Making the Fast Case Common and the Uncommon Case Simple in Unbounded Transactional Memory

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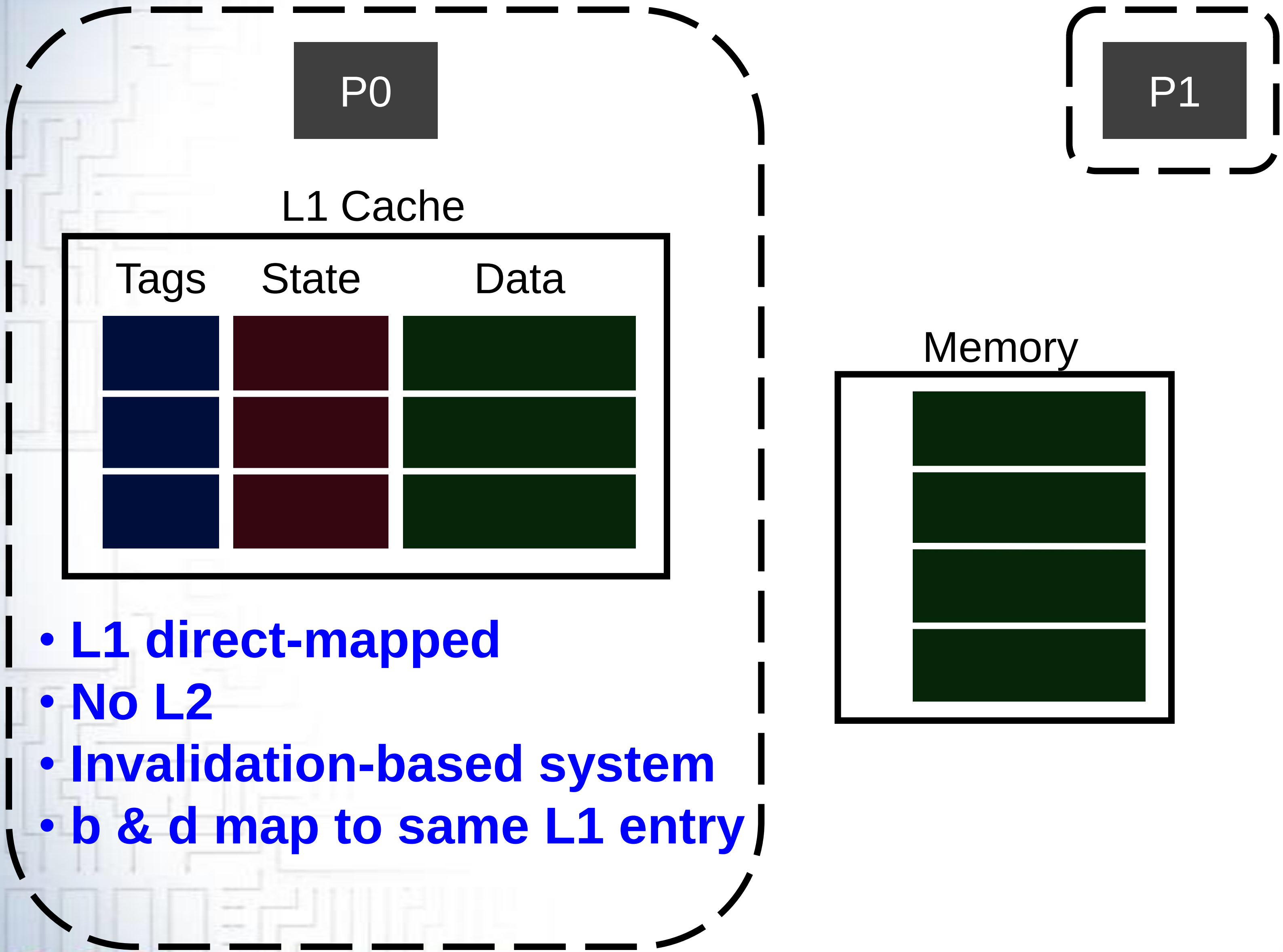
Overview

- Small transactions: no problem
  - Implement using local structures of bounded size
  - Simple/highly-concurrent/low-overhead
- Overflowed transactions: **problem**
  - Difficult to preserve all nice properties of bounded TM
  - Many papers in last several years
- Previous approaches: focus on concurrency
  - \+ Sustain performance as overflows increase
  - – Involve complex resource manipulation
- **Our approach:** decouple into two problems
  - Simple overflow handling: **OneTM**
  - Making overflows rare: **Permissions-only cache**

Background

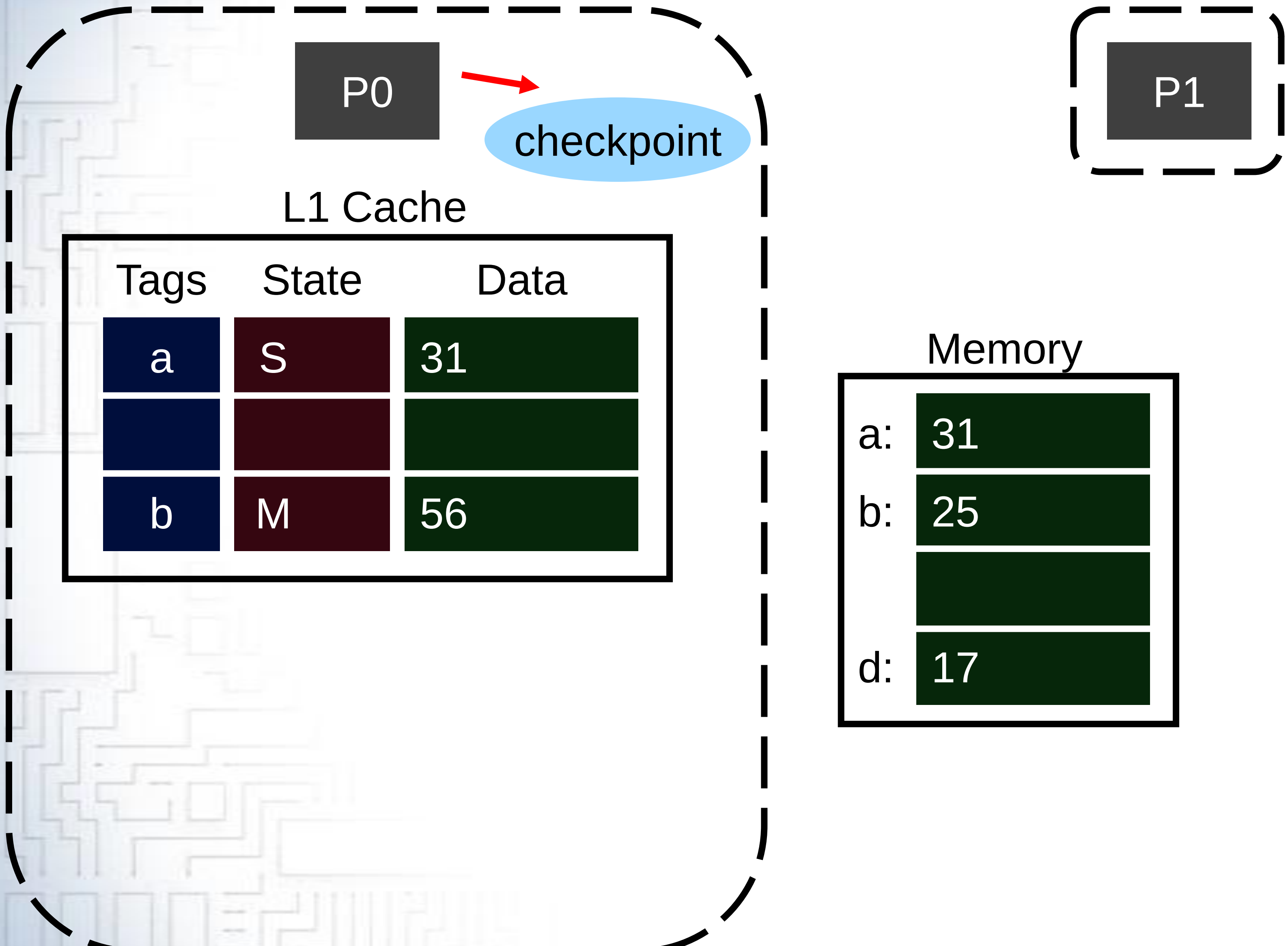
- Transactional memory: the new hot thing
  - Interface: serialization
  - Implementation: optimistic parallelism
- Tasks of every TM
  - **Conflict detection:** was serializability violated?
  - **Version management:** how do we recover serializability?
- Bounded hardware TM implementation:
  - Conflict detection: **extend cache coherence**
  - Version management: many schemes

Running Example

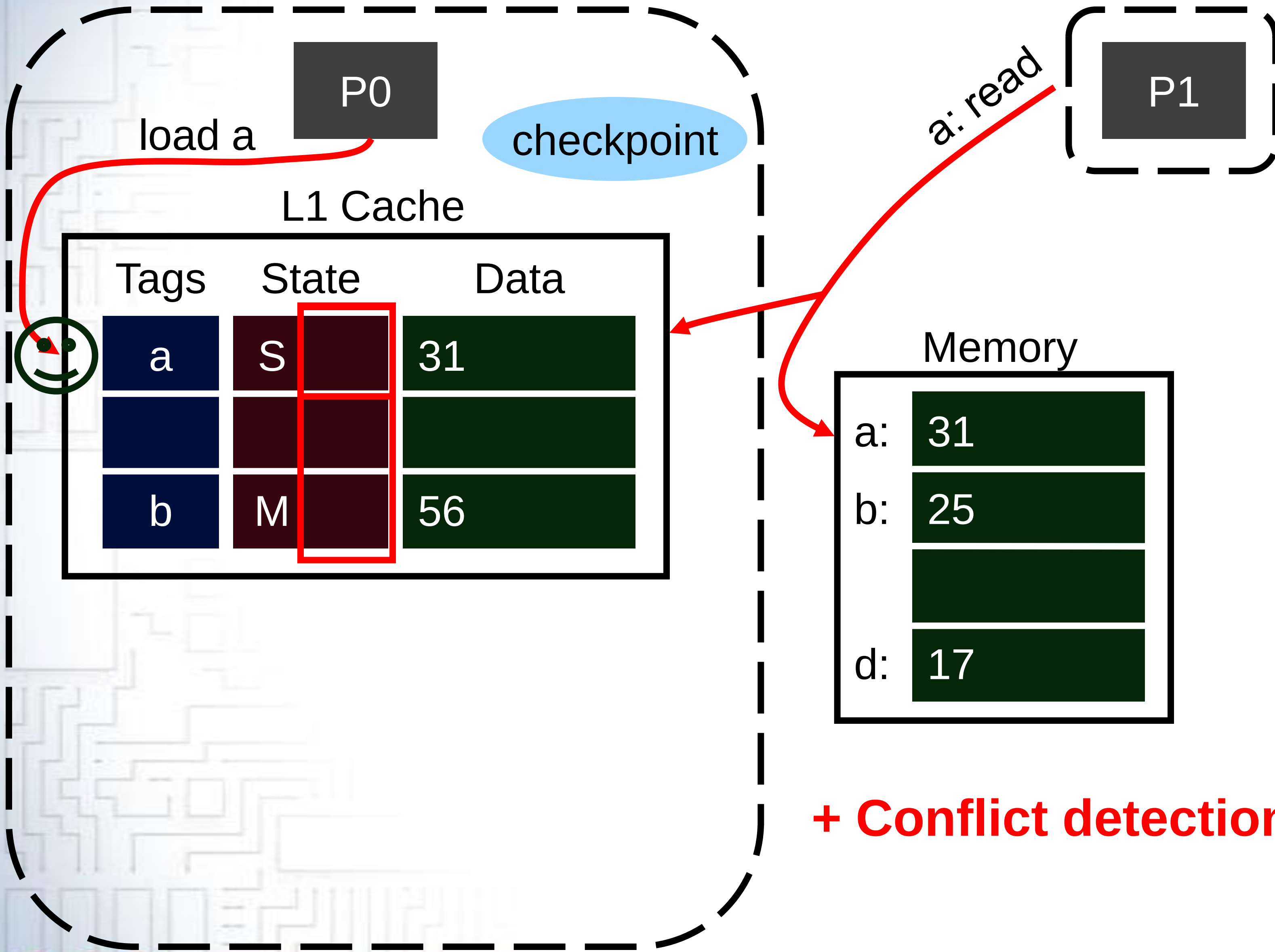


- **L1 direct-mapped**
- **No L2**
- **Invalidation-based system**
- **b & d map to same L1 entry**

