# “Explaining EXPLAIN“

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# *Agenda:*

- Introduction
- Understanding Performance
- Simple Searches
- Joins and Subqueries
- Prepared Statements, Stored Routines
- Views, FROM Subqueries and Templates
- Reading EXPLAIN Output
- Optimal Execution Order
- SQL Query Visualization
- Controlling Execution Plans
- Example Optimization

# SKIP Introduction: The “SQL“ Standard

- Structured [English] Query Language
- Does not cover all behavioral aspects
  - Indexes
  - Algorithms
  - Caching
  - etc.
- Not all vendors chose the same ways to implement the standard
  - Do not expect things to work the same on different databases!
  - But the common ground is large enough

# *Introduction: EXPLAIN*

- Show execution plan for a given query
  - How and in what order will the tables be read/scanned?
  - What indexes will be used?
  - What join algorithms will be used?
  - The [estimated] „execution cost“?
- Tool of choice for query optimizations
- Not part of the SQL standard
- All DBMS have some equivalent
  - SET EXPLAIN, SELECT .. PLAN, etc.

# *SKIP Introduction: Sakila and Pagila*

- Most examples use the Sakila/Pagila sample database
  - Table and column names shortened
    - a is address
    - c is customer
    - a_id is address_id
    - date is rental_date
    - etc.
- Contains various tables, triggers, views, stored routines and sample data
- Files should be in your home dir!

# *Introduction: Example Query for Sakila*

```
SELECT c.last_name, a.phone, f.title
   FROM r INNER JOIN c ON r.c_id = c.c_id
      INNER JOIN a ON c.a_id = a.a_id
      INNER JOIN i ON r.i_id = i.i_id
      INNER JOIN f ON i.f_id = f.f_id
   WHERE r.return_date IS NULL
      AND r.date < (CURRENT_DATE
        - INTERVAL f.duration DAY)
      AND a.phone LIKE '19%'
```

# *Introduction: Example Query for Pagila*

```
SELECT c.last_name, a.phone, f.title
   FROM r INNER JOIN c ON r.c_id = c.c_id
      INNER JOIN a ON c.a_id = a.a_id
      INNER JOIN i ON r.i_id = i.i_id
      INNER JOIN f ON i.f_id = f.f_id
   WHERE r.return_date IS NULL
      AND r.date < (CURRENT_DATE
        - (f.duration || ' DAY')::INTERVAL
      AND a.phone LIKE '19%'
```

# Introduction: Example Output

```
+-----------+--------------+--------------------+
| last_name | phone        | title              |
+-----------+--------------+--------------------+
| GREGORY   | 195003555232 | BERETS AGENT       |
| MYERS     | 196568435814 | CLUB GRAFFITI      |
| PATTERSON | 198123170793 | DOORS PRESIDENT    |
| GREGORY   | 195003555232 | FRIDA SLIPPER      |
| HITE      | 191958435142 | FROST HEAD         |
| FORSYTHE  | 199514580428 | GUNFIGHT MOON      |
| WADE      | 192459639410 | LUST LOCK          |
| WADE      | 192459639410 | PHILADELPHIA WIFE  |
+-----------+--------------+--------------------+
8 rows in set (0.19 sec)
```

# Introduction: EXPLAIN MySQL

```
*************************** 1. row ***************************
           id: 1
  select_type: SIMPLE
        table: film
         type: ALL
possible_keys: PRIMARY
          key: NULL
      key_len: NULL
          ref: NULL
         rows: 1058
        Extra:
*************************** 2. row ***************************
           id: 1
  select_type: SIMPLE
        table: inventory
         type: ref
possible_keys: PRIMARY,idx_fk_film_id
          key: idx_fk_film_id
      key_len: 2
          ref: sakila.film.film_id
         rows: 2
        Extra: Using index
```

