CS4221 Tutorial 2
Tuning in PostgreSQL

Yao LU

2024 Semester 2

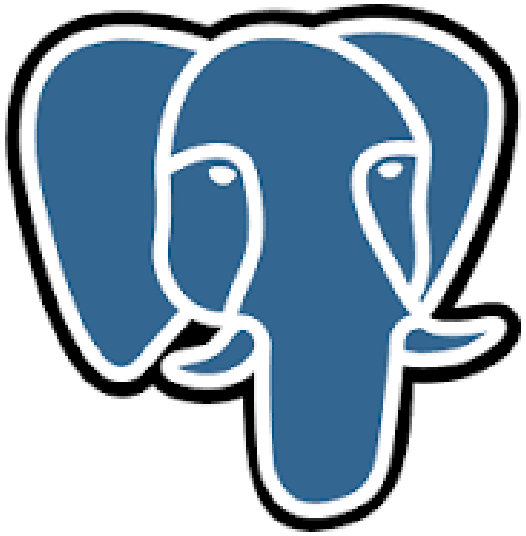
National University of Singapore
School of Computing

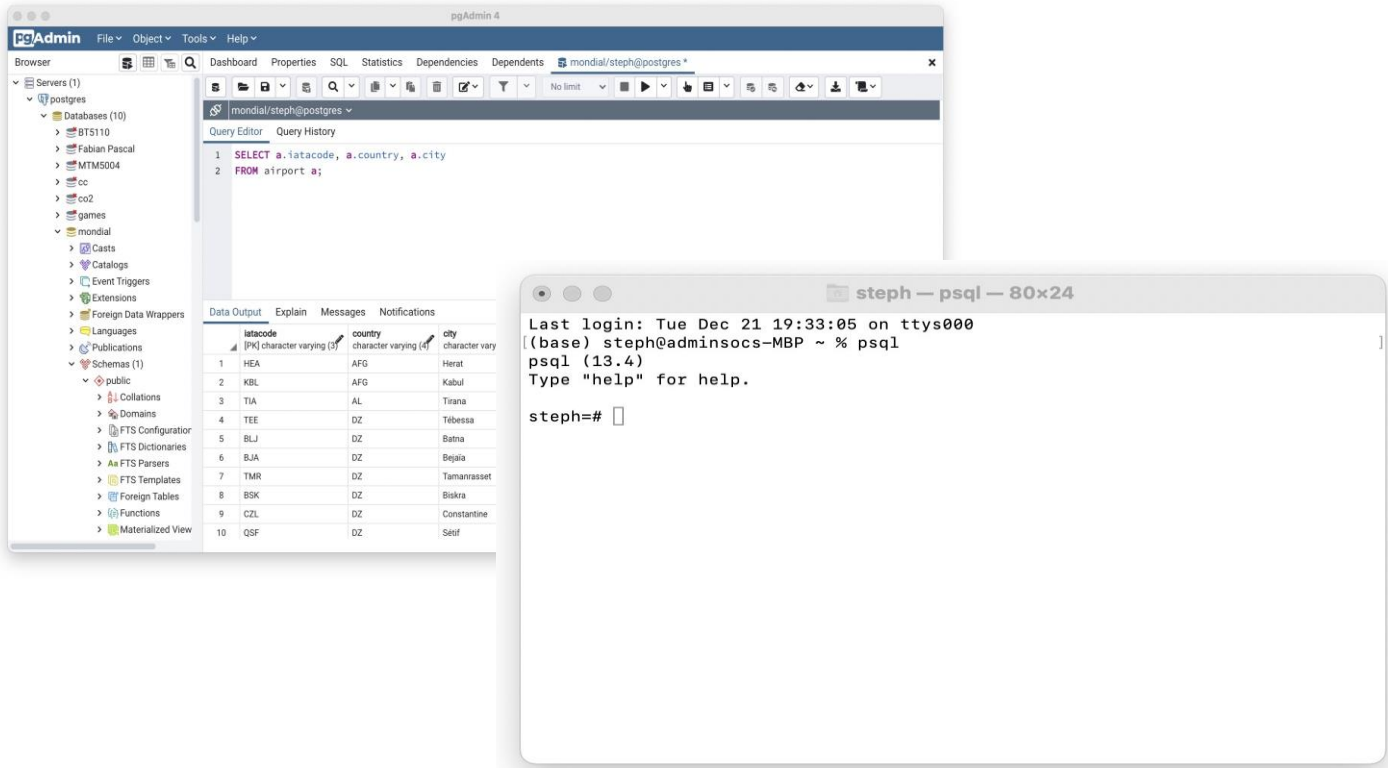
Goals

- Demo
  - How to Use pgAdmin 4 with PostgreSQL
- Tuning Strategies

