MySQL 8.0 Optimizer Guide

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Safe Harbor Statement

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Introduction

• SQL is declarative
• You state “what you want” not “how you want”
• Can’t usually sight check queries to understand execution efficiency
• Database management system is like a GPS navigation system. It finds the “best” route.
GPS...
MySQL Optimizer

```
SELECT a, b
FROM t1
JOIN t2
ON t1.a = t2.a
JOIN t3
ON t2.b = t3.c
WHERE
  t2.d > 20
  AND t2.a < 30;
```
Diagnostic Commands

• EXPLAIN (all versions)
• EXPLAIN FORMAT=JSON (5.6+)
  – Supported by Workbench in Visual format
• Optimizer Trace (5.6+)
Examples from “The World Schema”

• Contains Cities, Countries, Language statistics
• Download from:
  – https://dev.mysql.com/doc/index-other.html
• Very small data set
  – Good for learning
  – Not good for explaining performance differences
Primary Table we are using

CREATE TABLE `Country` (  
    `Code` char(3) NOT NULL DEFAULT '',  
    `Name` char(52) NOT NULL DEFAULT '',  
    `Continent` enum('Asia','Europe','North America','Africa','Oceania','Antarctica','South America') NOT NULL DEFAULT 'Asia',  
    `Region` char(26) NOT NULL DEFAULT '',  
    `SurfaceArea` float(10,2) NOT NULL DEFAULT '0.00',  
    `IndepYear` smallint(6) DEFAULT NULL,  
    `Population` int(11) NOT NULL DEFAULT '0',  
    `LifeExpectancy` float(3,1) DEFAULT NULL,  
    `GNP` float(10,2) DEFAULT NULL,  
    `GNPOld` float(10,2) DEFAULT NULL,  
    `LocalName` char(45) NOT NULL DEFAULT '',  
    `GovernmentForm` char(45) NOT NULL DEFAULT '',  
    `HeadOfState` char(60) DEFAULT NULL,  
    `Capital` int(11) DEFAULT NULL,  
    `Code2` char(2) NOT NULL DEFAULT '',  
    PRIMARY KEY (`Code`)  
) ENGINE=InnoDB DEFAULT CHARSET=latin1
1 row in set (0.00 sec)
Companion Website

- Content from “The Unofficial MySQL 8.0 Optimizer Guide”
  - http://www.unofficialmysqlguide.com/
- More detailed text for many of the examples here...
- Most still applies to 5.6+
  - EXPLAIN FORMAT=JSON in 5.6 does not show cost
  - Costs will be different
  - Output from Optimizer Trace may differ
  - Some features will be missing
**Danger: Code on slides!**

- Some examples may appear small
- Please feel free to download this deck from:
  - https://www.slideshare.net/morgo/mysql-80-optimizer-guide
- Follow along on your laptop
Agenda

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3. B+trees
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Server Architecture

- Negation elimination
- Equality and constant propagation
- Evaluation of constant expressions
- Conversions of outer to inner join
- Subquery transformation

- Access method selection
- Join order

- Optimizer
  - Logical Transformations
  - Prepare for cost-based-optimization
  - Cost-based optimizer: join order and access methods
  - Plan refinement
    - Query execution plan

- Query Execution
  - Storage Engines
    - MySQL
    - InnoDB

- ref access analysis
- Range access analysis
- Estimation of condition fan out
- Constant table detection

- Table condition pushdown
- Access method adjustments
- Sort avoidance
- Index condition pushdown
Just the Important Parts

• Comprised of the Server and Storage Engines
• Query Optimization happens at the Server Level
• Semantically there are four stages of Query Optimization
• Followed by Query Execution
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B+trees

• When we mean “add an index” we usually mean “add a B+tree index”:
  – Includes PRIMARY, UNIQUE, INDEX type indexes.

• Understanding the basic structure of B+trees helps with optimization
Binary Tree

• Not the same as a B+tree
• Understand Binary Tree first then compare and contrast

Locate 829813 in a (balanced) binary tree of 1MM ~ 20 hops.

is this good?
B+tree

• Amortizes disk accesses by clustering into pages:
• Can achieve same outcome in two hops:

```sql
CREATE TABLE users (  
id INT NOT NULL auto_increment,  
username VARCHAR(32) NOT NULL,  
payload TEXT,  
PRIMARY KEY (id) )
```
B+tree

- Amortizes disk accesses by clustering into pages
- Can achieve same outcome in two hops:
B-trees are wide not deep

- From the root page: values >= 800788 but < 829908 are on page 16386.
- From page 16386: values >= 829804 but < 829830 are on leaf page 32012.
- Large fan out factor; 1000+ keys/page which point to another index page with 1000+ keys/page
InnoDB uses a Clustered Index

- In InnoDB the data rows are also stored in a B+tree, organized by the primary key
- Secondary key indexes always include the value of the primary key
EXPLAIN

- Pre-execution view of how MySQL intends to execute a query
- Prints what MySQL considers the best plan after a process of considering potentially thousands of choices
EXPLAIN FORMAT=JSON

SELECT * FROM Country WHERE continent='Asia' and population > 5000000;

```
{
   "query_block": {
      "select_id": 1,
      "cost_info": {
         "query_cost": "25.40"
      },
      "table": {
         "table_name": "country",
         "access_type": "ALL",
         "rows_examined_per_scan": 239,
         "rows_produced_per_join": 11,
         "filtered": "6.46",
         "attached_condition": "((`world`.`country`.`Continent` = 'Asia')
                                 and (`world`.`country`.`Population` > 5000000))"
      }
   }
}
```
What indexes will make this query faster?

• Some Suggestions:
  – Index on p (population)
  – Index on c (continent)
  – Index on p_c (population, continent)
  – Index on c_p (continent, population)
ALTER TABLE Country ADD INDEX p (population);

EXPLAIN FORMAT=JSON
SELECT * FROM Country WHERE continent='Asia' and population > 5000000;

```json
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "25.40"
    },
    "table": {
      "table_name": "Country",
      "access_type": "ALL",
      "possible_keys": [
        "p"
      ],
      "rows_examined_per_scan": 239,
      "rows_produced_per_join": 15,
      "filtered": "6.46",
      ...
      "attached_condition": "(((\`world\`\`country\`\`Continent\` = 'Asia') and (\`world\`\`country\`\`Population\` > 5000000))"
    }
  }
}
```
Why would an index not be used?

```
SELECT * FROM Country
WHERE continent='Asia' AND population > 5000000;
```
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Optimizer Trace

- What other choices did EXPLAIN not show?
- Why was that choice made?
- Output is quite verbose
ALTER TABLE Country ADD INDEX p (population);
EXPLAIN FORMAT=JSON
SELECT * FROM Country WHERE continent='Asia' and population > 5000000;

{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "25.40"
    },
    "table": {
      "table_name": "Country",
      "access_type": "ALL",
      "possible_keys": [
        "p"
      ],
      "rows_examined_per_scan": 239,
      "rows_produced_per_join": 15,
      "filtered": "6.46",
      "cost_info": {
        "read_cost": "23.86",
        "eval_cost": "1.54",
        "prefix_cost": "25.40",
        "data_read_per_join": "3K"
      }
    },
    "attached_condition": "((`world`.`country`.`Continent` = 'Asia') and (`world`.`country`.`Population` > 5000000))"
  }
}
SET optimizer_trace="enabled=on";
SELECT * FROM Country WHERE continent='Asia' and population > 5000000;
SELECT * FROM information_schema.optimizer_trace;
{
 "steps": [
 {
  "join_preparation": {
   "select#": 1,
   "steps": [
    {
    }
   }
  },
  {
   "join_optimization": {
    "select#": 1,
    "steps": [
     {
      "condition_processing": {
       "condition": "WHERE",
      }
     }
    }
   }
  }
]
"original_condition": "((`country`.`Continent` = 'Asia') and (`country`.`Population` > 5000000))",
"steps": [
    {
        "transformation": "equality_propagation",
        "resulting_condition": "((`country`.`Population` > 5000000) and multiple equal('Asia', `country`.`Continent`))"
    },
    {
        "transformation": "constant_propagation",
        "resulting_condition": "((`country`.`Population` > 5000000) and multiple equal('Asia', `country`.`Continent`))"
    },
    {
        "transformation": "trivial_condition_removal",
        "resulting_condition": "((`country`.`Population` > 5000000) and multiple equal('Asia', `country`.`Continent`))"
    }
]
"depends_on_map_bits": [],

