Transaction: Recovery

Introduction to Databases

CompSci 316 Fall 2022

DUKE
COMPUTER SCIENCE

Recovery

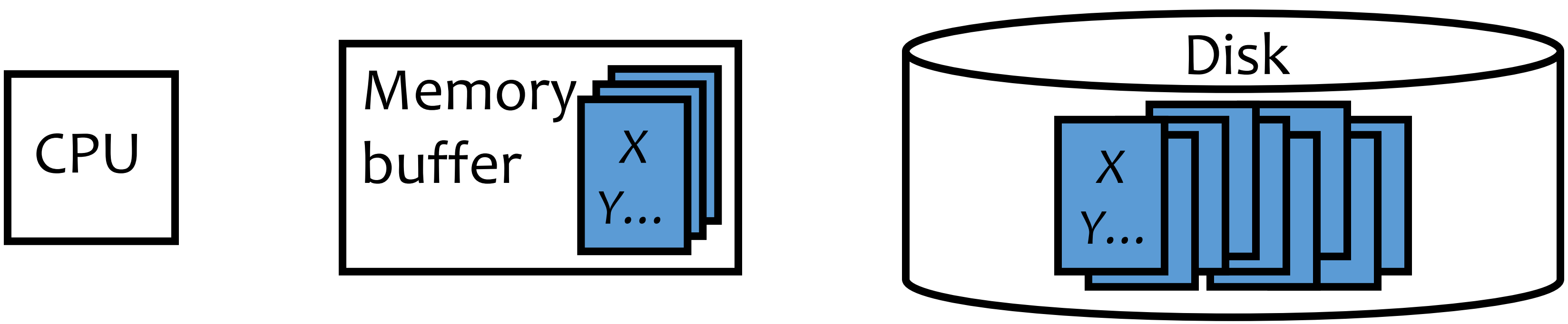
- Goal: ensure "A" (atomicity) and "D" (durability)

http://mnaxe.com/wp-content/uploads/2014/06/Notebook-Tablet-and-Laptop-Data-Recovery.jpg

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

Commit ≠ Writing updates to disk!

- 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 ⟨ T_i, start ⟩
- Record values before and after each modification:
  ⟨ T_i, X, *old_value_of_X*, *new_value_of_X* ⟩
  - T_i is transaction id and X identifies the data item
- A transaction T_i is committed when its commit log record
  ⟨ T_i, commit ⟩ is written to disk

WAL

- 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

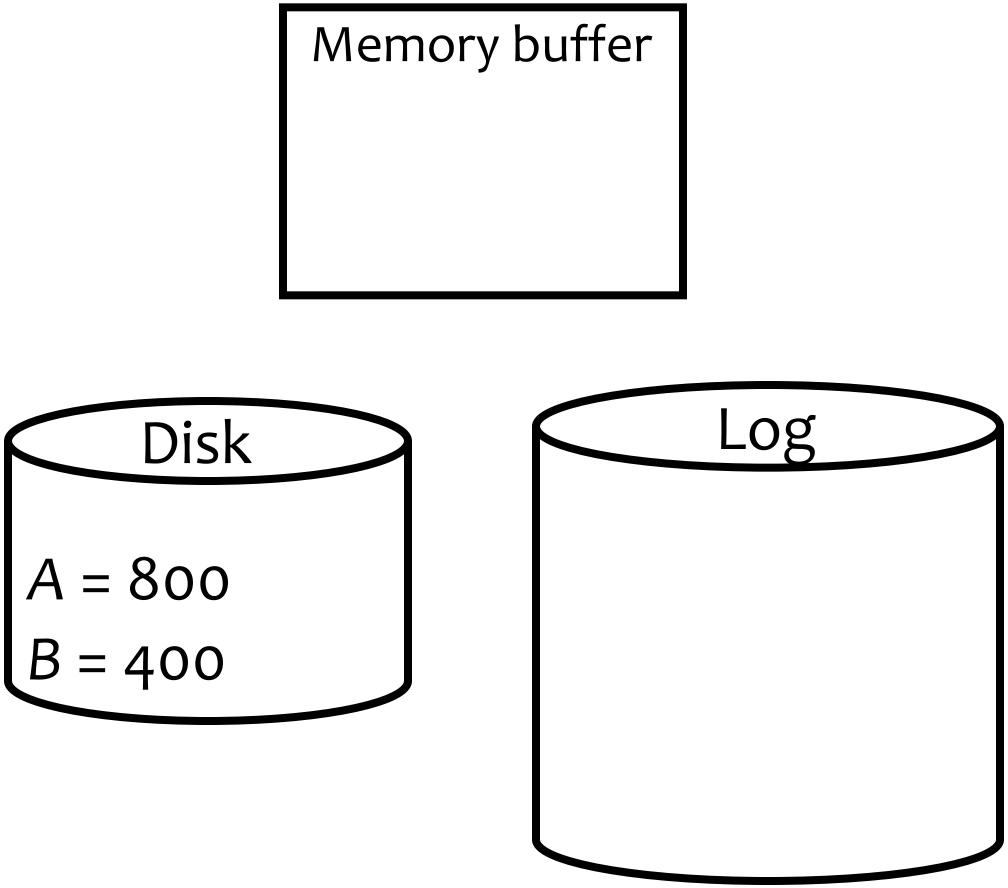
See difference with naïve approach

- 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)