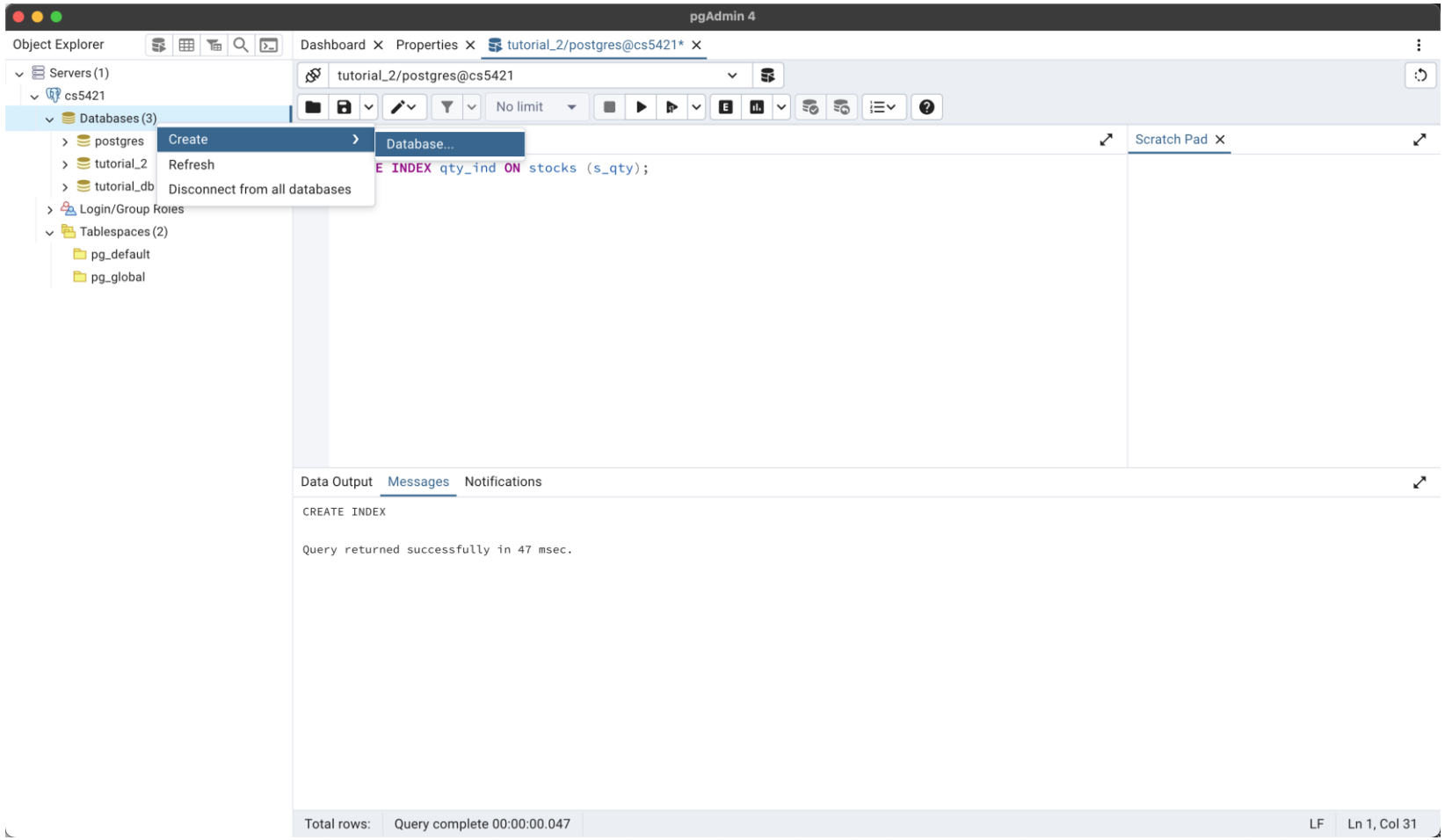
pgAdmin 4

- We use the relational database management system PostgreSQL with pgAdmin 4.





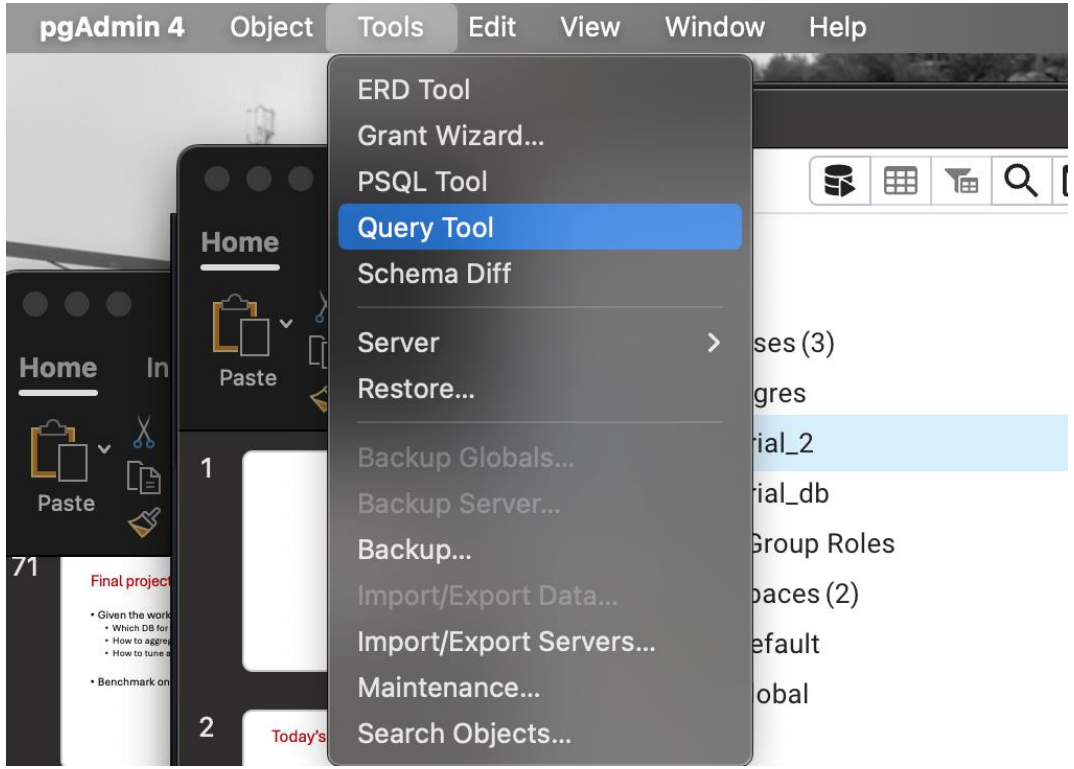
pgAdmin 4 – Create a new Database



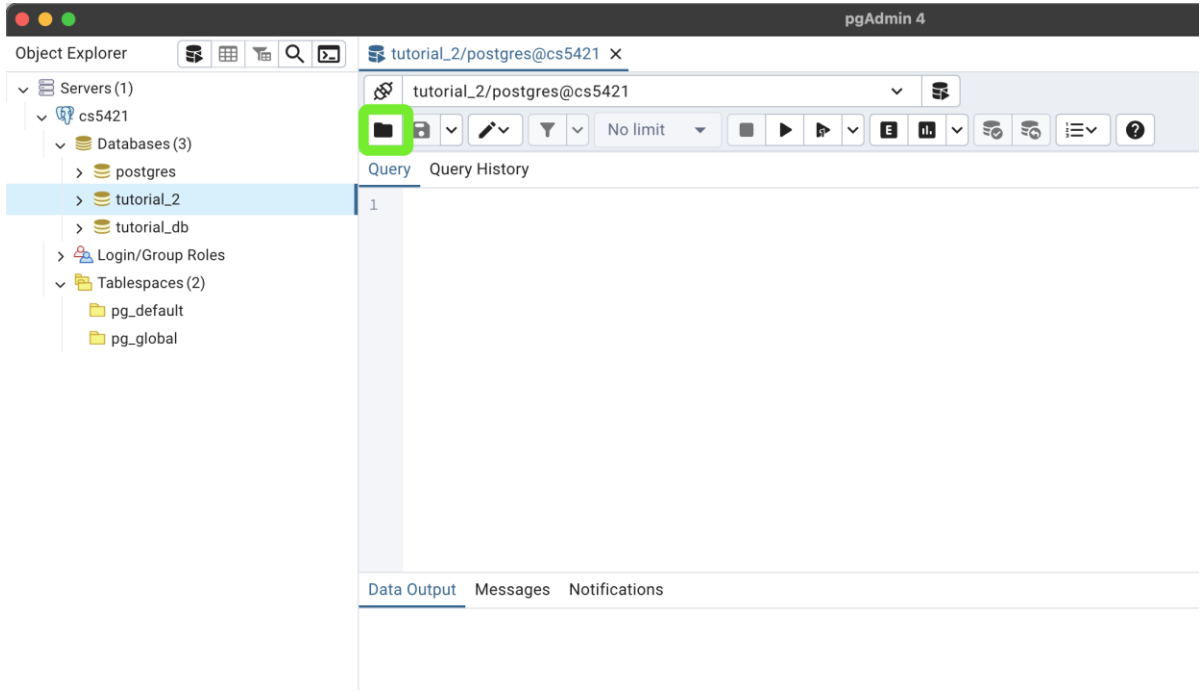
Name it as “tutorial_2”

