post-mortem (2024) attributes 68 % of payment-latency incidents to single-region database serialisation under high concurrency. Our current architecture mirrors this fragility: one `payments_ledger` table with 3.2 B rows, 14 secondary indexes, and no horizontal sharding. The re-architecture targets:

- Sub-50 ms P99 write latency at 50 k TPS sustained.
- Idempotent, exactly-once debit/credit semantics via outbox pattern.
- GDPR-compliant PII isolation per merchant shard.
- RPO ≤ 1 s, RTO ≤ 30 s in a region failover.

TiDB vs. CockroachDB vendor choice is not yet final. This doc assumes TiDB; §11 covers CockroachDB as the primary alternative. The infra cost delta is $180k/yr. Pending CFO sign-off.

Goals & Non-Goals

Goals

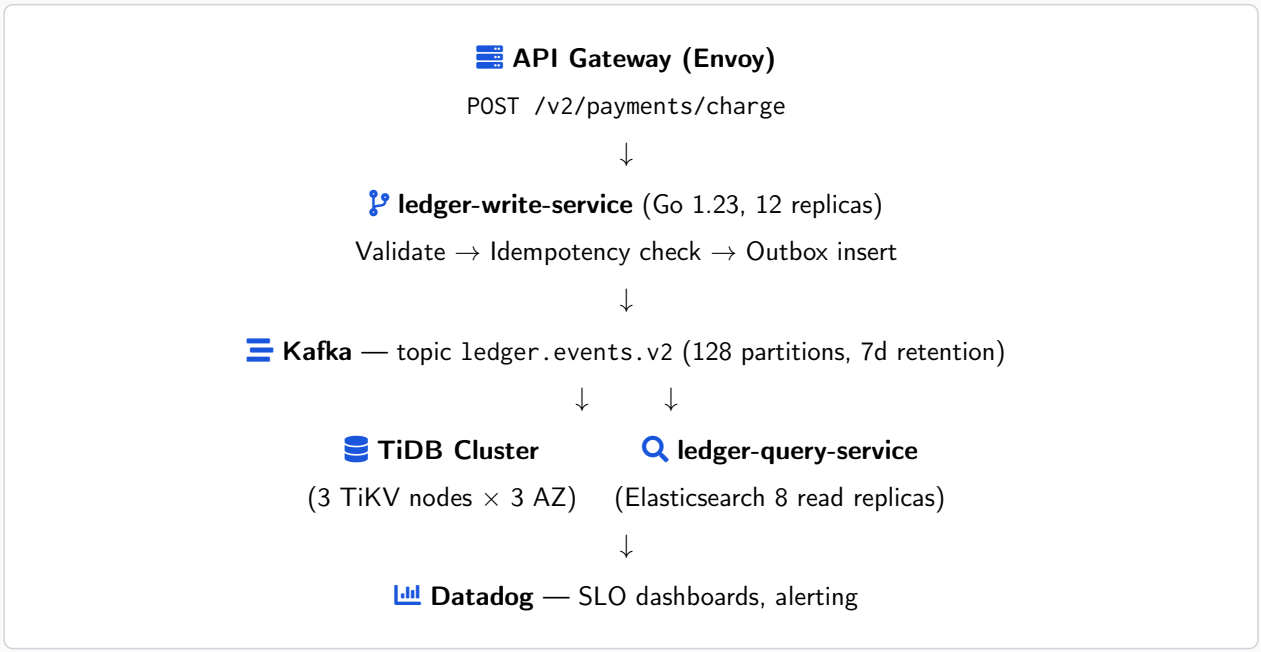
1. **Throughput.** Handle 50 k TPS peak write load with P99 $\leq$ 50 ms.
2. **Durability.** Zero data loss on single-node failure; 3-way replication across AZs.
3. **Idempotency.** Duplicate payment events must be deduplicated within a 24 h window using `idempotency_key`.
4. **Zero-downtime migration.** Dual-write bridge with read-traffic cut-over under feature flag; full cut-over in $\leq$ 4 h maintenance window.
5. **Observability.** Every write emits a structured OpenTelemetry span; Datadog dashboard auto-provisioned via Terraform.

Non-Goals

- Real-time fraud inference — remains in the existing ML scoring service.
- Re-architecture of the settlement or reconciliation batch tier.
- Support for non-USD currency ledgers (planned for Q3 2026, separate RFC).

Architecture

System Diagram



Key Design Decisions

Concern	Decision
Write path	Outbox pattern: write to `ledger_outbox` in same TiDB txn, Kafka relay picks up async. Guarantees atomicity without distributed 2PC.
Partition key	`merchant_id % 128` — keeps all events for a merchant on one partition (ordering guarantee).
Idempotency	`idempotency_key` stored in Redis (TTL 24 h); checked before outbox insert.
Schema evolution	Protobuf v3 with mandatory `schema_version` field; backward-compat enforced by schema registry.
Fan-out reads	CQRS: query service consumes Kafka and projects into Elasticsearch for merchant-facing queries; TiDB for internal accounting.

