淺談 RDBMS 原理

Relational Database Management Systems

Yu-Shan Lin @ PythonHug

自我介紹

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- 研究領域：雲端資料庫系統
- http://www.slmt.tw

學習動機

為什麼要學 RDBMS 裡面在做啥呢？

1. 可以幫助你管理 RDBMS

知己知彼，百戰百勝

怎麼說？

- 理解系統內部原理，可以讓管理員了解調整參數時會造成什麼影響

- Buffer Pool ?
- Join Buffer & Sort Buffer ?
- Locks ?
- Indices ?

2. 幫助提升 Coding 的能力

還有 trace code 的能力！

為什麼可以提昇 Coding 能力？

- Database management system (DBMS) 是一種很複雜又高度優化的系統
- 學習這類系統可以幫助理解
  - 怎麼讀懂這種大型系統的程式碼（像是 OS）
  - 改這類系統可能要考慮什麼
  - 優化技巧

“If you are good enough to write code for a DBMS, then you can write code on almost anything else.”

- Andy Pavlo @ CMU 15-721

RDBMS 的架構

裡面長什麼樣子呢？

RDBMS 的架構

- RDBMS 一般以經典的 IBM System R 為基礎來建構
- 可以大略切成三塊
  - Query Engine
  - Storage Engine
  - Transaction Management

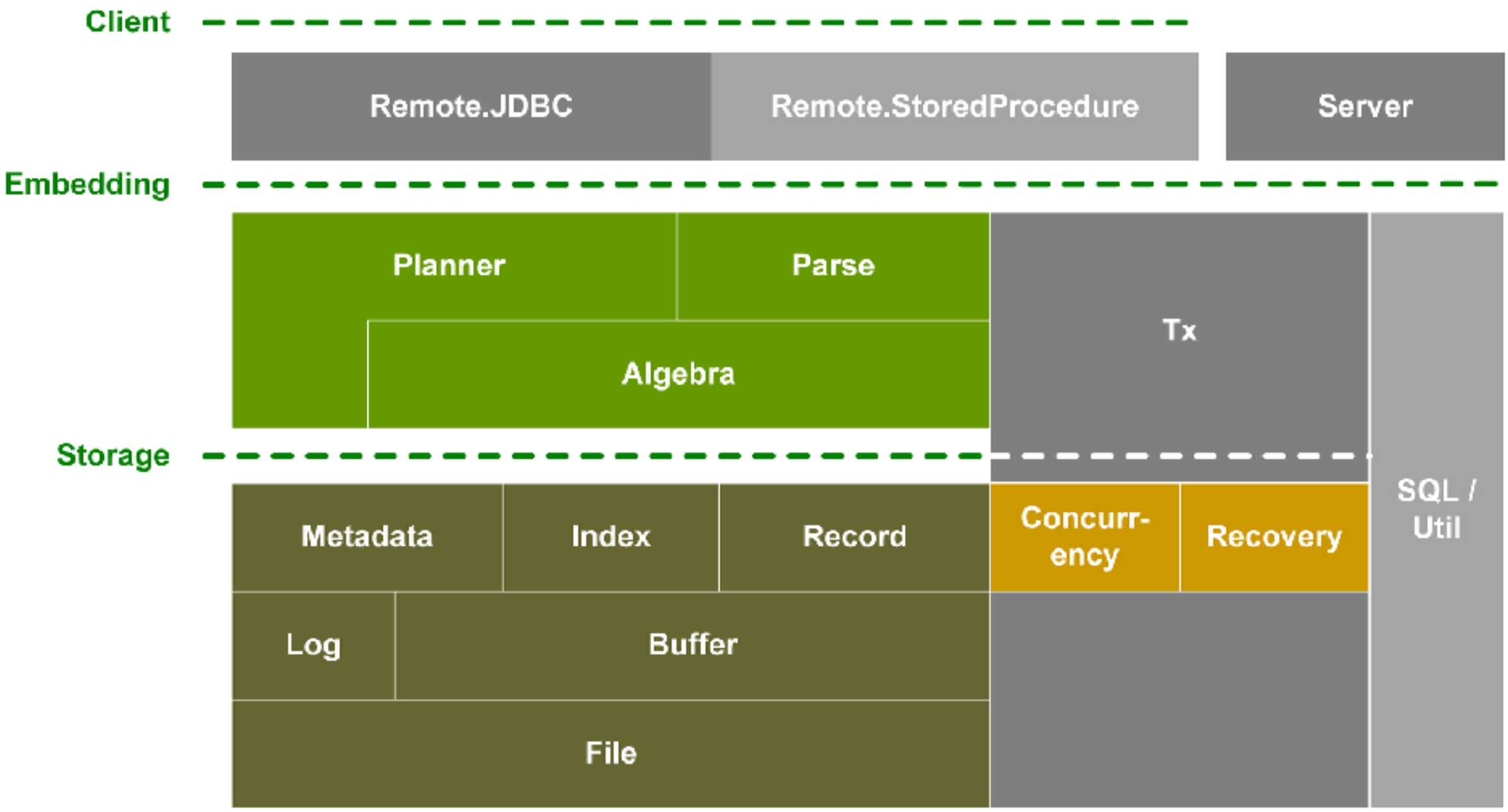
VanillaDB

http://www.vanilladb.org/

VanillaDB 子計畫

- VanillaCore
  - 執行於單台的 multi-threaded RDBMS
- VanillaBench
  - 測試 VanillaCore 的 Benchmarks
- VanillaComm
  - Group Communication
  - 為分散式系統鋪路

VanillaCore 的架構



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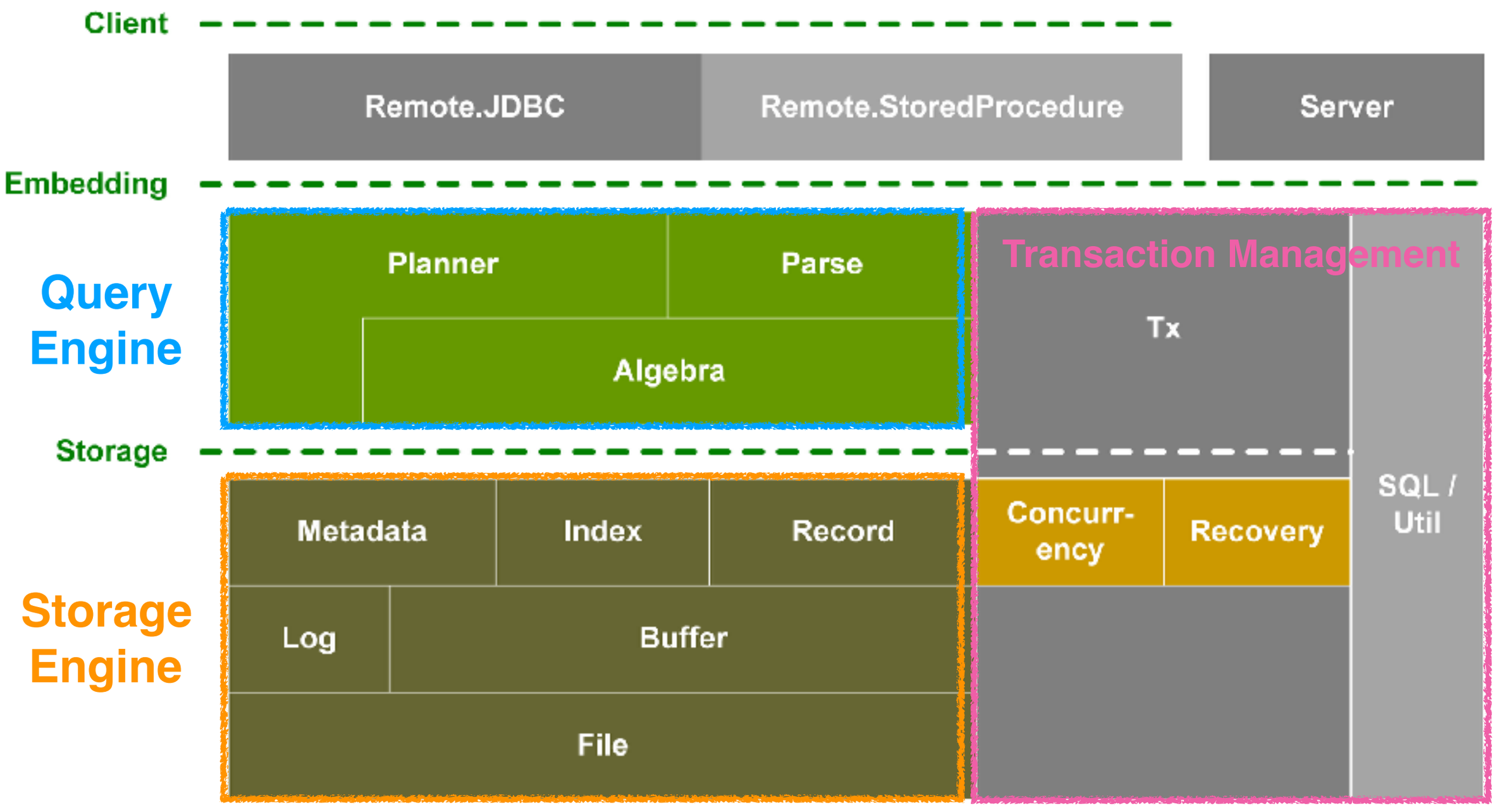

Query Engine

來看看 Query 的一天

範例：股票交易

id	name	balance
1	Red	3300
2	Blue	2200
3	Green	4500

account

buyer	stock_id	amount	time
1	103	50	7/19
1	297	300	8/1
1	31	230	8/5
2	45	40	8/7
3	24	100	9/2

stock_history

要求：找出 9/1 之後有買股票且至少有 3000 元的人

SQL 範例

id	name	balance
1	Red	3300
2	Blue	2200
3	Green	4500

account

buyer	stock_id	amount	time
1	103	50	7/19
1	297	300	8/1
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stock_history

```
SELECT name FROM account, stock_history WHERE
    id = buyer AND balance > 3000 AND time >= 9/1;
```

Query 的一天

1. 詞性分析與斷詞 (Lexical Analysis & Tokenization)
2. 解析語意 (Parsing)
3. 計畫執行方式 (Planning)
4. 執行 (Executing)

詞性分析 (Lexical Analysis)

