Lecture 12
Transactional Memory

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[Based on EE382A Material from Kozyrakis]

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CSAIL

Transactional Memory (TM)

- Memory transaction [Lomet'77, Knight'86, Herlihy & Moss'93]
  - An atomic & isolated sequence of memory accesses
  - Inspired by database transactions
- Atomicity (all or nothing)
  - At commit, all memory writes take effect at once
  - On abort, none of the writes appear to take effect
- Isolation
  - No other code can observe writes before commit
- Serializability
  - Transactions seem to commit in a single serial order
  - The exact order is not guaranteed though

Programming with TM


```
void deposit(account, amount){
   lock(account);
     int t = bank.get(account);
     t = t + amount;
     bank.put(account, t);
   unlock(account);
}
```

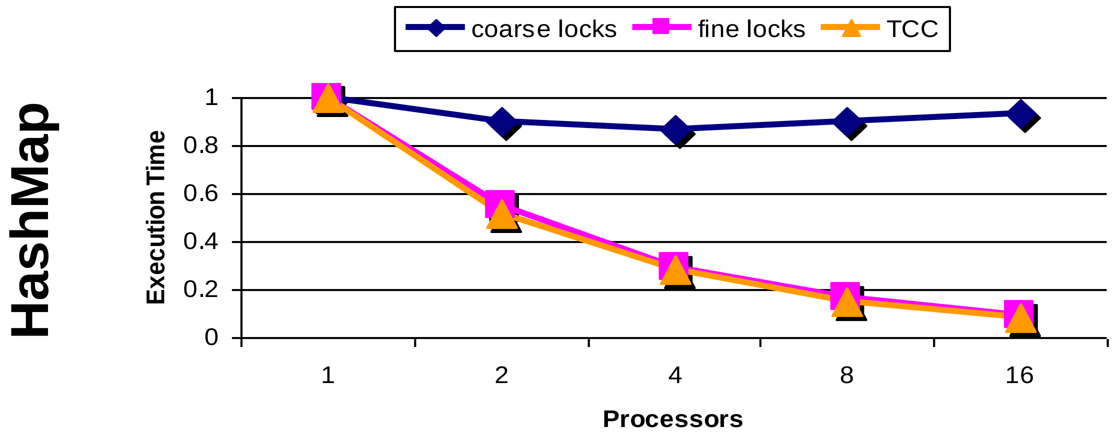
```
void deposit(account, amount){
   atomic {
     int t = bank.get(account);
     t = t + amount;
     bank.put(account, t);
   }
}
```

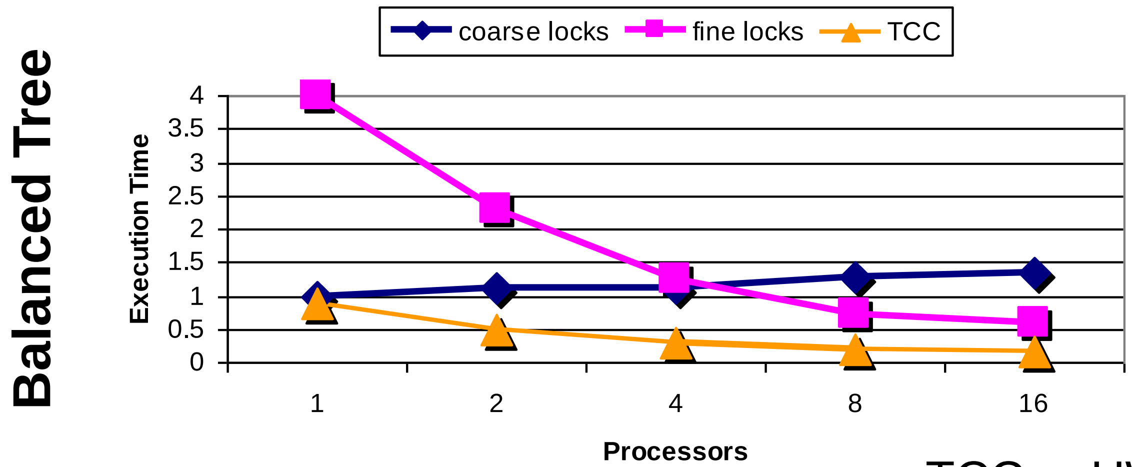
- Declarative synchronization
  - Programmers says what but not how
  - No explicit declaration or management of locks
- System implements synchronization
  - Typically with optimistic concurrency [Kung'81]
  - Slow down only on conflicts (R-W or W-W)

