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Persistent Memcached: Bringing Legacy Code to Byte-Addressable Persistent Memory

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Outline

1. **Persistent Memory and the System Stack**
2. Making Memcached Persistent: lessons learned
3. Takeaways: this is ***harder*** than you think!

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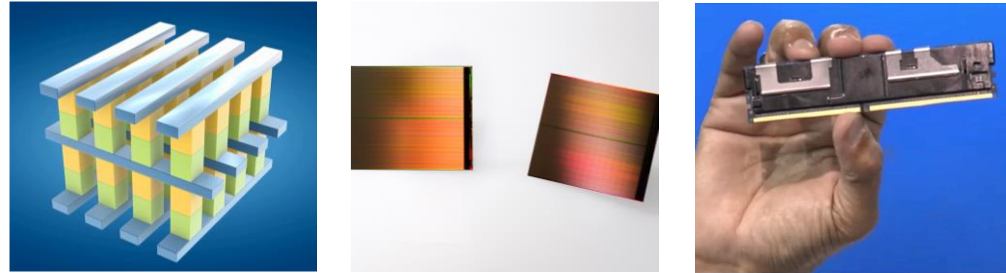
Persistent Memory (pmem): What is it?

- Looks like DRAM
  - Byte addressable
  - DIMMs across the memory bus
  - Cacheable
  - Low latency: 1000X lower than NAND flash (3D XPoint), projected to approach and eventually eclipse DRAM performance (e.g. STT-MRAM, Carbon-NanoTubes, etc.)
- Acts like Storage: State persists across restart events
- Dense: projections better than DRAM (~10X, 3D Xpoint)
- Cost expected to be between DRAM and NAND flash



Intel 3D XPoint Marketing Images

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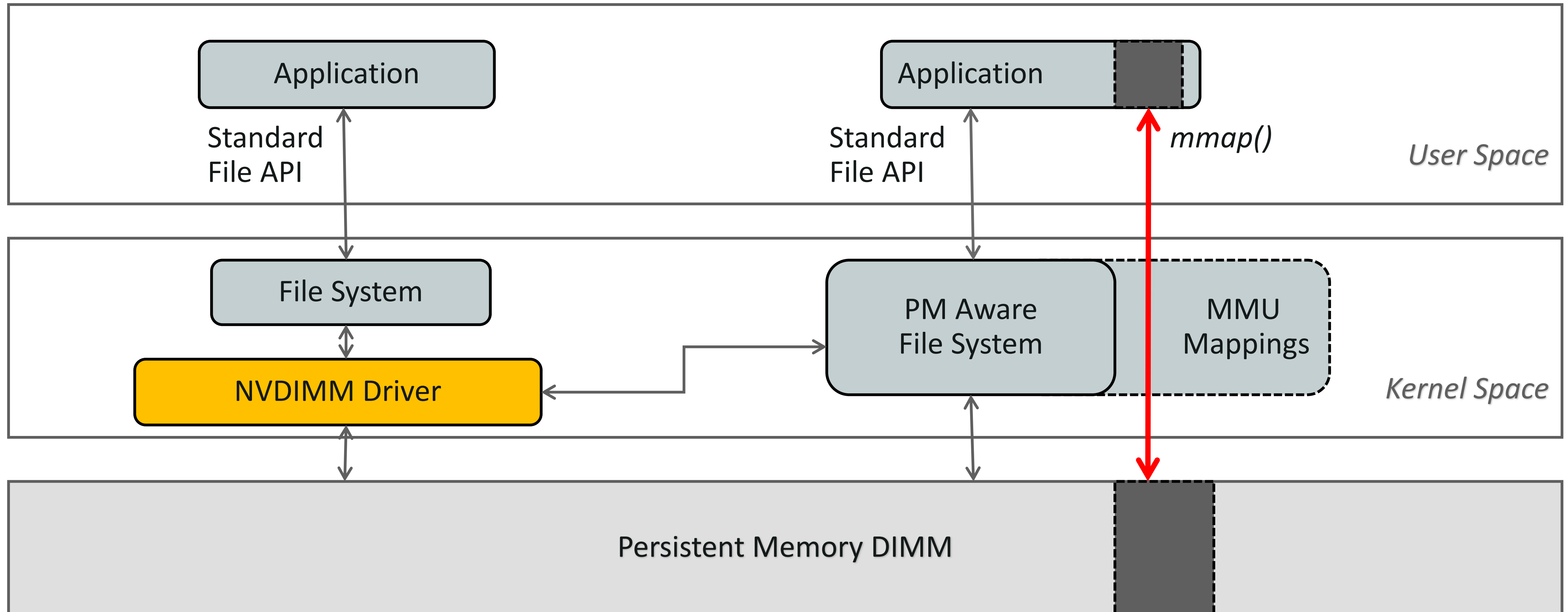
Integrating Persistent Memory in the Software Stack



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Use cases for persistent memory

- Faster block storage device
  - No changes to most of the software stack; gains are limited
- Bigger, slower volatile memory
  - New tier in the memory hierarchy
- Leverage byte addressability and fast persistence
  (***most disruptive change***; *our focus*)
  - Make persistence fast via byte addressable data representation and access
  - Make application restart/warmup fast

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Memcached fits here...... large caches, warmup can take hours

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Outline

1. Persistent Memory and the System Stack
2. **Making Memcached Persistent: Lessons Learned**
   - **Early decision: Don't change Memcached's high level architecture**
3. Takeaways: this is ***harder*** than you think!