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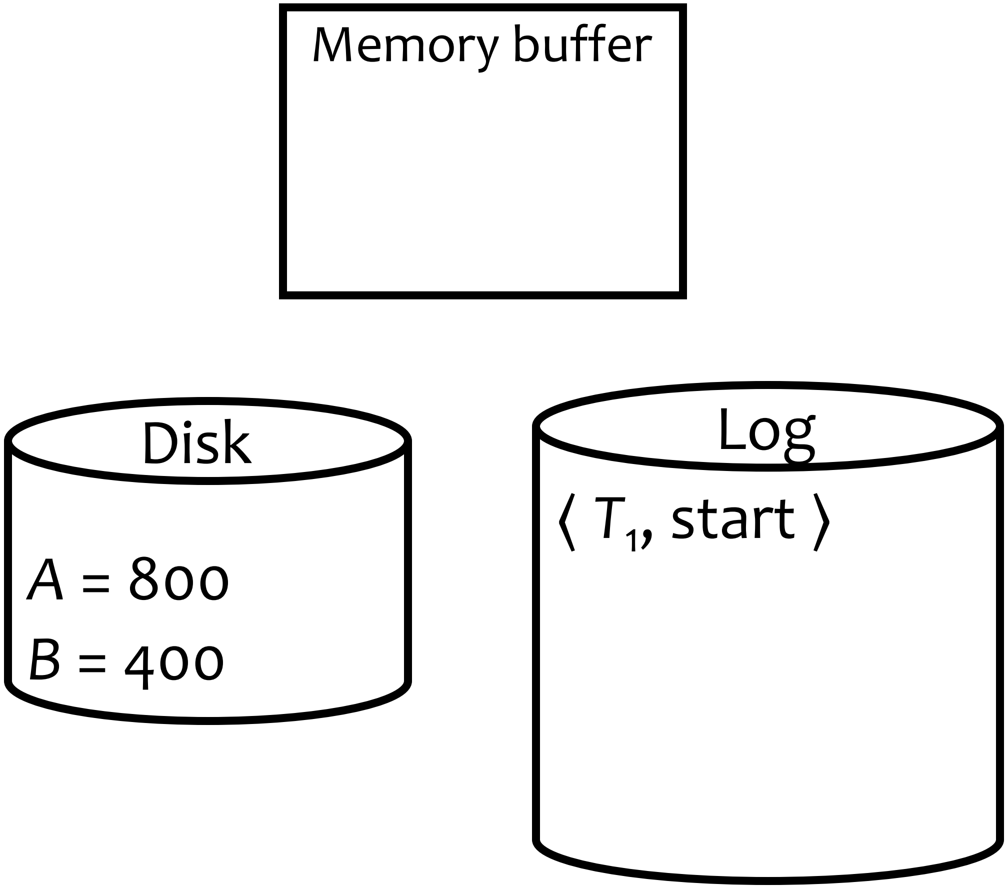
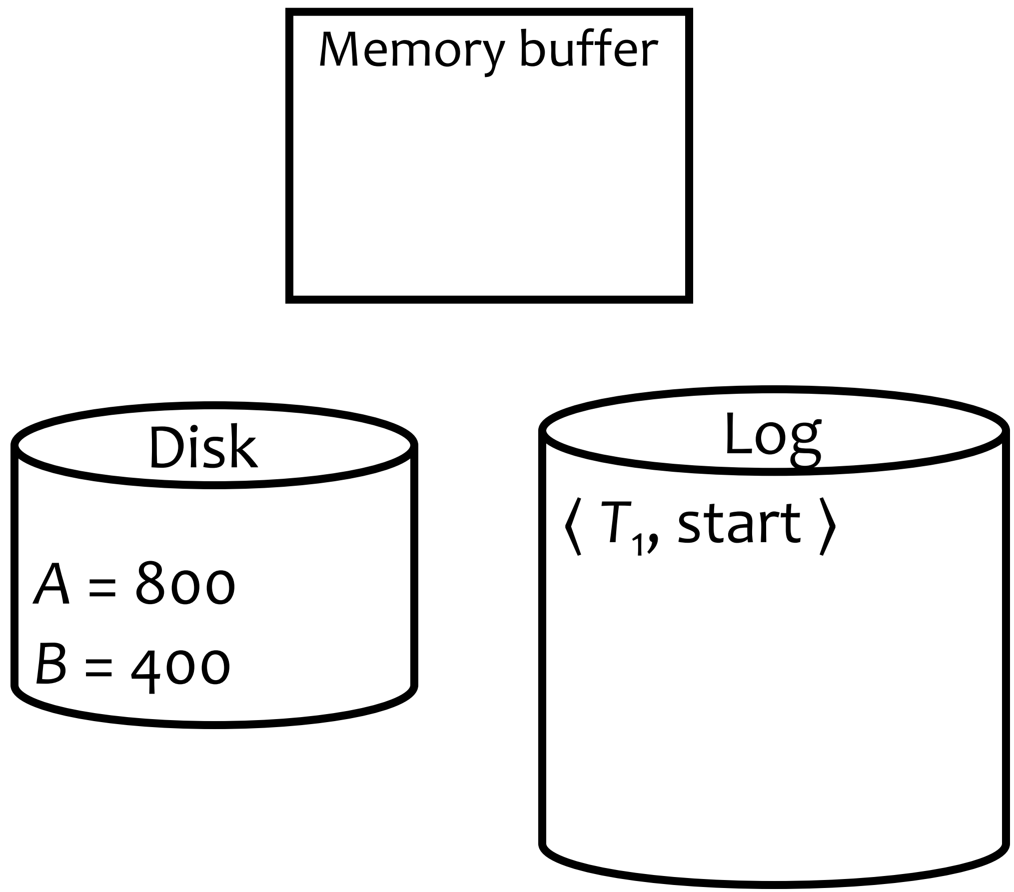