# Introduction: EXPLAIN MySQL (continued)

```
*************************** 3. row ***************************
           id: 1
  select_type: SIMPLE
        table: rental
         type: ref
possible_keys: rental_date,idx_fk_inventory_id,idx_fk_customer_id
          key: idx_fk_inventory_id
      key_len: 3
          ref: sakila.inventory.inventory_id
         rows: 1
        Extra: Using where
*************************** 4. row ***************************
           id: 1
  select_type: SIMPLE
        table: customer
         type: eq_ref
possible_keys: PRIMARY,idx_fk_address_id
          key: PRIMARY
      key_len: 2
          ref: sakila.rental.customer_id
         rows: 1
        Extra:
```

# *Introduction: EXPLAIN MySQL (continued)*

```
*************************** 5. row ***************************
           id: 1
  select_type: SIMPLE
        table: address
         type: eq_ref
possible_keys: PRIMARY
          key: PRIMARY
      key_len: 2
          ref: sakila.customer.address_id
         rows: 1
        Extra: Using where
5 rows in set (0.00 sec)
```

**Execution Order:**
**Film, Inventory, Rental, Customer, Address**

# *Introduction: EXPLAIN PostgreSQL*

```
Nested Loop  (cost=359.64..366.64 rows=1 width=43)"
  Join Filter: ("outer".rental_date < (('now'::text)::date - ((("inner".rental_duration.."
  ->  Nested Loop  (cost=359.64..363.57 rows=1 width=35)"
        ->  Merge Join  (cost=359.64..360.55 rows=1 width=37)"
              Merge Cond: ("outer".customer_id = "inner".customer_id)"
              ->  Sort  (cost=26.64..26.65 rows=3 width=29)"
                    Sort Key: customer.customer_id"
                    ->  Nested Loop  (cost=0.00..26.62 rows=3 width=29)"
                          ->  Seq Scan on address  (cost=0.00..17.54 rows=3 width=19)"
                                Filter: ((phone)::text ~~ '19%'::text)"
                          ->  Index Scan using idx_fk_address_id on customer  (cost=0.00.."
                                Index Cond: (customer.address_id = "outer".address_id)"
              ->  Sort  (cost=333.00..333.44 rows=176 width=14)"
                    Sort Key: rental.customer_id"
                    ->  Seq Scan on rental  (cost=0.00..326.44 rows=176 width=14)"
                          Filter: (return_date IS NULL)"
        ->  Index Scan using inventory_pkey on inventory  (cost=0.00..3.01 rows=1 width=6)"
              Index Cond: ("outer".inventory_id = inventory.inventory_id)"
  ->  Index Scan using film_pkey on film  (cost=0.00..3.04 rows=1 width=24)"
        Index Cond: ("outer".film_id = film.film_id)"
```

**Execution Order:**
**Address, Customer, Rental, Inventory, Film**

# SKIP Understanding Performance: Benchmarking

- Set of isolated performance test cases
- Indicator for how an application would perform if it were to use the given code
- Beware of caching
- Change one parameter at a time
- Store results for later reference
- Understand all aspects of benchmark before making conclusions!
- Tools: EXPLAIN and other DBMS tools, Super Smack,  ApacheBench, etc.

# SKIP Understanding Performance: Profiling

- Method of diagnosing the performance bottlenecks of a specific application
- Pin point trouble spots that to isolate, benchmark and tweak
- Focus on areas where application spends the most time in
- Profile real world user pattern
- Beware of caching
- Tools: user land profiler like APD, xDebug or Zend Server or GUI test tools

# *Understanding Performance: Optimizers*

- Rule-based optimizers use non volatile data and fixed assumptions
- Cost-based optimizers additionally use table statistics and other volatile data
  - Biggest advantage for cost-based optimizers is for joins
- Physical I/O vs. Logical I/O
- Statistics and on disk representation of data and indexes may change over time
  - Use ANALYZE, OPTIMIZE, VACUUM etc.