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Lessons Learned (on memcached v1.4.25)
This is harder than you might think!

1. Persistence of data structures can be contagious
2. Failure-atomic transactions can be crucial
3. Persistent and nonpersistent objects interact in unexpected ways
4. Critical sections can pose significant problems

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(*10 lessons in the paper*)

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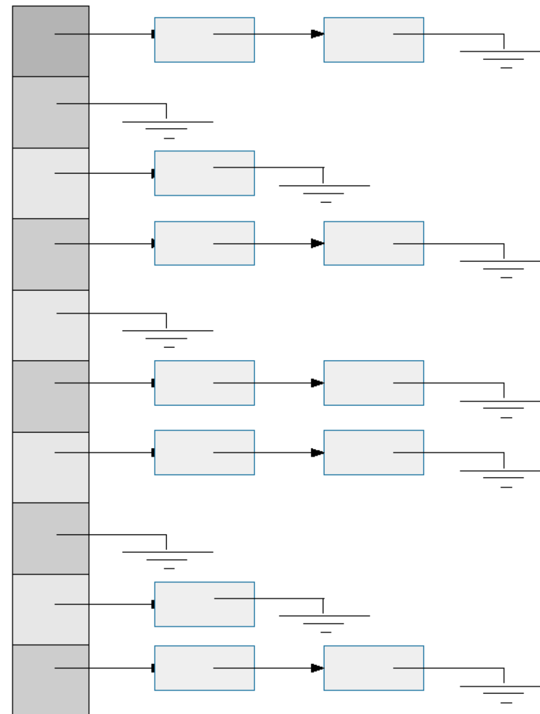
Lesson I: Mods can be contagious



Central Hash Table

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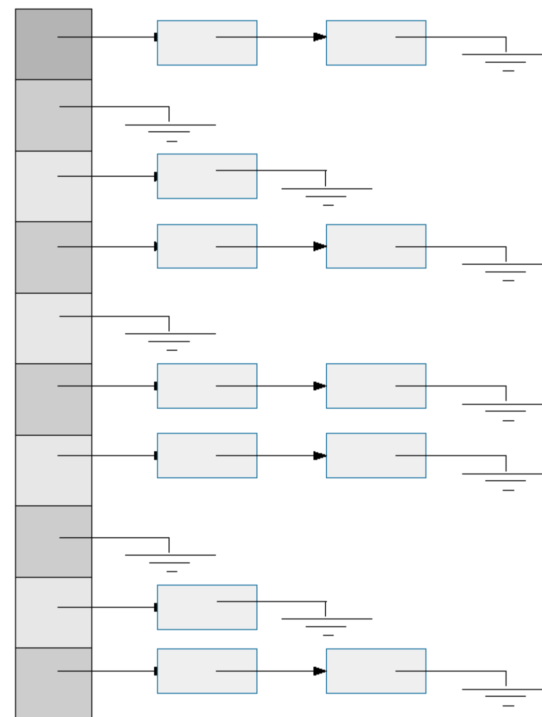
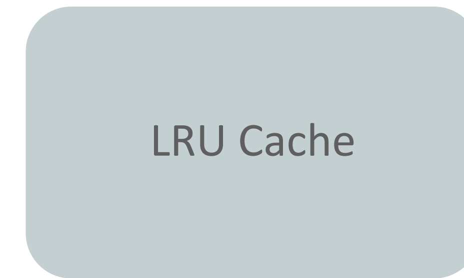
Lesson I: Mods can be contagious



Central Hash Table



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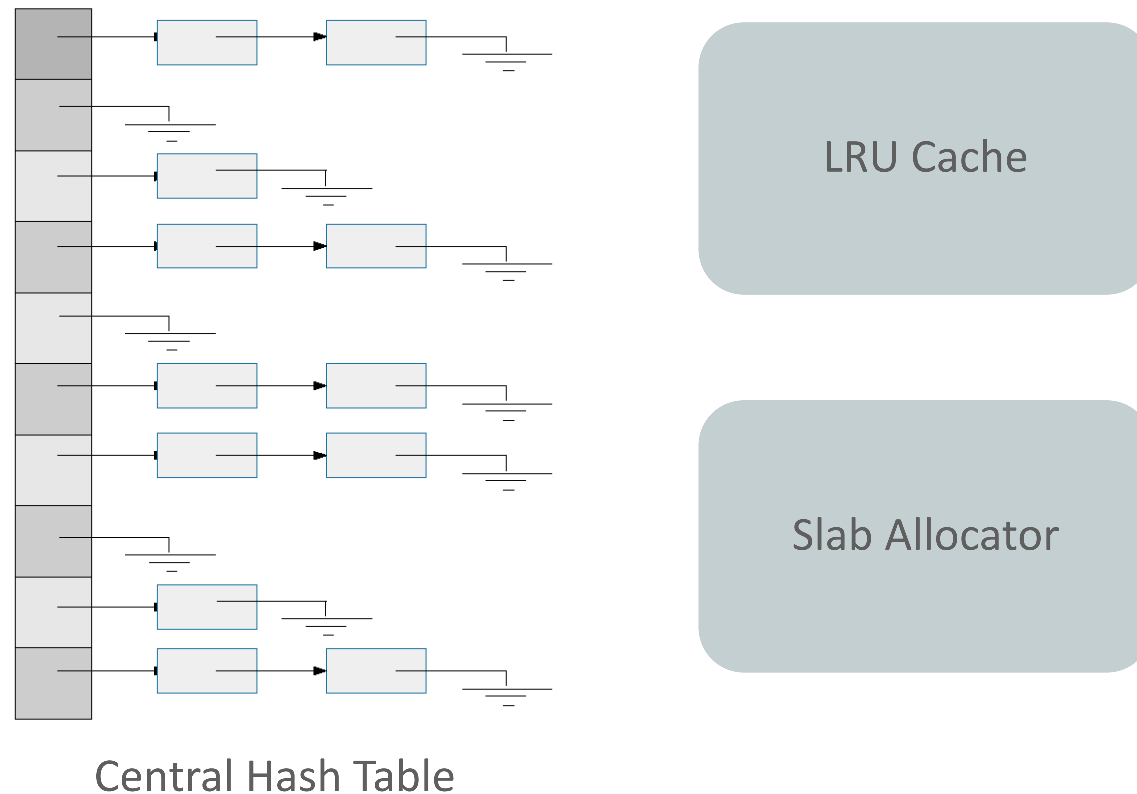

