Concurrency control & recovery system

Transaction Processing

Introduction to Database Management

CS348 Spring 2021

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

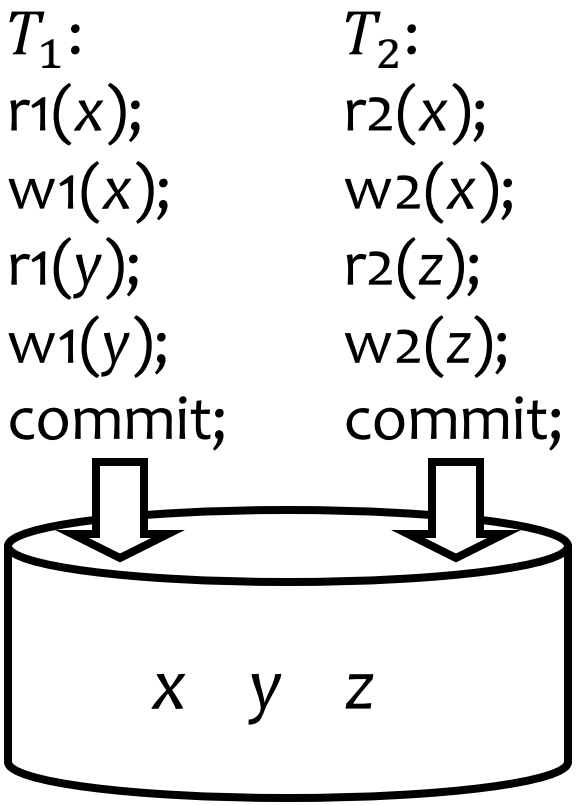
```
-- Begins implicitly
SELECT ...;
UPDATE ...;
ROLLBACK | COMMIT;
```

Outline

- Concurrency control -- isolation
  - Review serializable execution histories
  - Locking-based concurrency control
- Recovery – atomicity and durability
  - Naïve approaches
  - Logging for undo and redo

Concurrency control

- Goal: ensure the "I" (isolation) in ACID



Good versus bad execution histories

Serial

Good!

T_1	T_2
r1(x)	
w1(x)	
r1(y)	
w1(y)	
	r2(x)
	w2(x)
	r2(z)
	w2(z)

H_a

Bad!

T_1	T_2
r1(x)	
	r2(x)
w1(x)	
	w2(x)
r1(y)	
	r2(z)
w1(y)	
	w2(z)

Read 400

Write 400 – 100

Read 400

Write 400 – 50

H_b

Good! Why?

T_1	T_2
r1(x)	
w1(x)	
	r2(x)
	w2(x)
r1(y)	
	r2(C)
w1(y)	
	w2(C)

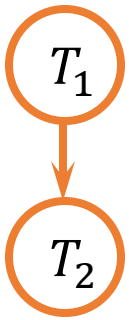
H_c

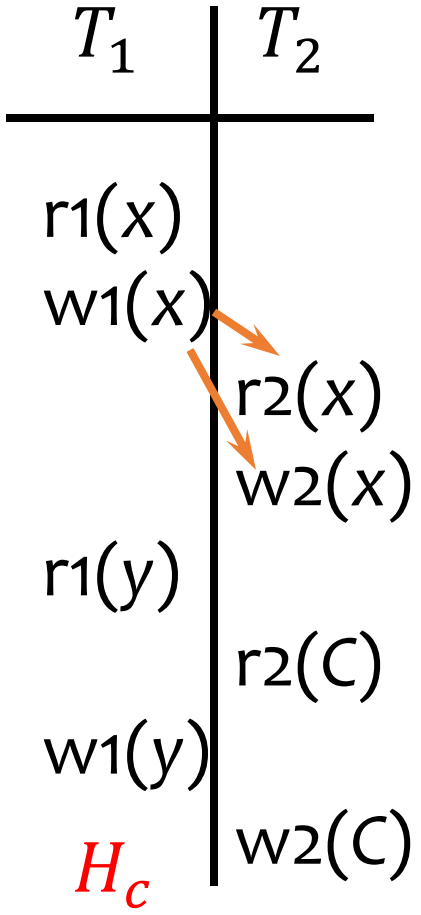
Good versus bad execution histories

Serializable

Good!

Serialization graph
(Lecture 15)



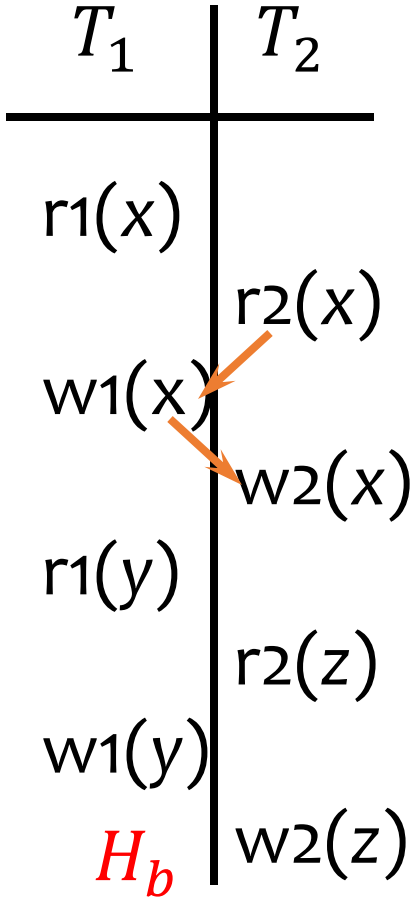


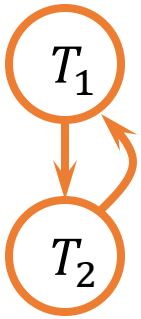
Good versus bad execution histories

Not serializable

Bad!

How to avoid this?





Concurrency control

Possible classification

- Pessimistic – assume that conflicts will happen and take preventive action
  - Two-phase locking (2PL)
  - Timestamp ordering
- Optimistic – assume that conflicts are rare and run transactions and fix if there is a problem
- We will only review 2PL

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

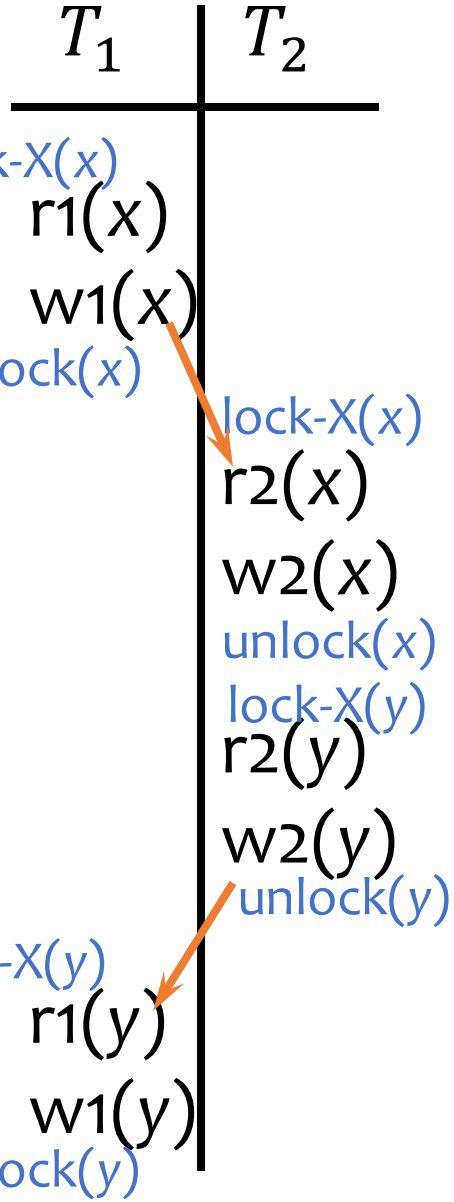
Mode of lock(s) currently held by other transactions

	S	X
S	Yes	No
X	No	No

Grant the lock?