"ref_optimizer_key_uses": [
],

"rows_estimation": [
{
   "table": `country`,
   "range_analysis": {
      "table_scan": {
         "rows": 239,
         "cost": 27.5
      },
      "potential_range_indexes": [
         {
            "index": "PRIMARY",
            "usable": false,
            "cause": "not_applicable"
         },
         {
            "index": "p",
            "usable": true,
            "key_parts": [
               "Population",
               "Code"
            ]
         }
      ]
   }
}
Aha! It was too expensive.
```
]
},

"considered_execution_plans": [

{
   "plan_prefix": [
       
   ],
   "table": "`country`",
   "best_access_path": {
       "considered_access_paths": [

       {
            "rows_to_scan": 239,
            "access_type": "scan",
            "resulting_rows": 239,
            "cost": 25.4,
            "chosen": true
       }
       ]
   },
   "condition_filtering_pct": 100,
   "rows_for_plan": 239,
   "cost_for_plan": 25.4,
   "chosen": true
    }

}
],

"attaching_conditions_to_tables": {

   "original_condition": "((`country`.`Continent` = 'Asia') and (`country`.`Population` > 5000000))",

```
"attached_conditions_computation": [ 
],
"attached_conditions_summary": [ 
  {
    "table": "country",
    "attached": "((country.Continent = 'Asia') and (country.Population > 5000000))"
  }
],
"refine_plan": [ 
  {
    "table": "country"
  }
],
"join_execution": { 
  "select#": 1,
  "steps": [ 
  ]
}
Why would an index not be used?

OPTIMIZER TRACE:

"analyzing_range_alternatives": {
    "range_scan_alternatives": [
        {
            "index": "p",
            "ranges": [
                "5000000 < Population"
            ],
            "index_dives_for_eq_ranges": true,
            "rowid_ordered": false,
            "using_mrr": false,
            "index_only": false,
            "rows": 108,
            "cost": 38.06,
            "chosen": false,
            "cause": "cost"
        }
    ],
    "cause": "cost"
}

FORCE INDEX (p):

.. "query_block": {
    "select_id": 1,
    "cost_info": {
        "query_cost": "48.86"
    },
    "table": {
        "table_name": "Country",
        "access_type": "range",
        "possible_keys": ["p"],
        "key": "p",
        "cost": 38.06,
        "chosen": false,
        "cause": "cost"
    }
}
Reason again...

```
SELECT * FROM Country
WHERE continent='Asia' AND population > 5000000;
```
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Logical Transformations

• First part of optimization is eliminating unnecessary work
Why eliminate unnecessary work?

• Short-cut/reduce number of execution plans that need to be evaluated
• Transform parts of queries to take advantage of better execution strategies
• Think of how a compiler transforms code to be more efficient
  • MySQL does similar at runtime
Example:

```
SELECT * FROM Country
WHERE population > 5000000 AND continent='Asia'
AND 1=1;
```
SHOW WARNINGS says:

EXPLAIN FORMAT=JSON SELECT * FROM Country WHERE population > 5000000 AND 1=1;
SHOW WARNINGS;

/* select#1 */ select
`world`.`Country`.`Code` AS `Code`,
`world`.`Country`.`Name` AS `Name`,
`world`.`Country`.`Continent` AS `Continent`,
`world`.`Country`.`Region` AS `Region`,
`world`.`Country`.`SurfaceArea` AS `SurfaceArea`,
`world`.`Country`.`IndepYear` AS `IndepYear`,
`world`.`Country`.`Population` AS `Population`,
`world`.`Country`.`LifeExpectancy` AS `LifeExpectancy`,
`world`.`Country`.`GNP` AS `GNP`,
`world`.`Country`.`GNPOld` AS `GNPOld`,
`world`.`Country`.`LocalName` AS `LocalName`,
`world`.`Country`.`GovernmentForm` AS `GovernmentForm`,
`world`.`Country`.`HeadOfState` AS `HeadOfState`,
`world`.`Country`.`Capital` AS `Capital`,
from `world`.`Country`
where (`world`.`Country`.`Population` > 5000000)
OPTIMIZER TRACE says:

```
.. "steps": [
    {
      "condition_processing": {
        "condition": "WHERE",
        "original_condition": "((`Country`.`Population` > 5000000) and (1 = 1))",
        "steps": [
          {
            "transformation": "equality_propagation",
            "resulting_condition": "((`Country`.`Population` > 5000000) and (1 = 1))"
          },
          {
            "transformation": "constant_propagation",
            "resulting_condition": "((`Country`.`Population` > 5000000) and (1 = 1))"
          },
          {
            "transformation": "trivial_condition_removal",
            "resulting_condition": "(`Country`.`Population` > 5000000)"
          }
        ]
      }
    ]
..```
What sort of transformations can occur?

• Merging views back with definition of base tables
• Derived table in FROM clause merged back into base tables
• Unique subqueries converted directly to INNER JOIN statements
• Primary key lookup converted to constant values.
  – Shortcut plans that will need to be evaluated.
### Primary Key Lookup

```sql
SELECT * FROM Country WHERE code='CAN'
/* select#1 */
select
'CAN' AS `Code`,
'Canada' AS `Name`,
'North America' AS `Continent`,
'North America' AS `Region`,
'9970610.00' AS `SurfaceArea`,
'1867' AS `IndepYear`,
'31147000' AS `Population`,
'79.4' AS `LifeExpectancy`,
'598862.00' AS `GNP`,
'625626.00' AS `GNPOld`,
'Canada' AS `LocalName`,
'Constitutional Monarchy, Federation' AS `GovernmentForm`,
'Elisabeth II' AS `HeadOfState`,
'1822' AS `Capital`,
'CA' AS `Code2`
from `world`. `Country` where 1
```
Primary key does not exist

```sql
SELECT * FROM Country WHERE code='XYZ'
/* select#1 */ select NULL AS `Code`,NULL AS `Name`,NULL AS `Continent`,NULL AS `Region`, NULL AS `SurfaceArea`,NULL AS `IndepYear`,NULL AS `Population`,NULL AS `LifeExpectancy`,NULL AS `GNP`, NULL AS `GNPOld`,NULL AS `LocalName`,NULL AS `GovernmentForm`,NULL AS `HeadOfState`,NULL AS `Capital`, NULL AS `Code2` from `world`.`Country` where multiple equal('XYZ', NULL)
```
Impossible WHERE

SELECT * FROM Country WHERE code='CAN' AND 1=0

Are transformations always safe?

• Yes they should be

• New transformations (and execution strategies) may return non-deterministic queries in a different order

• Some illegal statements as a result of derived_merge transformation
MySQL 5.7.6-m16 default optimizer_switch derived_merge=on causes Error: You can't specify target table 'pets' for update in FROM clause: #19281

yahonda opened this issue on Mar 10, 2015 • 8 comments

yahonda commented on Mar 10, 2015

MySQL 5.7.6-m16 has been released.
Since upgrading my environments to this version, some of mysql and mysql2 test cases get errors.
These errors can be resolved by setting `optimizer_switch=derived_merge=off` in `etc/my.cnf`.
I then am not sure these errors can be addressed in Rails yet.

- Testcases

