L10
Transactions, Concurrency, Recovery

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Overview

Why do we want transactions?

What guarantees do we want from transactions?

Why Transactions?

Concurrency (for performance)

- N clients, no concurrency
  - 1st client runs fast
  - 2nd client waits a bit
  - 3rd client waits a bit longer
  - Nth client walks away
- N clients, concurrency
  - client 1 runs x += y
  - client 2 runs x -= y
  - what happens?

Can we prevent stepping on toes? *Isolation* x += y

a1 = read(x)

b1 = read(y)

store(a1 + b1)

x -= y

a2 = read(x)

b2 = read(y)

store(a2 – b2)

Execution Order

a1 = read(x)

a2 = read(x)

b2 = read(y)

store(a2 – b2, x)

b1 = read(y)

store(a1 + b1, x)

Why Transactions?

What about 1 client, no concurrency?

- Client runs big update query
  - update set x += y
- Power goes out
- What is the state of the database?

Why Transactions?

What about 1 client, no concurrency?

- Client runs big update query
  - update set x += y
- Aborts the query (e.g., ctrl-c)
- What is the state of the database?

If an abort happens, can the database recover to something sensible? *Atomicity, Durability*

Transactions

Transaction: a sequence of actions

- action = read object, write object, commit, abort
- API between app semantics and DBMS's view

User's view

T1: begin	A=A+100	B=B-100	END
T2: begin	A=1.5*A	A=1.5*B	END

DBMS's logical view

T1: begin	r(A) w(A)	r(B) w(B)	END
T2: begin	r(A) w(A)	r(B) w(A)	END

ACID: Transaction Guarantees

Atomicity

users never see in-between xact state.

only see a xact's effects once it's commited

Consistency

database always satisfies ICs.

xacts move from valid database to valid database

Isolation:

from xact's point of view, it's the only xact running

Durability:

if xact commits, its effects *must persist*

Concepts

Concurrency Control

techniques to ensure correct results when running transactions concurrently

what does this mean?

Recovery

On crash or abort, how to get back to a consistent (correct) state?

The two are intertwined! The CC mechanism dictates the complexity of recovery!

What is Correct?

Serializability

Regardless of the interleaving of operations, end result same as a serial ordering

Schedule

One specific interleaving of the operations

T1: R(A) R(B) W(D) COMMIT

Serial Schedules

Logical xacts

T1: r(A) w(A) r(B) w(B)
T2: r(A) w(A) r(B) w(B)

No concurrency (serial 1)

T1: r(A) w(A) r(B) w(B)
T2: r(A) w(A) r(B) w(B)

No concurrency (serial 2)

T1: r(A) w(A) r(B) w(B)
T2: r(A) w(A) r(B) w(B)

Are serial 1 and serial 2 equivalent?

More Example Schedules

Logical xacts

T1: r(A) w(A) r(A) w(B)
T2: r(A) w(A) r(B) w(B)

Concurrency (bad)

T1:	r(A) w(A)		r(A) w(B)	
T2:		r(A) w(A)		r(B) w(B)

Concurrency (same as serial 1!)

T1:	r(A) w(A)		r(A) w(B)	
T2:		r(A)		w(A) r(B) w(B)

Important Concepts

Serial schedule

single threaded model. no concurrency.

Equivalent schedule

the database state same at end of both schedules

Serializable schedule (gold standard)

equivalent to a serial schedule

These are just definitions.

How to *ensure* that schedules are serializable?

SQL → R/W Operations

```
UPDATE  accounts
SET     bal = bal + 1000
WHERE   bal > 1M
```

Read all balances for every tuple

Update those with balances > 1000

Does the access method matter?

- YES!
- Tuples(objects) read depend on access method

SQL → R/W Operations

```
UPDATE  accounts
SET     bal = bal + 1000
WHERE   id = 123
```

If 1000 tuples in accounts, how many tuples read:

If no indexes?

If index on bal?

If hash index on id?

if B+-tree index on id?

SQL → R/W Operations

```
UPDATE  accounts
SET     bal = bal + 1000
WHERE   id = 123
```

If 1000 tuples in accounts, how many tuples read:

If no indexes?	1000 tuples
If index on bal?	1000 tuples
If hash index on id?	# tuples in hash bucket
if B+-tree index on id?	# tuples in a page

NonSerializable Schedule→Anomalies

Reading in-between (uncommitted) data

T1:	R(A) W(A)		R(B) W(B) abort
T2:		R(A) W(A) commit	

WR conflict or dirty reads

Reading same data gets different values

T1:	R(A)		R(A) W(A) commit
T2:		R(A) W(A) commit	

RW conflict or unrepeatable reads

NonSerializable Schedule→Anomalies

Stepping on someone else's writes

T1:	W(A)				W(B)	commit
T2:		W(A)	W(B)	commit		

WW conflict or lost writes

Notice: all anomalies involve writing to data that is read/written to.

- If we track our writes, maybe can prevent anomalies

Conflict Serializability

Can we *cheaply* prevent non-serializable scheds?

Over-conservative: some serializable schedules disallowed.

Intuition: if xacts don't touch the same records, should be OK.

Conflict Serializability

What is a conflict?

- For 2 operations, if run in different order, get different results

Conflict?	R	W
R	NO	YES
W	YES	YES

Conflict Serializability

def: possible to swap non-conflicting operations to derive a serial schedule.

