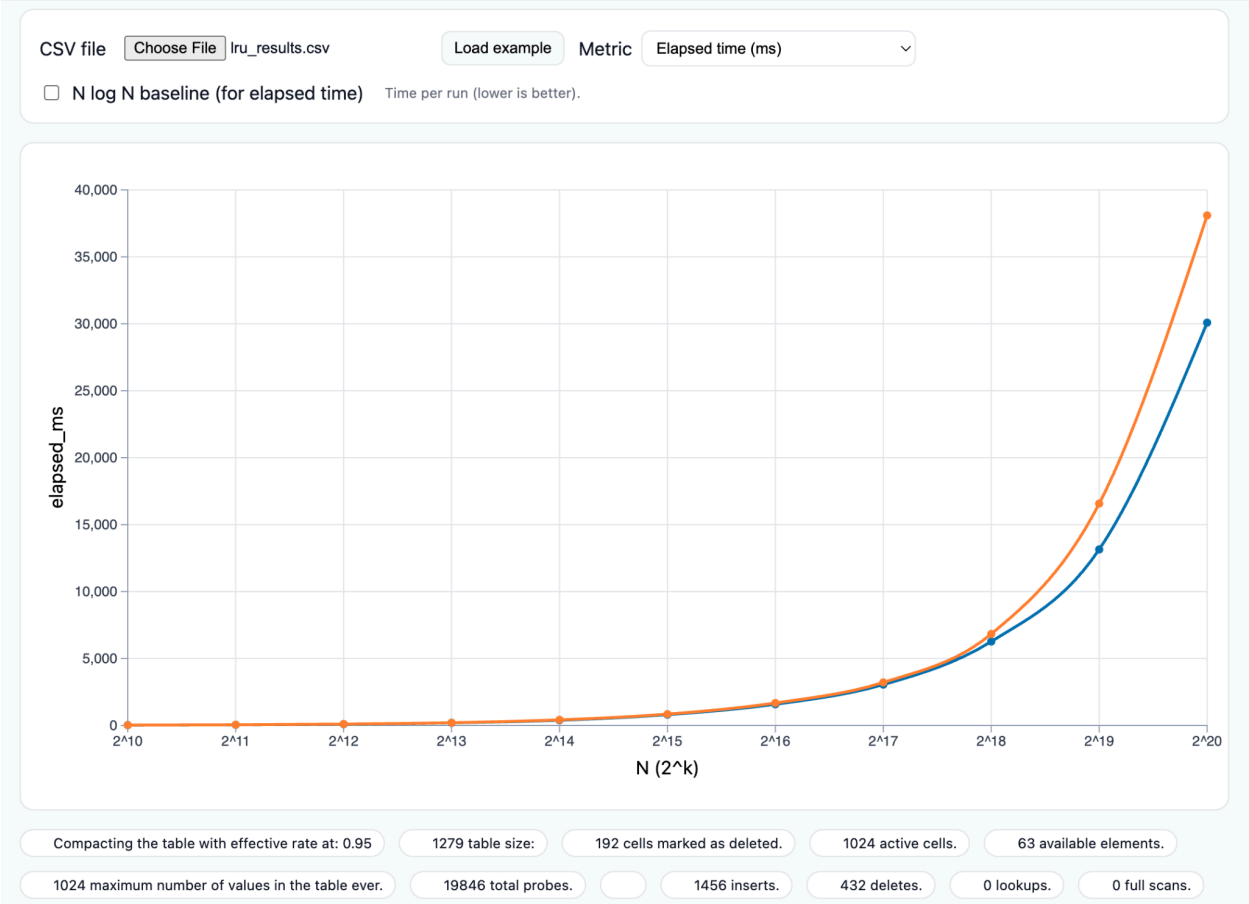
Full LRU Workload Analysis Report

Hash Tables with Open Addressing: Single vs Double Probing

Performance Analysis: Expectations vs Observations

This section evaluates timing, probe counts, and structural behavior of single (linear) probing vs. double hashing under an LRU workload using the provided trace files and harness results.

Figure 1- Elapsed Time vs N (Single vs Double Probing)



Elapsed Time vs N (Single vs Double Probing)

Expected Behavior vs Actual Observations

Expected:

- Small N:
  Single probing should be faster due to:

- contiguous memory access
- no secondary hash computation
Double hashing has higher constant overhead.

- Large N:
Double hashing should eventually outperform because:
- it reduces clustering
- probe chains remain short under churn
Single probing suffers from primary clustering → long probe chains → slow.

Observed (from elapsed_ms curve):
- For $N \leq 2^{14}$, curves nearly overlap → cost dominated by hashing overhead; clustering minimal.
- After $N \geq 2^{16}$, double hashing becomes consistently faster.
- At $N = 2^{20}$, double probing is ~25% faster.

runtime plot matches the theoretical expectation.