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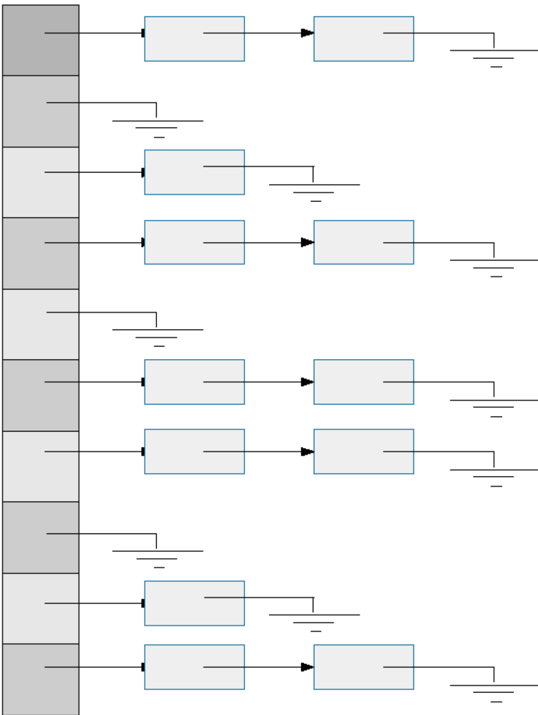

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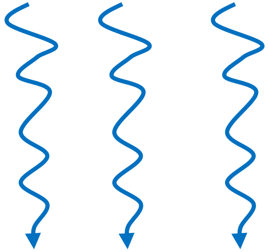
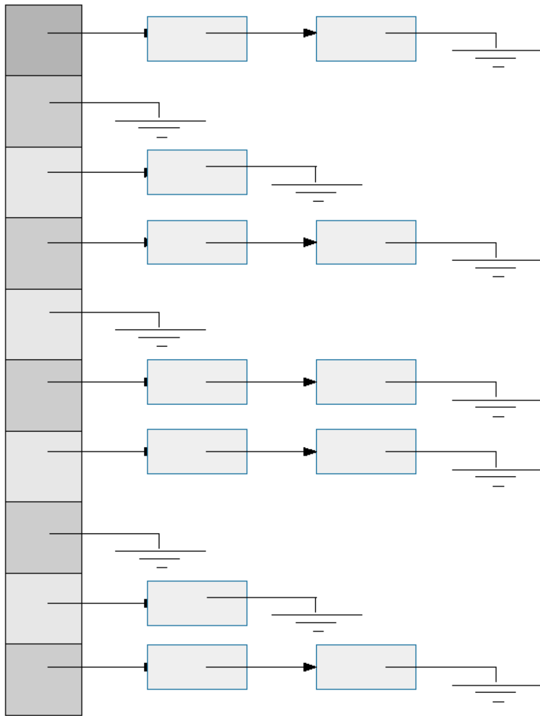


Background Maintenance
Threads



Central Hash Table

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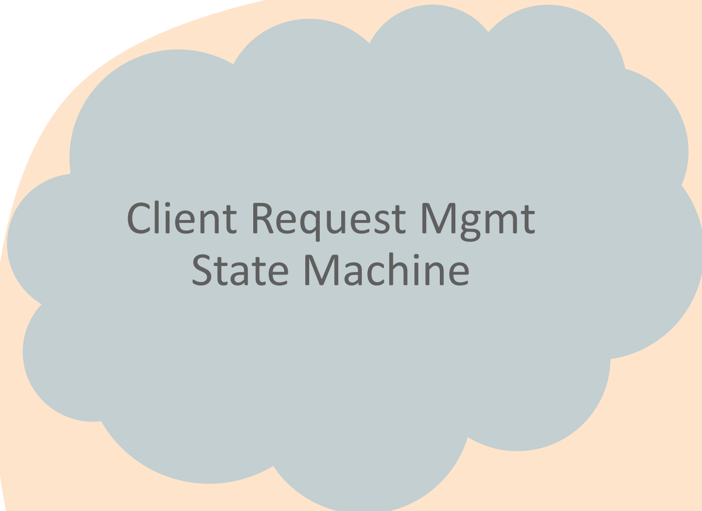