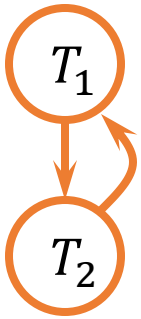
Compatibility matrix

Basic locking is not enough

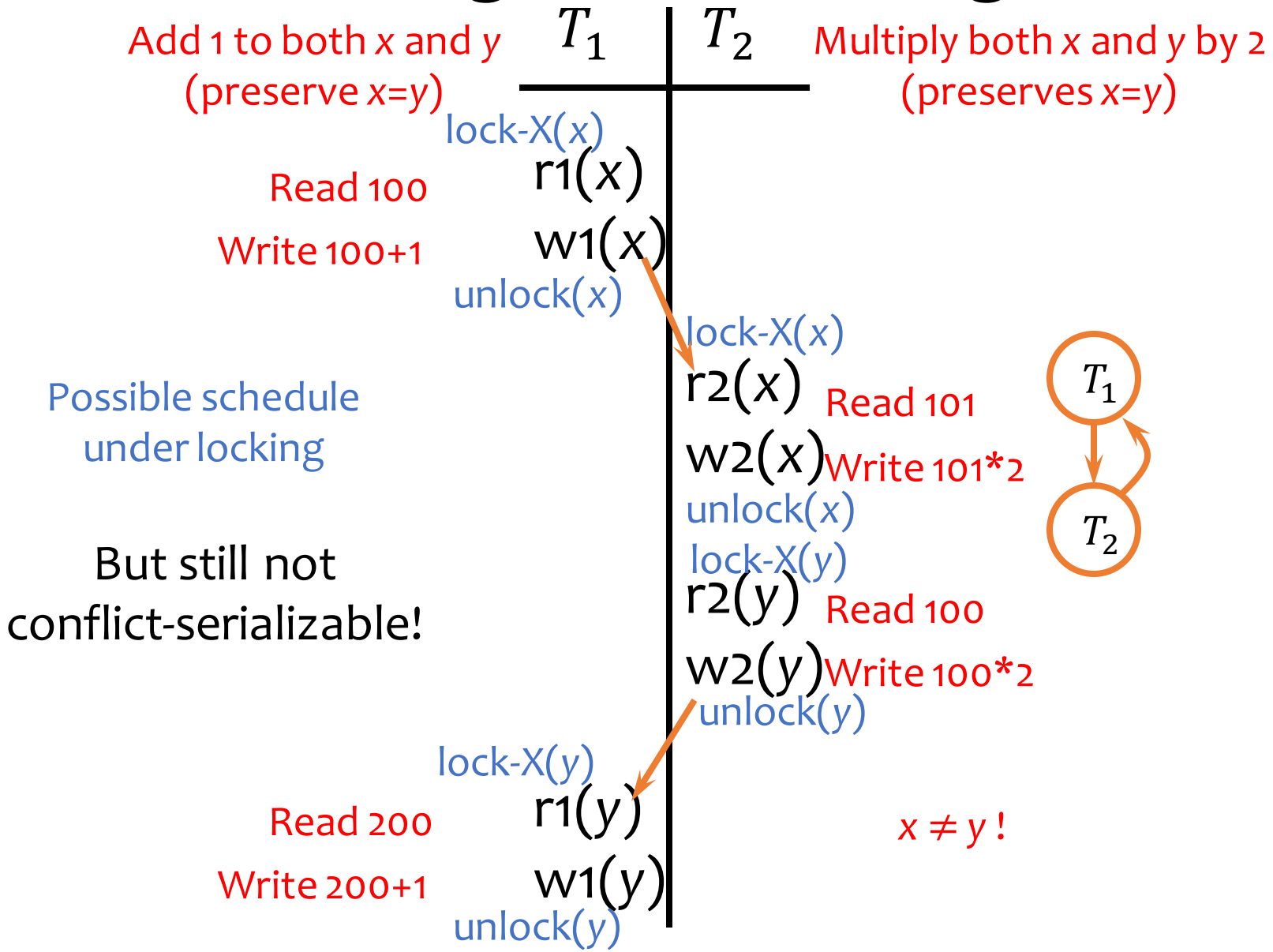


Possible schedule under locking

But still not conflict-serializable!

