L10
Transactions, Concurrency, Recovery

Eugene Wu

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*

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?

X Y are records

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*

1为数据库操作提供了一个从失败中恢复到正常状态的方法
同时提供了数据库即使在异常状态下仍能保持一致性的方法。
2当多个应用程序在并发访问数据库时，可以在这些应用程序之间提供一个隔离方法，
以防止彼此的操作互相干扰。

当一个事务被提交给了DBMS（数据库管理系统），则DBMS需要确保该事务中的所有操作都成功完成且其结果被永久保存在数据库中，如果事务中有的操作没有成功完成，则事务中的所有操作都需要被回滚，回到事务执行前的状态（要么全执行，要么全都不执行）;同时，该事务对数据库或者其他事务的执行无影响，所有的事务都好像在独立的运行。

但在现实情况下，失败的风险很高。在一个数据库事务的执行过程中，有可能会遇上事务操作失败、数据库系统/操作系统失败，甚至是存储介质失败等情况。这便需要DBMS对一个执行失败的事务执行恢复操作，将其数据库状态恢复到一致状态（数据的一致性得到保证的状态）。为了实现将数据库状态恢复到一致状态的功能，DBMS通常需要维护事务日志以追踪事务中所有影响数据库数据的操作。

原子性（**Atomicity**）：事务作为一个整体被执行，包含在其中的对数据库的操作要么全部被执行，要么都不执行。
一致性（**Consistency**）：事务应确保数据库的状态从一个一致状态转变为另一个一致状态。一致状态的含义是数据库中的数据应满足完整性约束。
隔离性（**Isolation**）：多个事务并发执行时，一个事务的执行不应影响其他事务的执行。
持久性（**Durability**）：一个事务一旦提交，他对数据库的修改应该永久保存在数据库中。

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 done!you have to tell
T2: begin A=1.5*A A=1.5*B END DB or it will keep waiting

DBMS's logical view read write

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

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. **constraints**

xacts move from valid database to valid database

Isolation:

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

transactions'

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) **violating properties**

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)	
	1 2		2	
T2:		r(A)		w(A) r(B) w(B)
		2		3

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

We can ensure consistency of the database under concurrent execution by making sure that any schedule that is executed has the same effect as a schedule that could have occurred without any concurrent execution. That is, the schedule should, in some sense, be equivalent to a serial schedule. Such schedules are called serializable schedules.

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

We say that I and J conflict if they are operations by different transactions on the same data item, and at least one of these instructions is a write operation.

	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

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:

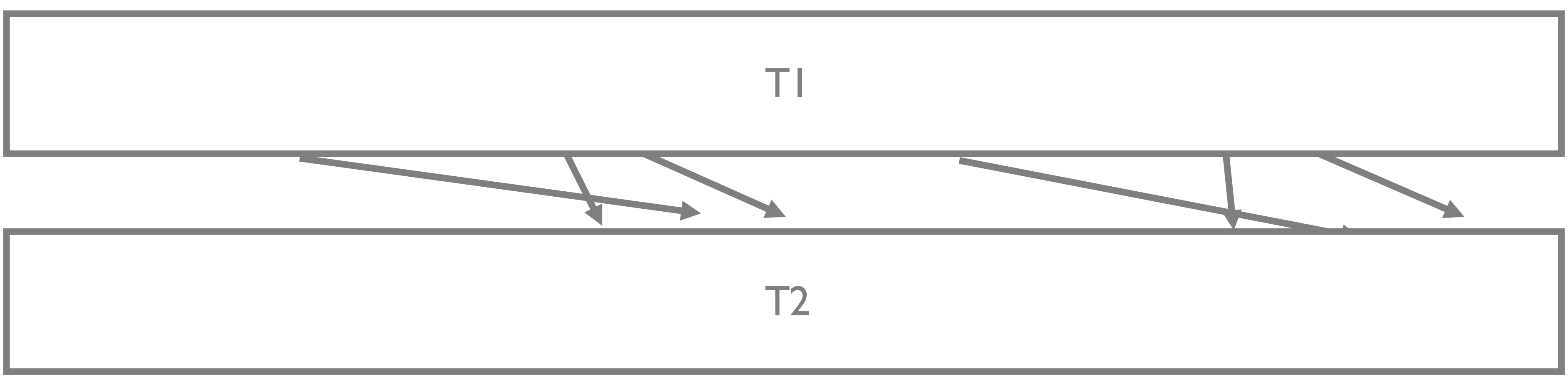
1. Ti read/write A before Tj writes A or
2. Ti writes some A before Tj reads A

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)

