

Transaction Processing

Introduction to Databases

CompSci 316 Fall 2019



DUKE
COMPUTER SCIENCE

Announcements (Mon., Dec. 2)

- **Homework 4** due today
 - Except X2 (due Wed.)
- **Project demos**—sign-up instructions emailed
 - **Early in-class demos** this Wed. if you are up for it
 - Last weekly progress update due Wed. on Piazza
- **Final exam** Thu. Dec. 12 2-5pm
 - Open-book, open-notes
 - Comprehensive, but with strong emphasis on the second half of the course
 - Sample final will be posted tomorrow
 - Past Gradiance exercises will be reopened as a study aid
 - Feel free to redo any; your grades have already been recorded

Review

- ACID

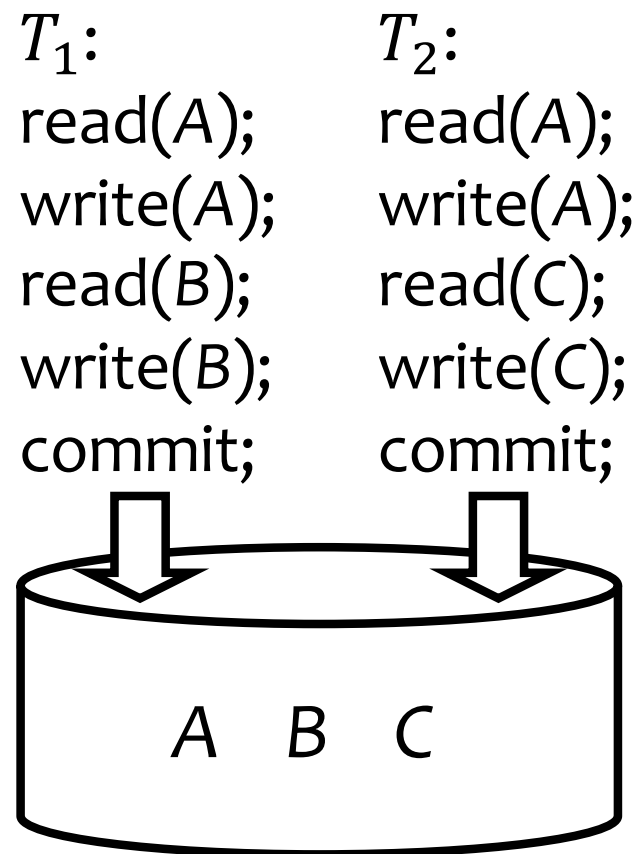
- **Atomicity**: TX's are either completely done or not done at all
- **Consistency**: TX's should leave the database in a consistent state
- **Isolation**: TX's must behave as if they are executed in isolation
- **Durability**: Effects of committed TX's are resilient against failures

- SQL transactions

```
-- Begins implicitly  
SELECT ...;  
UPDATE ...;  
ROLLBACK | COMMIT;
```

Concurrency control

- Goal: ensure the “I” (isolation) in ACID



Good versus bad schedules

Good!		Bad!		Good! (But why?)	
T_1	T_2	T_1	T_2	T_1	T_2
r(A)		r(A)		r(A)	
w(A)		Read 400	r(A)	w(A)	
r(B)		Write w(A)	Read 400		r(A)
w(B)		400 - 100	w(A)		w(A)
	r(A)		Write 400 - 50		
	w(A)	r(B)		r(B)	
	r(C)		r(C)		r(C)
	w(C)	w(B)		w(B)	
			w(C)		w(C)

