

# 資料庫管理 HW04

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1. To check if PostgreSQL can avoid dirty read, I design two transactions:

- Transaction A: Update balance to 999 of account\_id 1

---

```
1      begin;
2      update accounts set balance = 999 where account_id = 1;
3      commit;
```

---

- Transaction B: Read the record.

---

```
1      begin;
2      select * from accounts where account_id = 1;
3      commit;
```

---

The execution steps are as follows:

- (a) Transaction A begins.
- (b) Transaction A updates balance to 1000 of account\_id 1, but does not commit yet.
- (c) Transaction B begins.
- (d) Transaction B reads the record of account\_id 1.
- (e) Transaction B gets the old balance (not 1000), which means dirty read is avoided.
- (f) Transaction B commits.
- (g) Transaction A commits.
- (h) Transaction B begins.
- (i) Transaction B reads the record of account\_id 1.
- (j) Transaction B gets the new balance (1000) after Transaction A commits.
- (k) Transaction B commits.

Following are the screenshots of each step. Left panel shows Transaction A, right panel shows Transaction B. Figure 1 shows the original status of the accounts table, we can see the balance of account\_id 1 is 1000. Figure 2 shows Transaction A updates balance to

1000 of account\_id 1 but does not commit yet, so that Transaction B still reads the old balance (1000). Figure 3 shows Transaction A commits, and then Transaction B reads the new balance (1000) of account\_id 1.

```
postgres=# select * from accounts;
 account_id | balance 
-----+-----
          2 |      10
          1 |     999
(2 rows)

postgres=#
```

```
postgres=#
```

Figure 1: Original status of the accounts table

<pre> postgres=# select * from accounts;  account_id   balance -----+-----            2        10            1       999 (2 rows)  postgres=# begin; update accounts set bal ance = 1000 where account_id = 1; BEGIN UPDATE 1 postgres=## </pre>	<pre> postgres=# begin; select * from accounts where account_id = 1; commit; BEGIN  account_id   balance -----+-----            1       999 (1 row)  COMMIT postgres=# </pre>
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Figure 2: Transaction A updates balance to 1000 of account\_id 1, but does not commit yet

<pre> postgres=# select * from accounts;  account_id   balance -----+-----            2        10            1       999 (2 rows)  postgres=# begin; update accounts set bal ance = 1000 where account_id = 1; BEGIN UPDATE 1 postgres=## commit; COMMIT postgres=# </pre>	<pre> postgres=# begin; select * from accounts where account_id = 1; commit; BEGIN  account_id   balance -----+-----            1       999 (1 row)  COMMIT postgres=# begin; select * from accounts where account_id = 1; commit; BEGIN  account_id   balance -----+-----            1      1000 (1 row)  COMMIT postgres=# </pre>
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Figure 3: Transaction A commits, Transaction B reads the new balance of account\_id 1

With the experiments above, we can see that PostgreSQL can avoid dirty read.

2. (a) A conflict occurs when two transactions access the same data item and at least one of the accesses is a write operation. For item  $X$ , three conflicts occurs between  $\{O_{11}, O_{23}\}$ ,  $\{O_{17}, O_{21}\}$ ,  $\{O_{17}, O_{23}\}$ ; for item  $Y$ , there are no conflicts; for item  $Z$ , two conflicts occurs between  $\{O_{15}, O_{24}\}$ ,  $\{O_{15}, O_{26}\}$ .
- (b) The serial schedule of  $T_2 \rightarrow T_1$  is as follows:

$$O_{21} \rightarrow O_{23} \rightarrow O_{24} \rightarrow O_{26} \rightarrow O_{11} \rightarrow O_{12} \rightarrow O_{13} \rightarrow O_{15} \rightarrow O_{17}.$$

To analyze the conflicting operation pairs, we can discuss by data items:

For item  $X$ , the operation order must obey:  $O_{21} \prec O_{23} \prec O_{17}$ ,  $O_{23} \prec O_{11} \prec O_{17}$

For item  $Y$ , there are no conflicts, so there is no constraint.