Advantages of TM

- Easy to use synchronization
  - As easy to use as coarse-grain locks
  - Programmer declares, system implements
- Performs as well as fine-grain locks
  - Automatic read-read & fine-grain concurrency
  - No tradeoff between performance & correctness
- Failure atomicity & recovery
  - No lost locks when a thread fails
  - Failure recovery = transaction abort + restart
- Composability
  - Safe & scalable composition of software modules

Performance: Locks Vs Transactions





TCC: a HW-based TM system
[Hammond et al, ISCA'04]

TM Implementation Basics

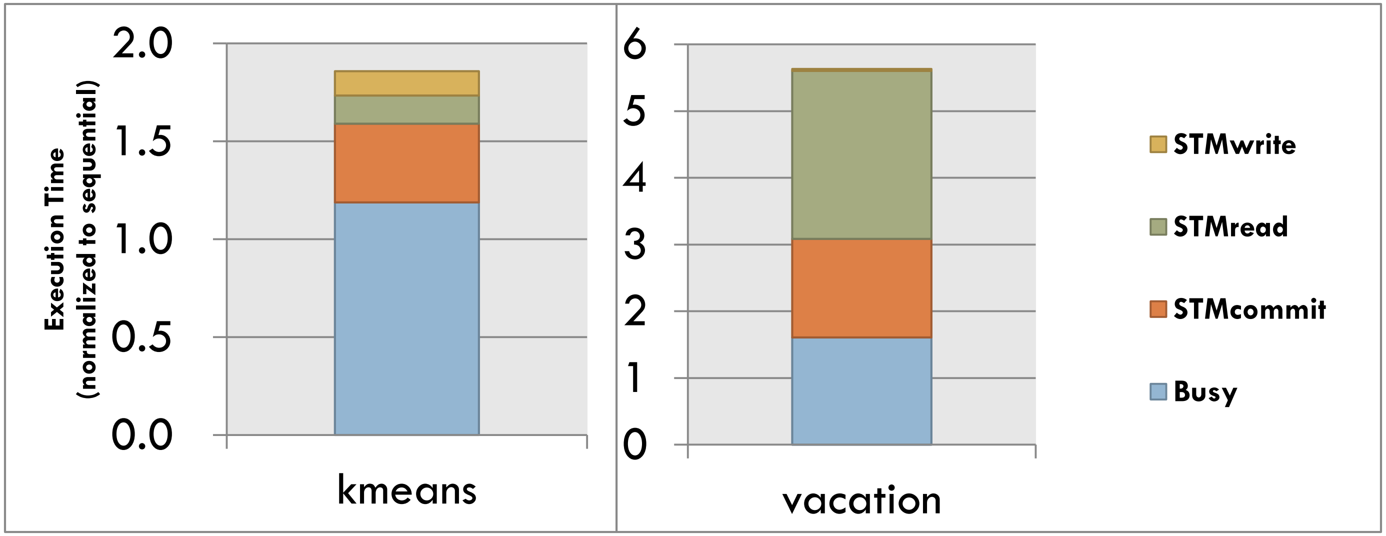
- TM systems must provide atomicity and isolation without sacrificing concurrency

- Basic implementation requirements
  - Checkpointing
  - Data versioning
  - Conflict detection & resolution

- Implementation options
  - Hardware transactional memory (HTM)
  - Software transactional memory (STM)
  - Hybrid transactional memory
    - Hardware accelerated STMs and dual-mode systems

Motivation for Hardware TM

- Measured single-thread STM performance:



- Software TM suffers 2-8x slowdown over sequential
  - Short term issue: demotivates parallel programming
  - Long term issue: not energy-efficient
- Industry adopting HTM: Sun (Rock), Intel (Haswell), IBM (Blue Gene and zSeries)