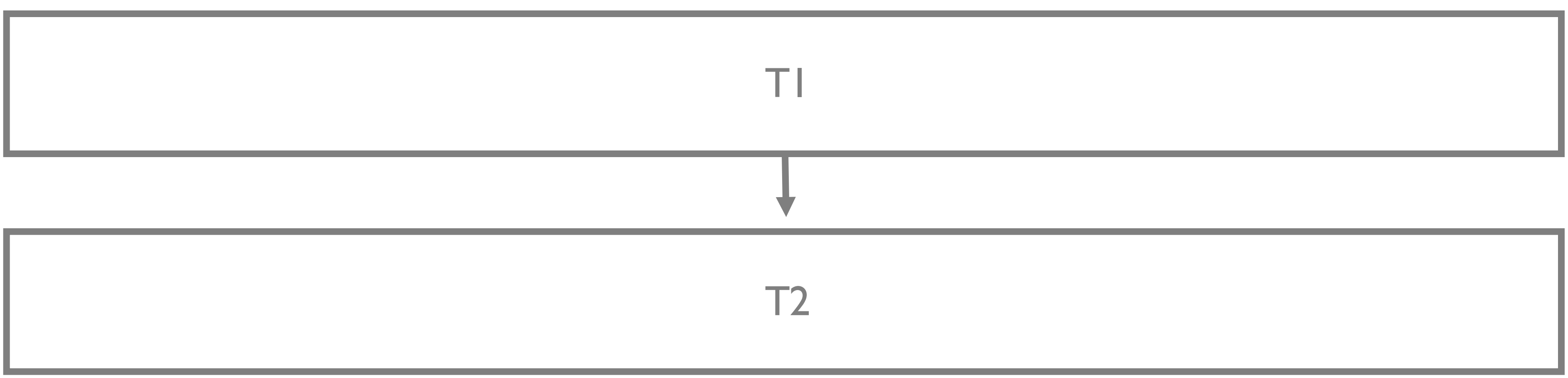
Serializable



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)