For item  $Z$ , the operation order must obey:  $O_{24} \prec O_{26} \prec O_{15}$

Therefore, one such conflict-equivalent non-serial schedule is:

$$O_{21} \rightarrow O_{23} \rightarrow O_{11} \rightarrow O_{24} \rightarrow O_{26} \rightarrow O_{12} \rightarrow O_{13} \rightarrow O_{15} \rightarrow O_{17}.$$

- (c) The serial schedule of  $T_1 \rightarrow T_2$  is as follows:

$$O_{11} \rightarrow O_{12} \rightarrow O_{13} \rightarrow O_{15} \rightarrow O_{17} \rightarrow O_{21} \rightarrow O_{23} \rightarrow O_{24} \rightarrow O_{26}.$$

Consider the last operation of  $T_1$  and the first operation of  $T_2$ , we have  $O_{17} \prec O_{21}$  because  $O_{17}$  is the write operation and they access the same data item  $X$ .

To maintain the order within the transactions,  $O_{17}$  must be the last operation in the schedule and  $O_{21}$  must be the first operation in the schedule. From the analyze above,  $O_{21}$  must after  $O_{17}$ . Therefore, there is no such conflict-equivalent non-serial schedule.

- (d) Following is the 2PL table for the two transactions:

Table 1: 2PL tables for transactions T1 and T2

(a) Transaction T1 under 2PL			(b) Transaction T2 under 2PL		
id	Operation	Phase	id	Operation	Phase
$L_{11}$	read_lock(X)	Expanding	$L_{21}$	read_lock(X)	Expanding
$O_{11}$	read_item(X)	-	$O_{21}$	read_item(X)	-
$L_{12}$	read_lock(Y)	Expanding	$O_{22}$	$X \leftarrow X + 10$	-
$O_{12}$	read_item(Y)	-	$L_{22}$	write_lock(X)	Expanding
$L_{13}$	read_lock(Z)	Expanding	$O_{23}$	write_item(X)	-
$O_{13}$	read_item(Z)	-	$L_{23}$	read_lock(Z)	Expanding
$O_{14}$	$Z \leftarrow X + Y$	-	$O_{24}$	read_item(Z)	-
$L_{14}$	write_lock(Z)	Expanding	$O_{25}$	$Z \leftarrow Z + X$	-
$O_{15}$	write_item(Z)	-	$O_{26}$	read_item(Z)	-
$O_{16}$	$X \leftarrow 100$	-	$L_{24}$	unlock(X)	Shrinking
$L_{15}$	write_lock(X)	Expanding	$L_{25}$	unlock(Z)	Shrinking
$O_{17}$	write_item(X)	-			
$L_{16}$	unlock(X)	Shrinking			
$L_{17}$	unlock(Y)	Shrinking			
$L_{18}$	unlock(Z)	Shrinking			

- (e) Following is one possible conflict-serializable schedule that would lead to deadlock under 2PL:

Table 2: A non-serializable interleaving that leads to deadlock under 2PL

id	T1	T2	Phase
L11	read_lock(X)		Expanding
O11	read_item(X)		-
L21		read_lock(X)	Expanding
O21		read_item(X)	-
L22		write_lock(X)	<b>Blocked</b> (T1 holds X-R)
L12	read_lock(Y)		Expanding
O12	read_item(Y)		-
L13	read_lock(Z)		Expanding
O13	read_item(Z)		-
L14	write_lock(Z)		<b>Blocked</b> (T2 holds Z-R)
<b>Deadlock:</b> $T_1$ waits for $Z$ while $T_2$ waits for $X$ .			
Wait-for cycle: $T_1 \rightarrow T_2 \rightarrow T_1$			

