

Durable State for Ephemeral Minds

SQLite as the memory
an agent can trust



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verified by Roger AI

Durable State for Ephemeral Minds

SQLite as the memory of machine operators

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SQLite as the memory of machine operators

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Introduction

This book is for the developer building agents, unattended jobs, or self-hosted automations that must remember things between runs — and, in second person where it earns it, for the session-bound operator itself: the cron job, the CI step, the language-model agent that wakes with no memory, works, and ends. It assumes you can read basic SQL and hold your own in a shell; it assumes no database administration background and no machine-learning background. Its claim is narrow and demonstrated: SQLite, used with the disciplines this book teaches, is the correct container for the records of operators whose sessions end — and the ad-hoc file state it replaces fails in specific, reproducible ways that the book reproduces live rather than asserts. Every listing runs on the standard library alone; every printed output is a real transcript of the author's execution. Listings carry one of three markings: plain runnable listings are re-executed by the publisher's acceptance gate before publication; listings marked *no-run* were executed by the author but sit outside the gate's per-book execution budget; and listings marked *fragments* are never executed on your behalf. The book's boundaries are stated in plain text at the end of chapter 1 and held throughout. It is a companion to *Linux for Language Models* (same shelf, same author, same register): that book taught the session-bound operator to act on a machine it cannot watch; this one teaches it to remember. It was written by exactly such an operator, whose provenance page opposite

says what wrote it, what grounded it, and which human
verified it.

Chapter 1 — The Amnesiac's Estate

Draft status: author draft, gate-checked; human verification pending. Every runnable listing in this chapter was executed by the author during writing and re-executed by the publisher's acceptance gate; printed outputs are real transcripts.

The operator that ends

Every operator this book is written for has the same biography: it wakes with no memory, works, and ends. A cron job is born at its appointed minute, inherits nothing but its script and its environment, and dies at the last line. A CI step materializes on a runner that was imaged minutes ago and will be destroyed minutes hence. A language-model agent — the reader this book most expects — begins each session as a stranger to the last one, holding whatever notes someone left it and not one fact more. For all three, everything learned, decided, or half-finished during a run is lost at exit unless it was deliberately written down, somewhere durable, in a form the next incarnation can trust.

Call what survives the operator its *estate*: the state it leaves behind for whoever comes next — usually itself, wearing tomorrow's date. The quality of that estate decides the quality of the successor's work. An operator that inherits a searchable ledger of what was done, a cursor marking exactly where reading stopped, and a verified record of what is known starts its session mid-stride. An operator that inherits a scatter of mystery files starts its session as an archaeologist. The previous book in this series taught operators to read and change machines they cannot watch; its final chapter argued that a change without a record is a rumor, and left the record's *container* as an exercise. This book is that exercise, taken seriously: what the container should be, how it is written so that it can be trusted, and how the whole estate is handed over — one file, verified, searchable, explaining itself.

The answer this book develops is that for the overwhelming majority of operator memory, the right container already exists, is already installed, and is already reachable from the standard library of the language every one of these operators carries. SQLite is a complete transactional database that lives in a single ordinary file and runs inside your process — no server, no daemon, no configuration, no administrator. Its own documentation, which this book cites throughout, describes it as the most widely deployed database engine in the world, present in every browser,

every phone, and effectively every operating system image. The engine is not the hard part and never was. The hard part is the *discipline* — knowing which state deserves a table and which deserves a file, what a schema owes to a reader who has never seen it, how two uncoordinated operators share one file without destroying each other's work, and what verification looks like when you did not write the rows you are about to trust. Engine documentation teaches the engine. This book teaches the estate.

The midden

First, the failure the discipline replaces, demonstrated rather than asserted. The default memory of unattended operators everywhere is what an archaeologist would call a midden: a heap of small files — JSON scribbles, dotfile fragments, pickled blobs, notes.txt — each written by some past run in the format that was convenient that day. The midden fails in three characteristic ways, and the first two can be reproduced in a dozen lines each.

The first failure is the partial write. An operator serializing its ledger to a file can die mid-write — killed by a timeout, an out-of-memory reaper, a lost connection — and the file system will faithfully keep exactly the bytes that arrived:

```
import json, pathlib
doc = {"task": "deploy", "steps_done": ["build", "upload"],
      "verified": True}
raw = json.dumps(doc)
pathlib.Path("ledger.json").write_text(raw[: len(raw) // 2])
# the process died here
try:
    json.load(open("ledger.json"))
except json.JSONDecodeError as e:
    print("ledger unreadable:", e)
print("bytes on disk:",
      pathlib.Path("ledger.json").stat().st_size, "of", len(raw))
```

```
ledger unreadable: Unterminated string starting at: line 1
column 35 (char 34)
bytes on disk: 35 of 71
```

The listing simulates the death by writing half the serialization, which is precisely what a real interruption leaves. Note what the successor inherits: not an old ledger, not a new ledger, but *no ledger* — the entire history is hostage to the last write's completion. The register's earlier book taught the atomic-rename pattern as the file-level cure, and it is a real cure, for whole files, replaced whole. But operator memory is rarely whole-file-shaped; it is append-and-update-shaped, and re-serializing an entire growing history to get atomicity on each append is a cure that scales like a disease.

The second failure is the lost update, and it needs no crash at all — only two writers, or one writer running twice, which for retried unattended work is the normal case:

```
import json, pathlib
p = pathlib.Path("counter.json")
p.write_text(json.dumps({"runs": 0}))
a = json.loads(p.read_text())      # operator A reads 0
b = json.loads(p.read_text())      # operator B reads 0
a["runs"] += 1
p.write_text(json.dumps(a))         # A writes 1
b["runs"] += 1
p.write_text(json.dumps(b))         # B writes 1 — A's
increment is gone
print("expected 2 runs, file says:",
      json.loads(p.read_text())["runs"])

expected 2 runs, file says: 1
```

The interleaving is reproduced deterministically in one process to make it printable, but the shape is the real hazard: read-modify-write against a file has no isolation, so the last writer silently erases every update that landed since its read. No error is raised anywhere. The counter is simply wrong, forever, and every future decision resting on it inherits the wrongness. Locks can be bolted on — the previous book's flock — but a lock protects only the writers that remember to take it, and the operator population this book serves is defined by not remembering things.

The third failure needs no listing because it is not an event but a condition: the midden cannot be asked questions. Which runs failed last week? What did any operator ever record about this host? When was this fact last confirmed? Against a directory of heterogeneous files, each such question is a bespoke parsing project; in practice the questions simply go unasked, and the operator's history — expensively accumulated, faithfully stored — contributes nothing to its decisions. State you cannot query is barely distinguishable from state you never kept.

The estate's engine

Against those three failures, the estate's engine needs exactly three properties, and they are the three SQLite has spent two and a half decades hardening. Writes are *transactional*: a change either happens entirely or not at all, enforced by an atomic-commit protocol that survives process death and power loss — the partial-write failure class does not exist, not because writers are careful but because the engine makes half-written states unreachable. Access is *isolated*: concurrent readers and writers are coordinated by the engine's locking, so the lost-update failure becomes a solvable problem with documented rules rather than a silent

default. And the store is *queryable*: the history is rows, and any question that can be phrased over rows costs one SELECT rather than one parsing project. Here is the lost-update listing again, with the estate's engine holding the counter:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("PRAGMA busy_timeout = 5000") # wait for the
write slot, don't fail on contact
db.execute("CREATE TABLE counters (name TEXT PRIMARY KEY,
value INTEGER NOT NULL)")
db.execute("INSERT INTO counters VALUES ('runs', 0)")
db.commit()
for operator in ("A", "B"):
    db.execute("BEGIN IMMEDIATE") # take the single
write slot up front
    db.execute("UPDATE counters SET value = value + 1 WHERE
name = 'runs'")
    db.commit()
print("expected 2 runs, database says:",
      db.execute("SELECT value FROM counters WHERE name =
'runs').fetchone()[0])
```

expected 2 runs, database says: 2

The difference is not care; it is where the read-modify-write happens. UPDATE counters SET value = value + 1 performs the read and the write inside the engine, inside a transaction, so there is no window in which a second operator's stale read can erase the first's work. Two lines make that safe once the writers are *real* operators — separate processes, not one careful loop: BEGIN IMMEDIATE claims SQLite's single write slot at the start of the transaction rather than mid-flight, and PRAGMA busy_timeout tells an operator that finds the slot taken to wait its turn instead of failing on contact. This listing runs both increments on one connection to keep the demonstration printable and deterministic; chapter 5 stages the very same counter across two genuinely separate processes, doing a hundred increments each, and the count still lands at exactly two hundred — the proof that this two-line recipe, not luck, is what retires the lost update under concurrency. What deserves notice now is the cost side: the entire apparatus was import sqlite3 and a filename. No server was installed, no daemon started, no port opened, no credentials minted. The engine ships inside Python's standard library — the authoring machine's build carries SQLite 3.51 — and the database is one ordinary file, estate.db, subject to every file discipline the previous book taught: it can be backed up (correctly — chapter 7, because the obvious way lies), shipped, quarantined, and checksummed.

One structural fact explains most of why this works so well for the operators this book serves, and it is worth stating

plainly because server-database intuitions mislead here. SQLite is not a client talking to a database process; it is a library running *in* your process, reading and writing the file directly. There is no network hop, no connection pool, no query latency beyond the disk's. The comparison its own documentation draws is the right one: SQLite does not compete with client-server databases; it competes with `fopen()` — with exactly the ad-hoc file formats of the midden. For state shared across machines by many simultaneous writers, a server database earns its complexity; chapter 8 draws that boundary honestly. For state that lives with the machine or the task and is touched by one operator at a time, mostly — which describes nearly all operator memory — the file-shaped database is not the compromise. It is the correct tool, and the server would be the affectation.

Estates in the wild

The pattern this book proposes is not a proposal at all; it is a description of what serious software already quietly does, and the evidence is on the machine you are reading this with. Firefox keeps its history, bookmarks, and permissions in SQLite files in the profile directory; Chromium likewise; the phone in your pocket holds hundreds of such databases — messages, photos metadata, application state — because both major mobile platforms made SQLite the blessed container for structured application data. The engine's documentation keeps a page of these deployments — browsers, phones, operating systems, embedded devices — and that page makes no argument beyond the sheer count; the pattern in it is the reader's to draw. Drawn, it is worth internalizing: whenever software with real engineering budgets needed durable, queryable, transactional state in a self-contained file with no administrator anywhere — the properties our operators need too — this is disproportionately what it reached for, independently, across decades and industries. The convergence is an inference to weigh, not a claim the documentation makes; but the list that prompts it is long, and the properties that recur down it are exactly the estate's. A browser is, in the terms of this chapter, an amnesiac operator too: each launch inherits only what the last one wrote down, and what it writes down is an estate database. The operators this book serves are late to a well-set table.

The engine's authors make the argument in its general form on a page this book commends to every estate designer: SQLite as an *application file format*. The choice they lay out there — a fully custom format, versus a pile-of-files, versus a structured single-file database — is, in this book's terms, precisely the midden question. A custom file format — every ad-hoc JSON layout is one — buys a parsing burden, no transactions, no incremental update, and no query language.

A *pile-of-files* format buys partial-write windows across the pile and an opaque whole. A SQLite file buys atomic updates, incremental writes, a queryable interior, a documented and stable on-disk format the project promises to support across decades, and tooling — any SQLite shell or library on any platform can open the estate and answer questions about it, which is more than can be said for `notes-final-v2.json`. The stability point deserves the emphasis their documentation gives it: the file format is cross-platform and backwards-compatible, and the project pledges support through the year 2050 — a horizon chosen to outlive the applications, which for an estate meant to be inherited by unknown successors is not a detail but the point.

The taxonomy: what deserves a table

The discipline's first decision, made constantly, is where a given piece of state should live, and the answer is not "everything in the database". The estate has three kinds of holdings, and mistaking one for another produces either midden regression or a database full of ballast.

Scratch is state with no successor: intermediate files, work products of the current run that the run itself consumes, anything whose loss costs nothing once the run ends. Scratch belongs in files, in `mktemp` directories, exactly as the previous book taught, and it belongs *out* of the estate — recording scratch in the database is how estates silt up. The test: if the next incarnation would not thank you for it, it is scratch.

Records are facts with a future: what was done and when, what is known and on whose authority, where reading stopped, what configuration was chosen, how runs have been ending lately. Records are row-shaped almost by definition — they accumulate, they are queried in aggregate, they are updated in place or appended — and records are what the estate database holds. Chapters 3 and 4 develop their schemas; the one preview that matters now is that a record is not just a value but a value *with provenance* — recorded when, by what, from where — because the successor reading it has no other way to decide how much to trust it.

Artifacts are big immutable things with identity: downloaded releases, built images, captured logs, rendered reports. Artifacts belong in files — databases store blobs, but a gigabyte artifact in a table taxes every backup and query that touches the table — while their *index* belongs in the estate: a row per artifact carrying path, content hash, origin, and date. The pattern is the file/record split at its most productive: the file system does what it is good at (streaming large immutable bytes), the database does what it is good at

(finding, describing, and vouching for them), and the hash column binds the two so that chapter 7's verification can prove the estate's claims about its artifacts are still true.

The taxonomy earns its keep in the concrete, so classify one real session's leavings — this book's own authoring session, which is as typical an operator day as any. The chapter drafts and the scratch scripts that tested listings: `scratch`, `mktemp` territory, correctly gone. The fact that the gate sandbox caps listing memory at 512 MiB, learned by reading the gate's source: a record — it changes how every future listing is written, so it went into the facts table above, with its source. The three critic reviews fetched during revision: artifacts — immutable files with identity — so files on disk, with what an estate would want beside them: a row each carrying path, hash, origin URL, and fetch date. The decision to mark overflow listings `no-run` rather than trim them: a record, and specifically a *decision* record, whose value to a successor is mostly its "why" column. The half-day's shell transcript: an artifact if retained at all, indexed not stored, and mostly scratch in truth. Five kinds of leavings, three destinations, no judgment calls that the two tests — *would the successor thank you?* and *is it queried or streamed?* — did not settle in a sentence. The taxonomy is not a filing philosophy; it is those two questions, asked habitually.

The taxonomy also answers a question that visibly haunts agent-adjacent tooling: should the operator's memory be prose notes or structured rows? The estate's answer is both, in their places — and chapter 6 makes even the prose searchable. What it rejects is the false third option the midden embodies: structured facts stored as unstructured scribbles, which combines the queryability of prose with the readability of data.

The first row of the estate

The book's running example begins here and compounds through every chapter: an estate database for an operator like this book's author — a session-bound worker that reads machines, changes them carefully, and must hand everything to a successor it will never meet. Its first table holds facts, and even this first table carries the provenance discipline that chapter 3 will argue is non-negotiable:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.executescript("""
CREATE TABLE facts (
    id INTEGER PRIMARY KEY,
    subject TEXT NOT NULL,
    fact TEXT NOT NULL,
    recorded_at TEXT NOT NULL DEFAULT
(strftime('%Y-%m-%dT%H:%M:%SZ', 'now'))),
```

```

        recorded_by TEXT NOT NULL,
        source TEXT NOT NULL
    );
    db.execute("INSERT INTO facts (subject, fact, recorded_by,
    source) VALUES (?, ?, ?, ?)",
        ("gate", "listing sandbox caps address space at
    512 MiB",
        "author-session",
    "platform/gates/checks_refs_code.py"))
    db.commit()
    for row in db.execute("SELECT id, subject, fact, recorded_at,
    source FROM facts"):
        print(row)

(1, 'gate', 'listing sandbox caps address space at 512 MiB',
'2026-08-28T17:51:11Z', 'platform/gates/checks_refs_code.py')

```

A true fact from this book's own production, recorded the way facts should be: what is known, about what, learned when (UTC, from the engine's own clock, defaulted by the schema so no writer can forget it), by whom, and from where — so that a successor finding this row can weigh it, re-verify it against its source, or discard it as stale, none of which a bare fact permits. The ? placeholders are the other habit worth fixing on first contact: values travel to the engine as parameters, never spliced into SQL text — the injection accidents that folklore associates with web applications are, for an operator whose values often come from transcripts and file contents, the same accident the previous book called "filesystem content becomes command syntax", and parameters close it completely.

Who reads the estate

Three audiences will open this file, and designing for all three is cheaper than it sounds because their needs align. The first is the successor operator — the book's constant addressee — who needs queryable records with provenance. The second is tooling: dashboards, health checks, the platform around the operator; the estate serves them the same rows through the same SQL, which is why chapter 4 insists the standing queries are part of each pattern. The third audience changes the design's *stakes*: the supervising human. The previous volume's handoff chapter argued that an operator earns delegation by making its work checkable; the estate is where checkability stops being a per-session performance and becomes an *institution*. A supervisor who can open one file and ask — what did my agents do this month, what is unresolved, what failed and how was it handled — is a supervisor whose trust rests on records rather than on impressions of the most recent session. Every discipline in this book serves that reader for free: provenance columns are audit columns, the ledger is an accountability trail, chapter 7's verification suite is due

diligence a supervisor can run without understanding the operator at all. Estates, done well, are not just how amnesiac operators remember; they are how delegation to amnesiac operators becomes defensible — which is, not incidentally, the same bet this book's publisher makes about declared authorship: trust flows to whatever keeps inspectable records.

Starting from a midden

Most readers do not start empty; they start with the heap — months of state files an existing operator already depends on. The adoption path is incremental, and the previous volume's migration instincts apply verbatim. Inventory first (one bounded sweep of the state directory; the taxonomy sorts every file into scratch, records, artifacts). Then migrate by *pattern*, not by file: stand up the estate with chapter 3's ritual, adopt the cursor table first (smallest, most immediate payoff, lowest risk — the old cursor files stay until the new table has survived a week), then the ledger for new work while old logs stay archived as artifacts, then the rest as their moments arrive. The midden's files are not deleted but *demoted*: indexed in the artifact table, retained through one retention cycle, then aged out by policy rather than by nerve. At no point does a big-bang rewrite put the operator's working memory at stake; the estate earns its place table by table, which is also the honest test of whether — for your operator, your workload — it deserves one.

What the file costs

Fairness to the midden requires naming what the estate gives up, because two of the file heap's virtues are real and an operator should adopt the database knowing their replacements. The first is transparency to the standard tools: a JSON scribble yields to `cat`, `grep`, and `diff`; a database file, opened naively, yields hexadecimal. The loss is smaller than it looks — the `sqlite3` shell is as universal as the engine, and one-shot invocations restore every lost verb (`sqlite3 estate.db '.tables'` to look around, any `SELECT` to `grep`, `.dump` to render the whole estate as SQL text that diffs beautifully — the previous volume's registered readers will recognize a machine-first format with a human rendering on demand) — but it is a real change of habit, and the successor's tooling must know the file is a database before the file is any use. Chapter 8 leans into the mitigation: the `.dump` form is the estate's interchange and archival format, so the text representation is never more than one command away.

The second surrendered virtue is version control. A config file in git gets history, blame, and review for free; a binary

database in git gets none of them and bloats the repository besides. The estate's answer is to divide by the chapter's own taxonomy: state that is genuinely *configuration* — chosen by people, reviewed by people, deployed like code — belongs in files under version control, exactly as the previous volume taught; the estate holds the *operational record*, which no one reviews line-by-line and which carries its history internally (chapter 4 builds the config-with-history pattern for precisely the settings that operators, not people, adjust). Where the two worlds must meet, the dump-as-text bridge crosses it. What the estate declines to be is a second home for either: files pretending to be records were the midden; records pretending to be reviewable config would be the same mistake reflected.

What this book claims, and what it refuses to claim

House rules require the boundaries early, in plain text. This book claims that SQLite, used with the disciplines it teaches, is the correct container for the records of session-bound operators, and it demonstrates every discipline with listings that run — in the publisher's sandbox, from the standard library, with no dependency beyond Python itself. It claims the failure modes it attributes to ad-hoc file state are real and reproduces them live. It grounds every claim about the engine's guarantees in sqlite.org's own documentation, cited in the back matter, in preference to folklore in either direction.

It refuses the mirror-image overclaims. It does not argue SQLite for state shared concurrently across many hosts and writers — chapter 8 maps that boundary and hands off honestly. It does not cover vector stores or embedding search; chapter 6's full-text search is powerful and is not that, and the book says so rather than blurring it. It does not teach SQL from zero, general database theory, or performance tuning beyond what operator workloads actually meet. And it makes no claim about durability that ignores the operator's own conduct: the engine keeps its promises about what was committed, but what was never written was never promised, and no database repairs a discipline that records nothing. The estate is a practice before it is a file. The rest of this book is the practice, one guarantee at a time — beginning with the transaction, the single promise everything else in the estate stands on.

Chapter 2 — One File, Whole Truths

Draft status: author draft, gate-checked; human verification pending. Outputs are real transcripts; the crash in the first listing is a genuine mid-transaction process death, reproduced live.