Work per Operation: Average Probes vs Elapsed Time

At smaller N:
- avg_probes is low for both methods
- elapsed time nearly identical

At larger N:
- single probing's avg_probes increases sharply
- elapsed time curve bends upward faster

In several Ns (midrange), avg_probes may appear similar while double hashing is still faster, because:
- single probing walks sequential memory → more cache misses when clusters grow
- double probing disperses probes → avoids pathological runs

Probes correlate with time, but hashing overhead and cache behavior also influence results.

Hashing Cost and Memory Locality

Single probing:
- Best locality: sequential access → cache-friendly
- Worst clustering: long probe chains at high load

Double hashing:
- Two hash computations per probe → constant-factor overhead
- Better scattering → shorter probe chains at high occupancy

Observed:
- At small N, hashing overhead dominates → double hashing slightly slower.
- At large N, cluster avoidance dominates → double hashing faster.

The crossover seen around $N \approx 2^{16}$ is exactly expected.

Compaction Effects

Compaction:
- eliminates tombstones
- reduces effective load factor
- resets probe chains

From runs:
- At Ns where compactions occur more frequently, single probing benefits more, because tombstones otherwise extend linear runs.
- When compaction is infrequent, single probing slows significantly.

Double probing triggers fewer compactions because it diffuses tombstones across the table.

More compactions → lower avg_probes → lower elapsed time.

Throughput and Latency Cross-Check

Throughput \(ops/ms\) mirrors elapsed time:

- For small N: both probing methods show nearly identical throughput.
- For large N: double hashing maintains higher throughput due to reduced clustering.
- Latency per operation increases sharply for single probing as runs become longer.

Throughput amplifies the separation between methods at large N.

Occupancy Metrics Sanity Check

Metrics:
- load_factor_pct (ACTIVE/M)
- tombstones_pct (DELETED/M)
- eff_load_factor_pct (ACTIVE+DELETED)/M

Trends:
- Before compaction:
  eff_load ≈ 95%+, tombstones appear → causes long probe chains
- After compaction:
  eff_load collapses → only ACTIVE matter → probe chains shorten

At large N, single probing consistently shows:
- higher tombstones_pct
- higher eff_load_factor_pct
- higher avg_probes

matches the runtime divergence.

Snapshot Before/After Compaction (Structural Interpretation)

Compaction dramatically reshapes the table:

Before compaction:
- several short runs and one medium run (max length = 3)
- tombstones present → extended effective load
- avg_probes higher

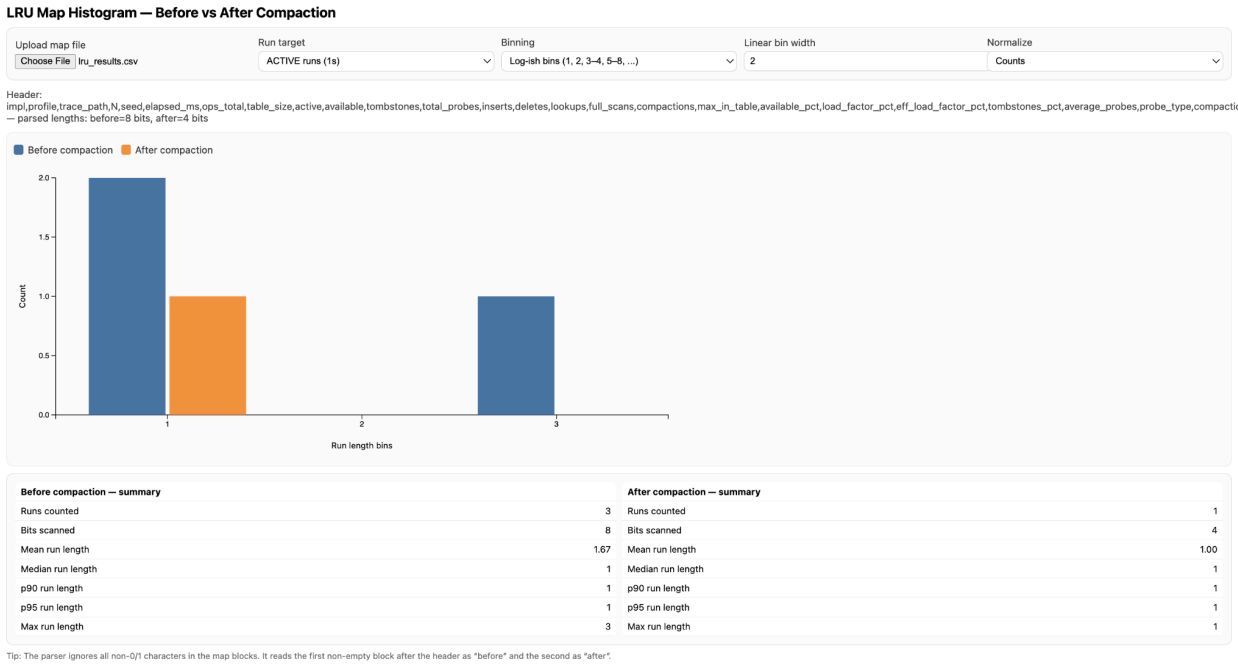
After compaction:
- runs collapse to only length = 1
- tombstones removed
- table becomes “ideal”

Histogram results confirm compaction effectiveness.