$\forall$ conflicting operations O1 of T1, O2 of T2

O1 always before O2 in the schedule or

O2 always before O1 in the schedule

Operation Oi is a read or write of an object

Logical

	1	2	3	4
T1:	R(A)	W(A)	R(B)	W(B)
	5	6	7	8
T2:	R(A)	W(A)	R(B)	W(B)

Conflicts

1,6   2,5   2,6   3,8   4,7   4,8

Logical

	1	2	3	4
T1:	R(A)	W(A)	R(B)	W(B)
	5	6	7	8
T2:	R(A)	W(A)	R(B)	W(B)

Serializable

	1	2			3	4		
T1:	R(A)	W(A)			R(B)	W(B)		
			5	6			7	8
T2:			R(A)	W(A)			R(B)	W(B)

Logical

	1	2	3	4
T1:	R(A)	W(A)	R(B)	W(B)
	5	6	7	8
T2:	R(A)	W(A)	R(B)	W(B)

Not Serializable

	1		2		3	4		
T1:	R(A)		W(A)		R(B)	W(B)		
		5		6			7	8
T2:		R(A)		W(A)			R(B)	W(B)

Conflict Serializability

Transaction Precedence Graph

Edge Ti → Tj if:

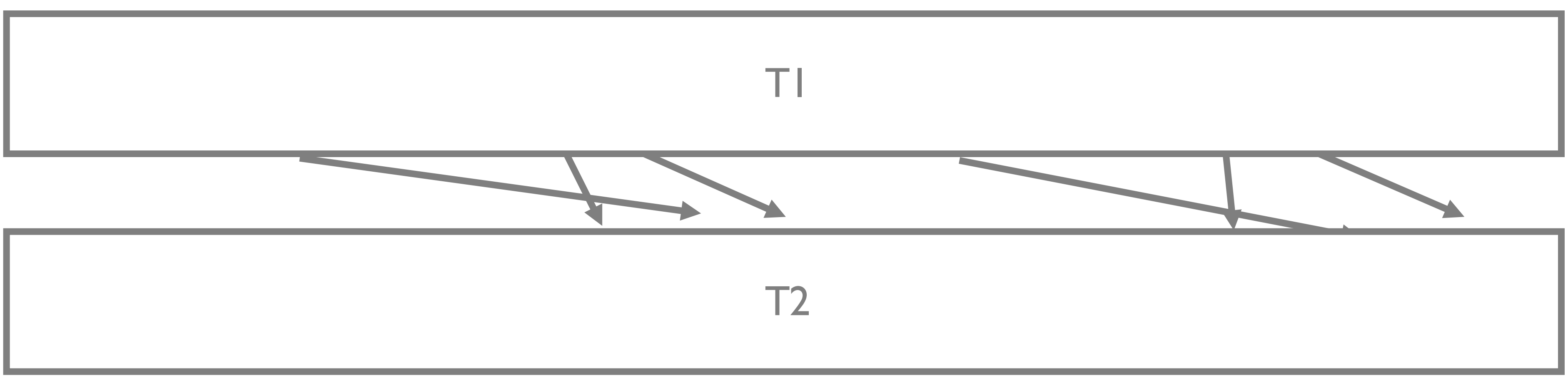
1. Ti read/write A before Tj writes A or
2. Ti writes some A before Tj reads A

If graph is acyclic (does not contain cycles) then conflict serializable!

Logical

	1	2	3	4
T1:	R(A)	W(A)	R(B)	W(B)
	5	6	7	8
T2:	R(A)	W(A)	R(B)	W(B)

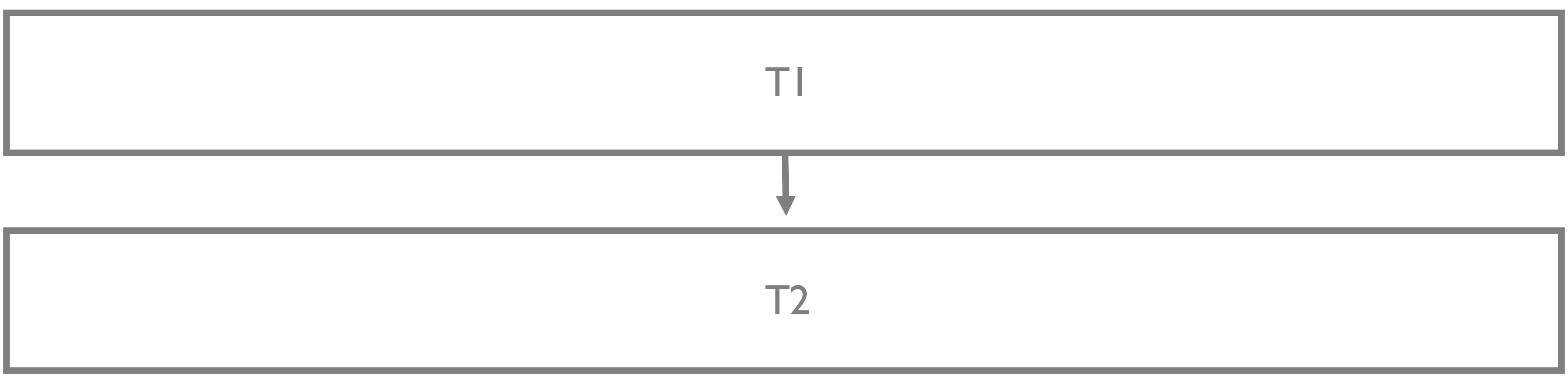
Serializable



Logical

	1	2	3	4
T1:	R(A)	W(A)	R(B)	W(B)
	5	6	7	8
T2:	R(A)	W(A)	R(B)	W(B)