pgAdmin 4 – Import/Edit SQL

1. Open Query Tool

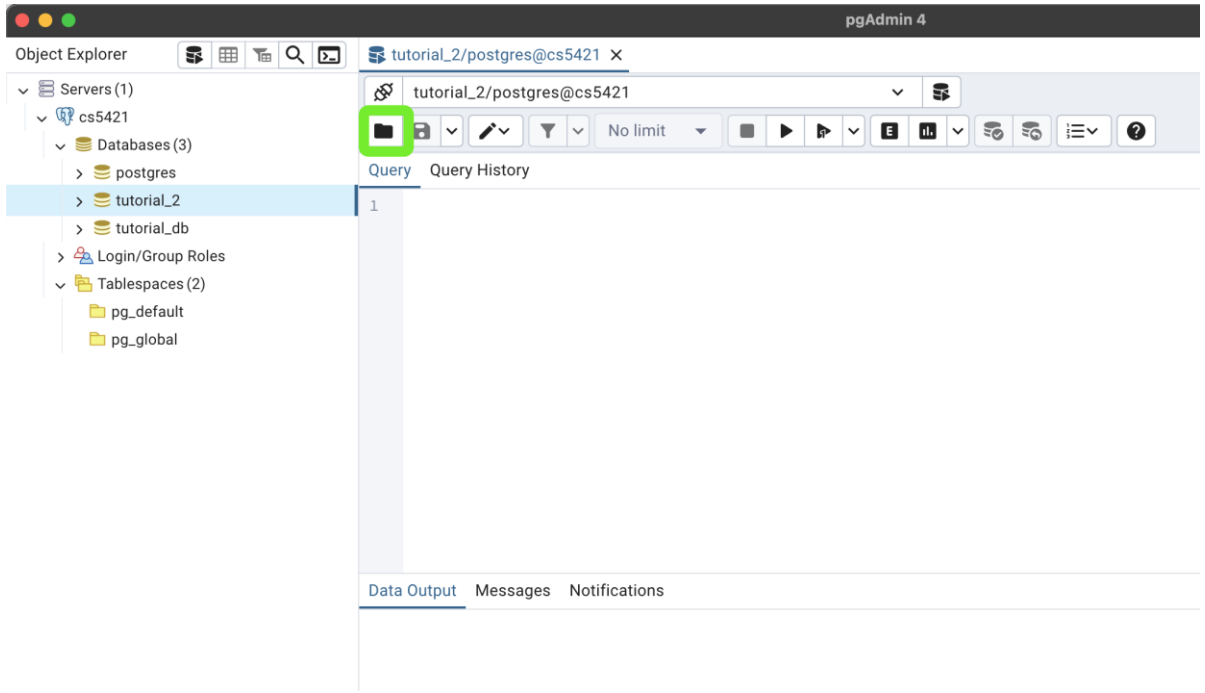


2. Select the prepared SQL files and run it



pgAdmin 4 – Import/Edit SQL

2. Select the prepared SQL files and run it

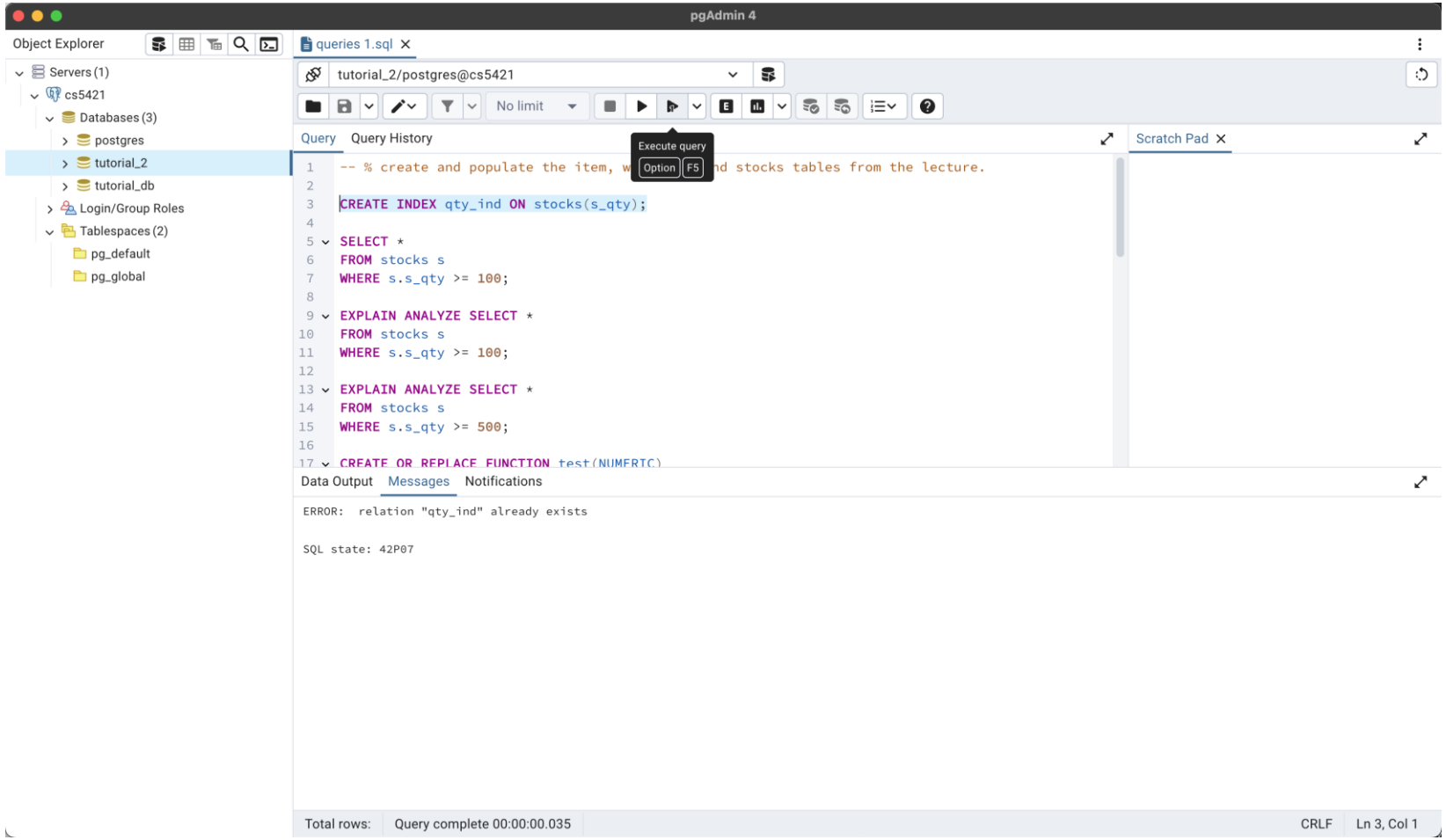


- Import the TPC-C data (items, stocks, warehouses) from TPC-C folder
- Import the crossword data (crossword.sql).
- Prepare queries 1.sql and queries 2.sql file