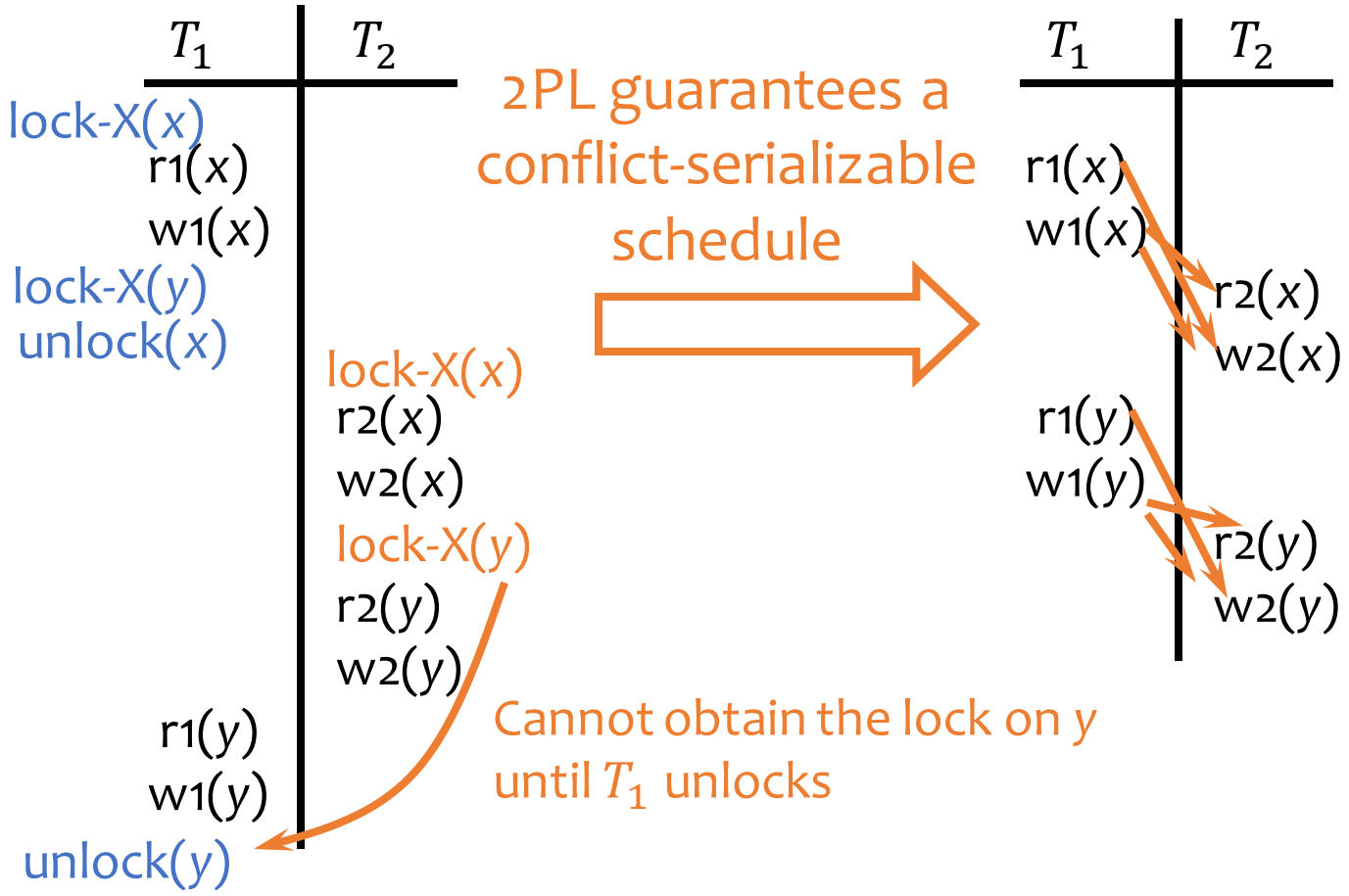


Basic locking is not enough

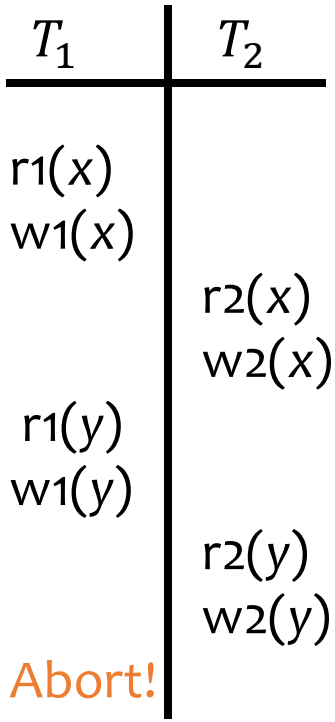


Two-phase locking (2PL)

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



Remaining problems of 2PL

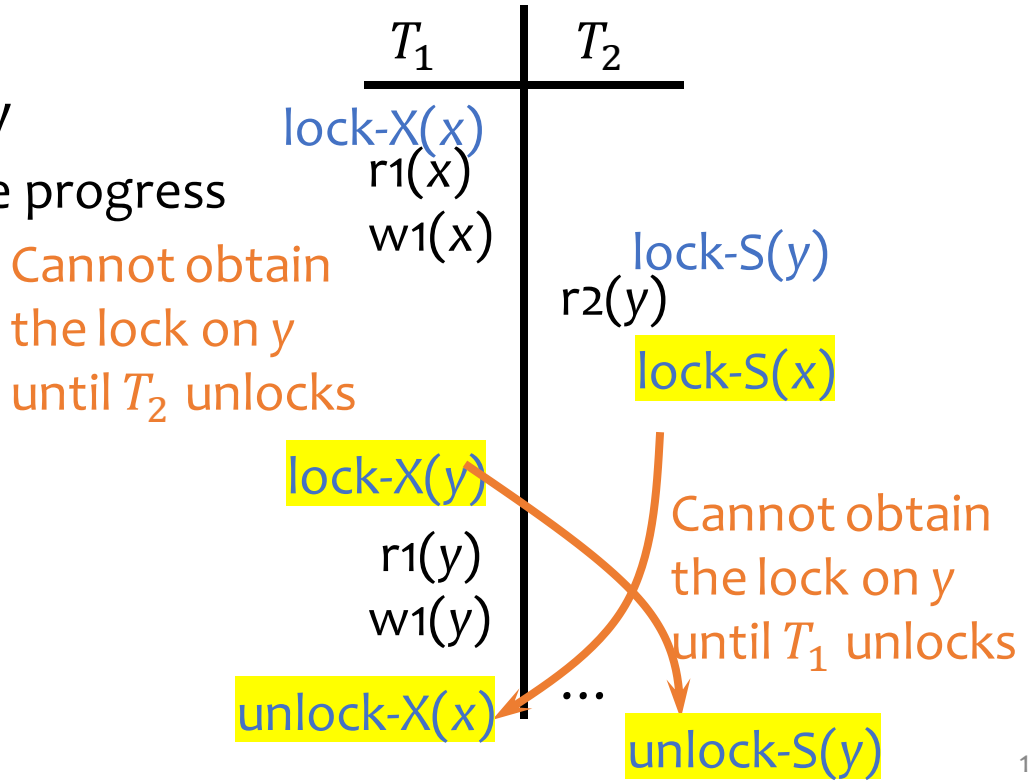


- T_2 has read uncommitted data written by T_1
- If T_1 aborts, then T_2 must abort as well
- Cascading aborts possible if other transactions have read data written by T_2

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

Deadlocks

- A transaction is deadlocked if it is blocked and will remain blocked until there is an intervention.
- Locking-based concurrency control algorithms may cause deadlocks requiring abort of one of the transactions
- Consider the partial history
  - Neither T_1 nor T_2 can make progress



Strict 2PL

- Only release X-locks at commit/abort time
  - A writer will block all other readers until the writer commits or aborts
- Used in many commercial DBMS
  - Oracle is a notable exception
- Why do we use strict 2PL? (assignment question)

Outline

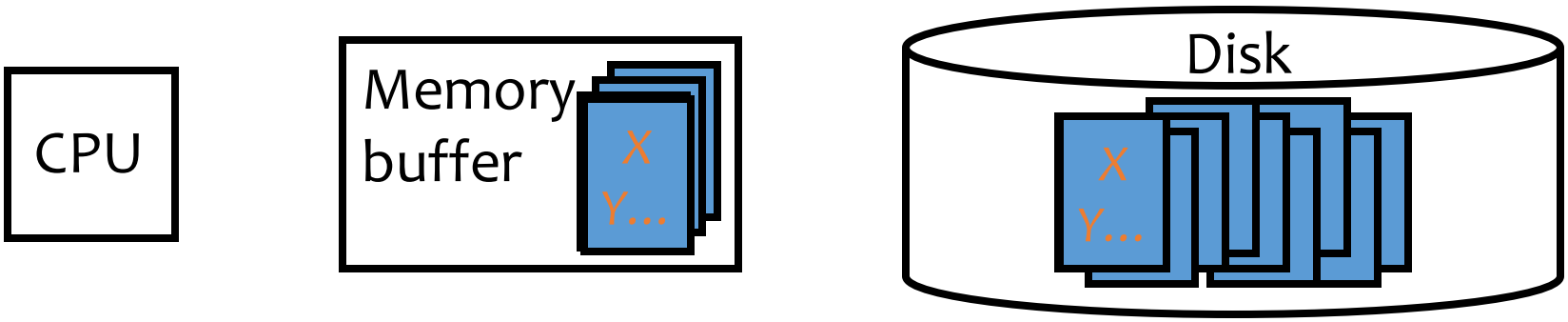
- Concurrency control -- isolation
  - Review serializable execution histories
  - Locking-based concurrency control

- Recovery – atomicity and durability
  - Naïve approaches
  - Logging for undo and redo