# *Simple Searches: Index Basics*

- Optimal search condition form
  - <column> <operator> <literal>
    - c1 - 12 = c2 x 2 vs. c1 = (c2 x 2) + 12
    - c1 = c2 AND c1 = 12 vs. c1 = 12 AND c2 = 12
  - Some DBMS allow indexes on expressions
  - Merging two indexes is expensive (*)
- Tablescan reading > 20% table rows
- Use index reading < 0.5% table rows
- No generic advice reading 0.5% - 20% table rows
  - Oracle 13%, MySQL 30%

# *SKIP* *Simple Searches: Index Types*

- Btree indexes
  - Best general purpose index type
  - Sorting, equality and range searches
    - bday = CURRENT_DATE AND name LIKE 'T%'
- Bitmap indexes
  - Equality searches with multiple indexes (*)
  - Distinct values should be < 1% of rowcount
- Hash indexes
  - Equality searches
- Custom index types
  - GiST (PostgreSQL), Fulltext (MySQL)

# SKIP Simple Searches: Covering and Compound Indexes

- Covering Index
  - DBMS skips reading table when index contains all data required from the table
    - SELECT indexed_col FROM t1
      WHERE indexed_col = 'A%';
    - PostgreSQL must reads table due to their MVCC
- Compound Index
  - Index (c1, c2, c3) implies (c1, c2) and (c1)
    - SELECT * FROM t1 WHERE c1 = 'A%';
  - Index (c1, c2, c3) not usable in this case
    - SELECT * FROM t1 WHERE c2 = 'A%';
    - Oracle supports “index skip scan”

# SKIP Simple Searches: Code Points

| Operator | Points | Operand | Points |
|---|---|---|---|
| = | 10 | Literal alone | 10 |
| > | 5 | Column alone | 5 |
| >= | 5 | Parameter alone | 5 |
| < | 5 | Multiop. Expression | 3 |
| <= | 5 | Exact numeric type | 2 |
| LIKE | 3 | Other numeric type | 1 |
| <> | 0 | Temporal type | 1 |
| | | Character type | 0 |
| | | NULL | 0 |

# *SKIP Simple Searches: Code Points Examples*

- WHERE some_char = 'The answer: 42!'
  - Left side
    - 0 Points for „character type"
    - 5 Points for „column alone"
  - Operator
    - 10 Points for „equal"
  - Right side
    - 10 Points for „literal alone"
  - 25 Points Total

# SKIP Simple Searches: Code Points Examples (continued)

- WHERE some_int <= another_int + 23
  - Left side
    - 2 Points for „exact numeric type"
    - 5 Points for „column alone"
  - Operator
    - 5 Points for „smaller or equal"
  - Right side
    - 3 Points for „multi operand expression"
    - 2 Points for „exact numeric type"
  - 17 Points Total

# *Joins and Subqueries: Nested Loop Joins*

```
for (each row in outer_table) {
  for (each row in inner_table) {
    if (join column matches) {
      pass;
    } else {
      fail;
    }
  }
}
```

# *Joins and Subqueries: Nested Loop Joins (continued)*

- Stable performance and memory usage
- Outer table
  - Table with most restrictive/expensive WHERE clause
  - Table that allows fewer rows through filter
- Inner table
  - Table with a good index
  - Small table that fits into memory
- Join Condition
  - Should be done on indexes
  - Should be done on same data type and size

# *Joins and Subqueries: Hash Joins*

- Fast when joining a large table with a small table on an equality condition
- Fall back from nested loop joins when
  - Inner table hash fits into memory
  - No index for join condition on the inner table
  - No restrictions on large outer table
- Disadvantages
  - Memory requirements
  - Hash generation overhead

# Joins and Subqueries: Sort Merge Joins

```
sort (t1); sort (t2); // <- expensive
get first row (t1); get first row (t2);
while (rows in t1 || rows in t2) {
  if (join-col in t1 < join-col in t2) {
    get next row (t1);
  } elseif (join-col in t1 > join-col in t2) {
    get next row (t2);
  } elseif (join-col in t1 = join-col in t2) {
    pass;
    get next row (t1); get next row (t2);
}}
```

# *Joins and Subqueries: Sort Merge Joins (continued)*

- Only single pass when data is presorted
- Fall back for nested loop joins and hash joins when
  - Both tables are about equal in size
  - Both tables are large
- Disadvantages
  - Startup time and memory cost for the initial sorting

# SKIP Joins and Subqueries: Join Advantages over Subquery

- Optimizer has more choices
  - Correlated subqueries force a nested loop
  - More freedom in the execution order
- Ability to include columns from both tables in the select list
- Due to their greater popularity they are used more and therefore optimized more in DBMS
  - Some DBMS can parallelize joins better
  - Subqueries in MySQL 4.1 – 5.0.x often slow