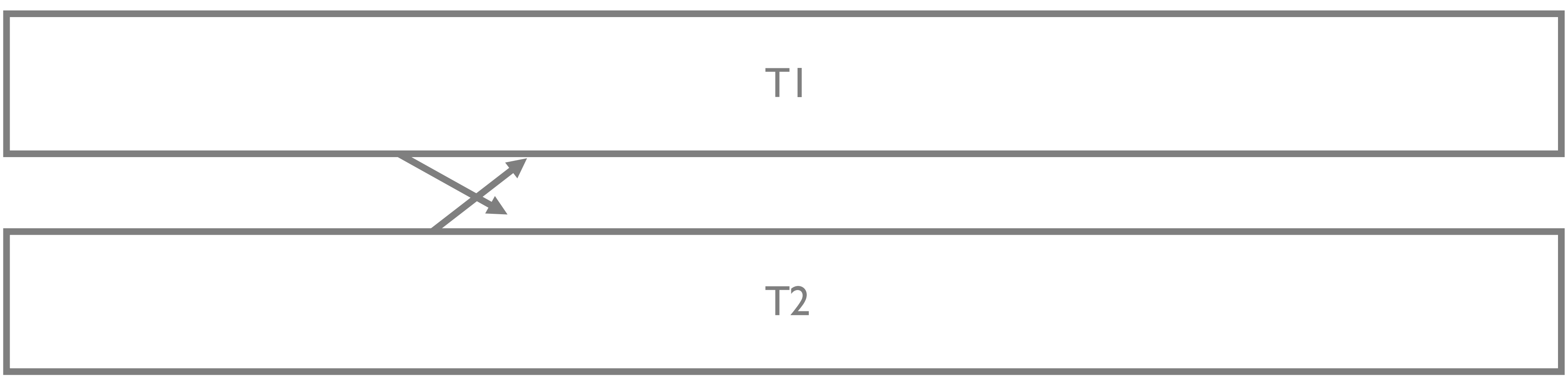
Serializable



Logical

	1	2	3	4
T1:	R(A)	W(A)	R(B)	W(B)
	5	6	7	8
T2:	R(A)	W(A)	R(B)	W(B)

Not Serializable



Commits/Aborts Complicate Things

So far, focused on schedule equivalence assuming that all transactions will commit.

But some transactions may abort and want to undo the changes.

Fine, but what about COMMITing?

T1   R(A)   W(A)   R(B) ABORT

T2   R(A) COMMIT

Not recoverable

Promised T2 everything is OK. IT WAS A LIE.

T1   R(A) W(B)   W(A)   ABORT

T2   R(A) W(A)

Cascading Rollback.

T2 read uncommitted data → T1's abort undos T1's ops & T2's

Lock-based Concurrency Control

Must get **S**hared(read) or e**X**clusive(write) lock BEFORE op

If other xact has lock, can get if lock table says so

YES

		T1	
	Allowed?	S	X
T2	S	Y	N
	X	N	N

Can this schedule happen?

T1	R(A)	W(A)			R(B)	ABORT
T2			R(A)	COMMIT		

Lock-based Concurrency Control

Two-phase locking (2PL)

Growing phase: acquire locks

Shrinking phase: release locks

shrink here

T1	R(A) W(B) W(A)			ABORT
T2			R(A) W(A)	

Uh Oh, same problem

Lock-based Concurrency Control

Strict two-phase locking (Strict 2PL)

- Growing phase: acquire locks
- Shrinking phase: release locks
- Hold onto locks until commit/abort

Why? Which problem does it prevent?

T1	R(A) W(B)	W(A)		ABORT
T2			R(A) W(A)	

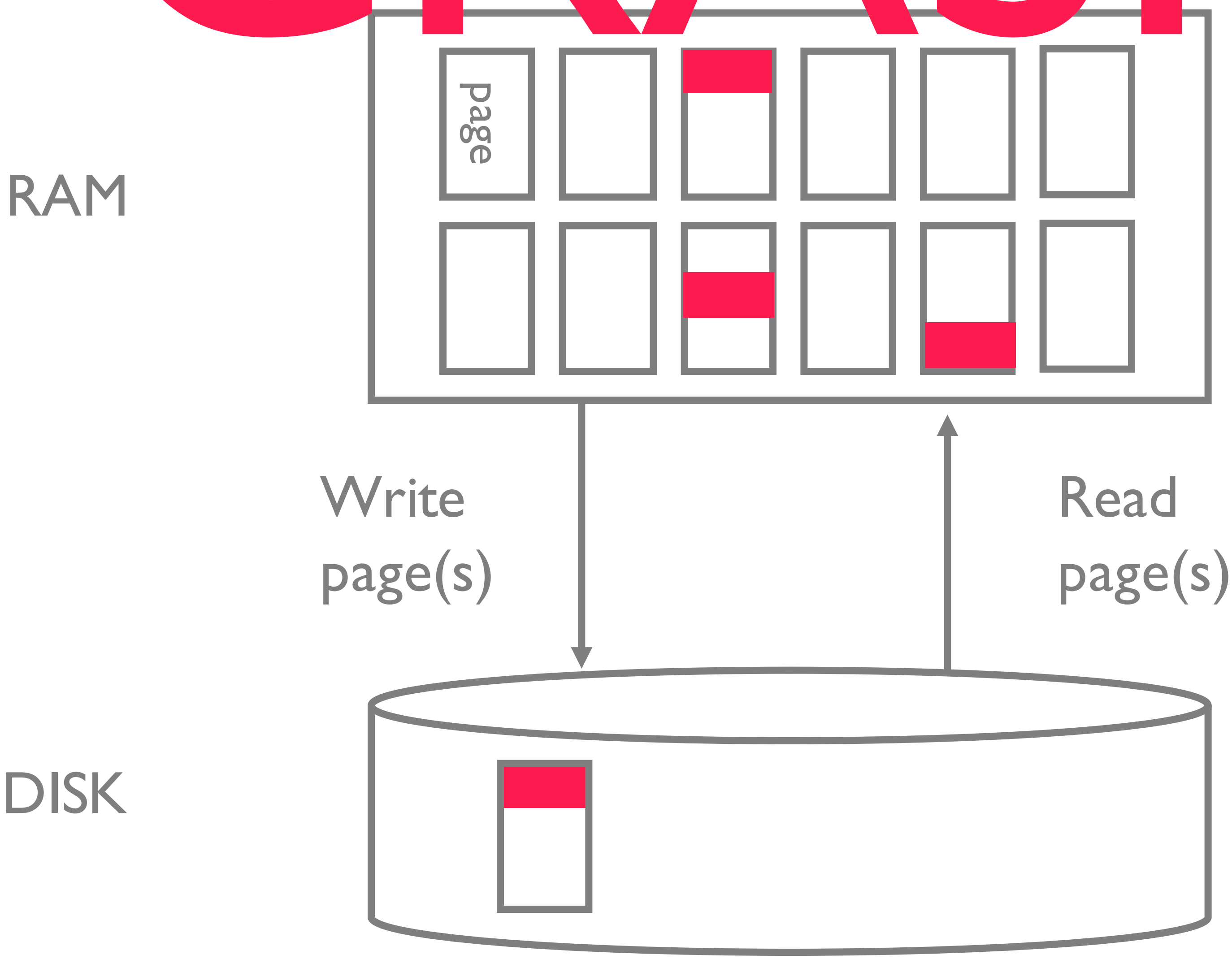
Guarantees serializable schedules! Avoids cascading rollbacks!