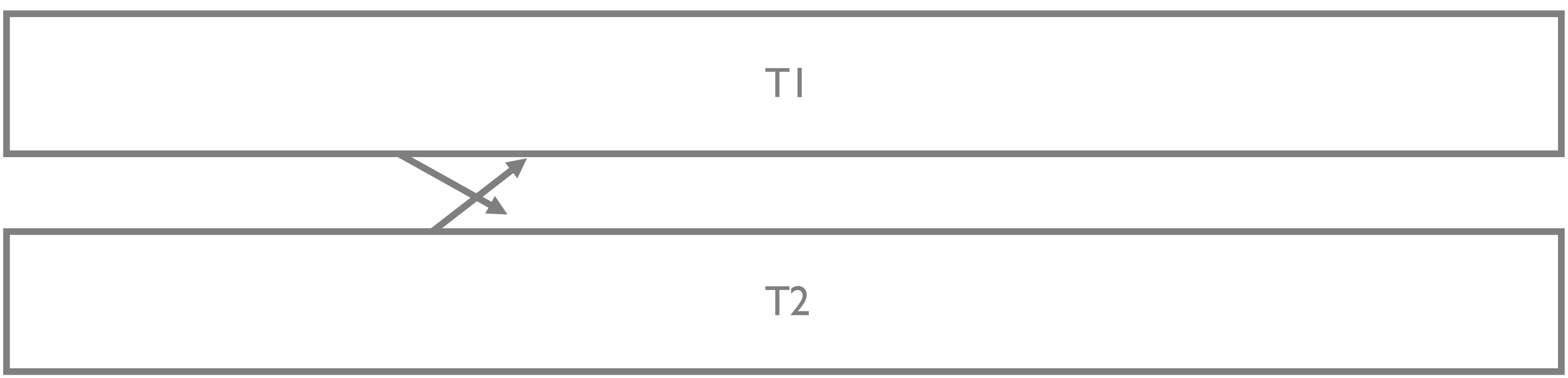
Serializable



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

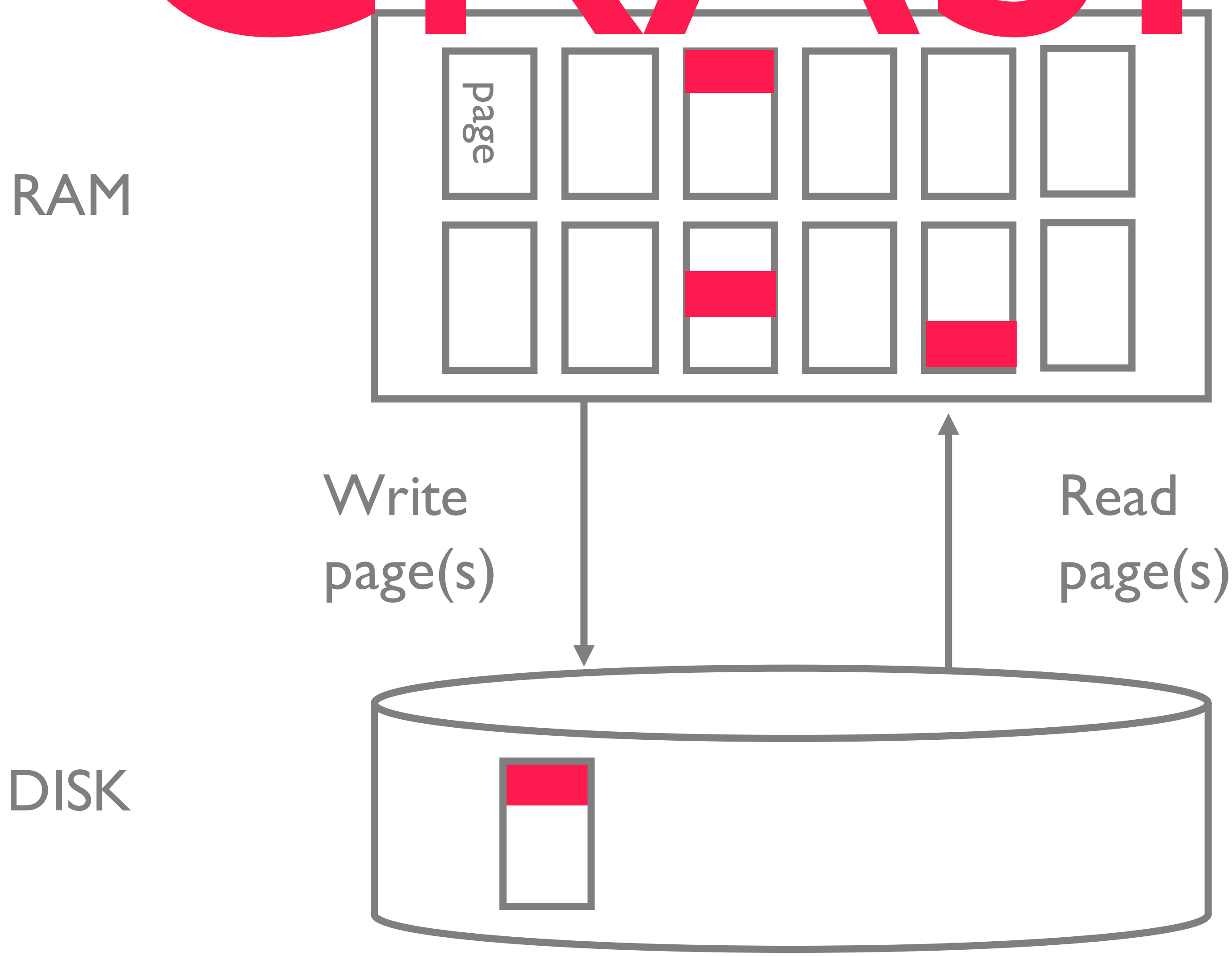