Outbox Relay

The relay is a single Go goroutine per TiDB shard using `SELECT FOR UPDATE SKIP LOCKED` on the `ledger_outbox` table. Batch size: 500 rows, flush interval: 50 ms. On Kafka producer ACK the rows are deleted. Relay lag is exposed via `ledger_outbox_depth_gauge` (alert if $> 10\,\text{k}$).

API Contract

REST Endpoints

Method	Path	Description
POST	/v2/payments/charge	Initiate debit from merchant wallet
POST	/v2/payments/refund	Reverse a prior charge
GET	/v2/ledger/balance/{mid}	Current balance for merchant ID
GET	/v2/ledger/events	Paginated event log (cursor-based)
POST	/v2/payouts/schedule	Enqueue a payout to bank account

Protobuf Schema — `ChargeRequest`

```proto
syntax = "proto3";
package payments.ledger.v2;

message ChargeRequest {
  string  idempotency_key  = 1;  // UUID v4, required
  string  merchant_id      = 2;  // e.g. "mid_4xR9a..."
  int64   amount_cents      = 3;  // positive, USD cents
  string  currency          = 4;  // ISO 4217 ("USD")
  string  description       = 5;  // max 255 chars
  map<string, string> metadata = 6;
  int32   schema_version    = 7;  // must == 2
}
```

```

message ChargeResponse {
  string  charge_id     = 1;  // "chg_..." globally unique
  string  status        = 2;  // PENDING | COMPLETED | FAILED
  int64   balance_cents  = 3;
  int64   created_at_us  = 4;  // Unix microseconds
}

service LedgerService {
  rpc Charge  (ChargeRequest)  returns (ChargeResponse);
  rpc Refund  (RefundRequest)  returns (RefundResponse);
  rpc Balance (BalanceRequest) returns (BalanceResponse);
}
```

Error Codes

HTTP	gRPC Code	Meaning
400	INVALID_ARGUMENT	Missing/malformed field
409	ALREADY_EXISTS	Duplicate `idempotency_key` (safe to retry)
422	FAILED_PRECONDITION	Insufficient balance
429	RESOURCE_EXHAUSTED	Rate limit exceeded (50 rps per merchant)
500	INTERNAL	Unexpected server error
503	UNAVAILABLE	Kafka relay lag > 60s or TiDB unavailable

Data Model

TiDB Schema

```
CREATE TABLE ledger_events (
    event_id        CHAR(36)      NOT NULL,
    merchant_id     VARCHAR(64)   NOT NULL,
    amount_cents    BIGINT        NOT NULL,
    currency        CHAR(3)       NOT NULL DEFAULT 'USD',
    event_type      ENUM('CHARGE','REFUND','PAYOUT') NOT NULL,
    idempotency_key CHAR(36)      NOT NULL,
    created_at      DATETIME(6)   NOT NULL,
    metadata        JSON,
    PRIMARY KEY (merchant_id, created_at, event_id)  -- composite PK = shard key
) PARTITION BY HASH(merchant_id) PARTITIONS 128;

CREATE TABLE ledger_outbox (
    id          BIGINT AUTO_INCREMENT PRIMARY KEY,
    event_id    CHAR(36)    NOT NULL,
    payload     BLOB        NOT NULL,  -- serialised proto
    created_at  DATETIME(6) NOT NULL,
    published   TINYINT(1)  NOT NULL DEFAULT 0,
    INDEX idx_unpublished (published, created_at)
```

```
);
```

Migration Plan

The existing ledger table has 3.2 B rows and 14 live consumer services. A phased cut-over with automated rollback is mandatory.

Phases

Phase	Window	Description
0	Week 0	Provision TiDB cluster; schema DDL; seed with last 90d of history via Spark job. Shadow-write mode (writes go to both old DB and TiDB, reads from old).
1	Week 1–2	Enable dual-write via feature flag `ledger_dual_write`. Monitor TiDB lag vs. Postgres baseline. Alert on $> 0.1\,\%$ divergence.
2	Week 3	Shift 10 % of read traffic to TiDB (canary). Validate P99 latency and correctness via checksum comparison job.
3	Week 4	Ramp reads to 100 % TiDB. Keep Postgres in standby for 48 h rollback window.
4	Week 5	Disable Postgres writes. Decommission old DB after 30-day hold for audit.

Rollback Procedure

In Phase 1–3, flip `ledger_dual_write=false` in LaunchDarkly. Traffic immediately reverts to Postgres. Estimated rollback time: $< 30\,\text{s}$ (flag propagation SLA). Phase 4 rollback requires point-in-time recovery from Postgres daily snapshot — RTO $\approx 4\,\text{h}$.

A nightly reconciliation job (`ledger-recon-job`) runs a row-count and checksum comparison between Postgres and TiDB for the previous 24 h window. Any delta $> 0.01\,\%$ pages the on-call via PagerDuty and halts Phase advancement.