```ruby
for i in mysql mysql2
echo $i
APCOMMS - i=01 test cases/scoping/relation scoping test.rb -t test delete all default
APCOMMS - i=10 test cases/perf_test.pl -u test delete all with java and done
```

- Environments

Server version: 5.7.6-4394 MySQL Community Server (GPL)
$ ruby -v
ruby 2.3.3p157 (2016-10-03 revision 55875) [x86_64-linux]
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Query Optimizer Strategy

• Model each of the possible execution plans (using support from statistics and meta data)
• Pick the plan with the lowest cost
Model you say?

1. Assign a cost to each operation
2. Evaluate how many operations each possible plan would take
3. Sum up the total
4. Choose the plan with the lowest overall cost
How are statistics calculated?

- Dictionary Information
- Cardinality Statistics
- Records In Range Dynamic Sampling
- Table Size
Example Model: Table Scan

\[ \text{SELECT} \ast \text{ FROM Country WHERE continent='Asia' and population > 5000000;} \]

**IO Cost:**
\# pages in table * (IO\_BLOCK\_READ\_COST | MEMORY\_BLOCK\_READ\_COST)

**CPU Cost:**
\# records * ROW\_EVALUATE\_COST

**Defaults:**
- IO\_BLOCK\_READ\_COST = 1
- MEMORY\_BLOCK\_READ\_COST = 0.25
- ROW\_EVALUATE\_COST = 0.1

**Values:**
- \# pages in table = 6
- \# records = 239

100% on Disk:
\[ (6 \times 1) + (0.1 \times 239) \]
\[ = 29.9 \]

100% in Memory:
\[ (6 \times 0.25) + (0.1 \times 239) \]
\[ = 25.4 \]

**New! MySQL 8.0 estimates how many of the pages will be in memory.**

SELECT clust\_index\_size from INNODB\_SYS\_TABLESTATS WHERE name='world/country'

EXPLAIN said cost was 25.40
Example Model: Range Scan

```
SELECT * FROM Country WHERE continent='Asia' and population > 5000000;
```

**IO Cost:**
# records_in_range * (IO_BLOCK_READ_COST | MEMORY_BLOCK_READ_COST)

**CPU Cost:**
# records_in_range * ROW_EVALUATE_COST
+ # records_in_range * ROW_EVALUATE_COST

\[
= (108 \times 0.25) + (108 \times 0.1) + (108 \times 0.1)
= 48.6
\]

100% in memory. 
On disk = 129.6

Evaluate range condition
Evaluate WHERE condition
Compares to "query_cost": "48.86" in EXPLAIN.
```json
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "25.40"
    },
    "table": {
      "table_name": "country",
      "access_type": "ALL",
      "possible_keys": [
        "p"
      ],
      "cost_info": {
        "read_cost": "23.86",
        "eval_cost": "1.54",
        "prefix_cost": "25.40",
        "data_read_per_join": "3K"
      }
    }
  }
}
```
### Cost Constant Refinement

```sql
select * from mysql.server_cost;
```

<table>
<thead>
<tr>
<th>cost_name</th>
<th>cost_value</th>
<th>last_update</th>
<th>comment</th>
<th>default_value</th>
</tr>
</thead>
<tbody>
<tr>
<td>disk_temptable_create_cost</td>
<td>NULL</td>
<td>2017-04-14 16:01:42</td>
<td>NULL</td>
<td>20</td>
</tr>
<tr>
<td>disk_temptable_row_cost</td>
<td>NULL</td>
<td>2017-04-14 16:01:42</td>
<td>NULL</td>
<td>0.5</td>
</tr>
<tr>
<td>key_compare_cost</td>
<td>NULL</td>
<td>2017-04-14 16:01:42</td>
<td>NULL</td>
<td>0.05</td>
</tr>
<tr>
<td>memory_temptable_create_cost</td>
<td>NULL</td>
<td>2017-04-14 16:01:42</td>
<td>NULL</td>
<td>1</td>
</tr>
<tr>
<td>memory_temptable_row_cost</td>
<td>NULL</td>
<td>2017-04-14 16:01:42</td>
<td>NULL</td>
<td>0.1</td>
</tr>
<tr>
<td>row_evaluate_cost</td>
<td>NULL</td>
<td>2017-04-14 16:01:42</td>
<td>NULL</td>
<td>0.1</td>
</tr>
</tbody>
</table>

6 rows in set (0.00 sec)

```sql
select * from mysql.engine_cost\G
```

*************** 1. row ***************

| engine_name: default
| device_type: 0
| cost_name: io_block_read_cost
| cost_value: NULL
| last_update: 2017-04-14 16:01:42
| comment: NULL
| default_value: 1
Cost Constant Refinement

UPDATE mysql.server_cost SET cost_value=1 WHERE cost_name='row_evaluate_cost';
UPDATE mysql.engine_cost set cost_value = 1;
FLUSH OPTIMIZER_COSTS;
EXPLAIN FORMAT=JSON SELECT * FROM Country WHERE continent='Asia' and population > 5000000;

{  
    "query_block": {  
        "select_id": 1,  
        "cost_info": {  
            "query_cost": "245.00"  
        },  
        "table": {  
            "table_name": "Country",  
            "access_type": "ALL",  
            ..
    }
}

Increase row evaluate cost from 0.1 to 1. Make memory and IO block read cost the same.

New Table Scan Cost:
= (6 * 1) + (1 * 239)
= 245
Are plans exhaustively evaluated?

- Short cuts are taken to not spend too much time in planning:
  - Some parts of queries may be transformed to limit plans evaluated
  - The optimizer will by default limit the search depth of bad plans:
    \[
    \text{optimizer\_search\_depth}=64 \\
    \text{optimizer\_prune\_level}=1
    \]
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How often is the query optimizer wrong?

• Yes it happens
• Similar to GPS; you may not have traffic data available for all streets
• The model may be incomplete or imperfect
• There exist method(s) to overwrite it
Hints and Switches

• Typically a better level of override to modifying cost constants
• Come in three varieties:
  – Old Style Hints
  – New Comment-Style Hints
  – Switches
Old Style Hints

• Have SQL and Hint intermingled
• Cause errors when indexes don’t exist

```sql
SELECT * FROM Country FORCE INDEX (p) WHERE population > 5000000;
SELECT * FROM Country IGNORE INDEX (p) WHERE population > 5000000;
SELECT * FROM Country USE INDEX (p) WHERE population > 5000000;
SELECT STRAIGHT_JOIN ..;
SELECT * FROM Country STRAIGHT_JOIN ..;
```
New Comment-Style Hints

• Can be added by a system that doesn’t understand SQL
• Clearer defined semantics as a hint not a directive
• Fine granularity

SELECT

/*+ NO_RANGE_OPTIMIZATION (Country) */
* FROM Country
WHERE Population > 1000000000 AND Continent='Asia';
Switches

• As new optimizations are added, some cause regressions
• Allow the specific optimization to be disabled (SESSION or GLOBAL)

SELECT @@optimizer_switch;

index_merge=on,index_merge_union=on,index_merge_sort_union=on,index_merge_intersection=on,engine_condition_pushdown=on,index_condition_pushdown=on,mrr=on,mrr_cost_based=on,block_nested_loop=on,batched_key_access=off,materialization=on,semijoin=on,loosescan=on,firstmatch=on,duplicateweedout=on,subquery_materialization_cost_based=on,use_index_extensions=on,condition_fanout_filter=on,derived_merge=on
How to consider hints and switches

• They provide immediate pain relief to production problems at the cost of maintenance
• They add technical debt to your applications
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</table>
Our simple query with $n$ candidate indexes

- Indexes exist on $p(\text{population})$ and $c(\text{continent})$:

```sql
SELECT * FROM Country
WHERE population > 50000000 AND continent='Asia';
```

>50M, how many are less?

How many countries in Asia vs total world?

Does order of predicates matter? No.
Role of the Optimizer

• Given these many choices, which is the best choice?
• A good GPS navigator finds the fastest route!
• We can expect a good query optimizer to do similar
ALTER TABLE Country ADD INDEX c (continent);

EXPLAIN FORMAT=JSON # 50M

SELECT * FROM Country WHERE population > 50000000 AND continent='Asia';

