Administrivia

HW4 due today

Project 2 due 5/9, no late days.

Why? 5/9 is the most time we cane give you.
Grades due to registrar 5/13!

Exam 2: 5/13 10:10AM-12:40PM.

Same format as Exam 1

SQLite >

Analyzing iMessage with SQL

https://arctype.com/blog/search-imessage/

SQLite >

Analyzing iMessage with

message

ROWID	INTEGER
guid	TEXT
text	TEXT
replace	INTEGER
service_center	TEXT
handle_id	INTEGER
subject	TEXT
country	TEXT
attributedBody	BLOB
version	INTEGER
type	INTEGER
service	TEXT
account	TEXT
account_guid	TEXT
error	INTEGER
date	INTEGER
date_read	INTEGER
date_delivered	INTEGER
is_delivered	INTEGER
is_finished	INTEGER
is_emote	INTEGER
is_from_me	INTEGER
is_empty	INTEGER
is_delayed	INTEGER
is_auto_reply	INTEGER
is_prepared	INTEGER
is_read	INTEGER
is_system_message	INTEGER
is_sent	INTEGER
has_dd_results	INTEGER
is_service_message	INTEGER
is_forward	INTEGER
was_downgraded	INTEGER
is_archive	INTEGER
cache_has_attachme…	INTEGER
cache_roomnames	TEXT
was_data_detected	INTEGER
was_deduplicated	INTEGER
is_audio_message	INTEGER
is_played	INTEGER
date_played	INTEGER
item_type	INTEGER
other_handle	INTEGER
group_title	TEXT
group_action_type	INTEGER
share_status	INTEGER
share_direction	INTEGER
is_expirable	INTEGER
expire_state	INTEGER
message_action_type	INTEGER
message_source	INTEGER
associated_message…	STRING
balloon_bundle_id	STRING
payload_data	BLOB
associated_message…	INTEGER
expressive_send_st…	STRING
associated_message…	INTEGER
associated_message…	INTEGER
time_expressive_se…	INTEGER
message_summary_in…	BLOB
ck_sync_state	INTEGER
ck_record_id	TEXT
ck_record_change_t…	TEXT

handle

ROWID	INTEGER
id	TEXT
country	TEXT
service	TEXT
uncanonicalized_id	TEXT
person_centric_id	TEXT