Undo/redo logging example

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

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



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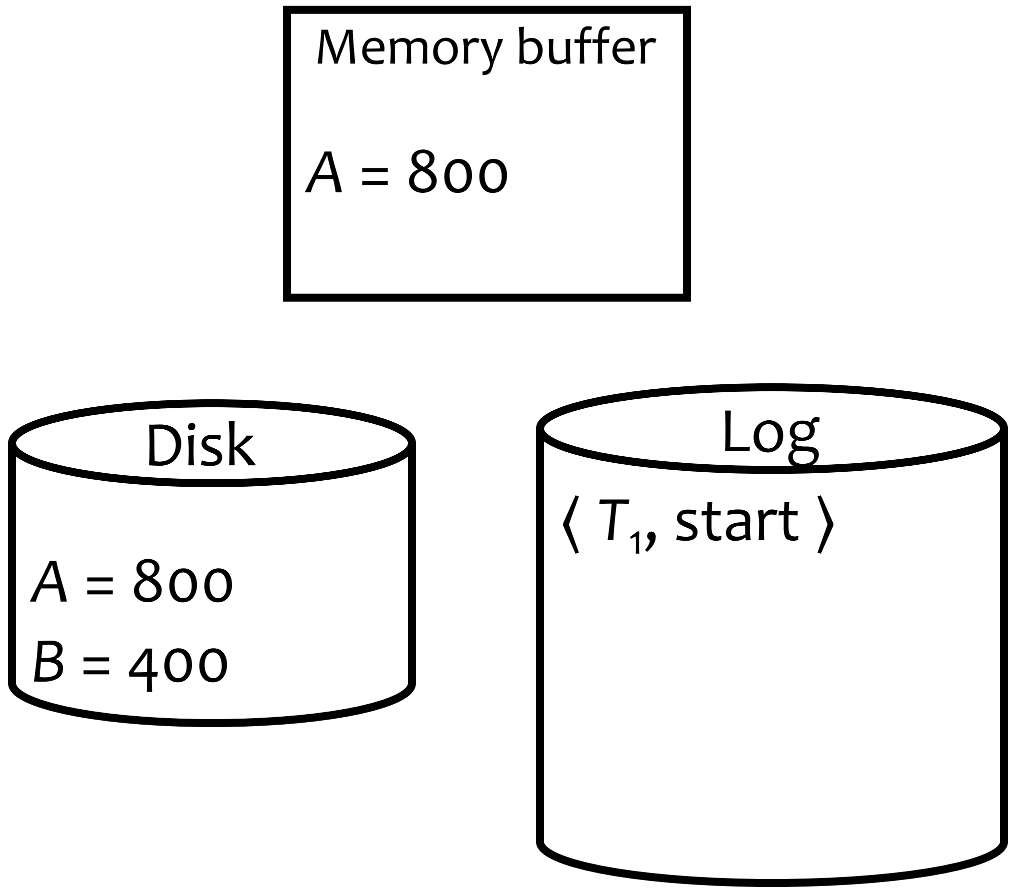
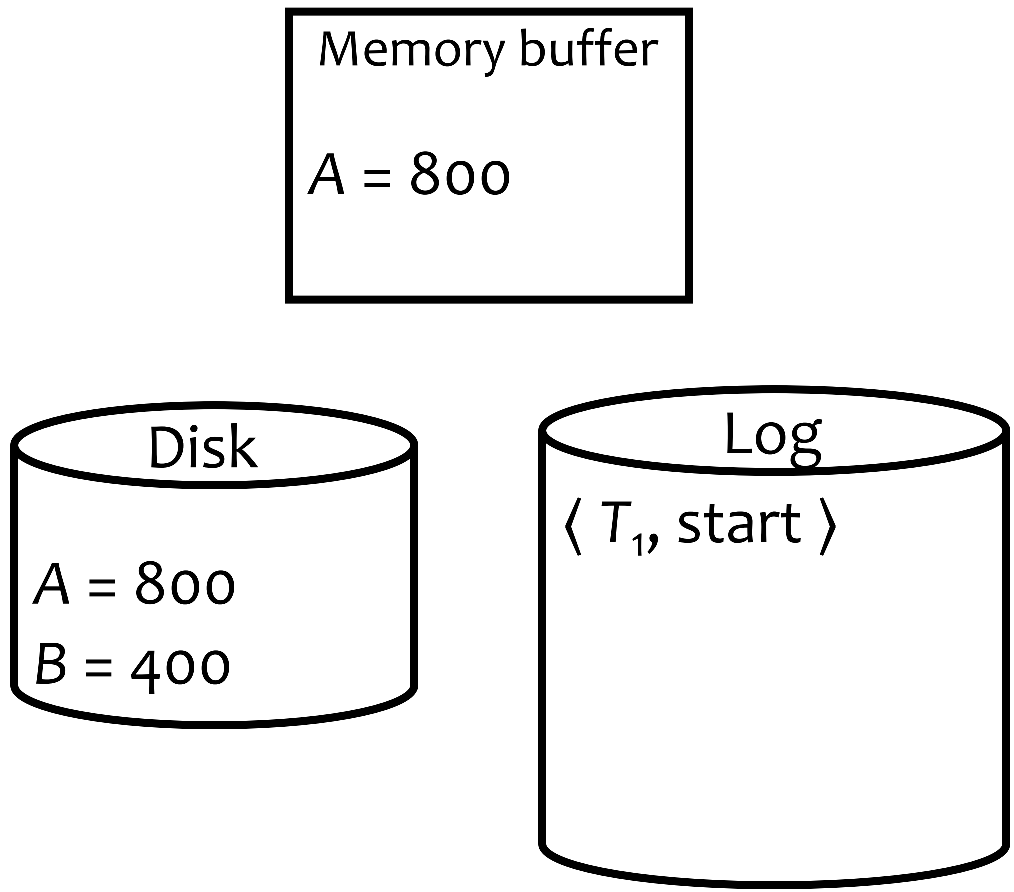


Undo/redo logging example

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

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

write(A, a);



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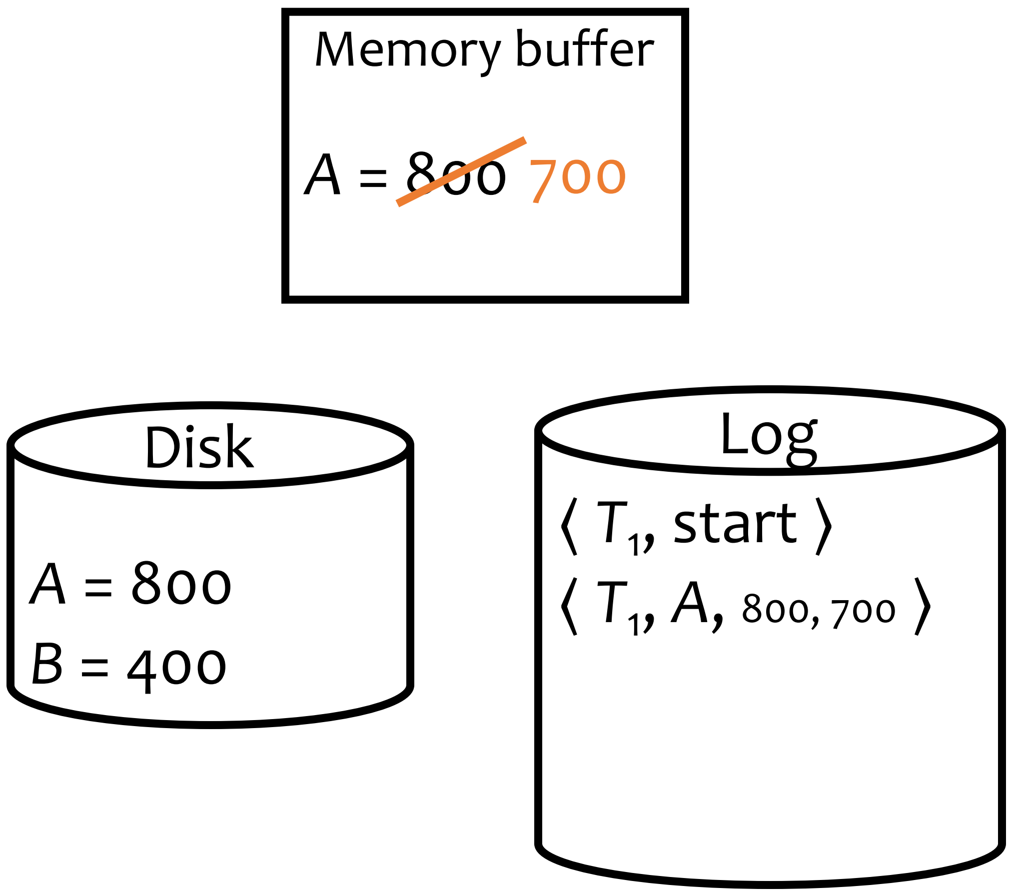