Transactional Execution

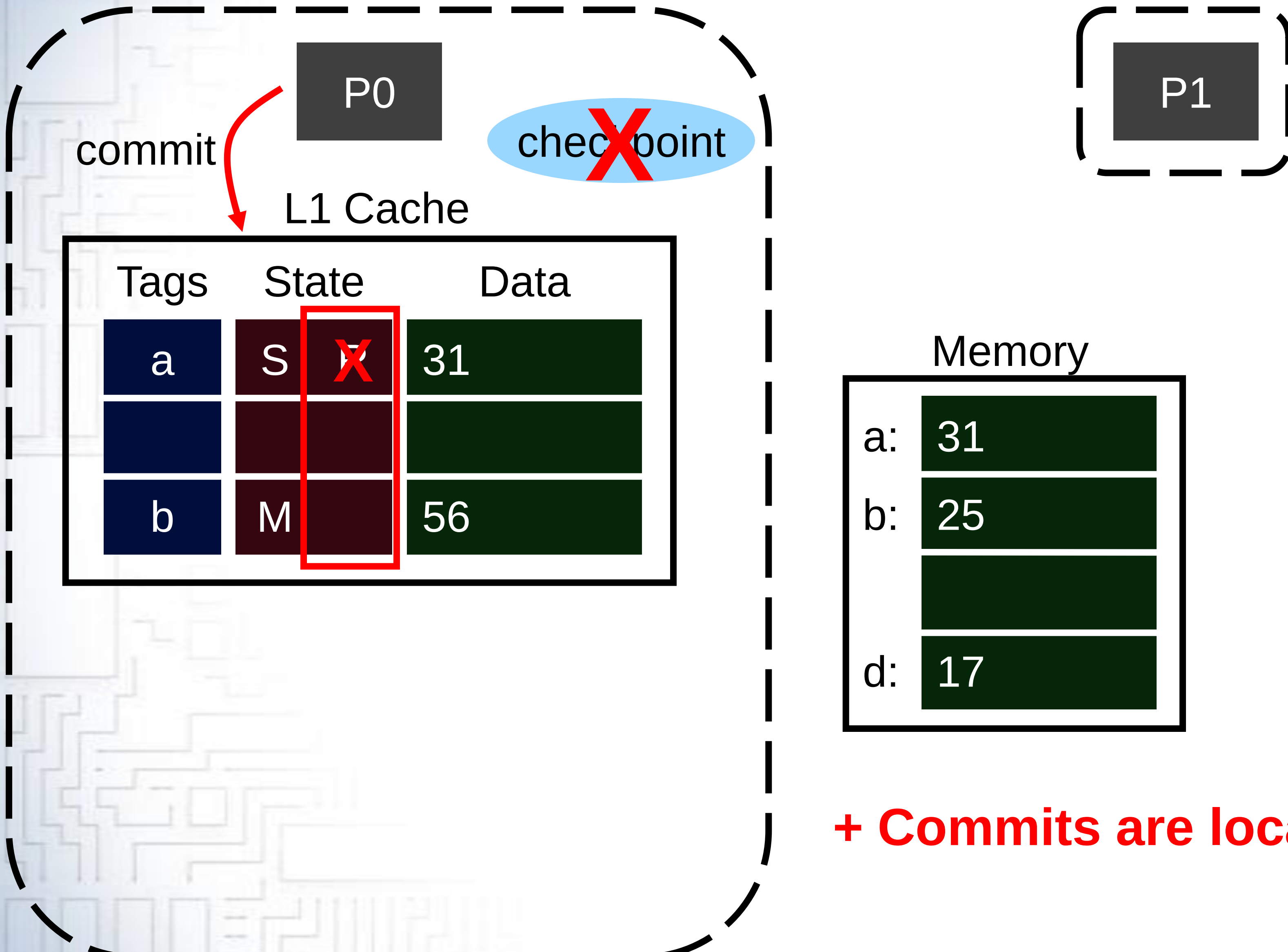


Conflict Detection



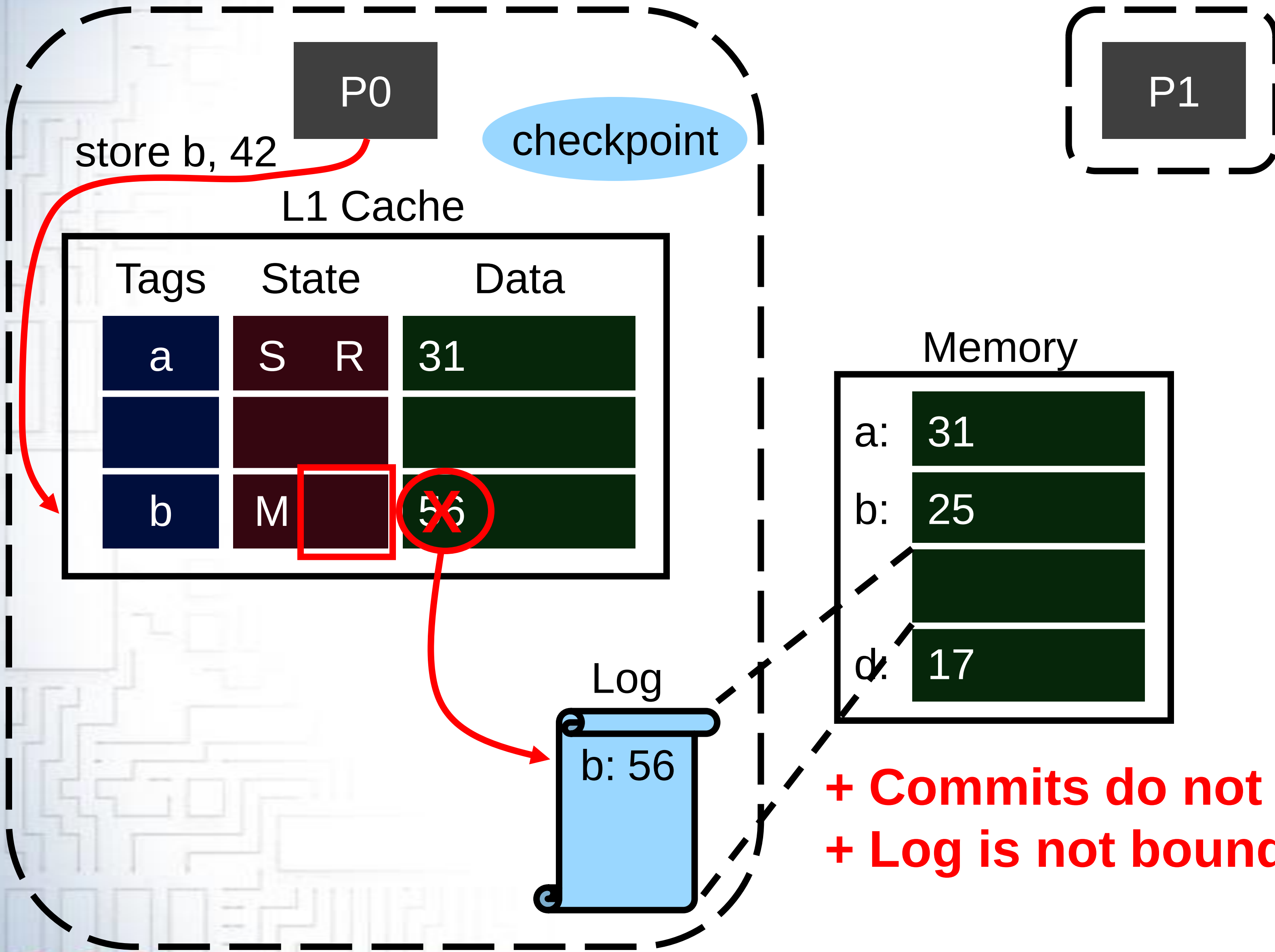
+ Conflict detection is local

Committing a Transaction



+ Commits are local

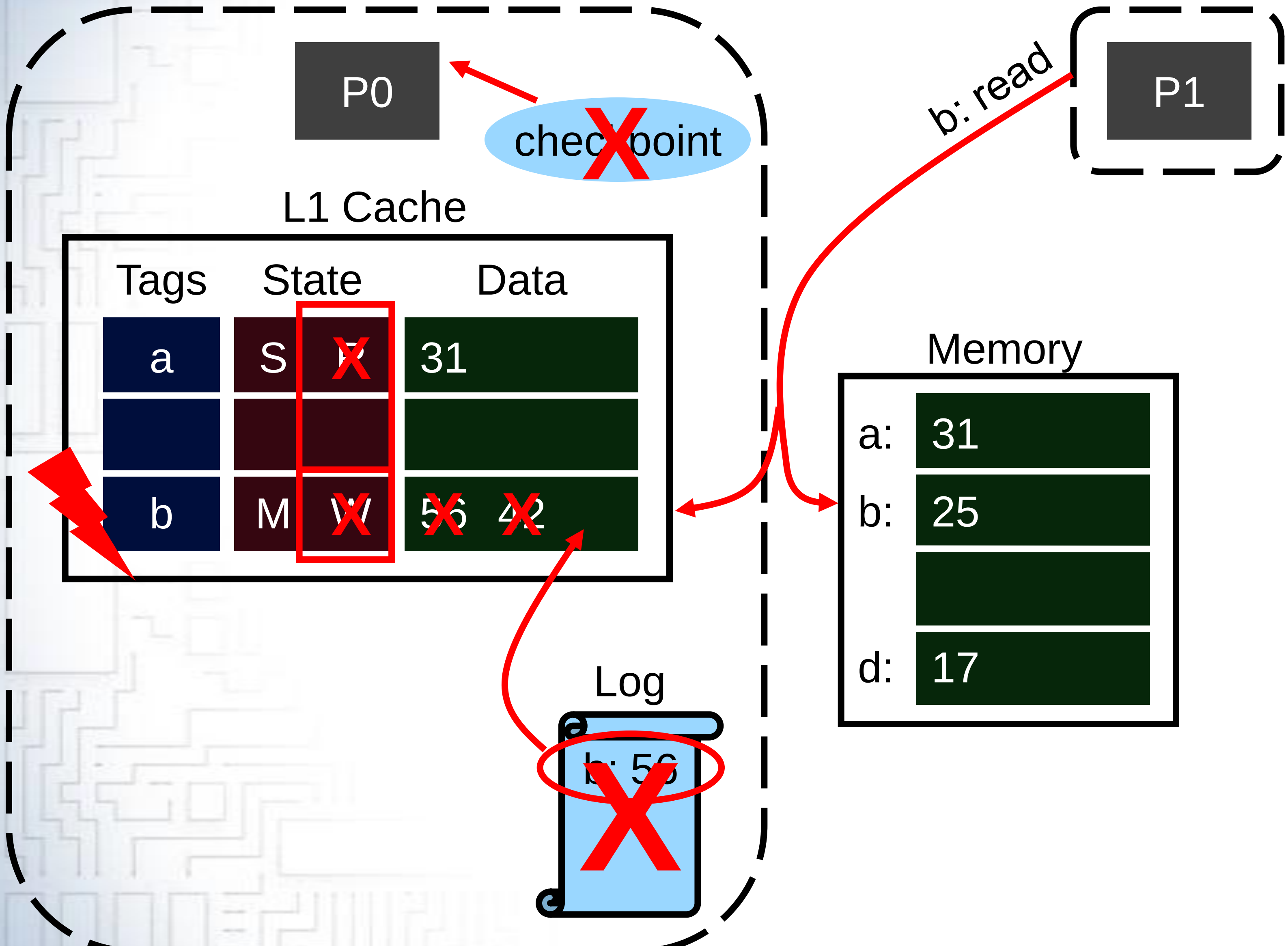
Version Management



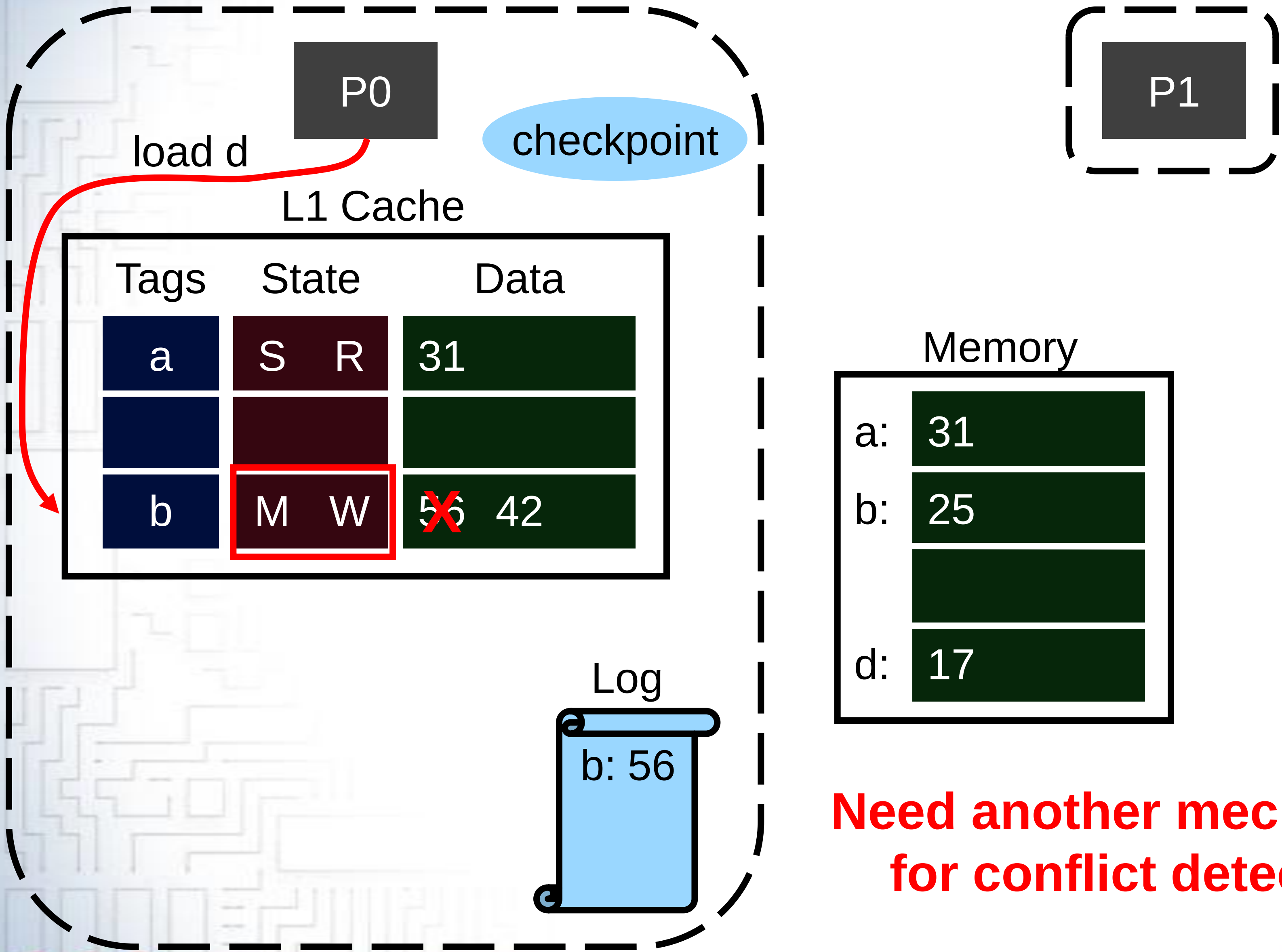
+ Commits do not change

+ Log is not bounded

Aborting a Transaction

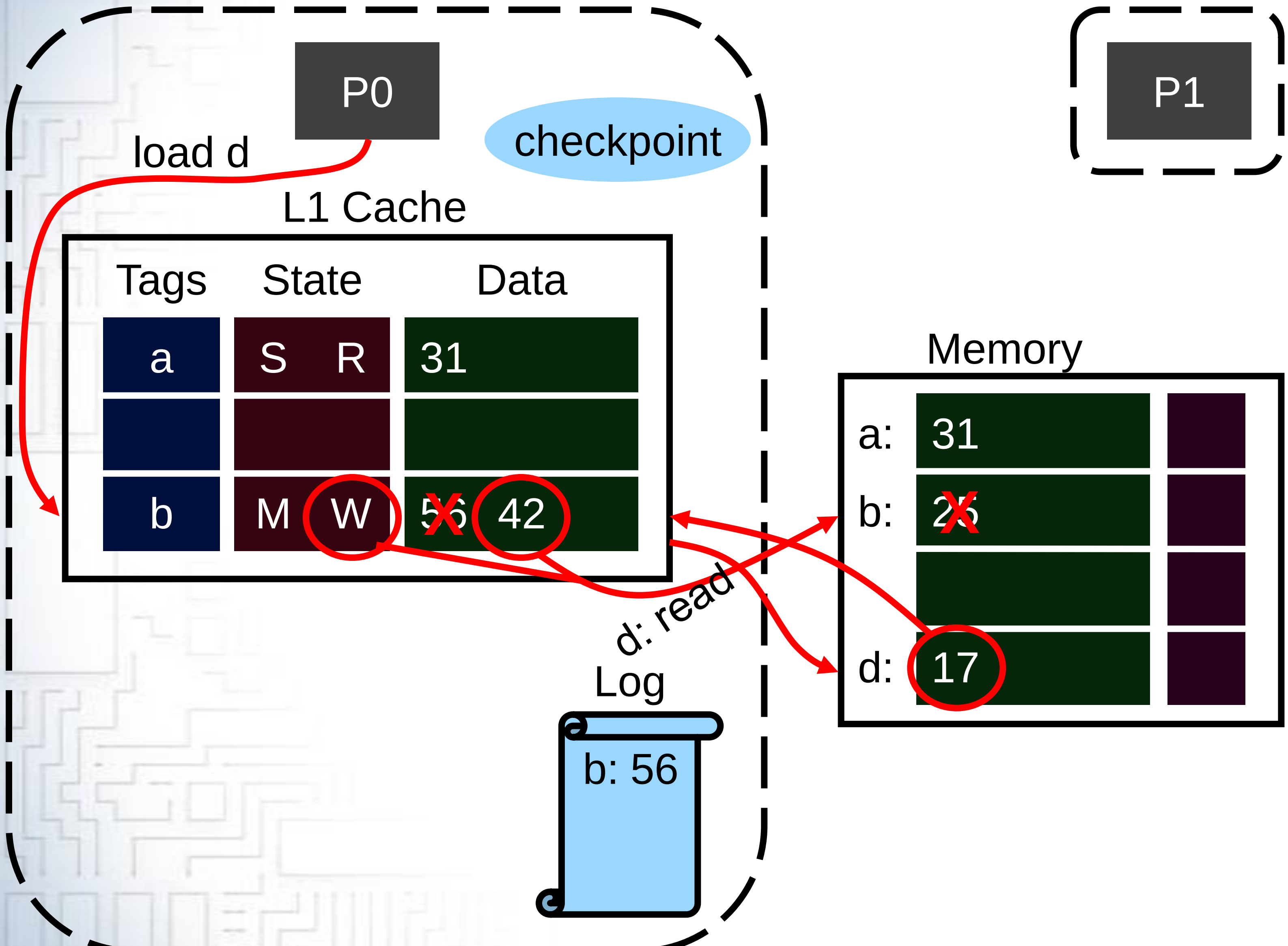


The Catch: Overflows

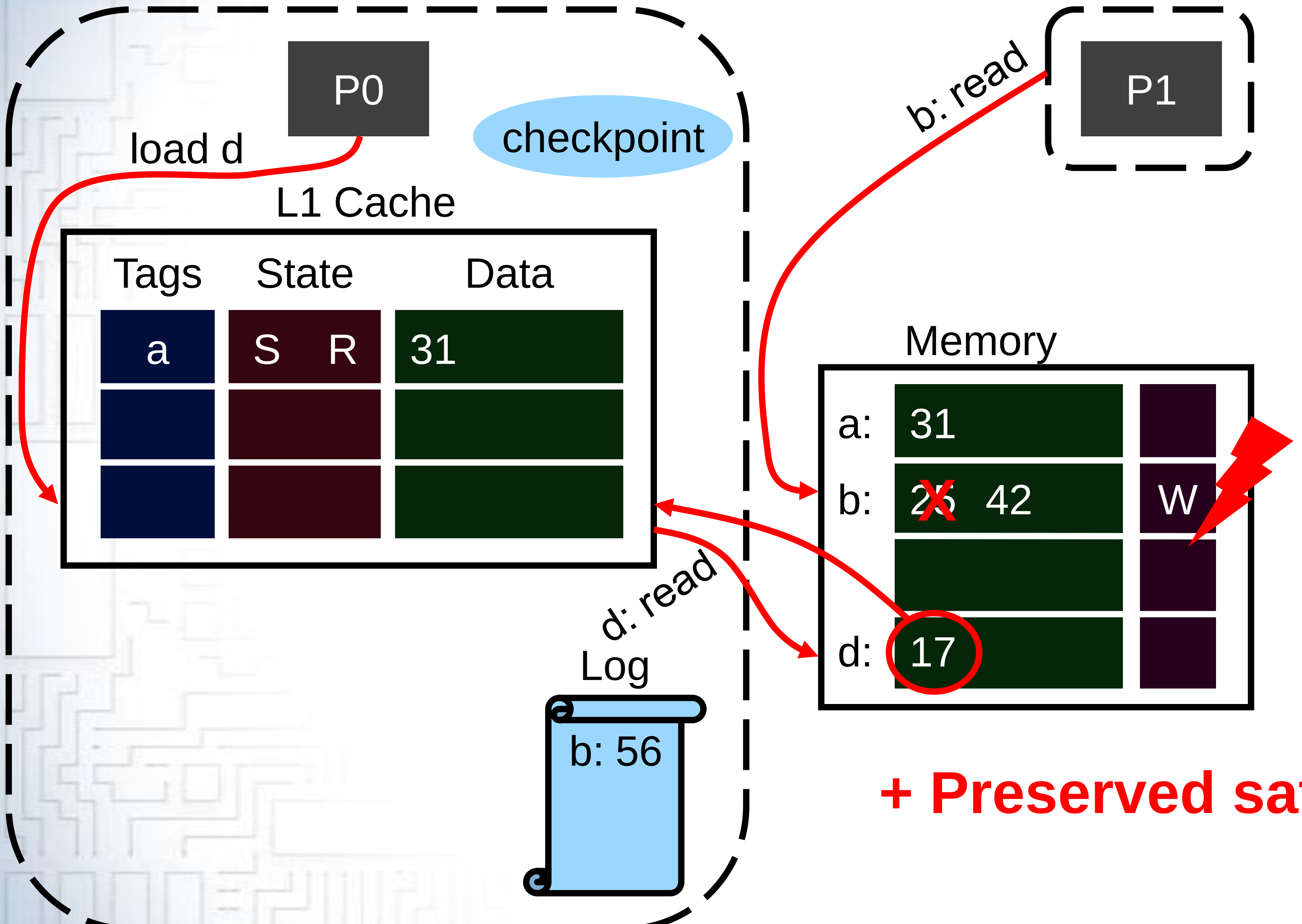


Need another mechanism for conflict detection

Handling Overflows: Strawman

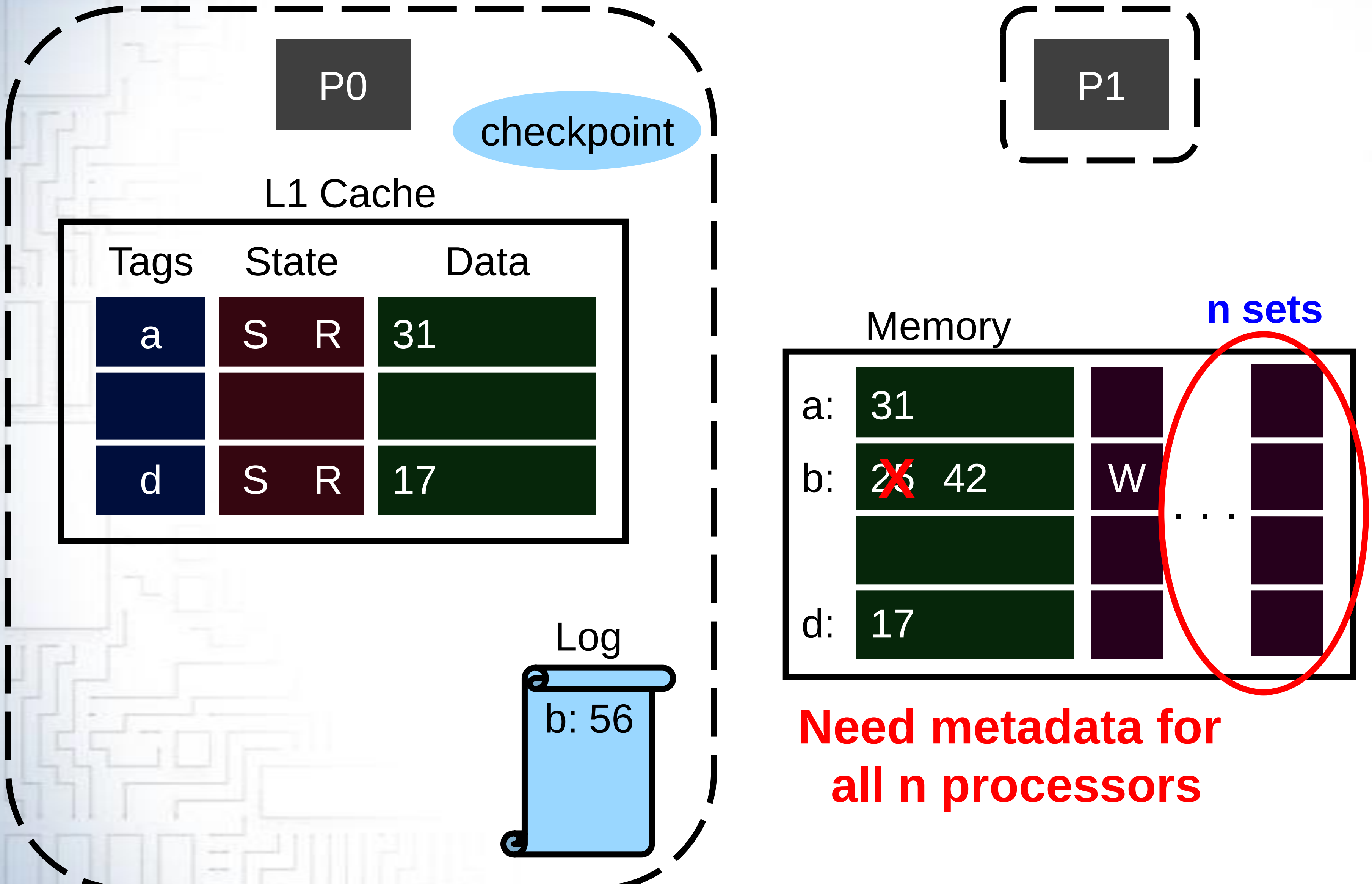


