CS 4604: Introduction to Database Management Systems

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Lecture #17: Logging and Recovery 1

General Overview

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

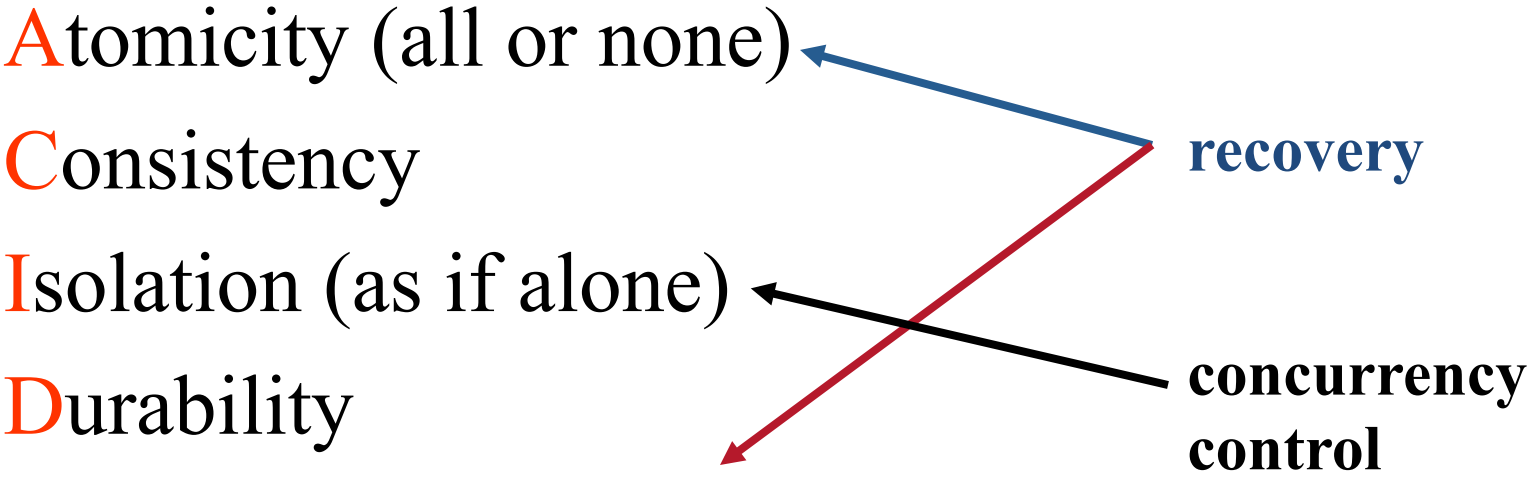
NOTICE:

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

rare; expensive

Problem definition

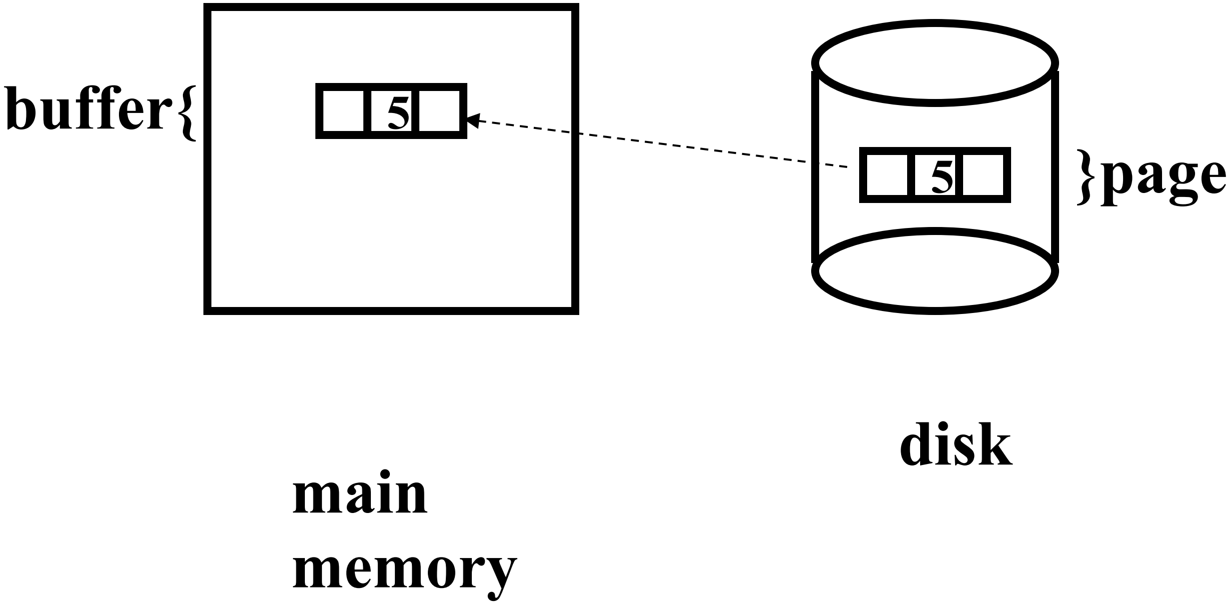
- Records are on disk
- for updates, they are copied in memory
- and flushed back on disk, *at the discretion of the O.S.!* (unless forced-output: ‘output(B)’ = fflush())

