Building a scalable row, column or document-style store with MySQL and Shard-Query

12/15/2012

Agenda

- Introduction
- The new age of multi-core
- Enter Shard-Query
- Focus on OLAP (reporting and analytics)
- Row store (normalized)
- Column store (star schema)
- Document store (hybrid schema)
- QA

Introduction

FOSS I maintain

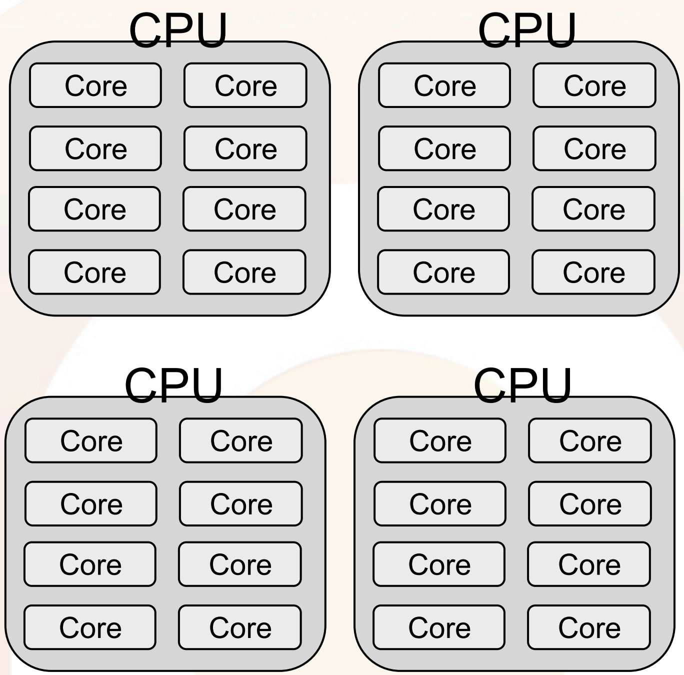
- Shard-Query
  - MPP distributed query middleware for MySQL
  - Work is divided up using sharding, table partitioning and SQL features.
  - Distributes work over many machines in parallel
  - http://code.google.com/p/shard-query

FOSS I maintain

- Flexviews
    - Caches result sets and can refresh them efficiently based on only the database changes since the last refresh
    - Refresh cost is directly proportional to the number of changes to the base data
    - http://code.google.com/p/flexviews

THE NEW AGE OF MULTI-CORE

The new age of multi-core



"If your time to you is worth saving,
then you better start swimming.
Or you'll sink like a stone.
For the times they are a-changing."

- **Bob Dylan**

Moore’s law

- The number of transistors in a CPU doubles every 24 months
- In combination with other component improvements, this allowed doubling of CPU clock speed approximately every 18 months
- Frequency scaling beyond a few GHz has *extreme* power requirements
- Increased power = increased heat

Moore’s law today

- Speed now doubles more slowly: 36 months
- Power efficient multiple-core designs have become very mature
- Larger number of slower cores which use less power in aggregate

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Question:

Is multi-core faster?

Answer: It depends

A program is only faster on a multiple core CPU *if it can use more than one core*

Why?

1. A physical CPU may have many logical cpu
2. Each logical CPU runs at most one thread at one time
3. Max running threads:
    1. Physical CPU count x CPU core density x threads per core
        - Dual CPU with 3 HT cores = 2 x 3 x 2 = 12 threads

What is a thread?

- Every program uses at least one thread
- A multithreaded program can do more work
  - **But only if it can split the work into many threads**
- If it *doesn't* split up the work: then there is no speedup.

What is a task?

- An action in the system which results in work
  - A login
  - A report
  - An individual query

- Tasks are single or multi-threaded
    - Tasks may have sub-tasks

Response Time

- Time to complete a task in wall clock time
- Response time includes the time to complete all sub-tasks
  - You must include queue time in response time

Throughput

- How many tasks complete in a given unit of time
- Throughput is a measure of overall work done by the system

Throughput vs Response time

Response time = Time / Task

Throughput = Tasks / Time

Efficiency

- This is a score about how well you scheduled the work for your task. Inefficient workloads underutilize resources

$$\left(\frac{\text{Resources Used}}{\text{Resources Available}} \times 100 \right)$$

Efficiency Example

$$\left(\frac{\text{Resources Used}}{\text{Resources Available}} \times 100 \right)$$

- CPU bound workload given 8 available cores
  - When all work is done in single thread:12.5% CPU efficiency
  - If the work can be split into 8 threads: 100% CPU efficiency

Lost time is lost money

- You are paying for wall clock time
  - Return on investment is directly proportional to efficiency.
- **You can’t bank lost time**
- If you miss an SLA or response time objective you lost the time investment, plus you may have to pay an penalty
- It may be impossible to get critical insight

Scalability

When resources are added what happens to efficiency?