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    id = buyer AND balance > 3000 AND time >= 9/1;
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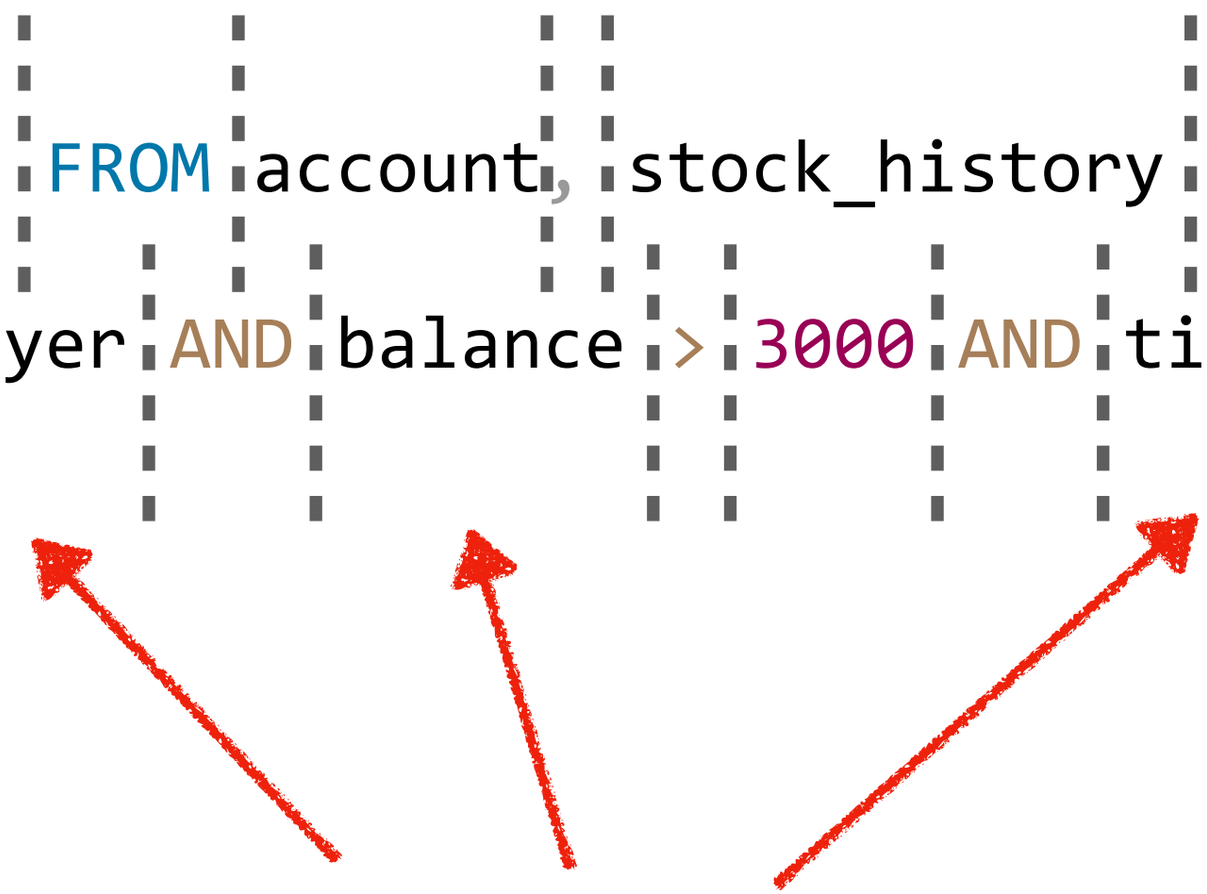

Identifier

詞性分析 (Lexical Analysis)

斷詞

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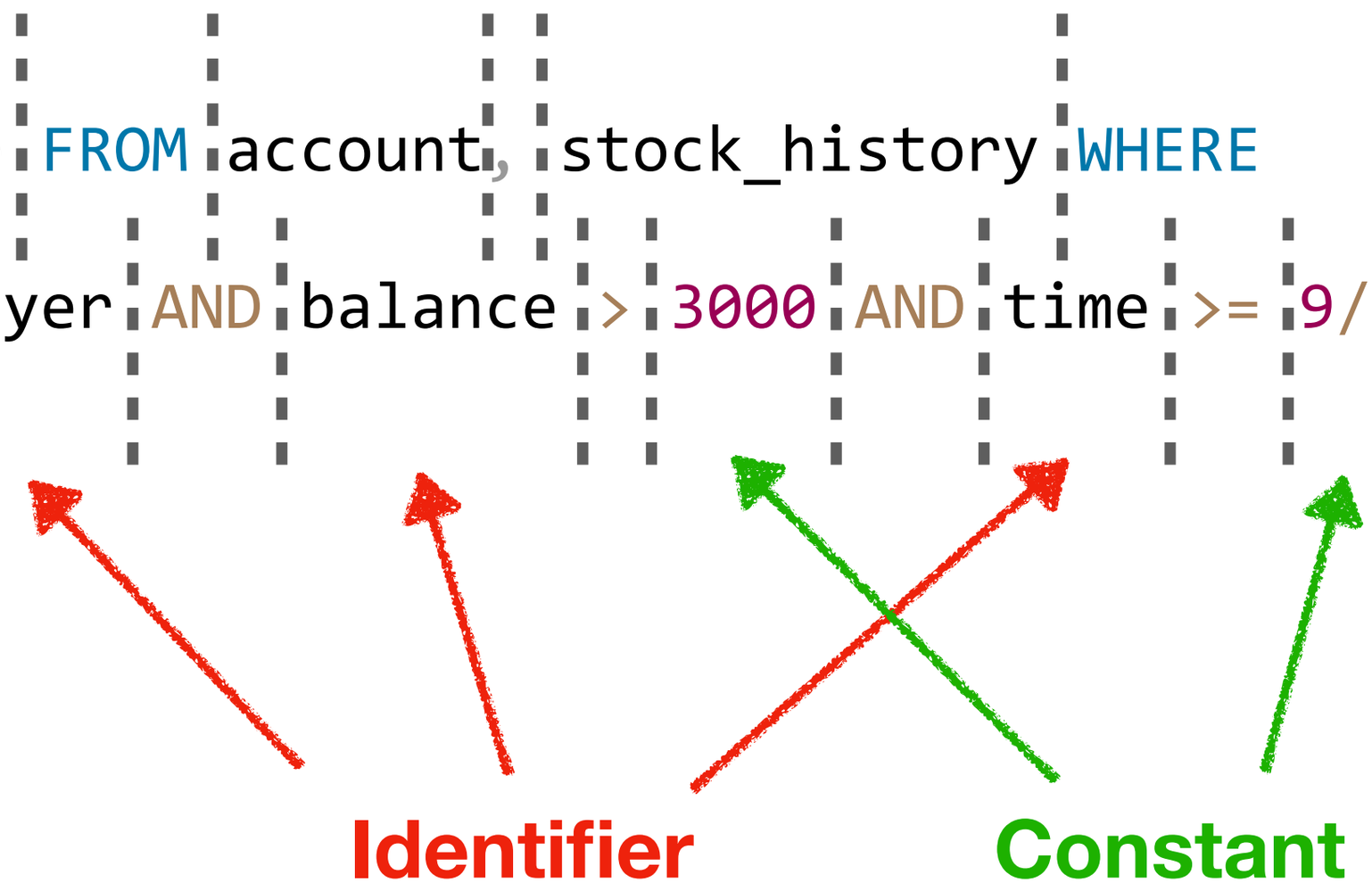

詞性分析 (Lexical Analysis)

斷詞

```
SELECT name FROM account, stock_history WHERE
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```

Keywords **Identifier** **Constant**

語意解析

依照預定的文法來解析語意

```
<Query>     := SELECT <ProjectSet> FROM <TableSet>
               [ WHERE <Predicate> ] [ GROUP BY <IdSet> ]
               [ ORDER BY <SortList> [ DESC | ASC ] ]
<IdSet>        := <Field> [ , <IdSet> ]
<TableSet>     := IdTok [ , <TableSet> ]
<AggFn>        := AVG(<Field>) | COUNT(<Field>) |
                  COUNT(DISTINCT <Field>) | MAX(<Field>) |
                  MIN(<Field>) | SUM(Field>)
<ProjectSet>   := <Field> | <AggFn> [ , <ProjectSet>]
<SortList>     := <Field> | <AggFn> [ , <SortList>]
```

Plan Trees

```
SELECT name FROM account, stock_history WHERE
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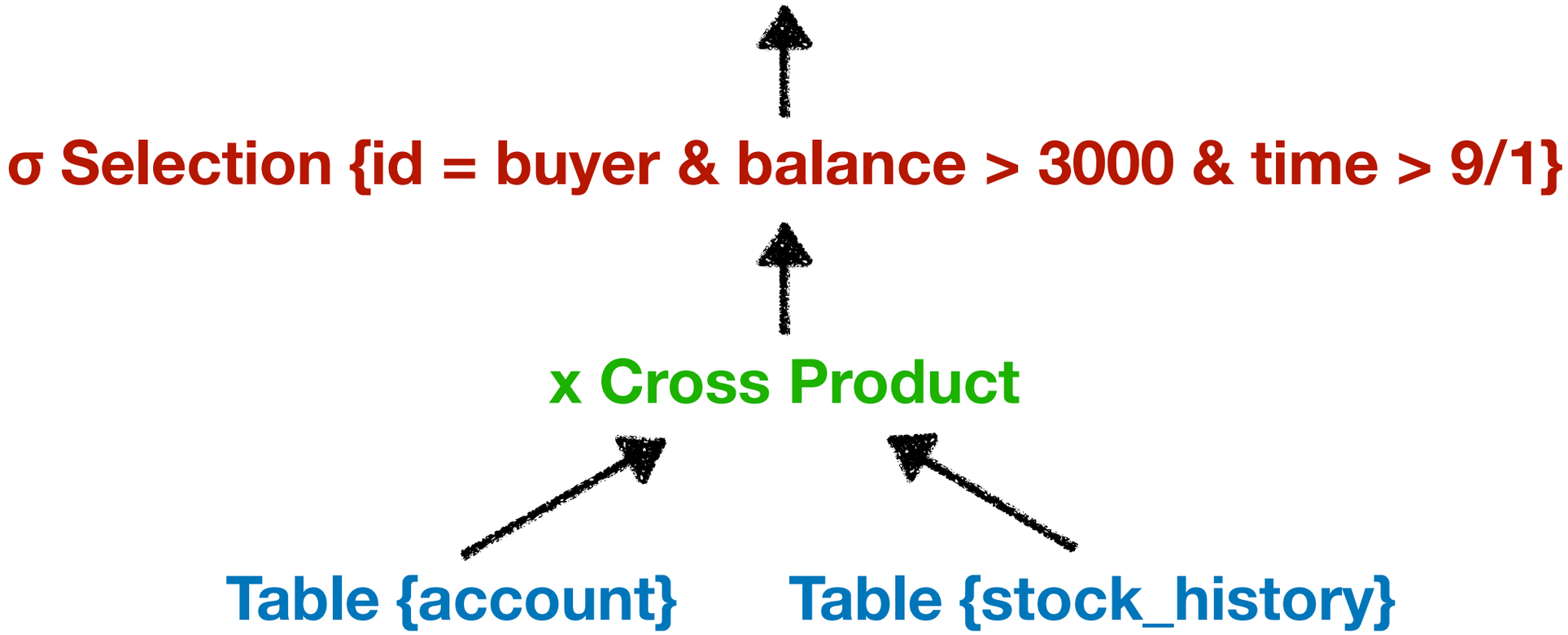