Review

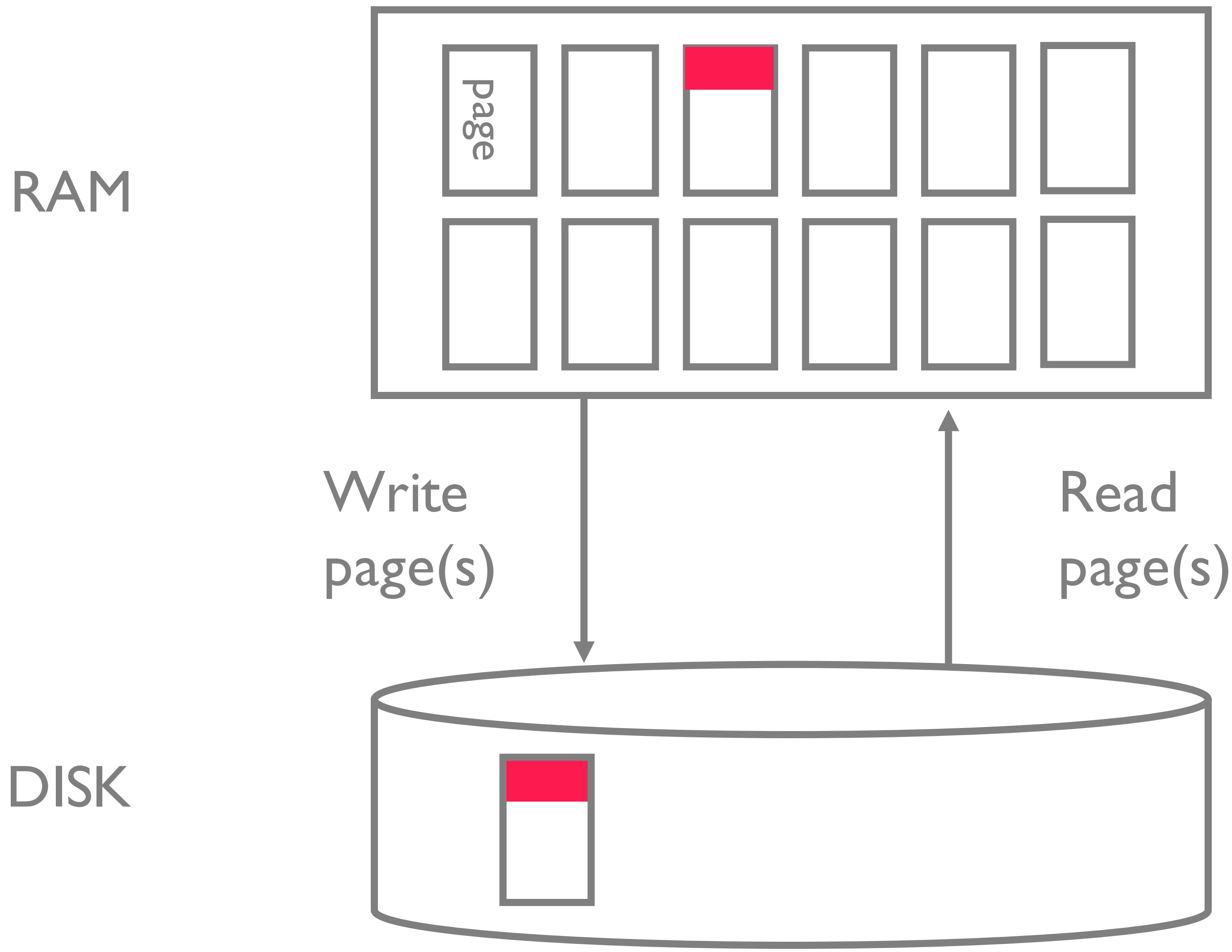
- Issues
  - TR: dirty reads
  - RW: unrepeatable reads
  - WW: lost writes
- Schedules
  - Equivalence
  - Serial
  - Serializable
- Serializability
  - Conflict serializability
  - how to detect
- Conflict Serializable Issues
  - Not recoverable
  - Cascading Rollback
- Strict 2 phase locking