chat_message_join

chat_id	INTEGER
message_id	INTEGER
message_date	INTEGER

chat_handle_join

chat_id	INTEGER
handle_id	INTEGER

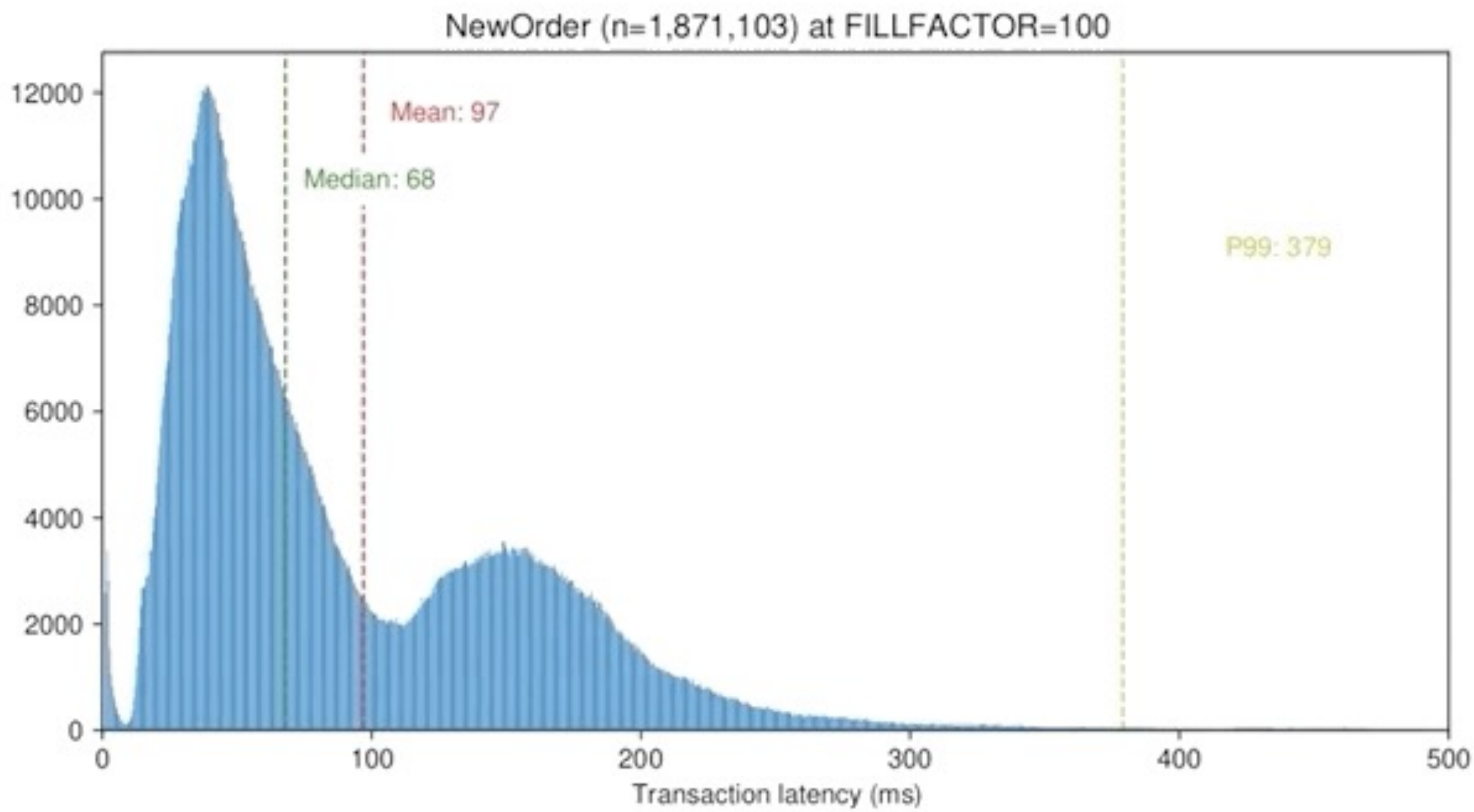
chat

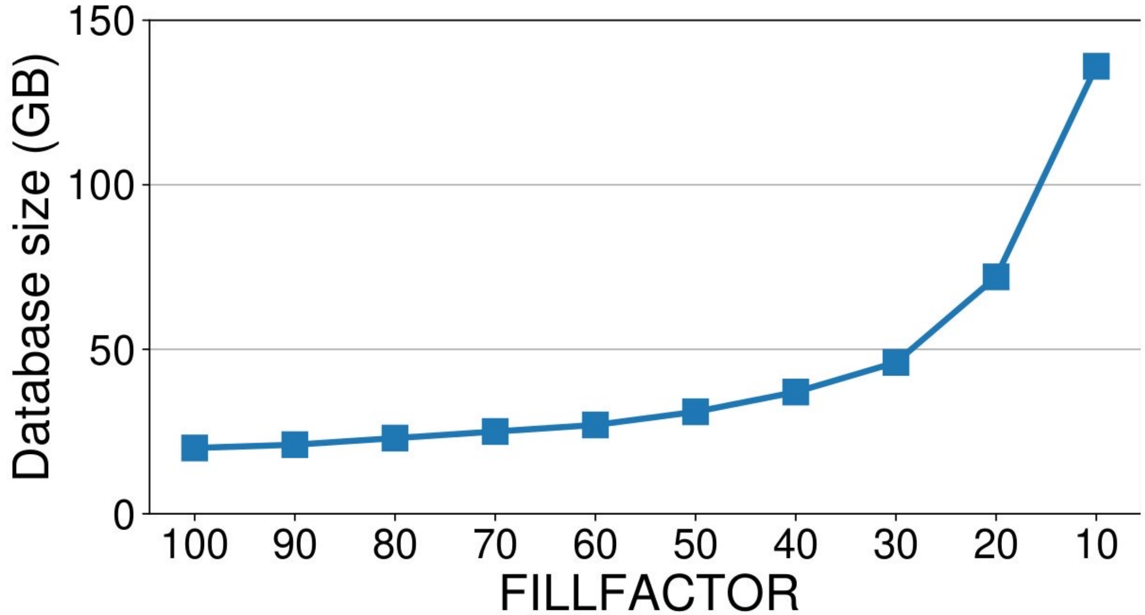
ROWID	INTEGER
guid	TEXT
style	INTEGER
state	INTEGER
account_id	TEXT
properties	BLOB
chat_identifier	TEXT
service_name	TEXT
room_name	TEXT
account_login	TEXT
is_archived	INTEGER
last_addressed_han…	TEXT
display_name	TEXT
group_id	TEXT
is_filtered	INTEGER
successful_query	INTEGER
engram_id	TEXT
server_change_token	TEXT
ck_sync_state	INTEGER
last_read_message_…	INTEGER
ck_record_system_p…	BLOB
original_group_id	TEXT
sr_server_change_t…	TEXT
sr_ck_sync_state	INTEGER
cloudkit_record_id	TEXT
sr_cloudkit_record…	TEXT
last_addressed_sim…	TEXT
is_blackholed	INTEGER
syndication_date	INTEGER
syndication_type	INTEGER

https://arctype.com/blog/search-imessage/

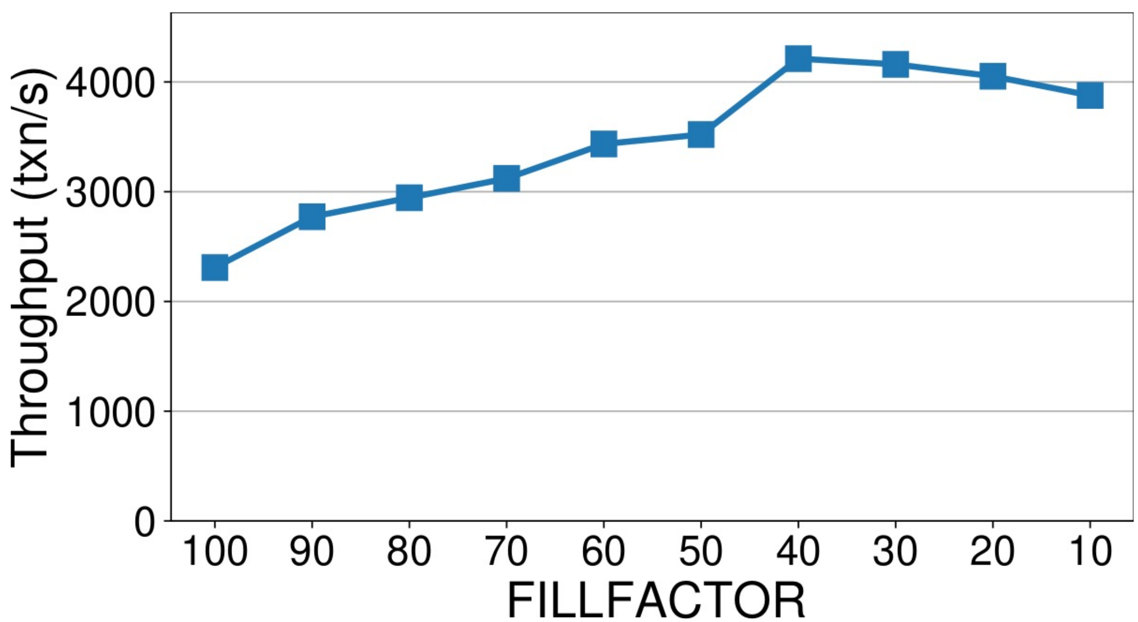
Matt Butrovich
@butro

We've been playing with @PostgreSQL's fillfactor for tables. This is a hard setting to get right because it depends on workload patterns. This graph shows TPC-C NewOrder latency as you change fillfactor on 5 tables. p99 gets tighter. Not sure of bimodal pattern at fillfactor=100.





150
100
50
0
Database size (GB)
100 90 80 70 60 50 40 30 20 10
FILLFACTOR



4000
3000
2000
1000
0
Throughput (txn/s)
100 90 80 70 60 50 40 30 20 10
FILLFACTOR

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*

```
User 1
x += y
a1 = read(x)
b1 = read(y)
store(a1 + b1)
```

```
User 2
x -= y
a2 = read(x)
b2 = read(y)
store(a2 – b2)
```

Good Execution Order

```
a1 = read(x)          // x=0
b1 = read(y)          // y=1
store(a1 + b1, x)     // 1→x
a2 = read(x)          // x=1
b2 = read(y)          // y=1
store(a2 – b2, x)     // 0→x
```

```
result:
x=0
```

```
User 1
x += y
a1 = read(x)
b1 = read(y)
store(a1 + b1)
```

```
User 2
x -= y
a2 = read(x)
b2 = read(y)
store(a2 – b2)
```

Bad Execution Order

```
a1 = read(x)          // x=0
a2 = read(x)          // x=0
b2 = read(y)          // y=1
store(a2 – b2, x)     // -1→x
b1 = read(y)          // y=1
store(a1 + b1, x)     // 1→x
```

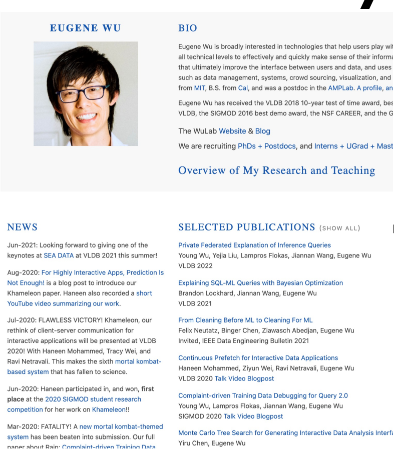
```
result:
x=1
```

Who… would ever do this?