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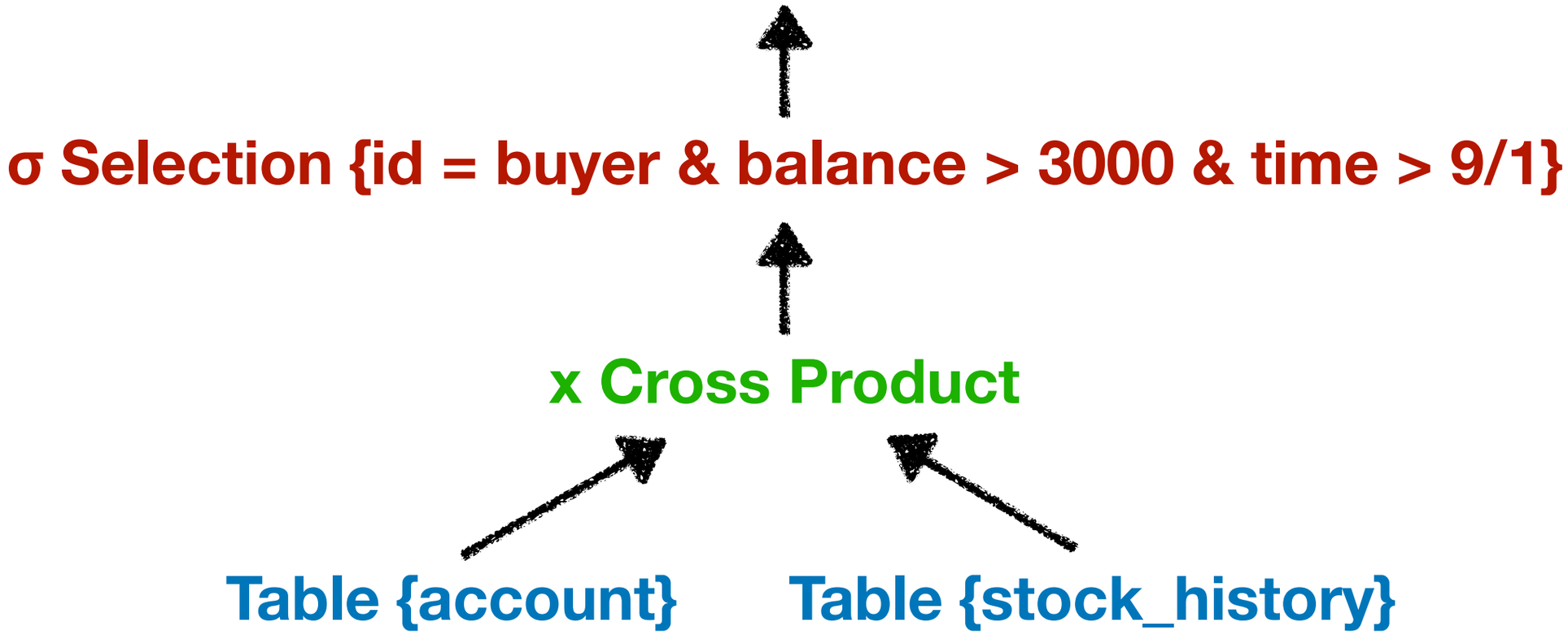
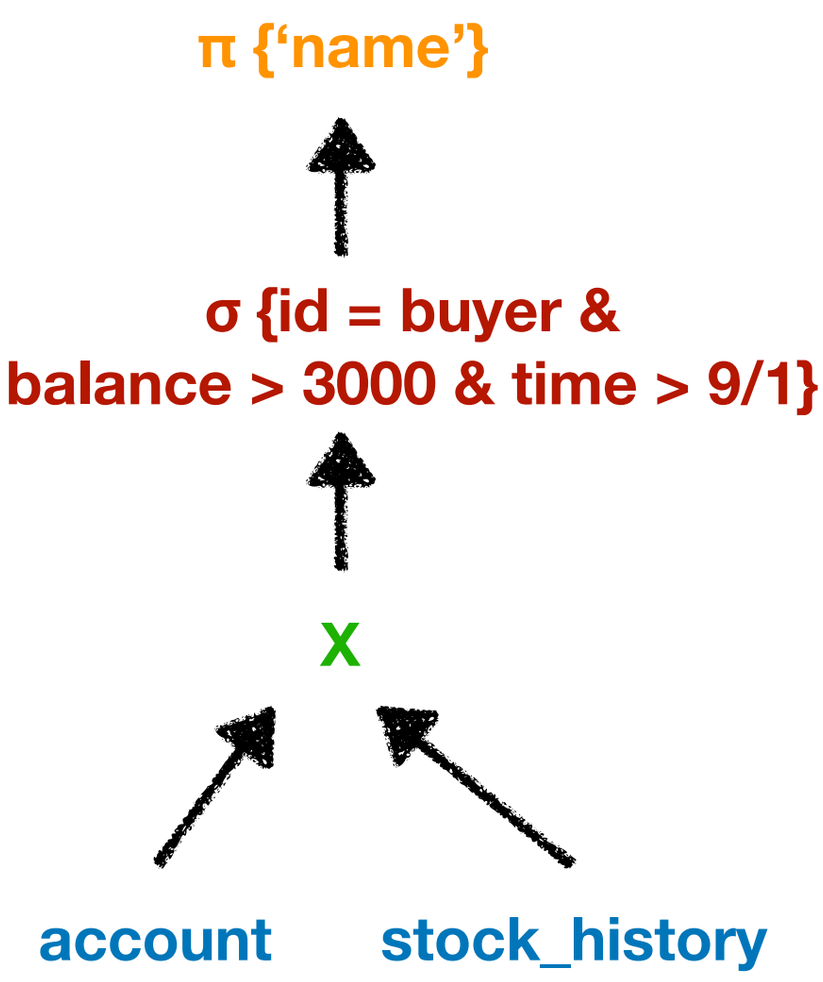


這些符號被稱為 Relational Algebra

執行計畫


π {‘name’}
σ {id = buyer &
balance > 3000 & time > 9/1}
X
account
stock_history

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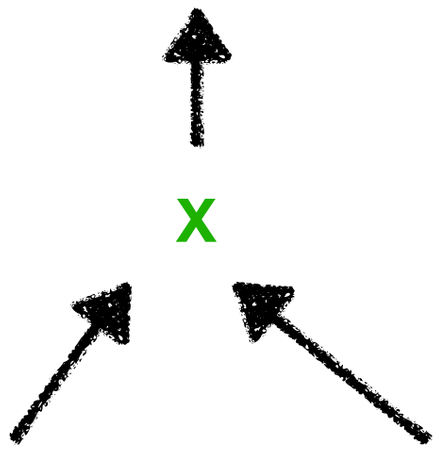

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…	…	…	…	…	…	…

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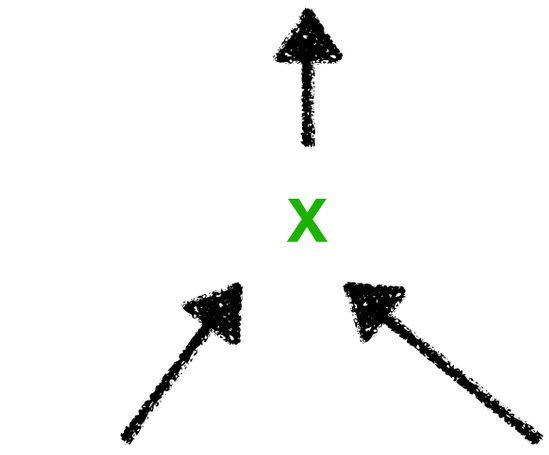

id	name	balance	buyer	stock_id	amount	time
3	Green	4000	3	24	100	9/2

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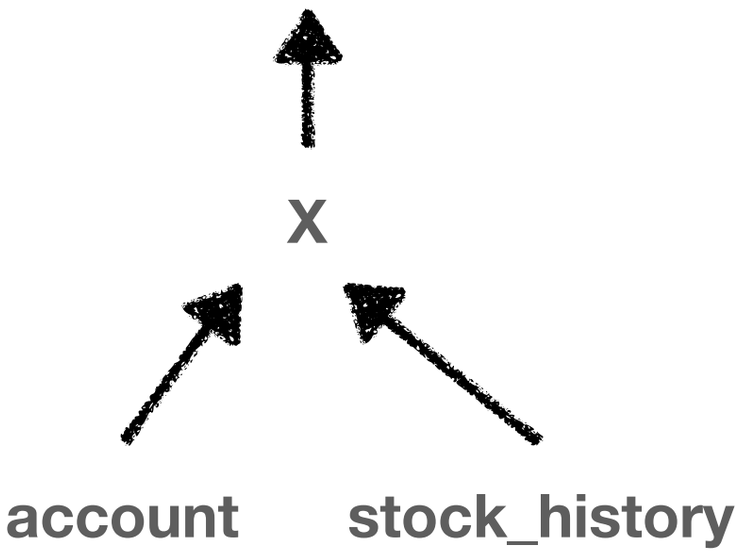
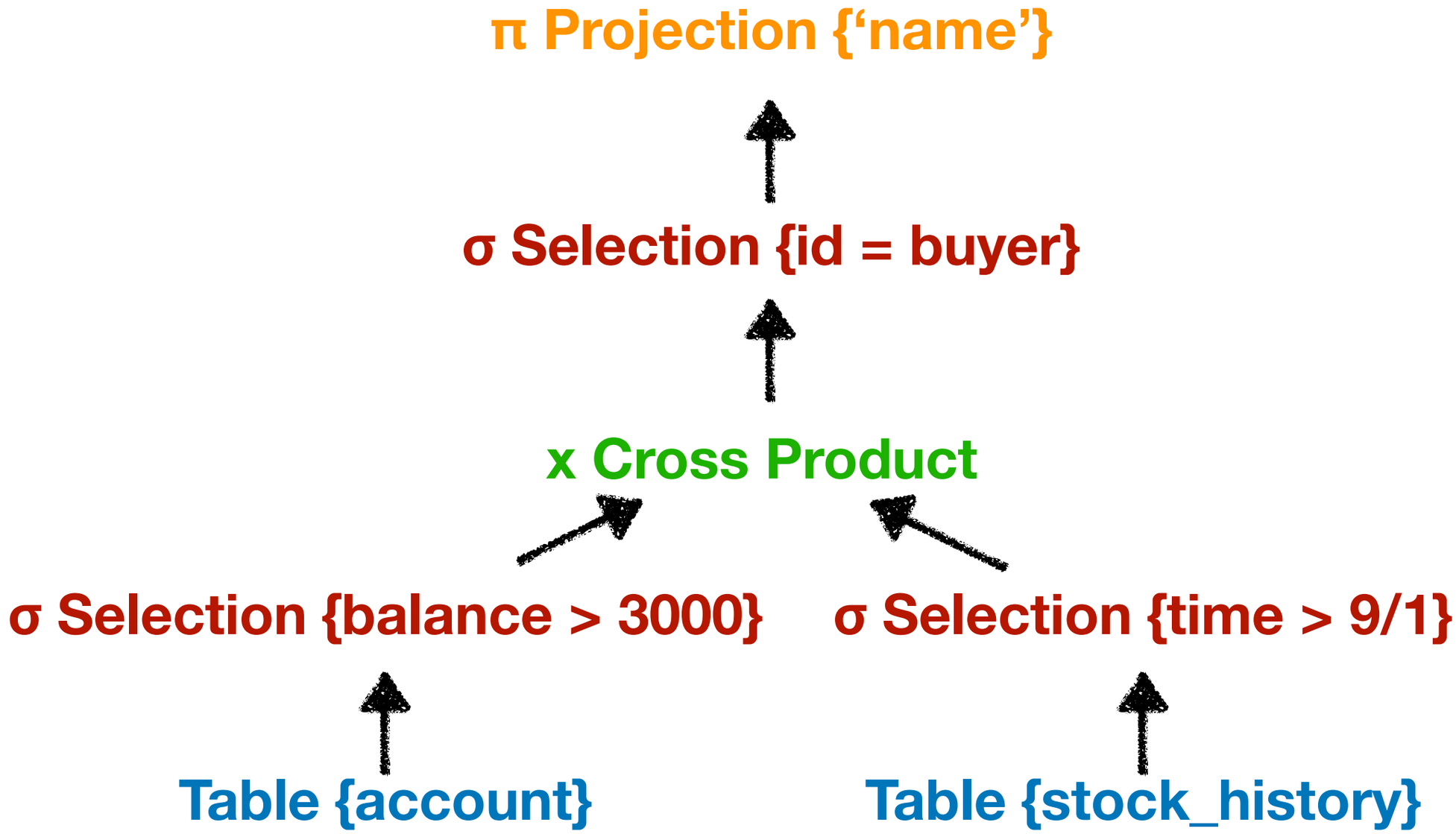