Normal Execution

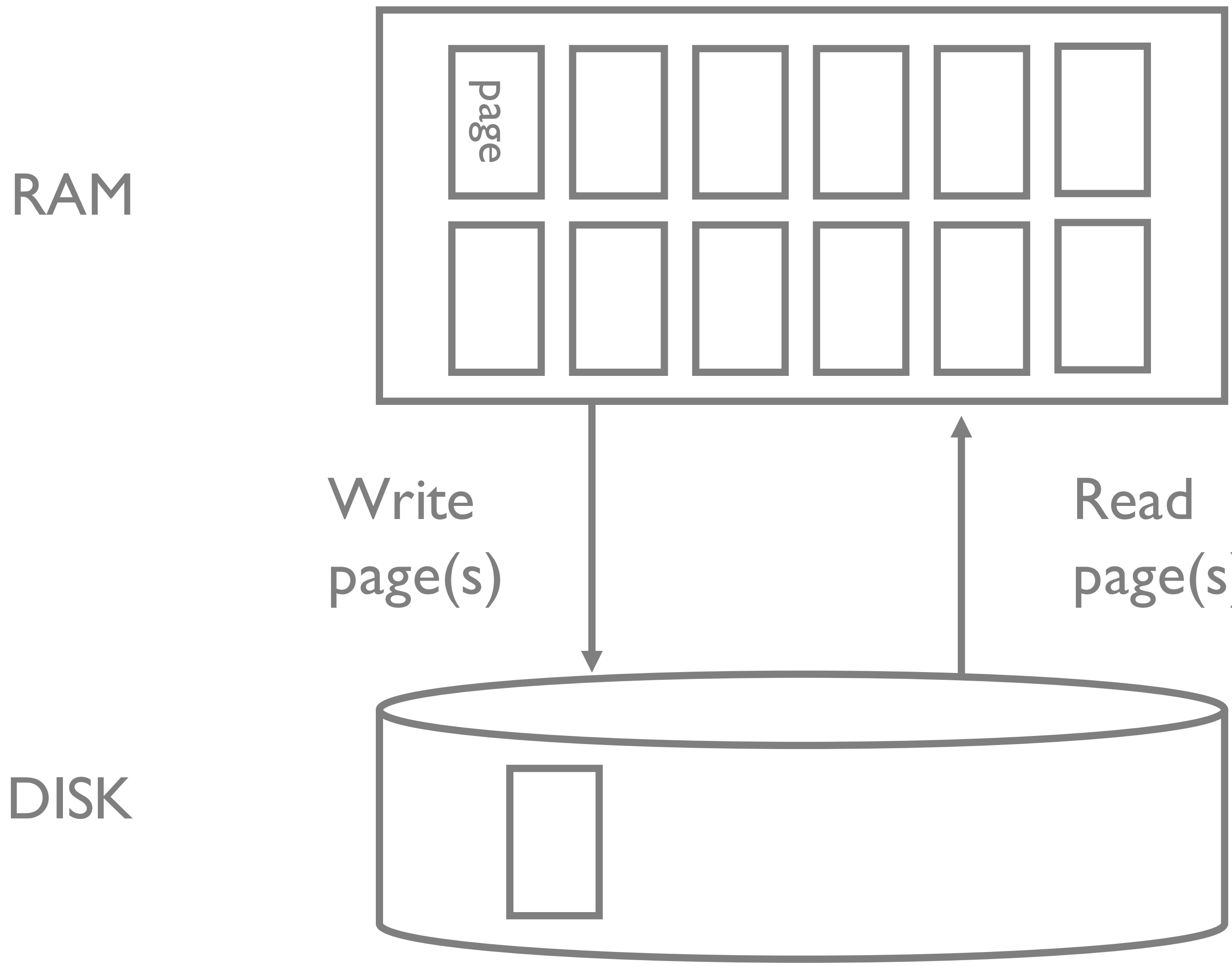
CRASH



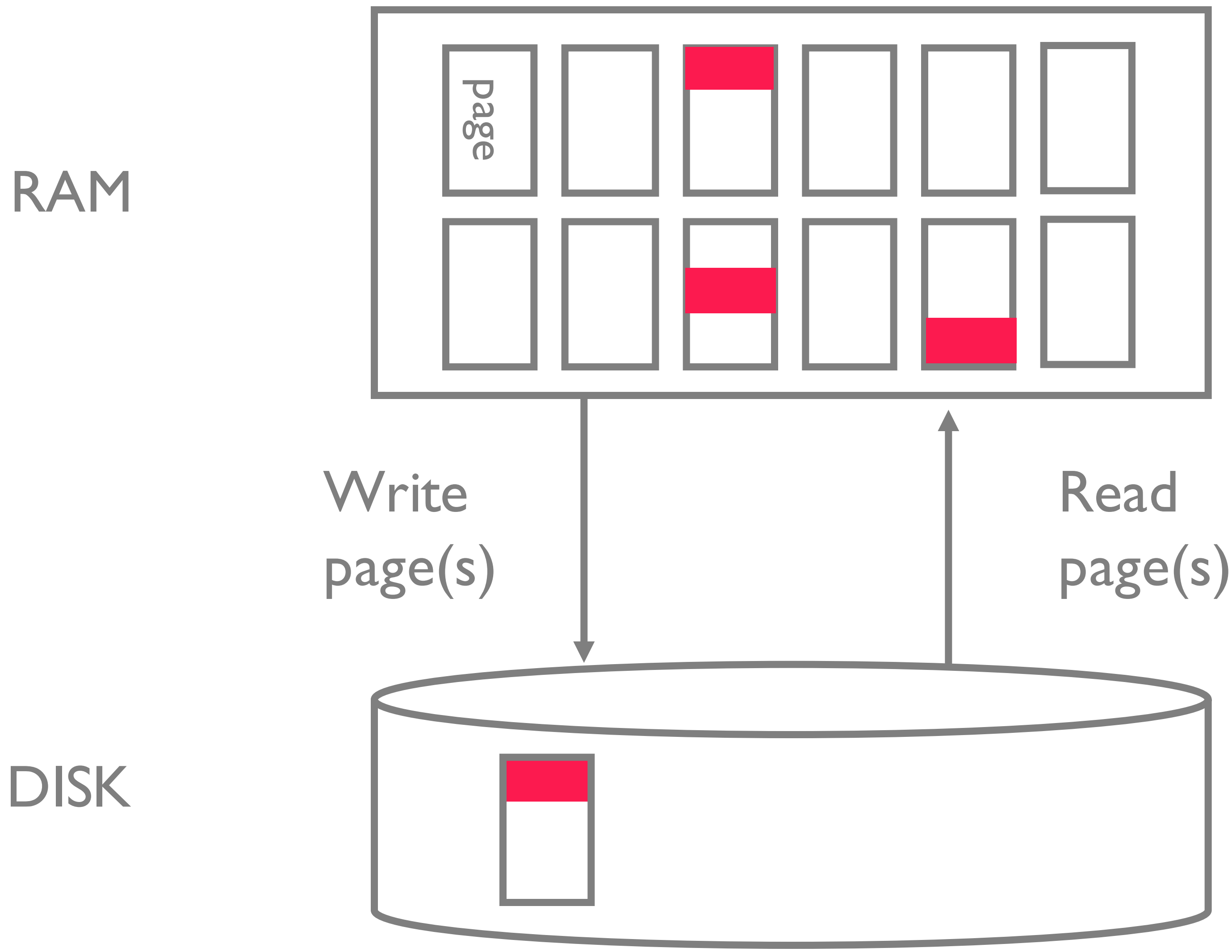
After a Crash



If DB did not say “OK, committed”