Real $1B+ Companies…

Store extracted data in a file

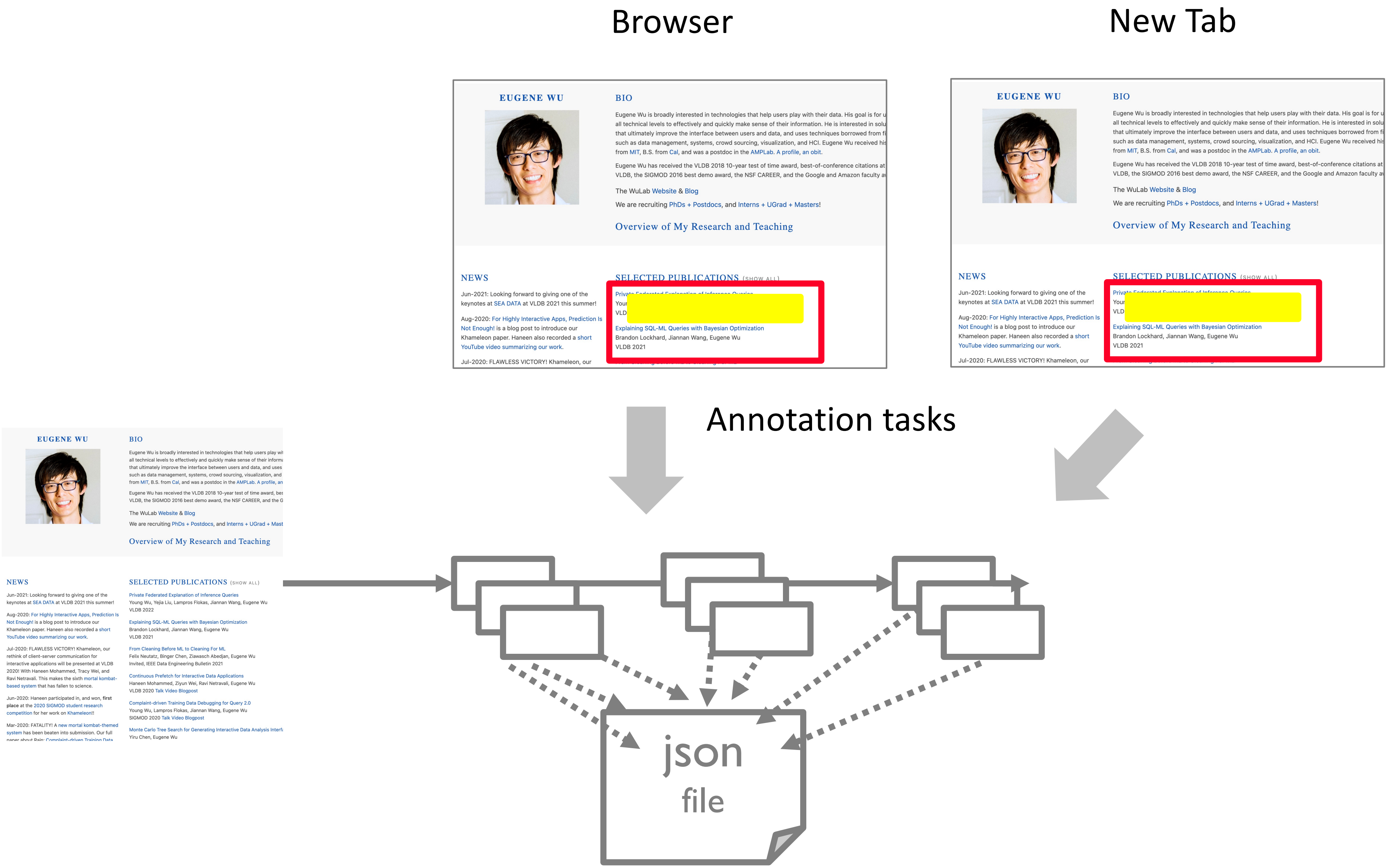
Every change → rewrite the file



Text extraction and transform tasks

```
[{
  obj: region
  box: 36,34,100,120
  text: “Private F..”
 }, { .. }, ..]
```

```
[{
  obj: authorlist
  box: 40,40,100,20
  text: “Eugene W..”
 }, { .. }, ..]
```


Browser
New Tab
Annotation tasks
json
file

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*

What does "sensible" mean?

Transactions = r/w over objects

Transaction: a sequence of actions

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

From app/user' point of view, the transaction (and its effects) are only "correct" once the DBMS has told the app/user that the transaction is COMMITed

Transactions = r/w over objects

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
- as if a xact runs instantaneously

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 (CC)

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 Does Correct Execution Mean?

Serializability

Regardless of the interleaving of operations, end result same as a serial ordering (no concurrency)

Schedule

One specific interleaving of the operations

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

How a Schedule Works

```
T1: A += 1
T2: A -= 1

Before T1 and T2, A is 0

   T1: R(A)      W(A,1) COMMIT
   T2:      R(A)               W(A,-1) COMMIT
State: A=0  A=0    A=1       A=1     A=-1      A=-1
           uncommitted committed uncommitted committed
```

How a Schedule Works

```
T1: A += 1
T2: A -= 1

Before T1 and T2, A is 0

   T1: R(A)       W(A)    COMMIT
   T2:       R(A)                  W(A)     COMMIT
State: A=0   A=0     A          A          A            A
               uncommitted committed uncommitted    committed
```

The value that is written doesn't matter

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 (not equivalent to any serial schedule)

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.

each xact finishes (commits or aborts) before next xact runs

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

R/W Operations Depend On Access Paths

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

If 1000 tuples in accounts, how many tuples are read:

If no indexes?

If index on bal?

If hash index on id?

if B+-tree index on id?

R/W Operations Depend On Access Paths

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

If 1000 tuples in accounts, how many tuples are 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

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

If we track our writes, maybe can prevent anomalies

Conflict Serializability

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(A)	W(A)
R(A)	NO	YES
W(A)	YES	YES
R(B)	NO	NO
W(B)	NO	NO

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

	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)

Conflict Serializable

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

Nodes are transactions

Edge Ti → Tj if:

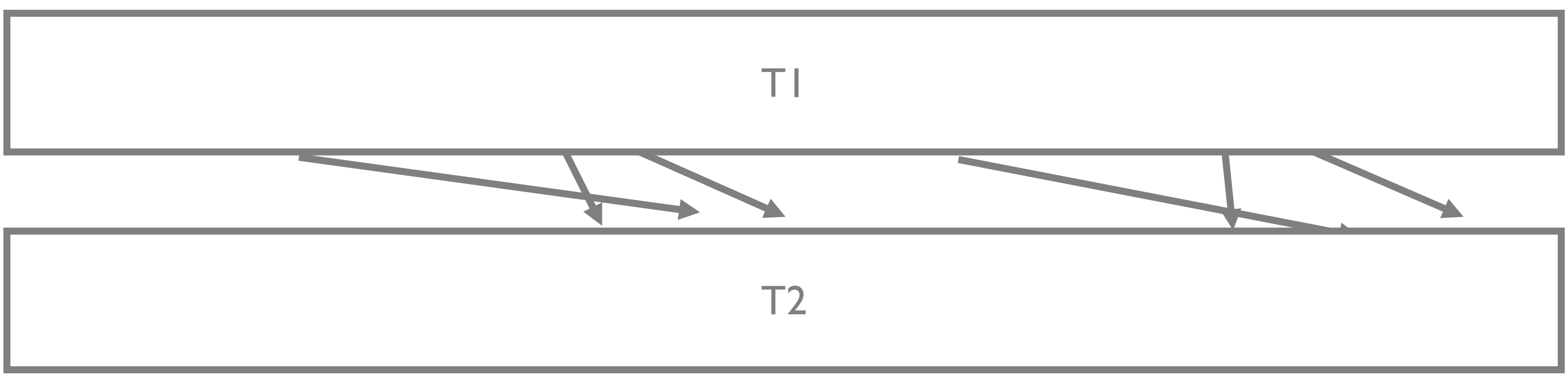
1. Ti read/write A before Tj writes A or
2. Ti writes some A before Tj reads A

Acyclic graph (no cycles) = 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)

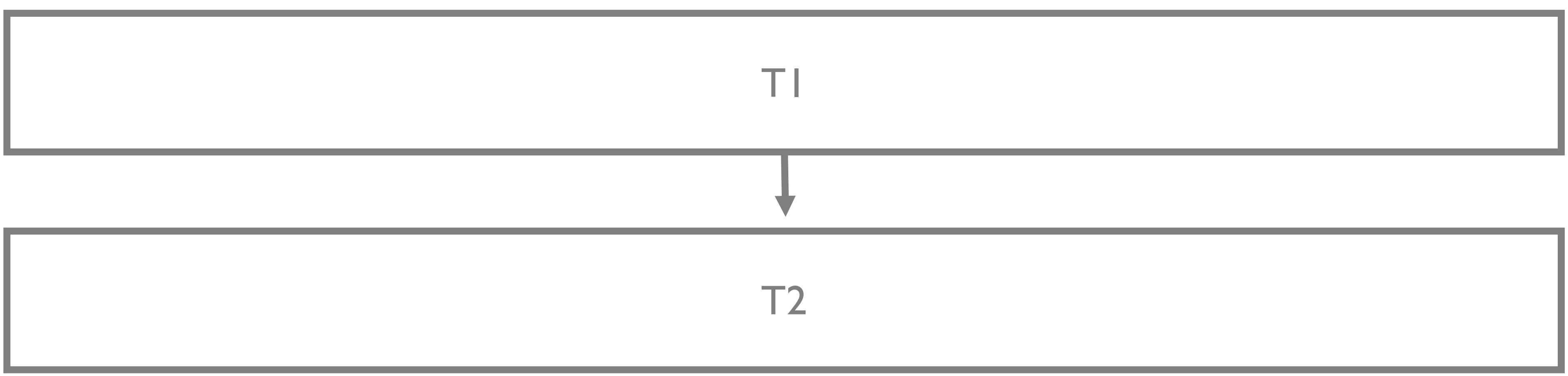
Conflict Serializable



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)