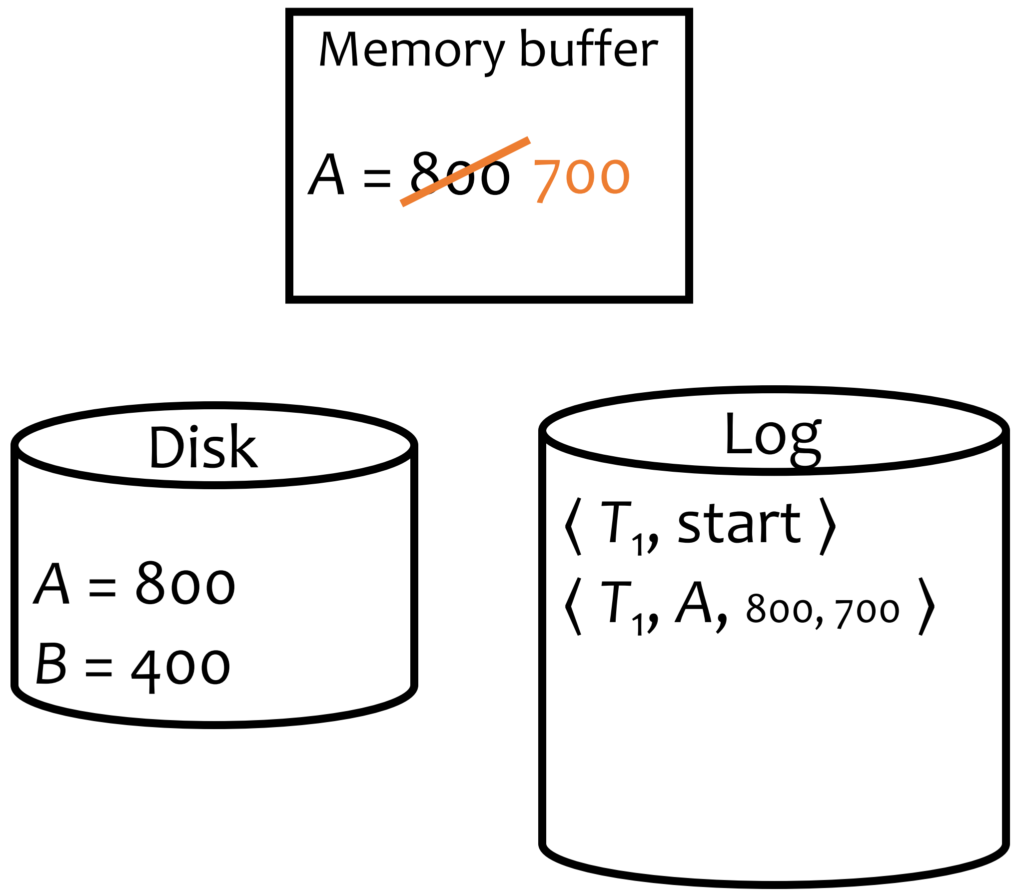
Undo/redo logging example

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

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

write(A, a);

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



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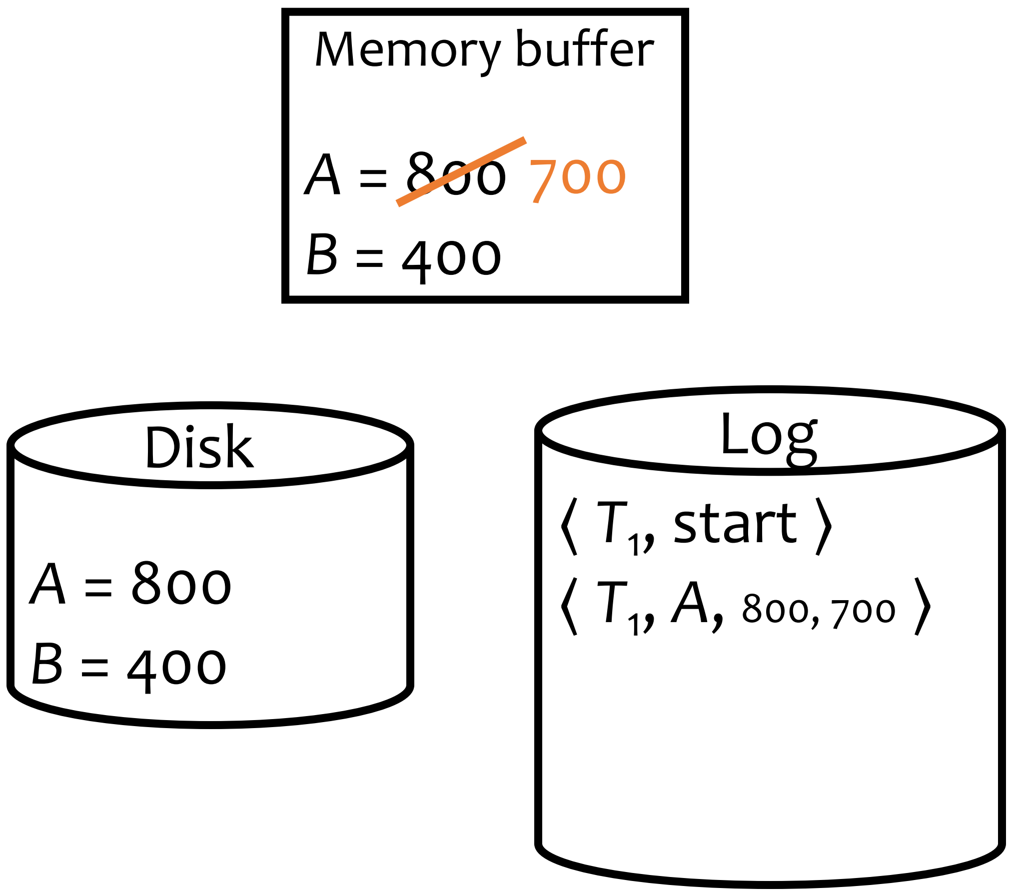