Serial schedule

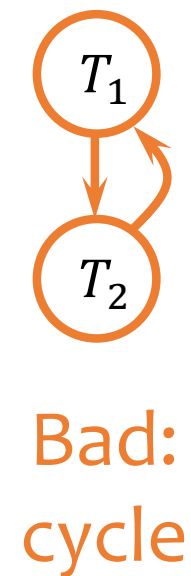
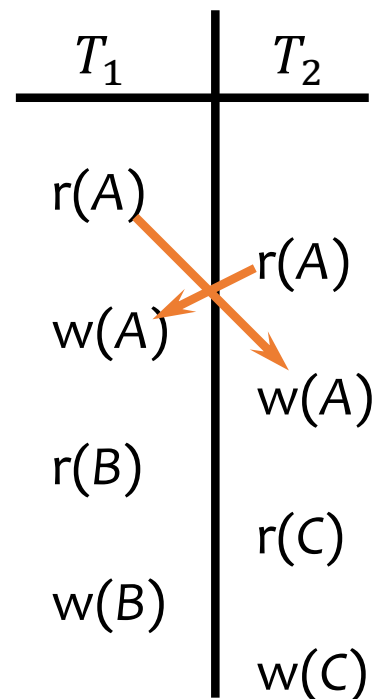
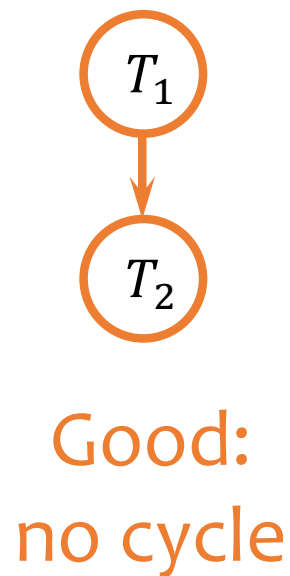
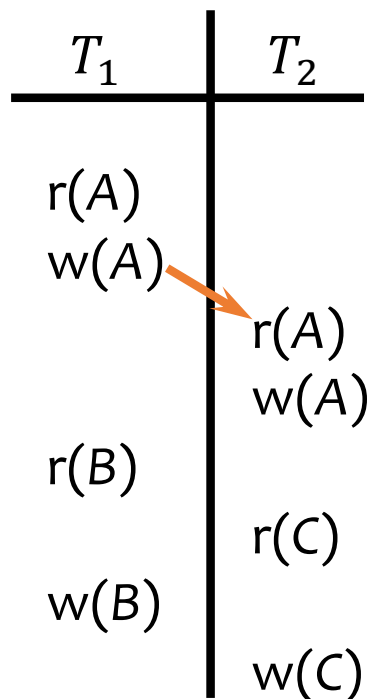
- Execute transactions in order, with **no interleaving** of operations
 - $T_1.r(A), T_1.w(A), T_1.r(B), T_1.w(B), T_2.r(A), T_2.w(A), T_2.r(C), T_2.w(C)$
 - $T_2.r(A), T_2.w(A), T_2.r(C), T_2.w(C), T_1.r(A), T_1.w(A), T_1.r(B), T_1.w(B)$
- ☞ Isolation achieved by definition!
- Problem: **no concurrency** at all
- Question: how to reorder operations to allow more concurrency

Conflicting operations

- Two operations on the **same** data item **conflict** if at least one of the operations is a write
 - $r(X)$ and $w(X)$ conflict
 - $w(X)$ and $r(X)$ conflict
 - $w(X)$ and $w(X)$ conflict
 - $r(X)$ and $r(X)$ do not conflict
 - $r/w(X)$ and $r/w(Y)$ do not conflict
- Order of conflicting operations matters
 - E.g., if $T_1.r(A)$ precedes $T_2.w(A)$, then conceptually, T_1 should precede T_2

Precedence graph

- A **node** for each transaction
- A **directed edge** from T_i to T_j if an operation of T_i precedes and conflicts with an operation of T_j in the schedule



Conflict-serializable schedule

- A schedule is **conflict-serializable** iff its precedence graph has **no cycles**
- A conflict-serializable schedule is equivalent to some serial schedule (and therefore is “good”)
 - In that serial schedule, transactions are executed in the topological order of the precedence graph
 - You can get to that serial schedule by repeatedly swapping adjacent, non-conflicting operations from different transactions