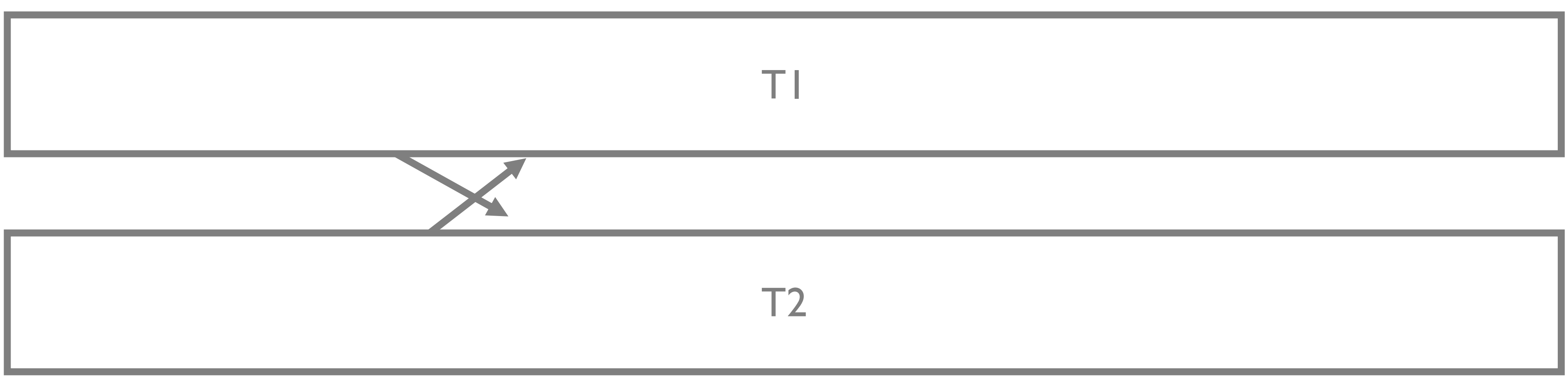
Conflict Serializable



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)

Not Conflict 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.

These are OK right?

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

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

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

Everything so far has been definitions.

Want a *procedure* that will guarantee serializable schedules

Naïve approach:

- Lock database when starting xact
- Unlock database when xact ends

Want something similar, but by locking objects (like records)

Lock-based Concurrency Control

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

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

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

Can this schedule happen?