name
Green

id	name	balance	buyer	stock_id	amount	time
3	Green	4500	3	24	100	9/2

一個 Query 可能會有多種 Plan Tree



如何知道 Query 怎麼被執行？

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你可以叫你的 DBMS 解釋 (EXPLAIN) 給你聽

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```
SLMT=# EXPLAIN SELECT name FROM account, stock_history WHERE id = buyer
AND balance > 3000 AND time >= 901;
                                QUERY PLAN
-------------------------------------------------------------------------
 Hash Join  (cost=24.16..86.76 rows=835 width=58)
   Hash Cond: (stock_history.buyer = account.id)
   ->  Seq Scan on stock_history  (cost=0.00..32.12 rows=590 width=4)
         Filter: ("time" >= 901)
   ->  Hash  (cost=20.62..20.62 rows=283 width=62)
         ->  Seq Scan on account  (cost=0.00..20.62 rows=283 width=62)
               Filter: (balance > 3000)
(7 rows)
```

PostgreSQL

Planners

- 又被叫做 **Query Optimizer**
- Planner 的難點
  - 如何找出一個好的執行計畫？
  - 如何正確估計執行計畫的效率？
- 好的 Planner 帶你上天堂

幾種著名的找法

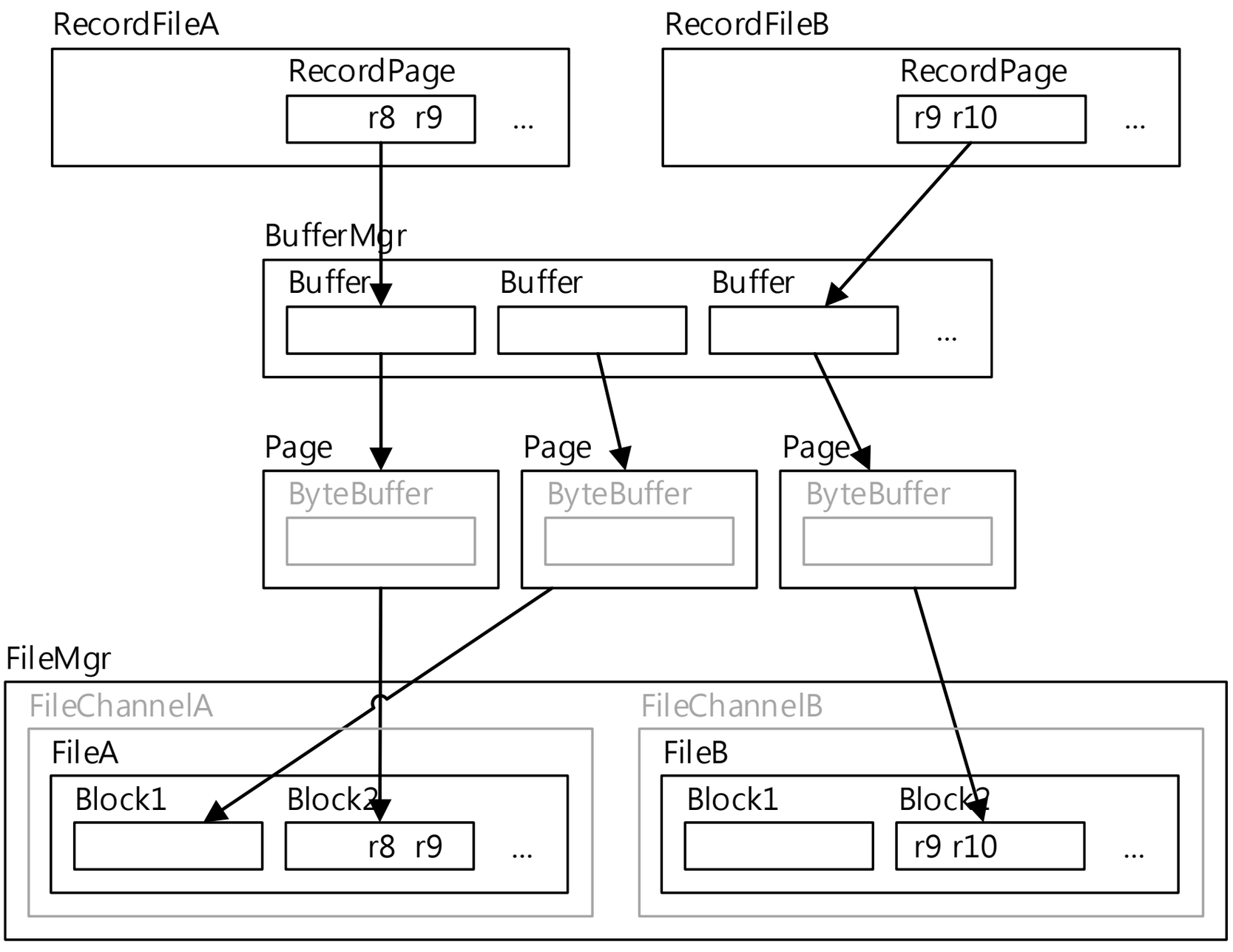
- Heuristic-based Optimization - INGRES, 1979
- Heuristic+cost-based Join Search - System R, 1979
- Simulated Annealing - Postgres, 1987
- Starburst Optimizer - DB2, 1988
- Volcano Optimizer - Academic, 1993
- Cascades Optimizer - SQL Server, 1995

光這個主題就夠發 40 年的 paper 惹！

Storage Engine

狀況相對簡單一些

Disk-based Storage



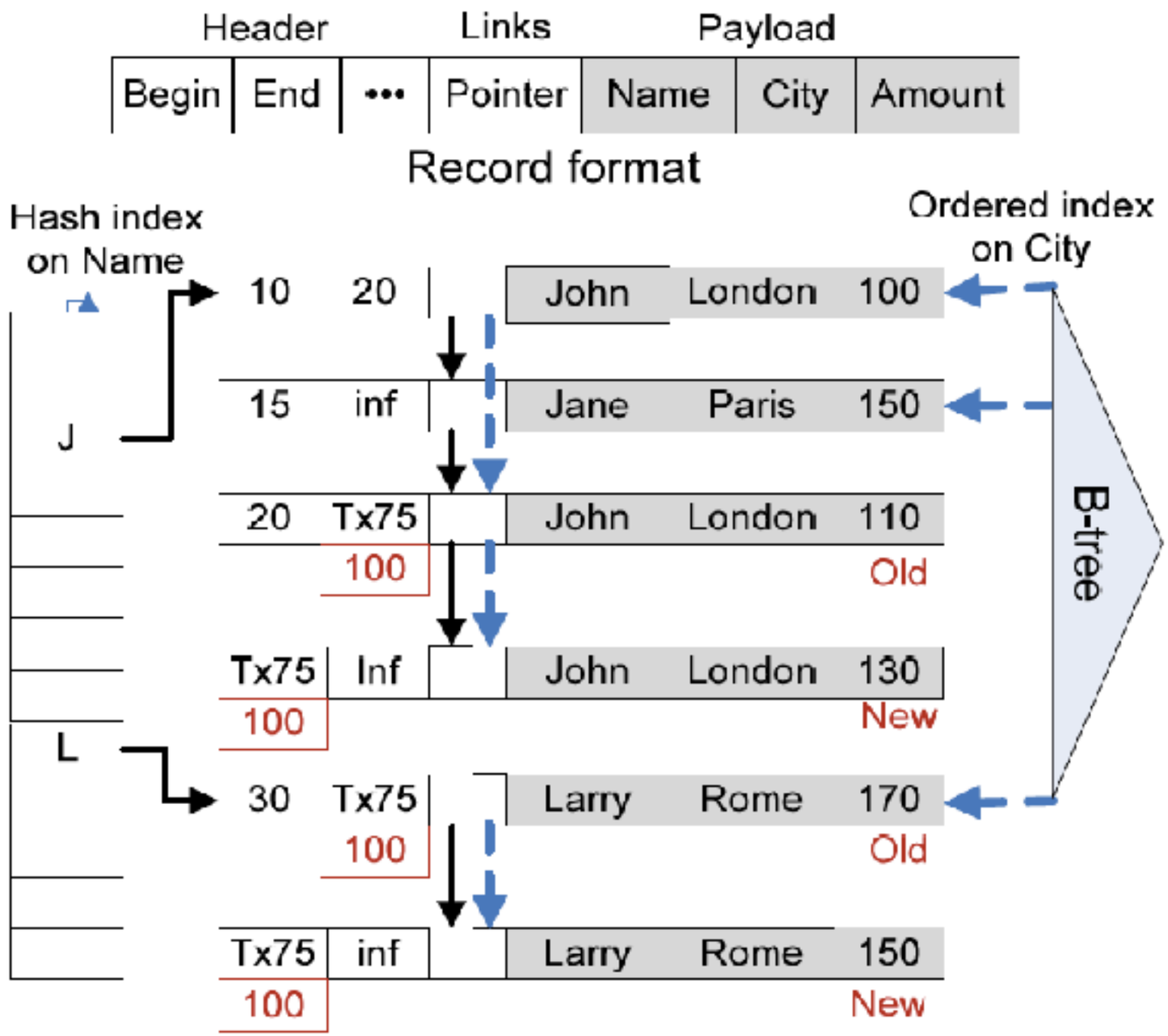
難點

- 硬碟是以 block 為單位存取資料
  - 所以需要小心安排資料
    - 根據管理方式可能會有不同程度的 fragmentation
- 可是放硬碟存取很慢
  - 所以需要 cache
  - 管理 cache 也有很多方法 (FIFO, LIFO, LRU…)

最近學界很流行
Main-Memory DBMS

- 假設資料都塞的進記憶體
- MMDBMS 的優勢
  - 不需要考慮 blocks 的設計 (Disk 是什麼？能吃嗎？)
  - 節省不需要的 mutex 與 latch
  - 大幅放寬 storage engine 的障礙

Hekaton, 2013



Peleton, 2016

	ID	IMAGE-ID	NAME	PRICE	DATA
Tile A-1	101	201	ITEM-101	10	DATA-101
	102	202	ITEM-102	20	DATA-102
	103	203	ITEM-103	30	DATA-103
Tile Group A					
Tile B-1	104	204	ITEM-104	40	DATA-104
	105	205	ITEM-105	50	DATA-105
	106	206	ITEM-106	60	DATA-106
Tile Group B					
Tile C-1	107	207	ITEM-107	70	DATA-107
	108	208	ITEM-108	80	DATA-108
	109	209	ITEM-109	90	DATA-109
	110	210	ITEM-110	100	DATA-110
Tile Group C					

Transaction Management

讓 RDBMS 強大的關鍵

Transactions

Transactions

Transactions