Locking

• Rules

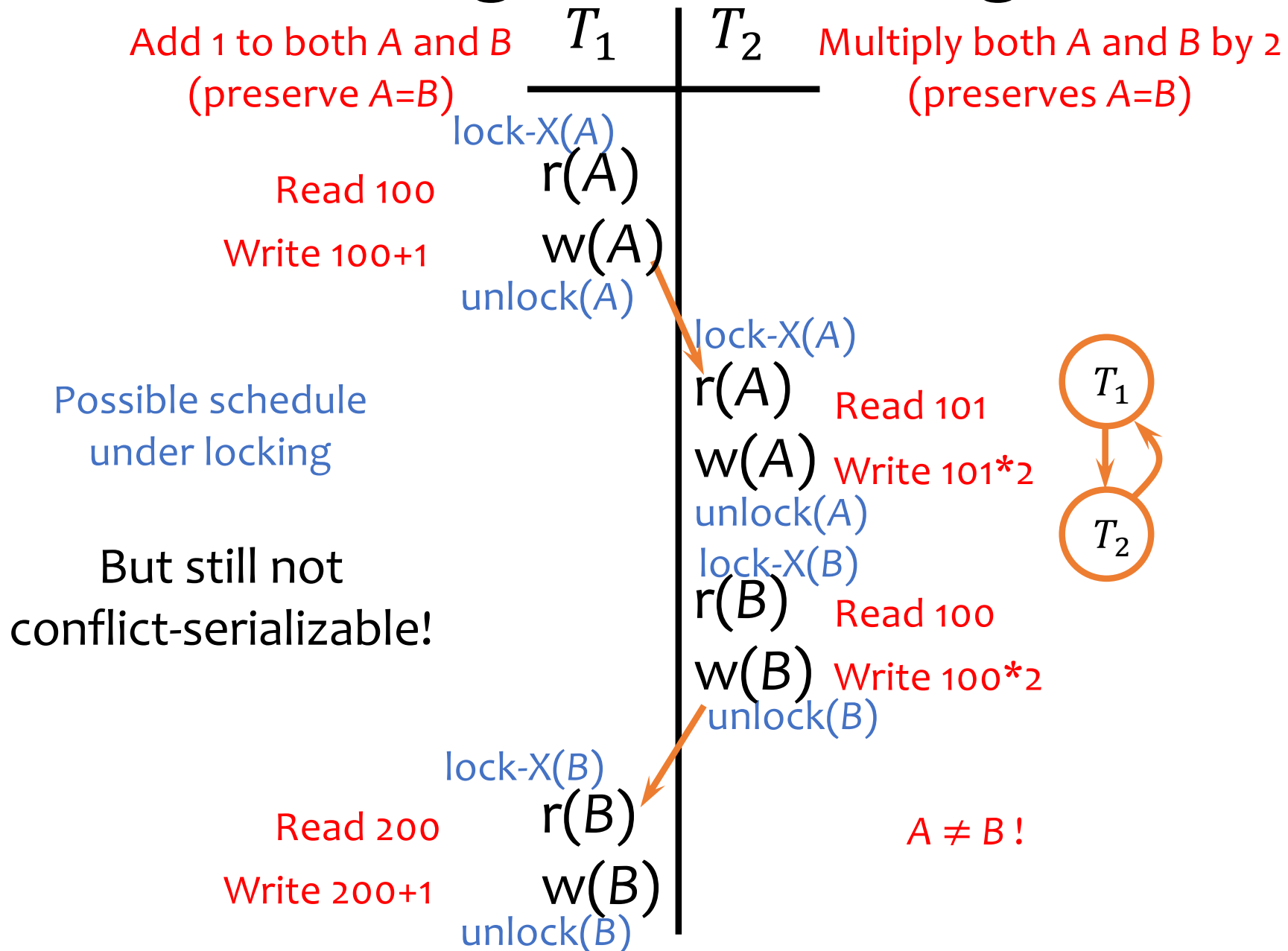
- If a transaction wants to **read** an object, it must first request a **shared lock (S mode)** on that object
- If a transaction wants to **modify** an object, it must first request an **exclusive lock (X mode)** on that object
- Allow one exclusive lock, or multiple shared locks

		Mode of the lock requested	
		S	X
Mode of lock(s) currently held by other transactions	S	Yes	No
	X	No	No

Grant the lock?