pgAdmin 4 – Run SQL

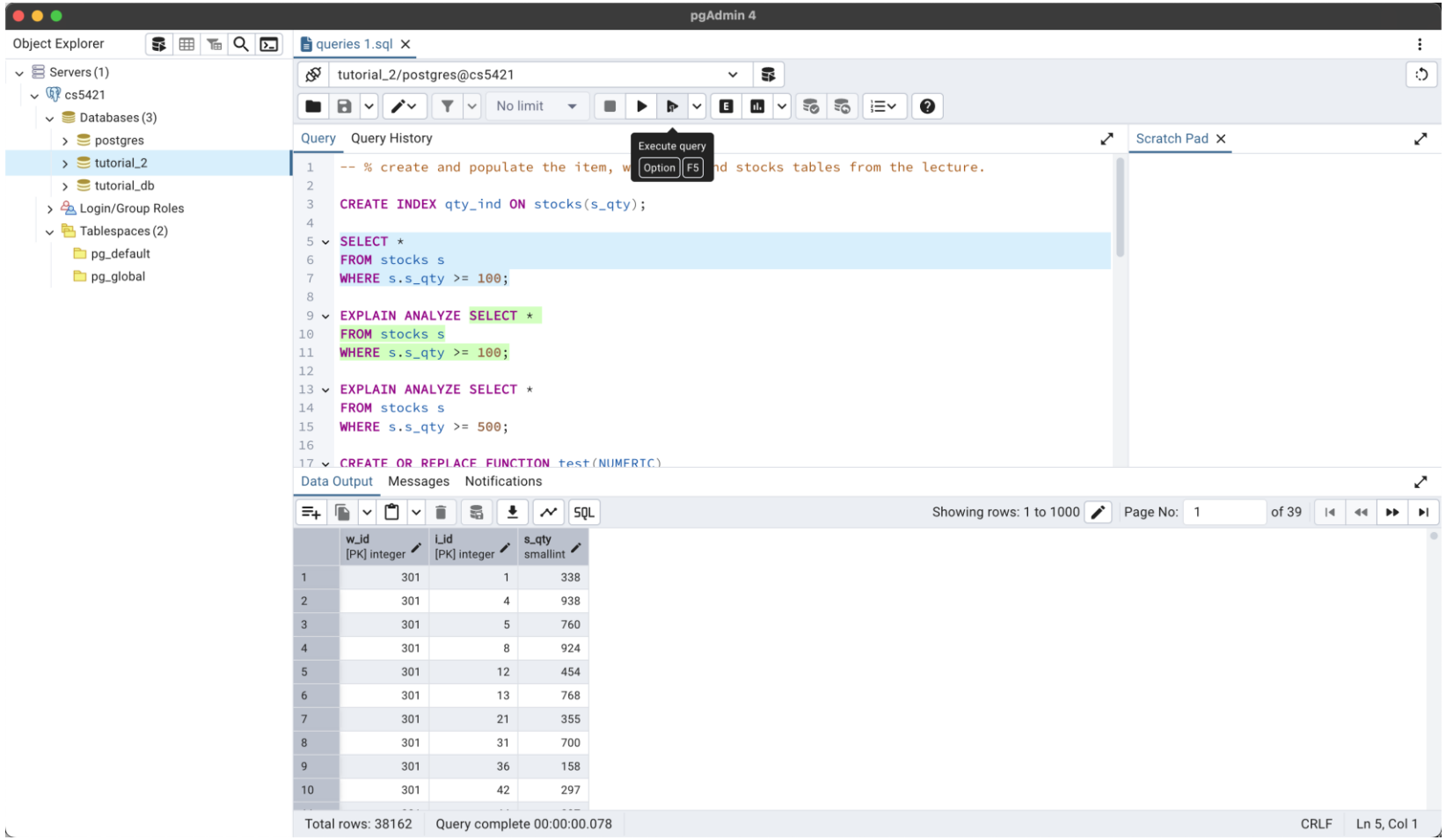
Let's start with queries 1.sql...

Select the desired SQL query and Press "Execute Query" to execute a single query each time



pgAdmin 4 – Run SQL

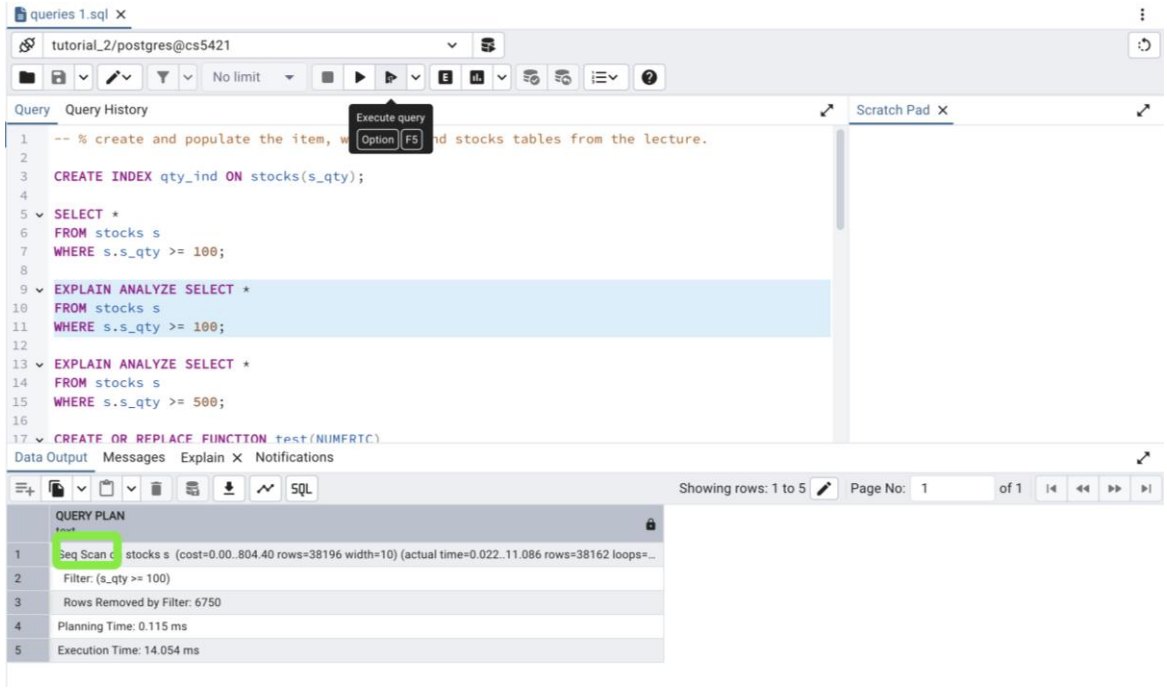
Write the SQL query that finds the items in quantity larger than or equal to 100.



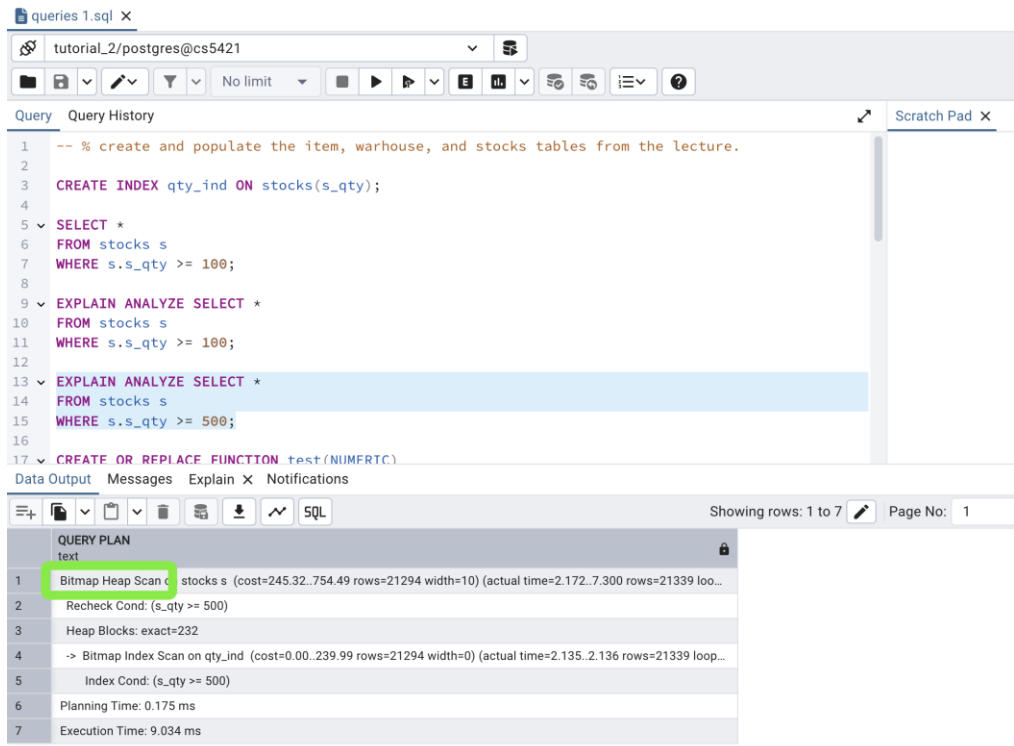
pgAdmin 4 – Run SQL

Print the query plan, planning time, and execution time for queries with different quantities.
"Use EXPALAIN ANALYZE"