Observability

SLOs

SLO	Target	Measurement
Write latency P99	≤ 50 ms	`ledger_write_duration_ms` histogram (Datadog)
Write availability	99.99 %	1 − (5xx / total) over 28-day rolling window
Outbox relay lag	≤ 10k rows	`ledger_outbox_depth_gauge`
Idempotency hit rate	< 0.5 %	`ledger_idempotency_hit_total`
Recon divergence	0 %	Nightly batch, alert on any mismatch

Key Metrics Emitted

```
// Example OpenTelemetry span in ledger-write-service (Go)
ctx, span := tracer.Start(ctx, "ledger.charge",
    trace.WithAttributes(
        attribute.String("merchant_id", req.MerchantId),
        attribute.Int64("amount_cents",  req.AmountCents),
        attribute.String("schema_version", strconv.Itoa(int(req.SchemaVersion))),
    ),
)
defer span.End()
```

Launch Checklist

🚀 Pre-Launch (Engineering)

- ✓ Unit tests: ≥ 90 % coverage on `ledger-write-service` (currently 93 %).
- ✓ Integration tests pass against TiDB staging cluster.
- ✓ Load test: 55 k TPS for 30 min in staging (P99 = 38 ms achieved).
- ✓ Schema registry: `ChargeRequest v2` registered, backward-compat verified.
- ☐ Chaos test: kill one TiKV node under 30 k TPS — verify no data loss.
- ☐ Runbook published to Confluence and linked in PagerDuty service.
- × **BLOCKED:** TiDB vendor contract not yet signed — see §1 decision.

🔒 Security Review

- ✓ PII fields (`metadata.card_last4`) encrypted at rest (TiDB TDE enabled).
- ✓ mTLS between `ledger-write-service` and TiDB cluster.
- ✓ Rate-limiting enforced at Envoy layer (50 rps / merchant).
- ☐ GDPR data-deletion flow for merchant-shard drop verified with Legal.
- ☐ Pen-test scheduled: 2026-02-03 (external vendor — NCC Group).

📊 Observability & On-Call

- ✓ Datadog dashboard `ledger-v2-prod` provisioned via Terraform.
- ✓ PagerDuty rotation updated; on-call rotation covers 3 engineers.

☐ Synthetic monitors for `/v2/payments/charge` (every 60 s) configured.

☐ Runbook walkthrough session scheduled with on-call team (2026-01-22).

🚩 Go/No-Go Gate

- Chaos test (above) passes with zero data loss.
- TiDB contract signed.
- GDPR deletion flow approved by Legal.
- Security pen-test findings rated $\leq$ Medium severity.

Risks

Risk	Likelihood	Severity	Mitigation
TiDB write-stall under GC pressure	Medium	High	Tune `gc_life_time` to 10 min; pre-warm GC worker thread pool.
Kafka consumer lag spike	Low	Medium	Auto-scaling consumer group (KEDA); dead-letter queue for retries.
Redis idempotency store OOM	Low	High	TTL = 24 h; eviction policy `allkeys-lru`; cluster sharding by `merchant_id`.
Dual-write divergence (Phase 1)	Medium	Critical	Nightly recon job halts Phase on > 0.01 % delta; automatic rollback flag.
Vendor lock-in (TiDB)	Low	Medium	Protobuf schema + CQRS read tier decoupled; CockroachDB migration path documented.

Open Questions

1. **[Infra]** Should the Kafka relay run as a sidecar to `ledger-write-service` or as a standalone `ledger-relay-service`? Sidecar reduces network hops; standalone allows independent scaling. Decision needed by 2026-01-25.
2. **[Product]** Do we need sub-second balance reads during Phase 1 dual-write, or is eventual consistency (100 ms lag from Kafka) acceptable for merchant dashboards?
3. **[Legal]** GDPR merchant data deletion — is a 30-day TiDB shard tombstone compliant, or must deletion be synchronous?
4. **[Security]** Should `idempotency_key` be stored in plaintext in Redis, or HMAC'd with merchant secret? K. Narayanan to advise by 2026-01-18.

Alternatives Considered

Alternative	Verdict
CockroachDB	Comparable feature set, 22 % higher p99 in our benchmark at 50 k TPS (see attached Notion doc). Cockroach charges per vCPU; $180k/yr delta vs TiDB. Keep as fallback if TiDB contract fails.
Postgres + Citus	Evaluated Q2 2025. Citus shard rebalancing caused 4-min read unavailability in staging under 30 k TPS. Disqualified.
PlanetScale (Vitess)	No multi-statement transactions — incompatible with outbox pattern. Disqualified.
Event sourcing on DynamoDB	Single-region without Global Tables; 10× cost at our volume. Disqualified.

References

Ref	Link / Description
[1] TiDB Docs	docs.pingcap.com/tidb/stable
[2] Outbox Pattern	Microservices.io — Transactional Outbox (microservices.io)
[3] Proto Schema Reg.	Internal Confluence: `/Payments/SchemaRegistry/LedgerV2`
[4] Stripe Post-mortem	Stripe Engineering Blog, Oct 2024 — Ledger Latency Incident
[5] Load Test Results	Notion: `Ledger v2 Load Test — 2025-12-14`
[6] Datadog Dashboard	`letx-datadog.internal/ledger-v2-prod`
[7] Chaos Eng. Runbook	Confluence: `/Infra/ChaosEngineering/LedgerV2`