Problem definition - eg.:

→ read(X)

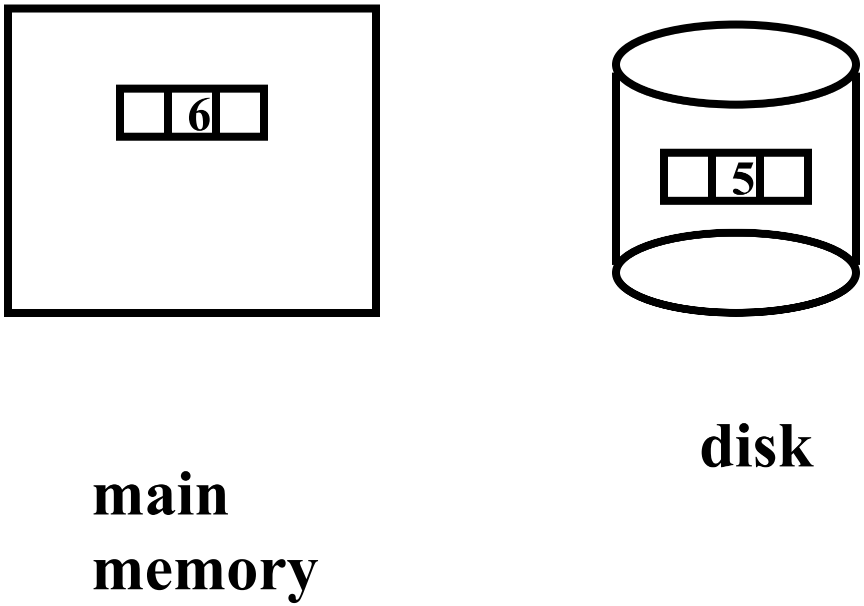
X=X+1

write(X)



Problem definition - eg.:

```
  read(X)
→ X=X+1
  write(X)
```

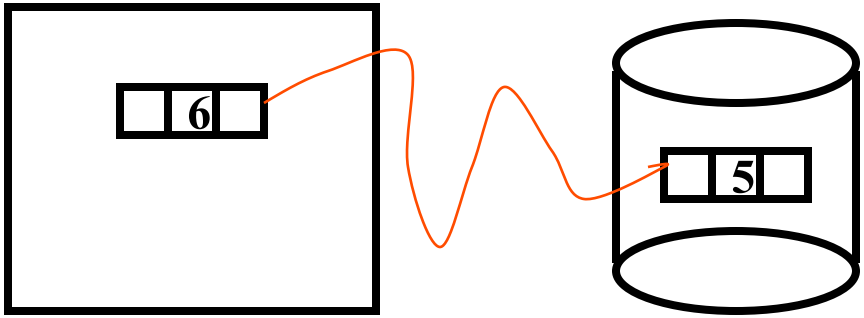


Problem definition - eg.:

read(X)

X=X+1

→ write(X)



buffer joins an ouput queue,
but it is NOT flushed immediately!
Q1: why not?
Q2: so what?

disk

Problem definition - eg.:

read(X)