s_qty > = 100:



s_qty > = 500:



pgAdmin 4 – Run SQL

Create a stored function test(N) that prints the plan for the query that finds the items in quantity larger than or equal to N.

```
CREATE OR REPLACE FUNCTION test(NUMERIC)

RETURNS SETOF TEXT AS $$

BEGIN

RETURN QUERY EXECUTE

'EXPLAIN SELECT *

FROM stocks s

WHERE s.s_qty >= ' ||$1 ;

END

$$ LANGUAGE plpgsql;
```

pgAdmin 4 – Run SQL

Create a stored function stat(N) that finds the percentage of items in quantity larger than N, that is the selectivity of the condition.

```
CREATE OR REPLACE FUNCTION stat(NUMERIC)

RETURNS SETOF NUMERIC AS $$

BEGIN

RETURN QUERY EXECUTE

'SELECT ROUND((COUNT(*)::NUMERIC /(SELECT COUNT(*)

                                FROM stocks))

                               *100)

FROM stocks s

WHERE s.s_qty >= ' ||$1 ;

END

$$ LANGUAGE plpgsql;
```

pgAdmin 4 – Run SQL

Write an SQL query that tabulates the type of access for varying quantity (in hundreds) and corresponding selectivity.

```
39
40  SELECT q.qty, stat(q.qty),
41  regexp_replace((SELECT *
42  FROM test(q.qty) LIMIT 1),'(\.*)\(.*','\1')
43  FROM (SELECT DISTINCT ROUND(s_qty::NUMERIC/100)*100
44  AS qty FROM stocks) AS q
45  ORDER BY q.qty;
```

Data Output | Messages | Explain | Notifications

Showing rows: 1 to 11

	qty numeric	stat numeric	regexp_replace text
1	0	100	Seq Scan on stocks s
2	100	85	Seq Scan on stocks s
3	200	76	Seq Scan on stocks s
4	300	66	Seq Scan on stocks s
5	400	57	Seq Scan on stocks s
6	500	47	Bitmap Heap Scan on stocks s
7	600	38	Bitmap Heap Scan on stocks s
8	700	28	Bitmap Heap Scan on stocks s
9	800	19	Bitmap Heap Scan on stocks s
10	900	9	Bitmap Heap Scan on stocks s
11	1000	0	Index Scan using qty_ind on stocks…

Practice

Context:

In April 1990, Hal Berghel and Richard Rankin proposed a crossword benchmark in an article titled “A Proposed Standard for Measuring Crossword Compilation Efficiency”

The five rows and the five columns of the crossword are five letter words from a lexicon containing 134 entries. There are 72 solutions.

There are 24 solutions with unique words and not counting transpositions (identical solutions after interchanging rows and columns.)

The following is an example solution.

A	A	R	O	N
C	L	I	T	E
A	L	A	T	E
R	O	T	A	L
A	W	A	R	D

```
('R','O','P','E','R'),
('N','A','M','E','R'),
('O','C','H','N','A'),
('R','A','T','E','R'),
('R','O','T','A','L'),
('N','A','N','N','Y'),
('O','M','I','N','A'),
('R','E','B','U','D'),
('R','U','D','A','S'),
('N','A','S','A','L'),
('O','N','S','E','T'),
('R','E','B','U','T'),
('S','A','L','A','L'),
('N','A','T','A','L'),
('O','R','A','O','N'),
('R','E','C','O','N'),
('S','A','L','A','Y'),
```

If the word “AARON” is removed, there is no solution.
The lexicon is stored in the table word created and populated with the SQL script crossword.sql

Crossword

Run the simplest possible queries that find the solutions to the crossword problem with and without unique words and transposition.

Solution: *The following query finds all the solutions.*

```
SELECT * FROM
 word r1, word r2, word r3, word r4, word r5,
 word c1, word c2, word c3, word c4, word c5
    WHERE r1.a1=c1.a1 AND r1.a2=c2.a1 AND r1.a3=c3.a1 AND r1.a4=c4.a1 AND r1.a5=c5.a1
      AND r2.a1=c1.a2 AND r2.a2=c2.a2 AND r2.a3=c3.a2 AND r2.a4=c4.a2 AND r2.a5=c5.a2
      AND r3.a1=c1.a3 AND r3.a2=c2.a3 AND r3.a3=c3.a3 AND r3.a4=c4.a3 AND r3.a5=c5.a3
      AND r4.a1=c1.a4 AND r4.a2=c2.a4 AND r4.a3=c3.a4 AND r4.a4=c4.a4 AND r4.a5=c5.a4
      AND r5.a1=c1.a5 AND r5.a2=c2.a5 AND r5.a3=c3.a5 AND r5.a4=c4.a5 AND r5.a5=c5.a5;
```

Crossword

Run the simplest possible queries that find the solutions to the crossword problem with and without unique words and transposition.

Solution: *The following query finds the solutions with unique words and no transposition symmetry.*

```
SELECT * FROM
 word r1, word r2, word r3, word r4, word r5,
 word c1, word c2, word c3, word c4, word c5
                        /* answer the crossword */
    WHERE r1.a1=c1.a1 AND r1.a2=c2.a1 AND r1.a3=c3.a1 AND r1.a4=c4.a1 AND r1.a5=c5.a1
      AND r2.a1=c1.a2 AND r2.a2=c2.a2 AND r2.a3=c3.a2 AND r2.a4=c4.a2 AND r2.a5=c5.a2
      AND r3.a1=c1.a3 AND r3.a2=c2.a3 AND r3.a3=c3.a3 AND r3.a4=c4.a3 AND r3.a5=c5.a3
      AND r4.a1=c1.a4 AND r4.a2=c2.a4 AND r4.a3=c3.a4 AND r4.a4=c4.a4 AND r4.a5=c5.a4
      AND r5.a1=c1.a5 AND r5.a2=c2.a5 AND r5.a3=c3.a5 AND r5.a4=c4.a5 AND r5.a5=c5.a5

      /* rows cannot be the same */
      AND r1 <> r2 AND r1 <> r3 AND r1 <> r4 AND r1 <> r5
      AND r2 <> r3 AND r2 <> r4 AND r2 <> r5
      AND r3 <> r4 AND r3 <> r5
      AND r4 <> r5

      /* columns cannot be the same */
      AND c1 <> c2 AND c1 <> c3 AND c1 <> c4 AND c1 <> c5
      AND c2 <> c3 AND c2 <> c4 AND c2 <> c5
      AND c3 <> c4 AND c3 <> c5
      AND c4 <> c5

      /* row and column cannot be the same */
            AND r1 <> c2 AND r1 <> c3 AND r1 <> c4 AND r1 <> c5
      AND r2 <> c1 AND r2 <> c2 AND r2 <> c3 AND r2 <> c4 AND r2 <> c5
      AND r3 <> c1 AND r3 <> c2 AND r3 <> c3 AND r3 <> c4 AND r3 <> c5
      AND r4 <> c1 AND r4 <> c2 AND r4 <> c3 AND r4 <> c4 AND r4 <> c5
      AND r5 <> c1 AND r5 <> c2 AND r5 <> c3 AND r5 <> c4 AND r5 <> c5

      /* break the symmetry */
      AND r1 < c1 ;
```

Crossword

Task 1.1 (submit the results later to CANVAS):

Print the query plan, planning time, and execution time for the two queries in the previous slides. Compare the results.