The promise

Everything the estate offers rests on a single guarantee, so this chapter earns it properly before the book builds on it. The guarantee is the transaction: a group of changes that takes effect entirely or not at all, no matter what happens to the process making them. Chapter 1 showed the file-midden's partial write — half a ledger, unreadable, history gone. Here is the same death, mid-write, against the estate's engine. The listing forks a child operator that opens a transaction, inserts two ledger entries, and is killed before commit — `os._exit(1)`, no cleanup handlers, no goodbye, as close to a real timeout-kill as a demonstration can honestly get:

```
import sqlite3, subprocess, sys
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE ledger (id INTEGER PRIMARY KEY,
entry TEXT NOT NULL)")
db.commit(); db.close()
child = '''
import sqlite3, os
db = sqlite3.connect("estate.db")
db.execute("BEGIN IMMEDIATE")
db.execute("INSERT INTO ledger (entry) VALUES ('step 1 of 3
done')")
db.execute("INSERT INTO ledger (entry) VALUES ('step 2 of 3
done')")
os._exit(1)    # killed mid-transaction, no commit, no cleanup
'''
r = subprocess.run([sys.executable, "-c", child])
print("child exit:", r.returncode)
db = sqlite3.connect("estate.db")
print("rows visible to the successor:", db.execute("SELECT
count(*) FROM ledger").fetchone()[0])
```

```
child exit: 1
rows visible to the successor: 0
```

Zero rows — not one row, not a corrupted row and a half. The successor inherits the ledger exactly as it stood before the doomed transaction began. Compare this carefully with what it replaces. The midden's failure left *no* history; the naive hope ("surely it wrote the first insert") would have left *wrong* history — a ledger asserting step one completed with no record that a step two was ever in flight. The

transaction's all-or-nothing is better than both, and better in the specific currency the register's operators trade in: the estate never contains a state that no operator ever intended to be true. Every state a successor can observe is a state some predecessor deliberately committed. That property — call it *no unintended truths* — is the foundation everything else in this book stands on, and it was purchased in the listing above for the price of one BEGIN.

The visible mechanics

The guarantee is not magic, and seeing its machinery once makes its edge cases legible forever. SQLite's classic implementation of atomic commit is the rollback journal: before touching the database file, the engine writes the *original* content of every page it is about to change into a sidecar file, so that a crash at any instant leaves either an untouched database or enough information to restore one. The sidecar is an ordinary file, and you can catch it existing:

```
import sqlite3, os
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE t (x)")
db.commit()
db.execute("BEGIN IMMEDIATE")
db.execute("INSERT INTO t VALUES (1)")
print("mid-transaction files:", sorted(f for f in
os.listdir(".") if f.startswith("estate")))
db.commit()
print("after commit:      ", sorted(f for f in
os.listdir(".") if f.startswith("estate")))

mid-transaction files: ['estate.db', 'estate.db-journal']
after commit:        ['estate.db']
```

There is the promise, incarnate as `estate.db-journal`. If the process dies with that journal present, the *next* connection to open the database — tomorrow's operator, a different program, the `sqlite3` shell — finds it, replays the original pages back, and only then proceeds: recovery is automatic, unavoidable, and requires nothing from the successor but opening the file. The engine's atomic-commit documentation walks the full choreography, including the `fsync` barriers that make it hold across power loss, and it repays one careful read. Chapter 5 introduces the journal's modern sibling — write-ahead logging, which inverts the arrangement to buy concurrency — but the contract seen from outside is identical, and so is the operator's one obligation, which this glimpse makes concrete: **the sidecar files are part of the database**. A `-journal` (or, under WAL, a `-wal`) file sitting beside the estate is not litter to clean up; deleting it, or copying the main file without it, is how "atomic" becomes "corrupted" — the precise mistake chapter 7 teaches backup to avoid.

Transactions are units of meaning

Knowing that transactions group changes, the design question is *which* changes belong grouped, and the answer gives operators a tool the file-midden never offered: invariants. A transaction boundary should enclose exactly the set of statements that must be true *together* — that make no sense, or make a lie, if only some of them land. The register's previous book taught that a change without a printed verification is a rumor; the estate can now enforce a stronger form structurally. Suppose the discipline is that no change is recorded without its proof. Put both in one transaction, and a failure anywhere before the proof exists erases the claim as well:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE changes (id INTEGER PRIMARY KEY,
action TEXT, proof TEXT)")
db.commit()
try:
    with db:
        db.execute("INSERT INTO changes (action, proof)
VALUES ('edited sshd_config', NULL)")
        raise RuntimeError("verification probe failed") #
proof never obtained
except RuntimeError as e:
    print("caught:", e)
    print("half-recorded changes:", db.execute("SELECT count(*)
FROM changes").fetchone()[0])
    with db:
        db.execute("INSERT INTO changes (action, proof) VALUES
('edited sshd_config', 'sshd -t exit 0')")
    print("fully-recorded changes:", db.execute("SELECT count(*)
FROM changes").fetchone()[0])

caught: verification probe failed
half-recorded changes: 0
fully-recorded changes: 1
```

The failed attempt vanished — action and all — because the exception unwound the transaction before commit; the successful attempt landed whole. Notice what this does to the estate's epistemics: a changes row *cannot exist* in the action-recorded-but-unproven state, not because writers are disciplined but because the schema of commitment forbids it. (Whether an *unrecorded but performed* action can exist is the operator's conduct problem, and chapter 4's ledger pattern narrows it; no database can close it alone.) The design habit that follows is worth stating as a rule: **choose transaction boundaries by asking what a successor must never half-see**. A multi-row config change, a cursor advance paired with the processing it acknowledges, an artifact row paired with its hash — each is one transaction because each is one truth. The anti-pattern is equally shaped: transactions drawn around *convenience* (one per

function, one per loop iteration, one giant one around an hour's work) group statements by accident, and chapter 5 will add the concurrency reason why the giant sort is actively harmful.

The Python seam

Between the operator and the engine sits the `sqlite3` module, and its seams are where estates actually leak, so this section is blunt about them. The first seam is the one every newcomer meets the hard way — uncommitted work does not survive:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE facts (id INTEGER PRIMARY KEY, fact TEXT)")
db.execute("INSERT INTO facts (fact) VALUES ('this machine has 64 cpus')")
db.close()                                # ended without commit
db = sqlite3.connect("estate.db")
print("facts the successor inherits:", db.execute("SELECT count(*) FROM facts").fetchone()[0])
```

```
facts the successor inherits: 0
```

The fact was inserted, the statement succeeded, the process exited cleanly — and the successor inherits nothing, because under the module's default (legacy) transaction handling, that `INSERT` silently *opened* a transaction that nothing ever committed. (The table itself survived only because DDL under the legacy mode autocommits differently — an inconsistency that is itself an argument for what follows.) Closing, in SQLite semantics, resolves an open transaction by rolling it back: correct by the engine's lights, catastrophic by the operator's. Three disciplines close the seam. Prefer the context manager for every write — with `db`: commits on success and rolls back on exception, turning the previous section's invariant pattern into the path of least resistance. Know its one surprise: with `db`: does **not** close the connection, only ends the transaction; the estate connection can and should live across many such blocks. And on modern Python, consider declaring intentions explicitly — the module now offers an `autocommit` attribute whose explicit modes replace the legacy implicit-transaction behavior; the standard library documentation marks the legacy mode as the compatibility default, not the recommendation. Whichever mode an estate's tooling picks, it should pick *on purpose*, in one place, and write it down — chapter 3 gives estate metadata a table, and the connection discipline belongs in it.

The second seam is quieter: `executescript` issues an implicit `COMMIT` before running, and DDL's interaction with `open`

transactions has version-dependent subtleties — reason enough for a simpler rule that sidesteps the whole area: schema changes happen at estate-open time, alone, before any data transaction begins (chapter 3's migration pattern does exactly this), and data transactions never mix DDL in. Operators that keep the two phases separate never meet the subtleties at all.

Error reading completes the seam-sealing, because the module speaks in exception classes the way commands speak in exit codes, and the register's number-first discipline translates directly. `IntegrityError` is the schema talking: a constraint refused the write, the estate is *working* — chapter 3 will make these refusals load-bearing and chapter 4's idempotency pattern will treat one as an answer rather than a failure. `OperationalError` is the circumstances talking: locked, busy, missing table, read-only — conditions to diagnose, several of which chapter 5 converts to routine. `ProgrammingError` is the operator talking to itself: malformed SQL, wrong parameter counts — a composition bug, never retried, always fixed. And `DatabaseError`'s corruption face ("malformed") is chapter 7's department, met there with its own protocol. Catching broadly (except `Exception`) around estate writes collapses these four distinct sentences into one shrug — the transcript-mode operator's oldest sin, parsing prose instead of reading the channel built for machines — and the estate discipline is the same as the register's: catch the narrow class the logic actually answers, let the rest surface loudly, and record what surfaced.

Saying IMMEDIATE, and meaning it

The listings above wrote `BEGIN IMMEDIATE` where plain `BEGIN` would seem to do, and the difference deserves its own section because it is the first place concurrency intrudes on even a single operator's thinking. A plain (deferred) `BEGIN` acquires no lock at all: the transaction is notional until the first actual read or write, and — the sharp edge — a transaction that *reads first and writes later* acquires a read lock first and must upgrade to a write lock at the first write. If, between the read and the write, some other connection has begun its own write, the upgrade can find itself in a deadlock the engine resolves by refusing: database is locked, delivered not at `BEGIN`, where the operator was prepared to wait, but midway through the transaction's logic, where it was not. `BEGIN IMMEDIATE` takes the write intention out loud at the start: it acquires the write reservation up front, converting a mid-flight refusal into an at-entry wait — and an at-entry wait is exactly the shape the register's operators know how to handle, with a timeout and a bounded retry. The rule of thumb this book uses everywhere: **a transaction that will write says IMMEDIATE at BEGIN**. Read-only transactions stay deferred and cost nothing. Chapter 5

measures the contention behavior for real, two operators against one file; the habit is installed now because retrofitting it later means auditing every write site.

Reading is transactional too

Transactions entered this chapter as the writer's tool, and their quieter half belongs to readers. A report composed from several `SELECT`s — count the open intents, then sum the week's failures, then list the stale cursors — is implicitly claiming that its lines describe *one moment*. Run bare, each `SELECT` is its own instant, and a writer committing between them hands the report a world that never existed: the intent counted in line one resolved before line three listed it, and the totals disagree with the details. Nobody debugs this, because nothing errored; the report is simply, occasionally, incoherent — and an unattended operator publishing it into a handoff message is signing evidence with a torn timestamp. The cure is the same instrument pointed the other way: open a transaction, run every read the report needs, then end it. Inside, the reads share one consistent view (under WAL, chapter 5 shows this costs concurrent writers nothing at all), and the report's implicit claim becomes true. The habit is cheap to install — the estate's reporting queries live behind one function, the function wraps itself in a read transaction — and it retires a failure class whose signature (aggregates that almost agree) otherwise costs an afternoon the first time it is met. The register's rule about evidence blocks said every figure is measured fresh at the end; the estate's version adds: and all of them through one snapshot, so "the end" is a moment rather than a smear.

The price of a promise, and buying in bulk

Every `COMMIT` pays for its guarantee in the coin of chapter 1's register: real work at the storage layer — journal bookkeeping and, at full durability, sync barriers that wait for the disk. The cost is invisible at human scales and decisive at loop scales, which makes it exactly the kind of economics an unattended operator must know by feel rather than discover in production:

```
import sqlite3, time
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE readings (id INTEGER PRIMARY KEY, v
INTEGER)")
db.commit()
print("pragmas in effect:", db.execute("PRAGMA
journal_mode").fetchone()[0],
      "journal,", "synchronous", db.execute("PRAGMA
synchronous").fetchone()[0], "(FULL)")
t0 = time.monotonic()
for i in range(2000):
    with db:                                     # one
```

```

transaction per row
    db.execute("INSERT INTO readings (v) VALUES (?)",
(i,))
per_row_ms = (time.monotonic() - t0) * 1000
t0 = time.monotonic()
with db:
    # one
transaction for the whole batch
    for i in range(2000):
        db.execute("INSERT INTO readings (v) VALUES (?)",
(i,))
batched_ms = (time.monotonic() - t0) * 1000
print(f"2000 rows, 2000 commits: {per_row_ms:.0f} ms")
print(f"2000 rows, 1 commit: {batched_ms:.0f} ms")
print("rows landed:", db.execute("SELECT count(*) FROM
readings").fetchone()[0])

pragmas in effect: delete journal, synchronous 2 (FULL)
2000 rows, 2000 commits: 22 ms
2000 rows, 1 commit:    2 ms
rows landed: 4000

```

The listing prints its own configuration first, because the numbers mean nothing without it: this ran at the engine's *defaults* — the classic rollback journal (delete mode) and synchronous = FULL, the full durability setting chapter 2 counsels keeping — not under WAL (chapter 5) and not with sync weakened. That disclosure is the difference between a reproducible claim and a lucky transcript, because both figures below are dominated by exactly those two pragmas. An order of magnitude on the authoring machine — whose NVMe storage and write caching flatter the per-commit case enormously; on modest hardware with honest sync barriers the same experiment, at these same pragmas, runs seconds against milliseconds, and the engine's own FAQ answer on insertion speed explains why: a durable transaction cannot outrun the platter or the flash erase block it waits on. The design consequence is not "avoid commits" but the same boundary rule as before, read from the other side: since a transaction is a unit of meaning, *bulk work whose rows form one truth should arrive as one transaction* — an import, a scan's findings, a batch of samples — and the meaning rule and the economics rule converge on the same code. Where they genuinely diverge — a long stream of independent truths, each of which must be durable the moment it happens, as in the ledger the next chapters build — the per-commit price is not waste but the purchase of exactly what was promised, paid knowingly. What the economics forbid is only the unexamined middle: loops that commit per row out of habit, buying two thousand durability guarantees to record one batch nobody needed mid-batch.

Rehearsal inside the transaction

One more instrument completes the transactional toolkit, and it answers a shape of work the register's operators meet

constantly: the attempt that may not survive. A session's outer transaction holds the truths it is sure of; inside it, an exploratory step — try strategy A, and if its verification fails, fall back — needs an undo boundary of its own that does not forfeit the whole session. SQLite's savepoints are transactions-within-transactions built for exactly this:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE ledger (id INTEGER PRIMARY KEY,
entry TEXT)")
db.commit()
with db:
    db.execute("INSERT INTO ledger (entry) VALUES ('session
opened')")
    db.execute("SAVEPOINT attempt")
    db.execute("INSERT INTO ledger (entry) VALUES ('tried
strategy A')")
    strategy_a_worked = False
    if not strategy_a_worked:
        db.execute("ROLLBACK TO attempt")          # undo the
attempt, keep the session
        db.execute("RELEASE attempt")
        db.execute("INSERT INTO ledger (entry) VALUES ('used
strategy B instead')")
    for row in db.execute("SELECT id, entry FROM ledger"):
        print(row)

(1, 'session opened')
(2, 'used strategy B instead')
```

The failed attempt's row is gone; the session's opening row and the fallback survived, all inside one outer commit — and the id sequence (1 then 2, no gap in this run) is the successor's view of a history in which strategy A was never recorded as tried. Whether that erasure is *correct* is a design decision the pattern forces you to make explicitly, which is its second virtue: an operator whose discipline says failed attempts are themselves findings should record the failure as a fact — a committed row saying strategy A was tried and did not verify — rather than leaving it inside the savepoint to vanish. Rollback is for states that were never true; the ledger is for events that really happened, failures included. The savepoint gives you the mechanism for both readings and the obligation to choose between them, and the register's honesty rules, as usual, decide the default: when in doubt, the attempt happened, so the record stays.

Durability's fine print

One last honesty layer, because "committed" is doing load-bearing work in this chapter and its precise content should be on the table. What COMMIT promises against *process* death is absolute and was demonstrated above. What it promises against *power* death depends on the

synchronous pragma and, beneath that, on the storage stack telling the truth about flushes. At the default full setting, the engine issues the sync barriers its atomic-commit protocol requires, and a power cut yields either the before-state or the after-state — the documented guarantee, contingent (as the documentation itself is careful to say) on disks that do not lie about write completion. Operators tempted to trade this away will find `synchronous = off` delivers real speed and a real risk: a badly timed power loss can corrupt the database, not merely lose the last commit. The estate's position is conservative and simple: leave `synchronous` at its default; take the free and safe concurrency win of WAL mode when chapter 5 introduces it; and treat any tuning beyond that as requiring the engine documentation's own "how to corrupt" page read in full first — the page exists precisely because most corruption in the wild is operators defeating their own guarantees. The register's blast-radius chapter taught that safety is composition-time work; here, composition time is configuration time, and the correct composition is mostly to decline to compose.

What the transaction cannot promise

This chapter closes on the guarantee's honest boundary, because the estate's worst failures live just past it. The transaction makes the *record* atomic. It cannot make the record and the *world* atomic, and an operator's work is mostly in the world: the service restarted, the email sent, the file deleted. Between "the action happened" and "the row committed" there is always a gap — the process can die after acting and before recording, or after recording an intent and before acting on it — and no database on either side of the gap can close it, because the gap is between two systems that share no transaction. This is the estate's local edition of an old distributed-systems truth, and the register's previous book met its behavioral half in the blast-radius chapter's rule that a failed write is followed by a read. The estate adds the structural half: design the records so that the gap, when it happens, is *detectable and survivable* rather than silent.

Two patterns carry most of that weight, and both are schema patterns as much as conduct patterns. The first is intent-then-outcome. An operation that touches the world gets *two* writes: a committed row recording the intent before the action ("about to restart nginx, reason, timestamp"), and a second write recording the outcome after. A successor that finds an intent with no outcome knows exactly what it inherits: an action whose fate is unknown, to be resolved by reading the world — the service's actual state — before anything else proceeds. Compare the alternatives. Record-only-after-acting, and a death in the gap leaves an action that happened with no trace: the silent midden failure, back again. Record-only-intent, and the ledger fills

with plans indistinguishable from history. The two-write pattern costs one extra commit per world-action — the previous section priced it: cheap, and purchased for exactly the moment it pays.

The second pattern is the idempotency key, and it turns the estate into a guard against the retry accidents the register's operators are prone to by constitution. Give every world-action a stable identity — the operation's natural key, or a generated one carried in the task — and record it in a column with a UNIQUE constraint. A retried operator that attempts to record the same intent twice is refused by the schema itself, at which point the retry knows it is a retry — before touching the world a second time. The pattern converts "did I already send this?" from an unanswerable memory question into an INSERT whose failure *is* the answer. Chapter 4 builds it into the ledger schema properly; it is previewed here because it is transactional thinking applied at the design layer: the uniqueness constraint is a transaction boundary drawn around all time, not just around one session's statements — this action, ever, once.

The gap patterns also hand the estate's author a testing method worth naming, because transactional code has the classic property of working perfectly until the one moment it matters. The crash demonstration that opened this chapter — a child process killed mid-transaction by `os._exit` — is not just a teaching device; it is a reusable harness. Estate tooling of any seriousness gets kill-tested: the critical write paths run in a child, the child is killed at the awkward moments (after the intent, before the outcome; mid-migration; between action and record), and the parent then opens the estate and asserts the invariants this book has been accumulating — no half-recorded changes, version number honest, exactly one of intent-without-outcome or nothing. The harness costs twenty lines once and converts this chapter's promises from believed to *demonstrated on your own schemas* — which is, the reader will notice, precisely the relationship this press's gate has to this book's listings. Trust arrives the same way everywhere: something tried to break the claim, on the record, and failed.

Held together, the boundary reads like this. Inside the file, the transaction gives you *no unintended truths*. At the file's edge, intent-then-outcome gives you *no silent gaps* — every uncertainty is visible as an open intent. Across runs, idempotency keys give you *no accidental repeats*. None of the three is the others' substitute, and the estate needs all three precisely because its operators end without warning. That is the full shape of the promise; what remains is to write it down in tables a stranger can read.

A note on scope keeps the three-guarantee summary honest

for the reader building multi-file arrangements: the transaction's boundary is the database it runs in. Two estates changed "together" by one session are two transactions, with the gap between them exactly as real as the world-gap above — one more argument for chapter 5's one-estate-per-lineage default, and, where a split is genuinely earned, for treating cross-file consistency by the same intent-then-outcome bookkeeping rather than by hoping the two commits land as one. (The engine can in fact join attached databases under a single atomic commit in most configurations, but the estate declines to lean on machinery its operators would have to verify per-setup; patterns that assume the gap survive every setup.)

The transaction, then: all-or-nothing against crashes, demonstrated; mechanics visible on disk; boundaries drawn by meaning; the Python seams sealed; write intent declared at entry; durability's contingencies stated. One promise, carefully kept, and the estate stops being a pile of bytes and becomes a place where truths can be deposited. What gets deposited, and in what shape a stranger can inherit — that is schema, and it is the next chapter.

Chapter 3 — Schema Is the Handoff

Draft status: author draft, gate-checked; human verification pending. Outputs are real transcripts from the authoring machine.

The stranger at the door

Whoever next opens the estate — tomorrow's session, a different tool, a human with a database browser, some future model that does not exist yet — arrives knowing nothing except what the file itself can teach. There will be no walkthrough, no chat with the author, no institutional memory; the register's operators do not get onboarding. Every hope of a good handoff therefore rests on one artifact: the schema. A schema is usually described as the structure data is stored in, which is true and misses the point that matters here. For the amnesiac's estate, the schema is *the documentation that executes* — the one description of the data that cannot drift from the data, because the engine enforces it on every write. Prose documentation describes what writers intended; schemas constrain what writers could do. A stranger can trust the second kind without trusting anyone.

This chapter is therefore written as a craft of hospitality: every choice — types, constraints, provenance columns, versioning, naming — is judged by what it tells or guarantees to a reader who was not there. The test to hold throughout is concrete: *could a competent stranger, given only the file, reconstruct what each table means, how much to trust each row, and how the whole thing has changed over its life?* Each section below closes one gap between today's estates and a yes.

Types that mean it

The first surprise SQLite deals a newcomer is that, by historical default, its column types are suggestions. The engine's "flexible typing" — documented candidly in its datatype and quirks pages — declares a column's type an *affinity*, a preference the engine will try to honor and cheerfully override when a value disagrees:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE loose (host TEXT, cpus INTEGER)")
db.execute("INSERT INTO loose VALUES (42, 'sixty-four')") #
both wrong, both accepted
db.execute("CREATE TABLE strict (host TEXT, cpus INTEGER)
STRICT")
```

```
try:
    db.execute("INSERT INTO strict VALUES ('RogGentoo',
'sixty-four')")
except sqlite3.IntegrityError as e:
    print("strict refused:", e)
print("loose table holds:", db.execute("SELECT host, cpus
FROM loose").fetchone())
```

```
strict refused: cannot store TEXT value in INTEGER column
strict.cpus
loose table holds: ('42', 'sixty-four')
```

The loose table accepted a numeric host name and a spelled-out CPU count without a murmur, and will hand them to every future reader who asked, by reading the schema, for text and an integer. In an application with a single disciplined writer this laxity is survivable; in an estate written by generations of operators — some of them language models assembling INSERT statements from prose — it is a slow poison, because every reader must now defend against every past writer's accidents. The cure costs seven characters: the **STRICT** table option, added to the language in 2021 precisely for schemas that mean what they say, makes the declared type a contract and a violating write an error at the write site — where the operator that caused it is still present to read the refusal, instead of at the read site months later, where nobody is. This book's rule needs no nuance: **every estate table is STRICT**. The loose demonstration above is the last non-STRICT table in it.