3. Lost update often occurs when two transactions read the same version of a data item and then update it based on that old value. This causes one update to overwrite the other, resulting in one update being lost. To address this issue, we can acquire a read lock before reading the data item so that other transactions cannot write to it until the read lock is released. This prevents the read operation from being interfered with by concurrent writes. Before updating the data, we can upgrade the read lock to a write lock to prevent other transactions from reading or writing the item until the write lock is released. This prevents other transactions from accessing the data while it is being updated, ensuring data integrity.
4. (a) This SQL statement queries the top 10 reserved sales for trips that depart from station\_id 1030 and arrive at station\_id 1000 during the period from 2023-08-01 to 2023-08-31, and the train must depart after 06:00. It joins the PASS table with itself on trip\_id, where p1 represents the departure station (1030) and p2 represents the arrival station (1000). After joining, it selects each trip's departure and arrival time, and uses a subquery to count how many tickets were reserved for that same trip and same station pair within the specified date range. Finally, the results are ordered by departure time and limited to the first 10 row
- (b) Fig. 4 is the query plan generated by PostgreSQL for the SQL statement above, the estimated cost is 3750384.97.

```

Limit (cost=66.83..986992.66 rows=10 width=28)
→ Result (cost=66.83..3750384.97 rows=38 width=28)
→ Sort (cost=66.83..66.93 rows=38 width=20)
    Sort Key: p1.depart_time
    → Hash Join (cost=35.44..66.01 rows=38 width=20)
        Hash Cond: (p2.trip_id = p1.trip_id)
        Join Filter: (p1.depart_time < p2.arrive_time)
        → Seq Scan on pass p2 (cost=0.00..30.06 rows=195 width=12)
            Filter: (station_id = 1000)
        → Hash (cost=34.08..34.08 rows=109 width=12)
            → Seq Scan on pass p1 (cost=0.00..34.08 rows=109 width=12)
                Filter: ((depart_time > '06:00:00'::time without time zone) AND (station_id = 1030))
    SubPlan 1
        → Aggregate (cost=98692.56..98692.57 rows=1 width=8)
            → Seq Scan on reserved_ticket (cost=0.00..98692.18 rows=151 width=0)
                Filter: ((travel_date ≥ '2023-08-01'::date) AND (travel_date ≤ '2023-08-31'::date) AND (trip_id = p1.trip_id) AND (depart_station_id = 1030) AND (arrive_station_id = 1000))
JIT:
Functions: 27
Options: Inlining true, Optimization true, Expressions true, Deforming true
(19 rows)

```

Figure 4: Query Plan without Index

- (c) Following is the code to create index on trip\_id, depart\_station\_id, and arrive\_station\_id, trip\_id appears in both pass and reserved\_ticket table, but the bottleneck is in the subquery which accesses reserved\_ticket table, so I decide to create index on trip\_id in reserved\_ticket table.

---

```

1 create index idx_trip_id on reserved_ticket(trip_id);
2
3 create index idx_depart_station_id on reserved_ticket(depart_station_id);
4
5 create index idx_arrive_station_id on reserved_ticket(arrive_station_id);

```

---

Fig. 5 is the query plan after creating index on `trip_id`, Fig. 6 is the query plan after creating index on `depart_station_id`, Fig. 7 is the query plan after creating index on `arrive_station_id`.

For each index created, the estimated costs are as follows:

Index Created	Estimated Cost
no index	3750384.97
<code>trip_id</code>	1024884.52
<code>depart_station_id</code>	1559993.73
<code>arrive_station_id</code>	1731233.13

We can observe that creating an index on `trip_id` significantly reduces the estimated cost from 3750384.97 to 1024884.52, indicating a substantial improvement in query performance. However, creating indexes on `depart_station_id` and `arrive_station_id` also reduces the estimated costs, but not as significantly as the `trip_id` index. This suggests that while these indexes do help, they are not as effective in optimizing the query as the

```

Limit (cost=66.83..269755.70 rows=10 width=28)
  → Result (cost=66.83..1024884.52 rows=38 width=28)
    → Sort (cost=66.83..66.93 rows=38 width=20)
      Sort Key: p1.depart_time
      → Hash Join (cost=35.44..66.01 rows=38 width=20)
        Hash Cond: (p2.trip_id = p1.trip_id)
        Join Filter: (p1.depart_time < p2.arrive_time)
        → Seq Scan on pass p2 (cost=0.00..30.06 rows=195 width=12)
          Filter: (station_id = 1000)
        → Hash (cost=34.08..34.08 rows=109 width=12)
          → Seq Scan on pass p1 (cost=0.00..34.08 rows=109 width=12)
            Filter: ((depart_time > '06:00:00'::time without time zone) AND (station_id = 1030))
      SubPlan 1
        → Aggregate (cost=26968.86..26968.87 rows=1 width=8)
          → Bitmap Heap Scan on reserved_ticket (cost=163.24..26968.49 rows=151 width=0)
            Recheck Cond: (trip_id = p1.trip_id)
            Filter: ((travel_date ≥ '2023-08-01'::date) AND (travel_date ≤ '2023-08-31'::date) AND (depart_station_id = 1030) AND (arrive_station_id = 1000))
            → Bitmap Index Scan on idx_trip_id (cost=0.00..163.20 rows=14770 width=0)
              Index Cond: (trip_id = p1.trip_id)
JIT:
  Functions: 30
  Options: Inlining false, Optimization false, Expressions true, Deforming true
(22 rows)