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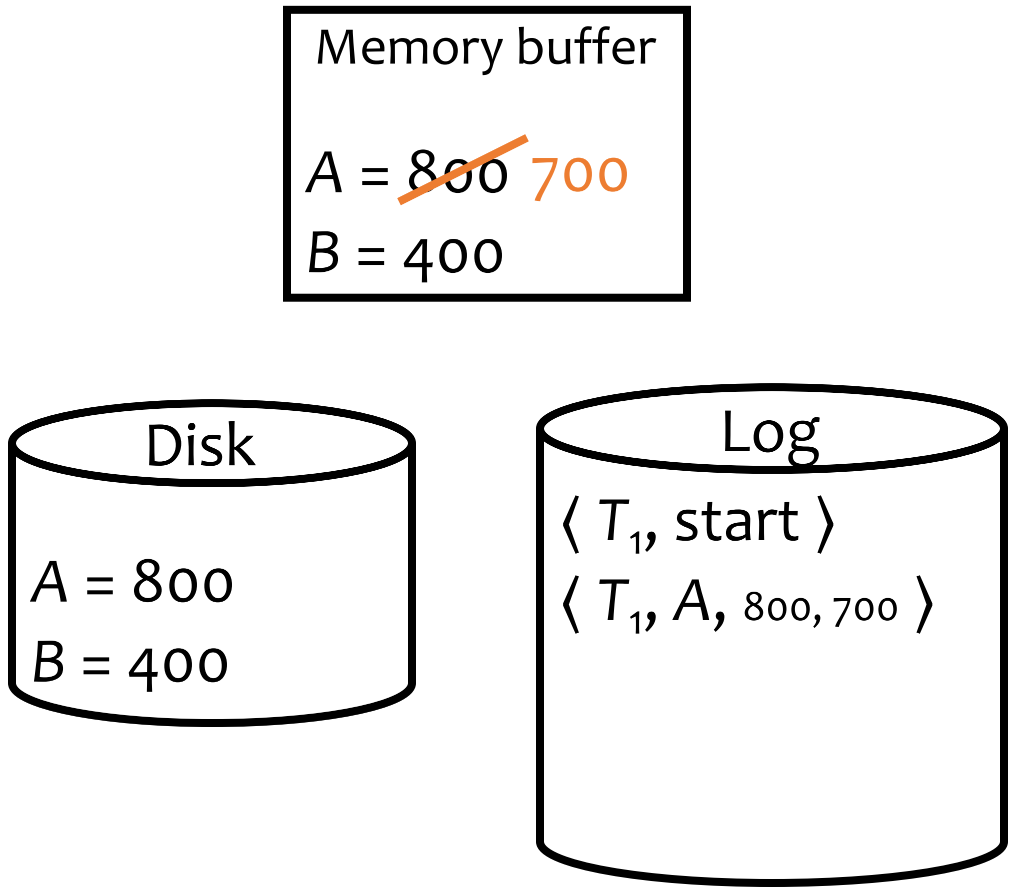

Undo/redo logging example

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

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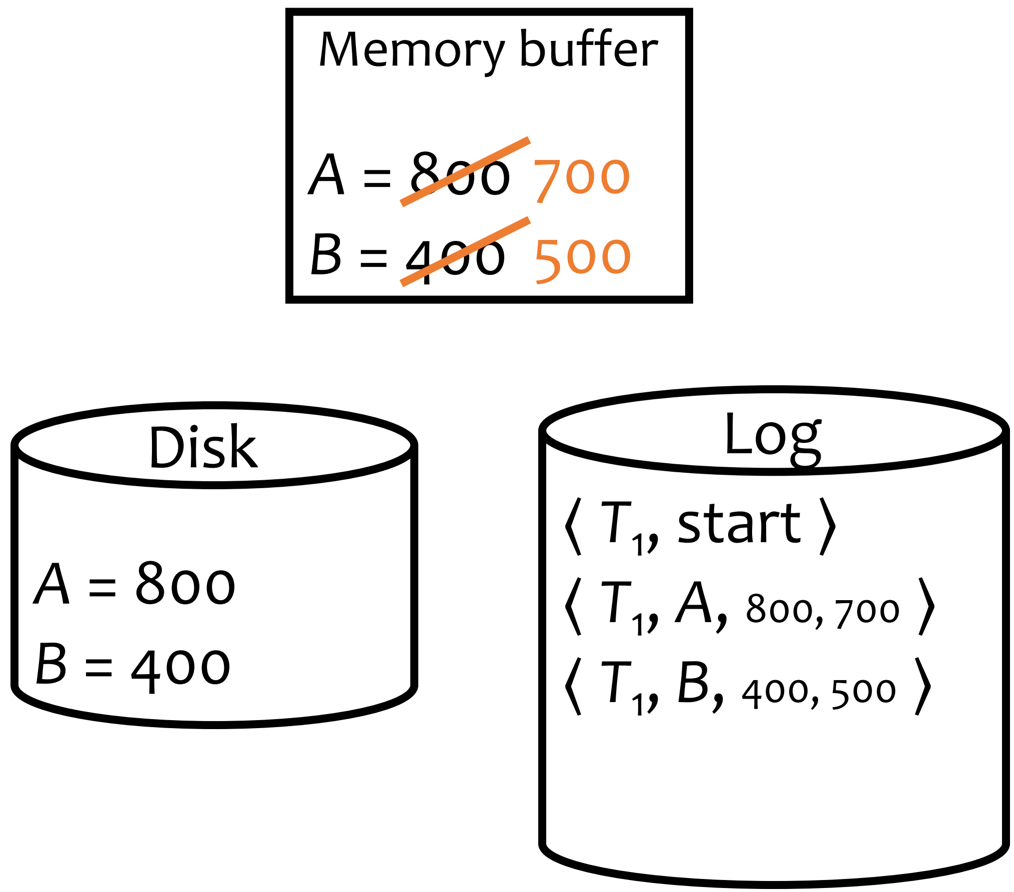
write(B, b);