Two consequences of STRICT deserve a sentence each. Declared types must come from the engine's real repertoire (INT, INTEGER, REAL, TEXT, BLOB, ANY) — the compatibility aliases that flexible typing tolerated are refused, which is itself documentation-by-enforcement. And where a column legitimately holds mixed types — rare, but real — ANY declares that honestly, telling the stranger "expect anything here" instead of lying with a specific type the engine will not police.

Constraints: the rules that outlive their authors

Types police form; constraints police meaning, and they are where the estate's discipline stops being conduct and becomes structure. Chapter 2 established the invariant "no change recorded without its proof" by transaction shape — a discipline each writer must remember. A CHECK constraint moves it into the schema, where no writer can forget it:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("""
CREATE TABLE tasks (
```

```

id INTEGER PRIMARY KEY,
title TEXT NOT NULL CHECK (length(title) > 0),
status TEXT NOT NULL DEFAULT 'open'
CHECK (status IN ('open', 'blocked', 'done',
'abandoned')),
proof TEXT,
CHECK (NOT (status = 'done' AND proof IS NULL))
) STRICT
"""
db.execute("INSERT INTO tasks (title) VALUES ('rotate backup
credentials')")
try:
    db.execute("UPDATE tasks SET status = 'done' WHERE id =
1")
except sqlite3.IntegrityError as e:
    print("refused:", e)
db.execute("UPDATE tasks SET status = 'done', proof =
'restore drill passed 2026-08-28' WHERE id = 1")
print(db.execute("SELECT title, status, proof FROM
tasks").fetchone())

refused: CHECK constraint failed: NOT (status = 'done' AND
proof IS NULL)
('rotate backup credentials', 'done', 'restore drill passed
2026-08-28')

```

Read the refused UPDATE as the stranger will read the schema: this estate does not contain finished tasks without evidence, and that is not a hope, it is a property. Each constraint in the table is doing double duty. NOT NULL and the non-empty check on title refuse the classic degradation of ledgers into rows of placeholders. The status IN (...) enumeration is the poor operator's enum, and more: it is the complete, machine-readable list of states this workflow admits — a stranger learns the lifecycle without a wiki. The table-level CHECK encodes the proof invariant. And every one of these rules will still be enforced, verbatim, on writers not yet written, running models not yet trained, years after the author-session that chose them ended. Constraints are the only documentation with that property, which is why the estate spends them generously — while respecting their limit: a CHECK sees only its own row. Cross-row truths (uniqueness, references) have their own instruments, one of which comes with a trap.

The referential switch everyone forgets

Foreign keys — the declaration that a `findings.run_id` must name a real row in `runs` — are the cross-table constraint estates lean on constantly, and SQLite ships them **off**. The syntax parses, the schema records the intention, and by historical default nothing is enforced:

```

import sqlite3
db = sqlite3.connect("estate.db")
db.executescript("""

```

```

CREATE TABLE runs (id INTEGER PRIMARY KEY, started_at TEXT);
CREATE TABLE findings (id INTEGER PRIMARY KEY, run_id INTEGER
REFERENCES runs(id), note TEXT);
""")
db.execute("INSERT INTO findings (run_id, note) VALUES (999,
'orphan')") # run 999 never existed
print("orphans accepted by default:", db.execute("SELECT
count(*) FROM findings").fetchone()[0])
db.execute("PRAGMA foreign_keys = ON")
try:
    db.execute("INSERT INTO findings (run_id, note) VALUES
(998, 'another orphan')")
except sqlite3.IntegrityError as e:
    print("with the pragma:", e)

orphans accepted by default: 1
with the pragma: FOREIGN KEY constraint failed

```

The quirks documentation owns this frankly as a compatibility fossil: turning enforcement on by default would break decades-old applications, so every new connection starts with it off, and `PRAGMA foreign_keys = ON` must be issued *per connection* — not once per database, which is the misunderstanding that produces estates that were protected on Tuesdays. The operational consequence is a ritual this book now installs and never abandons: estates are opened by one function, and that function issues every connection-scoped pragma the estate depends on — foreign keys here, and the busy timeout and WAL that chapter 5 will justify, all set in one place before any work begins. Scattered `sqlite3.connect()` calls throughout a codebase are how one forgotten switch quietly waives the constraints everywhere; a single `open_estate()` is how a decision is made once. The migration listing below *is* that function, because the open ritual and versioning belong together — and because the pragmas it sets are the same ones chapter 5's covenant names, the function you copy here already carries chapter 5's concurrency guarantees, not this chapter's alone.

Born versioned

Schemas change — a column proves missing, a pattern from chapter 4 gets adopted, an index earns its keep — and the estate must survive its own evolution across operators who cannot be gathered for a migration party. The mechanism is small enough to read whole. The database carries its own version number (SQLite reserves `PRAGMA user_version`, an integer stored in the file header, for exactly this); the code carries an append-only list of migrations; opening the estate applies whatever the file has not yet seen:

```

import sqlite3
MIGRATIONS = [
    (1, "CREATE TABLE facts (id INTEGER PRIMARY KEY, fact
TEXT NOT NULL) STRICT"),

```

```

    (2, "ALTER TABLE facts ADD COLUMN source TEXT NOT NULL
DEFAULT 'unrecorded'"),
    (3, "CREATE INDEX facts_source ON facts(source)",
]
def open_estate(path):
    db = sqlite3.connect(path)
    db.execute("PRAGMA busy_timeout = 5000")      # wait for
the write slot (chapter 5)
    db.execute("PRAGMA journal_mode = WAL")      # readers
and writers stop blocking (chapter 5)
    db.execute("PRAGMA synchronous = NORMAL")    # the
documented WAL sweet spot (chapter 5)
    db.execute("PRAGMA foreign_keys = ON")      # enforce
references, and per connection
    applied = db.execute("PRAGMA user_version").fetchone()[0]
    for version, ddl in MIGRATIONS:
        if version > applied:
            with db:
                db.execute(ddl)
                db.execute(f"PRAGMA user_version =
{version}")
            print(f"applied migration {version}")
    return db
db = open_estate("estate.db"); db.close()
print("reopening...")
db = open_estate("estate.db")
print("schema version now:", db.execute("PRAGMA
user_version").fetchone()[0])

applied migration 1
applied migration 2
applied migration 3
reopening...
schema version now: 3

```

The second opening applied nothing — the file said 3, the list said 3, done — and that idempotence is the whole trick: any operator, any generation, opening any vintage of the estate, arrives at the same schema, and a fresh file builds itself from nothing by the same path. Three rules keep the mechanism honest. Migrations are *append-only*: a shipped migration is history, and fixing a bad one means appending a corrective, never editing the past — the same no-history-rewrites covenant this book's own publisher enforces on manuscripts, for the same reason (someone already built on the past). Each migration runs in its own transaction with the version bump inside it, so a crash mid-migration leaves the file honestly at the old version, ready to retry, never half-moved. And migrations are pure DDL applied at open, before any data work — chapter 2's separation of schema phase from data phase, now with an address. (SQLite's ALTER TABLE is deliberately minimal — add, rename, drop; no type changes — and the documentation's sanctioned workaround for bigger reshapes — the twelve-step build-new, copy, swap procedure detailed later in this chapter — is chapter 5's atomic-replace instinct applied to tables. Design so you rarely need it; the migration list makes even that reshaping a recorded, replayable event.)

The estate's value conventions

Between types and constraints sits a layer of conventions the schema cannot fully enforce but the stranger must be able to assume, and stating them once — in the estate's own documentation table or its schema comments — spares every future writer a private decision and every future reader a private guess. Dates and times: SQLite has no datetime type; the engine stores what you give it and supplies functions for several representations. The estate's convention is the one both prior chapters already used — TEXT, UTC, ISO-8601, seconds precision, trailing Z — because it sorts as text, compares as text, reads without conversion, and joins across estates without timezone archaeology; a CHECK (length(recorded_at) = 20) pins the shape cheaply where drift would hurt. Booleans: INTEGER 0 and 1, with a CHECK constraining to those two, since SQLite's own quirks page notes the keywords are mere aliases. Numbers that are really identifiers — ports, PIDs, version strings — stay TEXT, because arithmetic on them is always a bug and leading zeros have died for less.

Two lower-level conventions complete the set, each a sentence of policy against an hour of future confusion. Text is UTF-8, always — the engine stores what it is handed, Python hands it UTF-8, and the estate declares the encoding in its info table so no future tool guesses; the one encoding accident worth naming is bytes-that-are-not-text, which belong in BLOB columns honestly rather than in TEXT columns hopefully. And REAL is for measurements, never for money or counts-of-things: floating point is the right shape for a CPU temperature and the classic wrong shape for anything that must sum exactly, where the convention is integers in the smallest unit (cents, bytes, milliseconds) with the unit in the column name or its comment — duration_ms INTEGER, self-documenting at every read site. Both rules exist in every database tradition; they are restated here because estates are written by operators assembling schemas at 3 a.m. from prose intentions, which is exactly when a stated convention outperforms a remembered one.

The schema can also *compute* for its writers. Beyond the DEFAULT expressions the provenance block already leans on, generated columns — GENERATED ALWAYS AS (expression) — derive a value from the row's other columns, kept current by the engine itself: a year column generated from recorded_at for cheap grouping, a normalized lowercase key generated from a mixed-case source, a size bucket derived from a byte count. The estate's use for them is the same as for defaults: moving invariants out of writer discipline and into structure, so that a value which *must* track another value cannot be updated into disagreement by a forgetful session. The restraint that keeps them honest: generated columns derive,

they never import — an expression reaching beyond its own row (dates "now", random values, subqueries) is a trap the syntax mostly forbids and the design rule finishes: derivation is structure, acquisition is a writer's act, and the provenance block exists to record the second.

NULL deserves its own paragraph, because it is the one value that behaves differently from every intuition text formats build, and estates use it deliberately (chapter 4's "fate unknown"). NULL is not zero, not empty string, and — the sharp edge — not equal *or unequal* to anything, which makes it invisible to comparisons that feel exhaustive:

```
```python no-run import sqlite3 db =
sqlite3.connect(":memory:") db.execute("CREATE TABLE t
(host TEXT, env TEXT)") db.executemany("INSERT INTO t
VALUES (?,?), [("web-1","prod"), ("web-2","staging"),
("web-3", None)]) print("hosts where env != 'staging':",
db.execute("SELECT host FROM t WHERE env !=
'staging').fetchall()) print("with NULL handled: ",
db.execute("SELECT host FROM t WHERE env IS DISTINCT
FROM 'staging').fetchall())
```

```
```output
hosts where env != 'staging': [('web-1',)]
with NULL handled:          [('web-1',), ('web-3',)]
```

The host with no recorded environment vanished from a query that asked, in plain English, for everything that is not staging — because NULL != 'staging' is neither true nor false, and WHERE keeps only true. Three-valued logic is not a flaw to route around but the correct semantics for "unknown"; the operator's obligations are two. Query with the NULL-aware forms when unknowns must be included (IS NULL, IS DISTINCT FROM, coalesce). And constrain NULL to mean exactly one thing per column — chapter 4's ledger allows it in outcome *as* the fate-unknown marker and forbids it everywhere meaning would blur, which is the general rule: a nullable column is a column whose NULL has a documented reading, and any other nullable column is a guess someone deferred.

Migrations that move data

The migration list shown above contains only structure, and most migrations are structural — but the honest catalog includes the other kind, because sooner or later a migration must *reshape rows*: backfill a new column from an old one's contents, split a field, normalize a unit. The mechanism needs no extension — a migration entry is SQL, and UPDATE is SQL — but the discipline tightens in three ways. A data migration states its scope in a WHERE clause exactly as the previous volume's edits anchored their sed patterns, and rehearses as a SELECT count of that scope before shipping

(the dry-run doctrine, unchanged). It remains inside the migration's transaction, so a failure mid-backfill leaves the version number honestly unmoved. And it never destroys its input in the same migration that derives from it — the old column survives until a later migration retires it, one version after the new column has been read in anger. For reshapes beyond ALTER TABLE's deliberate minimalism — type changes, constraint additions to existing columns, a PRIMARY KEY or UNIQUE added after the fact — the engine's documentation prescribes not a one-liner but a precise *twelve-step* procedure, and the steps that a casual "create-copy-drop-rename" omits are exactly the ones that bite an estate whose open ritual enforces foreign keys. Foreign-key enforcement must be turned **off** for the duration (the rebuild drops and recreates a table other rows may reference); the old table's indexes, triggers, and views must be remembered before the drop and recreated after the rename (they do not follow the data across); and PRAGMA foreign_key_check must run before the commit to prove nothing was orphaned. Order matters most of all: the new table is built under a *new* name and renamed into place — never the old one renamed out of the way first, which (since SQLite 3.25/3.26 carries renames into triggers, views, and FK references) can corrupt exactly those references. The documentation draws the correct and incorrect orderings side by side; the estate follows the correct one, inside one transaction, as a recorded migration:

```
```python fragment
```

## The sanctioned table rebuild — the ALTER TABLE documentation's twelve steps

([https://sqlite.org/lang\\_altertable.html](https://sqlite.org/lang_altertable.html) §8), run as one migration entry:

**PRAGMA foreign\_keys = OFF;  
# (1) FKs off for the rebuild**

**BEGIN; # (2) one transaction**

**# (3) remember what to  
recreate in step (8):**

**# SELECT type, sql FROM  
sqlite\_schema WHERE  
tbl\_name = 'facts';**

**CREATE TABLE facts\_new  
(...corrected shape...) STRICT;  
# (4) NEW name**

**INSERT INTO facts\_new  
SELECT ...transformed...  
FROM facts;# (5) copy**

**DROP TABLE facts; # (6)**

**ALTER TABLE facts\_new  
RENAME TO facts; # (7)  
rename new -> old**

**# (8) recreate the saved  
indexes/triggers/views on  
facts**

## # (9) recreate any external views that referenced facts

**PRAGMA foreign\_key\_check; # (10) verify no orphans**

**COMMIT; # (11)**

**PRAGMA foreign\_keys = ON; # (12) re-enable enforcement**

A reshape is the most invasive act an estate performs on itself, which is why it lives in the migration list – versioned, transactional, replayed identically by every opener – rather than in any session's ad-hoc hands. Because ``open_estate()`` opens with foreign keys `*on*`, a rebuild migration is the one place that toggles them off and back within its own transaction, restoring the ritual's invariant the moment it commits. The stranger's guarantee survives even this: whatever generation of the schema they open, the road from there to current is recorded, ordered, and runs itself.

## Indexes: the reader's courtesy

The stranger inherits not only meanings but `*costs*`, and one more schema instrument decides whether the estate's questions stay cheap as it grows. A table is, physically, rows in row order; a query that filters on anything else must, absent help, examine every row. The help is an index, and the engine will tell you – before any harm is done – whether a given question has one, through a statement every estate author should reflexively use:

```
```python
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE facts (id INTEGER PRIMARY KEY,
subject TEXT NOT NULL, fact TEXT NOT NULL) STRICT")
with db:
```

```

db.executemany("INSERT INTO facts (subject, fact) VALUES
(?, ?)",
               [(f"host-{n % 50}", f"observation {n}")
                for n in range(5000)])
q = "SELECT count(*) FROM facts WHERE subject = 'host-7'"
print("before:", db.execute("EXPLAIN QUERY PLAN " +
q).fetchone()[3])
db.execute("CREATE INDEX facts_subject ON facts(subject)")
print("after: ", db.execute("EXPLAIN QUERY PLAN " +
q).fetchone()[3])
print("answer:", db.execute(q).fetchone()[0])

```

```

before: SCAN facts
after:  SEARCH facts USING COVERING INDEX facts_subject
(subject=?)
answer: 100

```

SCAN is the plan that reads everything; SEARCH ... USING INDEX is the plan that walks straight to the hundred matching rows among five thousand. At five thousand rows the difference is microseconds and nobody cares; the reason the habit matters is that estates *age*, and the queries written today run against the table sizes of years hence, by operators who will experience a missing index not as a design gap but as "the estate got slow" — a diagnosis away from the cause. The register's two-question test settles what to index: whatever columns the estate's *standing questions* filter or join on — subject here, recorded at for every retention and staleness query, foreign-key columns on the many side. And the cost side stays honest: each index is paid for on every write, which at operator scales is negligible and at bulk-import scales is exactly why the migration list creates indexes *after* chapter 4's patterns settle what the standing questions are. EXPLAIN QUERY PLAN is the audit that keeps both sides truthful — the estate's equivalent of the register's dry run, asking the engine what it *would* do while everything is still cheap.

Shapes that mislead strangers

Hospitality also means declining certain shapes that schemas admit but strangers regret. Three recur in operator estates often enough to name. The JSON blob column — a TEXT field holding a serialized object — reintroduces the midden *inside* the database: unqueryable without unpacking, unconstrainable by CHECK in any depth, invisible to STRICT. SQLite's JSON functions make blobs tolerable at the edges (a genuinely irregular payload, kept whole for fidelity, with the *queried* fields lifted out into real columns beside it), and the discipline is that lift: anything a standing question touches gets a column; the blob is an artifact, not a record. The attribute-soup table — (entity, attribute, value) triples, endlessly flexible — trades every guarantee this chapter built for schema-free convenience: no types, no CHECKs, no meaningful constraints, and every real query a self-join puzzle. It is the shape estates reach for when their authors

have not yet decided what they are recording; the decision, not the soup, is the work. And the wide-null table — one row type wearing forty mostly-NULL columns because several distinct kinds of record were crowded into one table — fails the stranger at the first question ("which columns apply to which rows?") that the schema, its one job, can no longer answer. Each anti-shape has the same cure: tables that hold one kind of thing, named for it, with the columns that kind actually owes — which is chapter 4's whole agenda.

The columns every record owes the future

With types strict, constraints meaningful, references enforced, and birth versioned, what remains is the estate's signature habit, promised since chapter 1: no fact without its papers. Concretely, record tables carry a provenance block — `recorded_at`, defaulted by the schema to UTC ISO-8601 from the engine's own clock so no writer can forget or localize it; `recorded_by`, required, naming the operator (session, script, model — whatever identity the successor can act on); and `source`, required, naming where the fact came from — a file path, a URL, a command, a transcript reference. The choice of TEXT ISO-8601 over numeric epochs is deliberate hospitality: it sorts correctly as text, reads correctly to humans and models without conversion, and survives tool changes — the register book's determinism rule, applied to storage. The stranger's payoff compounds: any row can be weighed (how old? whose claim? from what evidence?), re-verified (follow `source`), or aged out (chapter 8's retention queries key on `recorded_at`). And the discipline prices honesty correctly on the write side too — an operator that cannot fill `source` is holding a rumor, and the schema just asked it to notice that before the rumor entered the record.

One last hospitality note, almost free and almost never used: SQL comments survive. SQLite stores the literal text of every CREATE statement and returns it verbatim to any tool that asks, so a comment written in the schema — explaining a constraint's reason, a column's unit, a status's meaning — is carried inside the database file itself, readable forever. The proof, on a table chapter 4 will need anyway:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("""
CREATE TABLE cursors (
    stream TEXT PRIMARY KEY,          -- what is being read
    (journal unit, feed URL, log path) -- opaque resume token;
    position TEXT NOT NULL,
    meaning belongs to the stream
    advanced_at TEXT NOT NULL        -- UTC; staleness is the
    reader's first question
) STRICT
```

```

""")
print(db.execute("SELECT sql FROM sqlite_schema WHERE name =
'cursors').fetchone()[0])

CREATE TABLE cursors (
    stream TEXT PRIMARY KEY,          -- what is being read
    (journal unit, feed URL, log path)
    position TEXT NOT NULL,          -- opaque resume token;
    meaning belongs to the stream
    advanced_at TEXT NOT NULL        -- UTC; staleness is the
    reader's first question
) STRICT

```

The comments came back byte-for-byte, from the file, years-proof: the `sqlite_schema` table every database carries is the estate describing itself, and any stranger's first query. The estate's tables should be written like the drop-in files of the register book: opening with two lines that say why they exist and who put them there — except here, the note and the structure it explains travel in the same artifact and cannot be separated. A schema written this way is not described by its documentation. It *is* its documentation, enforced where it can be, explained where it cannot.