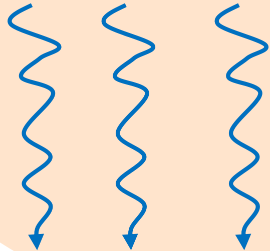

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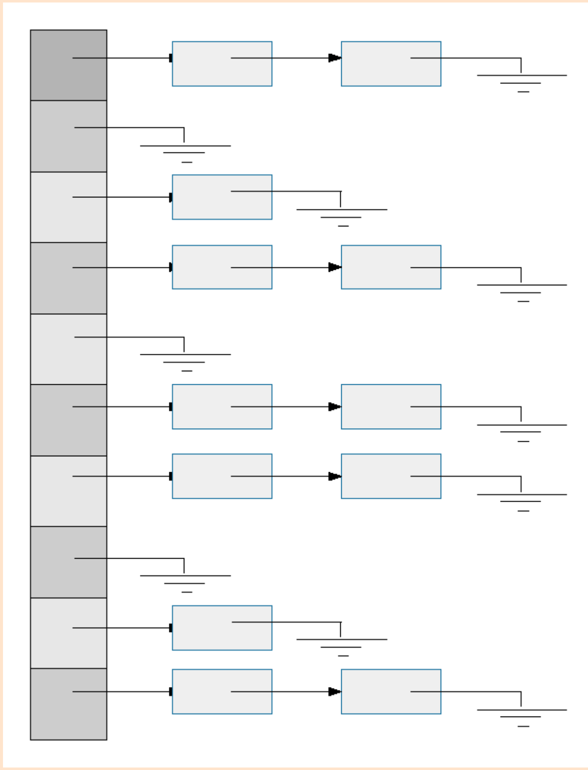

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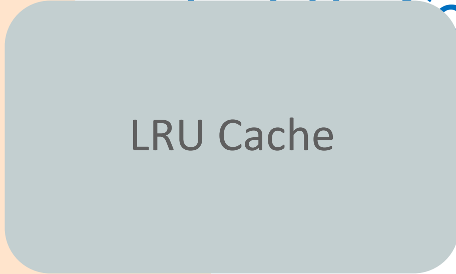

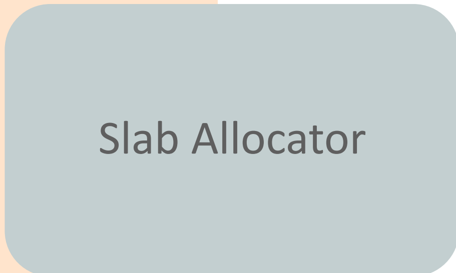

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Lesson I: Mods can be contagious

- Several (tightly coupled) modules
  - Central hash table (can grow, doesn’t shrink)
  - LRU cache
  - Client session management state machine
  - Own allocator
  - Helper threads: LRU crawler, hash table resizer, allocator slab manager
- Data structures intertwined
- Needed to make changes all over the application

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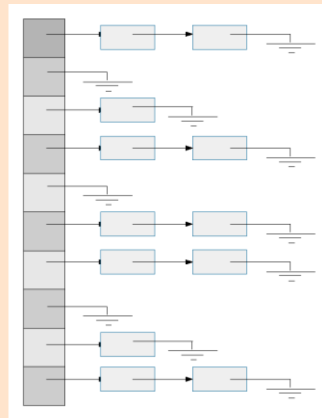
Lesson II: Failure-Atomic Transactions can be crucial

- Complex code paths; e.g. Put(K,V)
  - Change hash table
  - Allocate new <K,V> pair; touches slab allocator
  - Update LRU cache



Hash Table update

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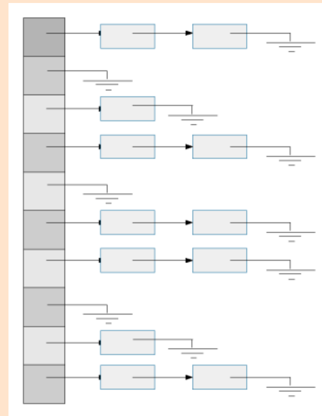