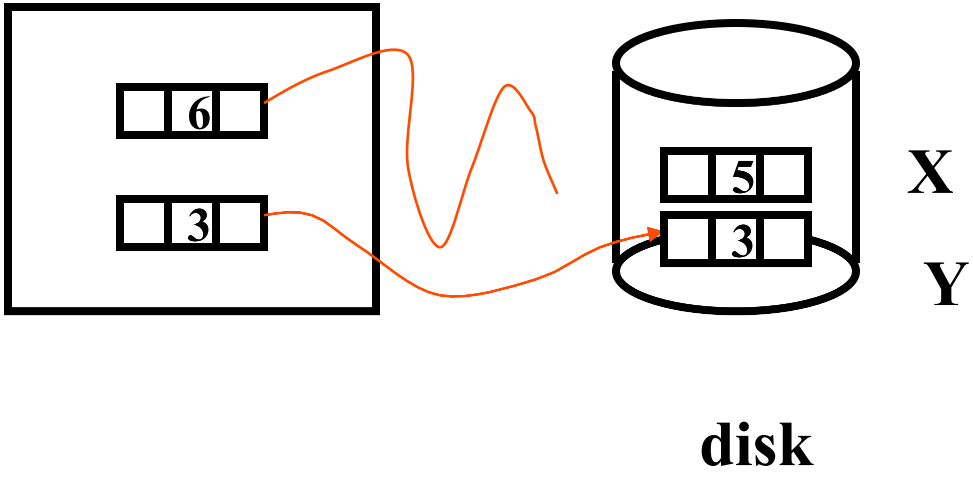
read(Y)

X=X+1

Y=Y-1

write(X)

→ write(Y)



Q2: so what?

Problem definition - eg.:

read(X)

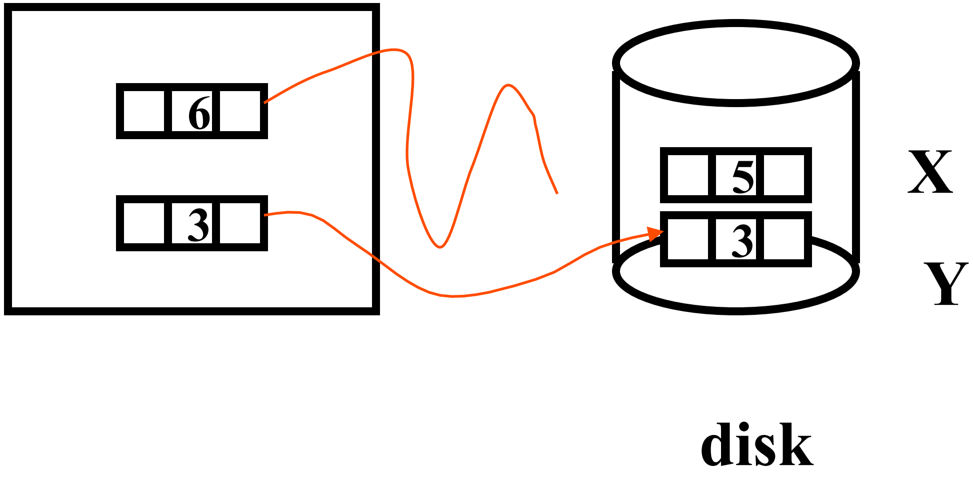
read(Y)

X=X+1

Y=Y-1

write(X)

→ write(Y)



Q2: so what?
Q3: how to guard against it?

Overview - recovery

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

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

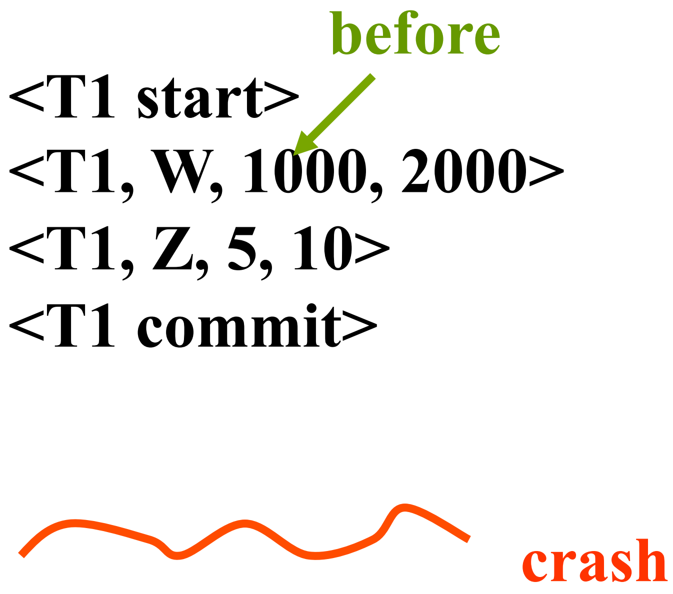
- in general: transaction-id, data-item-id, old-value, new-value
- (assumption: each log record is **immediately** flushed on stable store)
- each transaction writes a log record first, **before** doing the change
- when done, write a <commit> record & exit