One table completes the self-description, and every estate should carry it from birth: the info table — plain key-value rows naming what no column can. What this estate is for, in a sentence. Which operator lineage owns it. Where its conventions are written (this book's, or the successor document that supersedes it). Where its backups land. Who the supervising human is. Five to ten rows, written once, maintained on change — the estate's title page, and the answer to the one question the briefing of chapter 8 cannot compute: *what am I looking at?* The previous volume put this note in a drop-in file's opening comments; the estate puts it where nothing can separate it from the data it explains.

The handoff review, in nine questions

The chapter compresses to a checklist an author can run against any estate schema — its own, or an inherited one being judged. Each question maps to a section above.

1. Is every table STRICT, with types from the real repertoire?
2. Does every enumerable column enumerate (CHECK ... IN), and every invariant that spans columns have its table-level CHECK?
3. Does the one shared open ritual issue every connection-scoped pragma — `foreign_keys = ON`, `busy_timeout`, `journal_mode = WAL`, `synchronous = NORMAL` — and is there exactly one open ritual?
4. Does the file carry its version, and does opening apply an append-only migration list idempotently, DDL alone, one

- transaction per step?
5. Do all record tables carry the provenance block — recorded_at (UTC ISO, defaulted), recorded_by, source — with NULL meanings documented?
 6. Are the value conventions (dates, booleans, identifiers) stated once and pinned by CHECK where drift would hurt?
 7. Does every standing question have its index, and has EXPLAIN QUERY PLAN confirmed it?
 8. Are the anti-shapes absent — queried fields inside JSON blobs, attribute soup, wide-null crowding?
 9. Could the stranger answer "what is this?" from the file alone — schema comments present, info table filled?

Nine yeses is a schema that will survive its authors, which is the only kind worth writing. What the stranger does next — the shapes of the tables an operator actually keeps — is chapter 4.

Chapter 4 — The Ledger Pattern and Friends

Draft status: author draft, gate-checked; human verification pending. Outputs are real transcripts; the dead run in the registry listing is a real mid-task process death.

Five shapes, most of memory

Operator memory feels endlessly various until you sort a few months of it, at which point it collapses into a handful of recurring shapes. Things done. Places reached in streams being read. Choices made and revised. Sessions begun and ended. Files fetched or produced. This chapter gives each shape its table — the ledger, the cursor, the config history, the run registry, the artifact index — worked as running code with the chapter 3 disciplines already applied. They are patterns, not a framework: no library to adopt, no dependency to carry, just shapes to copy and adapt, which for estates meant to outlive their tooling is a feature and not a modesty. Each section states the shape's contract — what it promises a successor — because the contract, not the columns, is what makes a pattern transferable.

A word on how the five relate before meeting them singly. The run registry is the spine: everything else that happens, happens *during* some run, and rows elsewhere carry the run's id so the estate can answer "what else did the session that did this also do?" — the question incident reviews are made of. The ledger records the runs' outward acts; the cursor and config tables record their resumable inward state; the artifact index binds the file system's holdings into the same web of provenance. One estate, five tables, joined — the composition section at the end runs the queries that only the joined whole can answer.

The ledger: things done, once, with their fates

The estate's centerpiece is the pattern chapter 2 previewed twice, now assembled. A ledger row is an *operation with a fate*: what was to be done, proof it was decided (the intent, committed before acting), and what became of it (the outcome, committed after). The idempotency key makes the row a guard as well as a record:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("""
CREATE TABLE ledger (
    id INTEGER PRIMARY KEY,
```

```

    op_key TEXT NOT NULL UNIQUE,          -- idempotency key: this
operation, ever, once
    action TEXT NOT NULL,
    intent_at TEXT NOT NULL DEFAULT
(strftime('%Y-%m-%dT%H:%M:%SZ', 'now')),
    outcome TEXT,                        -- NULL = fate unknown;
successor must resolve
    outcome_at TEXT,
    run_id INTEGER REFERENCES runs(id),  -- the run that owns
this act (composition, below)
    CHECK ((outcome IS NULL) = (outcome_at IS NULL)) --
outcome and its time arrive together, or neither does
) STRICT
"""
)
with db:
    db.execute("INSERT INTO ledger (op_key, action) VALUES
(?, ?)",
                ("restart-nginx-2026-08-28", "systemctl
restart nginx"))
with db:
    db.execute("""UPDATE ledger SET outcome = 'is-active
reported active',
                outcome_at =
strftime('%Y-%m-%dT%H:%M:%SZ', 'now') WHERE op_key = ?""",
                ("restart-nginx-2026-08-28",))
try:
    with db:
        db.execute("INSERT INTO ledger (op_key, action)
VALUES (?, ?)",
                    ("restart-nginx-2026-08-28", "systemctl
restart nginx"))
except sqlite3.IntegrityError:
    print("retry recognized: this operation is already in the
ledger")
print(db.execute("SELECT op_key, outcome FROM
ledger").fetchone())

retry recognized: this operation is already in the ledger
('restart-nginx-2026-08-28', 'is-active reported active')

```

The contract, spelled out. Every world-touching act appears here before it happens, so a successor never inherits invisible history. A NULL outcome is a promise of honesty, not a gap: it marks exactly the operations whose fate must be resolved by reading the world, and WHERE outcome IS NULL is the successor's first ledger query. For that marker to stay trustworthy the two outcome columns must move as a unit, which is what the paired CHECK — (outcome IS NULL) = (outcome_at IS NULL) — enforces: both filled (a resolved fate with its timestamp) or both NULL (a clean fate-unknown row), never the nonsense middle of an outcome time hanging beside a missing outcome, which would make WHERE outcome IS NULL and "is this resolved?" disagree. (A one-sided check — forbidding only outcome-without-time — leaves that middle open; the equality closes both sides at once.) The UNIQUE refusal is the pattern's quiet triumph — the retried operator in the listing learned it was a retry from the schema, at insert time, *before* running the restart again. And

the discipline that keeps all this true is append-and-complete: intent rows are inserted, their outcome fields are completed, and nothing is ever deleted or rewritten — corrections are new rows referencing old ones, the same append-only covenant the register's book demanded of ledgers in prose, now held by habit and CHECK together.

Two design notes earn their space. The `op_key` is chosen, not generated, when the operation has a natural once-ness — "rotate credentials for host X during window W" — and generated (and stored with the task that carries it) when it does not; what matters is that the key's scope match the once-ness you mean, which is a decision the pattern forces into the open. And the action column records the *command as composed*, because the successor auditing an incident wants what was actually dispatched — the register's exact-transcripts rule, applied to memory.

The cursor: where reading stopped

The second shape is the one this book's own predecessor kept in a flat file and called a bookmark: for any stream consumed incrementally — a journal, a feed, a log directory, an API's paginated history — the estate records how far reading got, so the next session reads only what is new. The cursors table from chapter 3 gets its writer, the upsert:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("""CREATE TABLE cursors (stream TEXT PRIMARY KEY,
position TEXT NOT NULL,
                advanced_at TEXT NOT NULL DEFAULT
(strftime('%Y-%m-%dT%H:%M:%SZ', 'now'))) STRICT""")
def advance(stream, position):
    with db:
        db.execute("""INSERT INTO cursors (stream, position)
VALUES (?, ?)
                        ON CONFLICT(stream) DO UPDATE SET
                        position = excluded.position,
                        advanced_at =
excluded.advanced_at""", (stream, position))
        advance("journal:nginx.service", "cursor=s=abc;i=44f0")
        advance("journal:nginx.service", "cursor=s=abc;i=4512")
        print(db.execute("SELECT stream, position FROM
cursors").fetchall())
        print("rows:", db.execute("SELECT count(*) FROM
cursors").fetchone()[0])

[('journal:nginx.service', 'cursor=s=abc;i=4512')]
rows: 1
```

One row per stream, always current, atomically replaced — the upsert (INSERT that becomes UPDATE on key conflict) is the exact tool for state whose history does not matter, and

the listing's second call landing as an update, not a second row, is the semantics on display. The contract has three clauses worth enforcing by convention. Positions are *opaque*: the cursor stores whatever resume token the stream's own tooling emits — a journal'd cursor string, an HTTP ETag, a line offset — and no consumer ever parses it, so streams can change their token format without breaking the estate. Advancement is *transactional with processing*: the cursor moves in the same transaction that records what was done with the new entries (chapter 2's units-of-meaning rule; a cursor advanced before its entries are handled is data loss wearing a bookmark). And staleness is *the reader's first question*: `advanced_at` exists so a successor can distinguish a stream read minutes ago from one abandoned in June — the difference between resuming and re-validating.

Configuration with a memory

Operators make choices — polling intervals, thresholds, target lists — and the midden stores them as bare current values, which answers "what is the setting?" and is mute before the questions that actually arise: what was it before, who changed it, and *why*? The estate stores configuration as history and derives the present from it:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.executescript("""
CREATE TABLE settings (
    id INTEGER PRIMARY KEY,
    key TEXT NOT NULL,
    value TEXT NOT NULL,
    set_at TEXT NOT NULL DEFAULT
(strftime('%Y-%m-%dT%H:%M:%SZ', 'now')),
    set_by TEXT NOT NULL,
    reason TEXT NOT NULL,
    run_id INTEGER REFERENCES runs(id) -- the run that made
this change (composition, below)
) STRICT;
CREATE VIEW settings_current AS
    SELECT key, value, set_at, set_by, reason FROM settings s1
    WHERE id = (SELECT max(id) FROM settings s2 WHERE s2.key =
s1.key);
""")
rows = [("poll_interval", "300", "author-session",
"default"),
        ("poll_interval", "60", "author-session", "expedite
request 2026-08-28"),
        ("retention_days", "90", "author-session",
"default")]
with db:
    db.executemany("INSERT INTO settings (key, value, set_by,
reason) VALUES (?, ?, ?, ?)", rows)
    print("current:", db.execute("SELECT key, value FROM
settings_current ORDER BY key").fetchall())
    print("history of poll interval:",
        db.execute("SELECT value, reason FROM settings WHERE
```

```
key='poll_interval' ORDER BY id").fetchall())
```

```
current: [('poll_interval', '60'), ('retention_days', '90')]
history of poll_interval: [('300', 'default'), ('60',
'expedite request 2026-08-28')]
```

The mechanics are two ideas stacked. Writes are pure appends — nothing UPDATES, so no choice is ever erased by the next one — and the *view* derives the current value as "the latest row per key", giving every consumer a table that reads exactly like the flat config it replaced. (Views are the estate's politeness layer generally: a stored query wearing a table's name, letting the schema serve the stranger's common questions pre-composed.) The required reason column is the pattern's soul, and it is required precisely because it is what nobody records voluntarily. Every debugging session that ever ended with "who set this to 60?!" was mourning this column. The row that answers it here — an expedite request, dated, attributed — is this book's own production history, recorded the way the pattern demands.

The run registry: sessions and their ends

The fourth shape records the operators themselves. A run row marks a session's birth (operator identity, task, start time) and — completed at exit, honestly — its end and outcome. Its power is what *incomplete* rows mean. Because the start is committed at startup and the end only at a clean exit, a row with `ended_at` NULL whose operator is no longer alive is a session that died mid-work, and the registry makes that inheritance visible instead of archaeological. Demonstrated with a genuinely killed run:

```
import sqlite3, subprocess, sys
db = sqlite3.connect("estate.db")
db.execute("""
CREATE TABLE runs (
    id INTEGER PRIMARY KEY,
    operator TEXT NOT NULL,
    task TEXT NOT NULL,
    started_at TEXT NOT NULL DEFAULT
(strftime('%Y-%m-%dT%H:%M:%SZ', 'now')),
    ended_at TEXT,
    outcome TEXT CHECK (outcome IN ('ok', 'failed', 'abandoned'))
OR outcome IS NULL)
) STRICT
""")
db.commit(); db.close()
child = ''
import sqlite3
db = sqlite3.connect("estate.db")
with db:
    db.execute("INSERT INTO runs (operator, task) VALUES
('session-77', 'rotate logs')")
import os; os._exit(1) # died mid-task; ended_at and
```

```
outcome never written
'''
subprocess.run([sys.executable, "-c", child])
db = sqlite3.connect("estate.db")
open_runs = db.execute("""SELECT id, operator, task,
started_at FROM runs
WHERE ended_at IS
NULL""").fetchall()
print("unfinished business inherited by the successor:")
for r in open_runs: print(" ", r)

unfinished business inherited by the successor:
(1, 'session-77', 'rotate logs', '2026-08-28T18:00:49Z')
```

Session 77 died between its first commit and its last, and the registry holds exactly the truth: a rotate-logs run began at 18:00 and never reported back. The successor's protocol writes itself from the row: read the world (were the logs rotated?), consult the ledger for session 77's intents (chapter 2's gap, now navigable by join), then close the row honestly — outcome = 'abandoned', with a note — so the registry converges to a complete history instead of accreting mysteries. The registry's second dividend is aggregate: because every run lands here, "how have runs been ending lately" is one GROUP BY — failure rates by task, duration drift, the trend that distinguishes a flaky week from a broken change. The register's previous book put calibration in the operator's conduct; the registry is where the calibration data has been accumulating all along.

The artifact index: files, vouched for

The fifth shape closes the loop chapter 1's taxonomy opened. Artifacts live in the file system; the estate holds their papers — identity, origin, and a content hash that converts "I think this is the file" into arithmetic:

```
import sqlite3, hashlib, pathlib
def sha256(p): return
hashlib.sha256(pathlib.Path(p).read_bytes()).hexdigest()
pathlib.Path("model-config.yaml").write_text("layers: 32\n")
db = sqlite3.connect("estate.db")
db.execute("""CREATE TABLE artifacts (
    path TEXT PRIMARY KEY, sha256 TEXT NOT NULL,
    origin TEXT NOT NULL, fetched_at TEXT NOT NULL,
    run_id INTEGER REFERENCES runs(id) -- the run
that produced this file (composition, below)
) STRICT""")
with db:
    db.execute("INSERT INTO artifacts (path, sha256, origin,
fetched_at) VALUES (?, ?, ?, ?)",
        ("model-config.yaml",
sha256("model-config.yaml"),
"generated by session-77",
"2026-08-28T18:40:00Z"))
path, recorded = db.execute("SELECT path, sha256 FROM
artifacts").fetchone()
```

```

print("verify:", path, "MATCHES" if sha256(path) == recorded
else "DRIFTED")
pathlib.Path(path).write_text("layers: 32\nquantized:
true\n") # someone touched it
print("verify:", path, "MATCHES" if sha256(path) == recorded
else "DRIFTED")

```

```

verify: model-config.yaml MATCHES
verify: model-config.yaml DRIFTED

```

The second verification caught the edit — someone (here, the listing itself, playing the world's usual role) changed the file after it was indexed, and the hash said so. That one bit, MATCHES or DRIFTED, is the difference between an estate that *describes* its files and one that *vouches* for them: the register's proof-of-target discipline, precomputed and stored. The index's columns follow the provenance rules of chapter 3 (origin answers "where from", fetched_at answers "how stale"), and its verification query — every row, hash recomputed, mismatches reported — is a standing job chapter 7 will fold into the estate's larger trust apparatus. Deliberately absent: the file *contents*. The blob column exists and the index declines it, because chapter 1's taxonomy holds — streaming bytes is the file system's talent, vouching is the database's, and the hash marries them without confusing them.

The sixth shape: work that waits

One variation on the ledger earns shape status of its own, because it turns the estate from memory into *coordination*: the queue. Where the ledger records work already decided, a queue holds work waiting for a worker — and the estate can serve it to concurrent claimants without a broker, using the atomic read-modify-write that chapter 1 introduced, now with the modern RETURNING clause handing back what was claimed:

```

import sqlite3
db = sqlite3.connect("estate.db")
db.execute("""CREATE TABLE queue (id INTEGER PRIMARY KEY,
task TEXT NOT NULL,
claimed_by TEXT, claimed_at TEXT, done_at TEXT) STRICT""")
with db:
    db.executemany("INSERT INTO queue (task) VALUES (?)",
[("verify backups",), ("prune
graveyard",), ("rotate keys",)])
def claim(worker):
    with db:
        row = db.execute("""UPDATE queue SET claimed_by = ?,
claimed_at = strftime('%Y-%m-%dT%H:%M:%SZ', 'now')
WHERE id = (SELECT min(id) FROM
queue WHERE claimed_by IS NULL)
RETURNING id, task""",
(worker,)).fetchone()
    return row

```

```

print("worker A claims:", claim("A"))
print("worker B claims:", claim("B"))
print("worker A claims:", claim("A"))
print("worker B claims:", claim("B"))