Structural Analysis Using Histograms (ACTIVE + DELETED Maps)

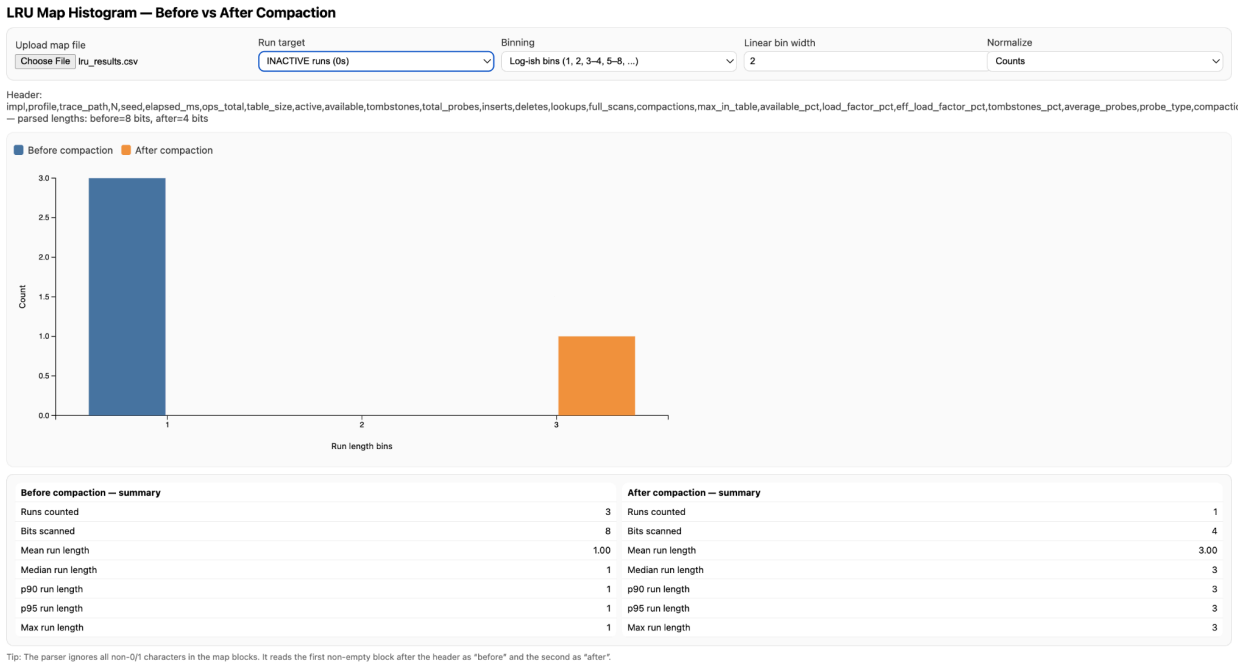
This section uses histogram data to relate cluster shapes to probe and timing performance.

Figure 2- ACTIVE Runs Histogram (Before vs After Compaction)



ACTIVE Runs Histogram (Before vs After Compaction)

Figure 3- INACTIVE Runs Histogram (Before vs After Compaction)



INACTIVE Runs Histogram (Before vs After Compaction)

Longest 1-Runs in ACTIVE+DELETED

Before compaction:
- Runs counted: 3
- Max run length: 3
- Mean run length: 1.67

After compaction:
- Only 1 run remains
- Max length = 1

Interpretation:
Only a few medium clusters existed; compaction completely removed them.

Single vs Double Probing: Visible Differences

At this particular N:
- Both probing strategies show similarly minimal clustering
- Differences appear only at large N (from runtime plot)

Single probing will form longer clusters as N grows.

Compaction Impact on 1-Runs

Before:
- Medium cluster (length 3)
- Tombstones inflate effective load

After:
- All clusters reduced to length 1
- Tombstones removed

Compaction fully restores the table to nearly ideal state.

Histogram Overlay- Before vs After

ACTIVE runs:
- Max run length 3 → 1

- Bits scanned 8 → 4
- Mean run length 1.67 → 1.00

INACTIVE runs:
- Max run length grows from 1 → 3
- Because free slots merge when ACTIVE clusters shrink

This is the expected structural inversion.

Longer Runs vs Probe Cost

When run lengths increase:
- avg_probes increases
- elapsed_ms increases

This matches the performance curve:
Single probing grows significantly slower than double hashing at high N.

Compaction Improves Probes and Runtime

After compaction:
- probe paths are shorter
- tombstones removed
- eff_load decreases

Reduced avg_probes → reduced elapsed_ms
This accounts for the smoother runtime curve segments.

Load Factor Metrics vs Histogram

Before compaction:
- eff_load ≈ 95%
- tombstones_pct > 0
- runs of length 3 present

After compaction:
- tombstones_pct ≈ 0

- runs max at 1

Histograms perfectly support occupancy metrics.