- Given the same workload, if throughput does not increase:
  - Adding even more resources will not improve performance
  - But you may have the resources for more concurrent tasks
  - This is the traditional database scaling model

Scalability

When resources are added what happens to efficiency?

- If throughput increases
  - **The system scales up to the workload**
  - When people ask if a system is scalable, this is usually what they want to know.

Scalability

When resources are added what happens to efficiency?

- If throughput goes down there is ***negative scalability***
  - Mutexes are probably the culprit
  - This is still the biggest contention point for databases with many cores
  - This means you can't just scale up a single machine forever. You will always hit a limit (currently 32-48 cores).

Response time is very important!

- Example:
  - It takes 3 days for a 1 day report
    - It doesn’t matter if you can run 100 reports at once
    - Response time for any 1 report is too high if you need to make decisions today about yesterday

Workload

- A workload consists of many tasks
- Typical database workloads are categorized by the nature of the individual tasks
  - Typical database workloads are OLTP and OLAP

OLTP

- Frequent highly concurrent reads and writes of **small** amounts data per query.
- **Simple queries, little aggregation**
- Many small queries naturally divide the work over many cores

Known OLTP scalability issues

- Many concurrent threads accessing critical memory areas leads to ***mutex contention***
- Reducing global mutex contention main dev focus
- Mutex contention is still the biggest bottleneck
  - Prevents scaling up forever (32 cores max)

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OLAP (analytical queries)

- Low concurrency reads of **large** amounts of data
- **Complex queries and frequent aggregation**
- STAR schema common (data mart)
- Single table (machine generated data) common
- Partitioning very common

Known OLAP scalability issues

- IO bottleneck usually gets hit first
- However, even if all data is in memory it still may be impossible to reach the *response time objective*
  - Queries may not be able to complete fast enough to meet business objectives because:
    - MySQL only supports nested loops*
    - **All queries are single threaded**

* MariaDB has some support for hash joins

You don’t need a bigger boat

- Buying a bigger server probably won’t help for individual queries that are CPU bound.
- **Queries are still single threaded.**

You need to change the workload!

- Turn OLAP queries into something more like OLTP
  - Split one complex query into many smaller queries
  - Run those queries in parallel
  - Put the results together so it looks like nothing happened
  - This leverages multiple cores and multiple servers

- Doing this *manually* for all queries is not practical.

Life sometimes give you lemons

Enter Shard-Query

- Shard-Query ***transparently*** splits up complex SQL into smaller SQL statements (sub tasks) which run concurrently
  - MySQL proxy (small LUA interface to shard-query)
  - REST / HTTP GUI
  - PHP OO interface

Why not get a different database?

- Because MySQL is a great database and sticking with it has advantages
  - Operations knows how to work with it (backups!)
  - It is FOSS (alternatives are very costly or very limited)
  - MySQL’s special dialect means changes to apps to move to an alternative database
  - The alternatives are either a proprietary RDBMS* or map/reduce.

* Vertica, Greenplum, Vectorwise, AsterData, Teradata, etc…

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Smaller queries are better queries

- This is closer to the OLTP workload that the database has been optimized for
  - Smaller queries use smaller temporary tables resulting in more in-memory aggregation
  - This reduces the usage of temporary tables on disk
- Parallelism reduces response time
  - The small queries run in parallel for a massive speedup

Data level parallelism

- Table level partitioning
  - One big table is split up into smaller tables internally
  - Reduce IO and contention on shared data structures in the database.
  - MySQL ***could*** operate on partitions in parallel
    - **But MySQL doesn't**
    - **Shard-Query *does***

Data level parallelism (cont)