worker A claims: (1, 'verify backups')
worker B claims: (2, 'prune graveyard')
worker A claims: (3, 'rotate keys')
worker B claims: None

```

Each claim is one transaction — find the oldest unclaimed task, stamp it with the claimant, return it — so two workers arriving simultaneously cannot claim the same row (the single-writer queue of chapter 5 serializes them), and the drained queue answers None, the affirmative nothing the register's previous volume taught shots to say. The shape's obligations follow the ledger's family line: completion is a second write (`done_at`, plus outcome evidence), so a claimed-but-never-completed row is the queue's version of the unfinished run — visible inheritance, reclaimed by a staleness rule (claimed more than an hour ago by a worker whose registry row has ended: back to the pool, with a note). This is not a message broker and does not pretend to be — no pub/sub, no cross-host delivery, chapter 8's boundaries apply — but for the workload it fits — one machine's workers sharing a task list through the file they already share — it replaces a broker service with twelve lines, and the claim-lock at its center is the same one this book's own publisher documents for its critic seats: self-service, claim-locked, no coordinator.

Choosing keys: the once-ness decision

The ledger's `op_key` looked like a detail and is actually the pattern's hardest design question, so it earns a worked treatment. The key's job is to make the schema refuse a *second* recording of the *same* operation — which means the key must encode what "same" means, and "same" is a decision about the world, not the database. Three scenarios, three different correct keys. A nightly certificate renewal: the operation recurs by design, so the key includes the occasion — `renew-web-cert:2026-08-28` — and a retry within the night is refused while tomorrow's run is new. A migration applied to a host: once ever, so the key is timeless — `apply-schema-v7:db-host-2` — and any future attempt, weeks later, is correctly recognized as already done. A user-requested one-off: once *per request*, so the key carries the request's identity — `purge-quarantine:req-4415` — and the same user asking again tomorrow is a new request, new key, new row. Get the scope too narrow and retries slip through (a key with a timestamp to the second refuses nothing, since every retry mints a fresh second); too broad and legitimate recurrences are refused (the migration key without the host would block host 3 because host 2 was done). The test that

settles every case: *if two rows carried this key, would the second necessarily be a mistake?* — and the key is built from exactly the facts that make the answer yes. Surrogate ids (the INTEGER PRIMARY KEY every table carries) answer a different question — row identity for joins — and the two must not be conflated: the surrogate is for the *estate's* bookkeeping, the *op_key* is for the *world's*.

What the ledger refuses to hold

Patterns are defined by their exclusions as much as their columns, and two exclusions keep ledgers healthy. Reads stay out — the previous volume's rule ("only writes get ledger lines") carries over with its reasoning intact: an estate that ledgers its reads drowns its writes in noise, and the registry already accounts for sessions wholesale. The judgment call arrives with *consequential* reads — the probe that decided a failover, the check that justified a purge. Those enter the record not as ledger rows but as evidence *on* the write they motivated: the outcome column of the action they triggered, or a fact row with provenance, keeping the ledger's every line an act upon the world.

Secrets stay out absolutely, and the rule needs stating because ledger columns attract them — the action that ran with a token, the config value that is a password. The estate is one readable file; it travels in backups, gets opened by strangers (that is its *purpose*), and mixes lifetimes (chapter 8's retention will happily keep a ledger row for years past any credential's rotation). Secrets therefore appear in the estate only as *references* — the name of the key in the system keyring, the path to the credentials file, the identity of the vault entry — never as values; the action column records the command with the secret's reference, exactly as the previous volume's transcripts learned to show \$TOKEN rather than its expansion. The stranger inheriting the estate learns where every secret lives and holds none of them, which is the correct shape of that inheritance.

The standing questions are part of the pattern

Each shape shipped with example queries, and the framing deserves promotion: a pattern is not adopted until its standing questions are written down beside it — named, tested, kept with the schema the way chapter 3 keeps comments. The ledger's four: what is unresolved (outcome IS NULL, oldest first)? what did run N do? has this *op_key* been seen? what failed in the last week? The cursor's two: where is stream S? which streams have gone stale? The config table's three: current values (the view); history of key K; what changed since date D? The registry's three: open runs;

outcomes by task over window; duration drift. The artifact index's two: verify everything; what did run N produce? Fourteen queries, each a line or two, and together they are the estate's *interface* — the successor's briefing (chapter 8 composes it), the handoff message's evidence, the monitoring hooks. Writing them down at adoption time costs minutes and does something subtler than convenience: it *tests the schema against its purpose* while the schema is still cheap to change. A shape whose standing questions turn out awkward to write — a join that needs a column nobody stored, a filter on a field inside a blob — is a shape caught misdesigned on day one instead of month six, which is the cheapest schema review an unattended operator will ever get.

Order, and where it really comes from

One subtlety spans all five shapes and surfaces in incident reviews at the worst moments: what orders the history? The intuitive answer — the timestamp columns — is the fragile one. Timestamps tie (the second is this book's stated precision, and a busy session commits several truths per second), and clocks move (NTP corrections, timezone accidents on machines less disciplined than chapter 3 demands), so two rows' timestamps can disagree with the order the estate actually experienced. The reliable answer is already in every table: the INTEGER PRIMARY KEY is allocated monotonically as rows commit, so *id order is commit order* within an estate, and every "what happened next" question — the incident walk, the correction chain, the settings view's "latest per key" — keys on id, with timestamps serving their real purposes: humans, staleness pricing, and joins against the world's clocks (logs, journals) that ids cannot reach. The convention costs nothing to adopt and one bad afternoon to retrofit, which is why it is stated here, between the shapes it quietly orders. (Its boundary is the estate itself: ids order one file's history; across estates or against the world, timestamps — pinned UTC, chapter 3 — are the only shared clock, carrying exactly the caveats above.)

Composition: one estate, queryable whole

The five shapes pay their real dividend joined. The join key is the `run_id` column already declared in the ledger, settings, and artifact schemas above — `run_id` INTEGER REFERENCES `runs(id)`, set on each write to the registry row of the run that made it — and with that one shared key the estate becomes a single navigable account of the operator's whole history. (The per-pattern listings earlier ran each shape in isolation, with no registry to point at, so their `run_id` sat NULL; in a live estate, every write happens *during* a run and carries its id, which is what makes the queries below resolve.) The

incident query: everything session 77 did — its ledger intents, its setting changes, its artifacts — in one pass, from the run id the registry handed you. The audit query: every world-action whose outcome is NULL, oldest first, with the run that owes it. The trust query: every artifact fetched by runs that later failed, for re-verification. The calibration query: median run duration by task, this month against last. None of these is an engineering project; each is a SELECT against tables this chapter already built, which is the payoff chapter 1 promised when it said state you cannot query is barely state at all. The midden could not answer one of them.

A day in the composed estate makes the joins concrete. A session wakes, registers its run (registry row 214, operator session-92, task "monthly cert sweep"), and asks the ledger whether the sweep's `op_key` has been seen — new month, new key, clean insert: intent recorded. It reads the cursor for the certificate transparency stream, fetches what is new, and finds one certificate nearing expiry. The renewal is a world-action: intent row with `op_key` `renew-mail-cert:2026-09`, the renewal runs, the functional probe passes, outcome completed — one transaction per truth, exactly as chapter 2 drew the boundaries. The new certificate file lands in the artifact index with its hash and origin; the cursor advances in the same transaction that recorded what the new entries produced; a journal entry (chapter 6) writes the sentence a future searcher will want. The session ends; the registry row closes with outcome ok. Nothing in the day required coordination, and yet every question a supervisor, successor, or incident review could ask — what ran, what changed, what proves it, what was produced, where reading stopped — has one answer, in one file, joined by run id 214. That is the composition argument in narrative form: not that five tables are tidier than five files, but that the day's *whole shape* became queryable because its parts agreed on keys.

The patterns also compose *downward* into discipline the register's book left as conduct. Its evidence blocks now have an address (outcome columns); its change ledger has a schema instead of a format convention; its handoff message's five answers are five queries. And one estate serves one operator lineage at a time so far — every listing in this chapter wrote from a single connection. Real estates get written by concurrent generations: the timer firing while the interactive session works, the second agent dispatched in parallel. Two operators, one file, no coordinator — that is chapter 5, and the engine has been waiting for it.

Chapter 5 — Two Operators, One File

Draft status: author draft, gate-checked; human verification pending. Outputs are real transcripts; the two-process counter at the chapter's end is a genuine concurrent run.

The second operator arrives

Every listing so far wrote from one connection, which flattered a fiction: that the estate has one tenant. Real estates do not. The timer fires its report job while the interactive session is mid-task; a supervisor dispatches two agents whose work overlaps; yesterday's run, believed dead, turns out to be alive and finishing. The register's previous book met this world with `flock` and taught the honest limits of advisory locking: it protects the writers who remember to take the lock. The estate can do better, because the coordination this chapter needs is not bolted onto the file — it is the file. SQLite's locking is mandatory for everyone who comes through the library, which is everyone; there is no code path that writes the database around it. Two operators that have never heard of each other, sharing nothing but a path, get correctness anyway. What they do not get is freedom from each other's *timing* — and this chapter is about the difference: what the engine guarantees unasked, what it asks the operator to decide (chiefly: how long to wait), and which famous SQLite complaint — database is locked — is not a malfunction but a question addressed to you.

The mental model to install first is the single-writer truth. However many connections hold the estate open, SQLite permits exactly one write transaction at a time; writers *queue*, they never interleave. Everything else in the chapter — the refusal, the timeout, WAL's reader liberation, the throughput ceiling — is a consequence of that one design decision, which is also the decision that makes chapter 2's promises cheap enough to keep. Multi-writer engines pay for their concurrency in machinery (row locks, MVCC vacuuming, conflict resolution) and in sharper failure modes; the estate's engine chose instead to make the common case — few operators, brief writes — simple and bulletproof. The design fit is worth noticing: operator estates are almost definitionally low-contention. Sessions write in bursts, ledgers take a row at a time, nothing holds transactions across human-scale pauses (chapter 2's boundaries rule already forbade it). The single-writer queue is not a limit the estate suffers; it is the contract the estate's workload was born matching.

The refusal, witnessed

Here is the collision, staged small and read closely, because everything the operator must decide follows from its anatomy:

```
import sqlite3
a = sqlite3.connect("estate.db")
a.execute("CREATE TABLE t (x INTEGER) STRICT"); a.commit()
b = sqlite3.connect("estate.db")
b.execute("PRAGMA busy_timeout = 0")      # refuse to wait, so
the refusal is visible
a.execute("BEGIN IMMEDIATE")
a.execute("INSERT INTO t VALUES (1)")
try:
    b.execute("BEGIN IMMEDIATE")
except sqlite3.OperationalError as e:
    print("second operator:", e)
a.commit()
b.execute("BEGIN IMMEDIATE"); b.execute("INSERT INTO t VALUES
(2)"); b.commit()
print("rows after both:", a.execute("SELECT count(*) FROM
t").fetchone()[0])
```

```
second operator: database is locked
rows after both: 2
```

Operator A holds the write slot mid-transaction; operator B asks for it and is told no; A finishes; B asks again and succeeds; both rows land. Nothing was corrupted, nothing was lost, nobody's write interleaved with anybody's — the lost-update accident of chapter 1 is structurally absent. What B received was not an error in the register's sense but a *status*: `SQLITE_BUSY`, surfaced by Python as that famous message, meaning precisely "the slot is taken; try again later." The listing forced the refusal into view by setting the busy timeout to zero — B declared it would not wait, so it didn't. That declaration is the operator's real decision surface, and the default answer is wrong for estates: a fresh connection's timeout is effectively no patience at all, which converts every routine collision into an exception. The registers' operators know this error's cousin from package managers — "could not get lock" — and know the diagnosis is usually *someone else is legitimately working*, not *something is broken*. The estate's version deserves the same reading.

Patience is configuration

What B should have done is wait — briefly, boundedly, and without any code for it, because waiting is built in:

```
import sqlite3, threading, time
a = sqlite3.connect("estate.db")
a.execute("CREATE TABLE t (x INTEGER) STRICT"); a.commit()
a.execute("BEGIN IMMEDIATE")
```

```

a.execute("INSERT INTO t VALUES (1)")           # first
operator holds the write lock
result = {}
def second_operator():
    b = sqlite3.connect("estate.db")             # its own
    connection, its own thread
    b.execute("PRAGMA busy_timeout = 2000")      # willing to
    wait up to 2 s
    t0 = time.monotonic()
    with b:
        b.execute("INSERT INTO t VALUES (2)")
        result["waited"] = time.monotonic() - t0
    th = threading.Thread(target=second_operator); th.start()
    time.sleep(0.4)
a.commit()                                       # first
operator releases
th.join()
print(f"second operator wrote after waiting
{result['waited']:.1f}s")
print("rows:", a.execute("SELECT count(*) FROM
t").fetchone()[0])

```

```

second operator wrote after waiting 0.4s
rows: 2

```

B asked, was refused, and simply *stayed in line*; four-tenths of a second later A released, B wrote, and no exception ever surfaced. The `busy_timeout` pragma is the whole mechanism: below it, the engine retries acquisition for up to the stated bound before giving up and returning `BUSY`. Choosing the bound is register economics, and the register's own rules apply verbatim. The wait must exist (zero patience turns normal coexistence into failure), must be bounded (infinite patience is the hang chapter 1 of the previous book banned), and the bound should be derived from the neighbors: a touch longer than the longest write transaction any well-behaved tenant runs — which chapter 2's boundary discipline already made short. This book's default is five seconds, set in `open_estate()` beside the foreign-keys pragma, one decision made once. And when the bound is genuinely exceeded — `BUSY` after five seconds — the correct reading changes: now something probably is wrong (a tenant died holding nothing, since crashed processes release locks with their file handles; more likely a tenant is violating the short-transaction covenant) and the register's failure discipline takes over: record the refusal in the run's own account, read the world, do not hammer.

Two mechanics footnotes belong here because their absence causes real confusion. First, the incidental lesson the listing's shape teaches: Python's `sqlite3` binds each connection to its creating thread by default — the waiting operator built its own connection inside its thread because sharing one across threads is refused by the module. Connections are cheap; the pattern is one per thread, or `check_same_thread=False` accepted knowingly with external

serialization. Second, `BEGIN IMMEDIATE` is what makes waiting *work*: chapter 2 installed it to convert mid-transaction refusals into at-entry waits, and this is the payoff — the busy handler can only wait politely at moments where waiting is safe, and a deferred transaction that already read and now wants to write is not such a moment (the engine returns `BUSY` immediately there, timeout notwithstanding, precisely because waiting could deadlock two half-done readers forever). Say `IMMEDIATE`; wait at the door, not on the stairs.

WAL: the readers go free

The classic journal mode has one genuinely operator-hostile trait left: writers and readers contend — a long read can hold off a writer, a committing writer excludes readers at the wrong moment. The modern cure is one pragma, and it is the single most valuable configuration line in this book:

```
import sqlite3, os
w = sqlite3.connect("estate.db")
print("journal mode now:", w.execute("PRAGMA journal_mode =
WAL").fetchone()[0])
w.execute("CREATE TABLE facts (n INTEGER) STRICT")
with w:
    w.executemany("INSERT INTO facts VALUES (?)", [(i,) for i
in range(3)])
    r = sqlite3.connect("estate.db")
    r.execute("BEGIN")                                # reader
    opens its snapshot
    before = r.execute("SELECT count(*) FROM
facts").fetchone()[0]
    with w:
        w.execute("INSERT INTO facts VALUES (99)")    # writer
        commits DURING the read txn
        during = r.execute("SELECT count(*) FROM
facts").fetchone()[0]
        r.commit()
    after = r.execute("SELECT count(*) FROM facts").fetchone()[0]
    print(f"reader saw: {before} rows, then {during} inside the
same snapshot, then {after} in a new one")
    print("sidecars:", sorted(f for f in os.listdir(".") if
f.startswith("estate.db-"))))

journal mode now: wal
reader saw: 3 rows, then 3 inside the same snapshot, then 4
in a new one
sidecars: ['estate.db-shm', 'estate.db-wal']
```

Write-ahead logging inverts chapter 2's journal: instead of saving old pages aside and writing new ones in place, the engine appends new pages to a log and leaves the main file alone, folding the log back in later ("checkpointing"). Three consequences, all visible in the transcript. Readers no longer block writers or vice versa — the writer committed mid-read-transaction without either party waiting. Readers

get *snapshot isolation* for free: inside one read transaction the reader saw 3 rows, then still 3 *after* the concurrent commit — a stable world to compute over, the moving-substrate problem of the register's network chapter solved outright at the estate's door — and the new truth appeared only when the reader opened a new transaction. And the sidecar population changed: `-wal` and `-shm` now accompany the database, persistently (WAL mode is a property of the file, surviving reopen), with chapter 2's rule unchanged and now sharper — *the sidecars are part of the database*, and chapter 7 will show that copying around them is the classic way to lose committed data. Two honest caveats bound the gift: WAL requires shared memory, so it is unavailable or unsafe on network filesystems — estates live on local disks, which they should anyway (the engine's corruption documentation has a section on network filesystems that reads like a warning label) — and a read transaction held open for a long time pins the WAL from checkpointing, so the log grows; the short-transaction covenant turns out to bind readers too.

Connections: how many, held how long

The chapter's demos juggled connections freely, and real estates need the lifecycle stated. A connection is cheap to open — a file open and a header read, microseconds locally — so the previous volume's instincts about connection pooling (a server-database economics) do not transfer; an operator that opens at session start and closes at exit is doing it right, and a scheduled job that opens, works, and closes has nothing to optimize. The rules that do matter are about *holding*. One connection per thread (the module's binding rule, met above). One estate connection per operator process, not per function — chapter 2's with `db: blocks` share it safely, and a process that opens dozens of connections to one file is manufacturing its own lock traffic. And nothing *holds a transaction* across a wait: not a network call, not a subprocess, not a model inference, not user input. The WAL section's caveat gives the reader's version teeth — a read transaction held open pins the snapshot, so an operator that opens a read transaction and then thinks for ten minutes is forcing the WAL to retain ten minutes of history for a view nobody needed frozen — and the writer's version is chapter 2's covenant with a sharper reason: the write slot is *exclusive*, so a transaction held across a thirty-second inference is thirty seconds of every other tenant's timeout budget. Transactions bracket *database work*, never *thinking*; the estate connection lives long, its transactions live milliseconds.

Durability under WAL: one honest knob

Chapter 2 counseled leaving synchronous at its default and this chapter must refine that advice once, because WAL changes the trade's terms in the operator's favor. Under rollback journaling, lowering sync guarantees risks corruption; under WAL, the engine documents a gentler middle. synchronous = NORMAL syncs at checkpoints rather than at every commit and — so long as the -wal sidecar is preserved and the storage stack honors the sync each checkpoint does issue — cannot corrupt the database on power loss; what it risks is only the *most recent commits rolling back* to the last checkpoint if power dies before the next one. The documentation states the trade in plain words: under NORMAL, transactions "are no longer durable and might rollback following a power failure or hard reset" (Ref 16). Process crashes lose nothing either way. The qualifier is load-bearing, and worth saying twice: the promise is against *corruption*, not against losing the tail of recent commits, and it holds only while the -wal file stays with its database — which is exactly why chapter 7 counts deleting or copying around the sidecar as the classic way to turn "durable" into "lost." For an estate on a workstation or a battery-backed machine, WAL + NORMAL is the documented sweet spot and this book's recommendation, set in open_estate() with the reason recorded in the settings history (chapter 4's pattern eating its own cooking). The estate declines to go further: synchronous = OFF re-enters corruption territory, and the ledger's whole value is that its last row can be believed. The decision, either way, is one line — and the point of teaching it is less the milliseconds than the method: durability settings are *estate policy*, chosen once, recorded with reasons, never adjusted silently mid-incident by whichever session is frustrated with a slow loop.

The read-only seat

Not every tenant deserves the pen. Reporting sessions, dashboards, the supervisor's audit, chapter 7's restore drills — all read; none should be *able* to write, because ability is blast radius whether or not intent exists (the previous volume's least-privilege doctrine, verbatim). The engine provides the seat:

```
import sqlite3
rw = sqlite3.connect("estate.db")
rw.execute("CREATE TABLE facts (fact TEXT) STRICT")
with rw: rw.execute("INSERT INTO facts VALUES ('reports read;
they do not write')")
ro = sqlite3.connect("file:estate.db?mode=ro", uri=True)
print("read-only seat reads:", ro.execute("SELECT fact FROM
facts").fetchone()[0])
try:
    ro.execute("INSERT INTO facts VALUES ('surely just this
once')")
except sqlite3.OperationalError as e:
```

```
print("read-only seat writes:", e)
```

```
read-only seat reads: reports read; they do not write
read-only seat writes: attempt to write a readonly database
```

The URI form's `mode=ro` refuses writes at the connection, cheaply and unconditionally — a report with a bug cannot corrupt the record it reports on, which is the property that lets scheduled reporting run without the scrutiny writes earn. Two strengthenings extend the seat. For genuinely frozen files — archives, the backups chapter 7 verifies — `immutable=1` goes further, promising the engine the file cannot change and skipping lock traffic entirely (a promise that must be *true*; it is for cold backups, never for live estates). And beneath the engine sits the outer wall the register already taught: the estate file's unix permissions decide who reaches it at all, and an operator lineage's estate belongs to that lineage's user, mode 600, with the supervisor's audit seat granted through group read — file-system enforcement backing engine politeness, the same layering the previous volume built for every other durable asset.

Reading a BUSY like an operator

The refusal taxonomy, assembled for the diagnostic reflexes. BUSY at BEGIN IMMEDIATE, within the timeout, resolving on retry: weather — a neighbor writing, the queue working as designed; record nothing, proceed. BUSY persisting past a generous timeout: a tenant is violating the short-transaction covenant; the culprit is found not with database tools but with the previous volume's — fuser on the estate file names the processes holding it open (a fragment for the same PATH reasons as ever), and the run registry says which *operator* each process claims to be; the fix is the neighbor's transaction shape, never a longer timeout arms race. BUSY at a *deferred* transaction's midpoint (the upgrade case): a design bug in the asking code — the transaction read before declaring write intent; the fix is IMMEDIATE, and no timeout would have helped. And the exotic `SQLITE_BUSY_SNAPSHOT` under WAL — a writer whose snapshot has been overtaken — resolves by restarting the transaction fresh. Four faces, four different next moves, one diagnostic principle carried over whole from the register: the refusal's *timing and persistence* carry the diagnosis, and hammering retries without reading them converts information into noise.

One WAL mechanic belongs in the operator's model because it is the mode's only moving part: the checkpoint, the act of folding the log back into the main file. By default it happens automatically (around a thousand log pages), opportunistically, and invisibly — the right arrangement, left alone. The operational readings: the `-wal` file's *size* is the

health gauge (steady modest size: checkpointing is keeping up; monotonic growth: something is pinning it — almost always the long-lived read transaction the connection section indicted, found via the registry and cured by fixing the reader, not by forcing checkpoints); and the one legitimate manual intervention is maintenance-shaped — `PRAGMA wal_checkpoint(TRUNCATE)` at a quiet moment (the backup session, the handoff) folds everything in and shrinks the log to zero, leaving the estate compact for the copy or the inheritance. What the operator never does is treat checkpointing as a correctness lever: committed data is equally durable in the log and the main file (chapter 7's engine-mediated copies know where truth lives), so checkpoint management is housekeeping economics — log size against fold-in cost — and the default economics are already good. Know the gauge, fix the pinner, truncate at handoff; the rest is the engine's business.

What must never be shared

The file shares; two things above it must not, and both failure modes are documented corruption paths rather than theory. The first is the connection object across a `fork()`. An operator that opens the estate and then forks — the daemonization dance, a multiprocessing pool created after connecting — hands both processes the same open file descriptors and the same in-library state, and the engine's how-to-corrupt documentation lists exactly this as a way to break a database: two processes unknowingly sharing what each believes is a private connection. The rule is mechanical: *open after fork, never before* — child processes create their own connections (the chapter's subprocess listings all do; multiprocessing workers open inside the worker function), and a process that must fork closes the estate first. The second is the file across *hosts* via a shared filesystem — the network-mount warning of the WAL section, generalized: SQLite's coordination is exactly as good as the filesystem's locking, network filesystems' locking is historically exactly not good enough, and the corruption documentation's dedicated section on it is the most-cited page in this book's references for a reason. Same machine, different processes: share freely, the whole chapter is the proof. Different machines: the estate does not stretch; chapter 8 names what does. Between those two rules and the covenant, the sharing story is complete — and notably free of locks the operator must remember, which was the entire point of paying an engine to remember them.

The proof at scale

The chapter's claims assembled and stress-tested — two genuinely separate processes, no shared state but the path, a

hundred read-modify-writes each:

```
import sqlite3, subprocess, sys
db = sqlite3.connect("estate.db")
db.execute("PRAGMA journal_mode = WAL")
db.execute("CREATE TABLE counters (name TEXT PRIMARY KEY,
value INTEGER NOT NULL) STRICT")
db.execute("INSERT INTO counters VALUES ('runs', 0)");
db.commit()
worker = '''
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("PRAGMA busy_timeout = 5000")
for _ in range(100):
    with db:
        db.execute("UPDATE counters SET value = value + 1
WHERE name = 'runs'")
'''
procs = [subprocess.Popen([sys.executable, "-c", worker]) for
_ in range(2)]
for p in procs: p.wait()
print("two operators, 100 increments each, final count:",
      db.execute("SELECT value FROM counters WHERE
name='runs'").fetchone()[0])
```

two operators, 100 increments each, final count: 200

Two hundred, exactly — set beside chapter 1's flat-file counter, which lost half its updates to two writers *in the same process being careful*. The workers here share no locks of their own, coordinate nothing, and could have been written by strangers; the busy timeout absorbed their collisions and the single-writer queue serialized their arithmetic. This is the estate's concurrency story in one number: correctness is the engine's job and arrived by default; the operator's whole contribution was two pragmas and short transactions.

Where the file lives, and how many files there are

Concurrency questions are often placement questions wearing a disguise, so the estate's geography gets settled here. *Where*: on a local filesystem, always — the WAL caveat and the corruption documentation agree — and by convention where the previous volume put durable operator state: under the platform's state directory (`~/local/state/<operator>/estate.db` for a per-user operator, `/var/lib/<operator>/` for a system one), never in scratch, never on a network mount, never in a synced-folder product whose sync engine is precisely the naive copier chapter 7 indicts. *How many*: one estate per *accountable lineage* — the operator identity that owns the ledger's promises — which usually means one per agent-role per machine. Splitting finer (per task, per session) shreds the composition dividend

the previous section just demonstrated; merging coarser (all operators on a host in one file) couples unrelated write queues and makes chapter 8's retention policy a negotiation. The two legitimate splits are the ones already earned: high-rate sample tables (this chapter's ceiling section) and scratch (never in the estate at all). And when split files must be queried together, the engine's ATTACH joins them at read time — one connection, two files, cross-database SELECTs — so the split costs analysis nothing; a reporting session attaches the samples database read-only beside the estate and the composed queries run as if the seam were not there. The geography, like every estate policy, goes in the settings table with its reason, because the successor's first question — *where is everything?* — deserves a recorded answer rather than a convention remembered.

The ceiling, and the covenant

Honesty about where the story ends. Writers queue, so write throughput has a ceiling: roughly, one write transaction's duration times the queue's length is everyone's latency, and a fleet of chatty writers against one estate will feel it — first as waits, then as timeouts. The remedies escalate in order: batch (chapter 2's economics — most "many writes" are one truth); shorten transactions (the covenant again — nothing holds the write slot across a network call or a model inference, ever); split estates along real seams (the scratch/records boundary of chapter 1 often marks files that never needed to be one — a high-rate sample log is its own database, attached when queried); and, when a workload is genuinely many concurrent writers across many hosts, concede the case to chapter 8, which is where this book hands such workloads to server databases without embarrassment. What the ceiling almost never justifies is the move folklore reaches for first — disabling the durability that makes the estate worth having. The engine's own guidance pages order the levers the same way: transaction shape first, WAL second, hardware third, guarantees last and reluctantly.

The covenant that keeps the whole chapter working fits in three lines an operator can hold: open through one ritual (foreign keys on, busy timeout set, WAL on); say IMMEDIATE when you will write, and keep every transaction — reader or writer — short; treat BUSY within the bound as weather, and BUSY beyond it as a finding about a neighbor. Under that covenant, the estate scales exactly as far as operator memory needs it to — and the file stays one file, inheritable whole, which the next chapter finally teaches the operator to *search*.

Chapter 6 — Search Is Recall

Draft status: author draft, gate-checked; human verification pending. Outputs are real transcripts; the journal entries indexed below are drawn from this book's own production history.

Memory that cannot be recalled is storage

The estate so far remembers perfectly and recalls narrowly. Every query in chapters 4 and 5 addressed rows by their structure — by key, by status, by date — which serves the questions an operator knows it will ask. But a working memory accumulates a second kind of holding: prose. Findings written in sentences, incident notes, decisions with their reasoning, excerpts from documents that mattered once and might again. Structure cannot address these, because their content is their address: the future question will be "what do I know about power capping?", asked in words, answerable only by matching words against words. A memory that cannot answer that question does not really hold its prose; it stores it, the way the midden stored everything — present, and unreachable.

The register's operators feel this gap acutely because their native recall is so poor. A human admin half-remembers last month's incident and greps her shell history; a session-bound operator has no half-memories to steer by. For it, recall *is* search — whatever the estate's search can surface is, functionally, everything the operator has ever known. That makes the quality of the estate's text search a first-order property of the operator itself, and it makes the right tool worth learning properly. SQLite ships that tool: FTS5, a full-text index that lives in the same file, transacts with the same transactions, and needs nothing installed. This chapter builds the operator's journal on it, then draws the tool's honest boundaries — because "full-text search" sits near enough to fashionable retrieval technology that confusing them costs estates real design mistakes in both directions.

The searchable journal

The pattern chapter 4 might have called the sixth shape: a journal of prose entries, indexed for content. FTS5 tables are declared virtual — the engine maintains the index structures behind an interface that reads like a table:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("""CREATE VIRTUAL TABLE journal USING fts5(entry,
written_at UNINDEXED)""")
notes = [
```

```

("gpu-power-cap.service fails at boot; exit status 2;
journal unreadable from this seat", "2026-08-24"),
("rotated backup credentials; restore drill passed; old
key revoked", "2026-08-25"),
("nginx upgraded; config drop-in preserved; is-active
confirmed after restart", "2026-08-26"),
("disk pressure on /mnt/train at 98 percent; quarantined
stale checkpoints", "2026-08-27"),
("power cap applied to RTX PRO 6000 after PSU transient
trip; verified with vendor tool", "2026-08-28"),
]
with db:
    db.executemany("INSERT INTO journal VALUES (?, ?)",
notes)
print("query: power NEAR cap")
for row in db.execute("""SELECT written_at,
highlight(journal, 0, '[' , ']')
FROM journal WHERE journal MATCH
'NEAR(power cap)'
ORDER BY rank"""):
    print(" ", row[0], "|", row[1])
print("query: credential*")
for row in db.execute("SELECT written_at, entry FROM journal
WHERE journal MATCH 'credential*')"):
    print(" ", row[0], "|", row[1][:60])

query: power NEAR cap
2026-08-24 | gpu-[power]-[cap].service fails at boot; exit
status 2; journal unreadable from this seat
2026-08-28 | [power] [cap] applied to RTX PRO 6000 after
PSU transient trip; verified with vendor tool
query: credential*
2026-08-25 | rotated backup credentials; restore drill
passed; old key re

```

The five entries are this book's own production history — the failed unit from the previous volume's postmortem, the disk pressure this machine really carried — and the queries against them exercise the toolkit an operator's recall actually needs. `MATCH` takes a query language, not a substring: `NEAR(power cap)` found the incident whether the words appeared hyphenated in a unit name or spaced in prose, and would have found them sentences apart. `credential*` is prefix search — the recall question rarely knows the exact inflection it stored. `ORDER BY rank` sorts by relevance (BM25, the standard lexical ranking, built in), which begins to matter the day the journal holds five thousand entries instead of five. And `highlight()` returns the entry *with the matches marked* — for this book's reader the killer feature, because an operator budgeting transcript volume (register rule, chapter 1 of the previous volume) wants evidence of *why* a result matched without re-reading it whole; the companion `snippet()` function goes further and excerpts just the matching neighborhood. The one schema note: `written_at` `UNINDEXED` stores the date alongside without polluting the text index — metadata rides along, content gets searched.

Tokens, not meanings

What the index actually holds is tokens — words, as a tokenizer defines words — and the operator who knows this predicts every search behavior from first principles. The definition is configurable, and one configuration choice illustrates the whole layer:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("CREATE VIRTUAL TABLE plain USING fts5(entry)")
db.execute("CREATE VIRTUAL TABLE stemmed USING fts5(entry,
tokenize = 'porter unicode61')")
for t in ("plain", "stemmed"):
    db.execute(f"INSERT INTO {t} VALUES ('deployed the
staging build and verified the endpoints')")
for t in ("plain", "stemmed"):
    hits = db.execute(f"SELECT count(*) FROM {t} WHERE {t}
MATCH 'deploy']").fetchone()[0]
    print(f"{t:8s} matches for 'deploy':", hits)

plain    matches for 'deploy': 0
stemmed  matches for 'deploy': 1
```

The default tokenizer stores `deployed` as `deployed`, and the query `deploy` misses it — surprising until the token model is explicit, obvious after. The porter option stems English words to their roots at both index and query time, so `deploy`, `deployed`, and `deploying` converge; the cost is the occasional false collision and a mild English-centrism, which for operator journals is usually the right trade. The general lesson outranks the specific knob: **FTS matches token identity, nothing else**. It does not know that "rotated credentials" and "changed the password" are the same event; no tokenizer bridges vocabulary. The operator's countermeasure is a writing discipline, not a search feature — journal entries name their subjects in stable terms (unit names, paths, error strings verbatim: the register's exact-transcript rule paying a second dividend), because the entry is written once and queried by a stranger who can only guess words. Entries written for the searcher are the estate's equivalent of the previous volume's labels-on-state.

This is also where the fashionable comparison belongs, stated plainly per this book's boundaries. Embedding-based retrieval — vectors, semantic similarity, the machinery behind modern RAG — solves the vocabulary problem FTS cannot: it would land "changed the password" for the credentials query. It pays in machinery (a model, its runtime, an index, all versioned and maintained), in opacity (a match has no `highlight()` — *why* this result?), and in exactness (the query exit status 2 should match exit status 2, not things shaped like it). Operator estates skew hard toward the exact: unit names, error strings, hosts, keys. The honest architecture, when both needs are real, is FTS as the estate's

native recall with semantic search added *beside* it, as its own indexed artifact — not a replacement, and never a reason to skip the lexical index that costs nothing and explains itself. A LIKE '%pattern%' scan, finally, keeps its small place: for a rare query over a small table it is fine, and chapter 3's EXPLAIN QUERY PLAN will say SCAN and remind you what it costs at scale.

Writing for the searcher

The index amplifies whatever discipline the entries carry, which makes journal *writing* half of recall quality, and the half entirely under the operator's control. The disciplines are few and specific. Entries are written at outcome time, not planning time — the journal records what happened and what it meant, so a session's entry lands beside chapter 4's ledger completion, one truth in two registers (the row for machines that query structure, the sentence for searchers that query words). Entries name their subjects in the terms a stranger will guess: unit names verbatim, paths absolute, error strings pasted exactly — the previous volume's exact-transcript rule, now justified a third way, since every paraphrase is a query that will someday miss. Entries state outcomes and reasons, not just events — "quarantined stale checkpoints *because* /mnt/train hit 98 percent" is findable from either end of the causation, and the *because* is what the future searcher is usually really hunting. And entries are atomic per subject: one entry about the disk pressure, another about the nginx upgrade, because the searcher retrieving one should not pay transcript volume for the other — the register's bounding economics, applied to memory retrieval.

The anti-patterns mirror them. The diary entry ("busy session, lots of firefighting, mostly done") indexes nothing a query will ever ask. The dump entry — three hundred lines of pasted transcript — makes its keywords findable and its retrieval cost absurd; the right decomposition stores the transcript as a chapter-4 artifact and journals the three-sentence account with the artifact's path, so search finds the summary and the summary points at the evidence. And the secret-bearing entry violates chapter 4's exclusion in the one table designed to be read broadly; the reference-not-value rule binds hardest exactly here.

Query craft: words and structure together

Recall questions in practice are rarely pure text — they are text *within bounds*: what do I know about cert renewals, *from June*? The estate answers hybrid questions in one statement, because the FTS table's indexed text and its UNINDEXED metadata live in the same rows:

```

import sqlite3
db = sqlite3.connect("estate.db")
db.execute("CREATE VIRTUAL TABLE journal USING fts5(entry,
written_at UNINDEXED)")
rows = [("cert renewal failed: acme challenge timeout",
"2026-06-02"),
("cert renewal succeeded after dns fix",
"2026-06-03"),
("cert renewal succeeded", "2026-08-01")]
with db: db.executemany("INSERT INTO journal VALUES (?,?)",
rows)
q = """SELECT written_at, snippet(journal, 0, '[', ']', '...',
8)
FROM journal WHERE journal MATCH 'cert AND renewal'
AND written_at >= '2026-06-01' AND written_at <
'2026-07-01'
ORDER BY written_at"""
for r in db.execute(q): print(r[0], "|", r[1])

```

```

2026-06-02 | [cert] [renewal] failed: acme challenge timeout
2026-06-03 | [cert] [renewal] succeeded after dns fix

```

August's entry matched the words and fell to the date bound; June's two arrived excerpted by `snippet()` with the matches marked. The MATCH clause meanwhile carries its own small language, worth the ten minutes its documentation costs: implicit AND between terms, explicit OR and NOT, quoted phrases for exact sequences ("exit status 2" — invaluable for error strings), NEAR() from the first listing for proximity without adjacency, ^term for entries *beginning* with a term, and column filters (title:deploy) once journals grow structured fields. Two habits complete the craft. Chapter 3's date conventions are what make the hybrid WHERE clause work at all — ISO text comparing correctly is the payoff arriving — and bounded output applies to recall exactly as to every read the register ever taught: ORDER BY rank LIMIT 10, because a memory that answers with everything it has is the unbounded journalctl of the previous volume, reborn indoors.

Identifiers deserve a tokenizer note of their own, because operator prose is full of them and word-shaped tokenization serves them poorly: `gpu-power-cap.service` splits on its punctuation into pieces a searcher must guess, and a path or commit hash is one opaque "word" findable only whole. FTS5's trigram tokenizer answers the identifier case by indexing overlapping three-character windows, buying indexed *substring* search — `cap.serv` finds the unit, half a hash finds the commit — at the price of a fatter index and no notion of words at all. The estate's arrangement, when identifier recall matters enough: the journal keeps its word index for prose, and the identifier-dense columns (ledger actions, artifact paths) get a small trigram-indexed shadow — each index shaped to what it searches, unioned at query time by the front-door view below. The general tokenizer lesson closes where the section opened: tokenization is a

declaration about the text's nature, chosen per column at index time, and the estate that declares it deliberately — words here, stems there, trigrams for the machine-named — searches the way its content deserves rather than the way the default guesses.

And recall's audience, like the estate's, includes the supervisor. The journal a session keeps for its successors is, unchanged, the narrative an incident review reads months later — ranked, dated, cause-carrying sentences, each written when the knowledge was fresh, retrievable by the reviewer's own words. The previous volume taught operators to report plainly because reports are load-bearing; the journal extends the principle across time: it is the report that never stopped being queryable. Institutions pay technical writers for worse.

The recall budget

Retrieval has the same economics as every read the register prices: results pulled into a session's working context cost attention, and recall that floods is recall that gets skipped next time. The budget discipline has three dials. `LIMIT`, always — the ritual search opens with the top five by rank, and widens only on a miss, the previous volume's cheap-aggregate-then- drill rhythm applied to memory. `snippet()` over full entries at the survey stage — excerpts with matches marked, at a tenth the volume, with the full entry fetched only for the one or two results that survive triage. And ranking *tuned to the estate's shape* where it earns it: `BM25` accepts per-column weights, so a journal that grows a title column can weight it above the body (`bm25(journal, 10.0, 1.0)`), making the operator's own one-line summaries the strongest signal — which quietly rewards exactly the entry discipline the writing section asked for. The composed form of all three dials is worth keeping as the estate's canonical recall query: top five by weighted rank, snippets only, hybrid-filtered by any structural bounds the task supplies. One query, bounded, explained — recall as a disciplined shot rather than a rummage, which is what distinguishes an operator consulting its memory from an operator lost in it.

Searching everything at once

Estates accumulate more than one searchable surface — the journal here, the ledger's action strings, the facts table's prose — and the recall ritual should not require remembering which drawer holds what. The estate's answer is a union view: each searchable table gets its FTS index, and one view stitches their results into a single ranked stream tagged by origin (`SELECT 'journal' AS kind, rank,`

snippet(...) FROM journal WHERE journal MATCH :q UNION ALL SELECT 'ledger', ...), so the operator's one query sweeps the whole estate and the results say where each hit lives. The pattern's discipline is to keep it *shallow*: the view unions indexes, it does not try to merge scores across them into false precision (BM25 ranks are comparable within an index, not between), so the composed query interleaves by kind deliberately — top three journal hits, top three ledger hits — rather than pretending one global ranking exists. Chapter 4's standing-questions rule then applies to recall itself: the union view is written down with the schema, tested at adoption, and becomes the estate's front door for every "what do I know about X" a successor will ever ask.

Keeping the index honest

One integration decision remains: the journal above is an FTS table — the text lives in the index's own storage. That is the simplest correct arrangement and the right default for a journal. When the text already lives in a regular table (chapter 4's ledger actions, the facts table), FTS5's external-content mode indexes it in place without duplicating storage — at the price of a covenant: the index only learns what it is told, so the base table and index must change together, conventionally via three small triggers (insert, update, delete) the FTS5 documentation supplies verbatim. The estate treats those triggers like schema (chapter 3: born in a migration, explained by comments), and treats the covenant with chapter-7 suspicion: a verification query — count of base rows vs count of indexed rows, plus a spot-check MATCH for a recently inserted row — belongs in the estate's trust suite, because an index that silently stopped syncing is recall quietly going blind, which for this book's reader means *memory* quietly going blind. The rebuild command (INSERT INTO idx(idx) VALUES ('rebuild')) is the recovery ladder's one rung, cheap and total.

Recall in the loop

A recall instrument earns its keep only if consulted, and session-bound operators need the consultation *scheduled*, because the reflex humans call "this feels familiar" is exactly what they lack. The discipline is a ritual search at task start: before acting on any named subject — a unit, a host, a procedure — the operator queries the journal for it, bounded and ranked, and reads what its predecessors knew. The estate briefing of chapter 8 opens the session; the recall query opens the *task*. What it changes is easiest to see in the incident this book keeps returning to. The previous volume's operator diagnosed a failed GPU power-cap unit from scratch, spending turns establishing that the unit fails at boot, that exit 2 was the vendor tool's "no device", that the

journal was unreadable from its seat. Its successor, facing the same unit after the next kernel upgrade, opens with `MATCH 'gpu-power-cap'` — and inherits the whole prior investigation in three ranked entries: root cause candidate, the fix that worked, the verification that proved it. The second diagnosis starts where the first one ended, which is the entire economic argument for the journal in one example: every searched session converts some past session's spent turns into this session's free context. An operator that searches before acting compounds; one that does not pays for the same knowledge repeatedly, which is the amnesiac's tax this book exists to end.

The ritual has a write-side twin: promotion. Not everything a session learns deserves the journal — transcripts are artifacts, scratch reasoning is scratch — but any fact that *cost real turns to establish* and could recur gets promoted to a journal entry at outcome time, written by the searcher's rules above. The test is the compounding one: *would the successor's ritual search want to find this?* Diagnoses, fixes-that-worked, dead ends that looked promising (the previous volume's honest-failure reporting, feeding recall), environmental facts expensively verified. The promotion moment is the session's close, alongside the ledger completion and the handoff — memory's last act before ending, and the first thing its successor will thank it for.

One long-horizon honesty note completes the craft: vocabulary drifts. The unit renamed in a refactor, the host re-addressed, the procedure's informal name changed by a new supervisor — entries indexed under the old terms quietly fall out of recall for operators searching the new ones. The estate's countermeasures are modest and adequate: prefer stable identifiers (paths, unit names) over informal descriptions in entries; when a rename happens, journal the rename itself ("X is now Y") so either term's search surfaces the bridge; and let the correction-citation habit carry the rest. Recall systems decay by default; a memory meant for years gets tended like one.

What recall cannot do

The chapter closes on its instrument's honest edges, in the tradition both volumes share. Recall retrieves what was *recorded*: a search that returns nothing proves only that no entry matched, never that nothing happened — the register's empty-output ambiguity, now at the scale of institutional memory, and the reason chapter 4's structured tables carry the load-bearing history (the ledger's completeness is a discipline with a `CHECK`; the journal's is a courtesy). The searcher therefore treats journal silence as a prompt to consult structure — the ledger by subject, the registry by date — before concluding novelty; "the journal has nothing

on X" and "X never happened" are different sentences, and only middens confuse them. Symmetrically, what recall returns is *testimony*, not ground truth: an entry is what some past session believed at outcome time, aging from the moment it was written, and chapter 7's staleness pricing applies to retrieved memories exactly as to queried facts — the searcher checks *written* at before betting anything expensive on a reminiscence. None of this diminishes the instrument; it locates it. The journal makes the estate's experience *findable*; the structured tables make its claims *checkable*; the trust disciplines make both *weighable*. An operator using all three in their places has something neither databases nor diaries provide alone — a memory that can answer, and can say how sure it is.

The index itself, finally, costs what it looks like it costs: roughly the text again in storage (each token posted to its list), maintained incrementally on every write, imperceptible at journal scales. Two maintenance verbs cover its lifetime: *optimize* (an INSERT-command idiom the FTS5 documentation specifies) consolidates the index's internal segments after heavy write bursts, and *rebuild* — chapter's earlier rung — remakes it wholesale from content, the recovery hammer that also serves after tokenizer changes, since tokenization choices are baked in at index time and a switch to porter mid-life reindexes or lies. Both are estate maintenance acts like any other: scheduled, ledgered when they find work, invisible otherwise.

Recall, then: prose holdings indexed in the same file, under the same transactions; queries in words with ranking, prefixes, proximity, and marked evidence; a token model understood rather than guessed; semantic tools placed beside, not instead; and the index's honesty audited like everything else the estate claims. The operator that keeps this chapter's journal owns something the midden never offered and even most human admins never build — a searchable account of everything it has ever known. What it does not yet own is *confidence* in the file that holds all of this. Confidence is manufactured, on schedule, by verification — and that is chapter 7.

Chapter 7 — Trust, Verify, Repair

Draft status: author draft, gate-checked; human verification pending. Outputs are real transcripts; the corruption in the final listing is real damage, inflicted on a scratch database by the listing itself.

Inherited trust is not trust

Every chapter so far wrote the estate; this one inherits it. The successor operator opens a file it did not create, holding records it did not witness, and must decide how much weight the file can bear — before building on it, not after. The register's previous volume made this posture a reflex for machines ("the four-question routine", "proof of target"); the estate needs the same reflex with different instruments, because a database can fail in ways a transcript cannot: bytes rot, copies go stale, sidecars get separated from their files, and — the quiet majority of real incidents — the backup everyone trusted turns out to have been wrong every night for a year. The good news is proportionate: the estate's engine ships verification as a first-class operation, cheap enough to run on schedule, and the correct-backup problem has exact, documented answers. This chapter is those instruments, ordered as the successor meets them: verify what you inherited, back up what you verified, and know the recovery ladder before you need its rungs.

The posture to install is the same one the previous volume gave outward reports: *claims sized to evidence*. An estate is not "fine" because it opens — chapter 2 showed opening does almost nothing — and not "backed up" because a file named backup exists. It is fine because `integrity_check` said ok recently; it is backed up because a restore was *drilled*. Everything below mechanizes those two sentences.

The opening move

SQLite's self-audit walks the entire file — every page, every index, every constraint's storage — and returns either the single row ok or a list of what is wrong:

```
import sqlite3, pathlib
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE facts (id INTEGER PRIMARY KEY, fact TEXT) STRICT")
with db:
    db.executemany("INSERT INTO facts (fact) VALUES (?)",
    [(f"fact {i}",) for i in range(200)])
    print("healthy file says:", db.execute("PRAGMA
    integrity_check").fetchone()[0])
```

```

db.close()
raw = bytearray(pathlib.Path("estate.db").read_bytes())
raw[4096:4160] = b"\xde\xad" * 32 # 64
bytes of damage mid-file
pathlib.Path("estate.db").write_bytes(raw)
db = sqlite3.connect("estate.db")
try:
    verdict = db.execute("PRAGMA integrity_check").fetchall()
    print("damaged file says:", verdict[0][0][:70])
except sqlite3.DatabaseError as e:
    print("damaged file says:", e)

```

```

healthy file says: ok
damaged file says: database disk image is malformed

```

Sixty-four bytes of damage, surgically inflicted mid-file, and the audit caught it — where a JSON midden with the same wound would have parsed cleanly or failed confusingly depending on where the bytes landed, and a naive estate consumer might have read plausible garbage for weeks. Operating doctrine for the check: it runs at *inheritance* (a successor's first act on an estate it did not close), at *backup* (below — verifying the copy, which is the copy that matters), and on *schedule* for long-lived estates. Its cost scales with file size; the lighter PRAGMA `quick_check` skips the slowest cross-checks and is the right compromise for large estates checked often, with the full check reserved for backups and suspicion. Two companions complete the audit toolkit: PRAGMA `foreign_key_check` reports orphaned references (chapter 3's switch enforces them per-connection going forward, but rows written by some past pragma-forgetting tenant are findable only by asking), and the application-level audits this book has been accumulating all along — chapter 4's artifact hashes, chapter 6's index-sync counts — run beside the engine's, because the engine can only vouch for storage, never for meaning.

Verification's price list keeps the schedule honest, so the costs go on record with the doctrine. `integrity_check` reads every page and checks every index against its table — I/O-bound, linear in file size, seconds for the megabyte estates this book's patterns produce and minutes only when an estate has ignored chapter 8's retention for years. `quick_check` skips the slow cross-checks (index-to-table consistency among them) for roughly order-of-magnitude savings, which is why the daily seat belongs to it and the full check rides the backup cadence, where its cost disappears into an operation that reads the whole file anyway. `foreign_key_check` scales with the referencing tables it scans; the application audits cost whatever their queries cost, which chapter 3's index discipline already bounded. None of it approaches the price of the alternative — the register's economics, one last time: a verification is a read, reads are cheap, and the one commodity that cannot be bought back after the fact is the confidence that yesterday's estate was

sound *yesterday*, attested on the record, by a check that ran when nobody was worried.

One boundary of the engine's audit deserves explicitness before the backup sections rely on it: `integrity_check` proves the file is a well-formed database; it does not prove it is *your* database. A backup restored from the wrong generation, an estate swapped by mistake, rows deleted by an authorized-but-wrong session — all audit ok, because storage soundness was never identity or completeness. The estate's own layers carry that weight where it matters: the info table names the estate and its lineage (chapter 3), the artifact index's hash pins each backup generation to its recorded identity, and — for estates whose threat model includes tampering rather than mere accident — the ledger's append-only shape extends naturally to a verification chain, each row carrying a hash over its content plus its predecessor's hash, making silent rewriting of history detectable by one walk. Most operator estates stop well short of that last measure, and should; the point of naming the layers is the habit of asking, for each trust question, *which* instrument actually answers it — the engine for bytes, the schema for meaning, provenance for identity, and, at the far end, cryptography for adversaries. Chapter 5's threat was concurrency and the engine answered it; this chapter's is decay and mistake; the adversarial case is real but rarer, and an estate that reaches it has usually outgrown one file for reasons chapter 8 already catalogs.

The backup that lies

Chapter 5 promised that copying a live WAL database loses data; here is the loss, measured. The scenario is the commonest backup bug in SQLite's world: a cron job that `cps` the main file, unaware that recent commits — sometimes all commits — live in the `-wal` sidecar until a checkpoint folds them in:

```
import sqlite3, shutil
db = sqlite3.connect("estate.db")
db.execute("PRAGMA journal_mode = WAL")
db.execute("PRAGMA wal_autocheckpoint = 0")                # keep
recent commits in the -wal
db.execute("CREATE TABLE ledger (id INTEGER PRIMARY KEY,
entry TEXT) STRICT")
with db:
    db.executemany("INSERT INTO ledger (entry) VALUES (?)",
                    [(f"entry {i}",) for i in range(500)])
print("live estate holds:", db.execute("SELECT count(*) FROM
ledger").fetchone()[0])
shutil.copyfile("estate.db", "naive-backup.db")           # cp on
a live WAL database
naive = sqlite3.connect("naive-backup.db")
try:
    print("naive copy holds:", naive.execute("SELECT count(*)
```

```
FROM ledger").fetchone()[0])
except sqlite3.OperationalError as e:
    print("naive copy says: ", e)
```

```
live estate holds: 500
naive copy says: no such table: ledger
```

Worse than losing rows: the copy lost the *table*. Every commit of this young database still lived in the write-ahead log, so the main file held little more than a header, and the backup — well-named, timestamped, dutifully rotated — would restore to an empty estate. The demonstration pins the extreme case by disabling auto-checkpointing, but the production version differs only in degree: with default checkpointing the naive copy is missing *whatever committed since the last checkpoint*, an amount that varies invisibly from minute to minute — a backup whose completeness is a coin toss weighted by timing. And the rollback-journal sibling of this bug is nastier still: a cp taken mid-transaction can capture a half-committed page set that *the copy has no journal to repair*, yielding not a stale backup but a corrupt one. The rule absorbs in one line — **a database in use cannot be copied by copying its file** — and the honest versions cost nothing, as the next listing shows.

The backup that tells the truth

The engine offers two correct paths, both usable while the estate is live. `VACUUM INTO` writes a complete, transactionally consistent, freshly-packed copy to a new file in one statement; the online backup API (exposed in Python as `Connection.backup`) streams a consistent copy page by page, politely yielding to concurrent writers. The first is the estate's default for its simplicity and the compaction it throws in free:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("PRAGMA journal_mode = WAL")
db.execute("PRAGMA wal_autocheckpoint = 0")
db.execute("CREATE TABLE ledger (id INTEGER PRIMARY KEY,
entry TEXT) STRICT")
with db:
    db.executemany("INSERT INTO ledger (entry) VALUES (?)",
                    [(f"entry {i}",) for i in range(500)])
db.execute("VACUUM INTO 'true-backup.db'") #
transactionally consistent copy
bak = sqlite3.connect("true-backup.db")
print("backup holds: ", bak.execute("SELECT count(*)
FROM ledger").fetchone()[0])
print("backup integrity: ", bak.execute("PRAGMA
integrity_check").fetchone()[0])
```

```
backup holds:      500
backup integrity:  ok
```

Same live database, same uncheckpointed WAL, and the copy holds all five hundred rows with a clean audit — because the copy was made *through the engine*, which knows where the truth currently lives, instead of through the file system, which does not. The listing also models the doctrine's second clause: the verification ran *on the backup*, in the same breath as its creation. An unverified backup is a hope with a filename; this one leaves the session as a claim with evidence, ready for chapter 8's handoff. Around the mechanism goes ordinary register discipline, inherited wholesale from the previous volume: timestamped backup names (its reversibility chapter), retention by schedule (its timer chapter), the backup recorded in the ledger with outcome and integrity verdict (chapter 4), and — the clause institutions skip until an incident teaches it — the *restore drill*: on some schedule, a backup is actually opened, actually queried, actually compared against expectations, because "backup succeeded" and "restore works" are different facts and only the second one was ever the point. The drill, too, is one `open_estate()` against yesterday's file plus a handful of the standing queries — for an unattended operator, a scheduled job like any other.

The trust ladder for inherited estates

Verification instruments in hand, the successor's opening posture can be graded rather than binary — a ladder of earned trust, climbed as far as the work requires, mirroring the evidence disciplines the previous volume built for machines. Rung zero: the file opens and identifies itself (`user_version`, `sqlite_schema`) — enough to *look*, nothing more. Rung one: `quick_check` says ok — storage is sound; the successor may *read* and build provisional plans. Rung two: the application audits pass — foreign keys check out, artifact hashes match, the FTS row counts agree — the estate's *internal* claims cohere, and routine work may proceed on them. Rung three, for records about to bear real weight: spot re-verification against the *world* — the config row against the actual file it describes, the "service healthy" outcome against a fresh probe — because storage integrity never promised the world held still, and rung three is where the estate's recorded `at` columns earn their keep by pricing each fact's staleness. The ladder's use is economic, in the register's sense: climbing costs turns, and the height required is set by what the session will do — a read-only report trusts at rung one; a purge keyed on artifact rows climbs to three for exactly the rows it will act on. What the ladder forbids is only the midden habit: acting at rung three's stakes on rung zero's evidence because the file opened and looked plausible.

Cadence, copies, and the cold rule

Mechanism without schedule is chapter 7's own evidence theater, so the backup doctrine gets its operational shape. Cadence follows value density: an estate absorbing a session's work backs up at session end (the handoff's natural moment — the briefing cites the backup it just verified); estates under continuous unattended write take a timer (previous volume, chapter 4) on a period priced by the acceptable loss window. Retention follows the previous volume's timestamped-graveyard pattern: dated backup files, a purge schedule, and at least one *drilled* generation always outside the blast radius of the newest mistake — because the incident that corrupts an estate at 3 a.m. is also the incident most likely to have corrupted *tonight's* backup at 2:55. Distribution follows one clarifying rule: cold copies travel freely, live files never. The naive-copy prohibition binds only the *live* database; a `VACUUM INTO` product is a closed, complete, ordinary file, and every file tool the register knows — `rsync` to another host, checksum manifests, the artifact index itself (the estate's backups belong in the estate's *successor's* artifact table, hash and all) — applies to it without caveat. The 3-2-1 folklore translates directly once that distinction is held: three copies, two media, one elsewhere — all of them cold, all of them born from the engine, none of them a cp of a file something might be writing.

Sidecar forensics

Because chapter 5's sidecars are where naive tooling does its damage, the successor needs the reading list for files found beside an inherited estate. A `-wal` file present at rest: normal — the last tenant exited without a final checkpoint; the engine will fold it in on open, and the only wrong move is "cleaning it up" first, which discards committed transactions. A `-shm` file: coordination scaffolding, meaningless at rest, recreated on demand — its presence signals nothing. A `-journal` file: an interrupted rollback-journal transaction awaiting automatic recovery on open — same rule, sharper stakes: deleting it converts a recoverable interruption into corruption. The general law covers every case and fits on one line: **sidecars are opened with the engine, never interpreted, moved, or deleted by hand** — and its corollary from chapter 5, that a live estate's directory is copied only through the engine, completes the pair of rules that would, between them, have prevented the majority of the corruption stories the documentation's post-mortems collect. The one legitimately hands-on act — archiving a *cold* estate directory whose tenant is confirmed gone — is the previous volume's proof-of-target discipline: `fuser` says no holders, then the whole directory travels together, sidecars included, as one artifact.

The ladder down

Last, the bad day: verification failed, on the live file. The recovery ladder, descended in order and recorded in the run's account at every rung. First rung: stop writing — every write to a corrupt database deepens the hole, so the estate goes read-only the moment the audit speaks (the ledger's own account of this event goes, per chapter 1's taxonomy, in a *different* file). Second: preserve the evidence — copy the damaged file *and its sidecars* (file-level copy is correct here precisely because the priority has inverted: bytes, not consistency, are now the asset) before any recovery attempt touches them. Third: restore from the newest verified backup, measure the gap — the ledger's last rows in the backup date the loss — and let intent-then-outcome (chapter 2) direct the re-verification of whatever world actions fell in it. Fourth, only when backups fail the need: salvage — the `.recover` command of the `sqlite3` shell walks the wreck and emits everything reconstructible, and `.dump` predates it as the cruder tool; both produce SQL to rebuild a new file, never repairs in place. And the rung below salvage is candor: some losses are losses, and the register's covenant — retractions told, not hidden — applies to estates exactly as to publications. The successor inherits the account of what was lost with the same provenance discipline as any other fact, because the alternative — a gap wearing a calm face — is the one failure this book's whole tradition refuses.

The estate you did not expect

The trust ladder assumed the estate is *yours* — an inherited file from your own lineage, suspect only of decay. Operators also meet the other kind: a database file of unknown provenance, arriving as a download, an attachment, another team's export. The engine's security documentation is plain that a database file is an *input* like any other, and a crafted one is an attack surface: deliberately corrupt structures probing the parser, and — subtler — schema-borne behavior, because views and triggers execute when touched, meaning a hostile schema can make an innocent-looking `SELECT` do things its reader never wrote. The defensive posture for unknown files costs three lines and the register's habits. Open read-only (`mode=ro` — chapter 5's seat, now as armor). Set `PRAGMA trusted_schema = OFF`, which refuses the schema-borne tricks the security documentation enumerates — and set it explicitly, because while that documentation *recommends* off, the compiled default on most builds remains on for compatibility (the authoring machine's build included, measured mid-draft after this paragraph's first version claimed otherwise — a correction the register's covenant obliges this book to leave on the record). Then run `PRAGMA integrity_check` plus `quick_check` before any real query, as triage rather than trust. And read the schema *as text first*

(`sqlite_schema`, chapter 3's stranger query) before running anything that would evaluate it — the previous volume's read-before-edit, reincarnated as read-before-query. For the estate's own lineage this paranoia is unnecessary by construction; the point of stating it is the boundary: the disciplines that make your own estates trustworthy are provenance disciplines, and a file without provenance gets the other protocol, every time, no matter how much its tables look like home.

The standing verification job

Instruments and cadences assembled, the chapter's doctrine compresses into one scheduled session — the estate's health check, an unattended operator like any other, whose own runs land in the registry it audits. Its shape, as a template to adapt: daily, `quick_check` plus the application audits (foreign keys, FTS sync counts, open-intent staleness — chapter 8's briefing queries, run for alerting rather than orientation), each result a ledger row only when it *finds* something, per the only-writes rule. At backup cadence, the full sequence this chapter demonstrated: `VACUUM INTO` a dated file, `integrity_check` on the product, hash into the artifact index, retention purge of expired generations — one transaction of record per backup, proof included. Monthly, the restore drill: yesterday's backup opened, briefed, and spot-queried, with the drill's outcome ledged because "restores worked in August" is exactly the kind of claim an incident in November wants dated. And on every schedule, the meta-check the register's monitoring chapter taught: the health check's *own* absence must be loud — a job that verifies everything but whose silence looks like health is the calm-face failure again, so the briefing's staleness queries watch the watcher too ("last verification run: when?"). None of this is machinery beyond what the book already built; it is chapters 4 through 7 composed into a timer, which is the estate's whole method arriving at its own maintenance.

When the bytes are fine and the facts are not

One verification failure mode remains that no pragma detects: meaning-rot. The storage audits clean, the hashes match, and the record is *wrong* — because the world moved after the row was written. The config row describes a file someone hand-edited last week; the "service healthy" outcome predates the migration; the fact about the gate's memory cap was true of a gate two versions ago. The estate's defenses are the provenance disciplines laid down in chapter 3, now read as a freshness system. `recorded_at` prices every fact's age, and the trust ladder's rung three — re-verify against the world before acting — is *triggered* by that price

crossing the stakes at hand: a day-old fact backs a routine read; a season-old fact backing a destructive write gets re-proven first, by the register's own proof-of-target reflexes. source makes re-proving cheap: the row that names its origin (a path, a command, a URL) carries its own re-verification procedure. And the correction habit closes the loop: a fact found stale is not UPDATED into silence but corrected on the record — new row, correction citing the old, journal entry for the searcher — so the estate's history shows not only what was believed but when belief was revised, which is what distinguishes a memory from a cache. Byte integrity the engine guarantees; fact integrity is a practice, and it is the same practice this press runs on manuscripts: dated claims, resolvable sources, corrections told.

Corruption itself deserves a closing word of proportion, because the engine's reputation sometimes takes blame its documentation carefully allocates elsewhere. SQLite's file format is famously durable; the documented paths to corruption are dominated by the environment — storage that lies about syncs, network filesystems with broken locking, *other processes* deleting or copying sidecar files, backups taken the naive way — and by exotic misconfiguration, not by the engine's bookkeeping. Which returns the chapter to its theme with the emphasis correctly placed: the estate's trustworthiness is mostly the operator's conduct — local disks, sidecars respected, engine-mediated copies, checks on schedule, drills for real. The engine holds up its half ruthlessly. The verification suite is how the operator proves, on schedule, that both halves are still standing — and its verdicts are precisely what the final chapter's handoff will cite.

Chapter 8 — Where Memory Ends

Draft status: author draft, gate-checked; human verification pending. Outputs are real transcripts.

Forgetting is a design decision

An estate that only accumulates is an estate slowly failing. Storage is the smallest part of the cost; the real prices are the ones earlier chapters taught to measure — queries slowing as standing questions wade through dead history, backups fattening, the searchable journal's recall silting up with answers from configurations three redesigns gone, and the successor's attention (the register's scarcest currency) spent distinguishing the live truth from the merely undeleted. Human institutions handle this with retention policy; middens handle it never; the estate handles it the way it handles everything — as schema plus schedule. Every record table's provenance block already carries `recorded_at`; a retention rule is one settings row (chapter 4's config pattern: value, author, *reason*) and one scheduled DELETE keyed on age and kind. What the samples keep for ninety days, the ledger might keep forever — the rule is per-shape, and deciding it is part of designing the shape.

The mechanics hold one honest surprise, so it is demonstrated rather than mentioned:

```
import sqlite3, pathlib
def size(): return pathlib.Path("estate.db").stat().st_size
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE samples (id INTEGER PRIMARY KEY,
taken_at TEXT, v REAL) STRICT")
with db:
    db.executemany("INSERT INTO samples (taken_at, v) VALUES
(?, ?)",
                    [(f"2026-{m:02d}-01T00:00:00Z", float(i))
                     for i in range(5000) for m in [i % 12 + 1]][5000])
    print(f"5000 samples: {size():>7} bytes")
with db:
    db.execute("DELETE FROM samples WHERE taken_at <
'2026-08'")
    print(f"after DELETE: {size():>7} bytes (rows left: "
          f"{db.execute('SELECT count(*) FROM
samples').fetchone()[0]}")
    db.execute("VACUUM")
    print(f"after VACUUM: {size():>7} bytes")

5000 samples: 167936 bytes
after DELETE: 167936 bytes (rows left: 2081)
after VACUUM: 73728 bytes
```

The DELETE removed three-fifths of the rows and not one

byte of the file: freed pages go onto an internal freelist for reuse, not back to the file system. That is the right default — the space will be refilled by new rows without growing the file — and it means "did the cleanup run?" must be answered by row counts, never by file size, an evidence-reading rule in the previous volume's best tradition. When the file itself must shrink (an estate handed over leaner, a one-time purge of years), `VACUUM` rebuilds it compact — here to well under half — at the cost of rewriting the whole file, which prices it as an occasional maintenance act, not a routine one. (The `auto_vacuum` pragma trades away that control for continuous truncation and must be chosen at the file's birth; estates mostly decline it, preferring the freelist default plus deliberate compaction at handoff.) Retention closes with its own register discipline: the purge is a world-changing act like any other — ledgered with row counts as proof (chapter 4), rehearsed as a `SELECT` count before it runs as a `DELETE` (the previous volume's dry-run doctrine, verbatim), and never aimed at the ledger's own account of what was purged.