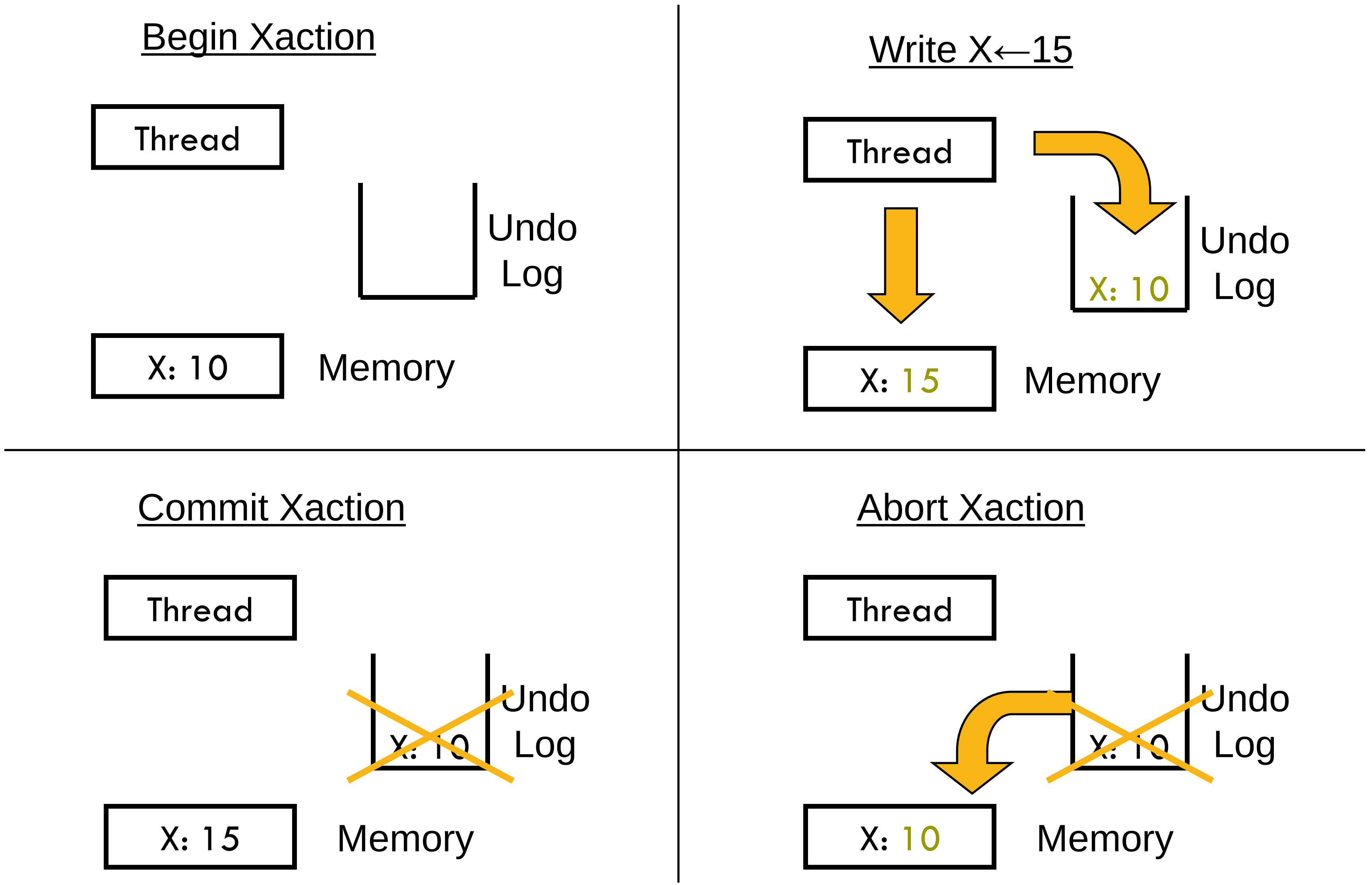
Data Versioning

- Manage uncommited (new) and commited (old) versions of data for concurrent transactions