# SKIP Joins and Subqueries: Subquery Advantages over Join

- ANY or EXISTS can break out early
- Column type mismatches are less costly
- Only recently DBMS are adding the ability to join in UPDATE/DELETE
  - MySQL limits subqueries in UPDATE/DELETE
- Simpler to read (“modular”)
  - Many RDBMS rewrite subqueries where possible to JOINs internally

# SKIP Prepared Statements and Stored Routines Execution Plans:

- MySQL disable query cache and prevent use of some statements
- Oracle execution plan are generated
  - < 9i at prepare time
  - since 9i with first bound values
- PostgreSQL execution plan generated
  - named prepared statements at prepare time
  - unnamed prepared statements with first bound values
- Similar issues for stored routines

# SKIP Views, FROM Subqueries and Templates:

- Control over execution plan is limited by the underlying view defining query
  - Any change may affect any number of other queries that use the given view
- Some view/subquery using queries cannot be translated into a simple query
  - Especially the case for outer joins to views or views with UNION and GROUP BY
- Lead to redundant or unnecessary work
  - SELECT .. FROM c LEFT OUTER JOIN a ON s.a_id = a.a_id WHERE a.phone = '555'

# SKIP Reading EXPLAIN Output: MySQL EXPLAIN Columns

| | |
|---|---|
| id | Sequential numer |
| select_type | SIMPLE, SUBQUERY .. |
| table | Table name |
| type | const, *ref*, index, ALL .. |
| possible_keys | List of possible indexes |
| keys | Index that is used |
| key_len | Length if the index used |
| ref | Expression compared |
| rows | Expected read rowcount |
| EXTRA | Using index, where, filesort, temporary etc. |

# SKIP Reading EXPLAIN Output: Example EXPLAIN

```
****************** 2. row ******************
           id: 1
  select_type: SIMPLE
        table: inventory
         type: ref
possible_keys: PRIMARY,idx_fk_film_id
          key: idx_fk_film_id
      key_len: 2
          ref: sakila.film.film_id
         rows: 2
        Extra: Using index
```

# *Optimal Execution Order: Robust Plan Characteristics*

- Cost is proportional to rowcount returned
- Require little sort or hash memory
- Require no changes when table sizes grow
- Have moderate sensitivity to distribution
- Are not necessarily the fastest, but usually pretty close to the fastest, execution plan

# *Optimal Execution Order: Robust Plan Requirements*

- Prefer very selective filters
  - Initial driving table is the most important choice
- Drive using nested loop joins on indexes
  - Only consider tables that join previous tables
- Drive to primary keys first
  - Keep number of rows low as long as possible

# *Optimal Execution Order: Further Optimization Strategies*

- Only when basic robust plan rules do not give the required performance
  - Prefer smaller tables/expensive filters
    - But make a very small table inner most table
  - Try to join to very selective filters earlier
    - Jump to single row join nodes
    - Join to tables with similar filter ratios
  - Hash joins for joining a large table with a small rowcount who's hash fits into memory
  - Sort merge joins when data is presorted or both table have equally large rowcounts
  - etc ..