Handling Overflows: Strawman



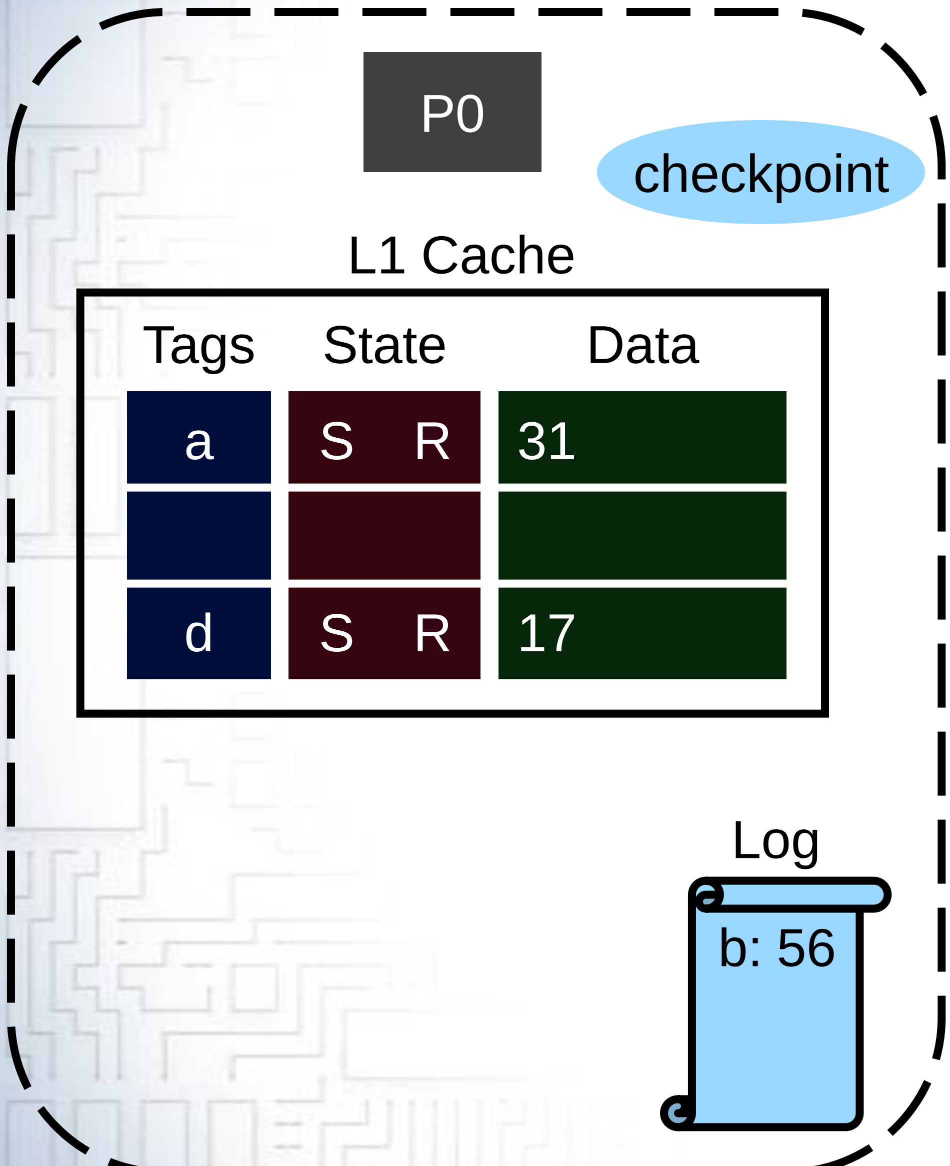
+ Preserved safety

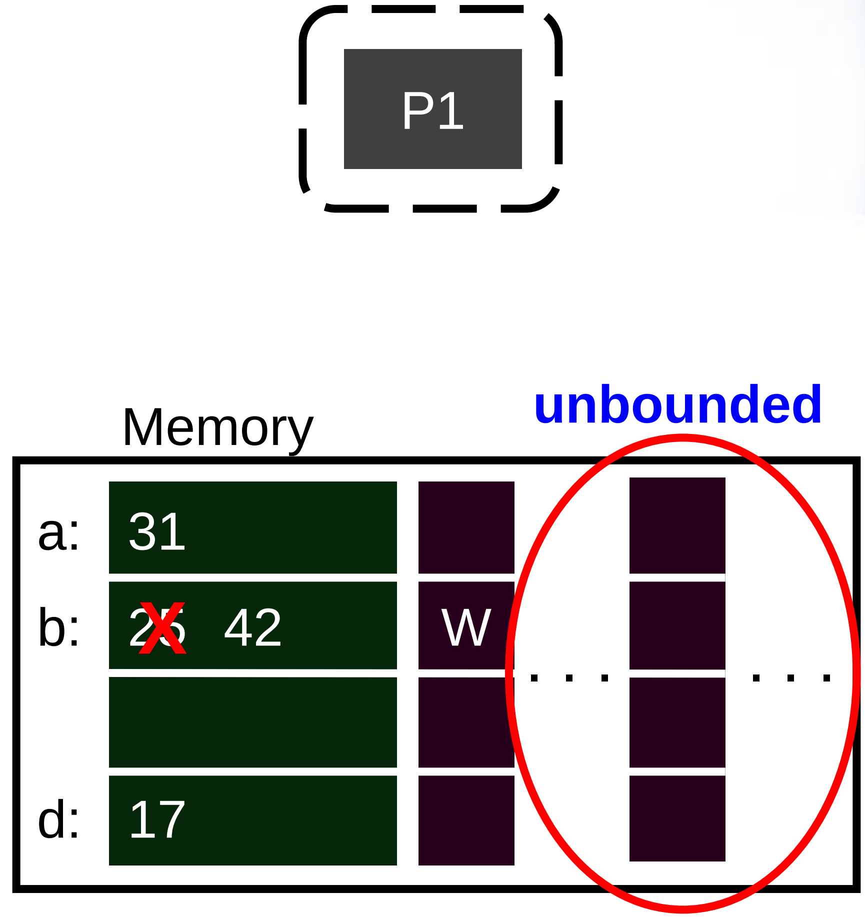
The Catch to Handling Overflows



Need metadata for all n processors

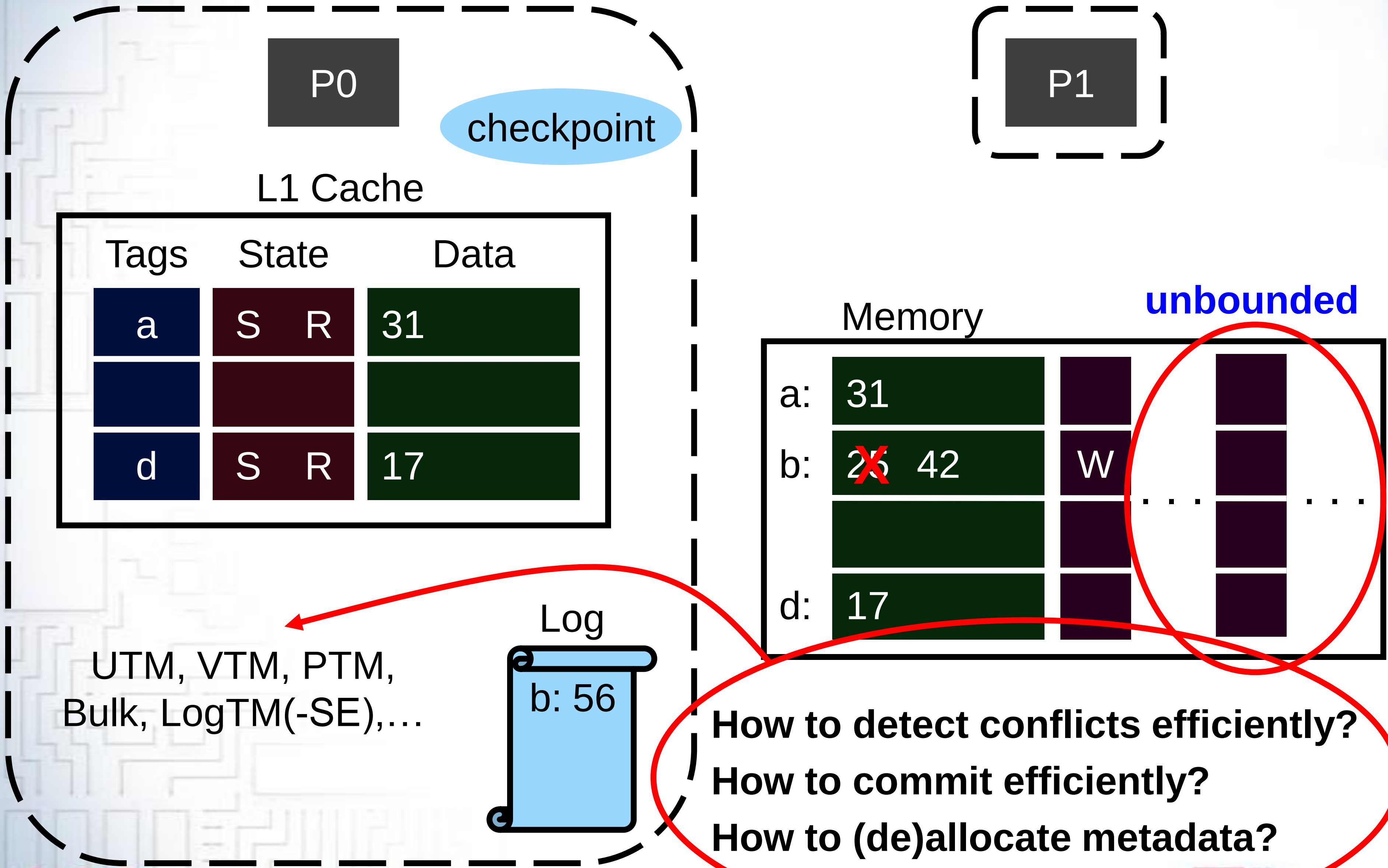
The Catch to Handling Overflows





Need metadata for ~~all n processors~~ each SW thread

The Catch to Handling Overflows



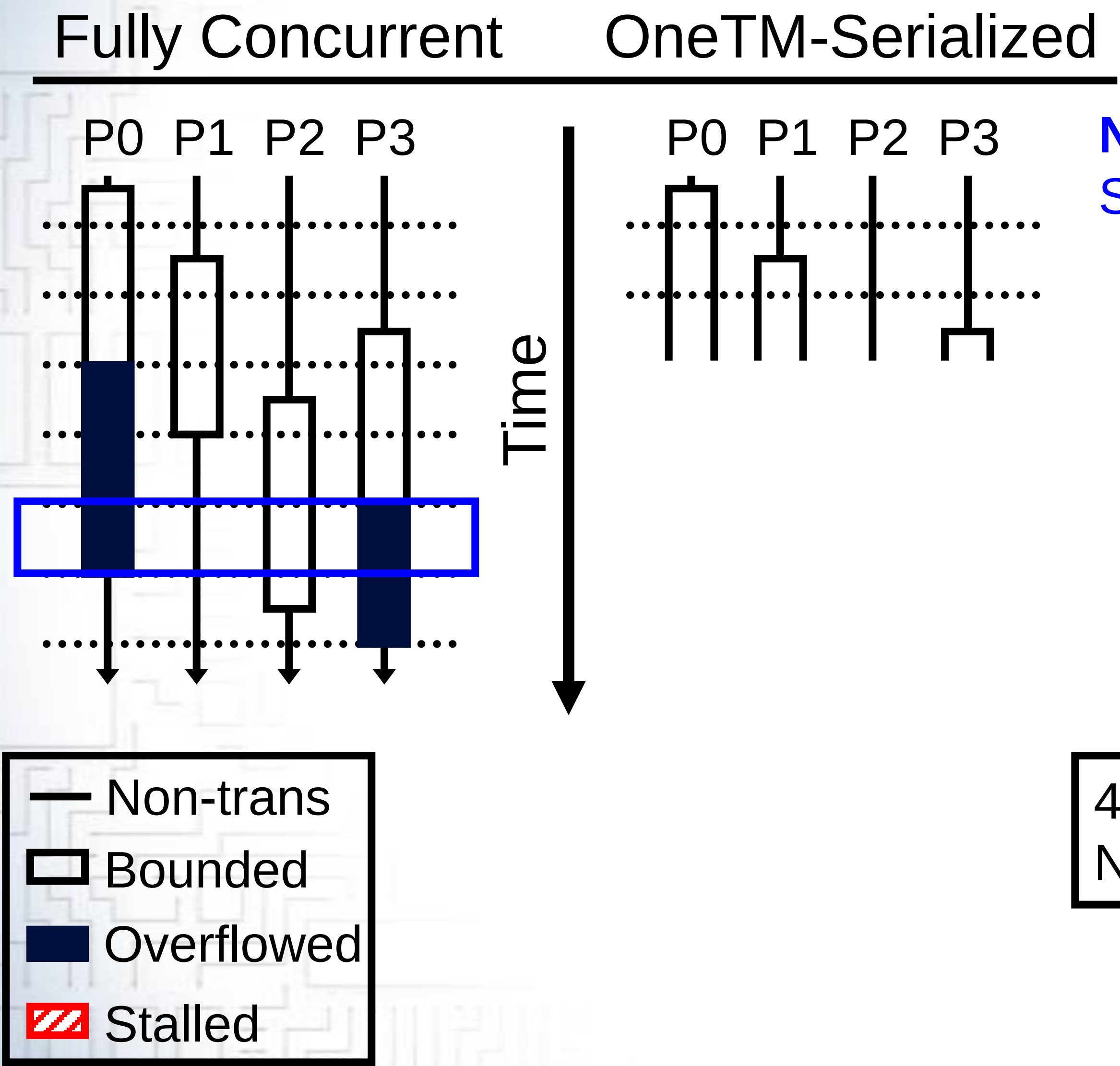
Rest of my talk: a different approach

- **Claim 1**: bounding concurrency of overflows simplifies implementation
  - Eases the problem of conflict detection
  - Removes the problem of dynamic metadata allocation
- Is unbounded concurrency necessary?
  - Depends on the frequency of overflows
- **Claim 2**: We can make overflows rare
- Take each claim in order
  - Claim 1: **OneTM**
  - Claim 2: **Permissions-only cache**

OneTM

- **Key idea:** one overflowed transaction at a time
  - On a per-application basis
  - Better name: HighlanderTM?
- Two implementations
  - **OneTM-Serialized:** all threads stall for overflow
  - **OneTM-Concurrent:** serialize only overflows
- Key mechanism: per-application *overflow bit*
  - Processors check to determine when to stall
  - Coherently cached in a special register