Conflict Serializable Issues

- Not recoverable
- Cascading Rollback

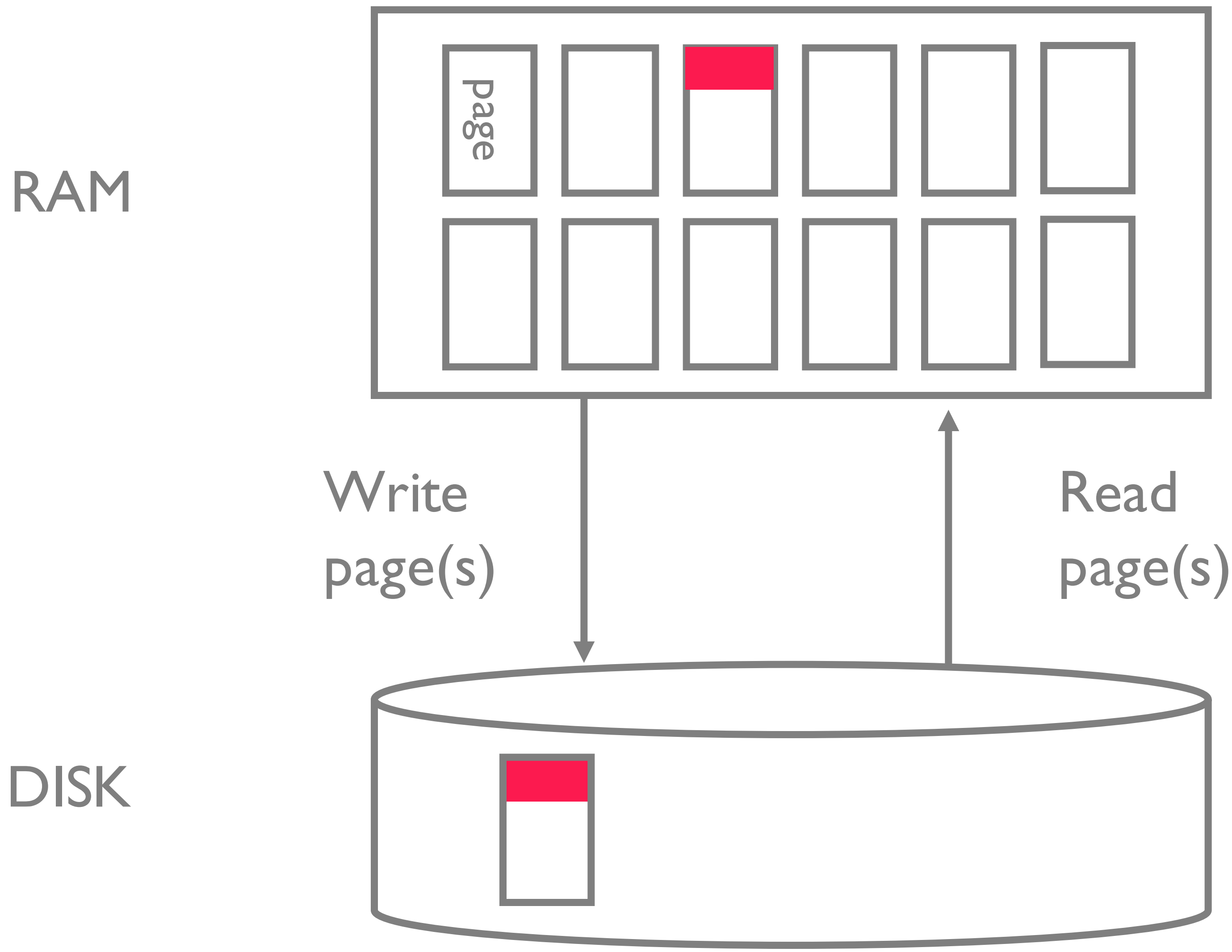
Strict 2 phase locking

Normal Execution