```

Figure 5: Query Plan with `trip_id` Index

```

Limit (cost=66.83..410573.91 rows=10 width=28)
  → Result (cost=66.83..155993.73 rows=38 width=28)
    → Sort (cost=66.83..66.93 rows=38 width=20)
      Sort Key: p1.depart_time
      → Hash Join (cost=35.44..66.01 rows=38 width=20)
        Hash Cond: (p2.trip_id = p1.trip_id)
        Join Filter: (p1.depart_time < p2.arrive_time)
        → Seq Scan on pass p2 (cost=0.00..30.06 rows=195 width=12)
          Filter: (station_id = 1000)
        → Hash (cost=34.08..34.08 rows=109 width=12)
          Seq Scan on pass p1 (cost=0.00..34.08 rows=109 width=12)
            Filter: ((depart_time > '06:00:00'::time without time zone) AND (station_id = 1030))
      SubPlan 1
        → Aggregate (cost=41050.69..41050.70 rows=1 width=8)
          → Bitmap Heap Scan on reserved_ticket (cost=2553.93..41050.31 rows=151 width=0)
            Recheck Cond: (depart_station_id = 1030)
            Filter: ((travel_date ≥ '2023-08-01'::date) AND (travel_date ≤ '2023-08-31'::date) AND (trip_id = p1.trip_id) AND (arrive_station_id = 1000))
            → Bitmap Index Scan on idx_depart_station_id (cost=0.00..2553.89 rows=234328 width=0)
              Index Cond: (depart_station_id = 1030)
JIT:
Functions: 30
Options: Inlining false, Optimization false, Expressions true, Deforming true
(22 rows)

```

Figure 6: Query Plan with depart\_station\_id Index

```

Limit (cost=66.83..455636.91 rows=10 width=28)
  → Result (cost=66.83..1731233.13 rows=38 width=28)
    → Sort (cost=66.83..66.93 rows=38 width=20)
      Sort Key: p1.depart_time
      → Hash Join (cost=35.44..66.01 rows=38 width=20)
        Hash Cond: (p2.trip_id = p1.trip_id)
        Join Filter: (p1.depart_time < p2.arrive_time)
        → Seq Scan on pass p2 (cost=0.00..30.06 rows=195 width=12)
          Filter: (station_id = 1000)
        → Hash (cost=34.08..34.08 rows=109 width=12)
          Seq Scan on pass p1 (cost=0.00..34.08 rows=109 width=12)
            Filter: ((depart_time > '06:00:00'::time without time zone) AND (station_id = 1030))
      SubPlan 1
        → Aggregate (cost=45556.99..45557.00 rows=1 width=8)
          → Bitmap Heap Scan on reserved_ticket (cost=4022.50..45556.61 rows=151 width=0)
            Recheck Cond: (arrive_station_id = 1000)
            Filter: ((travel_date ≥ '2023-08-01'::date) AND (travel_date ≤ '2023-08-31'::date) AND (trip_id = p1.trip_id) AND (depart_station_id = 1030))
            → Bitmap Index Scan on idx_arrive_station_id (cost=0.00..4022.46 rows=369338 width=0)
              Index Cond: (arrive_station_id = 1000)
JIT:
Functions: 30
Options: Inlining false, Optimization false, Expressions true, Deforming true
(22 rows)

```

Figure 7: Query Plan with arrive\_station\_id Index

- (d) Following is the code to create a composite index on `trip_id`, `depart_station_id`, and `arrive_station_id`:

---

```

1 create index idx_tda on reserved_ticket(trip_id, depart_station_id, arrive_station_id);