# *SQL Query Visualization: Example Query*

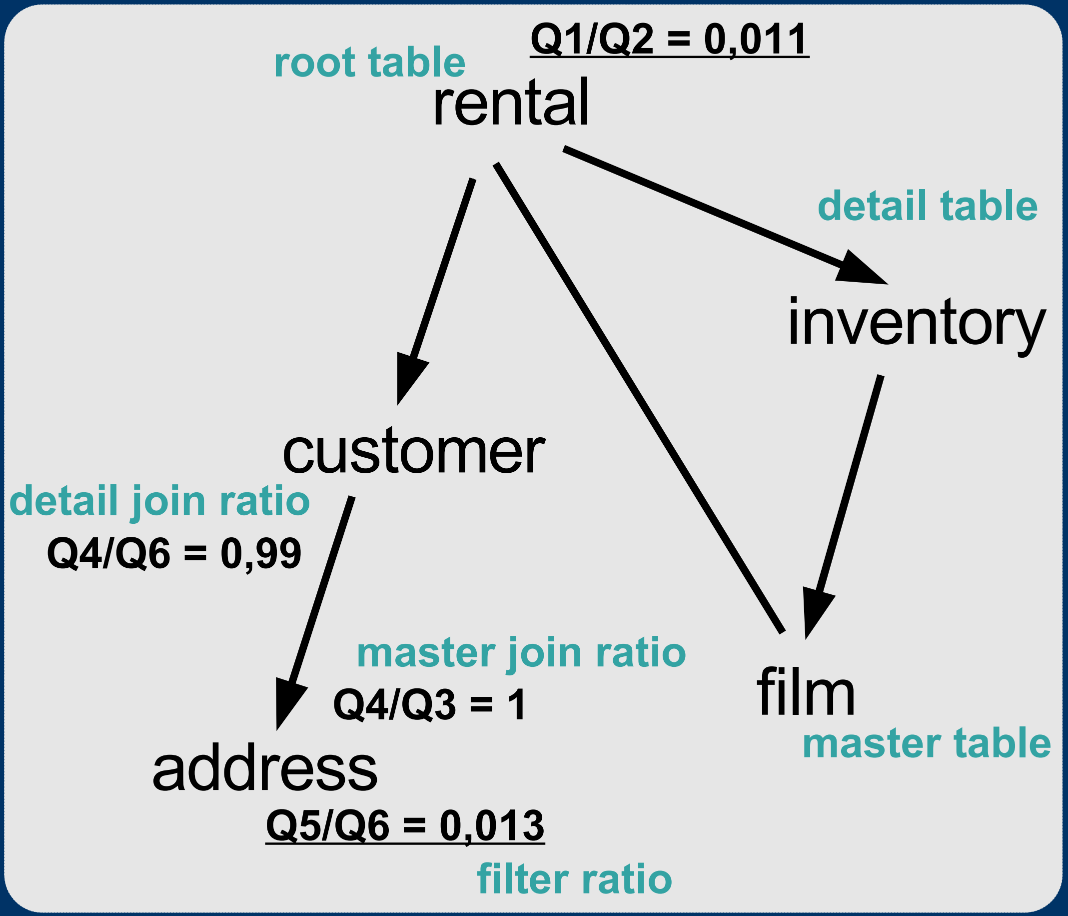
```
SELECT c.last_name, a.phone, f.title
   FROM r INNER JOIN c ON r.c_id = c.c_id
      INNER JOIN a ON c.a_id = a.a_id
      INNER JOIN i ON r.i_id = i.i_id
      INNER JOIN f ON i.f_id = f.f_id
   WHERE r.return_date IS NULL
      AND r.date < (CURRENT_DATE
        - INTERVAL f.duration DAY)
      AND a.phone LIKE '19%'
```

# SQL Query Visualization:

**Q1: SELECT COUNT(*) FROM rental WHERE return_date IS NULL => 183**

**Q2: SELECT COUNT(*) FROM rental => 16044**

**Q3: SELECT COUNT(*) FROM customer => 599**




**Q4: SELECT COUNT(*) FROM address a, customer c WHERE a.address_id = c.address_id => 599**

**Q5: SELECT COUNT(*) FROM address WHERE phone LIKE '19%' => 8**

**Q6: SELECT COUNT(*) FROM address => 603**

# SQL Query Visualization: Deducing Execution Plan

- Driving table choice
  - rental or address
  - similar filter ratio but address produces lower rowcount
- Best plan
  1. address
  2. customer
  3. rental
  4. inventory
  5. film

# SKIP Controlling Execution Plans: Strategy Overview

- SQL Level
  - Add SQL hints or (bogus) information
  - Rewrite SQL
- Statistics Level
  - ANALYZE table and indexes
  - Fake statistics
- Server Configuration
  - Enable/disable features
  - Set buffer sizes
- Schema Level
  - Denormalization