```json
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "9.60"
    },
    "table": {
      "table_name": "Country",
      "access_type": "ref",
      "possible_keys": [
        "p",
        "c"
      ],
      "key": "c",
      "used_key_parts": [
        "Continent"
      ],
      "key_length": "1",
      "ref": [
        "const"
      ],
      "attached_condition": "(\`world`\.\`country`\.\`Population` > 50000000)"
    }
  }
}
```

Continent is determined to be lower cost.
SELECT * FROM Country WHERE continent='Asia' and population > 500000000;

```
{
   "query_block": {
      "select_id": 1,
      "cost_info": {
         "query_cost": "1.16"
      },
      "table": {
         "table_name": "Country",
         "access_type": "range",
         "possible_keys": ["p", "c"],
         "key": "p",
         "used_key_parts": ["Population"],
         "key_length": "4",
         "attached_condition": "(`world`.`country`.`Continent` = 'Asia')"
      }
   }
}
```
Query Plan Evaluation

• Evaluated for each query, and thus each set of predicates
• Currently not cached*
• For prepared statements, permanent transformations are cached

* Cardinality statistics are cached. Don’t get confused.
## Cost Estimates

<table>
<thead>
<tr>
<th></th>
<th>p&gt;5M c='Asia'</th>
<th>p&gt;50M, c='Asia'</th>
<th>p&gt;500M, c='Asia'</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>48.86</td>
<td>11.06</td>
<td>1.16</td>
</tr>
<tr>
<td>c</td>
<td>9.60</td>
<td>9.60</td>
<td>9.60</td>
</tr>
<tr>
<td>ALL</td>
<td>25.40</td>
<td>25.40</td>
<td>25.40</td>
</tr>
</tbody>
</table>

**p**
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The role of composite indexes

• Useful when two or more predicates combined improves filtering effect. i.e.

Not all countries with a population > 5M are in Asia
Composite Indexes

- p_c (population, continent)
- c_p (continent, population)
ALTER TABLE Country ADD INDEX p_c (Population, Continent);

EXPLAIN FORMAT=JSON
SELECT * FROM Country FORCE INDEX (p_c) WHERE continent='Asia' and population > 5000000;

{  
  "query_block": {  
    "select_id": 1,  
    "cost_info": {  
      "query_cost": "48.86"
    },  
    "table": {  
      "table_name": "Country",  
      "access_type": "range",  
      "possible_keys": [  
        "p_c"
      ],  
      "key": "p_c",  
      "used_key_parts": [  
        "Population"
      ],  
      "key_length": "4",
      ..
  }
}
Rule of Thumb

• Index on (const, range) instead of (range, const)
• Applies to all databases
ALTER TABLE Country ADD INDEX c_p (Continent, Population);
SELECT * FROM Country WHERE continent='Asia' and population > 5000000;
{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "7.91"
        },
        "table": {
            "table_name": "Country",
            "access_type": "range",
            "possible_keys": ["p", "c", "p_c", "c_p"],
            "key": "c_p",
            "used_key_parts": ["Continent", "Population"],
            "key_length": "5",
            ...
        }
    }
}

Index Range Scan
Country

Query cost: 7.91

All of the key is used
Composite Left-most Rule

• An index on (Continent, Population) can also be used as an index on (Continent)
• It can not be used as an index on (Population)
EXPLAIN FORMAT=JSON
SELECT * FROM Country FORCE INDEX (c_p) WHERE population > 500000000;
{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "83.90"
        },
        "table": {
            "table_name": "Country",
            "access_type": "ALL",
            "rows_examined_per_scan": 239,
            "rows_produced_per_join": 79,
            "filtered": "33.33",
            "attached_condition": "(\`world`\.\`country`\.\`Population` > 500000000)"
        }
    }
}
Covering Indexes

• A special kind of composite index
• All information returned just by accessing the index
ALTER TABLE Country ADD INDEX c_p_n (Continent, Population, Name);
EXPLAIN FORMAT=JSON
SELECT Name FROM Country WHERE continent='Asia' and population > 5000000;

```
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "3.72"
    },
    "table": {
      "table_name": "Country",
      "access_type": "range",
      "possible_keys": [
        "c_p_n"
      ],
      "key": "c_p_n",
      "used_key_parts": [
        "Continent",
        "Population"
      ],
      "key_length": "5",
      "filtered": "100.00",
      "using_index": true,
      ...
    }
  },
  "cost": 1.85,
  "rows": 32
}
```

Cost is reduced by 53%

Using index means "covering index"
Use cases

• Can be used as in this example
• Also beneficial in join conditions (join through covering index on intermediate table)
• Useful in aggregate queries
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Visual Explain

• For complex queries, it is useful to see visual representation
• Visualizations in this deck are produced by MySQL Workbench.
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A quick recap:

• So far we’ve talked about 4 candidate indexes:
  – p (population)
  – c (continent)
  – p_c (population, continent)
  – c_p (continent, population)
• We’ve always used c=‘Asia’ and p > 5M
Cost Estimates

<table>
<thead>
<tr>
<th></th>
<th>p&gt;5M, c='Asia'</th>
<th>p&gt;5M, c='Antarctica'</th>
<th>p&gt;50M, c='Asia'</th>
<th>p&gt;50M, c='Antarctica'</th>
<th>p&gt;500M, c='Asia'</th>
<th>p&gt;500M, c='Antarctica'</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>p</strong></td>
<td>48.86</td>
<td>48.86</td>
<td>11.06</td>
<td>11.06</td>
<td>1.16</td>
<td>1.16</td>
</tr>
<tr>
<td><strong>c</strong></td>
<td>9.60</td>
<td>1.75</td>
<td>9.60</td>
<td>1.75</td>
<td>9.60</td>
<td>1.75</td>
</tr>
<tr>
<td><strong>c_p</strong></td>
<td>7.91</td>
<td>0.71</td>
<td>5.21</td>
<td>0.71</td>
<td>1.16</td>
<td>0.71</td>
</tr>
<tr>
<td><strong>p_c</strong></td>
<td>48.86</td>
<td>48.86</td>
<td>11.06</td>
<td>11.06</td>
<td>1.16</td>
<td>1.16</td>
</tr>
<tr>
<td><strong>ALL</strong></td>
<td>25.40</td>
<td>25.40</td>
<td>25.40</td>
<td>25.40</td>
<td>25.40</td>
<td>25.40</td>
</tr>
</tbody>
</table>
Cost Estimates

Cost as a function of Population

Continent = 'Asia' AND Population varying from 1M to 500M.
Actual Execution Time

Execution time vs cost using p (Population) index
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Subquery (Scalar)

- Can optimize away the inner part first and then cache it.
- This avoids re-executing the inner part for-each-row

```sql
SELECT * FROM Country WHERE Code = (SELECT CountryCode FROM City WHERE name='Toronto');
```
SELECT * FROM Country WHERE Code = (SELECT CountryCode FROM City WHERE name='Toronto');

```json
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "1.00"
    },
    "table": {
      "table_name": "Country",
      "access_type": "const",
      ...
      "key": "PRIMARY",
      ...
    },
    "optimized_away_subqueries": [
      {
        "dependent": false,
        "cacheable": true,
        "query_block": {
          "select_id": 2,
          "cost_info": {
            "query_cost": "425.05"
          },
          "table": {
            "table_name": "City",
            "access_type": "ALL",
            ...
          }
        }
      }
    ]
  }
}
```
ALTER TABLE city ADD INDEX n (name);
EXPLAIN FORMAT=JSON
SELECT * FROM Country WHERE Code = (SELECT CountryCode FROM City WHERE name='Toronto');