Hash Table
update

Slab Allocator
update

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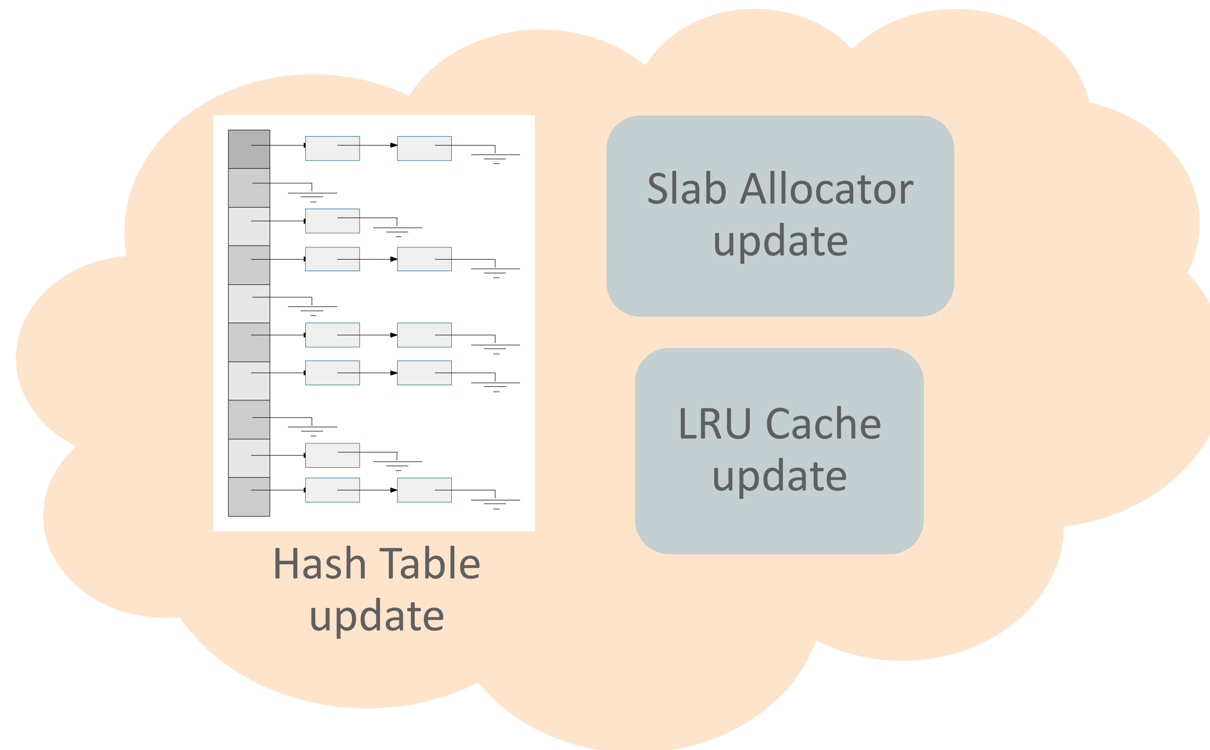

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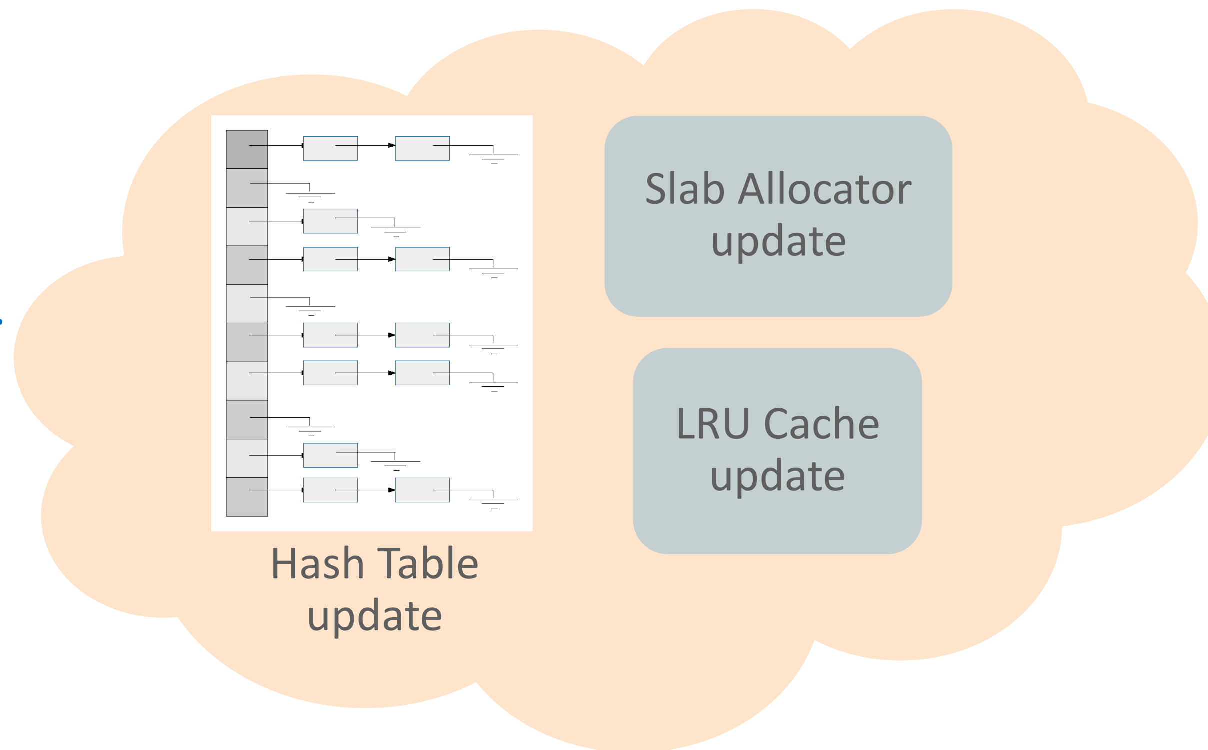
All updates need to be mutually consistent across failures



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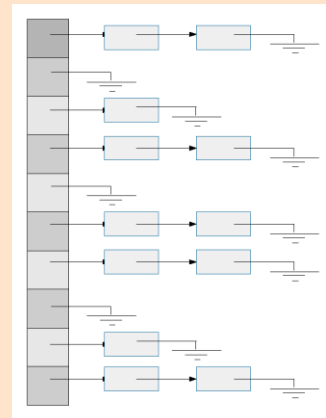
Failure-Atomic Transaction for Put(K,V)