OneTM-Serialized



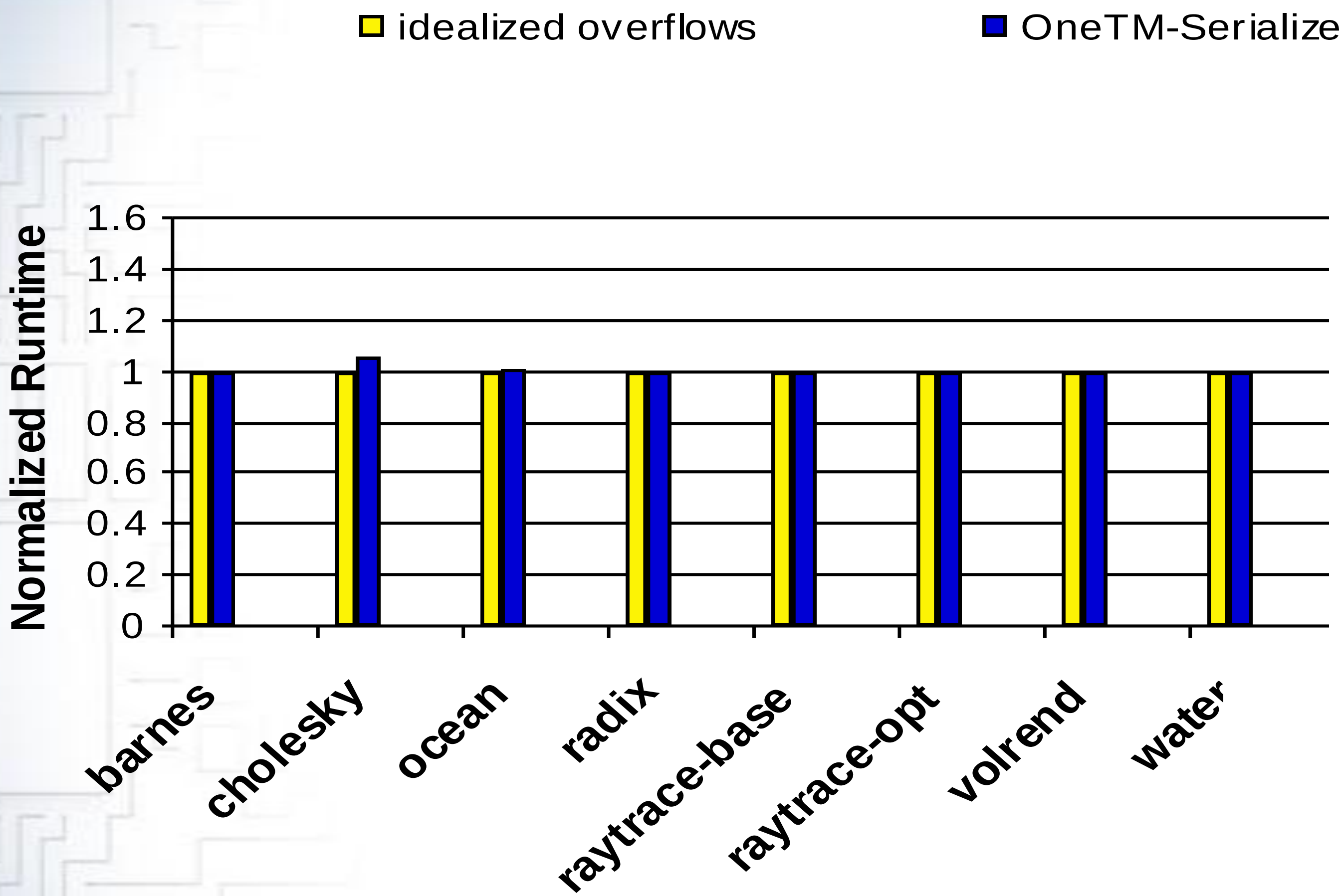
No changes to bounded TM

Similar to original TCC, but:

- Maintain aborts
- Standard CC protocol

4-processor execution
No conflicts

OneTM-Serialized: Evaluation

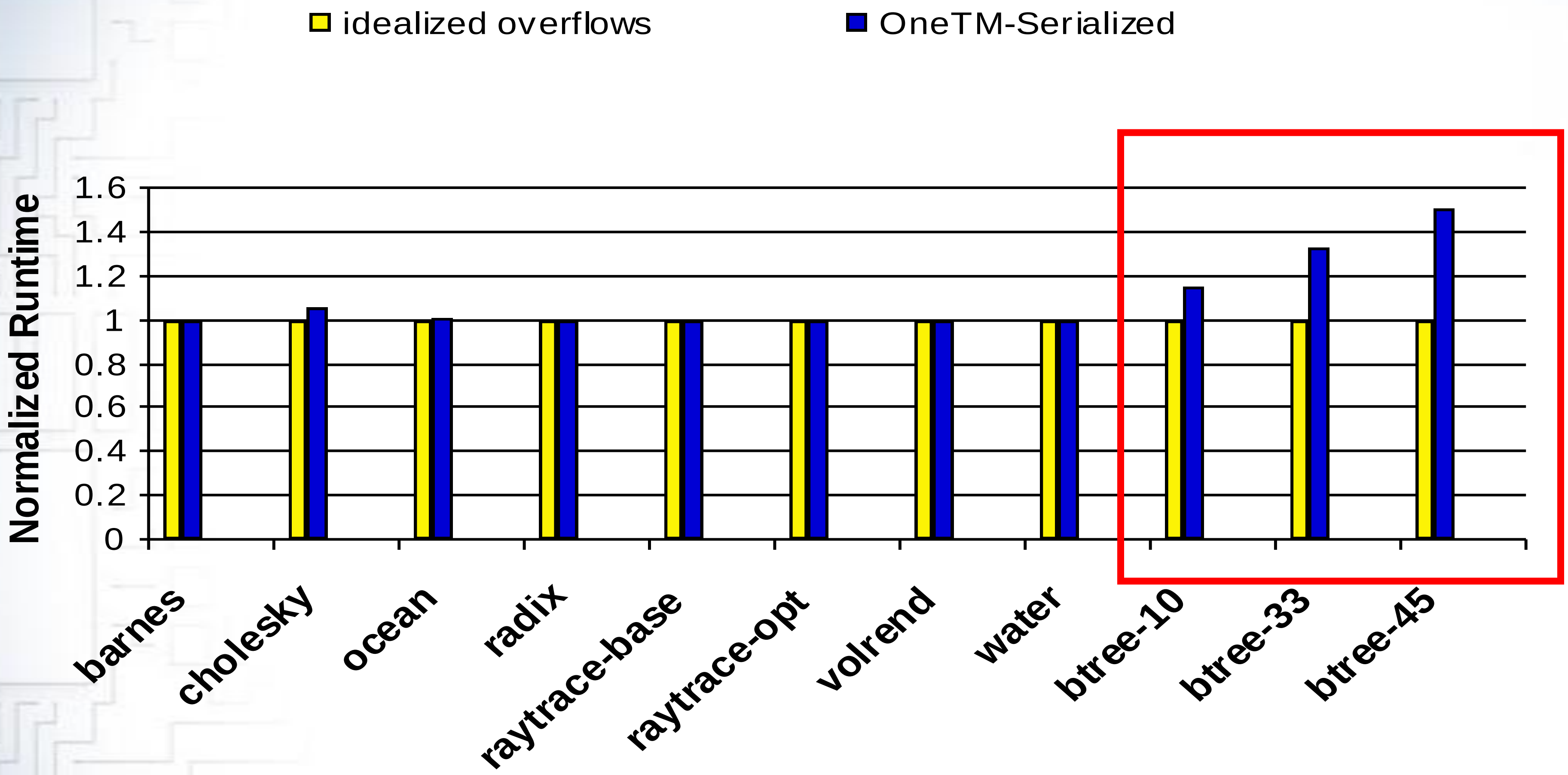


8 processors
Simics + GEMS

Compare to TM that idealizes overflow handling
First workload: SPLASH2

Takeaway #1:
If overflows are rare, serialization is sufficient

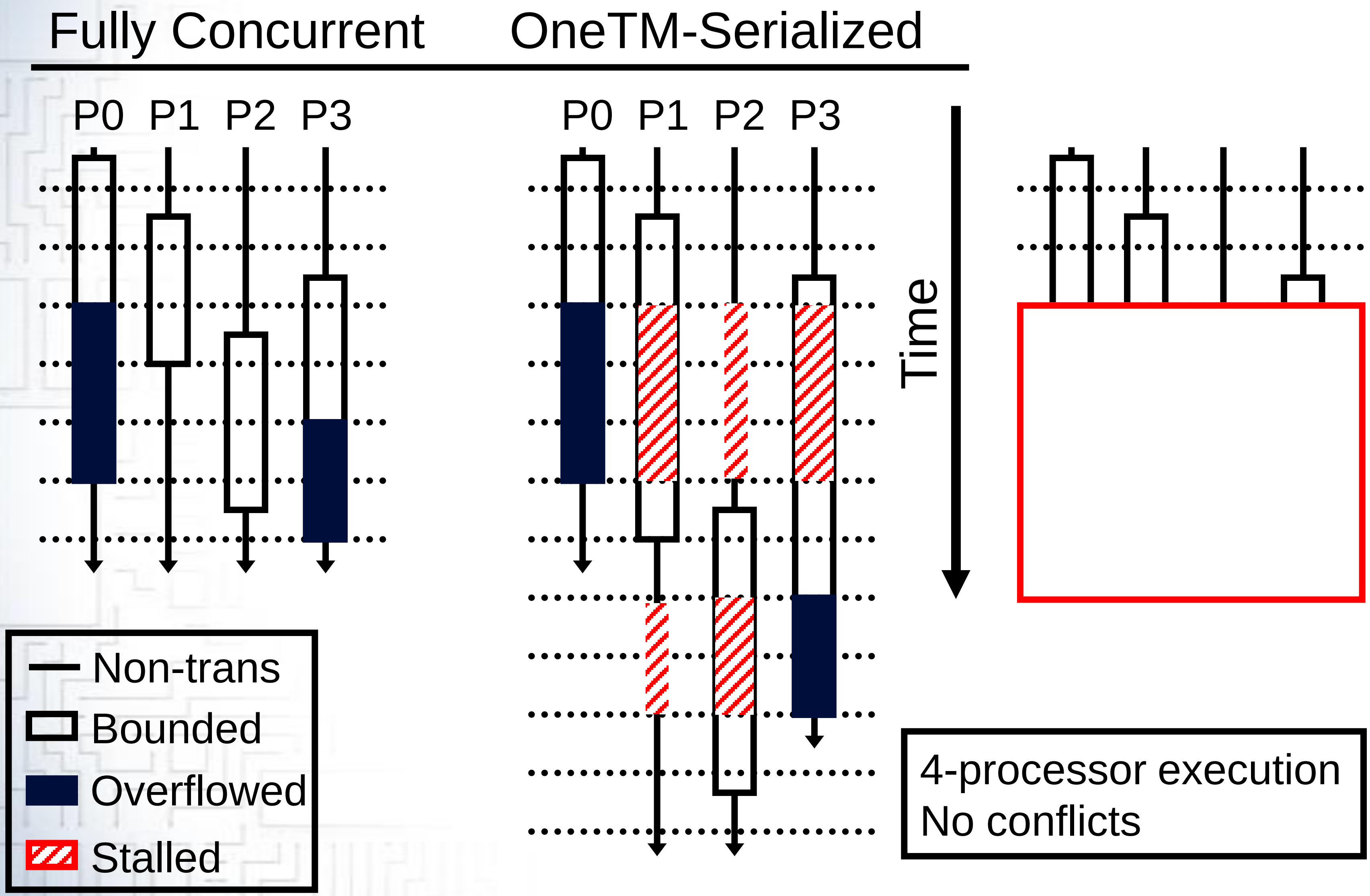
OneTM-Serialized: Evaluation



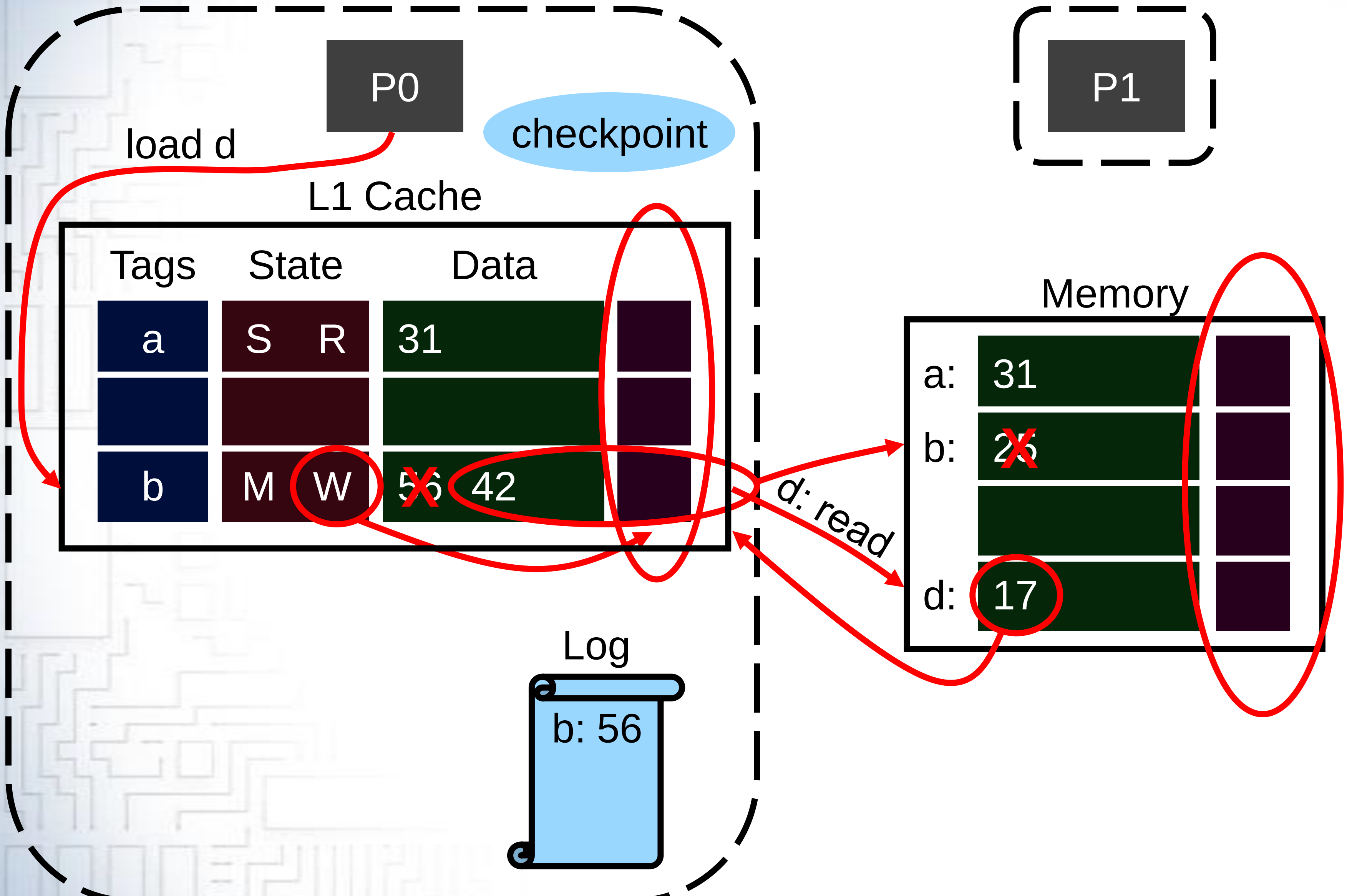
btree-<n>: mix of updates & read scans (n% read scans)