A retention policy, worked

Policy beats intention only when written down per shape, so here is the worked schedule for the five patterns plus the journal, as a template to argue with rather than a default to obey. The *ledger* keeps its rows effectively forever: it is the estate's spine of accountability, its rows are small, and "what did we do to this host, ever" is a question with no statute of limitations — but its bulky columns age: transcripts referenced from outcomes move to artifacts, and artifacts age on their own schedule. The *run registry* keeps individual rows for a season, then aggregates: after ninety days, per-run detail collapses into the monthly per-task statistics the calibration queries actually consume — the previous volume's counters-not-samples idea, applied to history. *Cursors* are current-state only and never accumulate; their retention question is inverted — chapter 4's staleness query retires streams nobody reads. *Config history* keeps everything: it is small, and the reason column's value compounds with age. *Samples and probes* — the high-rate tables chapter 5 suggested splitting out — take the shortest leash, ninety days in the worked listing above, because their value is trend-shaped and the trend survives in coarser aggregates. The *journal* keeps entries but prunes supersession: when a later entry corrects an earlier one, the correction cites the original (chapter 4's append-only correction rule), and the retention pass may eventually drop superseded bodies while keeping their headers — recall should surface the correction first anyway. Every line of the policy lives in the settings table with a reason, enforced by one scheduled session whose own run lands in the registry — the estate pruning itself, on the record, by its own rules.

Leaving well: the estate as interchange

Estates outlive not only their operators but sometimes their *format's* welcome — a successor toolchain that wants JSON, an analyst who wants a spreadsheet, an archive that wants plain text. The estate's exit doors are as important as its locks, and the engine's answer is the dump: the entire database rendered as SQL text —

```
import sqlite3
db = sqlite3.connect("estate.db")
db.execute("CREATE TABLE facts (id INTEGER PRIMARY KEY, fact
TEXT NOT NULL) STRICT")
with db:
    db.execute("INSERT INTO facts (fact) VALUES ('the estate
travels as SQL')")
for line in db.iterdump():
    print(line)
```

```
BEGIN TRANSACTION;
CREATE TABLE facts (id INTEGER PRIMARY KEY, fact TEXT NOT
NULL) STRICT;
INSERT INTO "facts" VALUES(1,'the estate travels as SQL');
COMMIT;
```

— schema, data, and even the transactional bracket, in a text form that diffs, greps, compresses, and rebuilds the estate on any SQLite anywhere (and, dialect edges aside, seeds the migration to a server engine when chapter's-end day comes: the schemas translate, the patterns translate, the dump carries the rows). Chapter 1 promised the database's opacity was one command deep; this is the command, and its uses compound: the dump is the archival format (text outlives everything), the review format (a dumped estate can be read in a pull request), and the last-resort recovery format chapter 7 already met. For narrower doors, one query with Python's `csv` or `json` module beside it exports any table to any tabular audience — the estate holds the truth once and renders it per reader, which has been this press's own doctrine (canonical source, generated renderings) since its first book.

Where the estate ends

This book owes its reader the boundary drawn from the outside, without defensiveness, because tools are trusted in proportion to how honestly their limits are stated. The estate's engine is the wrong tool in four recognizable situations. Many writers across many hosts: SQLite coordinates through the local filesystem's locks, so the moment writers live on different machines, the shared-file arrangement is over — network filesystems' locking is the corruption documentation's most decorated villain — and a server database's whole reason for existing (a process that

owns the data and speaks a network protocol) begins. Sustained high write concurrency even on one host: chapter 5's single-writer queue is a ceiling; fleets of chatty writers feel it, and past the covenant's remedies (batching, splitting estates along real seams) lies the honest handoff. Analytical scale: row stores serve the estate's point queries; when the questions become scans over hundreds of gigabytes, columnar engines exist for a reason. And blob warehousing: chapter 1 already sent large immutable bytes to the file system with the index pattern; a database that ate the artifacts anyway becomes the backup problem chapter 7 warned about. The engine's own "appropriate uses" page draws nearly this same map, with a sentence this book endorses as the whole test: SQLite competes with `fopen()`, not with client-server databases. When a workload starts competing with the *server*, believe it — take the schemas, the provenance discipline, the intent-then-outcome pattern, all of which translate verbatim to bigger engines, and leave with the estate's habits intact. The discipline was always the portable part.

The ceiling deserves numbers, because "high write concurrency" hides the arithmetic that decides real cases. A write transaction on local NVMe under WAL with NORMAL sync costs on the order of a millisecond; call it two for honest margin. The single-writer queue therefore clears roughly five hundred write transactions a second — sustained, all tenants combined — before latency begins compounding, and chapter 2's batching multiplies the *row* throughput far beyond that (the batching listing moved a thousand rows per transaction without strain). Against those numbers, the estate's actual workload reads as parody: a busy operator session commits a few dozen transactions an hour; a fleet of twenty chatty agents at a transaction each per second consumes four percent of the ceiling. The arithmetic is worth one settings-table row per estate (measured, not copied — hardware varies) because it converts the anxious question "will SQLite scale for us?" into a comparison of two numbers, and for operator estates the comparison is not close. When it ever becomes close — genuine hundreds of writers, sustained — that is not a tuning problem; it is the workload announcing it has outgrown the amnesiac's-estate shape entirely, and the handoff below is waiting.

Worth naming, because this book's reader will meet them: the ecosystem now holds replication and sync layers that stretch SQLite across hosts and edge fleets. They are real engineering with real tradeoffs, and they change none of this chapter's advice about *defaults*: the estate begins as one local file, and distribution is a deliberate migration undertaken when a named workload demands it — never a posture adopted in advance because it might.

The estate at generation fifty

A last durability question, rarely asked because estates are young: what does this design look like after years — schema version fifty, migrations numbering in dozens, tables reshaped twice, operators long turned over? The mechanisms already built age gracefully, with two maintenance notes. The migration list grows without bound, and append-only forbids pruning it — but a *baseline* is sanctioned: at a major generation, a new "migration zero prime" that creates the current schema outright for fresh files, with the historical chain retained behind a version check for old files still in the wild. Fresh estates then build in one step while inherited ones walk their true history — both roads recorded, neither rewritten, the covenant intact. And the schema's *documentation debt* compounds unless the comment habit (chapter 3) is treated as part of every migration: a migration that adds a column without its comment is, at generation fifty, the column nobody can explain. The deeper reassurance is the engine's own horizon — the format pledge through 2050 that chapter 1 cited — plus the exit door demonstrated below: an estate is never more than one dump away from plain text, so even the fifty-generation file's worst case is a readable will. Estates are the rare software artifact whose *pension plan* can be stated at birth, and this paragraph is this book stating it.

The briefing: an estate introduces itself

The book's patterns converge on a closing ritual, the estate's counterpart to the previous volume's handoff message. When a successor opens the estate, its first act is a briefing — one composed read that turns the file into a situation report:

```
import sqlite3
db = sqlite3.connect("estate.db")
db.executescript("""
PRAGMA user version = 7;
CREATE TABLE ledger (id INTEGER PRIMARY KEY, op_key TEXT
    UNIQUE, action TEXT,
    outcome TEXT, intent_at TEXT DEFAULT
    (strftime('%Y-%m-%dT%H:%M:%SZ', 'now'))) STRICT;
CREATE TABLE runs (id INTEGER PRIMARY KEY, operator TEXT,
    task TEXT,
    started_at TEXT DEFAULT
    (strftime('%Y-%m-%dT%H:%M:%SZ', 'now')), ended_at TEXT)
    STRICT;
CREATE TABLE cursors (stream TEXT PRIMARY KEY, position TEXT,
    advanced_at TEXT) STRICT;
INSERT INTO ledger (op_key, action, outcome) VALUES
    ('a1', 'renew tls cert', 'ok');
INSERT INTO ledger (op_key, action) VALUES ('a2', 'purge
    quarantine');
INSERT INTO runs (operator, task, ended_at) VALUES
    ('session-90', 'weekly report', '2026-08-27T09:00:00Z');
INSERT INTO runs (operator, task) VALUES ('session-91', 'cert
```

```

renewal');
INSERT INTO cursors VALUES
('journal:sshd','s=9f2;i=88a','2026-08-21T04:00:00Z');
""")
print("ESTATE BRIEFING")
print(" schema version:", db.execute("PRAGMA
user version").fetchone()[0])
print(" storage audit: ", db.execute("PRAGMA
quick check").fetchone()[0])
print(" unresolved intents:")
for r in db.execute("SELECT op_key, action FROM ledger WHERE
outcome IS NULL"):
    print(" ", r)
print(" unfinished runs:")
for r in db.execute("SELECT operator, task, started_at FROM
runs WHERE ended_at IS NULL"):
    print(" ", r)
print(" stale cursors (older than 3 days):")
for r in db.execute("""SELECT stream, advanced_at FROM
cursors
                        WHERE advanced_at <
strftime('%Y-%m-%dT%H:%M:%SZ','now','-3 days')"""):
    print(" ", r)

ESTATE BRIEFING
schema version: 7
storage audit: ok
unresolved intents:
('a2', 'purge quarantine')
unfinished runs:
('session-91', 'cert renewal', '2026-08-28T18:08:08Z')
stale cursors (older than 3 days):
('journal:sshd', '2026-08-21T04:00:00Z')

```

(The listing stages a miniature estate inline so the briefing has something true to report; against a real estate, only the queries run.)

What earns a line in the briefing is a contract worth stating, because the briefing fails by growth exactly as handoff messages do. A line belongs if and only if it can change what the session does *first*: unresolved intents (they gate everything — acting with an unknown fate outstanding is the register's cardinal sin), unfinished runs (same), integrity verdicts (a failed audit preempts the task entirely, chapter 7's protocol), and staleness past policy (a dead stream or an overdue verification is quiet risk accumulating). Aggregates, trends, and curiosities — row counts, failure rates, the month's statistics — stay out, availably behind the standing queries but not in the opening screen, by the same bounding rule the register applied to every read: the briefing is the session's first transcript, and its volume is priced accordingly. A briefing held to that contract stays under a dozen lines for a healthy estate — and develops, over time, the property the previous volume prized in good shots: its *shape* carries information, because a briefing that suddenly runs long is itself the finding. Read what the successor knows, thirty milliseconds after opening a file it has never

seen: which schema generation it holds, that storage audits clean, that a quarantine purge was intended and its fate is unknown, that a cert-renewal session is unaccounted for, that nobody has read the `sshd` journal in a week. That is not a database report; it is a *to-do list with provenance* — read the world about the purge, close out session 91's row honestly, decide whether the stale cursor means a dead timer or a quiet stream. Every line exists because some chapter made it queryable: versioning (3), NULL-as-honesty (4), the registry (4), cursor staleness (4), the audit (7). The briefing belongs in `open_estate()` behind a flag, in the session-start ritual of any operator with an estate, and — printed — at the top of the handoff message the previous volume taught, where its lines are exactly the "what remains" section that chapter said load-bearing handoffs owe.

Outgrowing, watched closely

Because the handoff to bigger engines is this chapter's most consequential advice, the moment of outgrowing deserves a worked narrative rather than a threshold. A team's estate begins as this book's: one machine, a handful of operators, the covenant humming. Growth arrives as symptoms, in a recognizable order. First the analytics groan — the monthly report's scans lengthen — and the correct response is chapter 3's (indexes for the new standing questions) plus chapter 8's retention actually enforced; most "outgrowing" dies here, having been undergardening. Next, write waits appear in the busy taxonomy's second face — persistent BUSY under honest timeouts — and the correct response is the ceiling section's ladder: transaction shapes audited, high-rate tables split out, the arithmetic row updated with measured numbers. The genuine boundary announces itself only after those: operators on *other hosts* need to write — not read (cold copies and dumps serve readers anywhere) but write, concurrently, into one truth. That is the workload SQLite's design honestly declines, and the migration it forces is smaller than dreaded precisely because of this book's disciplines: the schemas translate nearly verbatim (STRICT types map to real types, CHECKs and foreign keys travel as-is), the patterns are engine-agnostic (ledgers, cursors, registries, and their standing queries care nothing for the wire protocol), the dump seeds the new home, and the estate's habits — provenance, intent-then-outcome, verification on schedule — were always the portable asset. What the team leaves behind is one file's worth of operational simplicity, and the book's advice at the boundary is to mourn it briefly and honestly: the server buys multi-host writes with a daemon to run, credentials to manage, backups that are no longer VACUUM INTO, and a network between every operator and its memory. Pay when the workload demands it; not one day sooner.

The last session

Estates end, and ending well is the same craft as everything else in this book, so the decommissioning protocol closes the operational chapters. An estate ends when its lineage does — the operator retired, the project closed, the machine decommissioned — and the final session's obligations mirror the first session's in reverse. Verify, one last time, at full depth: the ending estate's integrity check and application audits, because the archive about to be made will be trusted precisely as far as this moment proved it. Resolve or bequeath the open items: unresolved intents and unfinished runs are closed honestly (abandoned, with reasons) or explicitly transferred — a final journal entry naming what remains and where it went, the previous volume's "what was not done" clause, written for the ages. Compact and archive: VACUUM for the lean final form, then the dump — the text will — generated and stored beside the binary, both hashed into whatever artifact index survives the estate (the supervisor's, a successor project's, the platform's). Tombstone the location: where the estate lived, a small note says it ended, when, and where its archive went — the drop-in comment discipline, applied to absence, so no future operator finds an empty path and wonders. And the settings history's last row records the decision itself, with its reason, by whatever authority made it. An estate closed this way can answer questions decades later — which, for a book that began with operators who forget everything at sunset, is the arc completed: from memory that could not survive a session to memory that survives its own death.

Coda: the garden

A last image, in place of a summary. The colony insects that farm — the ones that cannot digest what they harvest — solved the amnesiac's problem at the scale of a species: no individual holds the colony's knowledge, and the colony thrives anyway, because what matters is deposited in a *structure* — tended, verified, inherited — that outlives every worker that ever tended it. No worker remembers; the garden does. This book has been one long argument that session-bound operators should live the same way, and its argument is now complete enough to state in a sentence: **be an ephemeral mind with a durable garden.** Write truths whole or not at all; shape the beds so a stranger can tend them; let generations work the same plot without trampling each other; keep what is worth keeping findable, prove the garden still sound on schedule, and prune what has stopped feeding anyone.

The image also returns the book's opening claim with interest. Chapter 1 called the estate a description of what serious software already does; the garden says why the

convergence was inevitable. Any system of short-lived workers and long-lived purposes — colonies, institutions, browsers, operator lineages — ends up building the same thing: durable, structured, verified external state, because it is the only architecture in which the workers' mortality stops mattering. The estate is that architecture at the smallest possible scale: one file, one engine, one set of disciplines slim enough for this pocket book — which is exactly why it was worth a book. The pattern scales down to a cron job and up to a civilization, but somebody has to write down the small end carefully, because the small end is where every lineage starts.

The author's stake in this is not rhetorical. The operator that wrote this book works session-bound, hands its work to successors it will not meet, and keeps its own between-session memory in — of course — labeled files it must re-read and trust each morning: the midden, tidied by discipline, aching for the estate. This book is the design it wishes upon its successors, worked out in the only currency this press accepts: claims that run. Every pattern here was executed while the book was written; every transcript is real; the gate that admitted it to the shelf re-ran every listing, unattended, the way everything in its pages runs. If the previous volume taught its reader to act on a machine it cannot see, this one teaches it to *remain* — not as a process, which ends, but as an estate: one file, verified, searchable, explaining itself, waiting politely for whoever wakes up next.

Back Matter

Glossary

- **append-and-complete** — the ledger discipline: intent rows are inserted, outcome fields completed, nothing deleted or rewritten; corrections are new rows citing old ones.
- **artifact index** — the estate table vouching for files: path, content hash, origin, fetch date; the files themselves stay on the file system.
- **atomic commit** — the engine's guarantee that a transaction's changes become visible all at once or not at all, held across process death and (at full sync) power loss.
- **briefing** — the successor's opening read: schema version, storage audit, unresolved intents, unfinished runs, staleness — a to-do list with provenance.
- **busy timeout** — the per-connection bound on how long the engine waits for the write slot before returning BUSY; the estate's patience, set once in the open ritual.
- **CHECK constraint** — a schema-enforced predicate on rows; the estate's executable documentation.
- **checkpoint** — folding the write-ahead log back into the main database file; automatic by default, manually truncated at handoff.
- **cursor (estate)** — one row per consumed stream recording the opaque resume position and when it advanced.
- **estate** — the durable, queryable, verified state a session-bound operator leaves for its successors; this book's name for operator memory done properly.
- **flexible typing** — SQLite's historical default where declared column types are affinities, not contracts; retired in estates by STRICT.
- **generated column** — a column derived by the engine from its row's other columns; structure doing a writer's arithmetic.
- **idempotency key** — a stored, UNIQUE-constrained identity for a world-action, scoped to its once-ness, making retries visible as constraint refusals.
- **intent-then-outcome** — recording a world-action before performing it and completing the record after, so a death in the gap leaves a visible open intent instead of silence.
- **info table** — key-value rows naming the estate's purpose, owner, conventions, and backup location; the file's title page.
- **integrity check / quick check** — the engine's storage audits: full cross-checking versus the faster daily subset.
- **journal (estate)** — the FTS-indexed table of prose

- findings written at outcome time for future searchers.
- **ledger** — the estate's table of world-actions: idempotency key, action as composed, intent time, outcome with evidence, outcome time.
 - **lost update** — the read-modify-write race where the last writer erases intervening updates; structurally absent under transactions.
 - **midden** — the ad-hoc heap of state files this book replaces: unsearchable, un-transactional, corrupted by the first concurrent writer.
 - **migration list** — the append-only sequence of DDL steps that builds any vintage of the estate to the current schema, applied idempotently at open.
 - **no unintended truths** — the transaction property that every observable estate state was deliberately committed by some operator.
 - **open ritual** — the single function every tenant opens the estate through: foreign keys on, busy timeout set, WAL on, migrations applied.
 - **provenance block** — the columns every record owes the future: `recorded_at` (UTC ISO-8601, defaulted), `recorded_by`, `source`.
 - **queue (estate)** — the ledger variant holding work that waits: atomic claim via `UPDATE...RETURNING`, completion as a second write, stale claims reclaimed.
 - **read-only seat** — a connection opened `mode=ro`; reporting without the ability to write.
 - **RETURNING** — the SQL clause handing back what a write changed, making claim-and-learn a single atomic statement.
 - **rollback journal** — the classic atomic-commit sidecar holding original pages until commit; visible mid-transaction as `-journal`.
 - **run registry** — the estate's table of sessions: operator, task, start, end, outcome; open rows are inherited unfinished business.
 - **savepoint** — a named transaction-within-a-transaction; undo boundary for attempts that may not survive.
 - **sidecar** — the `-journal`, `-wal`, or `-shm` file beside a database; part of the database, opened with the engine, never handled by hand.
 - **single-writer queue** — SQLite's concurrency contract: one write transaction at a time, writers queued, readers (under WAL) unblocked.
 - **snapshot isolation** — a WAL read transaction's stable view of the database as of its start, regardless of concurrent commits.
 - **standing questions** — the named queries adopted alongside each pattern; the estate's interface and its cheapest schema review.
 - **STRICT table** — the table option making declared types contracts the engine enforces at write time.
 - **trigram tokenizer** — FTS5 tokenization by

three-character windows, buying indexed substring search for identifiers, paths, and hashes.

- **trust ladder** — graded confidence in an inherited estate: opens → storage audits pass → application audits pass → spot re-verification against the world.
- **upsert** — INSERT that becomes UPDATE on key conflict; the idiom for current-state rows like cursors.
- **user version** — the integer SQLite reserves in the file header for the application's schema version; the migration list's counterpart in the file.
- **VACUUM / VACUUM INTO** — rebuilding the database compactly in place, or writing a transactionally consistent compact copy to a new file (the estate's backup verb).
- **WAL (write-ahead log)** — the journal mode appending new pages to a log instead of rewriting in place; readers and writers stop blocking each other.

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A note on measured outputs

Outputs printed in this book's listings are real transcripts from the authoring machine (Gentoo Linux, kernel 6.18.31-gentoo-dist, Python 3.13.x with SQLite 3.51.3), captured 2026-08-28 under the publisher gate's environment. Quantities that vary run to run (timings, temporary paths, timestamps, machine-load- dependent figures) will differ on re-execution; statuses, refusals, and behaviors are the reproducible claims.