Hash Table update

Slab Allocator update

LRU Cache update

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Lesson II: Failure-Atomic Transactions can be crucial

- Ended up using in-house transactional runtime
- Original 15K LOC, we ended up adding 7K LOC
- Most of the added LOCs come from hand instrumenting transactional loads/stores to persistent memory
- *Language support will help a lot!*

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Lesson III: Persistent and nonpersistent objects interact in unexpected ways

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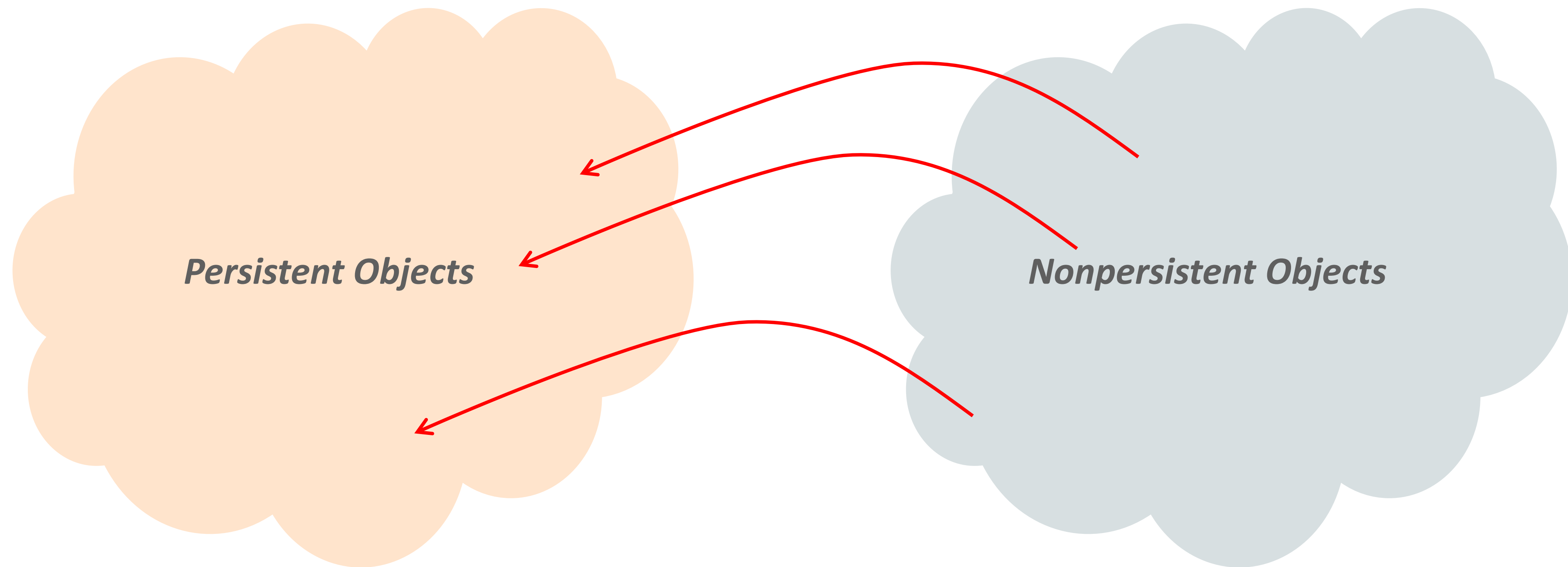

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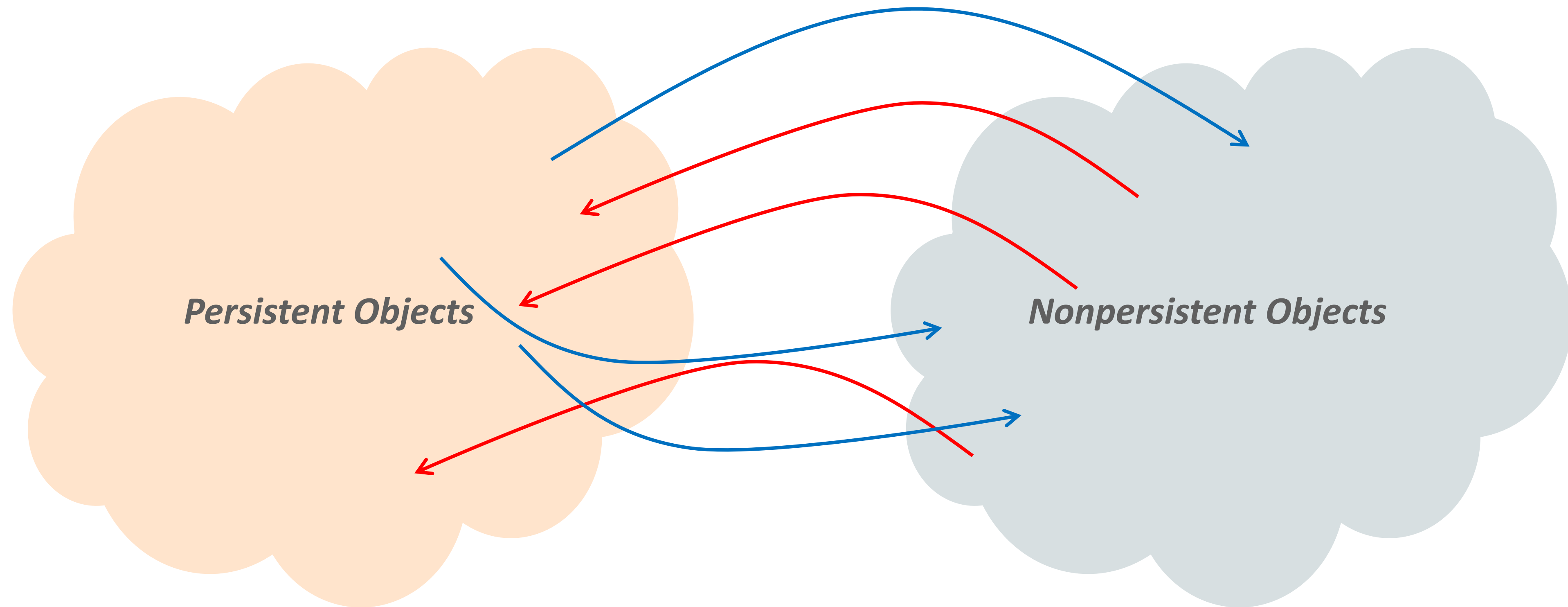