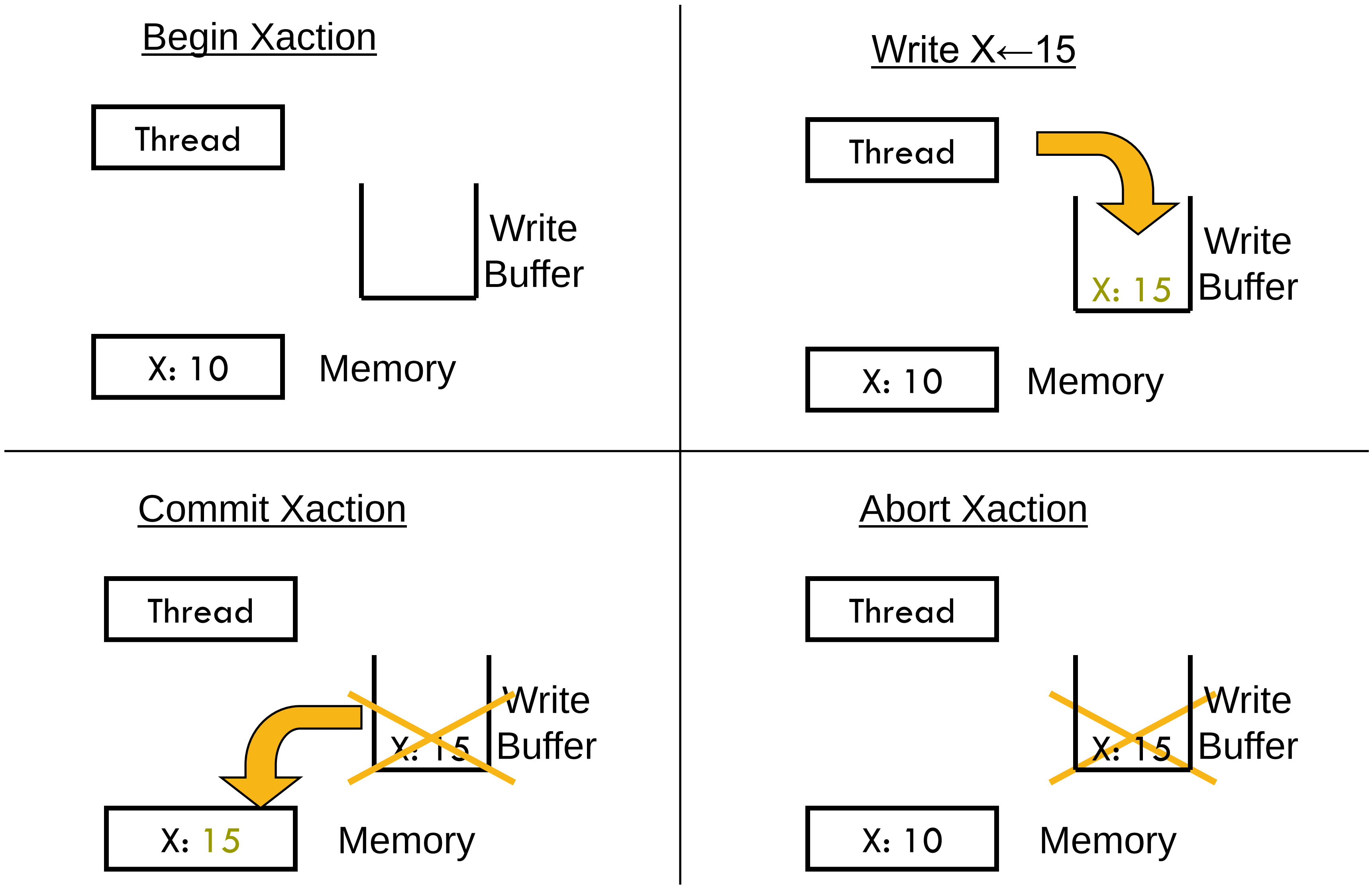
1. Eager versioning (undo-log based)
   - Update memory location directly
   - Maintain undo info in a log
   - \+ Faster commit, direct reads (SW)
   - – Slower aborts, fault tolerance issues

2. Lazy versioning (write-buffer based)
   - Buffer data until commit in a write-buffer
   - Update actual memory location on commit
   - \+ Faster abort, no fault tolerance issues
   - – Slower commits, indirect reads (SW)