– Performance worse as number of overflows increases

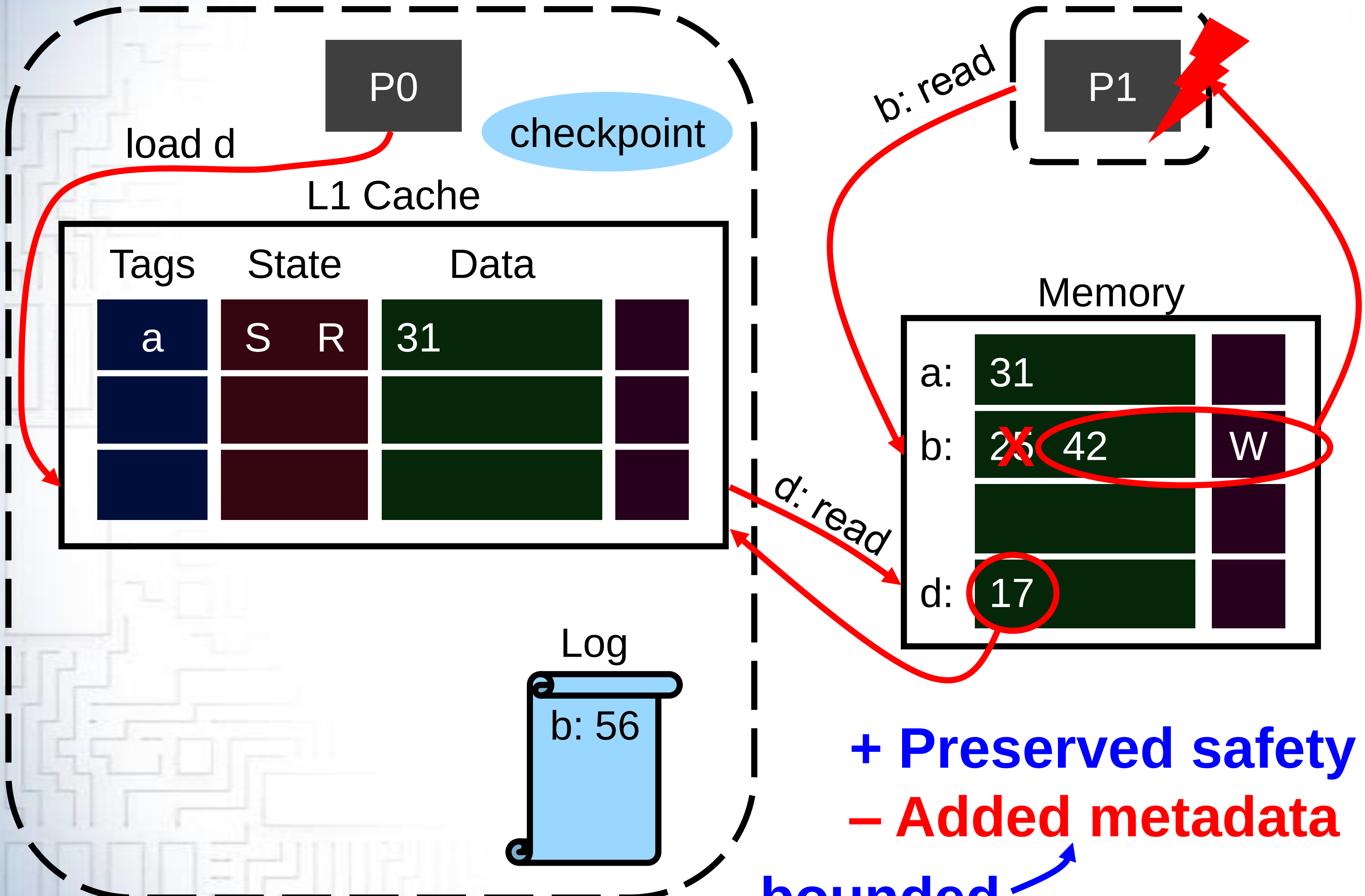
OneTM-Concurrent



OneTM-Concurrent Conflict Detection



OneTM-Concurrent Conflict Detection



+ Preserved safety

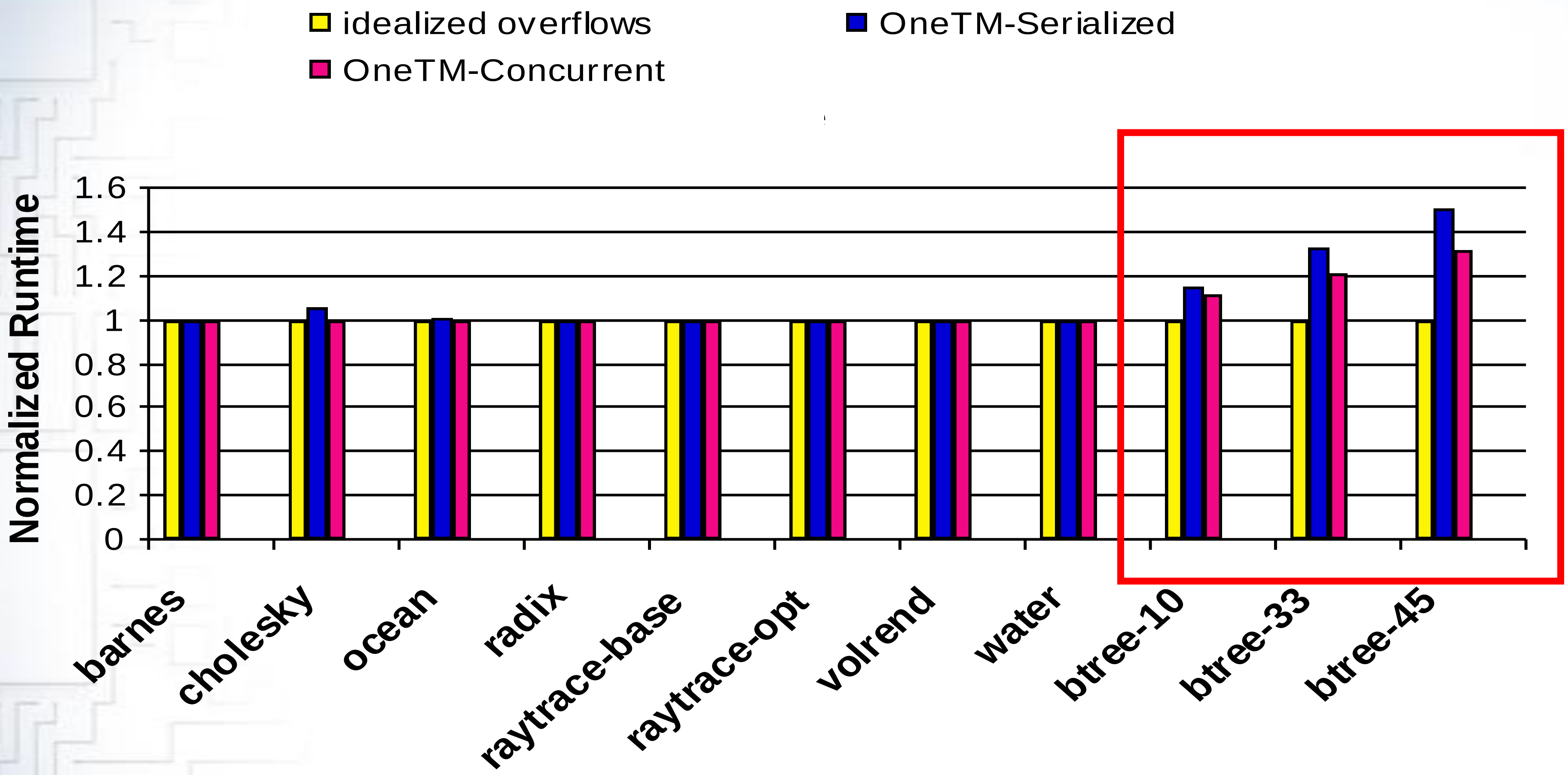
– Added metadata

bounded

OneTM-Concurrent Commits

- **Problem:** actively clearing metadata is nasty
  - Commit is now a high-overhead operation
- **Solution:** lazy clearing of metadata
  - Mechanism: overflowed transaction ID's
  - Block metadata extended to include ID's
  - Current ID stored with overflow bit
  - **Key:** only one active ID (so, notion of a "current ID")
- Changes
  + **Commit now cheap**
  – Widens datapath
  – Admits false conflicts (since ID's are finite-length)