Execution model

To read/write *X*

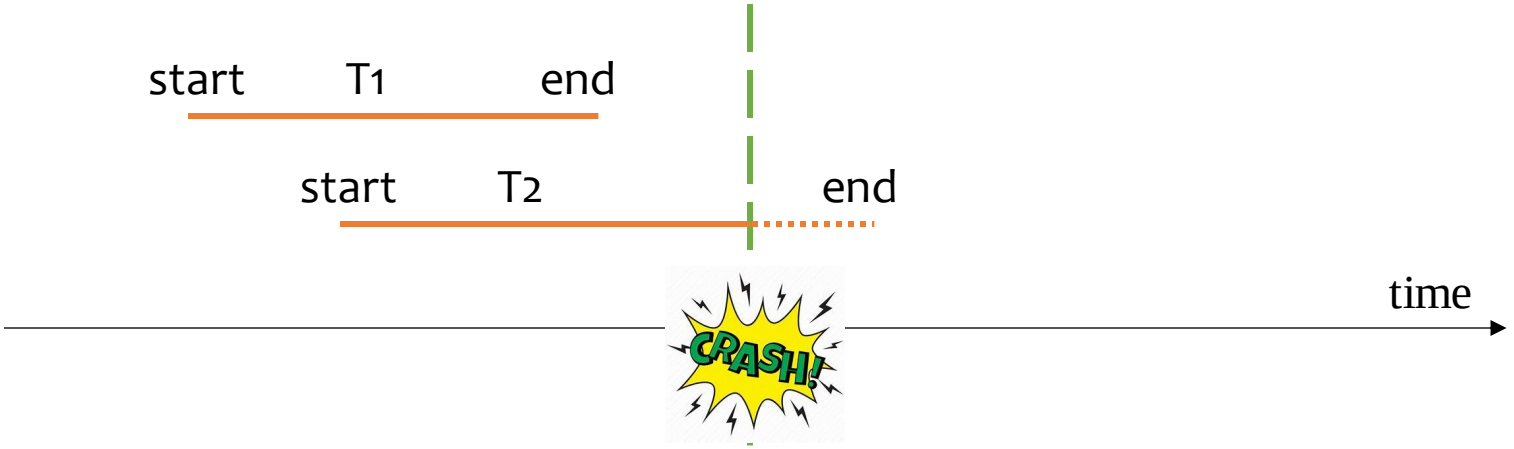
- The disk block containing *X* must be first brought into memory
- *X* is read/written in memory
- The memory block containing *X*, if modified, must be written back (flushed) to disk eventually



Failures

- System crashes right after a transaction *T1* commits; but not all effects of *T1* were written to disk
  - How do we complete/redo *T1* (durability)?

- System crashes in the middle of a transaction *T2*; partial effects of *T2* were written to disk
  - How do we undo *T2* (atomicity)?



Naïve approach: Force -- durability

T1 (balance transfer of $100 from *A* to *B*)

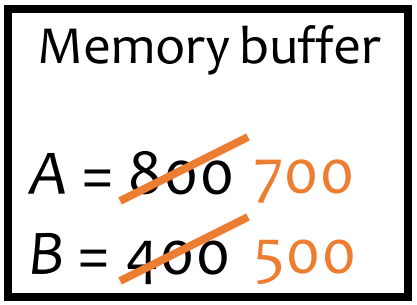
read(*A*, *a*); *a* = *a* – 100;

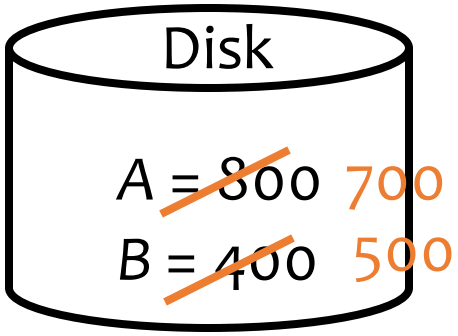
write(*A*, *a*);

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

write(*B*, *b*);

commit;





Force: all writes must be reflected on disk when a transaction commits

Naïve approach: Force -- durability

T1 (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;

Memory buffer

A = ~~800~~ 700

B = ~~400~~ 500

Disk

A = 800

B = 400

Force: all writes must be reflected on disk when a transaction commits

Bad!

Without force: not all writes are on disk when T1 commits

If system crashes right after *T1* commits, effects of *T1* will be lost

Naïve approach: No steal -- atomicity

T1 (balance transfer of $100 from *A* to *B*)

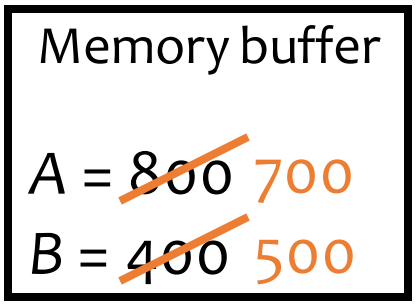
read(*A*, *a*); *a* = *a* – 100;

write(*A*, *a*);

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

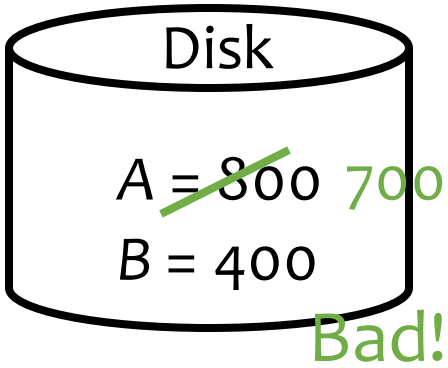
write(*B*, *b*);

commit;



No steal: Writes of a transaction can only be flushed to disk at commit time:

- e.g. A=700 cannot be flushed to disk before commit.



Bad!

With steal: some writes are on disk before T commits

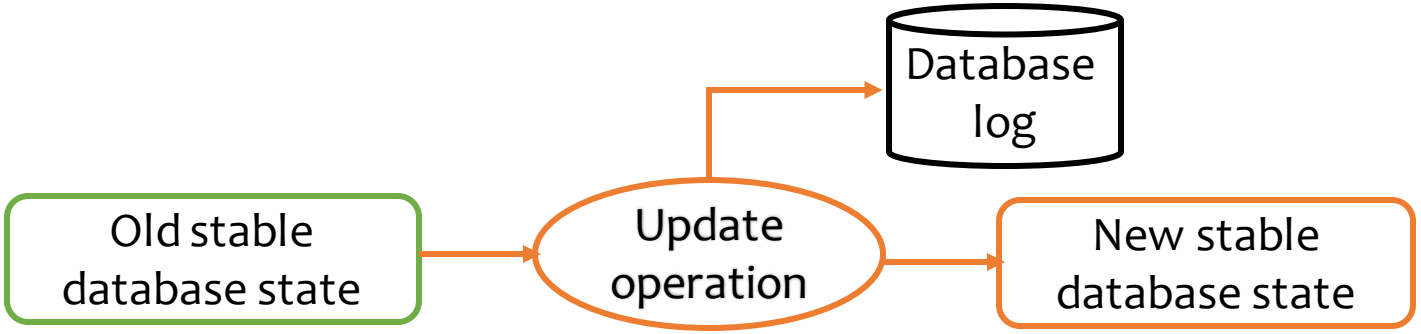
If system crashes before *T1* commits, there is no way to undo the changes

Naïve approach

- Force: When a transaction commits, all writes of this transaction must be reflected on disk
  - Ensures durability
  - ☞Problem of force: Lots of random writes hurt performance
- No steal: Writes of a transaction can only be flushed to disk at commit time
  - Ensures atomicity
  - ☞Problem of no steal: Holding on to all dirty blocks requires lots of memory