```json
{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "1.00"
        },
        "table": {
            "table_name": "Country",
            "access_type": "const",
            "key": "PRIMARY",
            ...
        },
        "optimized_away_subqueries": [
            {
                "dependent": false,
                "cacheable": true,
                "query_block": {
                    "select_id": 2,
                    "cost_info": {
                        "query_cost": "0.35"
                    },
                    "table": {
                        "table_name": "City",
                        "access_type": "ref",
                        "possible_keys": ["n"],
                        "key": "n",
                        ...
                    }
                }
            }
        ]
    }
}
```

First query + its cost

Second query + its cost

(misleading visualization)
Subquery (IN list)

- When the result inner subquery returns unique results it can safely be transformed to an inner join:

```sql
EXPLAIN FORMAT=JSON
SELECT * FROM City WHERE CountryCode IN
(SELECT Code FROM Country WHERE Continent = 'Asia');
```

```sql
show warnings;
1 row in set (0.00 sec)
```
EXPLAIN FORMAT=JSON

SELECT * FROM City WHERE CountryCode IN (SELECT Code FROM Country WHERE Continent = 'Asia');

{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "327.58"
        }
    },
    "nested_loop": [
        {
            "table": {
                "table_name": "Country",
                "access_type": "ref",
                "key": "c",
                "using_index": true,
                "used_columns": [
                    "Code",
                    "Continent"
                ]
            },
            "table": {
                "table_name": "City",
                "access_type": "ref",
                "possible_keys": [
                    "CountryCode"
                ],
                "key": "CountryCode",
                "ref": [
                    "world.Country.Code"
                ]
            }
        }
    ]
}
Subquery (cont.)

- When non-unique the optimizer needs to pick a semi-join strategy
- Multiple options: FirstMatch, MaterializeLookup, DuplicatesWeedout

```sql
SELECT * FROM Country WHERE Code IN (SELECT CountryCode FROM CountryLanguage WHERE isOfficial=1);
```

![Diagram of query execution plan]
ALTER TABLE CountryLanguage ADD INDEX i (isOfficial);
EXPLAIN FORMAT=JSON SELECT * FROM Country WHERE Code IN (SELECT CountryCode FROM CountryLanguage WHERE isOfficial=1);

```json
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "98.39"
    },
    "nested_loop": [
      {
        "table": {
          "table_name": "Country",
          "access_type": "ALL",
          "possible_keys": [
            "PRIMARY"
          ],
          "filtered": "100.00",
          ...
        },
        "table": {
          "table_name": "<subquery2>",
          "access_type": "eq_ref",
          "key": "<auto_key>",
          "key_length": "3",
          "ref": [
            "world.Country.Code"
          ],
          "rows_examined_per_scan": 1,
          "materialized_from_subquery": {
            "using_temporary_table": true,
            "query_block": {
              "table": {
                "table_name": "CountryLanguage",
                "access_type": "ref",
                "key": "i",
                "using_index": true,
              }
            }
          }
        }
      }
    ]
  }
}
```
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Views

• A way of saving a SELECT statement as a table
• Allows for simplified queries
• Processed using one of two methods internally:
  – **Merge** - transform the view to be combined with the query.
  – **Materialize** - save the contents of the view in a temporary table, then begin querying
ALTER TABLE country ADD INDEX c_n (continent, name);
CREATE VIEW vCountry_Asia AS SELECT * FROM Country WHERE Continent='Asia';
EXPLAIN FORMAT=JSON
SELECT * FROM vCountry_Asia WHERE Name='China';

```json
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "0.35"
    },
    "table": {
      "table_name": "country",
      "access_type": "ref",
      "possible_keys": [
        "c_n"
      ],
      "key": "c_n",
      "used_key_parts": [
        "Continent",
        "Name"
      ],
      "key_length": "53",
      "ref": [
        "const",
        "const"
      ]
    },
    ...
  }
}
```

This is the base table

Predicates from the view definition and query combined
SHOW WARNINGS;

/* select#1 */ select
`world`.`Country`.`Code` AS `Code`,
`world`.`Country`.`Name` AS `Name`,
`world`.`Country`.`Continent` AS `Continent`,
`world`.`Country`.`Region` AS `Region`,
`world`.`Country`.`SurfaceArea` AS `SurfaceArea`,
`world`.`Country`.`IndepYear` AS `IndepYear`,
`world`.`Country`.`Population` AS `Population`,
`world`.`Country`.`LifeExpectancy` AS `LifeExpectancy`,
`world`.`Country`.`GNP` AS `GNP`,
`world`.`Country`.`GNPOld` AS `GNPOld`,
`world`.`Country`.`LocalName` AS `LocalName`,
`world`.`Country`.`GovernmentForm` AS `GovernmentForm`,
`world`.`Country`.`HeadOfState` AS `HeadOfState`,
`world`.`Country`.`Capital` AS `Capital`,
from `world`.`Country`
where
((`world`.`Country`.`Continent` = 'Asia')
and (`world`.`Country`.`Name` = 'China'))
CREATE VIEW vCountrys_Per_Continent AS
SELECT Continent, COUNT(*) as Count FROM Country
GROUP BY Continent;
EXPLAIN FORMAT=JSON
SELECT * FROM vCountrys_Per_Continent WHERE Continent='Asia';
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "3.64"
    },
    "table": {
      "table_name": "vCountrys_Per_Continent",
      "access_type": "ref",
      "possible_keys": [
        "<auto_key0>"
      ],
      "key": "<auto_key0>",
      "used_key_parts": [
        "Continent"
      ],
      "key_length": "1",
      "ref": [
        "const"
      ],
      "materialized_from_subquery": {
        "using_temporary_table": true,
        "dependent": false,
        "cacheable": true,
        "query_block": {
          "select_id": 2,
          "cost_info": {
            "query_cost": "25.40"
          }
        }
      }
    }
  }
}
SHOW WARNINGS;

/* select#1 */ select
`vCountrys_Per_Continent`.`Continent` AS `Continent`,
`vCountrys_Per_Continent`.`Count` AS `Count`
from `world`.`vCountrys_Per_Continent`
where (`vCountrys_Per_Continent`.`Continent` = 'Asia')
WITH (CTE)

• A view for query-only duration
• Same optimizations available as views:
  – **Merge** - transform the CTE to be combined with the query.
  – **Materialize** - save the contents of the CTE in a temporary table, then begin querying
# Identical Queries - CTE and VIEW

WITH vCountry_Asia AS (SELECT * FROM Country WHERE Continent='Asia')
SELECT * FROM vCountry_Asia WHERE Name='China';

CREATE VIEW vCountry_Asia AS SELECT * FROM Country WHERE Continent='Asia';
SELECT * FROM vCountry_Asia WHERE Name='China';
CTEs are new!

• May provide performance enhancements over legacy code using temporary tables - which never merge.
• Derived tables may need to materialize more than once. A CTE does not! i.e.

```
SELECT * FROM my_table, (SELECT ... ) as t1 ...
UNION ALL
SELECT * FROM my_table, (SELECT ... ) as t1 ...
```
WITH RECURSIVE - new!

WITH RECURSIVE my_cte AS (  
  SELECT 1 AS n  
  UNION ALL  
  SELECT 1+n FROM my_cte WHERE n<10  
)  
SELECT * FROM my_cte;

+------+
| n    |
+------+
| 1    |
| 2    |
..  
| 9    |
| 10   |
+------+
10 rows in set (0.01 sec)
Requires a temporary table for intermediate results

Cost per iteration
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SELECT
  Country.Name as Country, City.Name as Capital, Language
FROM
  City
INNER JOIN Country ON Country.Capital=City.id
INNER JOIN CountryLanguage ON
  CountryLanguage.CountryCode=Country.code
WHERE
  Country.Continent='Asia' and
  CountryLanguage.IsOfficial='T';
Join Strategy (Nested Loop Join)

1. Pick Driving Table (Country)
2. For each row in Country step through to City table
3. For each row in City table step through to CountryLanguage table
4. Repeat
Join efficiency

• Important to eliminate work before accessing other tables (WHERE clause should have lots of predicates that filter driving table)
• Indexes are required on the columns that connect between driving table, and subsequent tables:

ON Country.Capital = City.id
INNER JOIN vs LEFT JOIN

- LEFT JOIN semantically says “right row is optional”.
  - Forces JOIN order to be left side first.
  - Reduces possible ways to join tables
Join Order Hints

• One of the most frequent types of hints to apply

• New join order hints in 8.0:
  – JOIN_FIXED_ORDER
  – JOIN_ORDER
  – JOIN_PREFIX
  – JOIN_SUFFIX
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Group By - Index Scan

- Scan the index from start to finish without buffering. Results are pipelined to client:

```sql
SELECT count(*) as c, continent FROM Country
GROUP BY continent;
```
Group By - Index Filtering Rows

• Use the index to eliminate as much work as possible
• Store rows in intermediate temporary file and then sort
Group By - Index Filtering + Guaranteed Order

- Use the index to eliminate as much work as possible
- The index also maintains order
UNION

- Requires an intermediate temporary table to weed out duplicate rows
- The optimizer does not really have any optimizations for UNION (such as a merge with views)
```sql
EXPLAIN FORMAT=JSON
SELECT * FROM City WHERE CountryCode = 'CAN'
UNION
SELECT * FROM City WHERE CountryCode = 'USA'
```

```json
{
  "union_result": {
    "using_temporary_table": true,
    "table_name": "<union1,2>",
    "access_type": "ALL",
    "query_specifications": [
      {
        "dependent": false,
        "cacheable": true,
        "query_block": {
          "select_id": 1,
          "cost_info": {
            "query_cost": "17.15"
          },
          "table": {
            "table_name": "City",
            "access_type": "ref",
            "possible_keys": ["CountryCode"],
            "key": "CountryCode",
            "used_key_parts": ["CountryCode"],
            "key_length": "3",
            "ref": ["const"],
            ..
            "key": "CountryCode",
            ..
```

Temporary table to de-duplicate
```
UNION ALL

• Results may contain duplicate rows
• Does not require an intermediate temporary table in simple use cases. i.e. no result ordering.
• Otherwise similar to UNION
EXPLAIN FORMAT=JSON
SELECT * FROM City WHERE CountryCode = 'CAN'
UNION ALL
SELECT * FROM City WHERE CountryCode = 'USA'

{  "query_block": {
    "union_result": {
        "using_temporary_table": false,
        "query_specifications": [{
            "dependent": false,
            "cacheable": true,
            "query_block": {
                "select_id": 1,
                "cost_info": {
                    "query_cost": "17.15"
                },
                "table": {
                    "table_name": "City",
                    "access_type": "ref",
                    "possible_keys": ["CountryCode"],
                    "key": "CountryCode",
                    "used_key_parts": ["CountryCode"],
                    "key_length": "3",
                    "ref": [
                        "const"
                    ]
                }
            }
        },
        "dependent": false,
        "cacheable": true,
        "query_block": {
            "select_id": 2,
            "cost_info": {
                "query_cost": "46.15"
            },
            "table": {
                "table_name": "City",
                "access_type": "ref",
                "possible_keys": ["CountryCode"],
                "key": "CountryCode",
                "used_key_parts": ["CountryCode"],
                "key_length": "3",
                "ref": [
                    "const"
                ]
            }
        }
    }
},
"no temporary table"
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Descending Indexes

• B+tree indexes are ordered
• In 8.0 you can specify the order
• Use cases:
  – Faster to scan in order
  – Can’t change direction in a composite index
EXPLAIN FORMAT=JSON
SELECT * FROM Country WHERE continent='Asia' AND population > 5000000
ORDER BY population DESC;
{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "7.91"
        },
        "ordering_operation": {
            "using_filesort": false,
            "table": {
                "table_name": "Country",
                "access_type": "range",
                ..
                "key": "c_p",
                ..
                "backward_index_scan": true,
                ..
        ....
        "Still uses the index, but about 15% slower"}
SELECT * FROM Country WHERE continent IN ('Asia', 'Oceania') AND population > 5000000 ORDER BY continent ASC, population DESC

{  
"query_block": {  
"select_id": 1,  
"cost_info": {  
"query_cost": "48.36"  
},  
"ordering_operation": {  
"using_filesort": true,  
"cost_info": {  
"sort_cost": "33.00"  
},  
"table": {  
"table_name": "Country",  
"access_type": "range",  
"key": "c_p",  
...  
"rows_examined_per_scan": 33,  
"rows_produced_per_join": 33,  
"filtered": "100.00",  
...  
}
}

Must sort values of population in reverse
ALTER TABLE Country DROP INDEX c_p, DROP INDEX c_p_n,
ADD INDEX c_p_desc (continent ASC, population DESC);

EXPLAIN FORMAT=JSON
SELECT * FROM Country WHERE continent IN ('Asia', 'Oceania') AND population > 5000000
ORDER BY continent ASC, population DESC;

TIP: The optimizer does not consider sort cost in evaluating plans. You may need to FORCE INDEX or DROP similar ascending indexes to use it.
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How is ORDER BY optimized?

1. Via an Index
2. Top N Buffer ("priority queue")
3. Using temporary files
Via an Index

- B+tree indexes are ordered
- Some ORDER BY queries do not require sorting at all

EXPLAIN FORMAT=JSON
SELECT * FROM Country WHERE continent='Asia' ORDER BY population;
{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "9.60"
        },
        "ordering_operation": {
            "using_filesort": false,
            "key": "c_p"
        }
    }
}

The order is provided by c_p
Via a Priority Queue

• Special ORDER BY + small limit optimization
• Keeps top N records in an in memory buffer
• Usage is **NOT** shown in EXPLAIN

```sql
SELECT * FROM Country IGNORE INDEX (p, p_c)
ORDER BY population LIMIT 10;
```
"select": 1,
"steps": [
    {
        "filesort_information": [
            {
                "direction": "asc",
                "table": `
``country`` IGNORE INDEX (`p_c`) IGNORE INDEX (`p`)`,
                "field": "Population"
            }
        ],
        "filesort_priority_queue_optimization": {
            "limit": 10,
            "chosen": true
        },
        "filesort_execution": [
        ],
        "filesort_summary": {
            "memory_available": 262144,
            "key_size": 4,
            "row_size": 272,
            "max_rows_per_buffer": 11,
            "num_rows_estimate": 587,
            "num_rows_found": 11,
            "num_examined_rows": 239,
            "num_tmp_files": 0,
            "sort_buffer_size": 3080,
            "sort_algorithm": "std::sort",
            "unpacked_addon_fields": "using_priority_queue",
            "sort_mode": "<fixed_sort_key, additional_fields>"
        }
    }
]
Using Temporary Files

- Either “Alternative Sort Algorithm” (no blobs present) or “Original Sort Algorithm”

```sql
SELECT * FROM Country IGNORE INDEX (p, p_c)
ORDER BY population;
```
select#": 1,
"steps": [
{
"filesort_information": [
{
"direction": "asc",
"table": `country` IGNORE INDEX (`p_c`) IGNORE INDEX (`p`)
,
"field": "Population"
}
],
"filesort_priority_queue_optimization": {
"usable": false,
"cause": "not applicable (no LIMIT)"
},
"filesort_execution": [
],
"filesort_summary": {
"memory_available": 262144,
"key_size": 4,
"row_size": 274,
"max_rows_per_buffer": 587,
"num_rows_estimate": 587,
"num_rows_found": 239,
"num_examined_rows": 239,
"num_tmp_files": 0,
"sort_buffer_size": 165536,
"sort_algorithm": "std::stable_sort",
"sort_mode": "<fixed_sort_key, packed_additional_fields>"
..
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Partitioning

• Split a table physically into smaller tables
• At the user-level make it still appear as one table
Use Cases

• Can be a better fit low cardinality columns than indexing
• Useful for time series data with retention scheme
  • i.e. drop data older than 3 months
• Data where queries always have some locality
  • i.e. store_id, region
Partition Pruning