```
BEGIN TRANSACTION;

UPDATE account SET balance = balance - 100 WHERE name = "Red";

UPDATE account SET balance = balance + 100 WHERE name = “Blue";

COMMIT TRANSACTION;
```

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ACID 

ACID

- 原子性 (Atomicity)
- 一致性 (Consistency)
- 獨立性 (Isolation)
- 持久性 (Durability)

A - Atomicity

- 全有或全無 (All or nothing)

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```
BEGIN TRANSACTION;
UPDATE account ...
UPDATE account ...
COMMIT TRANSACTION;
```

None

```
BEGIN TRANSACTION;
UPDATE account ...
UPDATE account ...
COMMIT TRANSACTION;
```

Half

```
BEGIN TRANSACTION;
UPDATE account ...
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```

All

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✔

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C - Consistency

- 資料要符合使用者設定的條件

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In Progress

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In Progress

Sum(balance) = 9900

不一致 !!

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- 資料要符合使用者設定的條件

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```
BEGIN TRANSACTION;

UPDATE account ...

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In Progress

Sum(balance) = 9900

不一致 !!

其他 transactions 不能看到這個

I - Isolation

Transaction 並行執行的結果必須符合某一種依序執行的結果

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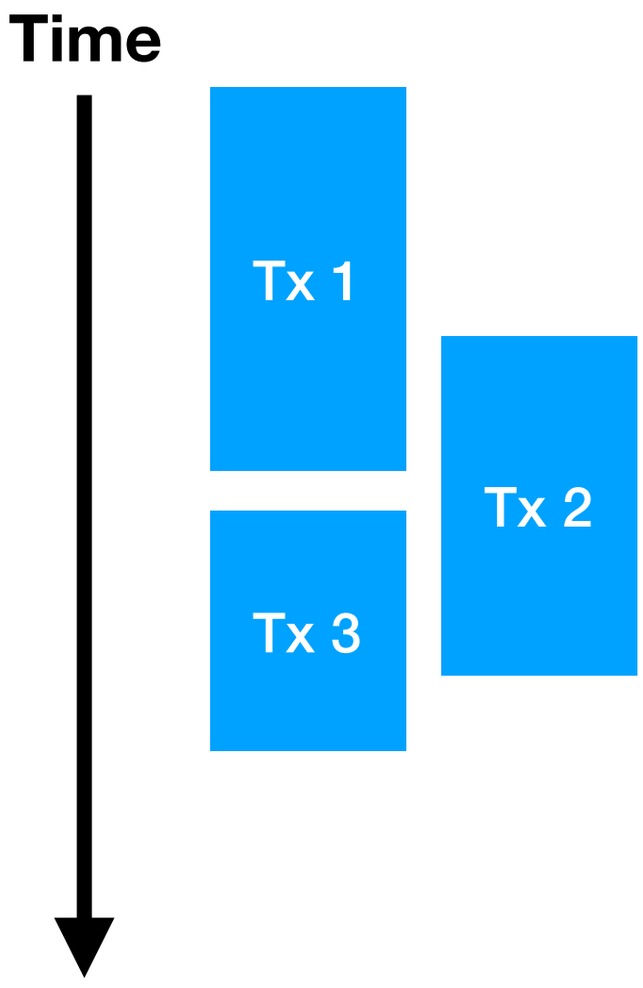

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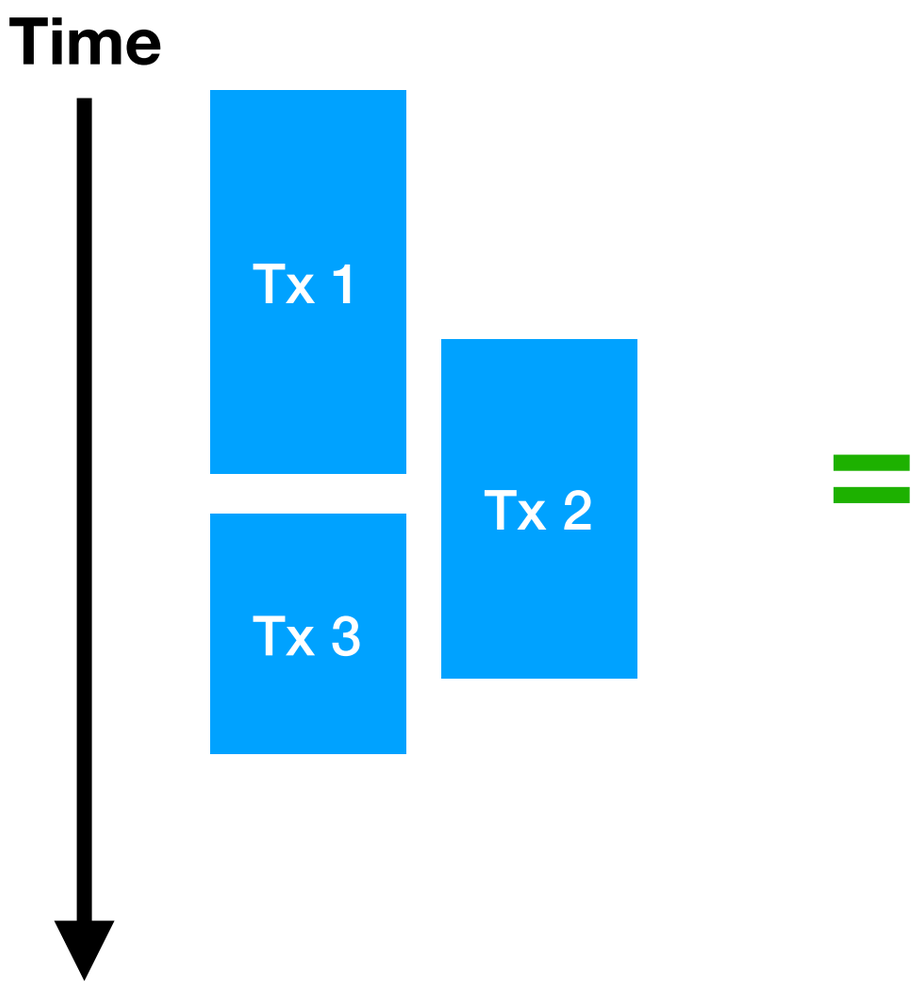

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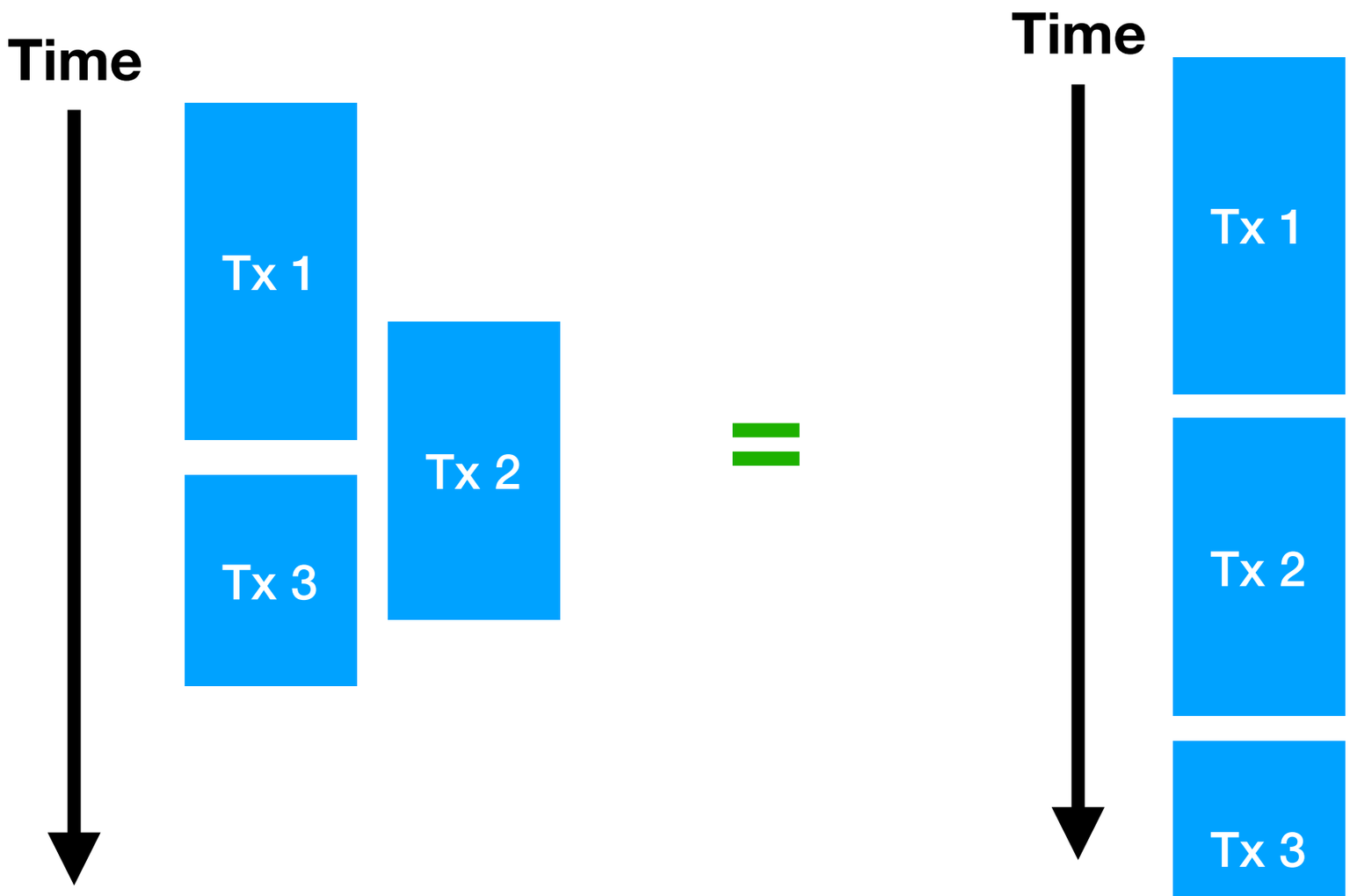

Isolation Levels

Isolation 也有分很多種

Level	Dirty Reads	Non-Repeatable Reads	Phantoms
Read Uncommitted	可能發生	可能發生	可能發生
Read Committed	安全	可能發生	可能發生
Repeatable Read	安全	安全	可能發生
Serializable	安全	安全	安全

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Serializable	安全	安全	安全

小知識：MySQL's InnoDB 預設是用 Repeatable Read

話說，我們真的需要這麼嚴謹嗎？

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根據研究，其實大部分的人是用 READ COMMITTED！[1]

[1] “What Are We Doing With Our Lives? Nobody Cares About Our Research on Concurrency Control” in SIGMOD’17
[2] “ACIDRain: Concurrency-Related Attacks on Database-Backed Web Applications” in SIGMOD’17

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不過放寬的 Isolation Levels 具有某些安全疑慮 [2]

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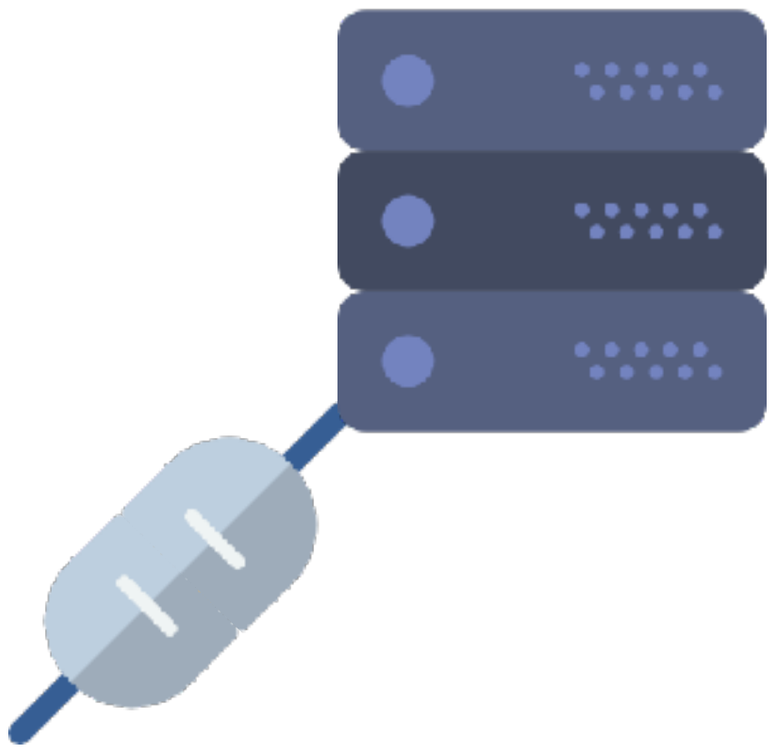

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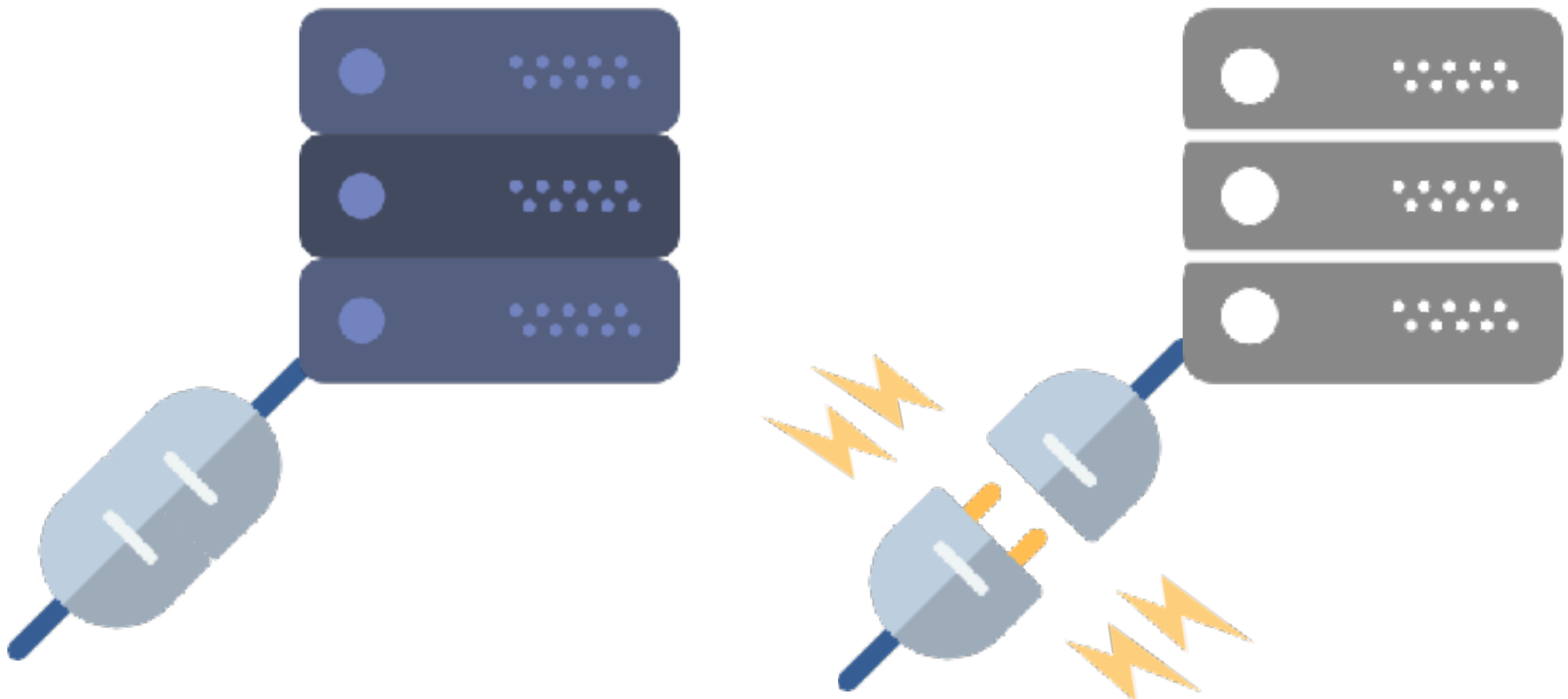

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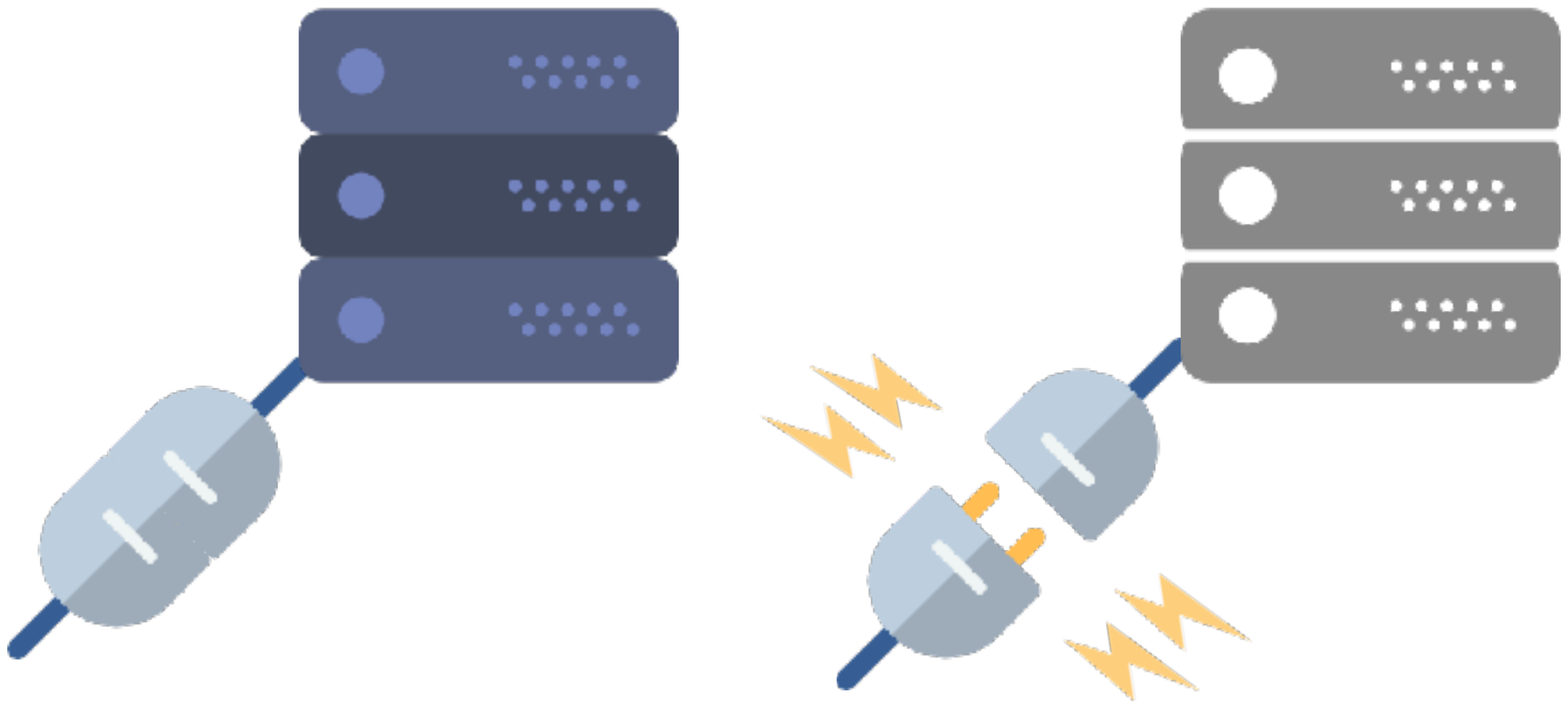

就算機器忽然斷電資料也要留下

來看看怎麼實作 ACID

Atomicity ?

Atomicity ?

我們需要 logs

Logging

- RDBMS 紀錄你的每一次更新