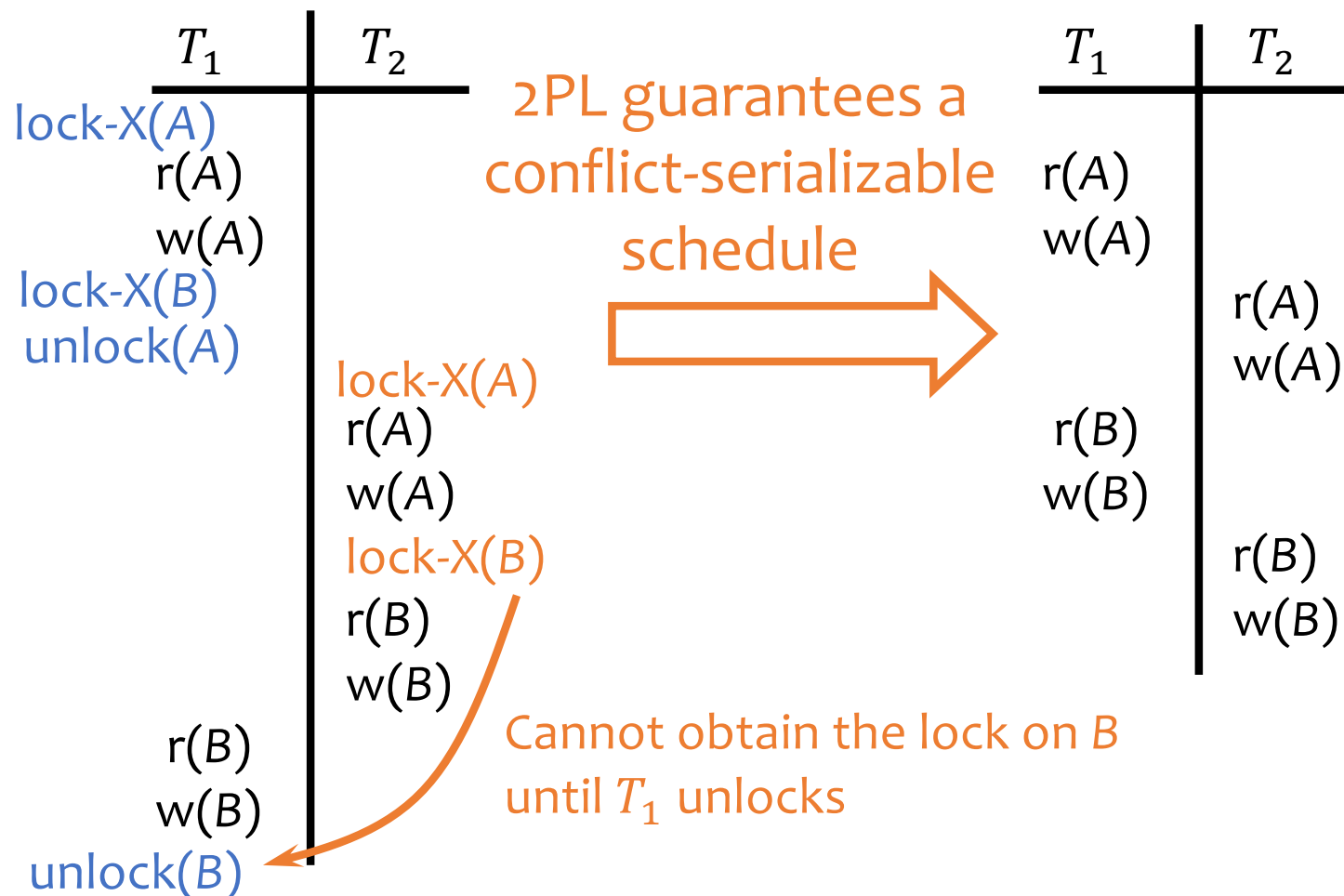
Compatibility matrix

Basic locking is not enough



Two-phase locking (2PL)

- All lock requests precede all unlock requests
 - Phase 1: obtain locks, phase 2: release locks



Remaining problems of 2PL

T_1	T_2
r(A)	
w(A)	
	r(A)
	w(A)
r(B)	
w(B)	
Abort!	r(B)
	w(B)

- T_2 has read uncommitted data written by T_1
- If T_1 aborts, then T_2 must abort as well
- **Cascading aborts** possible if other transactions have read data written by T_2

- Even worse, what if T_2 commits before T_1 ?
 - Schedule is **not recoverable** if the system crashes right after T_2 commits