Eager Versioning Illustration



Lazy Versioning Illustration

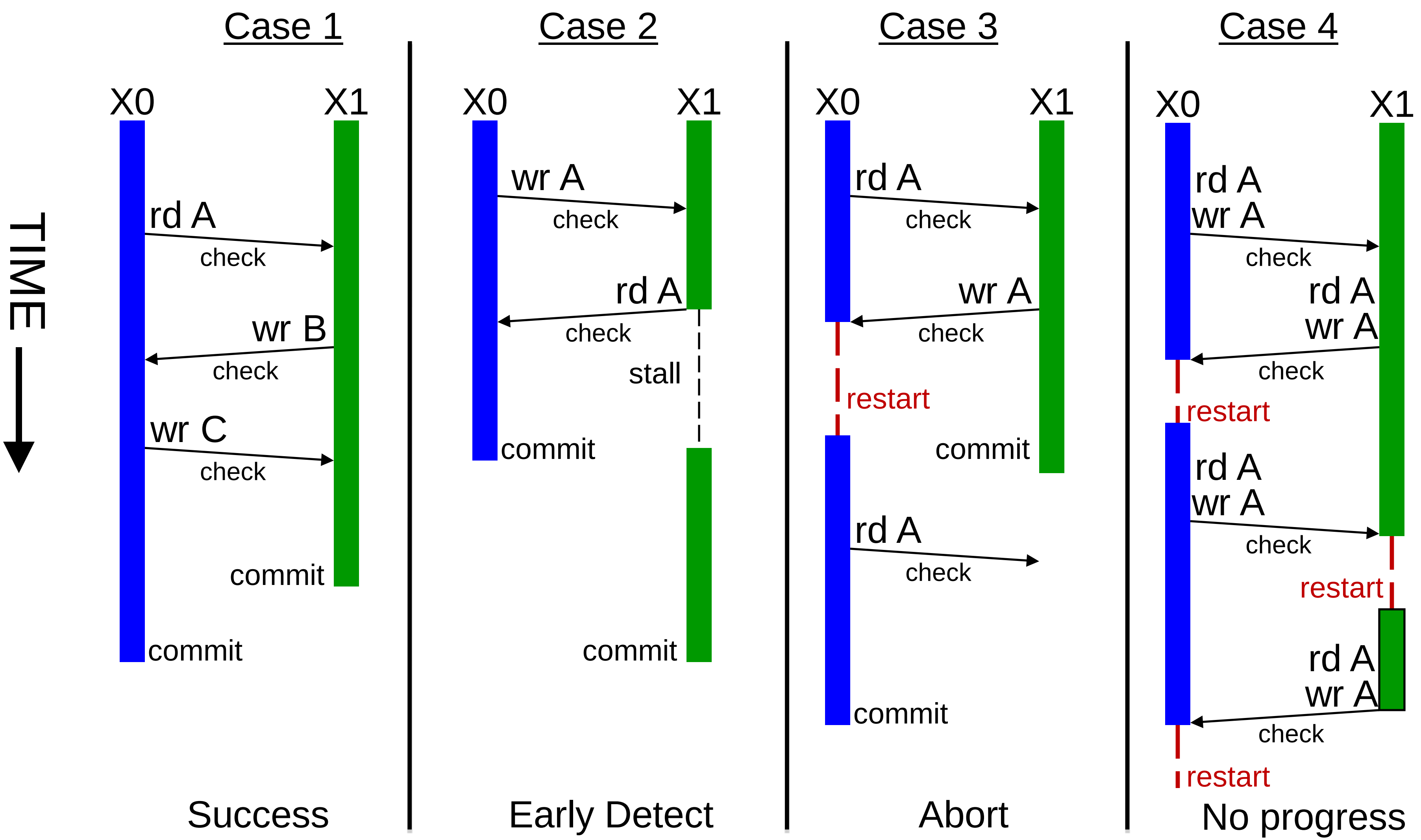


Conflict Detection

- Detect and handle conflicts between transaction
  - Read-Write and (often) Write-Write conflicts
  - Must track the transaction's read-set and write-set
    - Read-set: addresses read within the transaction
    - Write-set: addresses written within transaction

1. Pessimistic (Eager) detection
   - Check for conflicts during loads or stores
     - SW: SW barriers using locks and/or version numbers
     - HW: check through coherence actions
   - Use contention manager to decide to stall or abort
     - Various priority policies to handle common case fast