```
BEGIN TRANSACTION;
UPDATE account SET balance = balance - 100 WHERE name = "Red";
UPDATE account SET balance = balance + 100 WHERE name = “Blue";
COMMIT TRANSACTION;
```

SQLs

```
<Tx 1, Begin>
<Tx 1, Set Value, Record 1, Offset 30, Old 3300, New 3200>
<Tx 1, Set Value, Record 2, Offset 30, Old 2200, New 2300>
<Tx 1, Commit>
```

Logs

Undoing

- RDBMS 可以根據 logs 取消已經之前的操作

```
BEGIN TRANSACTION;
UPDATE account SET balance = balance - 100 WHERE name = "Red";
UPDATE account SET balance = balance + 100 WHERE name = “Blue";
COMMIT TRANSACTION;
```

```
<Tx 1, Begin>
<Tx 1, Set Value, Record 1, Offset 30, Old 3300, New 3200>
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Undo: 將值改回 3300

一個小問題

我該先更新 record

還是

先寫 log 呢？

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Quick Answer: Write-Ahead Logging

有興趣可以自己查查～

Consistency ?

Consistency ?

Locks 可以幫上忙！

把正在存取的東西鎖起來

```
UPDATE account
SET balance = balance - 100
WHERE name = "Red";
```

Transaction 1

id	name	balance
1	Red	3300
2	Blue	2200
3	Green	4000

把正在存取的東西鎖起來

```
UPDATE account
SET balance = balance - 100
WHERE name = "Red";
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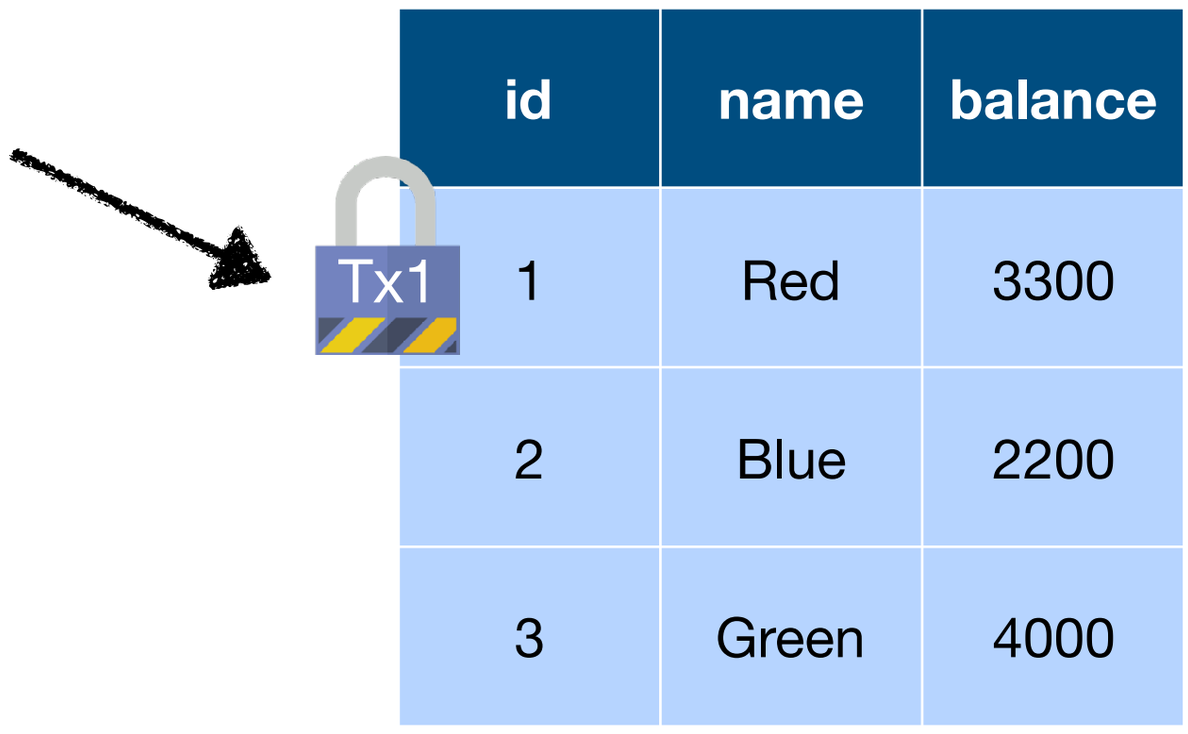
Transaction 1



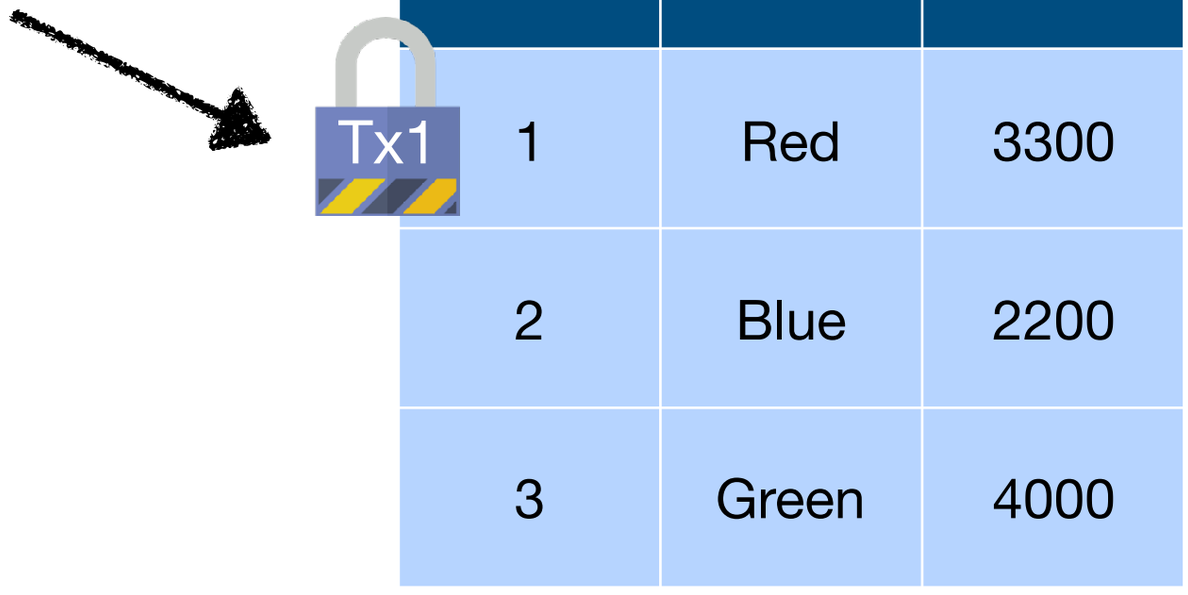
把正在存取的東西鎖起來

```sql
UPDATE account
SET balance = balance - 100
WHERE name = "Red";
```

Transaction 1