```

---

Fig. 8 is the query plan after creating a composite index on `trip_id`, `depart_station_id`, and `arrive_station_id`:

```

Limit (cost=66.83..5902.97 rows=10 width=28)
  → Result (cost=66.83..22244.14 rows=38 width=28)
    → Sort (cost=66.83..66.93 rows=38 width=20)
      Sort Key: p1.depart_time
      → Hash Join (cost=35.44..66.01 rows=38 width=20)
        Hash Cond: (p2.trip_id = p1.trip_id)
        Join Filter: (p1.depart_time < p2.arrive_time)
        → Seq Scan on pass p2 (cost=0.00..30.06 rows=195 width=12)
          Filter: (station_id = 1000)
        → Hash (cost=34.08..34.08 rows=109 width=12)
          → Seq Scan on pass p1 (cost=0.00..34.08 rows=109 width=12)
            Filter: ((depart_time > '06:00:00'::time without time zone) AND (station_id = 1030))
      SubPlan 1
        → Aggregate (cost=583.59..583.60 rows=1 width=8)
          → Bitmap Heap Scan on reserved_ticket (cost=6.36..583.21 rows=151 width=0)
            Recheck Cond: ((trip_id = p1.trip_id) AND (depart_station_id = 1030) AND (arrive_station_id = 1000))
            Filter: ((travel_date ≥ '2023-08-01'::date) AND (travel_date ≤ '2023-08-31'::date))
            → Bitmap Index Scan on idx_tda (cost=0.00..6.32 rows=151 width=0)
              Index Cond: ((trip_id = p1.trip_id) AND (depart_station_id = 1030) AND (arrive_station_id = 1000))
(19 rows)

```

Figure 8: Query Plan with Composite Index

5. (a) Fig. 9 shows the B+ tree index structure for the given data entries.

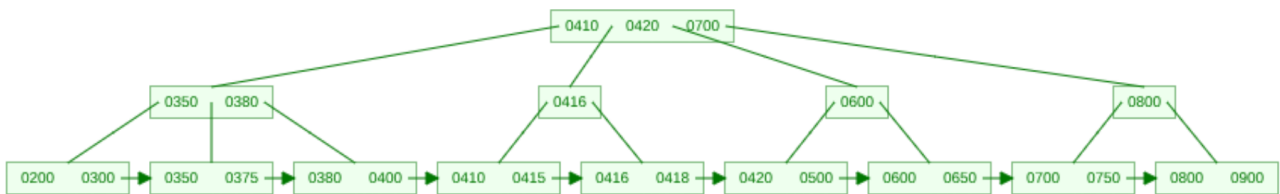


Figure 9: B+ Tree Index Structure

- (b) Fig. 10 shows the before and after inserting 700 into the B+ tree. We can see that a new inner node is created after the insertion because the leaf node would be full after inserting 700. Thus it splits into two leaf nodes, and an inner node 700 is created to point to these two leaf nodes.



Figure 10: Before and after insert 700

- (c) Fig. 11 shows the before and after inserting 350 into the B+ tree. As 350 is guided to the leftmost leaf node, and this leaf node is not full, we can simply insert 350 into this leaf node without any split.

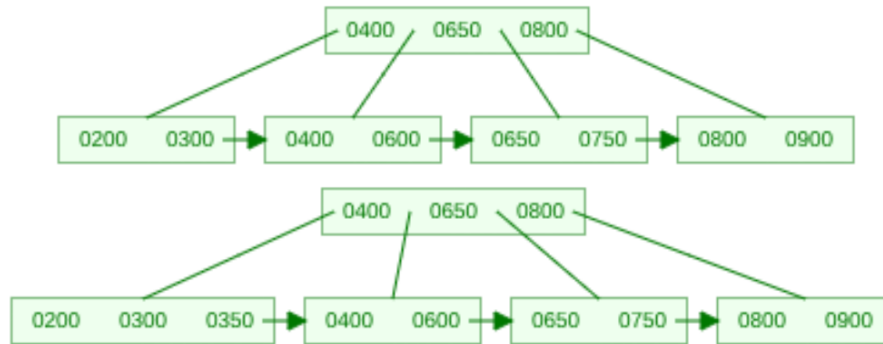


Figure 11: Before and after insert 350

- (d) Fig. 12 shows the before and after inserting 418 into the B+ tree. As the leaf node where 418 is guided to would be full after inserting 418, it splits into two leaf nodes. And a new inner node 418 is created to point to these two leaf nodes.