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

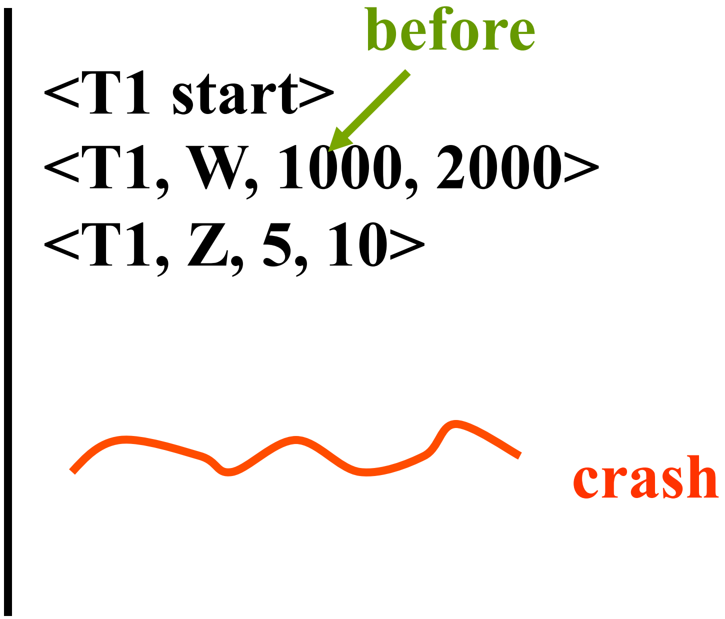
- Q: how, exactly?
  - – value of W on disk?
  - – value of W after recov.?
  - – value of Z on disk?
  - – value of Z after recov.?



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

W.A.L. - deferred updates

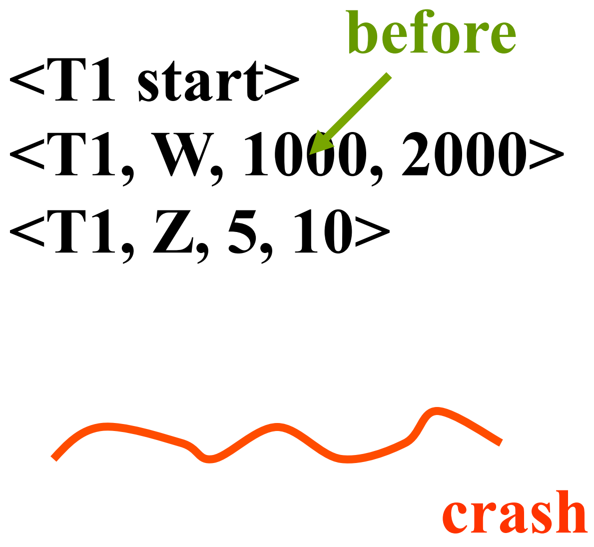
- Q: how, exactly?
  - – value of W on disk?
  - – value of W after recov.?
  - – value of Z on disk?
  - – value of Z after recov.?



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

W.A.L. - deferred updates

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



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

before

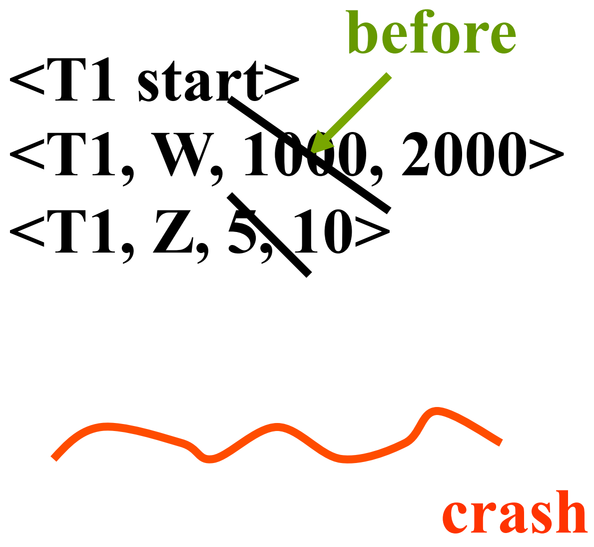
crash

W.A.L. - deferred updates

Observations:

- no need to keep ‘old’ values

- Disadvantages?



<T1 start>

<T1, W, ~~1000~~, 2000>

<T1, Z, ~~5~~, 10>

W.A.L. - deferred updates

- Disadvantages?