Query 1

```
SELECT * FROM
 word r1, word r2, word r3, word r4, word r5,
 word c1, word c2, word c3, word c4, word c5
    WHERE r1.a1=c1.a1 AND r1.a2=c2.a1 AND r1.a3=c3.a1 AND r1.a4=c4.a1 AND r1.a5=c5.a1
      AND r2.a1=c1.a2 AND r2.a2=c2.a2 AND r2.a3=c3.a2 AND r2.a4=c4.a2 AND r2.a5=c5.a2
      AND r3.a1=c1.a3 AND r3.a2=c2.a3 AND r3.a3=c3.a3 AND r3.a4=c4.a3 AND r3.a5=c5.a3
      AND r4.a1=c1.a4 AND r4.a2=c2.a4 AND r4.a3=c3.a4 AND r4.a4=c4.a4 AND r4.a5=c5.a4
      AND r5.a1=c1.a5 AND r5.a2=c2.a5 AND r5.a3=c3.a5 AND r5.a4=c4.a5 AND r5.a5=c5.a5;
```

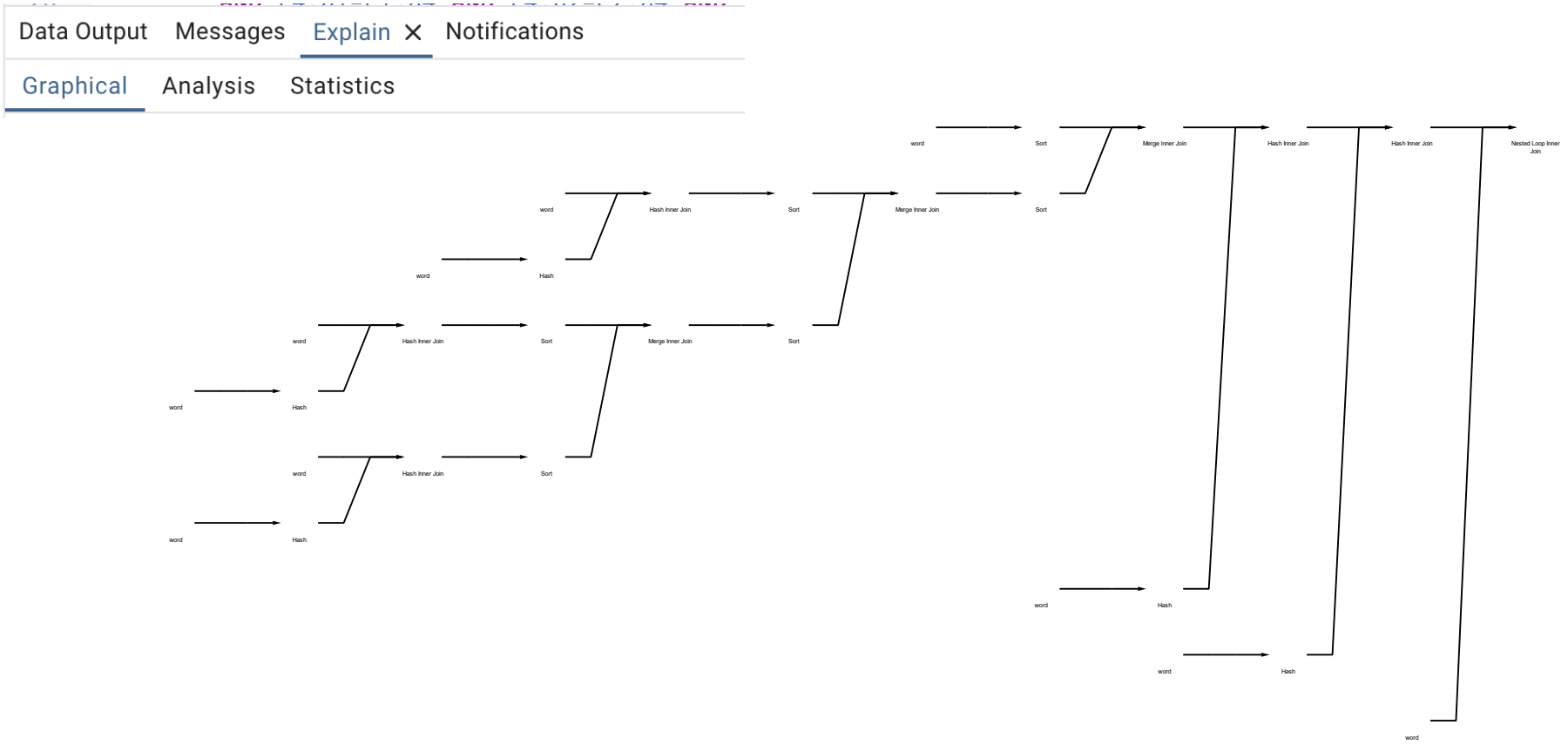
Query 2

```
SELECT * FROM
 word r1, word r2, word r3, word r4, word r5,
 word c1, word c2, word c3, word c4, word c5
                    /* answer the crossword */
    WHERE r1.a1=c1.a1 AND r1.a2=c2.a1 AND r1.a3=c3.a1 AND r1.a4=c4.a1 AND r1.a5=c5.a1
      AND r2.a1=c1.a2 AND r2.a2=c2.a2 AND r2.a3=c3.a2 AND r2.a4=c4.a2 AND r2.a5=c5.a2
      AND r3.a1=c1.a3 AND r3.a2=c2.a3 AND r3.a3=c3.a3 AND r3.a4=c4.a3 AND r3.a5=c5.a3
      AND r4.a1=c1.a4 AND r4.a2=c2.a4 AND r4.a3=c3.a4 AND r4.a4=c4.a4 AND r4.a5=c5.a4
      AND r5.a1=c1.a5 AND r5.a2=c2.a5 AND r5.a3=c3.a5 AND r5.a4=c4.a5 AND r5.a5=c5.a5

      /* rows cannot be the same */
      AND r1 <> r2 AND r1 <> r3 AND r1 <> r4 AND r1 <> r5
      AND r2 <> r3 AND r2 <> r4 AND r2 <> r5
      AND r3 <> r4 AND r3 <> r5
      AND r4 <> r5

      /* columns cannot be the same */
      AND c1 <> c2 AND c1 <> c3 AND c1 <> c4 AND c1 <> c5
      AND c2 <> c3 AND c2 <> c4 AND c2 <> c5
      AND c3 <> c4 AND c3 <> c5
      AND c4 <> c5

      /* row and column cannot be the same */
            AND r1 <> c2 AND r1 <> c3 AND r1 <> c4 AND r1 <> c5
      AND r2 <> c1 AND r2 <> c2 AND r2 <> c3 AND r2 <> c4 AND r2 <> c5
      AND r3 <> c1 AND r3 <> c2 AND r3 <> c3 AND r3 <> c4 AND r3 <> c5
      AND r4 <> c1 AND r4 <> c2 AND r4 <> c3 AND r4 <> c4 AND r4 <> c5
      AND r5 <> c1 AND r5 <> c2 AND r5 <> c3 AND r5 <> c4 AND r5 <> c5

      /* break the symmetry */
      AND r1 < c1 ;
```

Crossword

Task 1.2 (submit the results later to CANVAS):

Using the Explain (F7) option of pgAdmin 4, print the two queries' query plans in JSON, save the tree representation of the query plan in SVG, read and save the analysis and statistics.