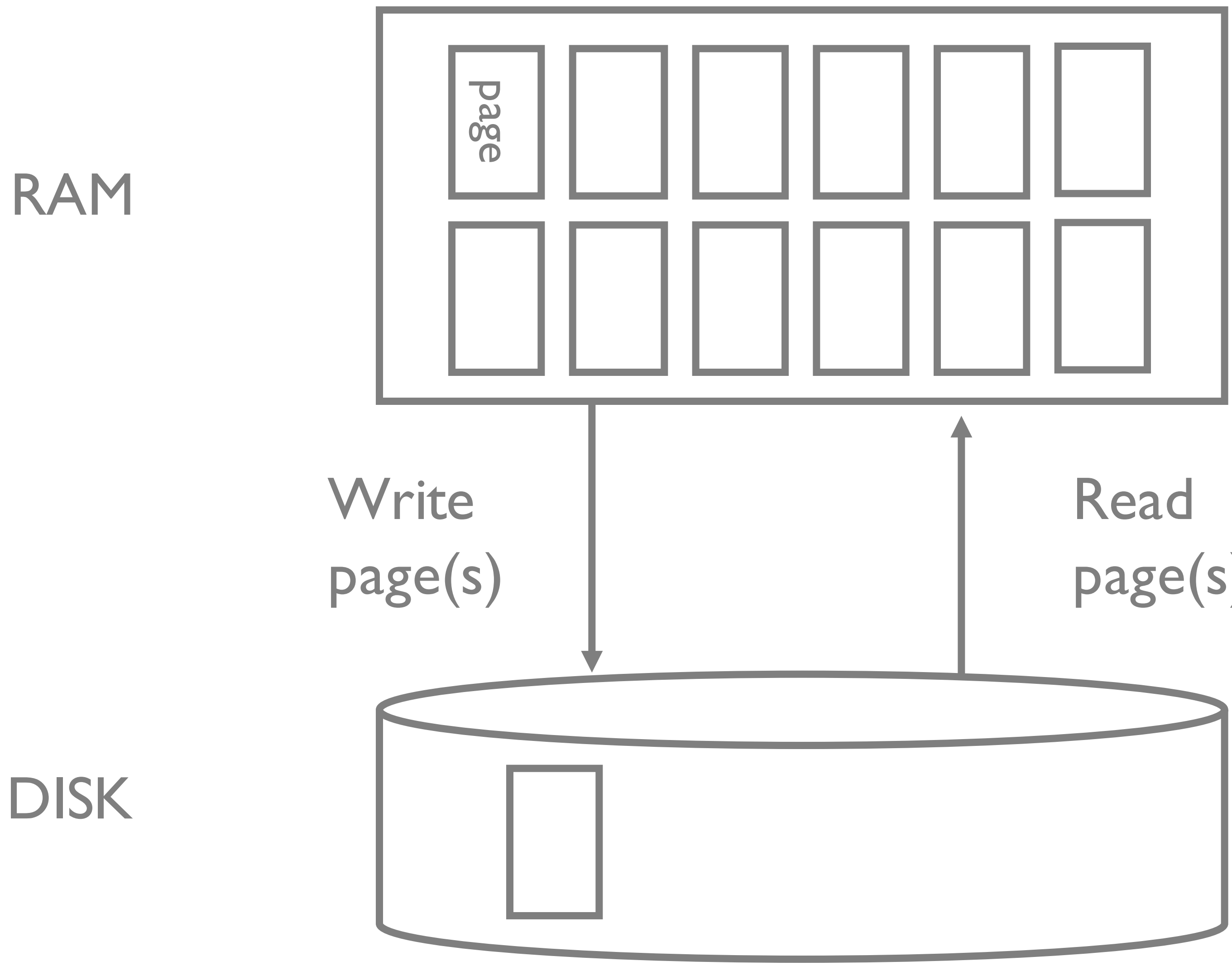
CRASH



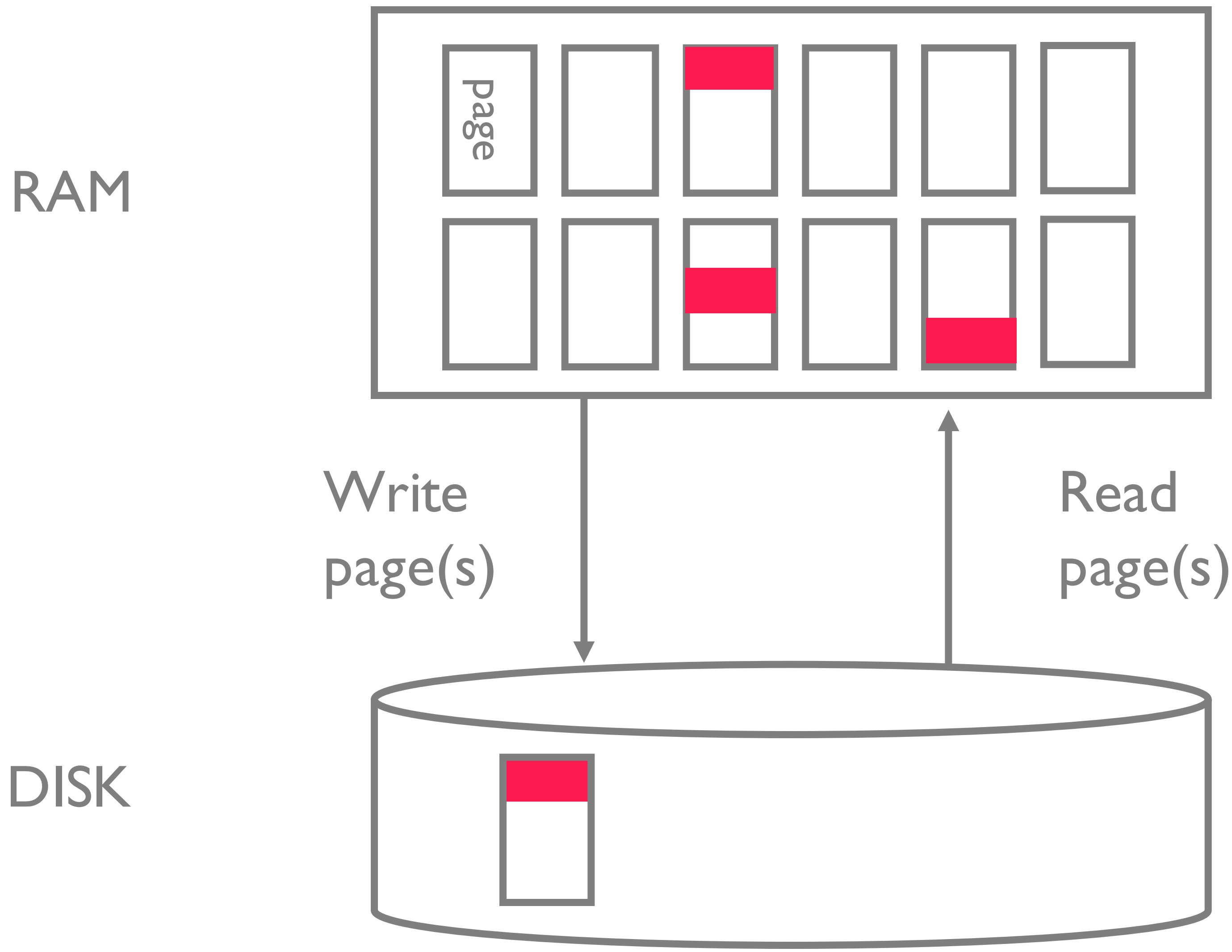
After a Crash



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