- Optimizer looks at query and identifies which partitions need to be accessed

```sql
ALTER TABLE CountryLanguage MODIFY IsOfficial CHAR(1) NOT NULL DEFAULT 'F', DROP PRIMARY KEY, ADD PRIMARY KEY(CountryCode, Language, IsOfficial);

ALTER TABLE CountryLanguage PARTITION BY LIST COLUMNS (IsOfficial) (  PARTITION pUnofficial VALUES IN ('F'),  PARTITION pOfficial VALUES IN ('T'));
```
SELECT * FROM CountryLanguage WHERE isOfficial='T' AND CountryCode='CAN';

{  
  "query_block": {  
    "select_id": 1, 
    "cost_info": {  
      "query_cost": "2.40" 
    },  
    "table": {  
      "table_name": "CountryLanguage",  
      "partitions": [  
        "pOfficial" 
      ],  
      "access_type": "ref",  
      ..  
      "key": "PRIMARY",  
      .. 
    }  
  }  
}
Explicit Partition Selection

• Also possible to “target” a partition
• Consider this similar to query hints

```
SELECT * FROM CountryLanguage PARTITION (pOfficial) 
WHERE CountryCode='CAN';
```
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Query Rewrite

- MySQL allows you to change queries before they are executed
- Insert a hint, or remove a join that is not required

mysql -u root -p < install_rewriter.sql

```
INSERT INTO query_rewrite.rewrite_rules(pattern_database, pattern, replacement) VALUES (
  "world",
  "SELECT * FROM Country WHERE population > ? AND continent=?",
  "SELECT * FROM Country WHERE population > ? AND continent=? LIMIT 1"
);
CALL query_rewrite.flush_rewrite_rules();
```
SELECT * FROM Country WHERE population > 5000000 AND continent='Asia';
SHOW WARNINGS;
 *********************** 1. row **********************
    Level: Note
    Code: 1105
Message: Query 'SELECT * FROM Country WHERE population > 5000000 AND continent='Asia'' rewritten to 'SELECT * FROM Country WHERE population > 5000000 AND continent='Asia' LIMIT 1' by a query rewrite plugin
1 row in set (0.00 sec)
id: 1

pattern: SELECT * FROM Country WHERE population > ? AND continent=?

pattern_database: world

replacement: SELECT * FROM Country WHERE population > ? AND continent=? LIMIT 1

enabled: YES

message: NULL

pattern_digest: 88876bb502cef6efddcc661cce77deb

normalized_pattern: select `*` from `world`.`country` where ((`population` > ?) and (`continent` = ?))

1 row in set (0.00 sec)
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Changing Indexes is a *Destructive Operation*

- Removing an index can make some queries much slower
- Adding can cause some existing query plans to change
- Old-style hints will generate errors if indexes are removed
Invisible Indexes, the “Recycle Bin”

• Hide the indexes from the optimizer
• Will no longer be considered as part of query execution plans
• Still kept up to date and are maintained by insert/update/delete statements
Invisible Indexes: Soft Delete

ALTER TABLE Country ALTER INDEX c INVISIBLE;
SELECT * FROM information_schema.statistics WHERE is_visible='NO';

*************************** 1. row ***************************
TABLE_CATALOG: def
TABLE_SCHEMA: world
   TABLE_NAME: Country
      NON_UNIQUE: 1
INDEX_SCHEMA: world
   INDEX_NAME: c
   SEQ_IN_INDEX: 1
   COLUMN_NAME: Continent
      COLLATION: A
   CARDINALITY: 7
      SUB_PART: NULL
      PACKED: NULL
      NULLABLE:
INDEX_TYPE: BTREE
   COMMENT: disabled
INDEX_COMMENT:
     IS_VISIBLE: NO
Invisible Indexes: Staged Rollout

```sql
ALTER TABLE Country ADD INDEX c (Continent) INVISIBLE;

# after some time
ALTER TABLE Country ALTER INDEX c VISIBLE;
```
Finding Unused Indexes

```
SELECT * FROM sys.schema_unused_indexes;
```

```
+---------------+-------------+------------+
| object_schema | object_name | index_name |
+---------------+-------------+------------+
| world         | Country     | p          |
| world         | Country     | p_c        |
+---------------+-------------+------------+
2 rows in set (0.01 sec)
```
Do indexes hurt reads or writes?

• They can have some impact on both:
  – On writes, indexes need to space, and to be maintained
  – On reads, let’s use an example...
Indexes Hurting Reads

CREATE TABLE t1 (  
id INT NOT NULL primary key auto_increment,  
a VARCHAR(255) NOT NULL,  
b VARCHAR(255) NOT NULL,  
c TEXT,  
d TEXT,  
INDEX a (a),  
INDEX ab (a,b));

# Sample Query
SELECT * FROM t1 WHERE a = 'abc' AND b = 'bcd';
A use case for invisible indexes!

CREATE TABLE t1 (  
id INT NOT NULL primary key auto_increment,  
a VARCHAR(255) NOT NULL,  
b VARCHAR(255) NOT NULL,  
c TEXT,  
d TEXT,  
INDEX a (a),  
INDEX ab (a,b));

# Consider:
SELECT count(*) FROM t1 FORCE INDEX (a)  
WHERE a='1234' AND id=1234;

Index (a) is made redundant by (a,b). Can we drop it?
No, due to clustered Index!

```sql
FORCE INDEX (a) WHERE a='1234' AND id=1234;
{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "0.35"
        }
    },
    "table": {
        "table_name": "t1",
        "access_type": "const",
        "possible_keys": ["a"],
        "key": "a",
        "used_key_parts": ["a", "id"]
    }
}
```

```sql
FORCE INDEX (ab) WHERE a='1234' AND id=1234;
{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "11.80"
        }
    },
    "table": {
        "table_name": "t1",
        "access_type": "ref",
        "possible_keys": ["ab"],
        "key": "ab",
        "used_key_parts": ["a"]
    }
}
```
Profiling

- Optimizer only shows estimates from pre-execution view
- Can be useful to know actual time spent
- Support for profiling is only very basic

wget http://www.tocker.ca/files/ps-show-profiles.sql
mysql -u root -p < ps-show-profiles.sql
CALL sys.enable_profiling();
CALL sys.show_profiles;
*************************** 1. row ***************************
  Event_ID: 22
  Duration: 495.02 us
  Query: SELECT * FROM Country WHERE country_name = 'China' or country_name = 'Asia' and population > 5000000
  1 row in set (0.00 sec)

CALL sys.show_profile_for_event_id(22);

+----------------------+-----------+
<table>
<thead>
<tr>
<th>Status</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>starting</td>
<td>64.82 us</td>
</tr>
<tr>
<td>checking permissions</td>
<td>4.10 us</td>
</tr>
<tr>
<td>Opening tables</td>
<td>11.87 us</td>
</tr>
<tr>
<td>init</td>
<td>29.74 us</td>
</tr>
<tr>
<td>System lock</td>
<td>5.63 us</td>
</tr>
<tr>
<td>optimizing</td>
<td>8.74 us</td>
</tr>
<tr>
<td>statistics</td>
<td>139.38 us</td>
</tr>
<tr>
<td>preparing</td>
<td>11.94 us</td>
</tr>
<tr>
<td>executing</td>
<td>348.00 ns</td>
</tr>
<tr>
<td>Sending data</td>
<td>192.59 us</td>
</tr>
<tr>
<td>end</td>
<td>1.17 us</td>
</tr>
<tr>
<td>query end</td>
<td>4.60 us</td>
</tr>
<tr>
<td>closing tables</td>
<td>4.07 us</td>
</tr>
<tr>
<td>freeing items</td>
<td>13.60 us</td>
</tr>
<tr>
<td>cleaning up</td>
<td>734.00 ns</td>
</tr>
</tbody>
</table>
+----------------------+-----------+
15 rows in set (0.00 sec)
```sql
SELECT * FROM Country WHERE Continent='Antarctica' and SLEEP(5);
CALL sys.show_profiles();
CALL sys.show_profile_for_event_id(<event_id>);

<table>
<thead>
<tr>
<th>Status</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>starting</td>
<td>103.89 us</td>
</tr>
<tr>
<td>checking permissions</td>
<td>4.48 us</td>
</tr>
<tr>
<td>Opening tables</td>
<td>17.78 us</td>
</tr>
<tr>
<td>init</td>
<td>45.75 us</td>
</tr>
<tr>
<td>System lock</td>
<td>8.37 us</td>
</tr>
<tr>
<td>optimizing</td>
<td>11.98 us</td>
</tr>
<tr>
<td>statistics</td>
<td>144.78 us</td>
</tr>
<tr>
<td>preparing</td>
<td>15.78 us</td>
</tr>
<tr>
<td>executing</td>
<td>634.00 ns</td>
</tr>
<tr>
<td>Sending data</td>
<td>116.15 us</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>User sleep</td>
<td>5.00 s</td>
</tr>
<tr>
<td>end</td>
<td>2.05 us</td>
</tr>
<tr>
<td>query end</td>
<td>5.63 us</td>
</tr>
<tr>
<td>closing tables</td>
<td>7.30 us</td>
</tr>
<tr>
<td>freeing items</td>
<td>20.19 us</td>
</tr>
<tr>
<td>cleaning up</td>
<td>1.20 us</td>
</tr>
</tbody>
</table>
```