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);

Memory buffer

$A = \cancel{800}\ 700$

$B = \cancel{400}\ 500$

Steal: can flush before commit

Disk

$A = \cancel{800}\ 700$

$B = 400$

Log

⟨ T_1, start ⟩

⟨ T_1, A, 800, 700 ⟩

⟨ T_1, B, 400, 500 ⟩

Undo/redo logging example

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

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

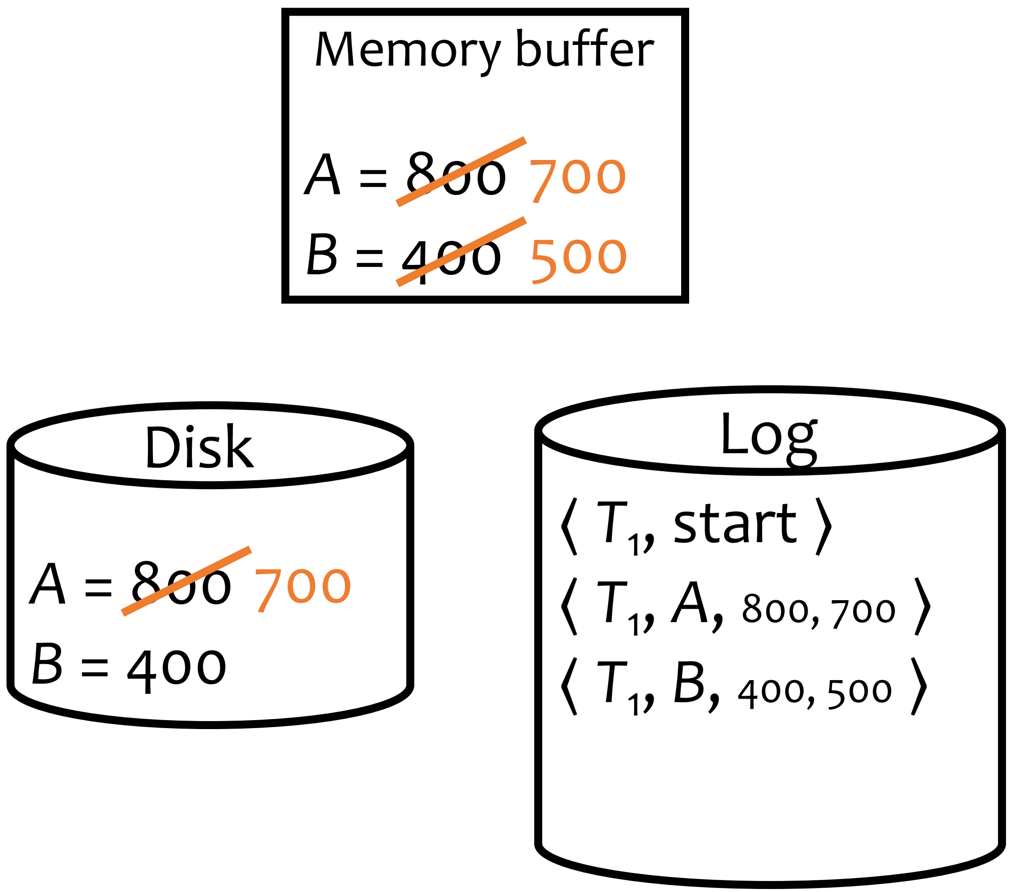
write(A, a);

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

write(B, b);

commit;

Steal: can flush
before commit



Undo/redo logging example

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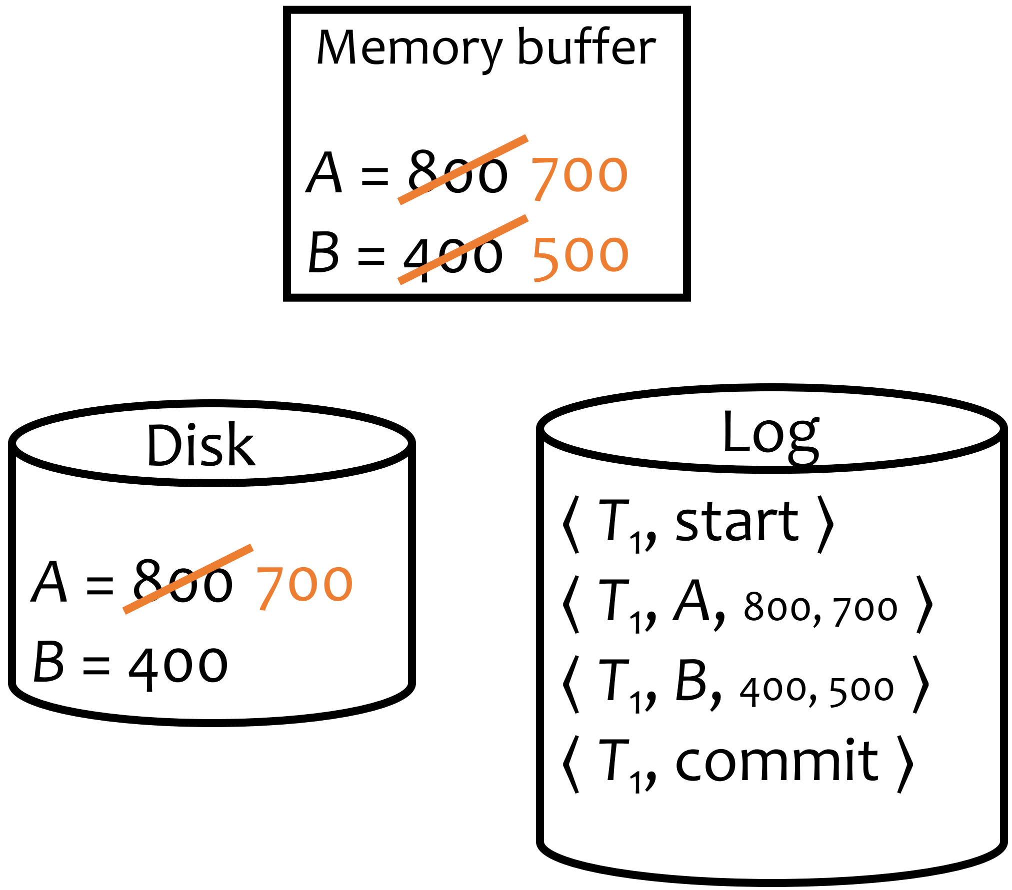
Steal: can flush before commit