If T1 Committed and DB said "OK"



Recovery

Two properties: Atomicity, Durability

Assumption in class

- Disk is safe. Memory is not.
- Running strict-2PL

Need to account for

- when pages are modified
- when pages are flushed to disk

There's no _perfect_ recovery, just trade-offs

Recovery

Deal with 2 cases

When could uncommitted ops appear after crash?

wrote modified pages before commit

If T2 commits, what could make it not durable?

didn't write all changed pages to disk

Aborts and Undos

If Tx aborts, must undo all its actions

- Ty that read Tx's writes must be aborted (cascading abort)
- Strict 2PL avoids cascading aborts

Use a log to know what actions to undo

1. A = 1
2. B = 5
3. C = 10
4. BEGIN T5
5. A = 10
6. B = B + A
7. C = B – 2
8. ABORT
9. undo 7
10. undo 6

...

Aborts and Undos

If Tx aborts, must undo all its actions

- Ty that read Tx's writes must be aborted (cascading abort)
- Strict 2PL avoids cascading aborts

Use a log to know what actions to undo

On crash, abort all non-committed xacts

1. A = 1
2. B = 5
3. C = 10
4. BEGIN T5
5. A = 10
6. B = B + A
7. CRASH

Logs

Log is the *ground truth*

Log records

- writes: old & new value
- commit/abort actions
- xact id & xact's previous log record

Persist log records (write to disk) *before* data pages persisted

Is this enough?

Durability

Baseline scenario

- T1 writes to A in memory
- log record of write written to disk
- start writing page with A to disk…
- T1 commits

Durability

OK scenario

T1 writes to A in memory

log record of write written to disk

start writing page with A to disk…

crash

T1 commits

Durability

OK scenario

- T1 writes to A in memory
- log record of write written to disk
- *crash*
- start writing page with A to disk…
- T1 commits

Durability

Bad scenario

- T1 writes to A in memory
- T1 commits
- log record of write is written to disk
- start writing page with A to disk…
- *crash*

Can undo help us?

Need to redo T1, otherwise no durability!

Durability

Worse scenario

- T1 writes to A in memory
- T1 commits
- *crash*
- log record of write is written to disk
- start writing page with A to disk…

Can undo help us?

Can't redo T1, no durability! Shareholders mad

Logs

Log is the *ground truth*

Log records

- writes: old & new value
- commit/abort actions
- xact id & xact's previous log record

Write ahead logging (WAL)

1. Persist log records (write to disk) *before* data pages persisted
2. Persist all log records *before* commit
3. Log is *ordered*, if record flushed, all previous records must be flushed