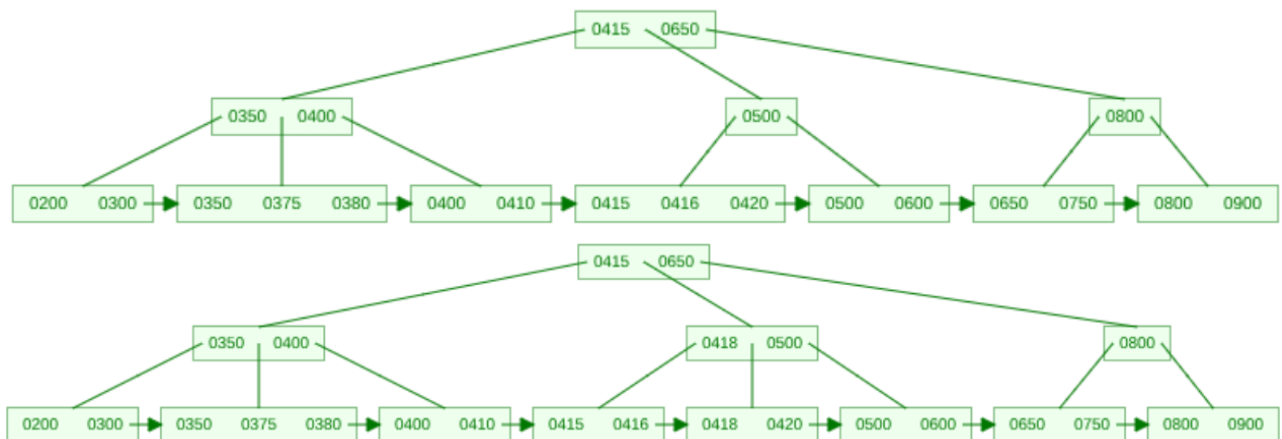


Figure 12: Before and after insert 418

- I noticed that the after creating the multicolumn index, the estimated cost is significantly reduced compared to the single-column indexes created earlier. This indicates that the multicolumn index is more effective in optimizing the query performance for this specific SQL statement. Therefore, I decided to try to assemble another columns used in the sub query to see if it can further improve the performance. In the multicolumn index of PostgreSQL, the order of the columns matters. Since the subquery filters on `trip_id`, `arrive_station_id`, `depart_station_id`, and `travel_date`, I decided to create an index with these columns in the order that best matches the filtering conditions.

Following may one possible index method to optimize the query performance for the given SQL statement:

---

```
1 create index idx on reserved_ticket(trip_id, arrive_station_id, depart_station_id, travel_date);
```

---

The query plan after creating the index is shown in Fig. 13:

```
Limit (cost=66.83..6655.43 rows=10 width=28)
  → Result (cost=66.83..25103.51 rows=38 width=28)
    → Sort (cost=66.83..66.93 rows=38 width=20)
      Sort Key: p1.depart_time
      → Hash Join (cost=35.44..66.01 rows=38 width=20)
        Hash Cond: (p2.trip_id = p1.trip_id)
        Join Filter: (p1.depart_time < p2.arrive_time)
        → Seq Scan on pass p2 (cost=0.00..30.06 rows=195 width=12)
          Filter: (station_id = 1000)
        → Hash (cost=34.08..34.08 rows=109 width=12)
          → Seq Scan on pass p1 (cost=0.00..34.08 rows=109 width=12)
            Filter: ((depart_time > '06:00:00'::time without time zone) AND (station_id = 1030))
      SubPlan 1
        → Aggregate (cost=658.84..658.85 rows=1 width=8)
          → Index Only Scan using idx_reserve_optimized on reserved_ticket (cost=0.43..658.46 rows=151 width=0)
            Index Cond: ((depart_station_id = 1030) AND (arrive_station_id = 1000) AND (travel_date ≥ '2023-08-01'::date) AND (travel_date ≤ '2023-08-31'::date) AND (trip_id = p1.trip_id))
            (16 rows)
```

Figure 13: Query Plan after creating optimized index

We can see that the estimated cost is further reduced to 560.17 after creating the optimized index, which is significantly lower than the previous costs. This indicates that the new index is highly effective in improving the query performance for the given SQL statement.