Crossword

Task 2: Try out several possible methods to improve efficiency

Prepare the queries and find their planning and execution time.

```
/*************** 2d ********************/
PREPARE q1 AS SELECT * FROM
word r1, word r2,  word r3,  word r4, word r5,
word c1, word c2, word c3,  word c4, word c5
WHERE r1.a1=c1.a1 AND r1.a2=c2.a1 AND r1.a3=c3.a1
AND r1.a4=c4.a1 AND r1.a5=c5.a1
AND r2.a1=c1.a2 AND r2.a2=c2.a2 AND r2.a3=c3.a2
AND r2.a4=c4.a2 AND r2.a5=c5.a2
AND r3.a1=c1.a3 AND r3.a2=c2.a3 AND r3.a3=c3.a3
AND r3.a4=c4.a2 AND r3.a5=c5.a3
AND r4.a1=c1.a4 AND r4.a2=c2.a4 AND r4.a3=c3.a4
AND r4.a4=c4.a4 AND r4.a5=c5.a4
AND r5.a1=c1.a5 AND r5.a2=c2.a5 AND r5.a3=c3.a5
AND r5.a4=c4.a5 AND r5.a5=c5.a5;

EXPLAIN ANALYZE EXECUTE q1;

DEALLOCATE q1;
```

Output | Messages | Explain | Notifications

Showing rows: 1

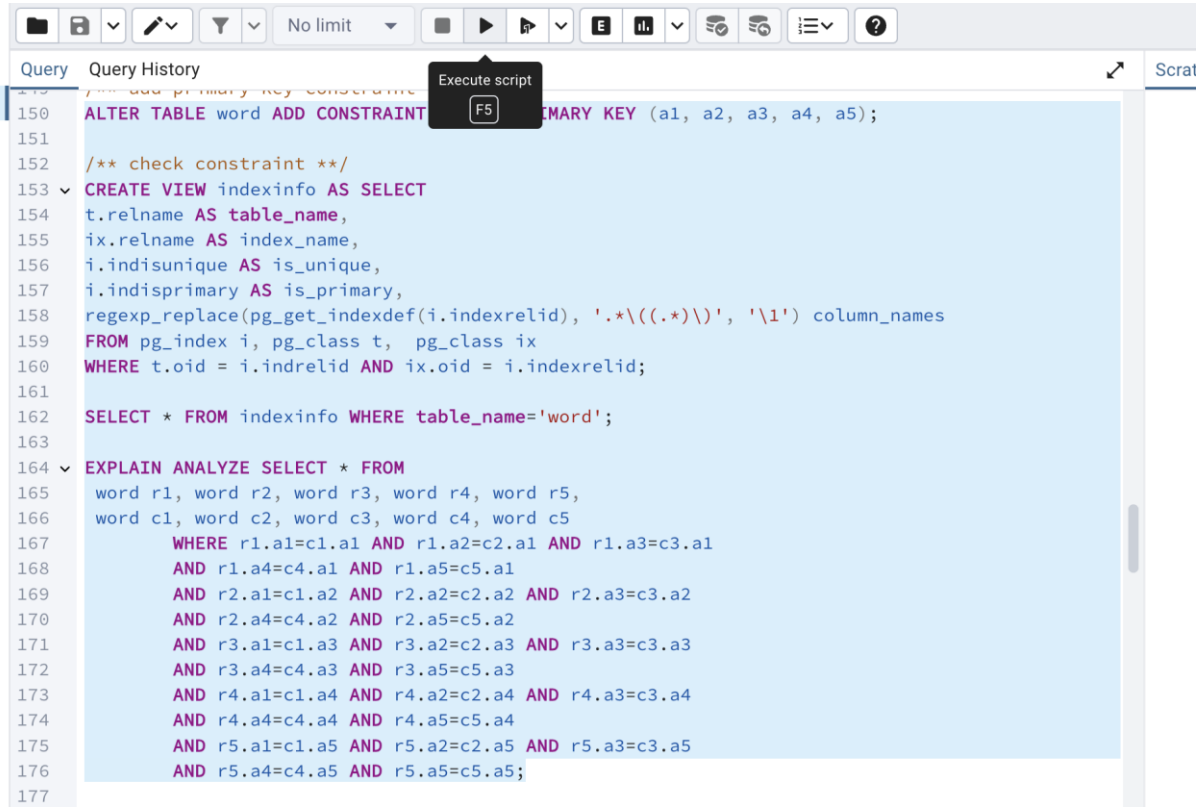
QUERY PLAN text
-> Index Only Scan using alls on word c2 (cost=0.14..0.25 rows=1 width=10) (actual time=0.001..0.0…
Index Cond: ((a1 = r1.a2) AND (a2 = r2.a2))
Heap Fetches: 42
-> Index Only Scan using alls on word r5 (cost=0.14..0.25 rows=1 width=10) (actual time=0.001..0.001 r…
Index Cond: ((a1 = c1.a5) AND (a2 = c2.a5))
Heap Fetches: 5
Planning Time: 3986.730 ms
Execution Time: 1.138 ms

Crossword

Task 2: Try out several possible methods to improve efficiency

Create indexes and see whether they improve the performance.

We try a primary key index first.



QUERY PLAN
"Nested Loop
(cost =209.70 . . 1869.69 rows=1 width=100)
(actual time =6.307. .43.911 rows=72 loops=1)"
. . . [62 lines]
"Planning Time : 10339.931 ms"
"Execution Time : 44.285 ms"

The planning is still very slow.

Crossword

Task 2: Try out several possible methods to improve efficiency

Create indexes and see whether they improve the performance.

Alternatively, it is possible to add a compound index on all columns .

-- Drop primary key index first
ALTER TABLE word DROP CONSTRAINT pkword;

CREATE INDEX alls ON word (a1, a2, a3, a4, a5);

-- Run this query again

```
EXPLAIN ANALYZE SELECT * FROM
 word r1, word r2, word r3, word r4, word r5,
 word c1, word c2, word c3, word c4, word c5
      WHERE r1.a1=c1.a1 AND r1.a2=c2.a1 AND r1.a3=c3.a1
      AND r1.a4=c4.a1 AND r1.a5=c5.a1
      AND r2.a1=c1.a2 AND r2.a2=c2.a2 AND r2.a3=c3.a2
      AND r2.a4=c4.a2 AND r2.a5=c5.a2
      AND r3.a1=c1.a3 AND r3.a2=c2.a3 AND r3.a3=c3.a3
      AND r3.a4=c4.a3 AND r3.a5=c5.a3
      AND r4.a1=c1.a4 AND r4.a2=c2.a4 AND r4.a3=c3.a4
      AND r4.a4=c4.a4 AND r4.a5=c5.a4
      AND r5.a1=c1.a5 AND r5.a2=c2.a5 AND r5.a3=c3.a5
      AND r5.a4=c4.a5 AND r5.a5=c5.a5;
```

DROP INDEX a l l ;

Task 2.1

Compare the results with previous methods. Is this method better or similar?