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

YES

didn't discuss when to release locks

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

- WR: dirty reads
- RW: unrepeatable reads
- WW: lost writes

Schedules

- Equivalence
- Serial
- Serializable

Serializability

- Conflict serializability
- how to detect

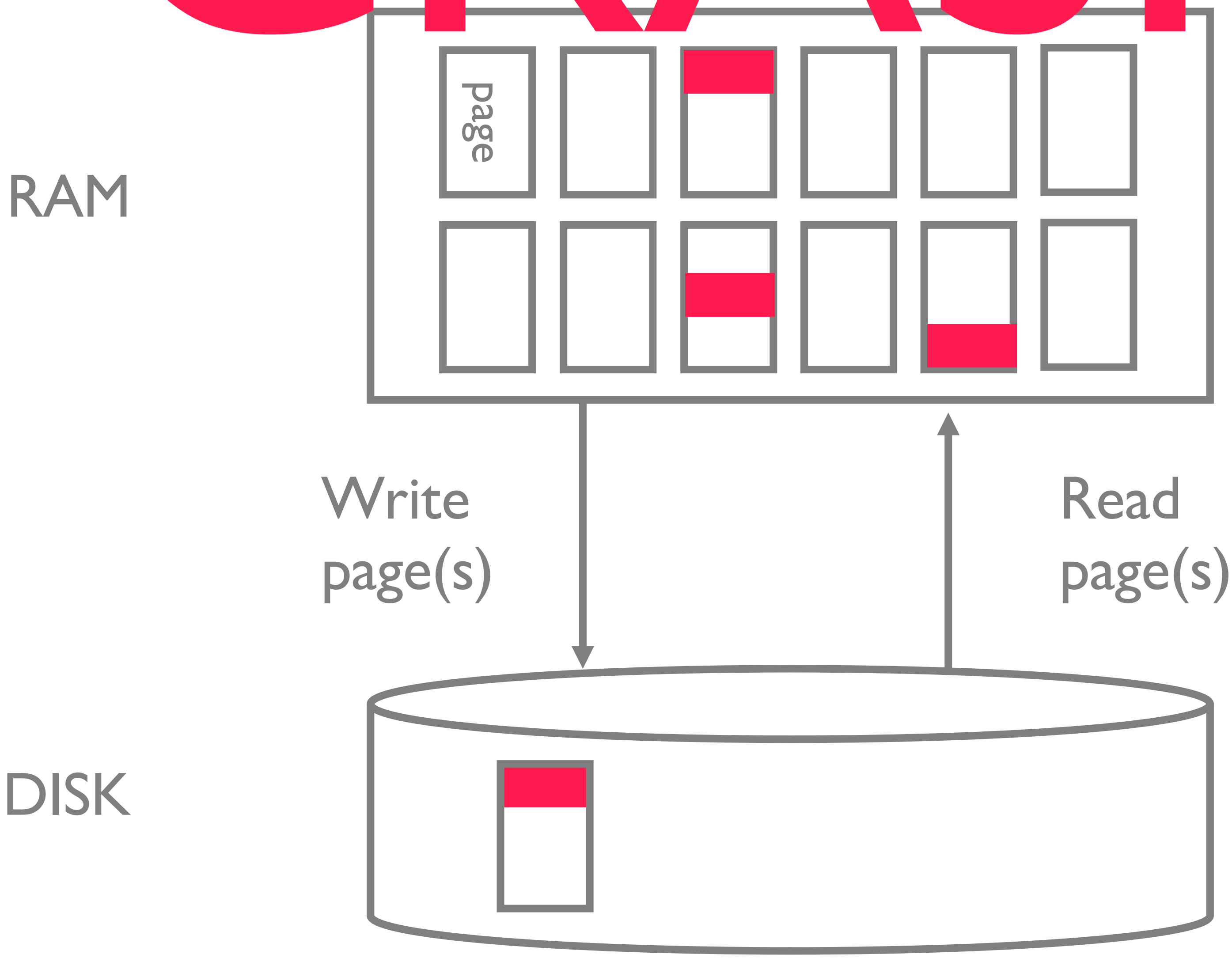
Conflict Serializable Issues

- Not recoverable
- Cascading Rollback

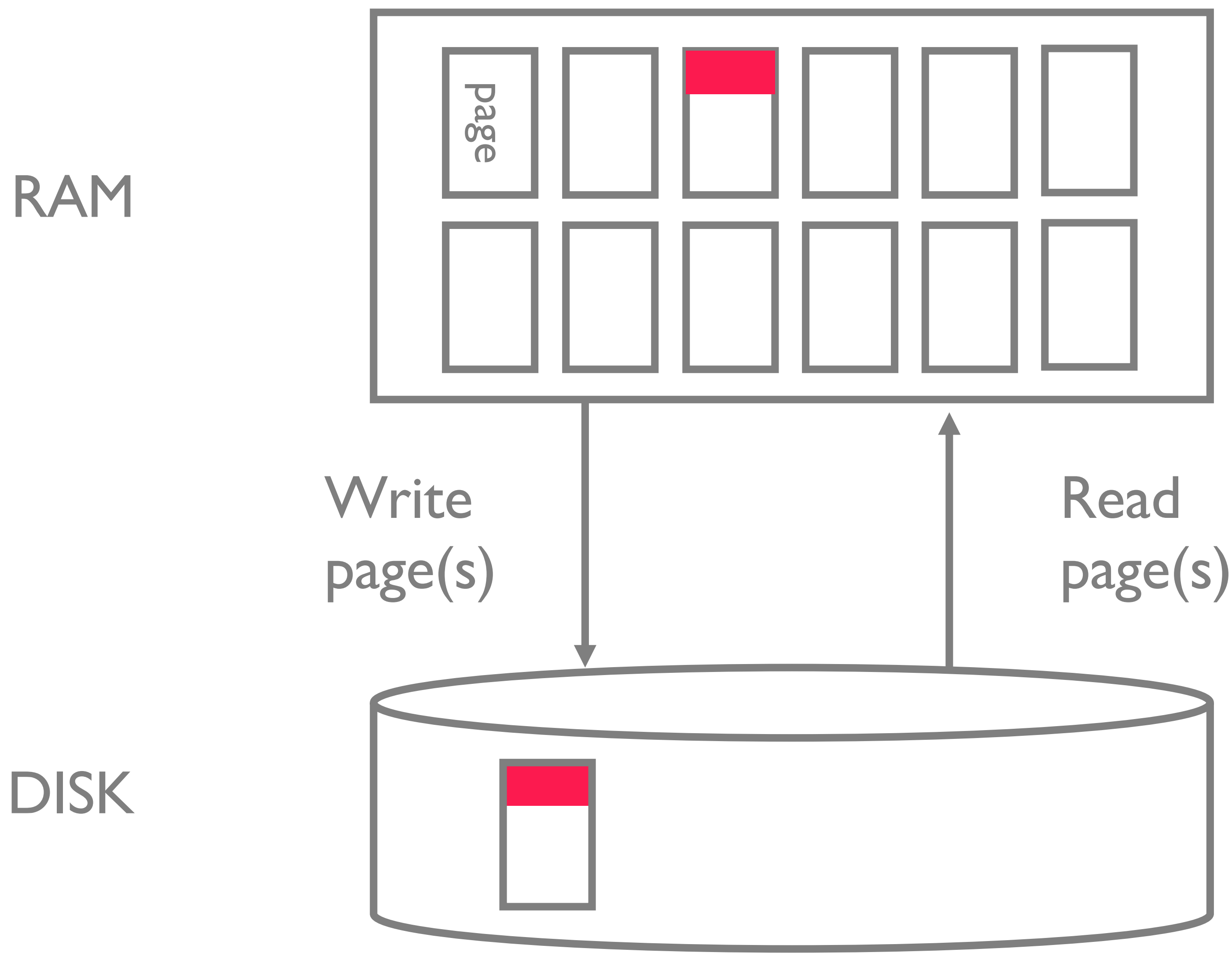
Strict 2 phase locking (2PL)