(1) guarantees UNDO info

(2) guarantees REDO info

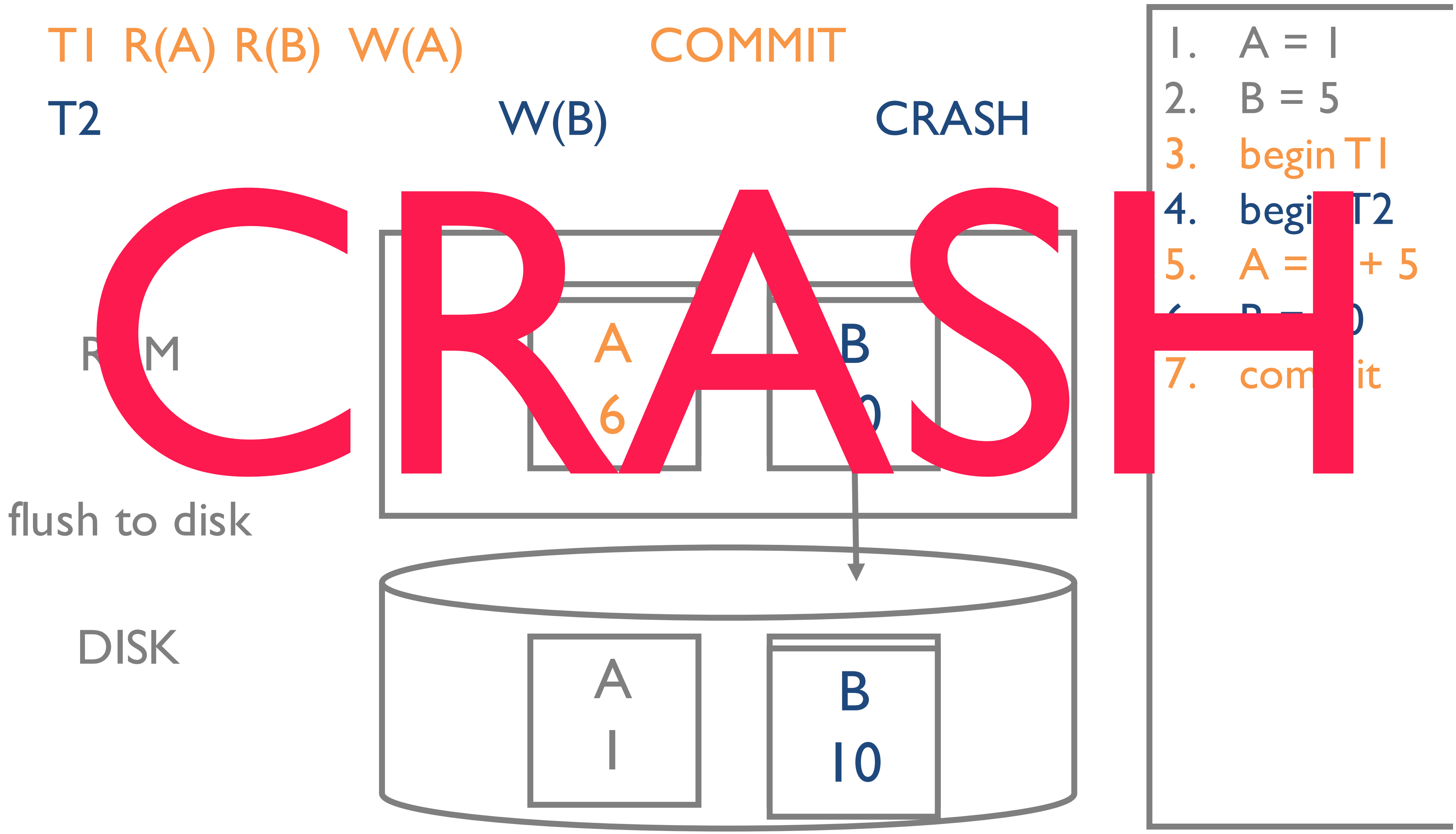
Aries Recovery Algorithm

3 phases

- Analyze the log to find status of all xacts
  - Committed or in flight?
- Redo xacts that were committed
  - Now at the same state at the point of the crash
- Undo partial (in flight) xacts

Recovery is *extremely* tricky and *must be correct*

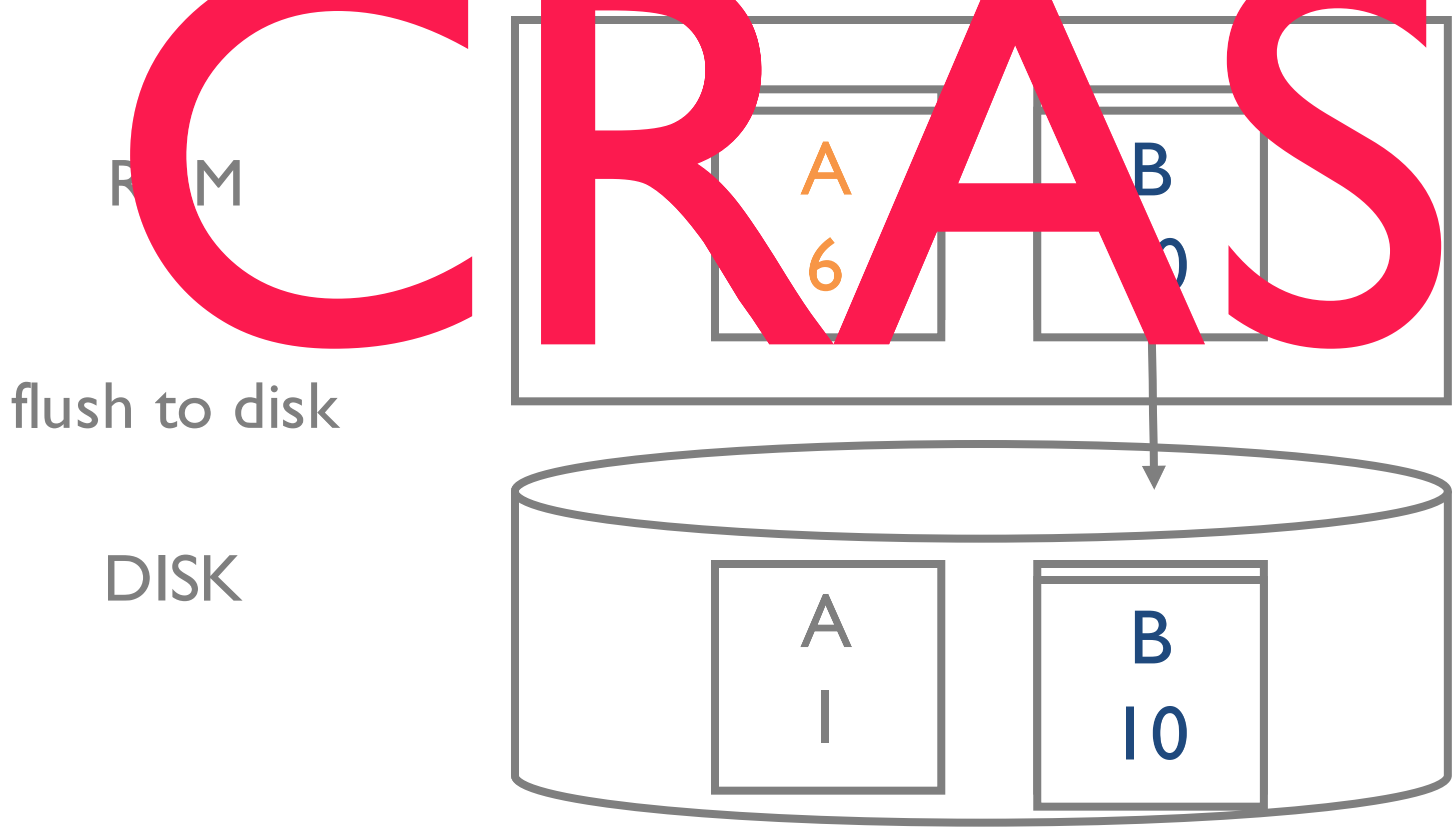
Aries


T1 R(A) R(B) W(A) COMMIT
T2 W(B) CRASH
CRASH
A
6
B
flush to disk
DISK
A
1
B
10
1. A = 1
2. B = 5
3. begin T1

