Announcements

- No class on April 20
  - Reason: instructor traveling for a workshop

- Recitation on Project Assignment 3 on April 22
  - Given by Elaheh and Yao
  - Will go over what you need to do for the assignment
  - In-class demo of a sample solution
General Overview

- Preliminaries
- Write-Ahead Log - main ideas
- (Shadow paging)
- Write-Ahead Log: ARIES
NOTICE:

- **NONE** of the methods in this lecture is used ‘as is’
- we mention them for clarity, to illustrate the concepts and rationale behind ‘ARIES’, which is the **industry standard**.
Transactions - dfn

= unit of work, eg.
  move $10 from savings to checking

Atomicity (all or none)
Consistency
Isolation (as if alone)
Durability

recovery
concurrency control
Overview - recovery

- problem definition
  - types of failures
  - types of storage
- solution #1: Write-ahead log - main ideas
  - deferred updates
  - incremental updates
  - checkpoints
- (solution #2: shadow paging)
Recovery

- Durability - types of failures?
Recovery

- Durability - types of failures?
- disk crash (ouch!)
- power failure
- software errors (deadlock, division by zero)
Reminder: types of storage

- volatile (eg., main memory)
- non-volatile (eg., disk, tape)
- “stable” (“never” fails - how to implement it?)
Classification of failures:

frequent; ‘cheap’

- logical errors (e.g., div. by 0)
- system errors (e.g. deadlock - pgm can run later)
- system crash (e.g., power failure - volatile storage is lost)
- disk failure

rare; expensive
Problem definition

- Records are on disk
- for updates, they are copied in memory
- and flushed back on disk, *at the discretion of the O.S.!* (unless forced-output: ‘output(B)’ = fflush())
Problem definition - eg.:

\[
\text{read}(X) \quad X = X + 1 \quad \text{write}(X)
\]
Problem definition - eg.: 

\[
\begin{align*}
\text{read}(X) & \quad \rightarrow \quad X &= X + 1 \\
\text{write}(X) & \\
\end{align*}
\]
Problem definition - eg.:

read(X)
X = X + 1
→ write(X)

buffer joins an output queue, but it is NOT flushed immediately!
Q1: why not?
Q2: so what?
Problem definition - eg.:

read(X)
read(Y)
X=X+1
Y=Y-1
write(X)
→ write(Y)

Q2: so what?
Problem definition - eg.:

read(X)
read(Y)
X = X + 1
Y = Y - 1
write(X)
→ write(Y)

Q2: so what?
Q3: how to guard against it?
Overview - recovery

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Solution #1: W.A.L.

- redundancy, namely
- write-ahead log, on ‘stable’ storage
- Q: what to replicate? (not the full page!!)
- A:
- Q: how exactly?
W.A.L. - intro

- replicate intentions: eg:
  - `<T1 start>`
  - `<T1, X, 5, 6>`
  - `<T1, Y, 4, 3>`
  - `<T1 commit>` (or `<T1 abort>`)
W.A.L. - intro

- in general: transaction-id, data-item-id, old-value, new-value
- (assumption: each log record is immediately flushed on stable store)
- each transaction writes a log record first, before doing the change
- when done, write a <commit> record & exit
W.A.L. - deferred updates

- idea: prevent OS from flushing buffers, until (partial) ‘commit’.
- After a failure, “replay” the log
W.A.L. - deferred updates

- Q: how, exactly?
  - value of W on disk?
  - value of W after recov.?
  - value of Z on disk?
  - value of Z after recov.?
W.A.L. - deferred updates

Q: how, exactly?