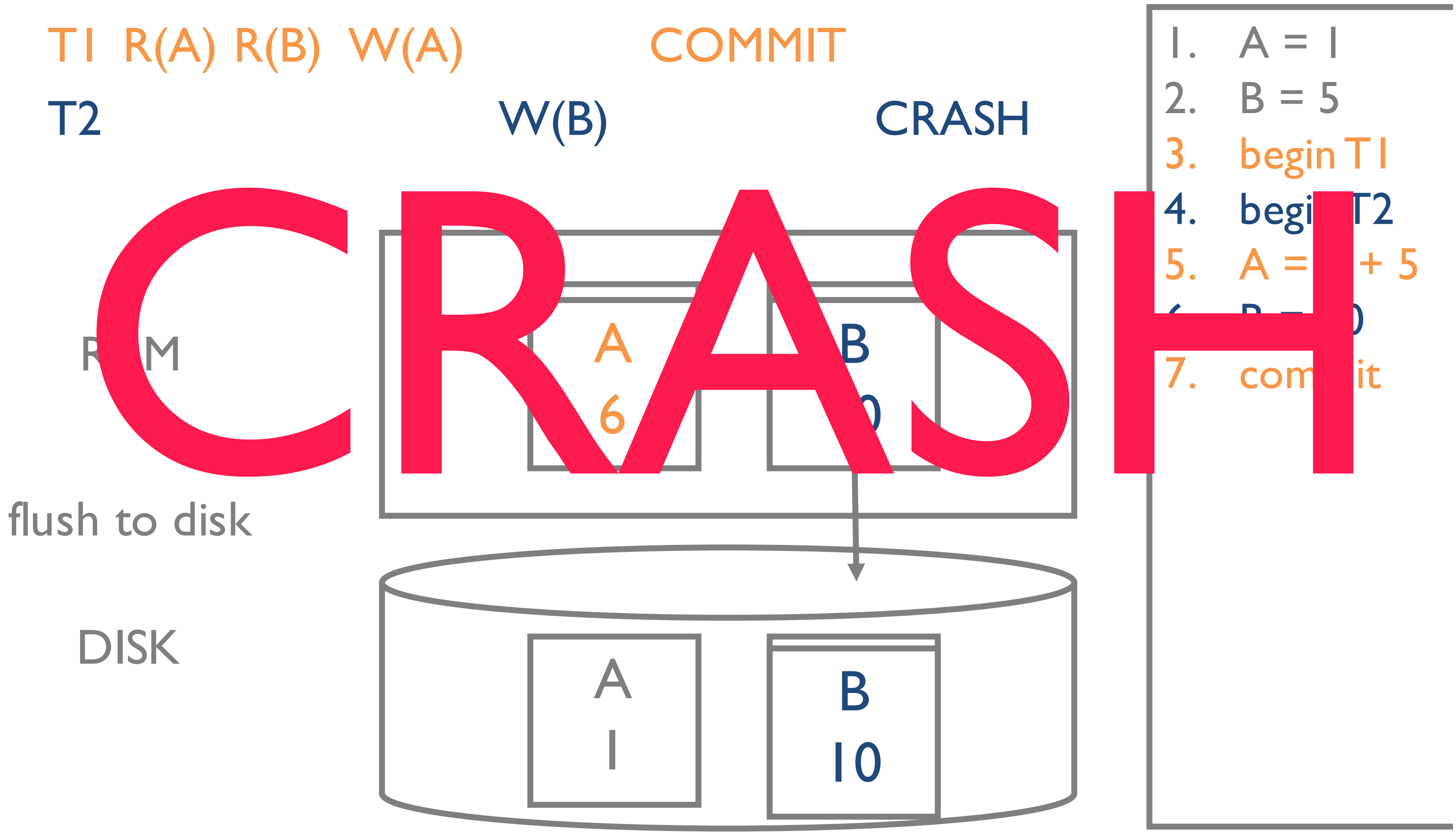
Aries Recovery Algorithm

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*

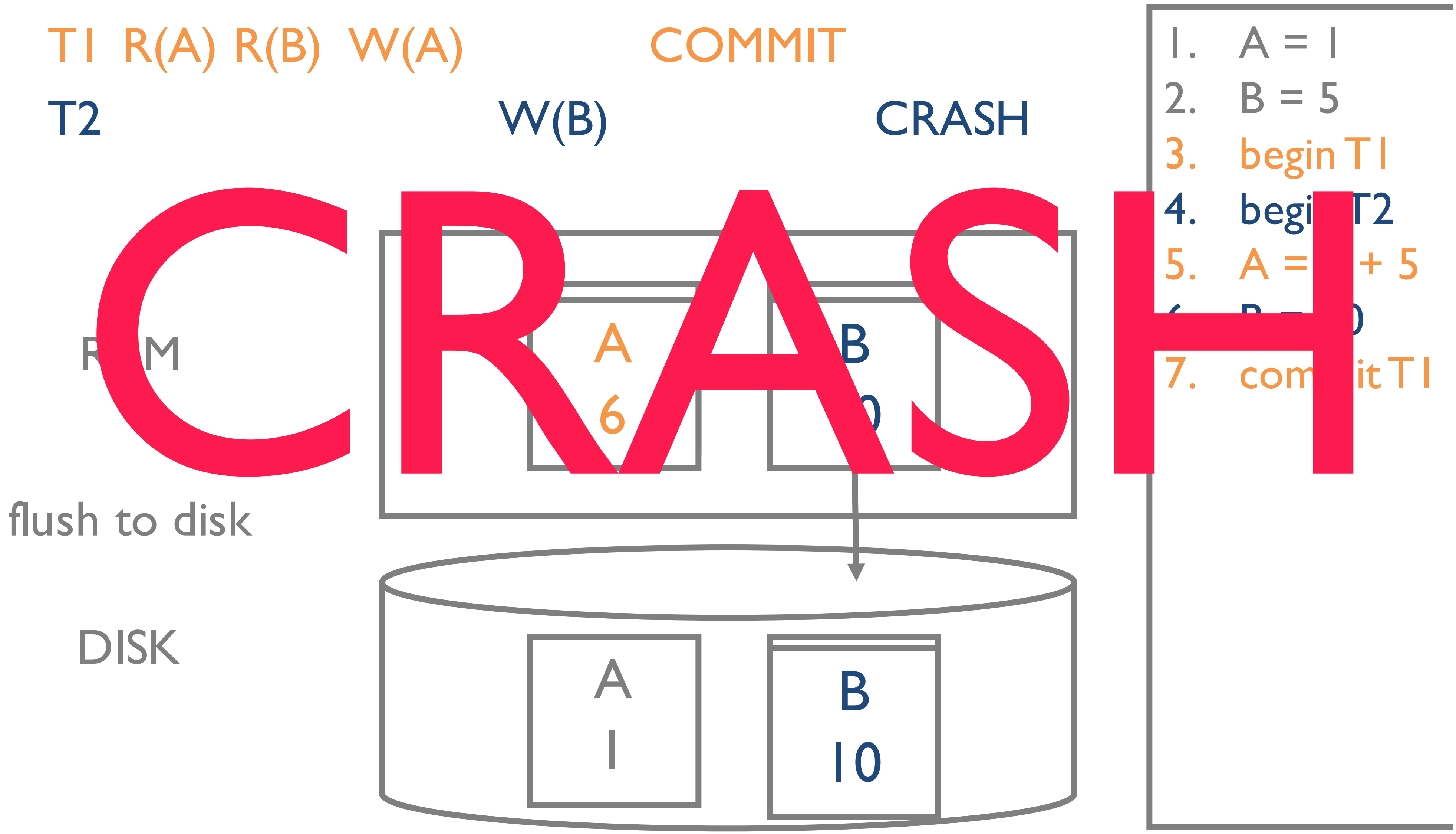
Aries


T1 R(A) R(B) W(A) COMMIT
T2 W(B) CRASH
CRASH
RAM
A
6
B
flush to disk
DISK
A
1
B
10
1. A = 1
2. B = 5
3. begin T1
4. begi T2
5. A = + 5
7. com it