Strict 2PL

- Only release locks at commit/abort time
 - A writer will block all other readers until the writer commits or aborts
- Used in many commercial DBMS

Recovery

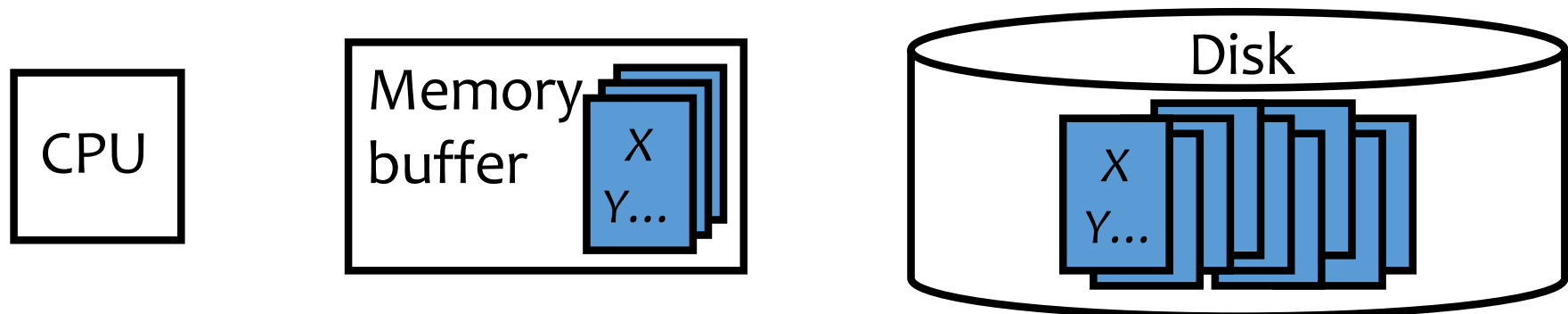
- Goal: ensure “A” (atomicity) and “D” (durability)



Execution model

To read/write X

- The disk block containing X must be first brought into memory
- X is read/written in memory
- The memory block containing X , if modified, must be written back (flushed) to disk eventually



Failures

- System crashes in the middle of a transaction T ; partial effects of T were written to disk
 - How do we undo T (atomicity)?
- System crashes right after a transaction T commits; not all effects of T were written to disk
 - How do we complete T (durability)?

Naïve approach

- **Force**: When a transaction commits, all writes of this transaction must be reflected on disk
 - Without force, if system crashes right after T commits, effects of T will be lost
 - ☞ Problem: Lots of random writes hurt performance
- **No steal**: Writes of a transaction can only be flushed to disk at commit time
 - With steal, if system crashes before T commits but after some writes of T have been flushed to disk, there is no way to undo these writes
 - ☞ Problem: Holding on to all dirty blocks requires lots of memory

Logging

- Log

- Sequence of **log records**, recording all changes made to the database
 - Written to stable storage (e.g., disk) during normal operation
 - Used in recovery
- Hey, one change turns into two—bad for performance?
 - But writes are sequential (append to the end of log)
 - Can use dedicated disk(s) to improve performance

Undo/redo logging rules

- When a transaction T_i starts, log $\langle T_i, \text{start} \rangle$
- Record values before and after each modification:
 $\langle T_i, X, \text{old_value_of_X}, \text{new_value_of_X} \rangle$
 - T_i is transaction id and X identifies the data item
- A transaction T_i is committed when its commit log record $\langle T_i, \text{commit} \rangle$ is written to disk
- **Write-ahead logging (WAL)**: Before X is modified on disk, the log record pertaining to X must be flushed
 - Without WAL, system might crash after X is modified on disk but before its log record is written to disk—no way to undo
- **No force**: A transaction can commit even if its modified memory blocks have not be written to disk (since redo information is logged)
- **Steal**: Modified memory blocks can be flushed to disk anytime (since undo information is logged)

Undo/redo logging example

T_1 (balance transfer of \$100 from A to B)