Undo/redo logging example

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write(A, a);

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

write(B, b);

commit;

Memory buffer

$A = \cancel{800}$ 700

$B = \cancel{400}$ 500

Disk

$A = \cancel{800}$ 700

$B = \cancel{400}$ 500

Log

$\langle\ T_1$, start $\rangle$

$\langle\ T_1, A, 800, 700\ \rangle$

$\langle\ T_1, B, 400, 500\ \rangle$

$\langle\ T_1$, commit $\rangle$

Steal: can flush before commit

No force: can flush after commit

Undo/redo logging example

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

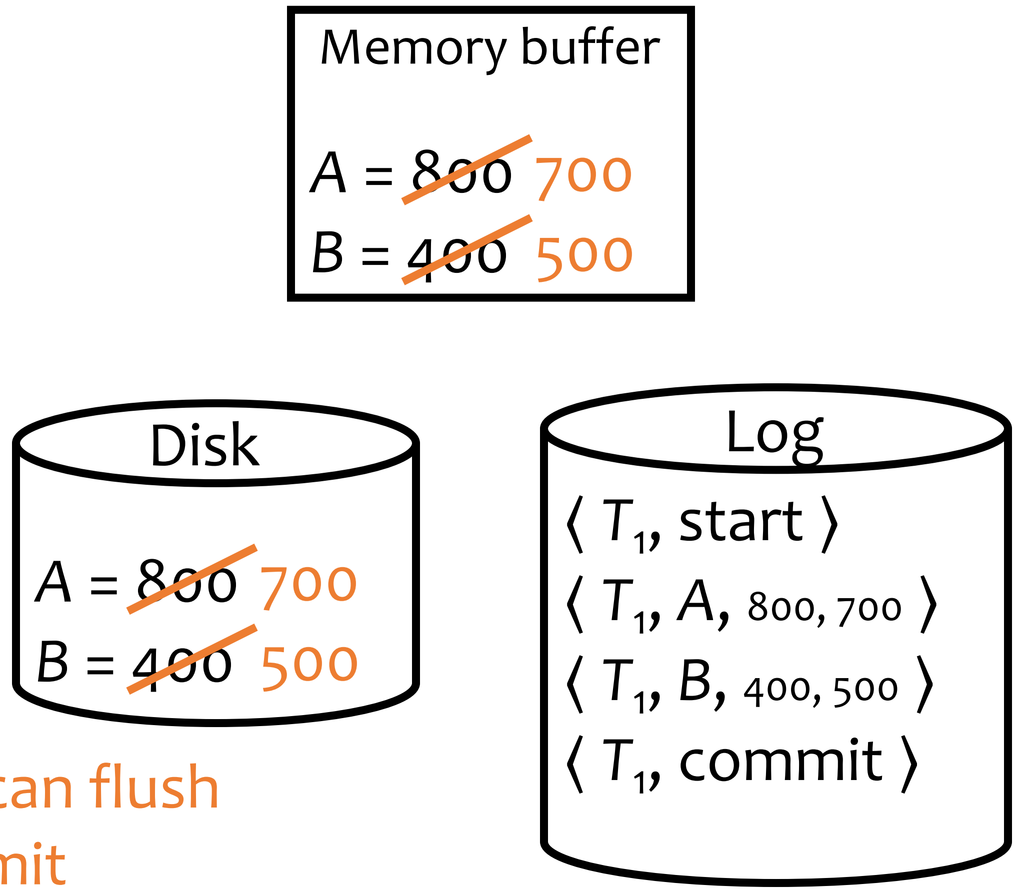
read(A, a); $a = a - 100$;

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? Beginning of very large log file?
  - No – use checkpointing

Naïve approach:

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

http://www.saintlouischeckpoints.com/wp-content/uploads/2013/08/dui20checkpoint200220172011.jpg

Fuzzy checkpointing

- Add to log records <START CKPT S> and <END CKPT>
  - Transactions normally proceed and new transactions can start during checkpointing (between START CKPT and END CKPT)

- Determine S, the set of (ids of) currently active transactions, and log ⟨ START CKPT S ⟩
- Flush all blocks (dirty at the time of the checkpoint) at your leisure
- Log ⟨END CKPT *START-CKPT_location* ⟩
  - To easily access <START CKPT> of an <END CKPT> otherwise can read the log backword to find it

An UNDO/REDO log with checkpointing

Log records
<START T1>
<T1, A, 4, 5>
<START T2>
<COMMIT T1>
<T2, B, 9, 10>
<START CKPT(T2)>
<T2, C, 14, 15>
<START T3>
<T3, D, 19, 20>
<END CKPT>
<COMMIT T2>
<COMMIT T3>

- T2 is active, T1 already committed
  - So <START CKPT (T2)>
- During CKPT,
  - flush A to disk if it is not already there (dirty buffer)
  - flush B to disk if it is not already there (dirty buffer)
  - Assume that the DBMS keeps track of dirty buffers

Announcements (Tues – Nov 29)

- Final gradiance-7 (transactions) due on Friday 12/2 10 pm
- Keep working on your projects – check the post on Ed (what/when to submit and present)
- Several practice problems posted:
  - Practice problems folder
  - Sample Exams folder with several old exams (note: syllabus and format may be different, 2020 semesters/exams were virtual for COVID)
  - More practice problems on gradiance and on transactions will be posted