(e.g., "increase all balances by 5%")

May run out of buffer space!

Hence:

Overview - recovery

- problem definition
  - – types of failures
  - – 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.?

before

<T1 start>

<T1, W, 1000, 2000>

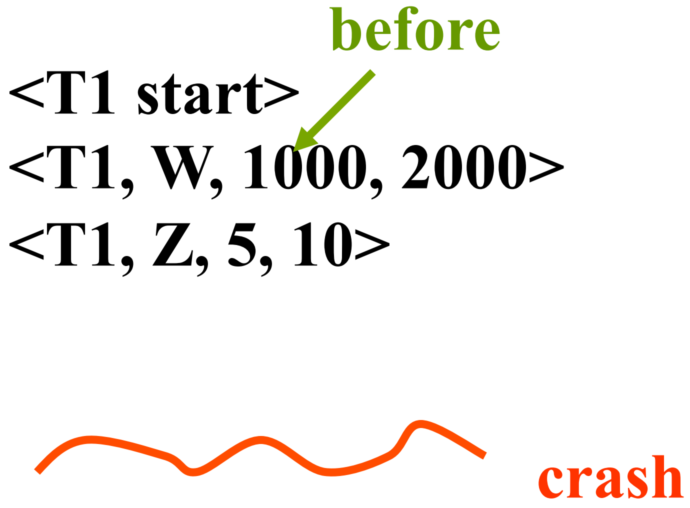
<T1, Z, 5, 10>

<T1 commit>

crash

W.A.L. - incremental updates

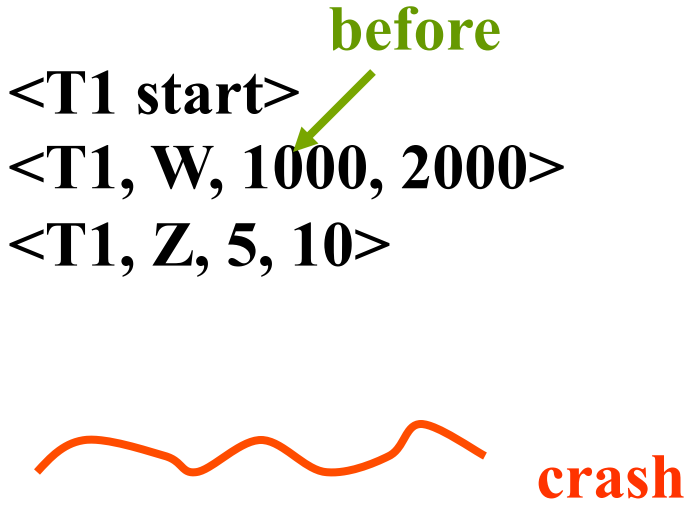
- Q: how, exactly?
  - – value of W on disk?
  - – value of W after recov.?
  - – value of Z on disk?
  - – value of Z after recov.?



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

W.A.L. - incremental updates

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

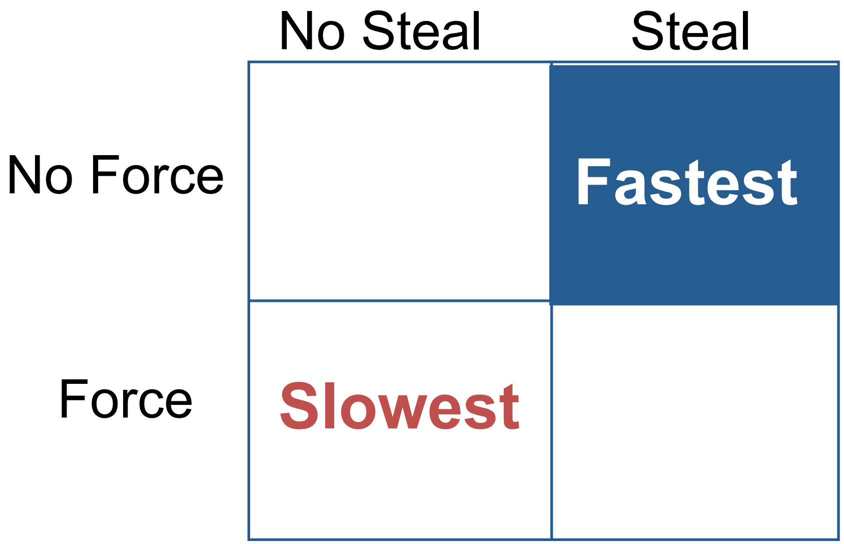


<T1 start>
<T1, W, 1000, 2000>
<T1, Z, 5, 10>

High level conclusion:

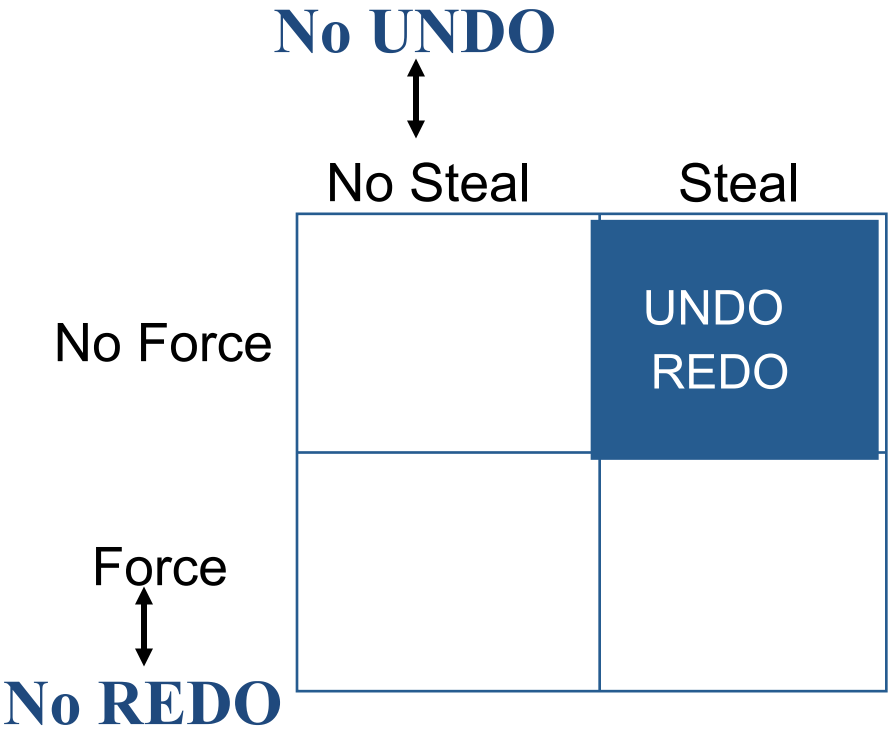
- Buffer management plays a key role
- FORCE policy: DBMS immediately forces dirty pages on the disk (easier recovery; poor performance)
- STEAL policy == 'incremental updates' : the O.S. is allowed to flush dirty pages on the disk

Buffer Management summary



	No Steal	Steal
No Force		**Fastest**
Force	**Slowest**	

Performance Implications



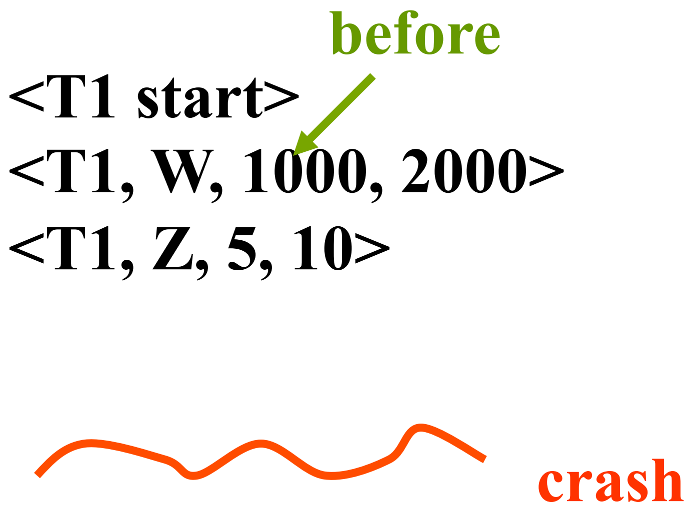
	No Steal	Steal
No Force		UNDO REDO
Force		

Logging/Recovery Implications

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>

Overview - recovery

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

W.A.L. - check-points

Idea: periodically, flush buffers

Q: should we write anything on the log?

before

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

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

W.A.L. - check-points

Q: how does it help us?

I.e., how is the recovery algorithm?

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

before

crash

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)

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

before

crash

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

<T1 start>

<checkpoint>

<T499 commit>

<T500 start>

<T500, A, 200, 400>

<T300 commit>

<checkpoint>

before ↙

<T500, B, 10, 12>

<T500 abort>

W.A.L. - w/ concurrent xacts

-recovery algo?