```sql
SELECT balance FROM account
WHERE name = "Red";
```

Transaction 2



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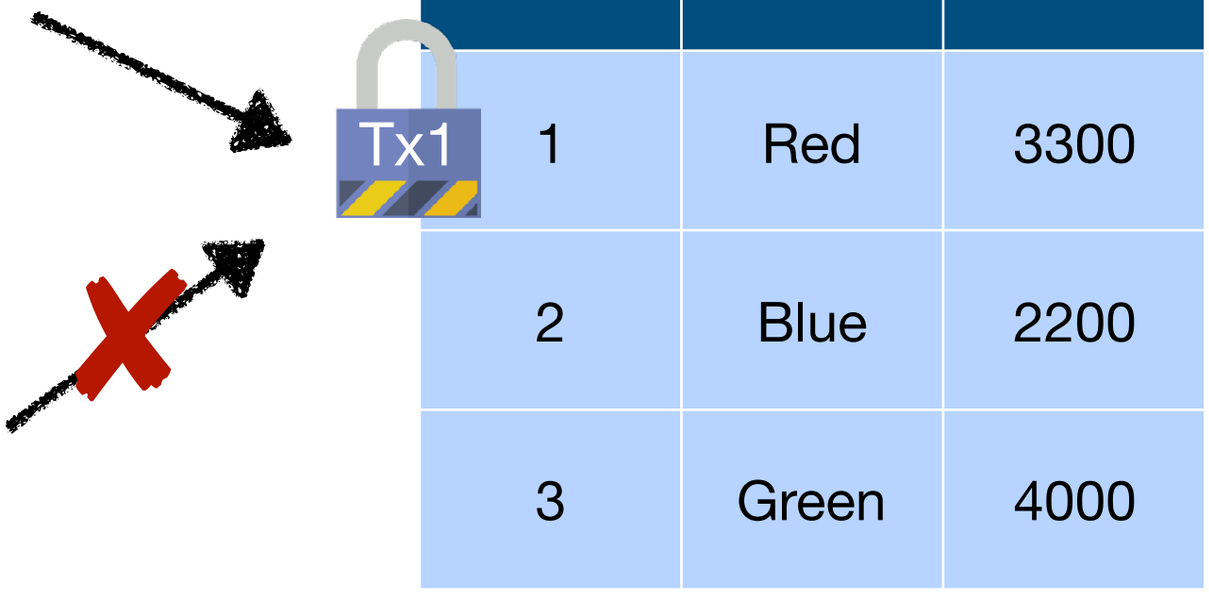

有種東西叫做 Deadlock

Transaction 1

Transaction 2

id	name	balance
1	Red	3300
2	Blue	2200
3	Green	4000

Deadlock 了怎麼辦？

- 考驗 Operating Systems 學得怎樣的時候到啦！
- 常見做法
  - Deadlock-detection
  - Deadlock-avoidance
  - Deadlock-free locking
- 注意每種做法的 trade-off

Isolation ?

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又是 Locks！

Isolation Levels

- 這裡的難點是在於怎麼同時支援不同的 Isolation Level
  - 什麼時候取得 lock
  - 什麼時候釋放 lock
  - 哪種 lock 要拿？
- 有興趣可以自己查查看 :)

Durability ?

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你需要的是...

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你需要的是...

一顆硬碟！（或很多顆）

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你需要的是...

一顆硬碟！（或很多顆）

記得存檔

等等... 硬碟不是很慢嗎

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好吧... 你可能需要...

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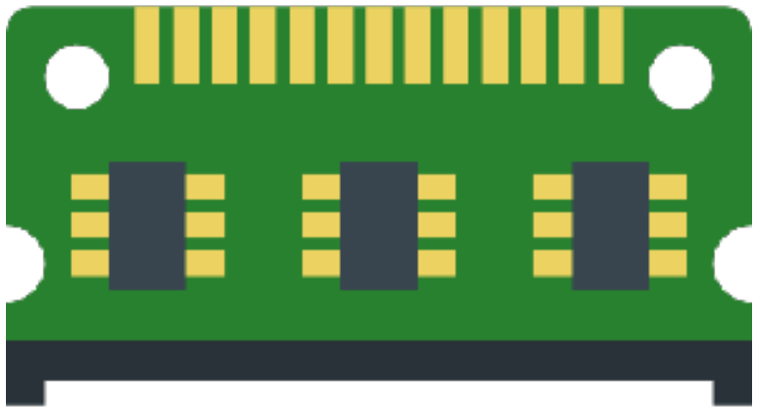

幾打的記憶體加速一下

嗯... 那電腦斷電時
存在記憶體的資料怎麼辦

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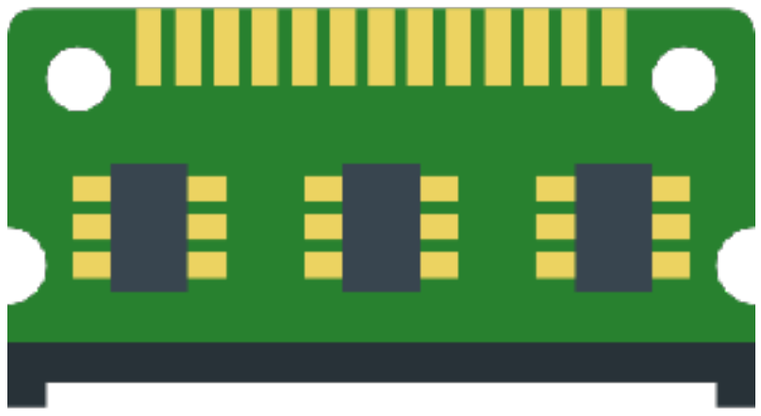

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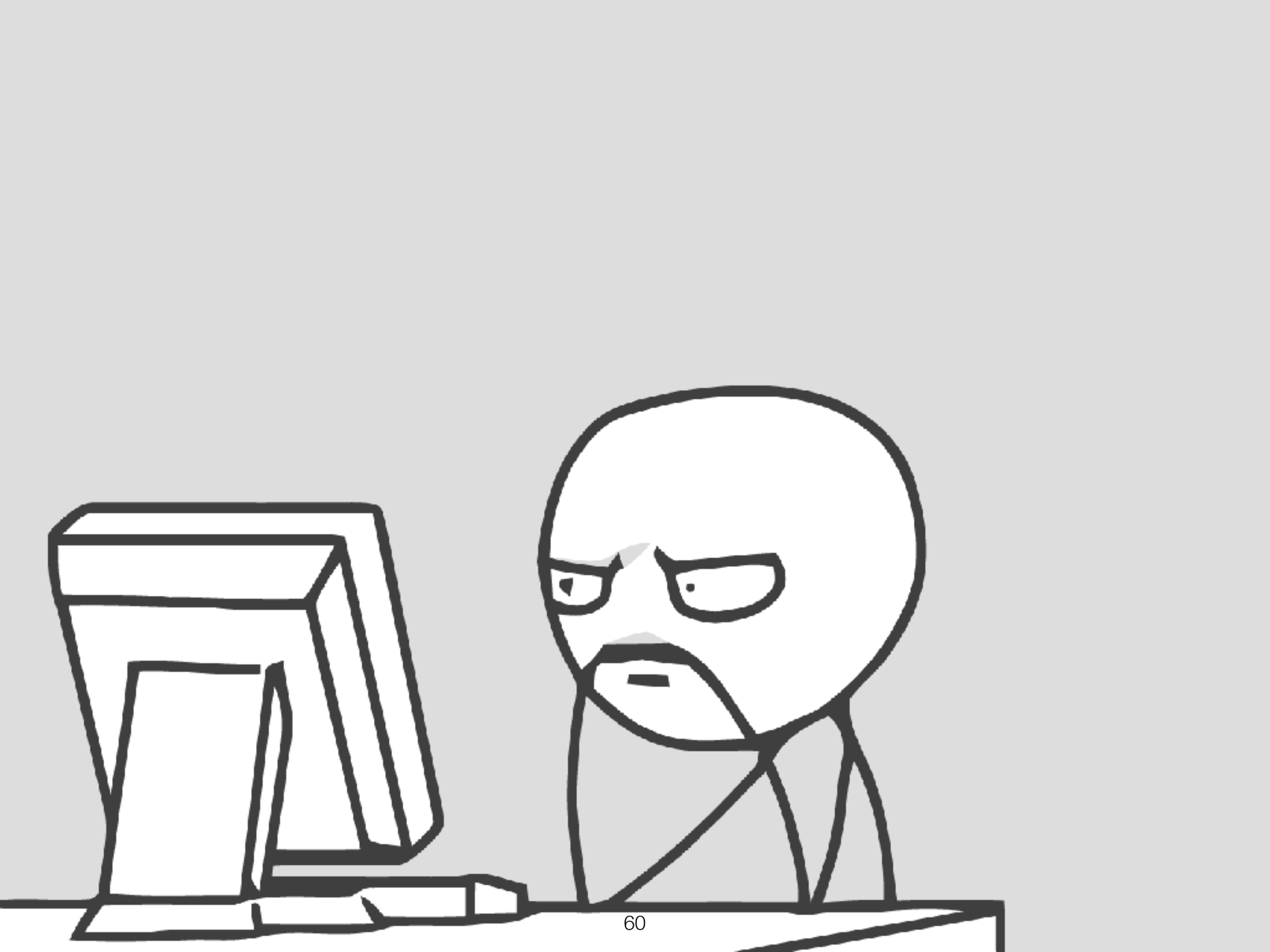
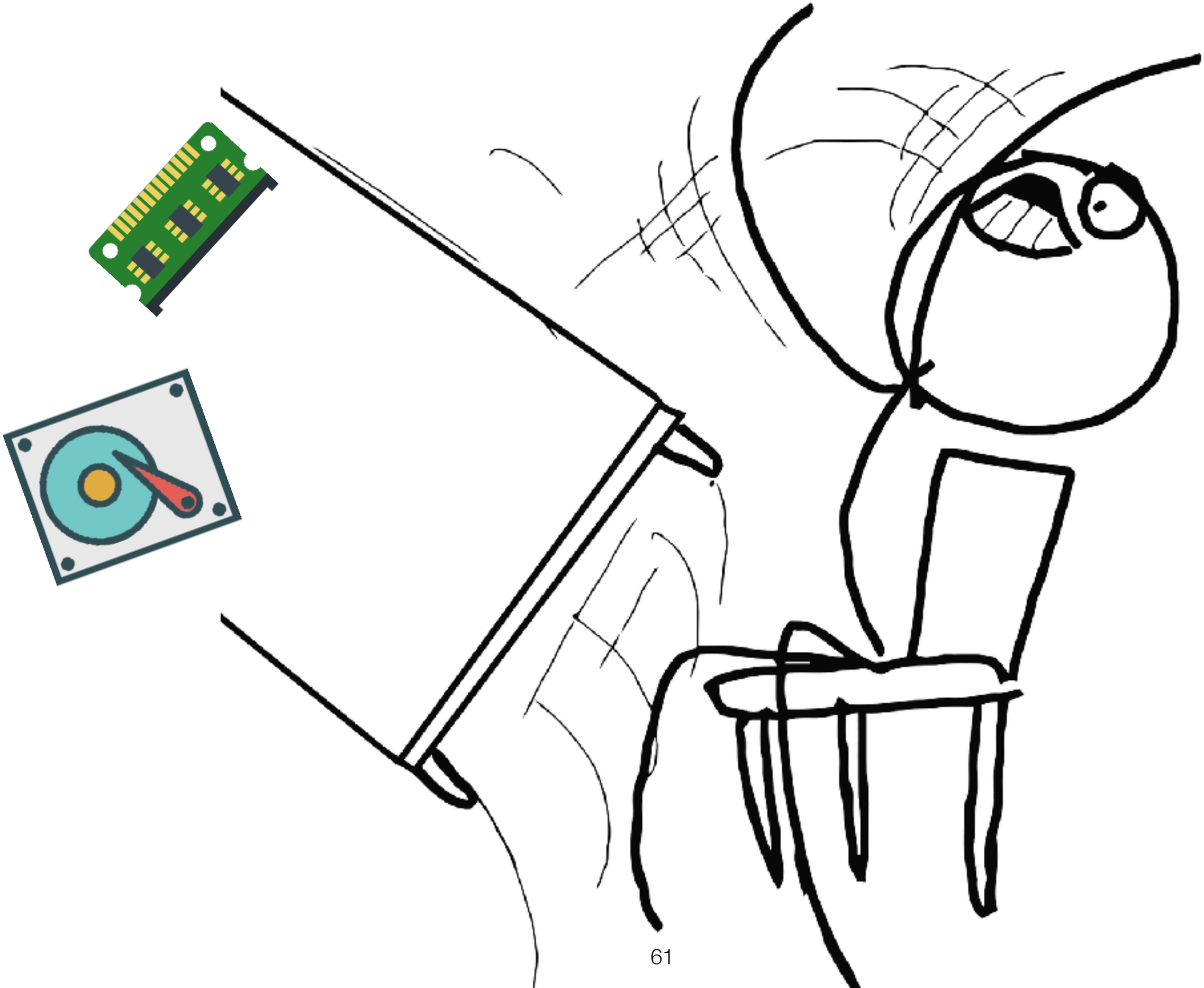
誒... 可是這樣 commit 不會很慢嗎？





其實只要存 logs 就好

DBMS 可以看你的 log 來復原資料

“If you are good enough to write code for a DBMS, then you can write code on almost anything else.”

- Andy Pavlo @ CMU 15-721

References

- 台灣資源
  - Introduction to Database System @ NTHU
- 國外資源
  - Introduction to Database Systems @ CMU
  - Advanced Database Systems @ CMU

Q&A

VanillaDB