- Sharding
  - Horizontally partition data over more than one server.
  - Shards can naturally be operated on in parallel.
  - This is called shared-nothing architecture, or data level parallelism.
  - This is also called **scaling out.**

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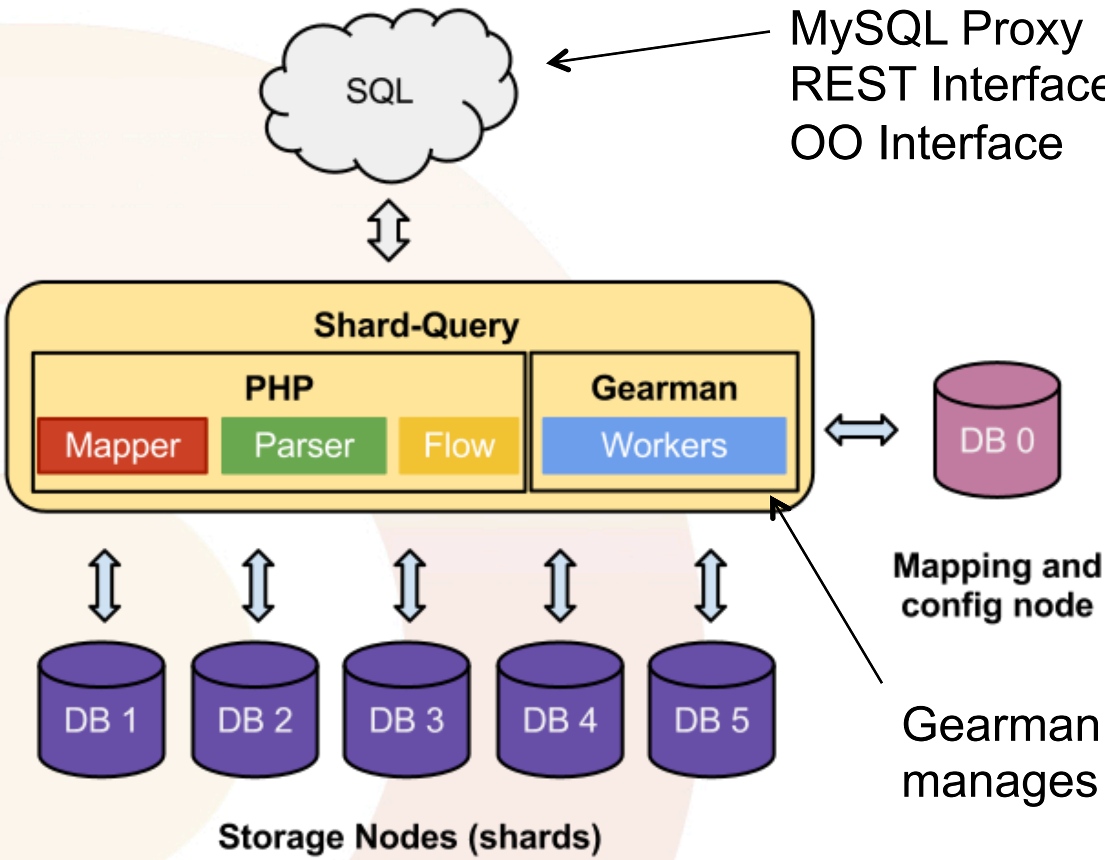
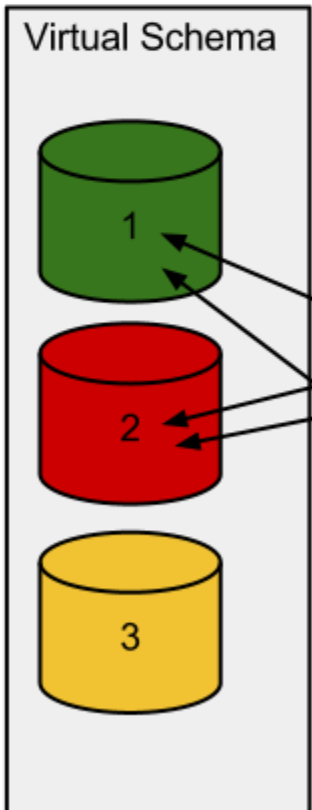
Shard-Query

MySQL Proxy
REST Interface
OO Interface



Gearman message queue manages work

Map/Config Node and Shards



Directory Mapper

Shard selection is based on a mapping table. The shard column value is looked up in the table.