Sleeps for each row after index used on (c)

20 rows in set (0.01 sec)
```
SELECT region, count(*) as c FROM Country GROUP BY region;
CALL sys.show_profiles();
CALL sys.show_profile_for_event_id(<event_id>);
```

<table>
<thead>
<tr>
<th>Status</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>starting</td>
<td>87.43 us</td>
</tr>
<tr>
<td>checking permissions</td>
<td>4.93 us</td>
</tr>
<tr>
<td>Opening tables</td>
<td>17.35 us</td>
</tr>
<tr>
<td>init</td>
<td>25.81 us</td>
</tr>
<tr>
<td>System lock</td>
<td>9.04 us</td>
</tr>
<tr>
<td>optimizing</td>
<td>3.37 us</td>
</tr>
<tr>
<td>statistics</td>
<td>18.31 us</td>
</tr>
<tr>
<td>preparing</td>
<td>10.94 us</td>
</tr>
<tr>
<td>Creating tmp table</td>
<td>35.57 us</td>
</tr>
<tr>
<td>Sorting result</td>
<td>2.38 us</td>
</tr>
<tr>
<td>executing</td>
<td>741.00 ns</td>
</tr>
<tr>
<td>Sending data</td>
<td>446.03 us</td>
</tr>
<tr>
<td>Creating sort index</td>
<td>49.45 us</td>
</tr>
<tr>
<td>end</td>
<td>1.71 us</td>
</tr>
<tr>
<td>query end</td>
<td>4.85 us</td>
</tr>
<tr>
<td>removing tmp table</td>
<td>4.71 us</td>
</tr>
<tr>
<td>closing tables</td>
<td>6.12 us</td>
</tr>
<tr>
<td>freeing items</td>
<td>17.17 us</td>
</tr>
<tr>
<td>cleaning up</td>
<td>1.00 us</td>
</tr>
</tbody>
</table>

19 rows in set (0.01 sec)
SELECT * FROM performance_schema.events_statements_history_long
WHERE event_id=<event_id>

*********************** 1. row ***********************
THREAD_ID: 3062
EVENT_ID: 1566
END_EVENT_ID: 1585
EVENT_NAME: statement/sql/select
    SOURCE: init_net_server_extension.cc:80
TIMER_START: 588883869566277000
TIMER_END: 588883870317683000
TIMER_WAIT: 751406000
LOCK_TIME: 132000000
SQL_TEXT: SELECT region,
count(*) as c FROM `Country` GROUP BY `region`
    DIGEST: d3a04b346fe48da4f1f5c2e06628a245
    DIGEST_TEXT: SELECT `region` ,
COUNT ( * ) AS `c` FROM `Country`
GROUP BY `region`
CURRENT_SCHEMA: world
OBJECT_TYPE: NULL
OBJECT_SCHEMA: NULL
OBJECT_NAME: NULL
OBJECT_INSTANCE_BEGIN: NULL
MYSQL_ERRNO: 0
RETURNED_SQLSTATE: NULL
MESSAGE_TEXT: NULL
ERRORS: 0
WARNINGS: 0

ROWS_AFFECTED: 0
ROWS_SENT: 25
ROWS_EXAMINED: 289
CREATED_TMP_DISK_TABLES: 0
CREATED_TMP_TABLES: 1
SELECT_FULL_JOIN: 0
SELECT_FULL_RANGE_JOIN: 0
SELECT_RANGE: 0
SELECT_RANGE_CHECK: 0
SELECT_SCAN: 1
SORT_MERGE_PASSES: 0
SORT_RANGE: 0
SORT_ROWS: 25
SORT_SCAN: 1
NO_INDEX_USED: 1
NO_GOOD_INDEX_USED: 0
NESTING_EVENT_ID: NULL
NESTING_EVENT_TYPE: NULL
NESTING_EVENT_LEVEL: 0

For non-aggregate queries rows sent vs. rows examined helps indicate index effectiveness.
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JSON

- Optimizer has native support for JSON with indexes on generated columns used for matching JSON path expressions

CREATE TABLE CountryJson (Code char(3) not null primary key, doc JSON NOT NULL);
INSERT INTO CountryJson SELECT code,
  JSON_OBJECT(
    'Name', Name,
    'Continent', Continent,
    ..
    'HeadOfState', HeadOfState,
    'Capital', Capital,
    'Code2', Code2
  ) FROM Country;
EXPLAIN FORMAT=JSON
SELECT * FROM CountryJSON where doc->>"$.Name" = 'Canada';
{
  "query_block": {
    "select_id": 1,
    "cost_info": {
      "query_cost": "48.80"
    },
  },
  "table": {
    "table_name": "CountryJSON",
    "access_type": "ALL",
    "rows_examined_per_scan": 239,
    "rows_produced_per_join": 239,
    "filtered": "100.00",
    "cost_info": {
      "read_cost": "1.00",
      "eval_cost": "47.80",
      "prefix_cost": "48.80",
      "data_read_per_join": "3K"
    },
  }
}
ALTER TABLE CountryJSON ADD Name char(52) AS (doc->>'$.Name'),
ADD INDEX n (Name);
EXPLAIN FORMAT=JSON
SELECT * FROM CountryJSON where doc->>'$.Name' = 'Canada';
{
    "query_block": {
        "select_id": 1,
        "cost_info": {
            "query_cost": "1.20"
        },
        "table": {
            "table_name": "CountryJSON",
            "access_type": "ref",
            "key": "n",
            "key_length": "53",
            "ref": [
                "const"
            ],
        }
    }
}
JSON Comparator

• JSON types compare to MySQL types

```sql
SELECT CountryJSON.* FROM CountryJSON
```

*************** 1. row ***************

Code: CAN

```json
doc: {
}
```

Name: Canada
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Character Sets

• The default character set in MySQL 8.0 is utf8mb4
• Utf8mb4 is variable length (1-4 bytes)
• InnoDB will always store as variable size for both CHAR and VARCHAR
• Some buffers inside MySQL may require the fixed length (4 bytes)
Character Sets (cont.)

- CHAR(n) or VARCHAR(n) refers to n characters - *x4 for maximum length*
- EXPLAIN will always show the maximum length
- Mysqldump will preserve character set

```sql
ALTER TABLE City DROP FOREIGN KEY city_ibfk_1;
ALTER TABLE CountryLanguage DROP FOREIGN KEY countryLanguage_ibfk_1;
ALTER TABLE Country CONVERT TO CHARACTER SET utf8mb4;
```
null
Conclusion

• Thank you for coming!
• This presentation is available as a website: www.unofficialmysqlguide.com