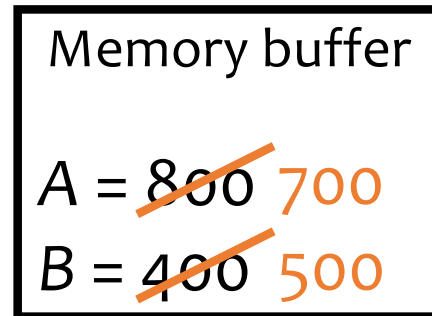
read(A, a); $a = a - 100$;

write(A, a);

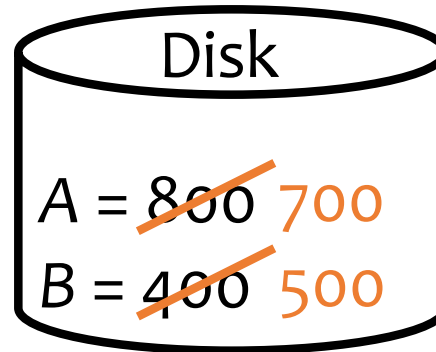
read(B, b); $b = b + 100$;

write(B, b);

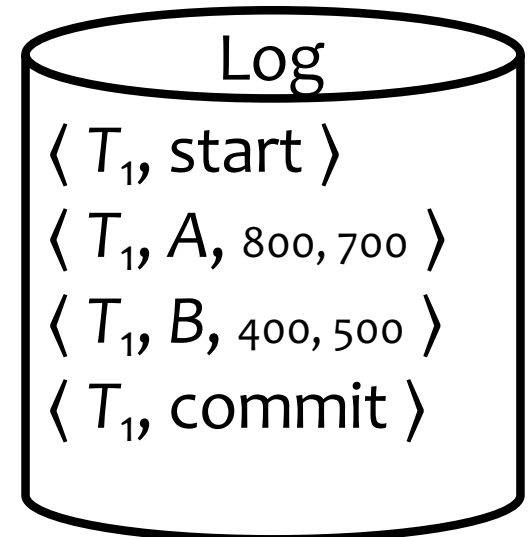
commit;



Steal: can flush
before commit



No force: can flush
after commit



No restriction (except WAL) on when memory blocks can/should be flushed

Checkpointing

- Where does recovery start?

Naïve approach:

- To checkpoint:
 - Stop accepting new transactions (lame!)
 - Finish all active transactions
 - Take a database dump
- To recover:
 - Start from last checkpoint



Fuzzy checkpointing

- Determine S , the set of (ids of) **currently active transactions**, and log $\langle \text{begin-checkpoint } S \rangle$
- Flush all blocks (dirty at the time of the checkpoint) at your leisure
- Log $\langle \text{end-checkpoint } \textit{begin-checkpoint_location} \rangle$
- Between begin and end, continue processing old and new transactions

Recovery: analysis and redo phase

- Need to determine U , the set of **active transactions at time of crash**
 - Scan log backward to find the **last end-checkpoint record** and follow the pointer to find the **corresponding $\langle \text{start-checkpoint } S \rangle$**
 - Initially, let U be S
 - Scan **forward** from that start-checkpoint to end of the log
 - For a log record $\langle T, \text{start} \rangle$, add T to U
 - For a log record $\langle T, \text{commit} \mid \text{abort} \rangle$, remove T from U
 - For a log record $\langle T, X, \text{old}, \text{new} \rangle$, issue $\text{write}(X, \text{new})$
- 👉 **Basically repeats history!**

Recovery: undo phase

- Scan log **backward**
 - Undo the effects of transactions in U
 - That is, for each log record $\langle T, X, old, new \rangle$ where T is in U , issue $write(X, old)$, and log this operation too (part of the “repeating-history” paradigm)
 - Log $\langle T, abort \rangle$ when all effects of T have been undone

An optimization

- Each log record stores a pointer to the previous log record for the same transaction; follow the pointer chain during undo

Summary

- Concurrency control
 - Serial schedule: no interleaving
 - Conflict-serializable schedule: no cycles in the precedence graph; equivalent to a serial schedule
 - 2PL: guarantees a conflict-serializable schedule
 - Strict 2PL: also guarantees recoverability
- Recovery: undo/redo logging with fuzzy checkpointing
 - Normal operation: write-ahead logging, no force, steal
 - Recovery: first redo (forward), and then undo (backward)