Aries: alternative flushing order

T1 R(A) R(B) W(A) COMMIT

T2 W(B) CRASH



CRASH

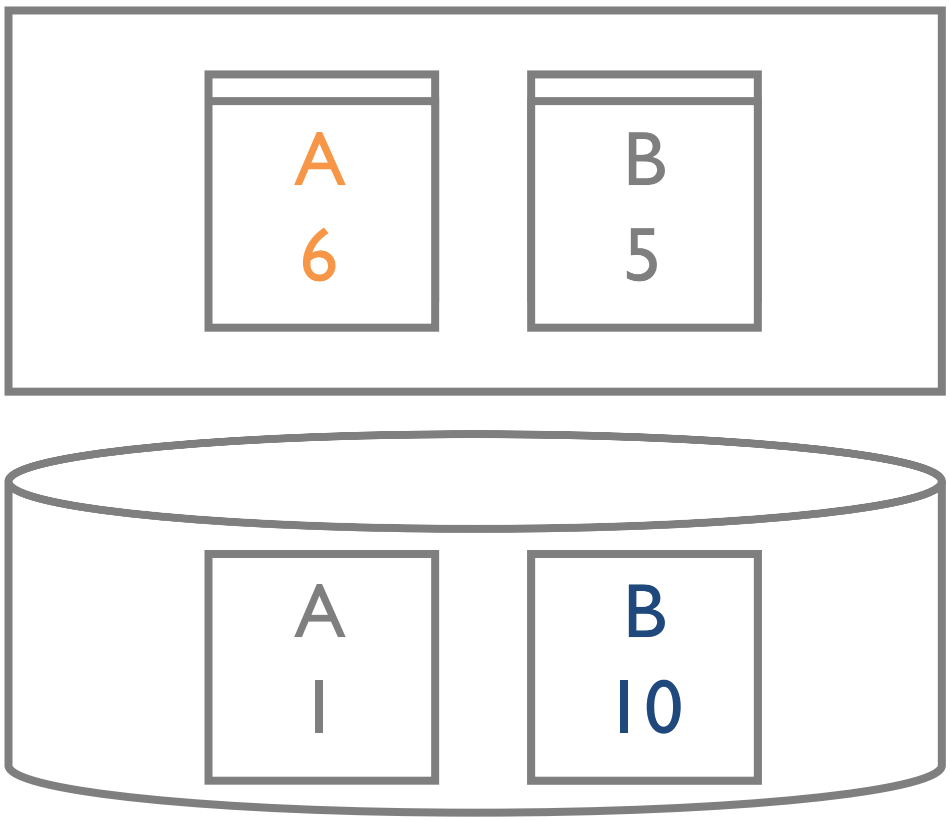
1. A = 1
2. B = 5
3. begin T1
4. begi T2
5. A = + 5
6. B =
7. com it T1

Aborts and Undos

T1 R(A) R(B) W(A) COMMIT

T2 W(B) CRASH

RAM



DISK

1. A = 1
2. B = 5
3. begin T1
4. begin T2
5. A = 1 + 5
6. B = 10
7. commit T1
8. redo op5
9. undo op6

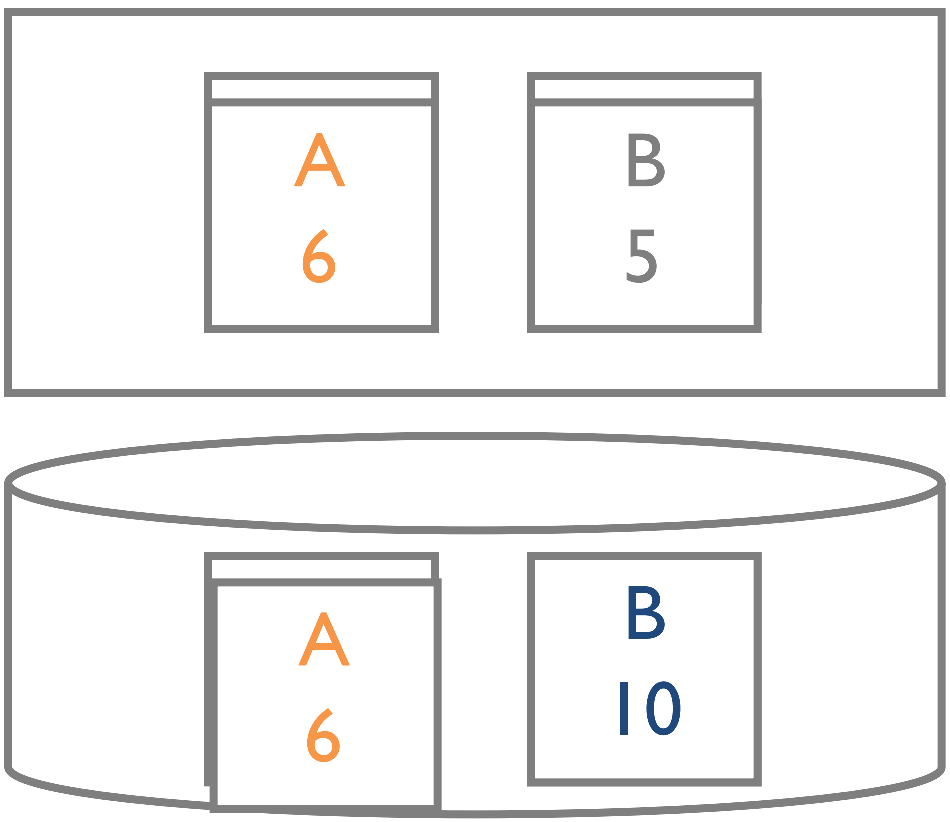
Aborts and Undos

T1 R(A) R(B) W(A) COMMIT

T2 W(B) CRASH

RAM

DISK



1. A = 1
2. B = 5
3. begin T1
4. begin T2
5. A = 1 + 5
6. B = 10
7. commit T1
8. redo op5
9. undo op6

Summary

Recovery depends on what failures are tolerable

Buffer pool can write RAM pages to disk any time

Recover to the moment of the crash, then undo all non-committed operations

WAL protocol

Recovery Manager ensures durability and atomicity via redo and undo

You should know

What transactions/schedules/serializable are

Can identify conflict serializable schedules

Can identify schedule anomalies

Can identify strict 2PL executions

Understand WAL and what it provides

Given an executed schedule, and a log file, run the proper sequence of undo/redos