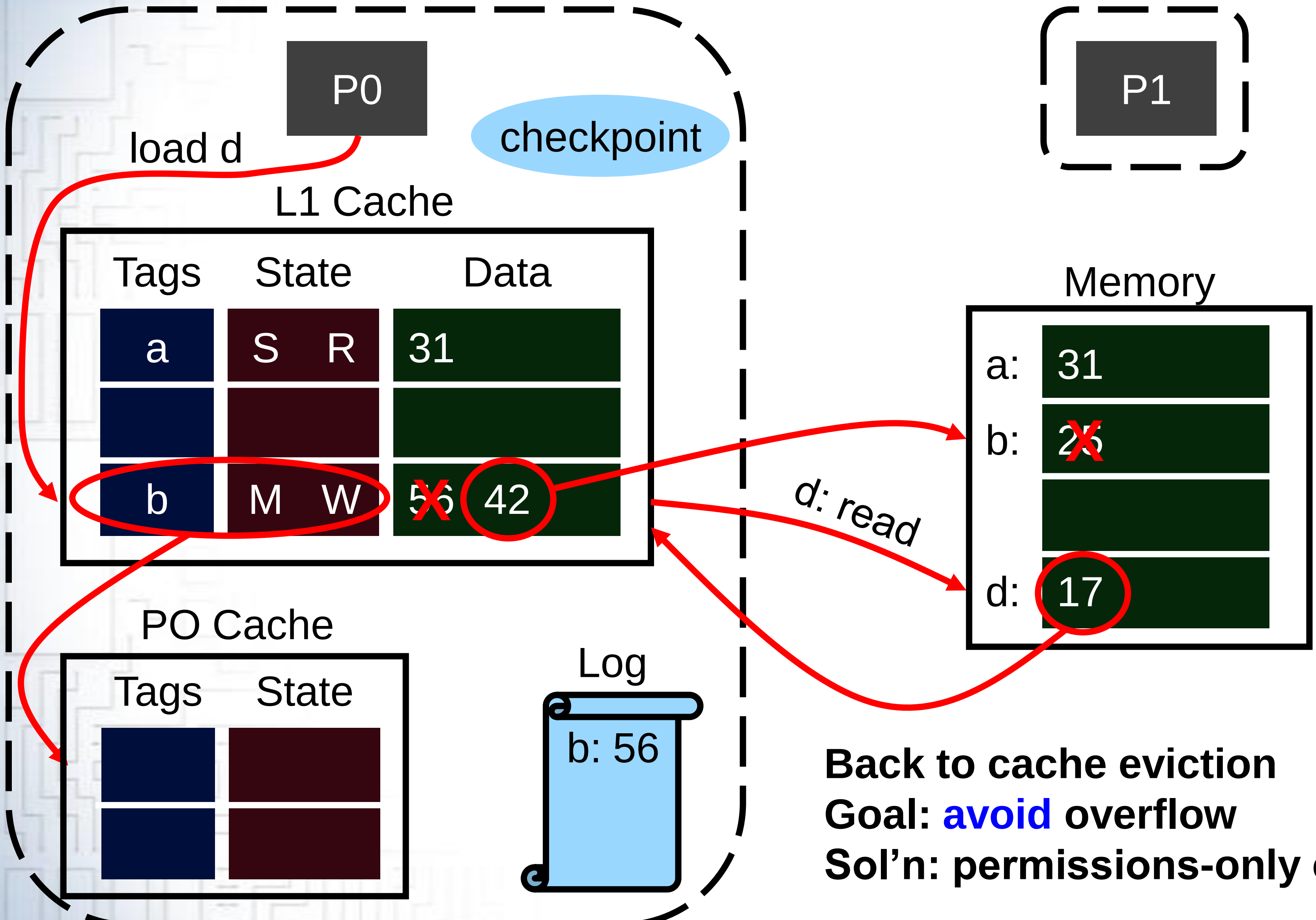
OneTM-Concurrent: Evaluation



+ Performance better than OneTM-Serialized

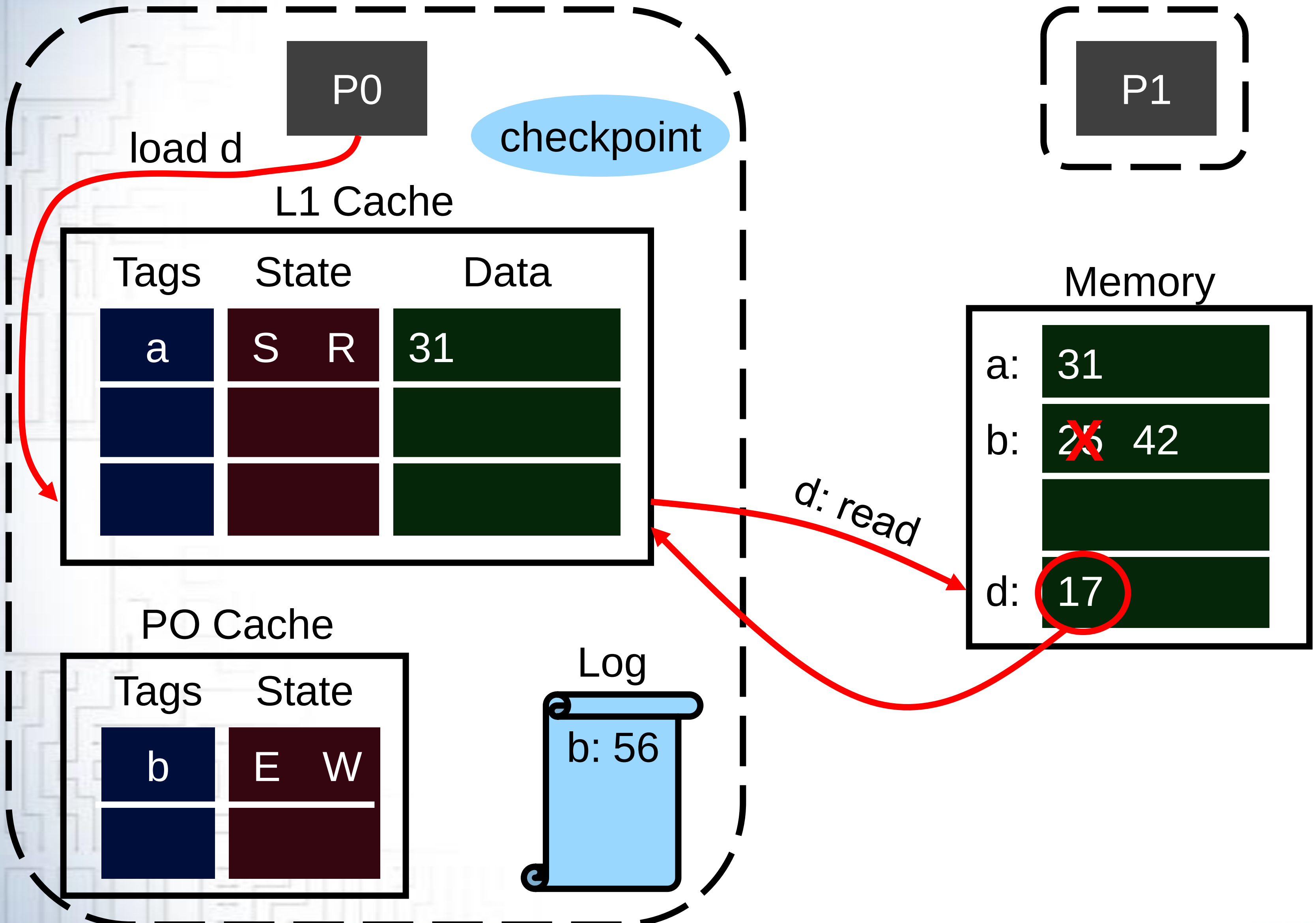
– Still falls off ideal as overflows increase

The Permissions-Only Cache

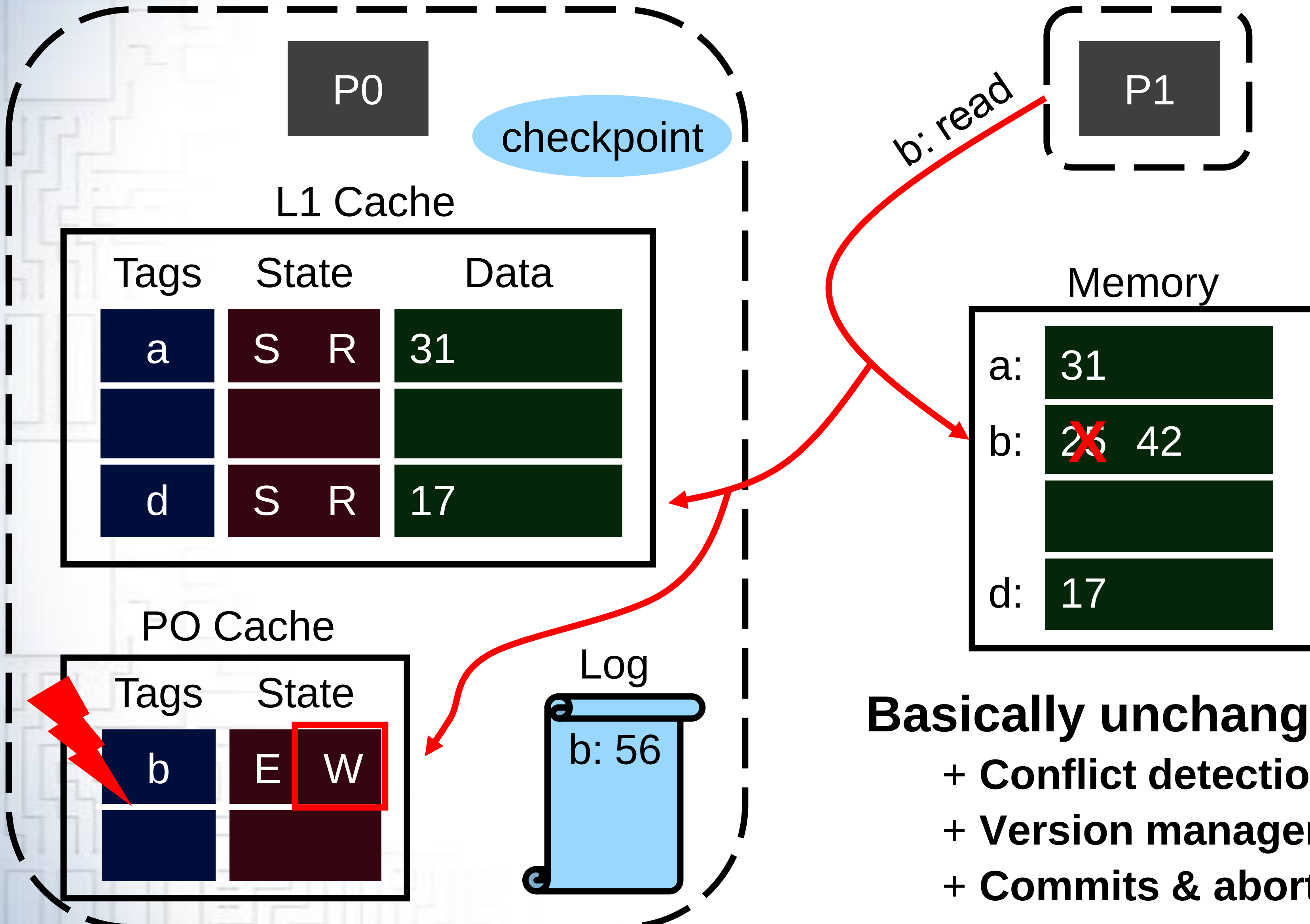


Back to cache eviction
Goal: avoid overflow
Sol'n: permissions-only cache

The Permissions-Only Cache



The Permissions-Only Cache



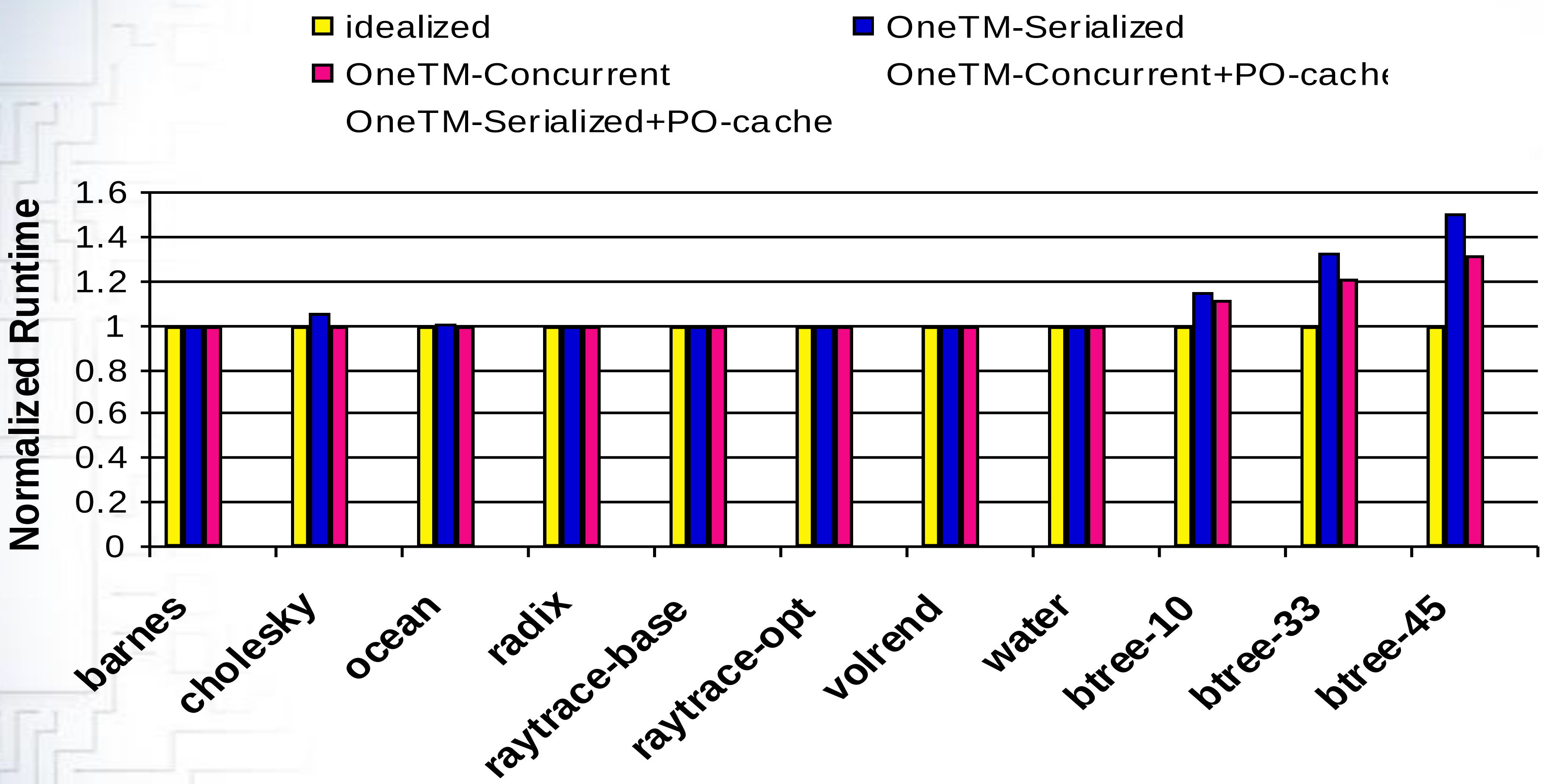
Basically unchanged:
- **+ Conflict detection**
- **+ Version management**
- **+ Commits & aborts**

The Permissions-Only Cache

- Two key features
  1. Accessed only on snoops and evictions
  2. Efficient encoding (sector cache)
- **Impact:** Extends overflow threshold
  - **4 KB** PO cache: **~1 MB** data
  - **64 KB** PO cache: **~16 MB** data
  - Store metadata in **4 MB** L2 data lines: up to **1 GB** data

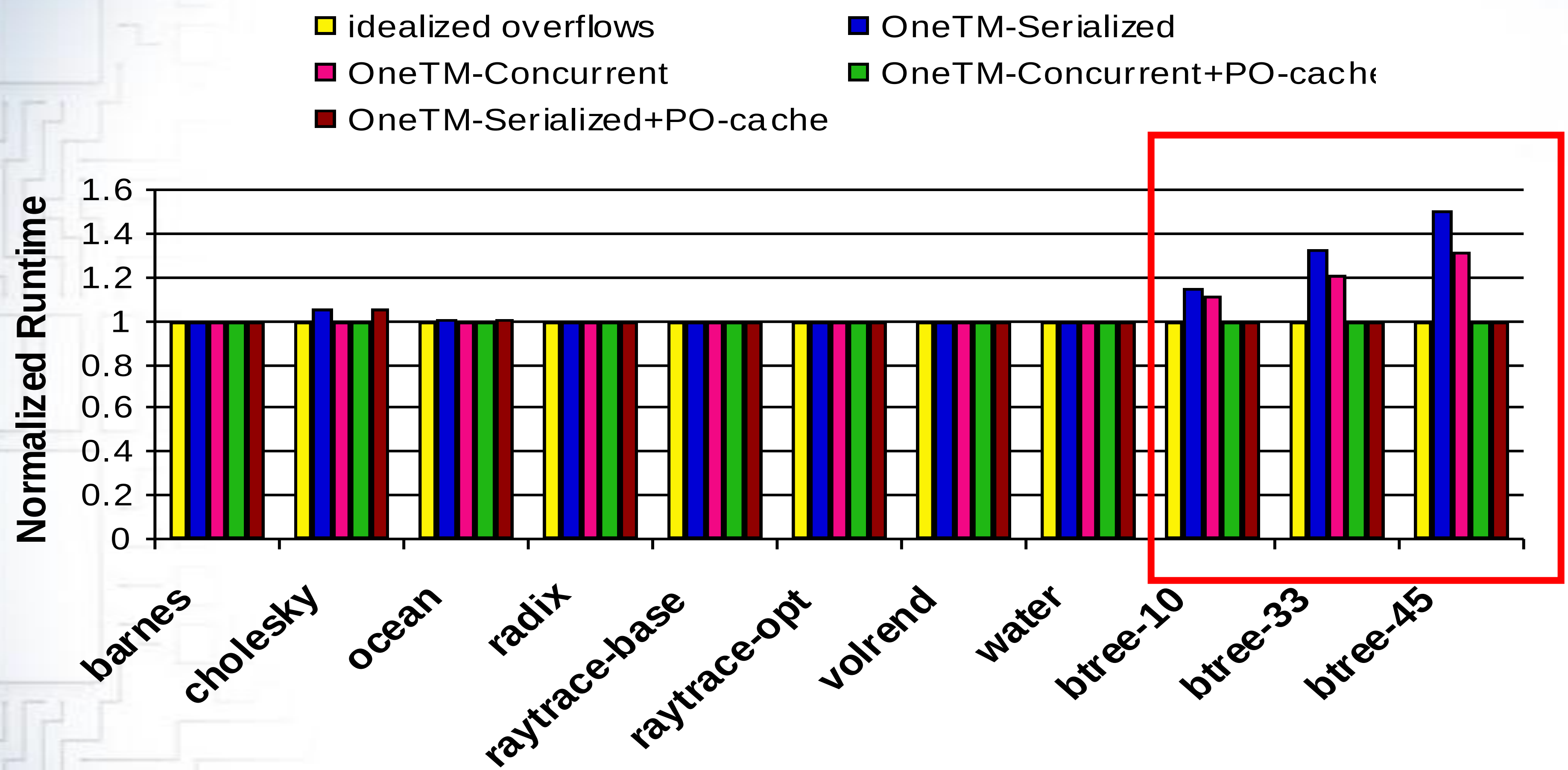
Takeaway #2:
We can engineer systems for rare overflows

The Permissions-Only Cache: Evaluation



Add **4 KB permissions-only cache** to OneTM

The Permissions-Only Cache: Evaluation



Overflows reduced to virtually nil

OneTM-Serialized + PO cache: a sweet spot?