Table: sales

customer_id	order_date	item	qty	price
100	1/2/2013	phone	1	250
200	1/4/2013	netbook	2	1000
300	1/5/2013	mouse	20	10
400	1/3/2013	printer	1	175

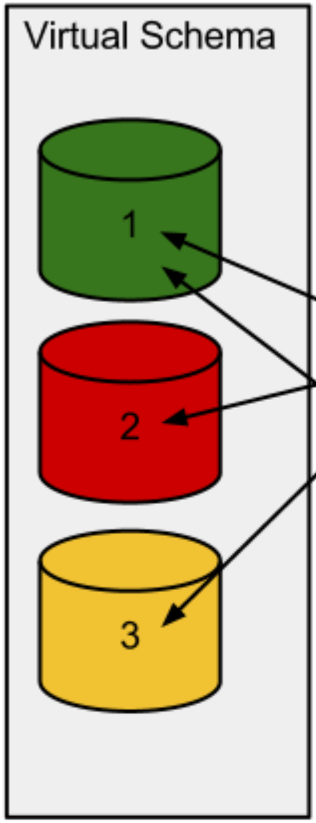
Shard Column: customer_id

Map Table

schema_name	column_name	column_value	shard_id
sales	customer_id	100	1
sales	customer_id	200	2
sales	customer_id	300	2
sales	customer_id	400	1

* simplification

Hash mapping of shards



Hash Mapper

Shard selection is based on the modulus of the shard column value over the number of shards.

Table: sales

customer_id	order_date	item	qty	price
100	1/2/2013	phone	1	250
200	1/4/2013	netbook	2	1000
300	1/5/2013	mouse	20	10
400	1/3/2013	printer	1	175

Shard Column: customer_id

Hash function:

COLUMN_VALUE % NUM_SHARDS = SHARD_ID

Unsharded tables and joins

- Tables that do not contain the shard key are replicated to all shards
- This allows joins between sharded and unsharded tables (lookup tables/dimension tables)
- This means Shard-Query works best for star and snowflake schema
- Many open source tools like Mondrian work well with a star schema.

But not just for sharding

- The name is misleading as you have choices:
  - **Partition** your data on one big server to scale up
  - **Shard** your data onto multiple servers to scale out
  - Do **both** for extreme scalability
    - Or neither, but with less benefits

Parallelism of SQL dataflow

- Shard-Query can add parallelism and improve query performance based on SQL language constructs:
  - IN lists and subqueries are parallelized
  - BETWEEN on date or integer operands adds parallelism too
  - UNION ALL and UNION queries are parallelized*
  - Uncorrelated subqueries are materialized early, are indexed and run in parallel (inside out execution)

* They have to have features necessary to enable parallelism.
 You really need to partition and shard for best results

Shard-Query is not for OLTP

- Parser and execution strategy is “relatively expensive”
  - For OLAP this time is a small fraction of the overall execution time and the cost is “cheap”
  - Tying to turn OLTP into OLTP is wasted effort and waste reduces efficiency
  - But OLTP still caps out at 32 cores on a single box
    - So what do I do for OLTP?