Normal Execution

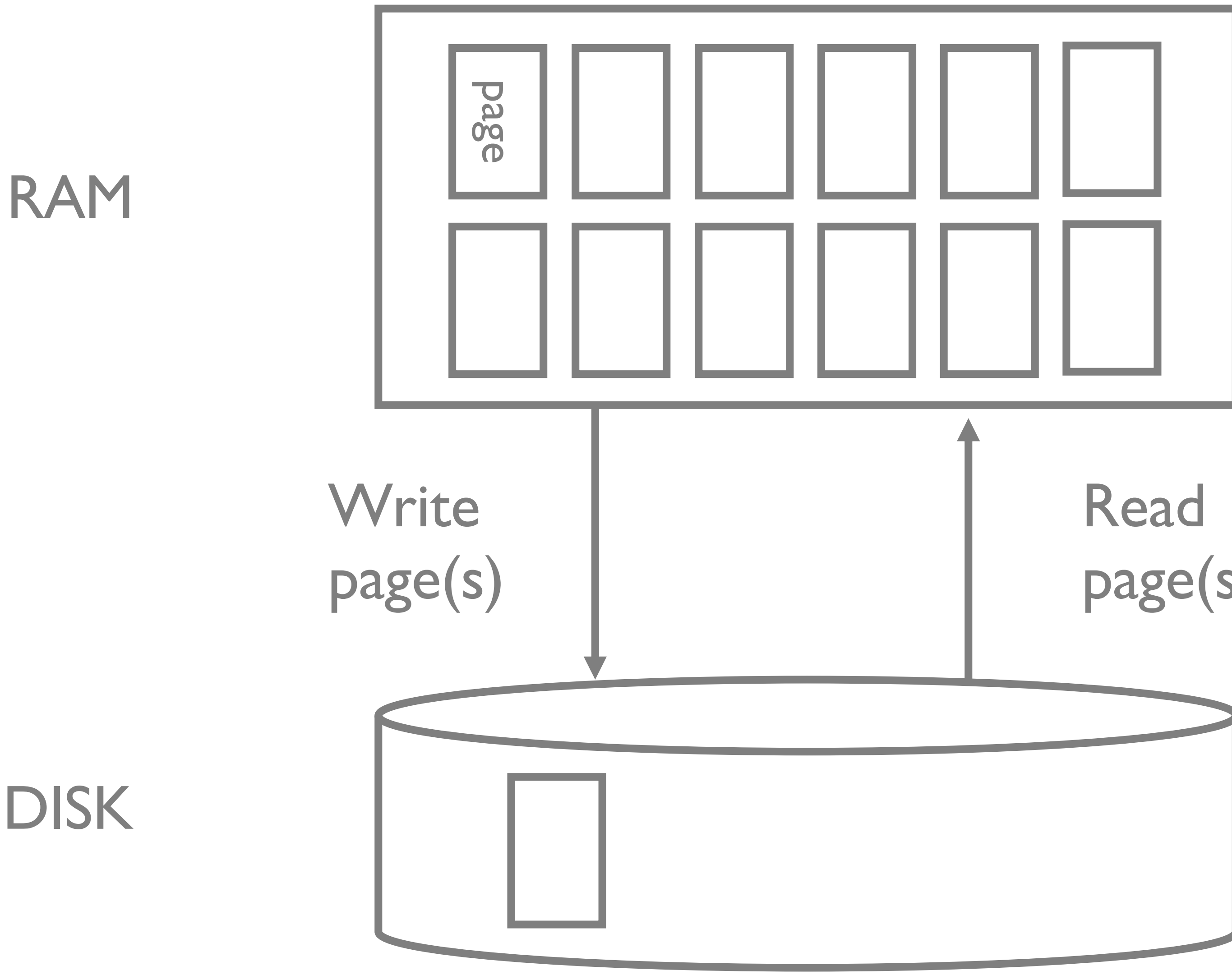
CRASH



After a Crash

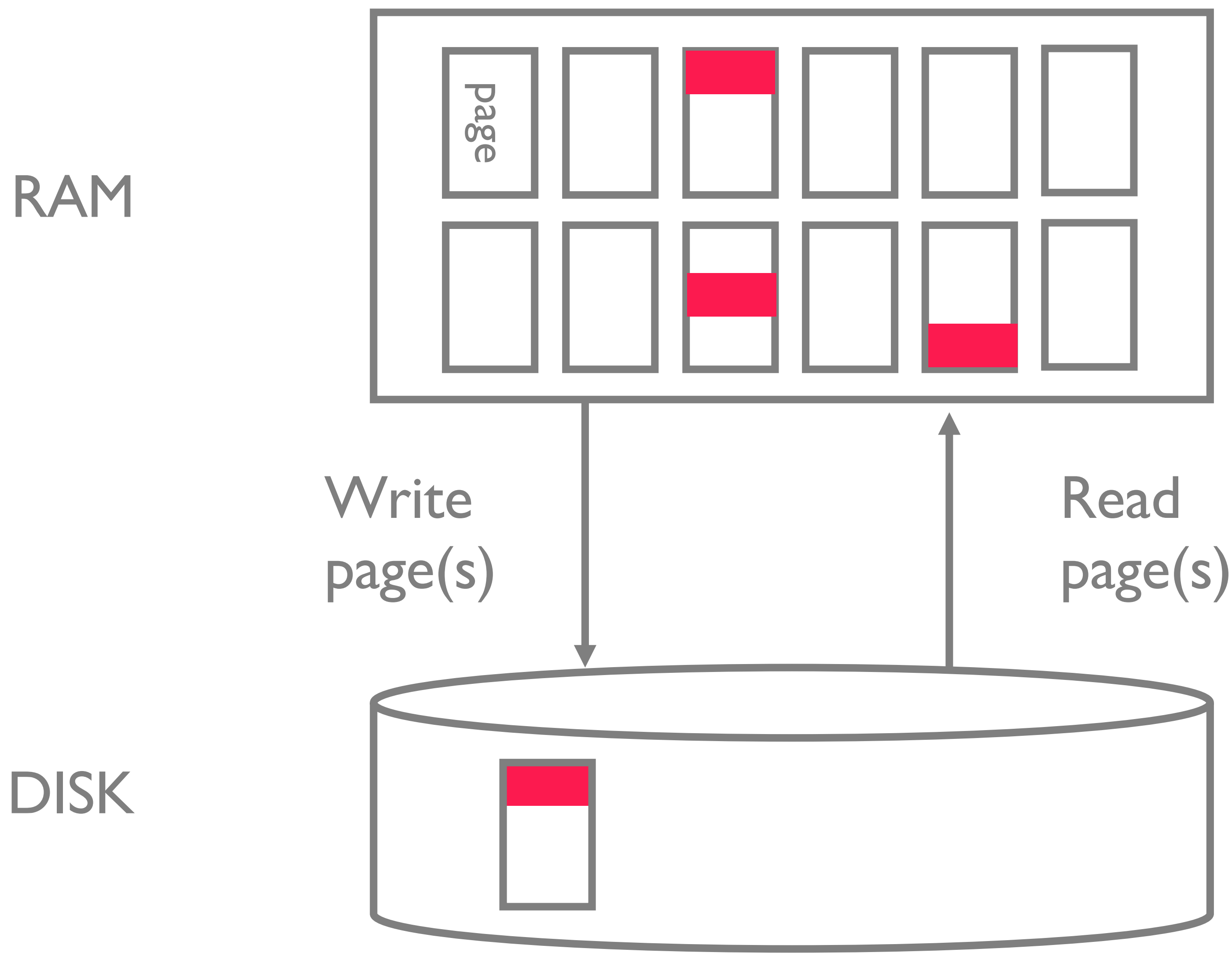


If DB did not say “OK, committed” State should look like:



If T1 Committed and DB said "COMMITED"

State should look like:



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 data 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

...

aborting

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. C = B – 2
8. CRASH
9. undo 7
10. undo 6

...

recovering

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

Is there an execution that
writes log records before data pages
but is incorrect?
(e.g., not ACID)

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?