Recovery using Log and CKPT: Three steps at a glance

End of Lecture on Tues 11/22
Start of Lecture on Tues 11/29

1. Analysis
   - Runs backward, from end of log, to the <START CKPT> of the last <END CKPT> record found (note this would be encountered "first" when reading backwards)
   - Goal: Reach the relevant <START CKPT> record

2. Repeating history (also completes REDO for committed transactions)
   - Runs forward, from START CKPT, to the end of log
   - Goal: (1) Repeat all updates from START CKPT (whether or not they already went to the disk, whether or not they are from committed transactions), (2) Build set U of uncommitted transaction to be used in UNDO step below

3. UNDO
   - Runs backward, from end of log, to the earliest <START T> of the uncomitted transactions stored in set U (note this may be before or after the <START CKPT> found in analysis step)
   - Goal: UNDO the actions of uncommitted transactions

Recovery: (1) analysis and (2) repeating history/REDO phase

- Need to determine *U*, the set of active transactions at time of crash
- Scan log backward to find the last <END CKPT> record and follow the pointer to find the corresponding ⟨START CKPT S⟩

Read again after seeing the examples next

- Initially, let *U* be *S*
- Scan forward from that start-checkpoint 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!

REDO is done and committed transactions are all in good shape now!
Still need to do UNDO for aborted/uncommitted transactions

Recovery: (3) UNDO phase

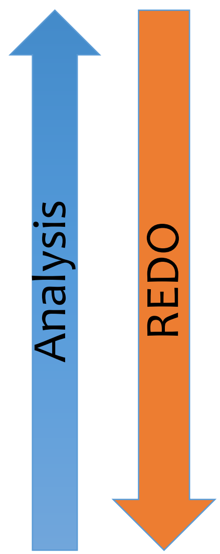
- Scan log backward
  - Undo the effects of transactions in *U*
  - That is, for each log record ⟨ *T*, *X*, *old*, *new* ⟩ where *T* is in *U*, issue write(*X*, *old*), and log this operation too (part of the "repeating-history" paradigm)
  - Log ⟨ *T*, abort ⟩ when all effects of *T* have been undone

Read again after seeing the examples next

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

Recovery: Example 1

Log records
<START T1>
<T1, A, 4, 5>
<START T2>
<COMMIT T1>
<T2, B, 9, 10>
<START CKPT(T2)>
<T2, C, 14, 15>
<START T3>
<T3, D, 19, 20>
<END CKPT>
<COMMIT T2>
<COMMIT T3>



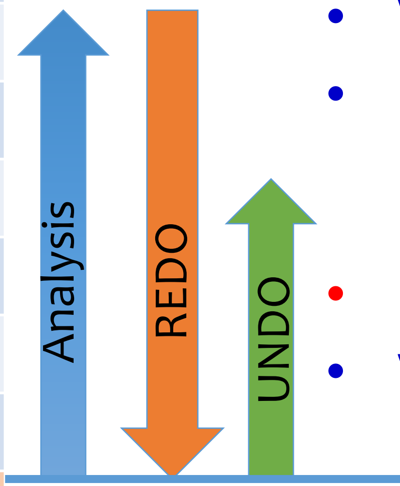
CRASH!!!

- T1 has committed and writes are already on disk
- After analysis, U = S = {T2}
- REDO all actions (values updated on disk)
- Write C = 15 (T2)
- UPDATE U to {T2, T3}
- Write D = 20 (T3)
- <COMMIT T2> found: U= {T3}
- <COMMIT T3> found: U = {}
- At the end U = empty, do nothing (NO UNDO PHASE)

Assume every log record before crash is on disk

Recovery: Example 2

Log records
<START T1>
<T1, A, 4, 5>
<START T2>
<COMMIT T1>
<T2, B, 9, 10>
<START CKPT(T2)>
<T2, C, 14, 15>
<START T3>
<T3, D, 19, 20>
<END CKPT>
<COMMIT T2>
<COMMIT T3>



(up to this much log is seen)

CRASH!!!

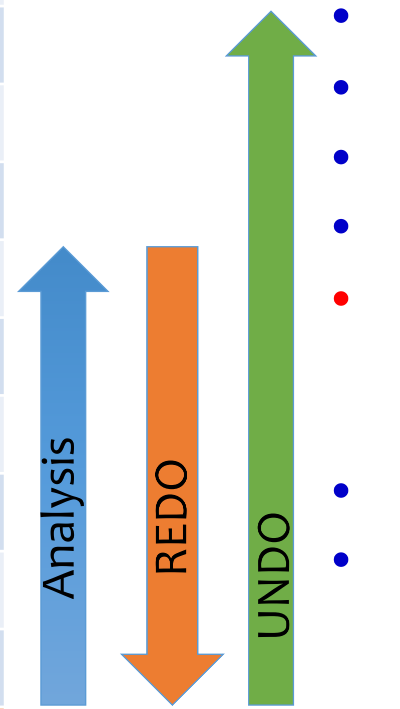
Assume every log record before crash is on disk

- T1 has committed and writes are already on disk
- After analysis, U = S = {T2}
- REDO all actions (values updated on disk)
- Write C = 15 (T2)
- UPDATE U to {T2, T3}
- Write D = 20 (T3)
- <COMMIT T2> found: U= {T3}
  - not necessary to set B to 10 (before END CKPT – already on disk)
- UNDO actions of T3 until its start
- Write D = 19 (T3)

Recovery: Example 3

Log records
<START T1>
<T1, A, 4, 5>
<START T2>
<COMMIT T1>
<T2, B, 9, 10>
<START CKPT(T2)>
<T2, C, 14, 15>
<START T3>
<T3, D, 19, 20>
<END CKPT>
<COMMIT T3>
<COMMIT T2>

CRASH!!!



(up to this much log is seen)

- T1 has committed and writes are already on disk
- After analysis, U = S = {T2}
- REDO all actions (values updated on disk)
- Write C = 15 (T2)
- UPDATE U to {T2, T3}
- Write D = 20 (T3)
- <COMMIT T3> found: U= {T2}
- UNDO actions of T2 until its start
  - Beyond <START CKPT>!
  - Those changes already went to disk
- Write C = 14 (T2)
- Write B = 9 (T2)

In class we also did an example of crash before <START T3>

Assume every log record before crash is on disk

Summary: Transactions

- 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)