- undo uncommitted ones
- redo ones committed
  after the last checkpoint

<T1 start>
...
<T300 start>
...
<checkpoint>
<T499 commit>
<T500 start>
<T500, A, 200, 400>
<T300 commit>
<checkpoint>
<T500, B, 10, 12>

before

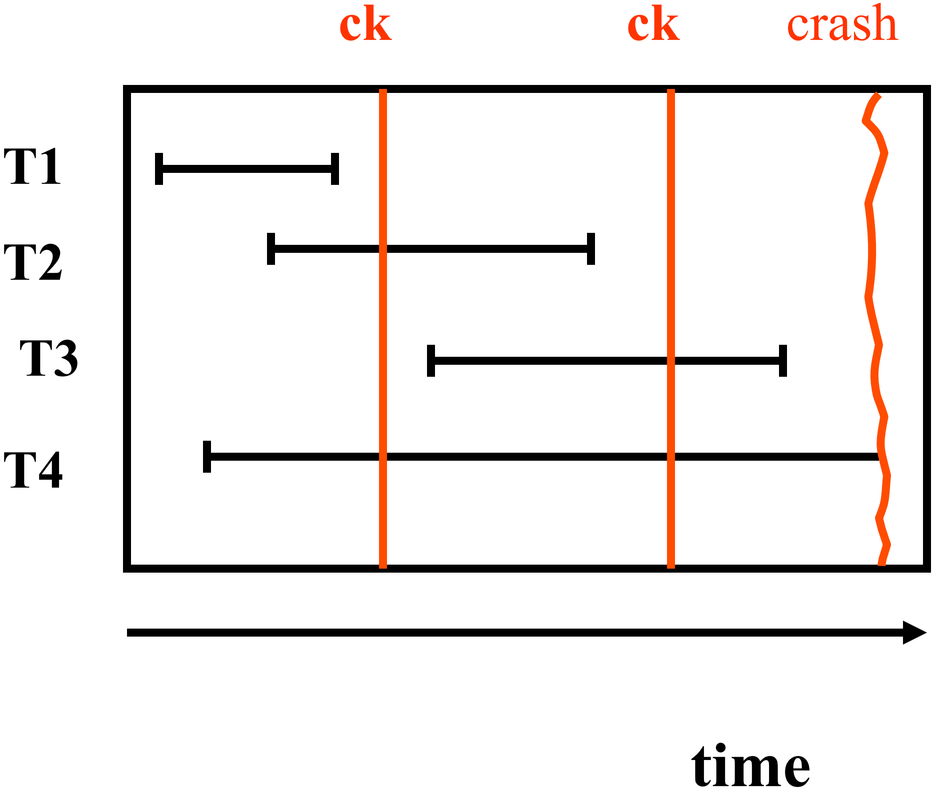
W.A.L. - w/ concurrent xacts

-recovery algo?

- undo uncommitted ones

- redo ones committed **after** the last checkpoint

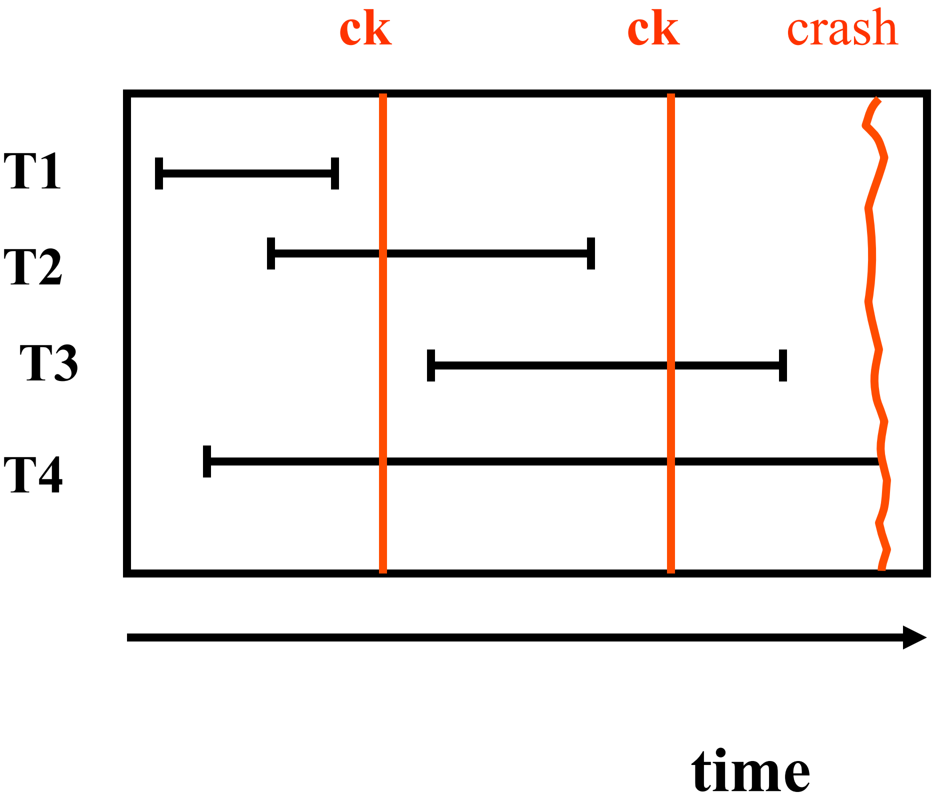
- Eg.?