No, 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

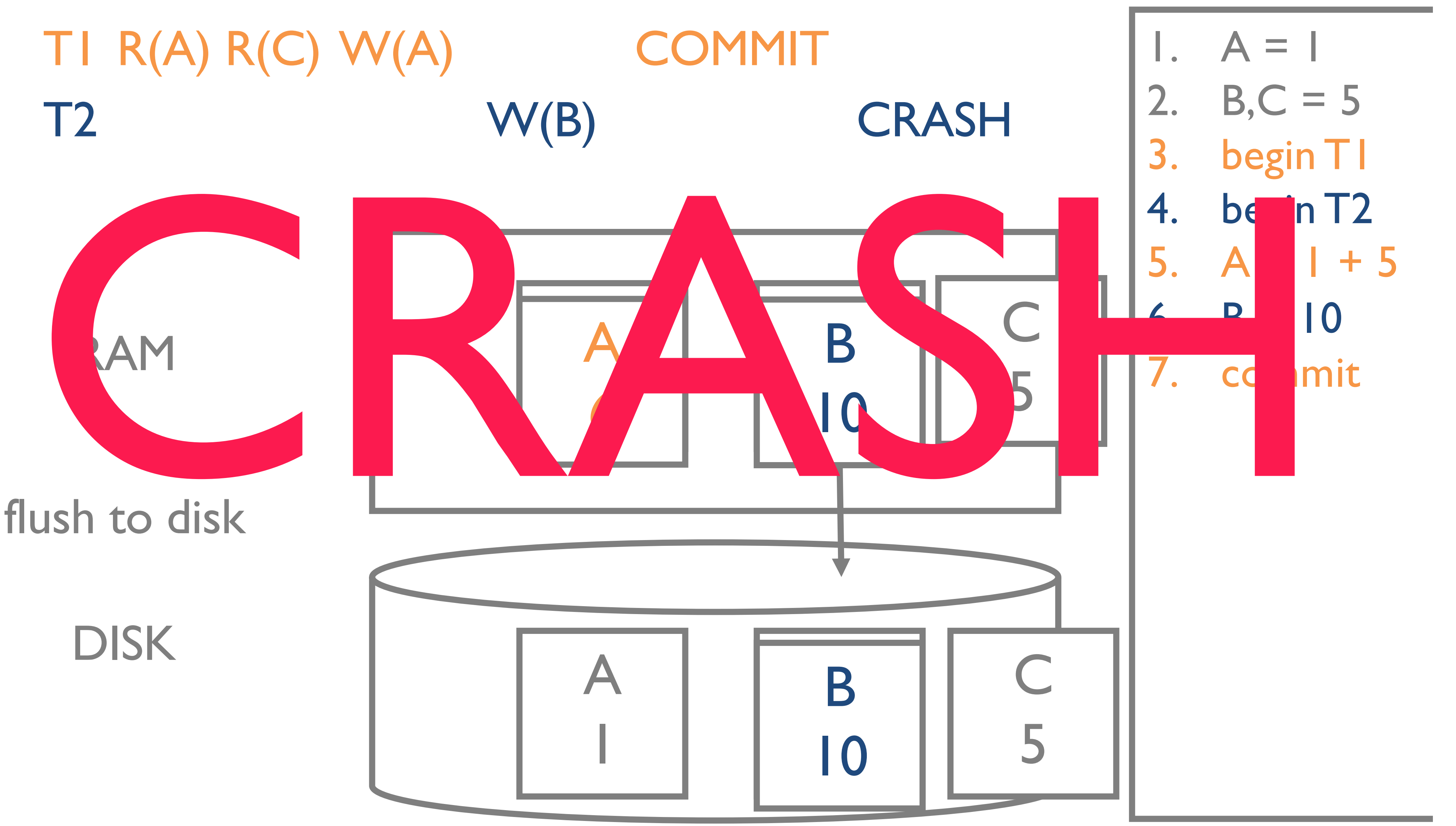
3 phases

- 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

Redo/Undo recovery ops participate in WAL

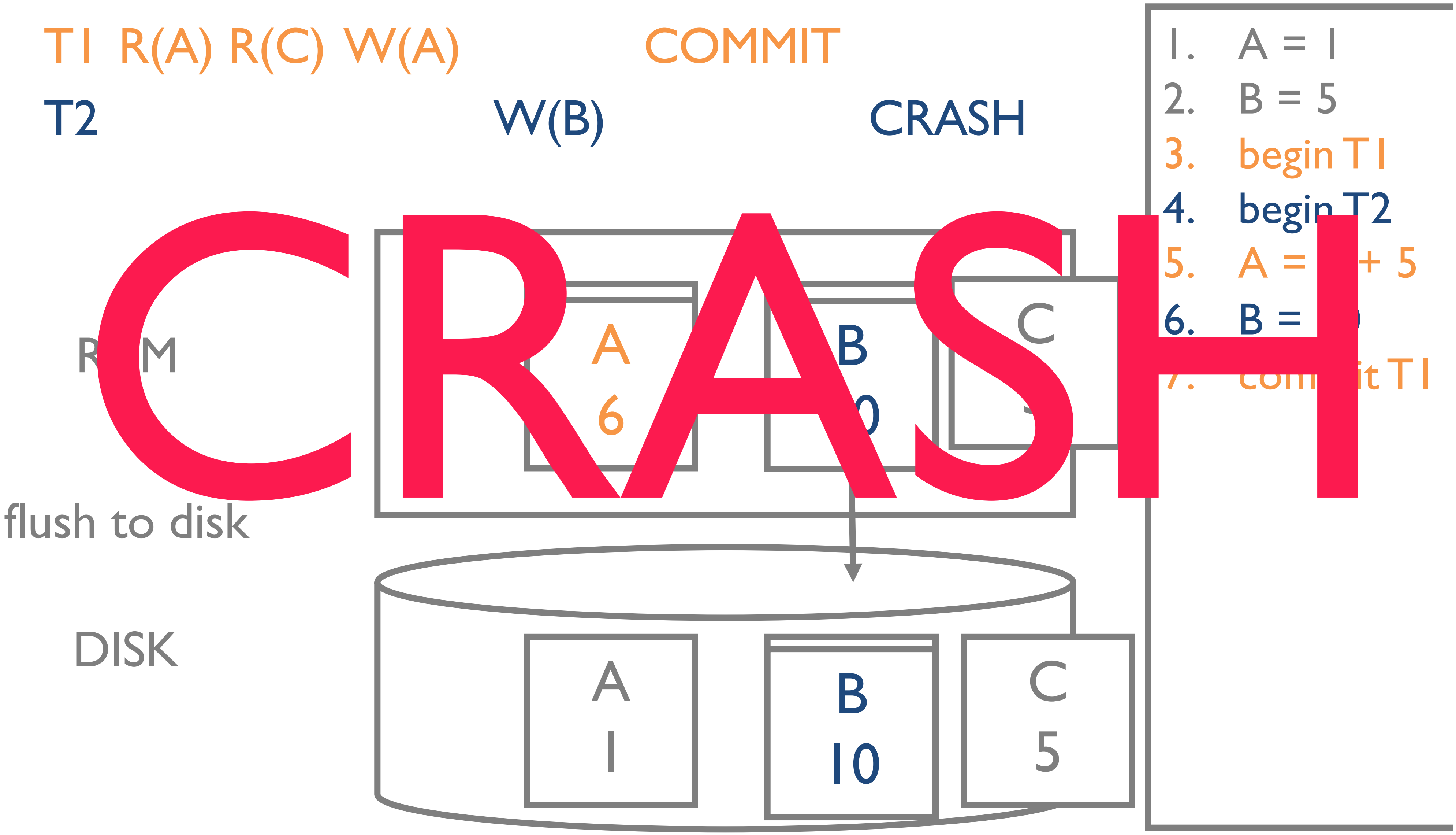
Recovery is *extremely* tricky and *must be correct*

Aries



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

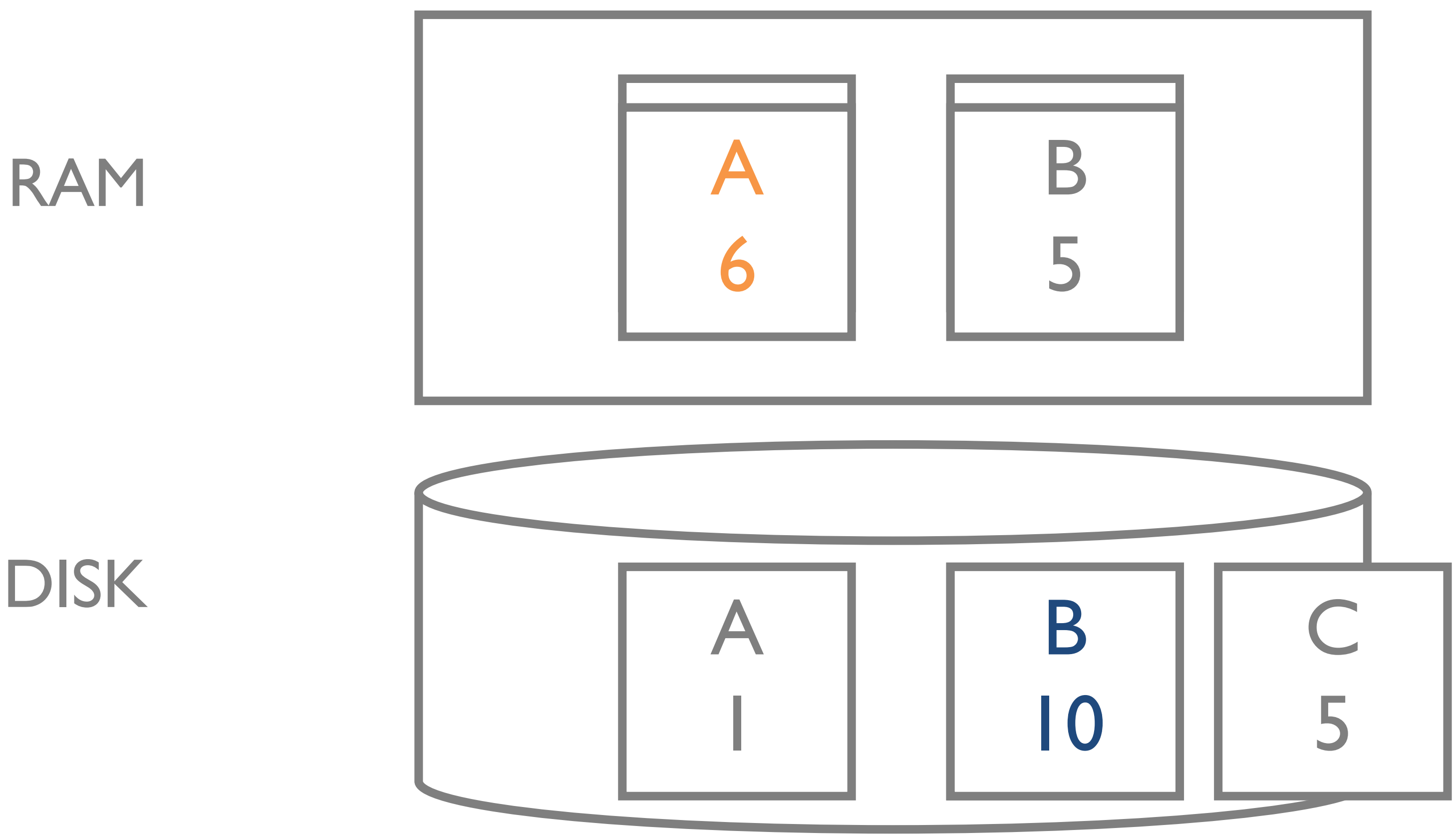
Aries: alternative flushing order



Aborts and Undos (1)