Logging

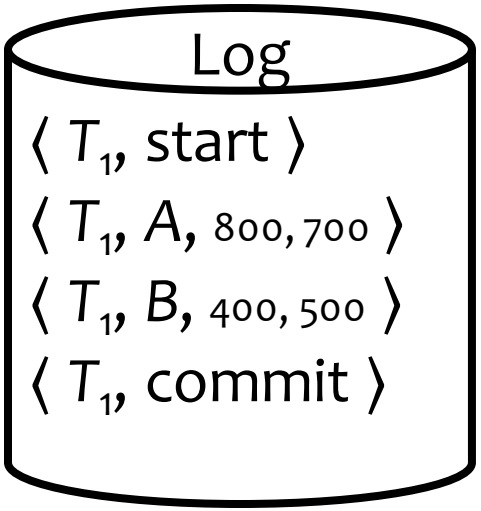
- Database log: sequence of log records, recording all changes made to the database, written to stable storage (e.g., disk) during normal operation



- Hey, one change turns into two—bad for performance?
  - But writes are sequential (append to the end of log)

Log format

- When a transaction T_i starts
  - $\langle T_i, \text{start} \rangle$
- Record values before and after each modification:
  - $\langle T_i, X, \textit{old\_value\_of\_X}, \textit{new\_value\_of\_X} \rangle$
  - T_i is transaction id
  - X identifies the data item
- A transaction T_i is committed when its commit log record is written to disk
  - $\langle T_i, \text{commit} \rangle$



When to write log records into stable store?

- 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

Undo/redo logging example

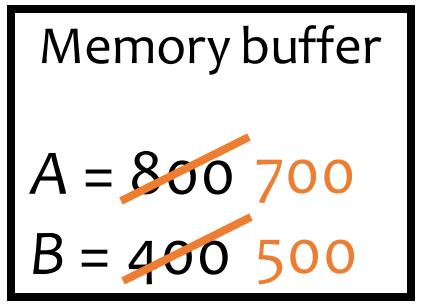
T1 (balance transfer of $100 from *A* to *B*)

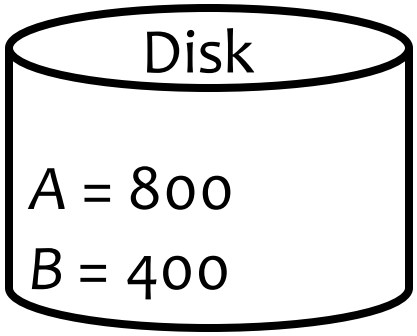
read(*A*, *a*); *a* = *a* – 100;

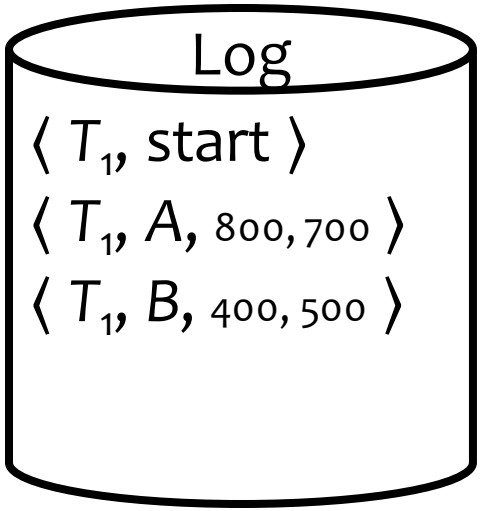
write(*A*, *a*);

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

write(*B*, *b*);







WAL: Before A,B are modified on disk, their log info must be flushed

Undo/redo logging example cont.

T1 (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*);

Memory buffer

A = ~~800~~ 700

B = ~~400~~ 500

Steal: can flush before commit

Disk

A = ~~800~~ 700

B = 400

Log

⟨ T_1, start ⟩

⟨ T_1, *A*, 800, 700 ⟩

⟨ T_1, *B*, 400, 500 ⟩

If system crashes before *T1* commits, we have the old value of A stored on the log to **undo** T1

Undo/redo logging example cont.

T1 (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;

Memory buffer

A = ~~800~~ 700

B = ~~400~~ 500

No force: can flush after commit

Disk

A = 800

B = 400

Log

⟨ T_1, start ⟩

⟨ T_1, *A*, 800, 700 ⟩

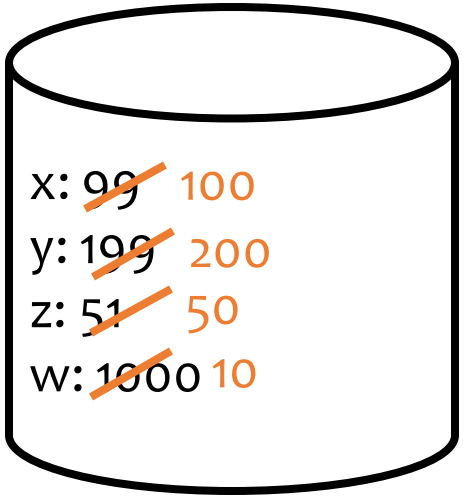
⟨ T_1, *B*, 400, 500 ⟩

⟨ T_1, commit ⟩

If system crashes before we flush the changes of A, B to the disk, we have their new committed values on the log to **redo** T1