# Controlling Execution Plans: SQL Level

- SQL hints for MySQL
  - SELECT SQL_SMALL_RESULT .. FROM ..
  - SELECT .. FROM t1 FORCE INDEX (idx1) ..
  - SELECT .. FROM t1 STRAIGHT_JOIN t2 ..
- Add more information
  - Add implicit join condition
    - WHERE a.postcal_code = 34221
      AND store.a_id = a.a_id AND staff.a_id = a.a_id
      AND staff.a_id = store.a_id
  - Improve driving table filter ratio for inner joins by applying the master join ratio early
    - t1.FKt2 IS NOT NULL

# Controlling Execution Plans: SQL Level (continued)

- Add bogus information
  - Disable index
    - rental_duration + 0 = :int
    - title || '' = :title
    - COALESCE(last_name, last_name)
  - Force join order
    - Add bogus filter to make it appear like having a restriction so that it is favored as the outer table
      - AND table1.column1 > ''
    - Force staff table to join before address table
      - AND store.manager_staff_id = staff.staff_id
        AND store.address_id + (0*staff.staff_id)
        = address.address_id

# *Controlling Execution Plans: SQL Level (continued)*

- Convert single SELECT into a UNION ALL to enable easier index use
  - SELECT .. FROM f
    WHERE (title = :1 OR lang_id = :2)
  - SELECT .. FROM f WHERE title = :1
    UNION ALL
    SELECT .. FROM f WHERE lang_id = :2
- Convert multiple queries (or a CURSOR) into a single query using CASE
  - r = CASE WHEN r > 2 THEN r * 0.90;
    ELSE r * 1.10 END;

# *Controlling Execution Plans: SQL Level (continued)*

- EXISTS may be expressed with an equivalent IN (same for NOT variants)
  - SELECT .. FROM inventory i WHERE EXISTS (SELECT NULL FROM rental WHERE i.inventory_id = rental.inventory_id)
    - Use to drive from inventory to rental
  - SELECT .. FROM .. i WHERE inventory_id IN (SELECT inventory_id FROM rental)
    - Use to drive from rental to inventory
- INTERSECT/EXCEPT may be expressed with an equivalent EXISTS/NOT EXISTS

# *Controlling Execution Plans: Statistics and Configuration Level*

- PostgreSQL statistics
  - ANALYZE [ table [ (column [, ...] ) ] ]
  - Statistics are stored in pg_statistics
    - May be manipulated as needed
    - Will be overwritten with the next ANALYZE
- PostgreSQL query planner configuration
  - SET SESSION ENABLE_HASHJOIN TO OFF
  - SET CPU_OPERATTOR_COST TO 0.003
  - SET GEQO_THRESHOLD TO 9

# *Controlling Execution Plans: Schema Level*

- Merge One-One relationships
- Split tables into One-One relationships
- Denormalization
  - Add (Join-)Indexes, Materialized Views
  - Cache data in application memory
  - Cache aggregate results in memory/DBMS
  - Move “inherited” properties to detail tables
    - SELECT country.country FROM city INNER JOIN country ON city.country_id = c.country_id
  - Copy country column from to city table
    - SELECT city.country FROM city

# *Example Optimization: Force Execution Order with a Hint*

```
SELECT c.last_name, a.phone, f.title
  FROM a STRAIGHT_JOIN c
                        ON a.a_id = c.a_id
    INNER JOIN r ON c.c_id = r.c_id
    INNER JOIN i ON r.i_id = i.i_id
    INNER JOIN f ON i.f_id = f.f_id
  WHERE r.return IS NULL
    AND r.date < CURRENT_DATE
      - INTERVAL f.duration DAY
    AND a.phone LIKE '19%';
```

# References:

- These slides
  - http://pooteeweet.org/files/phpworks06/explaining_explain.pdf
- “SQL Performance Tuning“
  by Peter Gulutzan and Trudy Pelzer
- “SQL Tuning” by Dan Tow
- Benchmarking and Profiling
  - http://dev.mysql.com/tech-resources/articles/pro-mysql-ch6.pdf
- Sakila 0.8.0
  - http://www.openwin.org/mike/download/sakila-0.8.zip
- Pagila 0.8.0
  - http://pgfoundry.org/frs/download.php/919/pagila-0.8.0.zip

Thank you for listening ..
Comments? Questions?

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