Crossword

Task 2: Try out several possible methods to improve efficiency

We can try out the B+ Tree and Hash indexes.

```
CREATE INDEX bi1 ON word USING BTREE (a1);
CREATE INDEX bi2 ON word USING BTREE (a2);
CREATE INDEX bi3 ON word USING BTREE (a3);
CREATE INDEX bi4 ON word USING BTREE (a4);
CREATE INDEX bi5 ON word USING BTREE (a5);

EXPLAIN ANALYZE SELECT * FROM
 word r1, word r2, word r3, word r4, word r5,
 word c1, word c2, word c3, word c4, word c5
        WHERE r1.a1=c1.a1 AND r1.a2=c2.a1 AND r1.a3=c3.a1
        AND r1.a4=c4.a1 AND r1.a5=c5.a1
        AND r2.a1=c1.a2 AND r2.a2=c2.a2 AND r2.a3=c3.a2
        AND r2.a4=c4.a2 AND r2.a5=c5.a2
        AND r3.a1=c1.a3 AND r3.a2=c2.a3 AND r3.a3=c3.a3
        AND r3.a4=c4.a3 AND r3.a5=c5.a3
        AND r4.a1=c1.a4 AND r4.a2=c2.a4 AND r4.a3=c3.a4
        AND r4.a4=c4.a4 AND r4.a5=c5.a4
        AND r5.a1=c1.a5 AND r5.a2=c2.a5 AND r5.a3=c3.a5
        AND r5.a4=c4.a5 AND r5.a5=c5.a5;
```

ata Output | Messages | Explain ✕ | Notifications

Showing rows: 1 to 75

QUERY PLAN text
Heap Fetches: 2361
-> Index Only Scan using alls on word c2 (cost=0.14..0.25 rows=1 width=10) (actual time=0.001..0.001 rows=5 l...
Index Cond: ((a1 = r1.a2) AND (a2 = r2.a2))
Heap Fetches: 989
Planning Time: 5255.290 ms
Execution Time: 24.656 ms

```
CREATE INDEX hi1 ON word USING HASH (a1);
CREATE INDEX hi2 ON word USING HASH (a2);
CREATE INDEX hi3 ON word USING HASH (a3);
CREATE INDEX hi4 ON word USING HASH (a4);
CREATE INDEX hi5 ON word USING HASH (a5);

EXPLAIN ANALYZE SELECT * FROM
 word r1, word r2, word r3, word r4, word r5,
 word c1, word c2, word c3, word c4, word c5
        WHERE r1.a1=c1.a1 AND r1.a2=c2.a1 AND r1.a3=c3.a1
        AND r1.a4=c4.a1 AND r1.a5=c5.a1
        AND r2.a1=c1.a2 AND r2.a2=c2.a2 AND r2.a3=c3.a2
        AND r2.a4=c4.a2 AND r2.a5=c5.a2
        AND r3.a1=c1.a3 AND r3.a2=c2.a3 AND r3.a3=c3.a3
        AND r3.a4=c4.a3 AND r3.a5=c5.a3
        AND r4.a1=c1.a4 AND r4.a2=c2.a4 AND r4.a3=c3.a4
        AND r4.a4=c4.a4 AND r4.a5=c5.a4
        AND r5.a1=c1.a5 AND r5.a2=c2.a5 AND r5.a3=c3.a5
        AND r5.a4=c4.a5 AND r5.a5=c5.a5;
```

Output | Messages | Explain ✕ | Notifications

Showing rows: 1 to 74

QUERY PLAN text
-> Index Scan using hi4 on word r2 (cost=0.00..0.25 rows=6 width=10) (actual time=0.000..0.001 rows=15 lo...
Index Cond: (a4 = c4.a2)
-> Index Only Scan using alls on word c2 (cost=0.14..0.25 rows=1 width=10) (actual time=0.001..0.001 rows=5 l...
Index Cond: ((a1 = r1.a2) AND (a2 = r2.a2))
Heap Fetches: 989
Planning Time: 4158.621 ms
Execution Time: 26.220 ms

And find there is no gain!

Crossword

Create a table of letters, add foreign key constraints referencing this table and see the consequences on insertions, deletions and updates.

```
CREATE TABLE alpha (letter CHAR(1) PRIMARY KEY);

INSERT INTO alpha (
select  a1 from word
union select  a2 from word
union select  a3 from word
union select  a4 from word
union select  a5 from word);

CREATE TABLE word2 (
a1 CHAR(1) REFERENCES alpha(letter),
a2 CHAR(1) REFERENCES alpha(letter),
a3 CHAR(1) REFERENCES alpha(letter),
a4 CHAR(1) REFERENCES alpha(letter),
a5 CHAR(1) REFERENCES alpha(letter)
);

EXPLAIN ANALYZE INSERT INTO word2 SELECT * FROM word;
```

a Output | Messages | Explain × | Notifications

SQL | Showing r

QUERY PLAN text
-> Seq Scan on word (cost=0.00..2.34 rows=134 width=10) (actual time=0.009..0.021 rows=134 loop…
Planning Time: 0.079 ms
Trigger for constraint word2_a1_fkey: time=1.270 calls=134
Trigger for constraint word2_a2_fkey: time=1.176 calls=134
Trigger for constraint word2_a3_fkey: time=0.960 calls=134
Trigger for constraint word2_a4_fkey: time=0.939 calls=134
Trigger for constraint word2_a5_fkey: time=0.957 calls=134
Execution Time: 5.749 ms

We notice that insertion (and updates) will now require to check the constraints (using triggers) and will be time consuming. Most of the time is spent in the triggers.

Crossword

Create a table of letters, add foreign key constraints referencing this table and see the consequences on insertions, deletions and updates.

The same thing happens for deletions.

```
INSERT INTO alpha VALUES ('J');

EXPLAIN ANALYZE DELETE FROM alpha WHERE letter = 'J';
```

Output | Messages | Explain | Notifications

Showing rows: 1 to 10

QUERY PLAN text
-> Index Scan using alpha_pkey on alpha (cost=0.15..8.17 rows=1 width=6) (actual time=0.010..0.011 rows=1 loop...
Index Cond: (letter = 'J'::bpchar)
Planning Time: 0.050 ms
Trigger for constraint word2_a1_fkey: time=0.297 calls=1
Trigger for constraint word2_a2_fkey: time=0.087 calls=1
Trigger for constraint word2_a3_fkey: time=0.076 calls=1
Trigger for constraint word2_a4_fkey: time=0.072 calls=1
Trigger for constraint word2_a5_fkey: time=0.071 calls=1
Execution Time: 0.636 ms

Notice the Index Scan on the primary key of alpha.

Delete on alpha (cost=0.15..8.17 rows=0 width=0) (actual time=0.022..0.022 rows=0 loops=1)
-> Index Scan using alpha_pkey on alpha (cost=0.15..8.17 rows=1 width=6) (actual time=0.010..0.011 rows=1 loop...
Index Cond: (letter = 'J'::bpchar)

Submission

Create a document and submit the following items:

Task 1.1 Print the query plan, planning time, and execution time for the two queries in the previous slides. Compare the results. (Page 16)

Task 1.2 Using the Explain (F7) option of pgAdmin 4, print the two queries' query plans in JSON, save the tree representation of the query plan in SVG, read and save the analysis and statistics (Page 17)

Task 2.1 Compare the results of adding compound index with methods of adding primary key index (by print and analysis the statistics). Is this method better or similar?