Pessimistic Detection Illustration

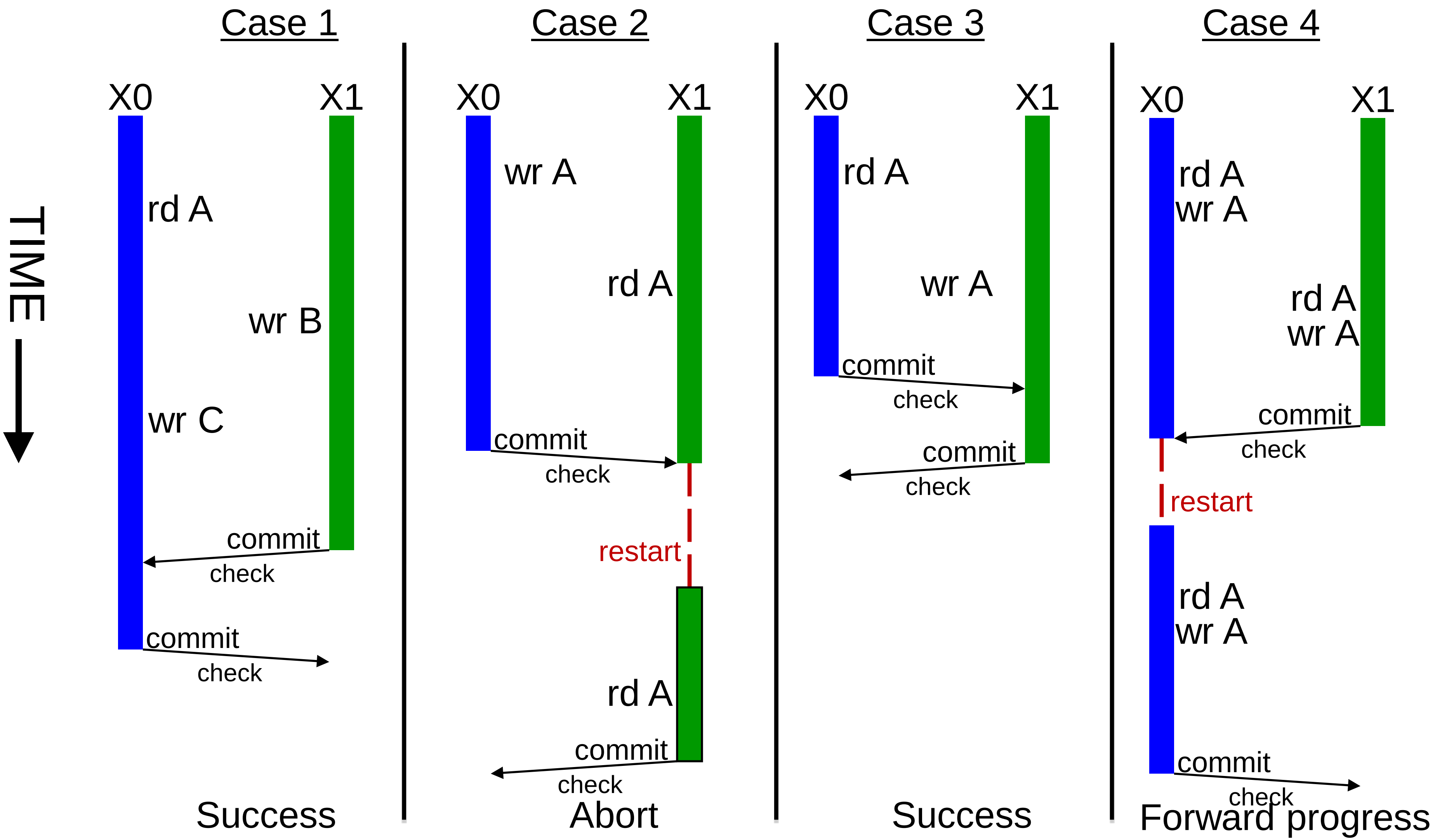


Conflict Detection (cont)

2. Optimistic (Lazy) detection
   - Detect conflicts when a transaction attempts to commit
     - SW: validate write/read-set using locks or version numbers
     - HW: validate write-set using coherence actions
       - Get exclusive access for cache lines in write-set
   - On a conflict, give priority to committing transaction
     - Other transactions may abort later on
     - On conflicts between committing transactions, use contention manager to decide priority

- Note: optimistic & pessimistic schemes together
  - Several STM systems are optimistic on reads, pessimistic on writes

Optimistic Detection Illustration



Conflict Detection Tradeoffs

1. Pessimistic conflict detection (aka eager, encounter)
   - \+ Detect conflicts early
     - Undo less work, turn some aborts to stalls
   - – No forward progress guarantees, more aborts in some cases
   - – Locking issues (SW), fine-grain communication (HW)

2. Optimistic conflict detection (aka lazy, commit)
   - \+ Forward progress guarantees
   - \+ Potentially less conflicts, shorter locking (SW), bulk communication (HW)
   - – Detects conflicts late, still has fairness problems