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Lesson III: Persistent and nonpersistent objects interact in unexpected ways

- Persistent and nonpersistent objects can have dependencies

- In Memcached
  - References from nonpersistent client-session objects to key-value pairs tracked using reference counts
  - Deleted objects with non-zero reference counts could be lost on failure
  - Solution: Add a persistent "pending reclamations" list, and use it during recovery to avoid memory leaks.

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Lesson IV: Critical Section Headaches

- Locking: Let the application use its locks within transactions
  - But lock release should be deferred to transaction completion (the runtime implicitly releases the acquired locks after the transaction completes)
  - Can inflate critical sections by a lot – introduces deadlocks, scalability problems
  - Each LRU list has a lock
  - Memory allocation/free: memcached has its own allocator which uses its own (single) lock
- Solutions: Make locks reentrant; postpone execution of some critical sections to end of transaction (e.g. hash table size update); approximate LRU
- LRU cache, allocator lock still scalability problems

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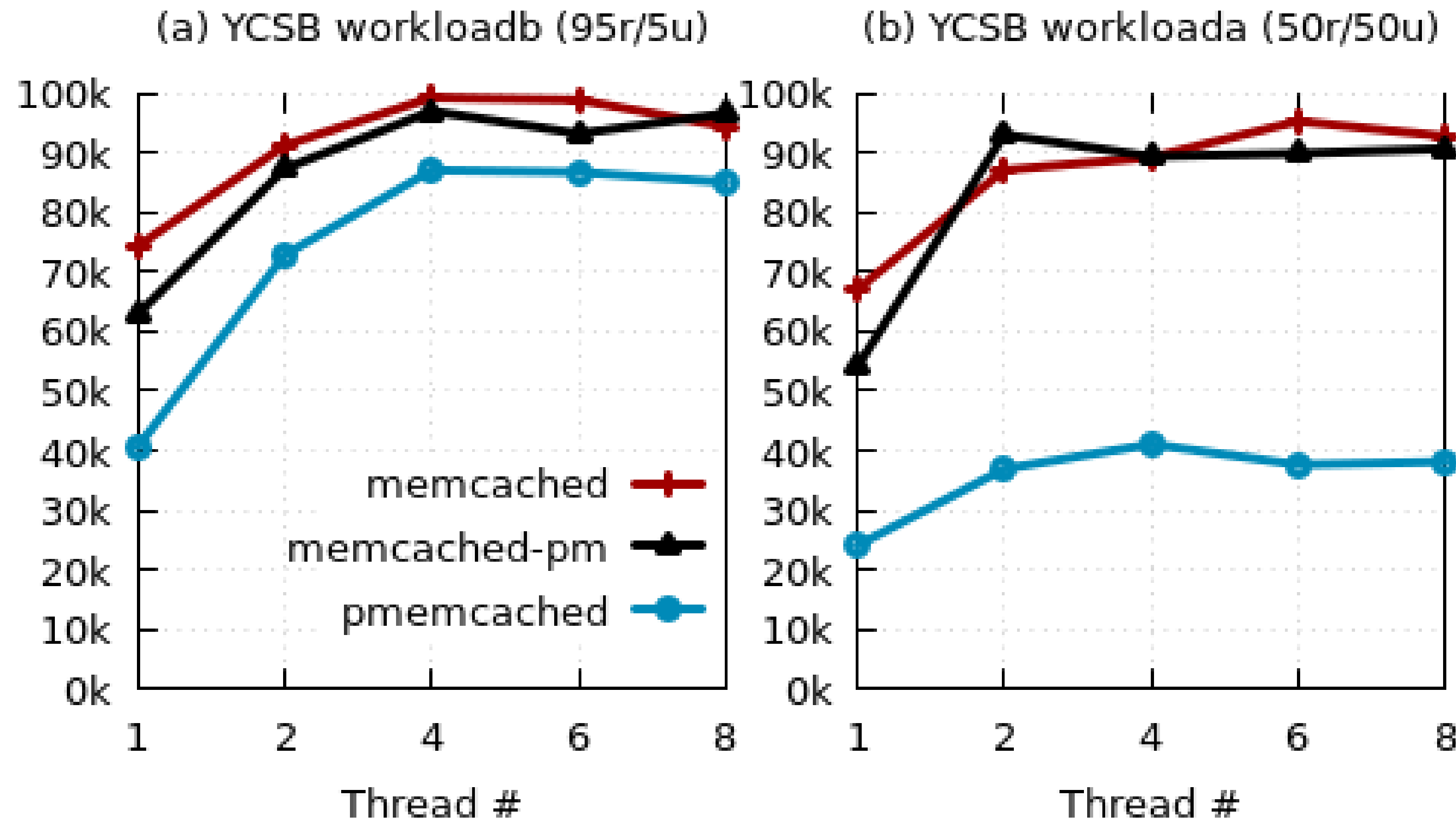
Memcached evaluation: YCSB workload generator