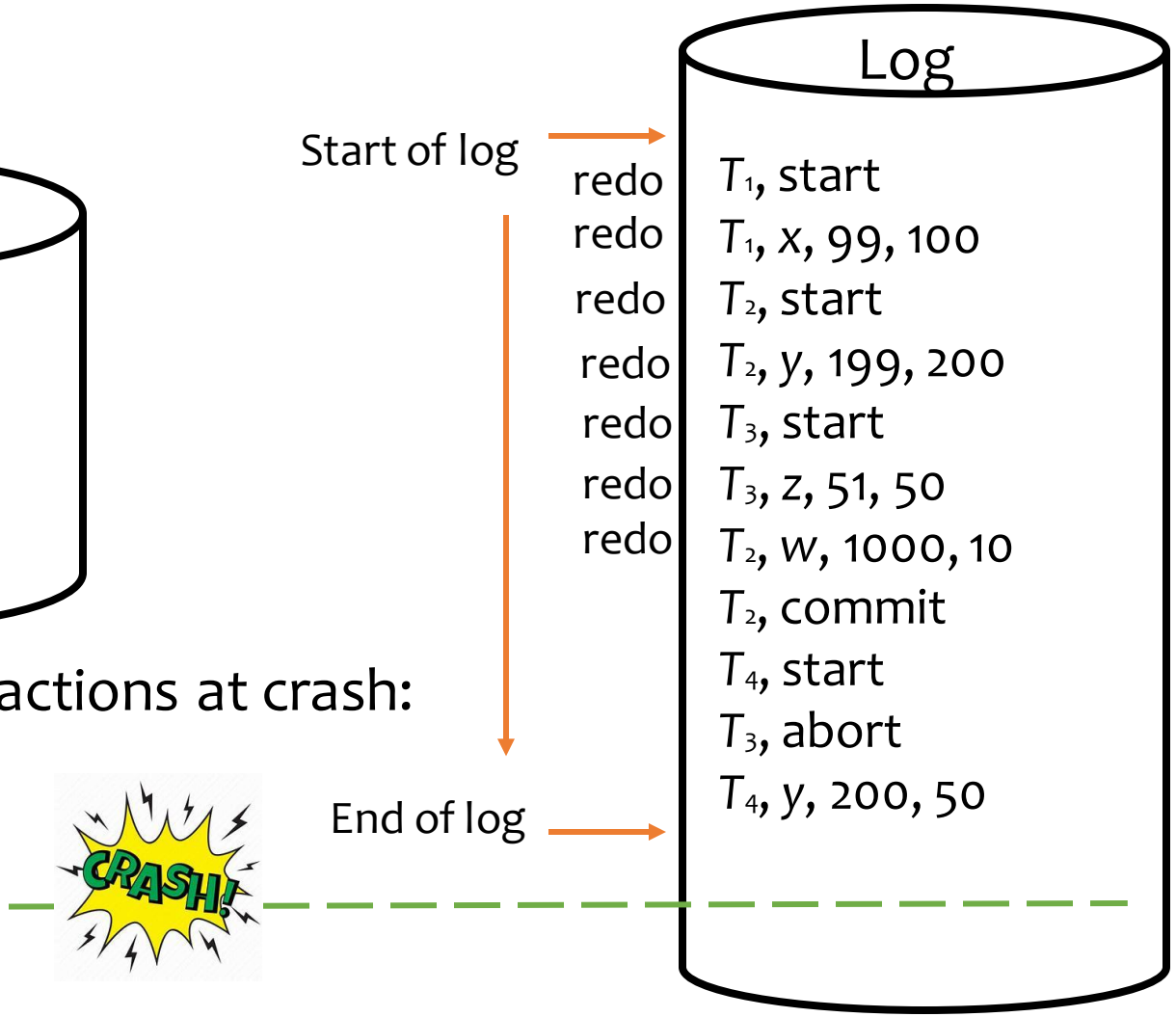
Log example

- Redo phase:



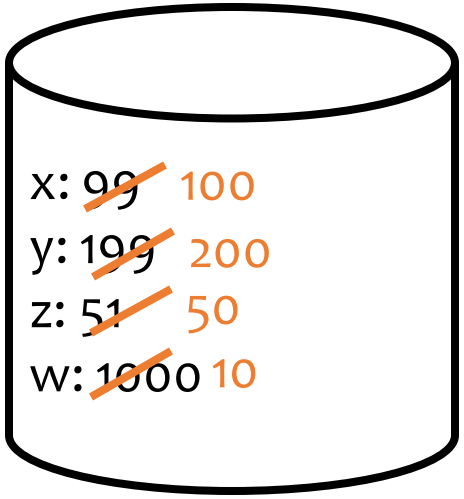
List of active transactions at crash:

T1 T2 T3



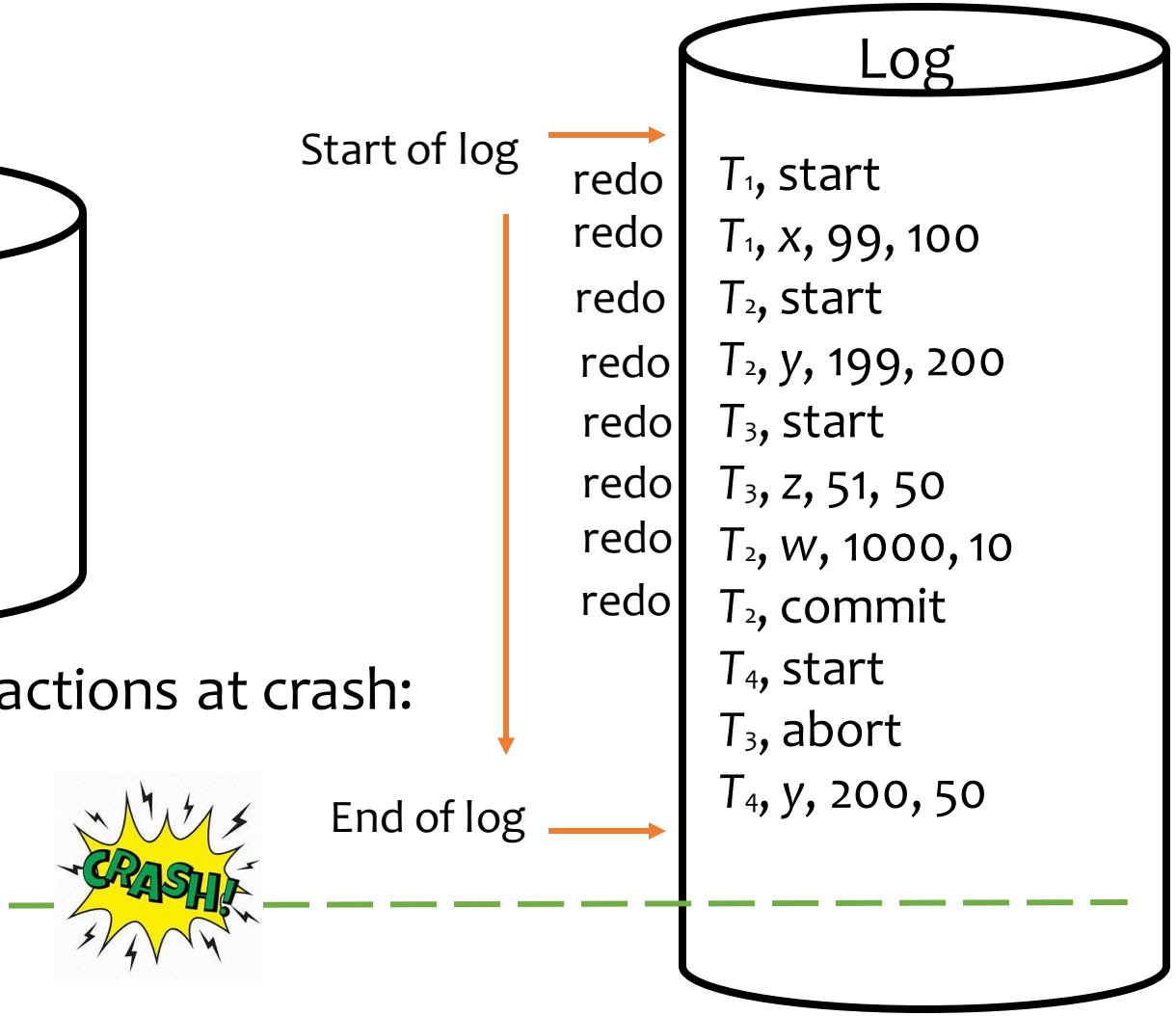
Log example

- Redo phase:



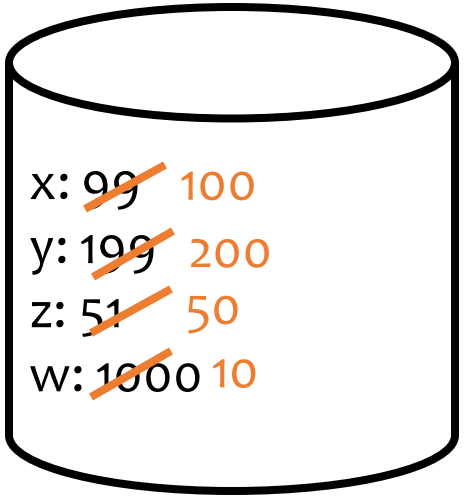
List of active transactions at crash:

T1 ~~T2~~ T3



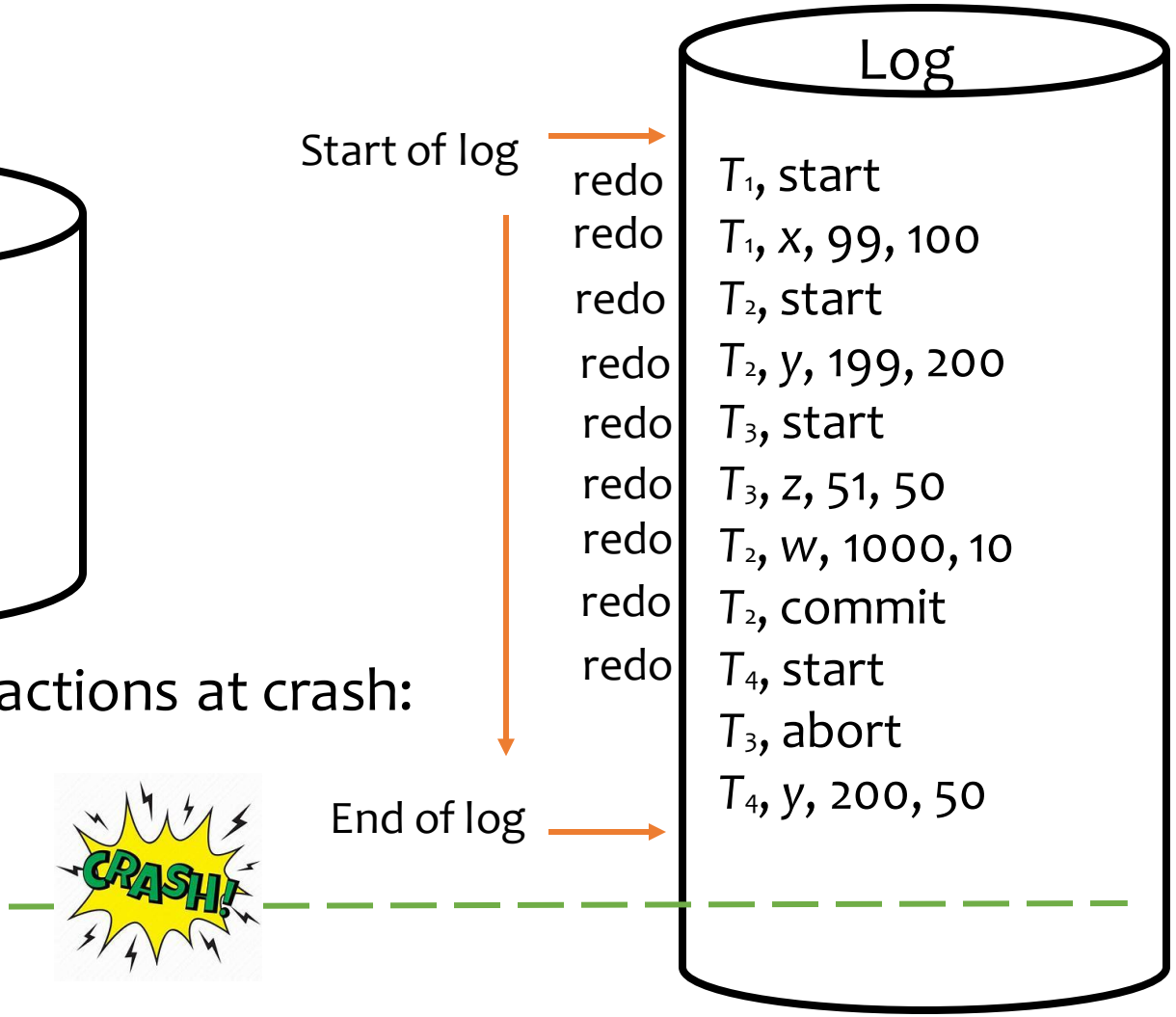
Log example

- Redo phase:



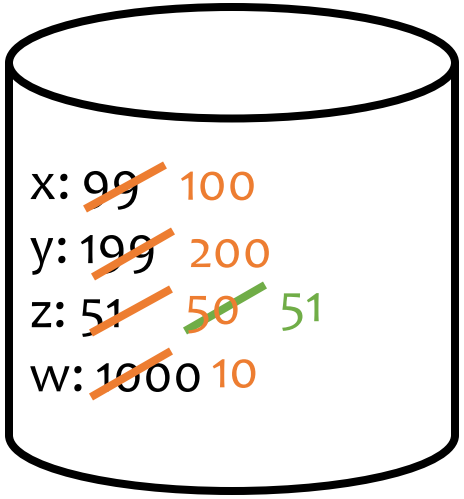
List of active transactions at crash:

T1 ~~T2~~ T3 T4



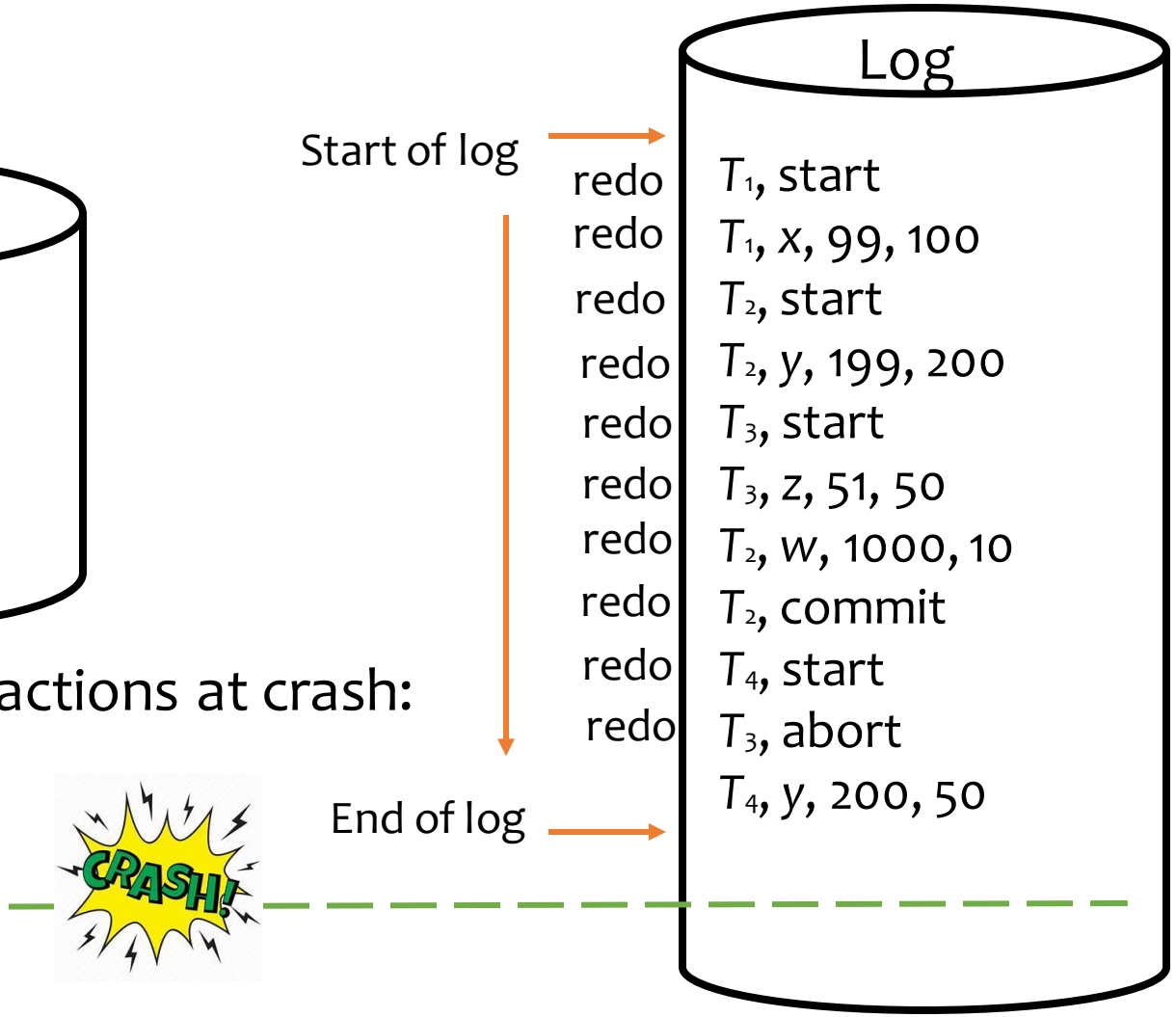
Log example

- Redo phase:



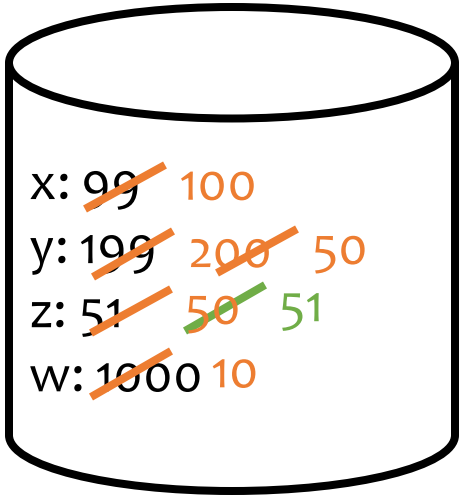
List of active transactions at crash:

T1 ~~T2~~ ~~T3~~ T4



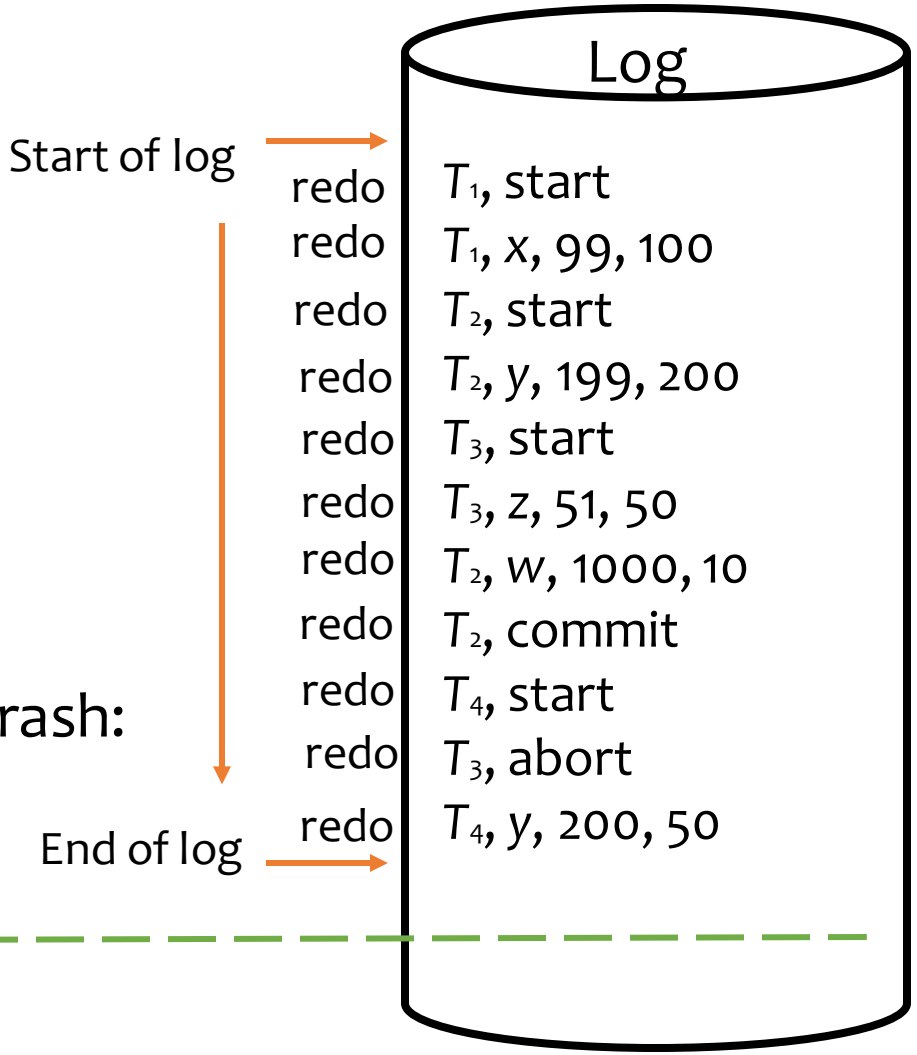
Log example

- Redo phase:



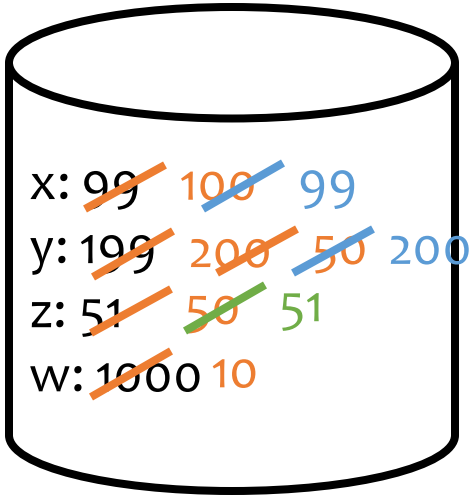
List of active transactions at crash:

T1 ~~T2~~ ~~T3~~ T4



Log example

- Undo phase: T1, T4



List of active transactions at crash:

T1 ~~T2~~ ~~T3~~ T4

Start of log

End of log

* undo

* undo

Log

T_1, start
T_1, x, 99, 100
T_2, start
T_2, y, 199, 200
T_3, start
T_3, z, 51, 50
T_2, w, 1000, 10
T_2, commit
T_4, start
T_3, abort
T_4, y, 200, 50

T_4, abort
T_1, abort

Undo/redo logging

- U: used to track the set of active transactions at crash

- Redo phase: scan forward to end of the log
  - For a log record ⟨ *T*, start ⟩, add *T* to *U*
  - For a log record ⟨ *T*, commit | abort ⟩, remove *T* from *U*
  - For a log record ⟨ *T*, *X*, *old*, *new* ⟩, issue write(*X*, *new*)

  ☞ Basically repeats history!

- Undo phase: scan log backward
  - Undo the effects of transactions in *U*
  - That is, for each log record ⟨ *T*, *X*, *old*, *new* ⟩ where *T* is in *U*, issue write(*X*, *old*), and log this operation too (part of the "repeating-history" paradigm)
  - Log ⟨ *T*, abort ⟩ when all effects of *T* have been undone

Checkpointing

- Shortens the amount of log that need to be undone or redone when a failure occurs

- A checkpoint record contains a list of active transactions

- Steps:
  1. Write a begin_checkpoint record into the log
  2. Collect the checkpoint data into the stable storage
  3. Write an end_checkpoint record into the log

Summary

- Concurrency control
  - 2PL: guarantees a conflict-serializable schedule
  - Deadlock problem

- Recovery: undo/redo logging
  - Normal operation: write-ahead logging, no force, steal
  - Recovery: first redo (forward), and then undo (backward)