Aries: alternative flushing order

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

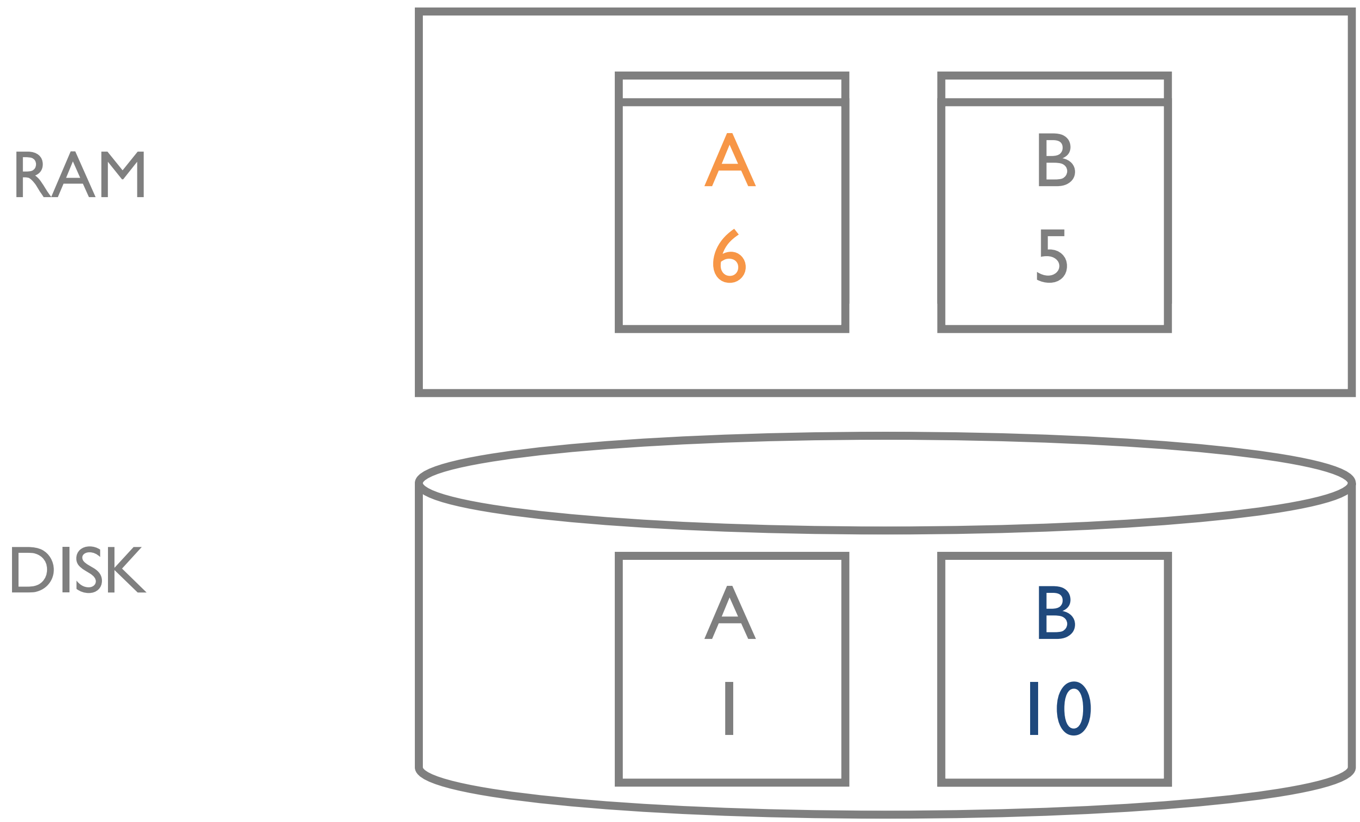
T2 W(B) CRASH



Aborts and Undos

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

T2 W(B) CRASH

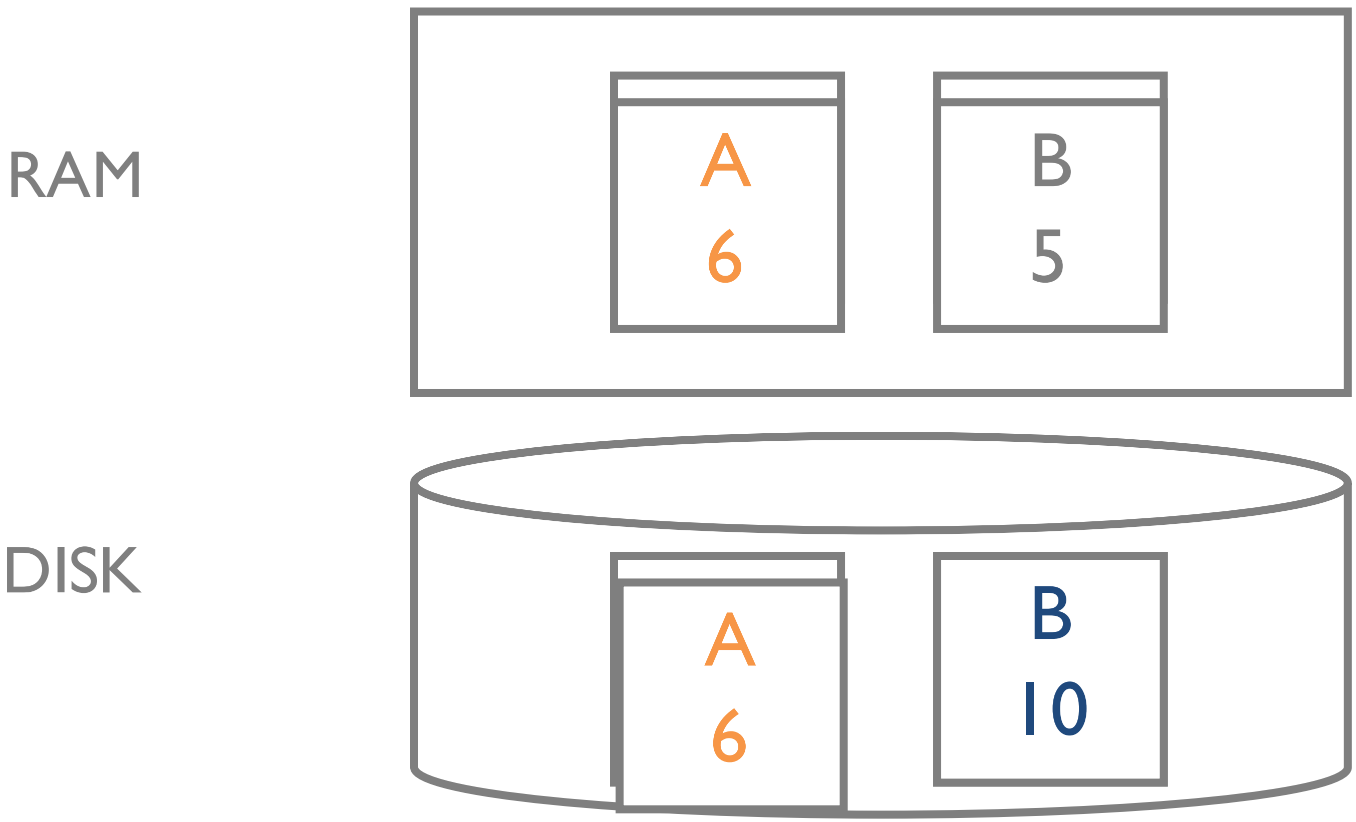


1. A = 1
2. B = 5
3. begin T1
4. begin T2
5. A = 1 + 5
6. B = 10
7. commit T1
8. redo op5
9. undo op6

Aborts and Undos

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

T2 W(B) CRASH



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