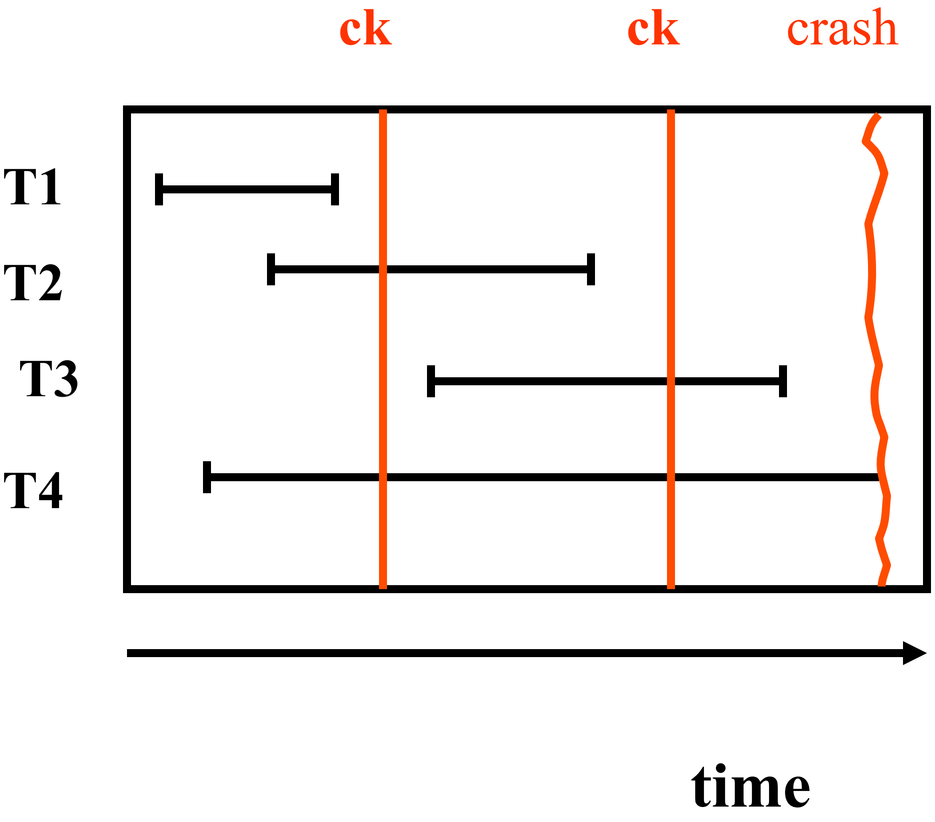
W.A.L. - w/ concurrent xacts

-recovery algo?
specifically:

- find latest checkpoint
- create the ‘undo’ and ‘redo’ lists



W.A.L. - w/ concurrent xacts



<T1 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 (= not commited 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, <u>undoing</u> ops by the 'undo'-list transactions

- go to most recent checkpoint

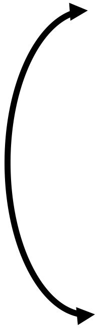
- scan forward, <u>re-doing</u> ops by the 'redo'-list xacts

<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:

swap?



- **build 'undo' and 'redo' lists**
- **scan backwards, <u>undoing</u> ops by the 'undo'-list transactions**
- **go to most recent checkpoint**
- **scan forward, <u>re-doing</u> 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>

W.A.L. - w/ concurrent xacts

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

Overview - recovery

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

NOT USED

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