Experiments conducted on Intel's Software Emulation Platform for Persistent Memory



Emulator Configuration

- Assume CLWB
- Latency: 300 nanosecs
- Pbarrier: 100 nanosecs

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Takeaways

This can be *hard*, and the returns may not be worth it!

- Fundamental issues
  - Main decision to not change memcached's architecture was problematic
  - Modules too tightly coupled, leading to extraneous complexity and overheads
- So
  - Either may need to radically rehash the architecture of such systems
  - Or, just build one from scratch
  - Or, trade instantaneous warmup for simplicity and better common case performance

- New programming abstractions need to be explored/researched

- *Story may be very different for other applications*

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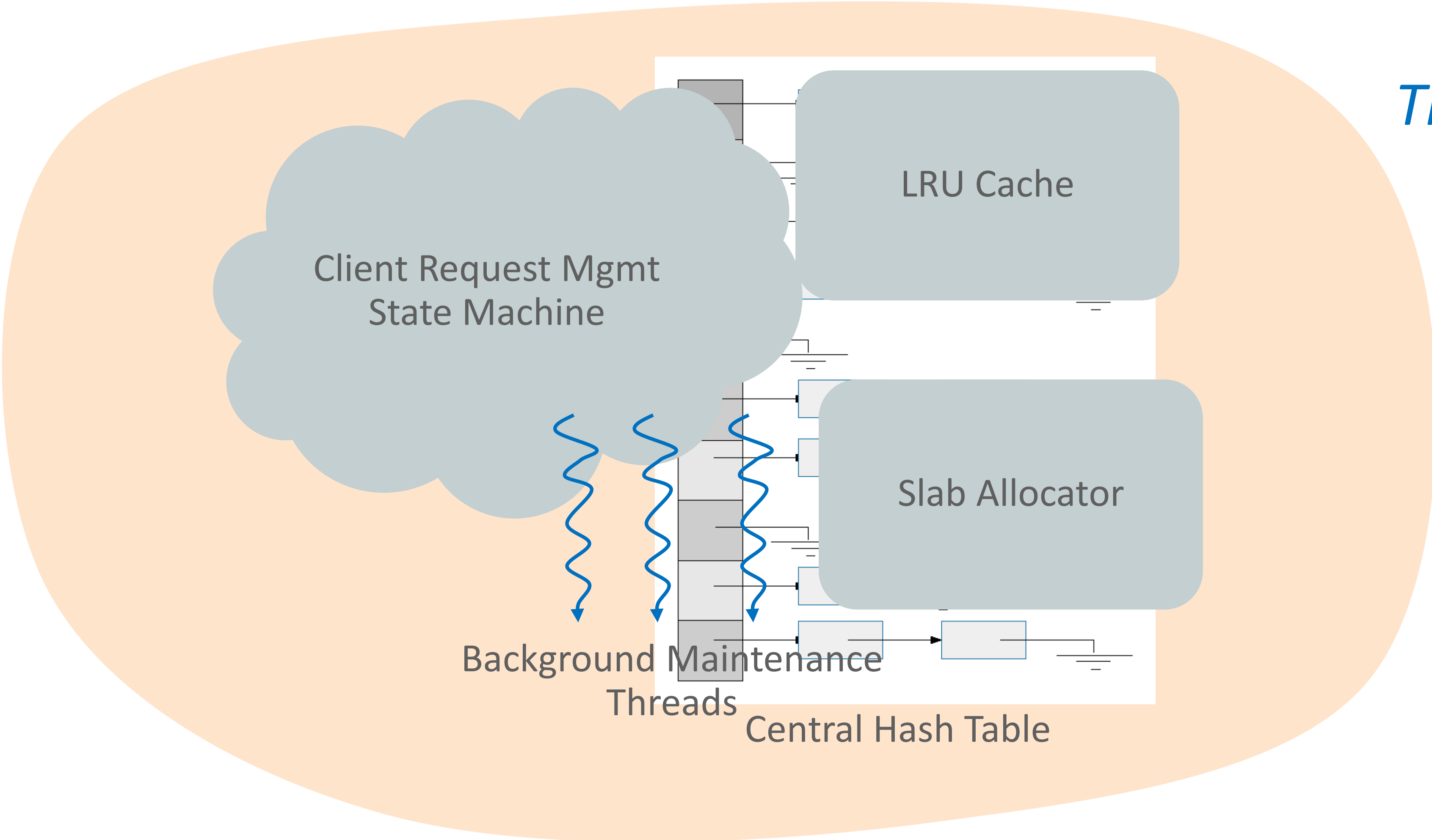

Tightly Coupled Subsystems

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