T1 R(A) R(C) W(A) COMMIT

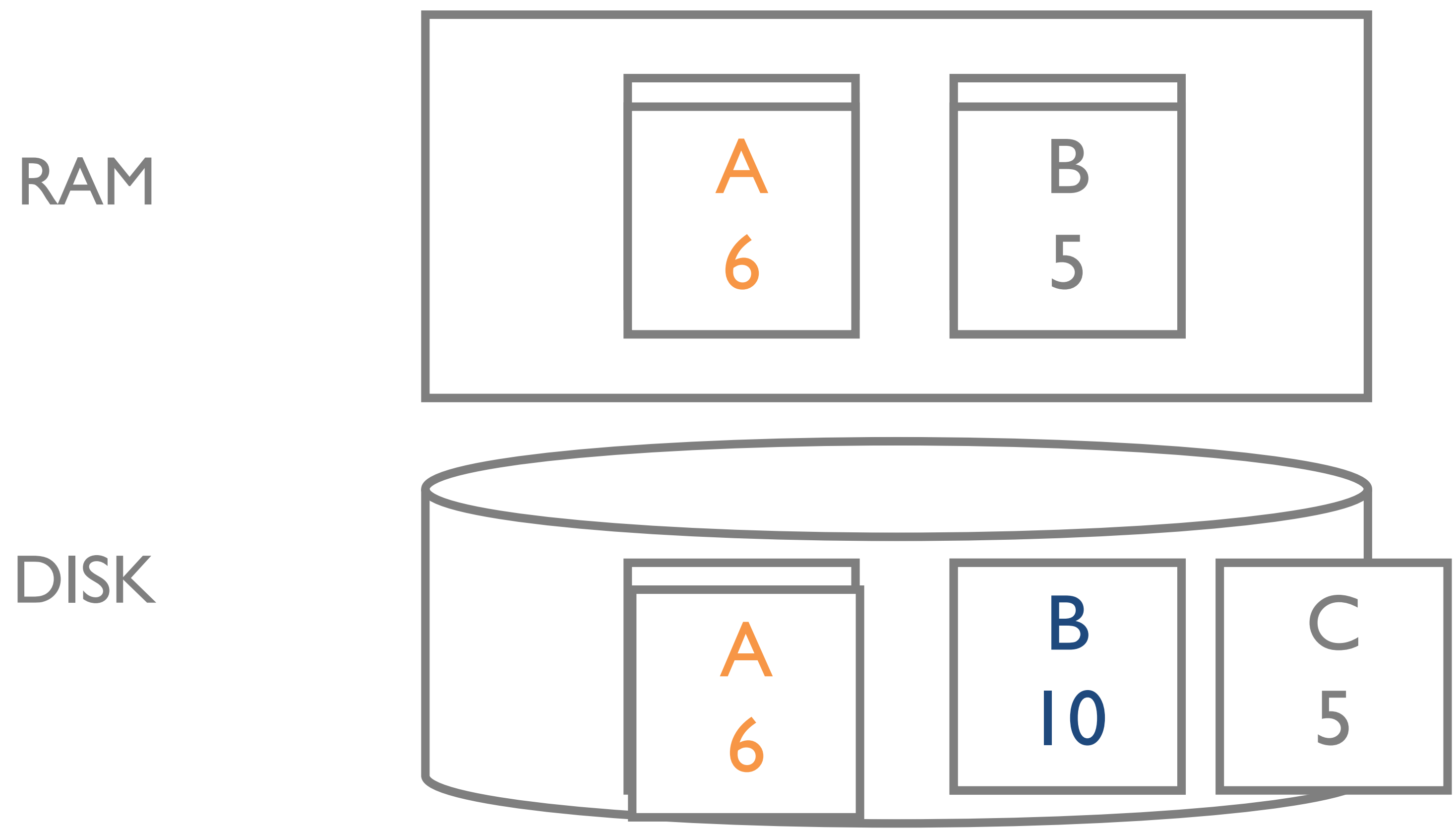
T2 W(B) CRASH



1. A = 1
2. B,C = 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 (2)

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

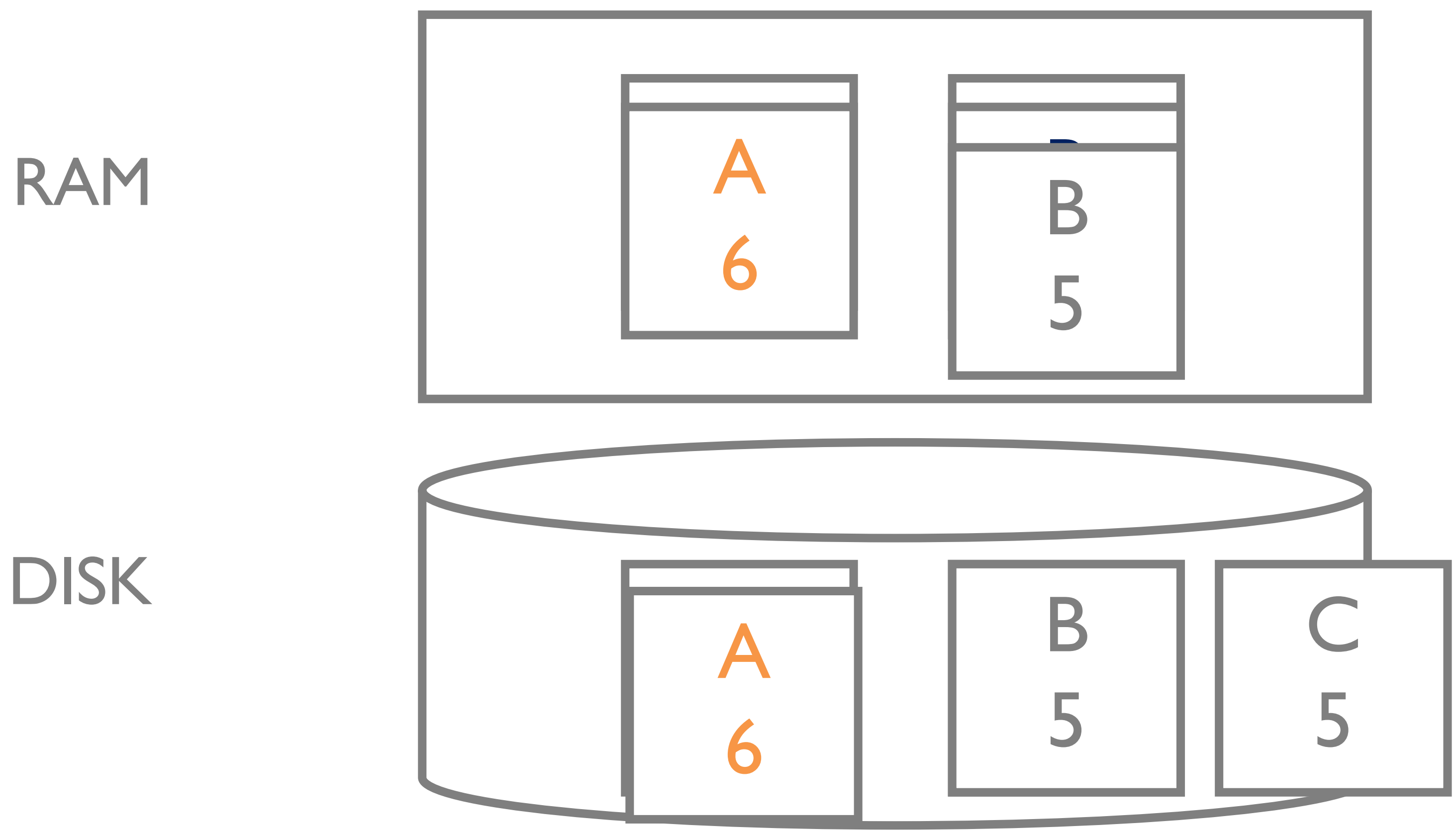


1. A = 1
2. B = 5
3. begin T1
4. begin T2
5. A = 1 + 5
6. B = 10
7. commit T1
8. redo op5
9. undo op6

Aborts and Undos (3)

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. redo op6
10. 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