- value of $W$ on disk?
- value of $W$ after recov.?
- value of $Z$ on disk?
- value of $Z$ after recov.?

before

<T1 start>
<T1, W, 1000, 2000>
<T1, Z, 5, 10>

crash
W.A.L. - deferred updates

- Thus, the recovery algo:
  - **redo** committed transactions
  - ignore uncommitted ones

\[
\begin{align*}
&T1 \text{ start} \\
&T1, W, 1000, 2000 \\
&T1, Z, 5, 10
\end{align*}
\]
W.A.L. - deferred updates

Observations:
- no need to keep ‘old’ values
- Disadvantages?
W.A.L. - deferred updates

- Disadvantages?
(e.g., “increase all balances by 5%”)
May run out of buffer space!
Hence:
Overview - recovery

- problem definition
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  - types of storage

- solution #1: Write-ahead log
  - deferred updates
  - incremental updates
  - checkpoints

- (solution #2: shadow paging)
W.A.L. - incremental updates

- log records have ‘old’ and ‘new’ values.
- modified buffers can be flushed at any time

Each transaction:
- writes a log record first, before doing the change
- writes a ‘commit’ record (if all is well)
- exits
W.A.L. - incremental updates

- Q: how, exactly?
  - value of W on disk?
  - value of W after recov.?
  - value of Z on disk?
  - value of Z after recov.?

\[ \langle T1 \text{ start} \rangle \]
\[ \langle T1, W, 1000, 2000 \rangle \]
\[ \langle T1, Z, 5, 10 \rangle \]
\[ \langle T1 \text{ commit} \rangle \]

(before) 

(crash)
W.A.L. - incremental updates

Q: how, exactly?
– value of W on disk?
– value of W after recov.?
– value of Z on disk?
– value of Z after recov.?

<T1 start>
<T1, W, 1000, 2000>
<T1, Z, 5, 10>

before

crash
W.A.L. - incremental updates

- Q: recovery algo?
- A:
  - redo committed xacts
  - undo uncommitted ones
- (more details: soon)

before
<T1 start>
<T1, W, 1000, 2000>
<T1, Z, 5, 10>
crash
High level conclusion:

- Buffer management plays a key role
- FORCE policy: DBMS immediately forces dirty pages on the disk (easier recovery; poor performance)
- STEAL policy == ‘incremental updates’: the O.S. is allowed to flush dirty pages on the disk
Buffer Management Summary

Performance Implications
- No Force: No Steal - Slowest
- Force: Steal - Fastest

Logging/Recovery Implications
- No UNDO
  - No Force: No Steal
  - Force: Steal
- No REDO
  - No Force: No Steal
  - Force: Steal

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W.A.L. - incremental updates

Observations

- “increase all balances by 5%” - problems?
- what if the log is huge?

<T1 start>
<T1, W, 1000, 2000>
<T1, Z, 5, 10>

before

crash
Overview - recovery

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- solution#1: Write-ahead log
  - deferred updates
  - incremental updates
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- (solution #2: shadow paging)
W.A.L. - check-points

Idea: periodically, flush buffers

Q: should we write anything on the log?

<T1 start>
<T1, W, 1000, 2000>
<T1, Z, 5, 10>
...
<T500, B, 10, 12>

before

crash
W.A.L. - check-points

Q: should we write anything on the log?
A: yes!
Q: how does it help us?

before

<T1 start>
<T1, W, 1000, 2000>
<T1, Z, 5, 10>
<checkpoint>
...
<checkpoint>
<T500, B, 10, 12>

crash
W.A.L. - check-points

Q: how does it help us?
   A=? on disk?
   A=? after recovery?
   B=? on disk?
   B=? after recovery?
   C=? on disk?
   C=? after recovery?

<T1 start>
...
<T1 commit>
...
<T499, C, 1000, 1200>
<checkpoint>
<T499 commit>
<T500 start>
<T500, A, 200, 400>
<checkpoint>
<T500, B, 10, 12>

before crash

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Q: how does it help us? I.e., how is the recovery algorithm?

before

<T1 start>
...
<T1 commit>
...
<T499, C, 1000, 1200>
<checkpoint>
<T499 commit>
<T500 start>
<T500, A, 200, 400>
<checkpoint>
<T500, B, 10, 12>
W.A.L. - check-points

Q: how is the recovery algorithm?
A:
- undo uncommitted xacts (eg., T500)
- redo the ones committed after the last checkpoint (eg., none)
W.A.L. - w/ concurrent xacts

Assume: strict 2PL
W.A.L. - w/ concurrent xacts

Log helps to rollback transactions (eg., after a deadlock + victim selection)

Eg., rollback(T500): go backwards on log; restore old values
W.A.L. - w/ concurrent xacts