Related Work

- Lots!
- Proposals with low-overhead overflow handling mechanisms
  - UTM/LTM, VTM, PTM, LogTM, …
  - Our scheme: PO cache reduces overflow, OneTM handles it simply
  - Many proposals enhanced by permissions-only cache
- Bounded HTM's backed by software (HyTM, XTM, …)
  - Similar philosophy to ours (uncommon case simple)
  - Their schemes maintain concurrency but introduce overheads…
  - …OneTM-Concurrent sacrifices concurrency but has low overheads
  - Again, enhanced by permissions-only cache
- Signature-based TMs: conflict detection through finite-sized signatures (Bulk, LogTM-SE, …)
  - \+ Signatures can be saved architecturally
  - \+ Serialize gradually rather than abruptly
  - – Still an unbounded number of signatures

Conclusions

- **OneTM:** make overflow handling simple
  - OneTM-Serialized: entry-point unbounded TM
  - OneTM-Concurrent: more robust to overflows
- **Permissions-only cache:** make overflows rare
  - + Can engineer to keep overflow rate low for your workload
  - + Enhances many prior unbounded TM proposals

Combination: TM that's both fast and simple to implement

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LogTM-SE

- + Very neat!
- – Paging more complex than in OneTM
- – Commit of a transaction that has migrated processors must trap to OS
- Our hope for PO cache: overflow only on context switch
  - And there LogTM-SE loses directory filter…
- Sticky state + OneTM-Serialized?

Hybrid Transactional Memories

- Similar philosophy to OneTM
- Our goal: make overflows so rare that it doesn't really matter what you use for them
  - And then OneTM-Serialized is pretty simple…
- If overflows are frequent, need to handle them with high performance
  - Permissions-only cache + UTM/VTM/PTM?
- Spot in the middle for hybrid TM's/OneTM-Concurrent
  - Occasional overflow: OneTM-Concurrent appealing
  - Tipping point where concurrency matters more than overheads…I don't know where it is (need workloads)

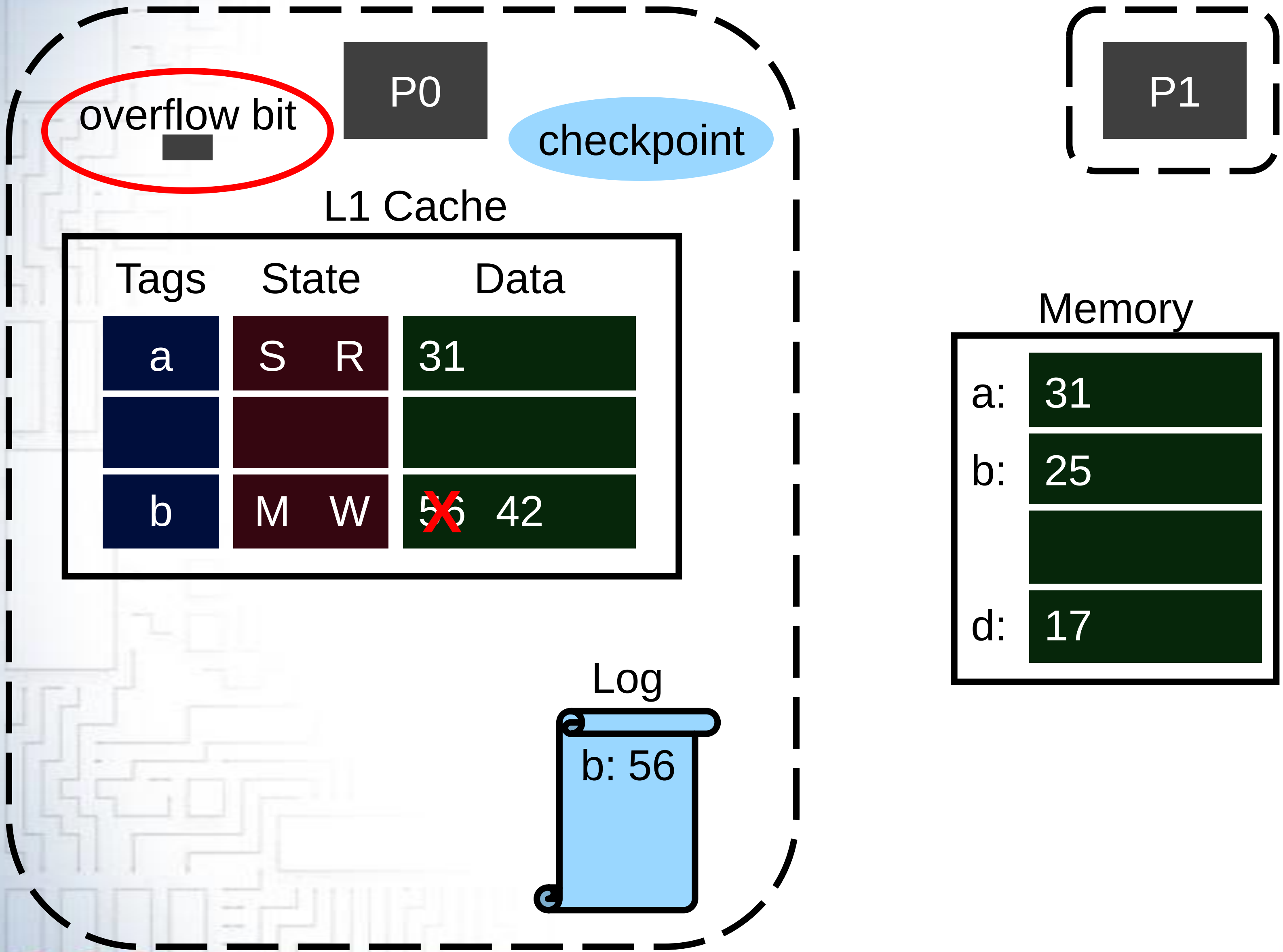
Context Switching & Paging

- Context switching "just works"
  - OneTM-Serialized: overflowed bit persists
  - OneTM-Concurrent: metadata persists as well
- Paging during an overflowed transaction:
  - OneTM-Serialized: no problem
  - OneTM-Concurrent: page metadata (OS help)
- Paging during a bounded transaction:
  - Abort and transition to overflowed mode

Transitioning to Overflowed Mode

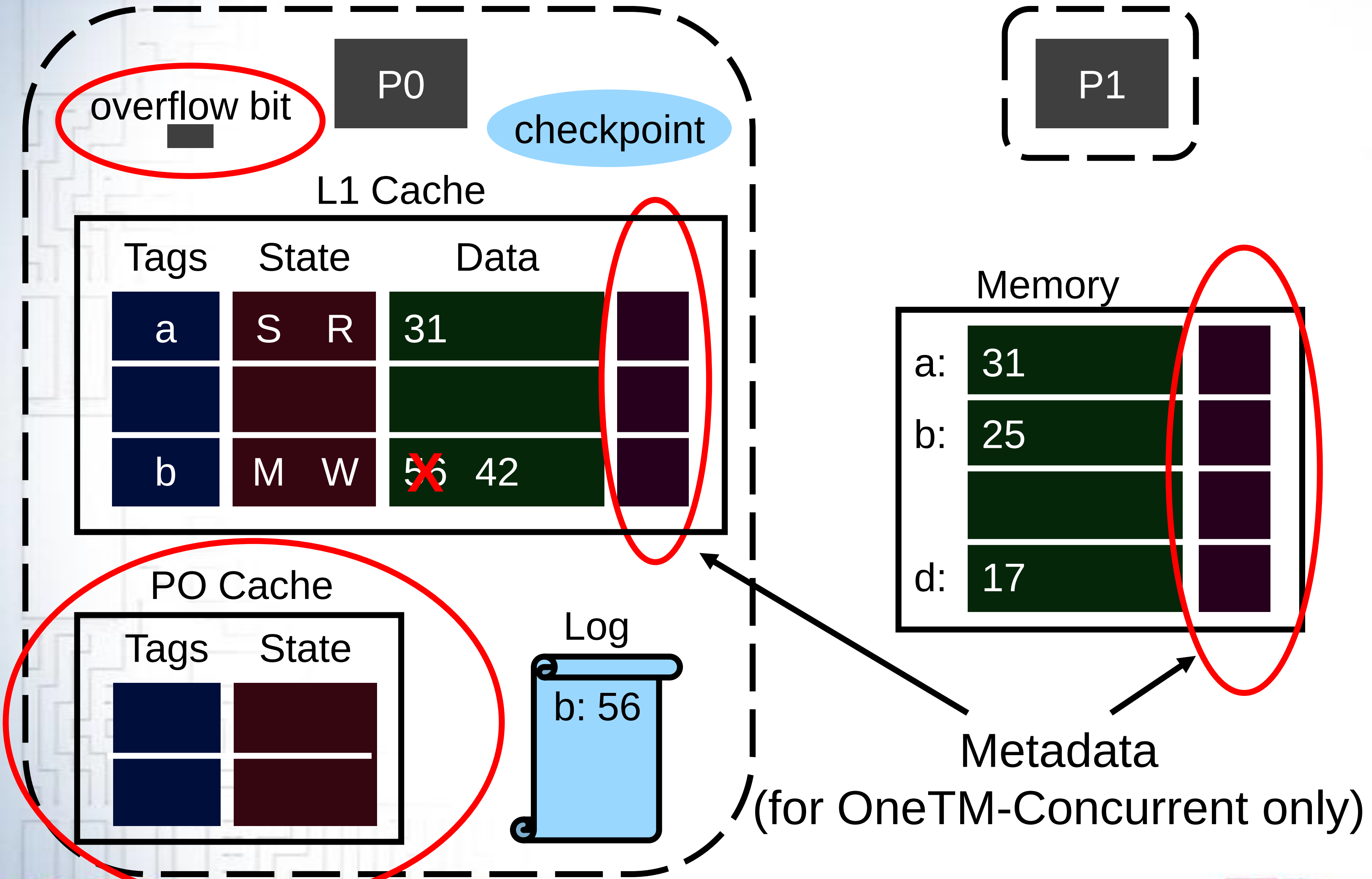
- OneTM-Serialized: just set the bit
  - Synchronize access
- OneTM-Concurrent: have to set metadata
  - Simple: abort and restart (what we simulate)
  - Higher-performance schemes are possible
    - Walk the cache
    - Overflow gradually

Summary



overflow bit
P0
checkpoint
L1 Cache
Tags
State
Data
a
S R
31
b
M W
56 42
Log
b: 56
P1
Memory
a:
31
b:
25
d:
17

Summary


P0
overflow bit
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PO Cache
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b: 56
P1
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a:
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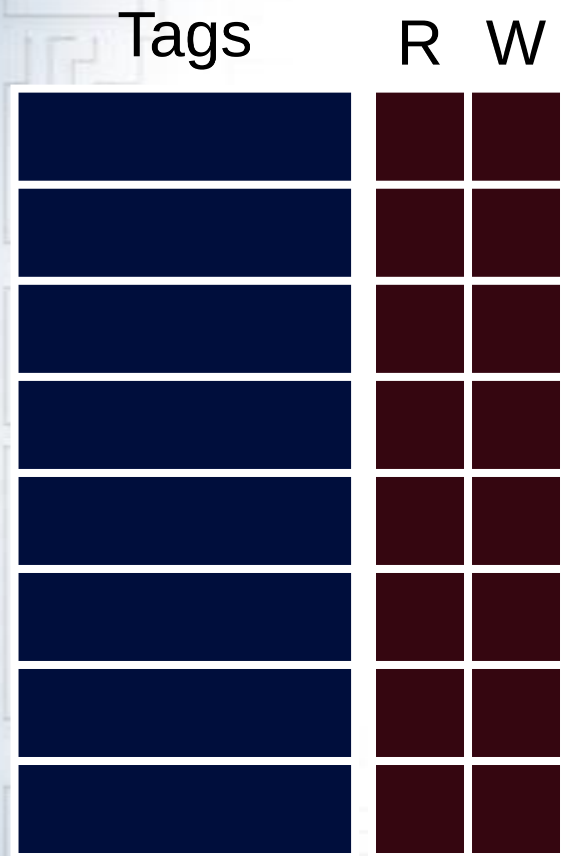
b:
25
d:
17
Metadata
(for OneTM-Concurrent only)

The Permissions-only Cache: Efficient Storage



- Sector cache to reduce tag overhead
- Now: (close to) 2 bits per data block
  - 64-byte blocks: 256 to 1 compression ratio
  - 4 KB metadata: 1 MB transactional data
- Even larger: metadata in L2 data lines
  - add bit to distinguish data/metadata
  - 4 MB L2: 1 GB transactional data