- recovery algo?
- undo uncommitted ones
- redo ones committed after the last checkpoint

<T1 start>
...
<T300 start>
...
<T499 commit>
<T500 start>
<T500, A, 200, 400>
<T300 commit>
<Tcheckpoint>
<Tcheckpoint>
<T500, B, 10, 12>
W.A.L. - w/ concurrent xacts

- recovery algo?
- undo uncommitted ones
- redo ones committed after the last checkpoint
- Eg.?
W.A.L. - w/ concurrent xacts

-recovery algo?
specifically:
- find latest
  checkpoint
- create the ‘undo’
  and ‘redo’ lists
W.A.L. - w/ concurrent xacts

T1
T2
T3
T4

ck  ck  crash

<T1 start>
<T2 start>
<T4 start>
<T1 commit>
<checkpoint>
<T3 start>
<T2 commit>
<checkpoint>
<T3 commit>

time
W.A.L. - w/ concurrent xacts

<checkpoint> should also contain a list of ‘active’ transactions (= not committed yet)

<T1 start>
<T2 start>
<T4 start>
<T1 commit>
<checkpoint >
<T3 start>
<T2 commit>
<checkpoint >
<T3 commit>
W.A.L. - w/ concurrent xacts

<checkpoint> should also contain a list of ‘active’ transactions

<T1 start>
<T2 start>
<T4 start>
<T1 commit>
<checkpoint {T4, T2}>
<T3 start>
<T2 commit>
<checkpoint {T4, T3}>
<T3 commit>
W.A.L. - w/ concurrent xacts

Recovery algo:
- build ‘undo’ and ‘redo’ lists
- scan backwards, **undoing** ops by the ‘undo’ -list transactions
- go to most recent checkpoint
- scan forward, **redoing** ops by the ‘redo’ -list xacts

<T1 start>
<T2 start>
<T4 start>
<T1 commit>
<checkpoint {T4, T2}>
<T3 start>
<T2 commit>
<checkpoint {T4,T3} >
<T3 commit>
W.A.L. - w/ concurrent xacts

Recovery algo:
- build ‘undo’ and ‘redo’ lists
- scan backwards, undoing ops by the ‘undo’-list transactions
- go to most recent checkpoint
- scan forward, re-doing ops by the ‘redo’-list xacts

Actual ARIES algorithm: more clever (and more complicated) than that

<T1 start>
<T2 start>
<T4 start>
<T1 commit>
<checkpoint \{T4, T2\}>
<T3 start>
<T2 commit>
<checkpoint \{T4, T3\}>
<T3 commit>
Observations/Questions
1) what is the right order to
undo/redo?
2) during checkpoints: assume
that no changes are allowed by
xacts (otherwise, ‘fuzzy
checkpoints’ )
3) recovery algo: must be
idempotent (ie., can work, even
if there is a failure during
recovery!
4) how to handle buffers of
stable storage?

<T1 start>
<T2 start>
<T4 start>
<T1 commit>
<checkpoint {T4, T2}>
<T3 start>
<T2 commit>
<checkpoint {T4,T3} >
<T3 commit>
Observations

ARIES (coming up soon) handles all issues:
1) redo **everything**; undo after that
2) ‘fuzzy checkpoints’
3) idempotent recovery
4) buffer log records;
   – flush all necessary log records before a page is written
   – flush all necessary log records before a x-act commits
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- (solution #2: shadow paging)
Shadow paging

- keep old pages on disk
- write updated records on new pages on disk
- if successful, release old pages; else release ‘new’ pages
- tried in early IBM prototype systems, but
- not used in practice - why not?
Shadow paging

- **not used** in practice - why not?
- may need too much disk space ("increase all by 5%")
- may destroy clustering/contiguity of pages.
Other topics

- against loss of non-volatile storage: dumps of the whole database on stable storage.
Conclusions

- Write-Ahead Log, for loss of volatile storage,
- with incremental updates (STEAL, NO FORCE)
- and checkpoints
- On recovery: *undo* uncommitted; *redo* committed transactions.
Next time:

ARIES, with full details on

– fuzzy checkpoints
– recovery algorithm