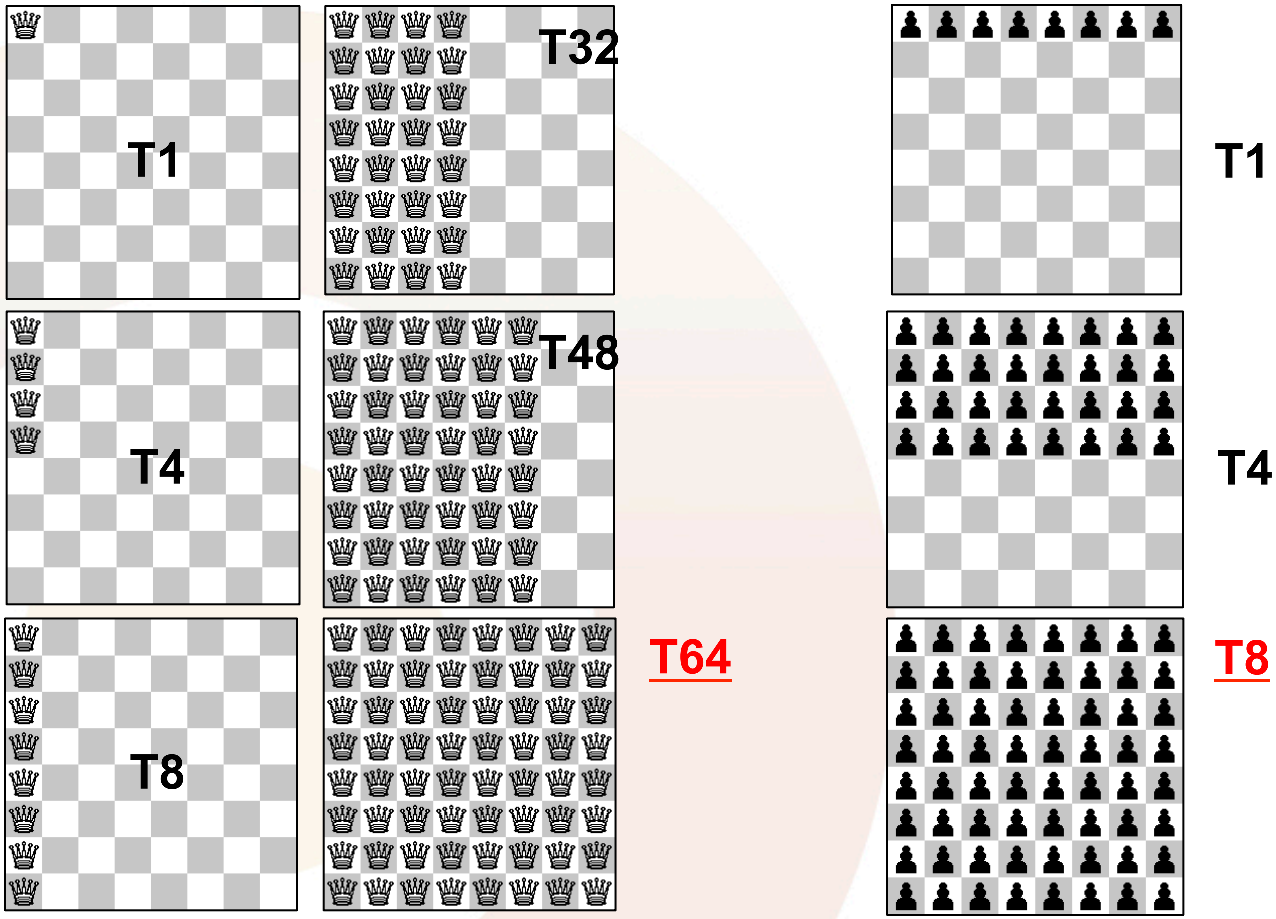
Sharding for OLTP

- Use **Shard-Key-Mapper**
  - Use this helper class to figure out which shard to use
  - Then send queries directly to that shard (bypass parser)
  - This could be made transparent with mysqlnd plugins
- You can then still use SQ when complex query tasks are needed
- This is a topic for another day

Shard-Query Parallelism

- Shard-Query adds *intra-query* parallelism to MySQL
  - This means that more than one thread operates on a SQL query
  - This can result in massive speedups because the work is divided up between multiple threads and even multiple machines
  - Data distribution should be even to ensure best parallelism

Intra-Query Parallelism
You get to move all the pieces at the same time



Shard-Query 2.0 Features

- **Automatic sharding and massively parallel loading**
  – Add new shards then spread new data over them automatically
  – You can manually move records between shards
- **Complex query support**
  – GROUP BY, HAVING, LIMIT, ORDER BY, WITH ROLLUP, derived tables, UNION, etc
- But not:
  – Joins between tables sharded on different keys (soon)

Shard-Query 2.0 Features

- **Massively parallel loader / distributed loader**
  - Can split loading into chunks split over many threads
- **Long query support**
  - Supports asynchronous jobs for running long queries
- **DML/DDL support**
  - Supports almost all MySQL SQL including INSERT, UPDATE, DELETE
  - DDL is intelligently broadcast to all shards

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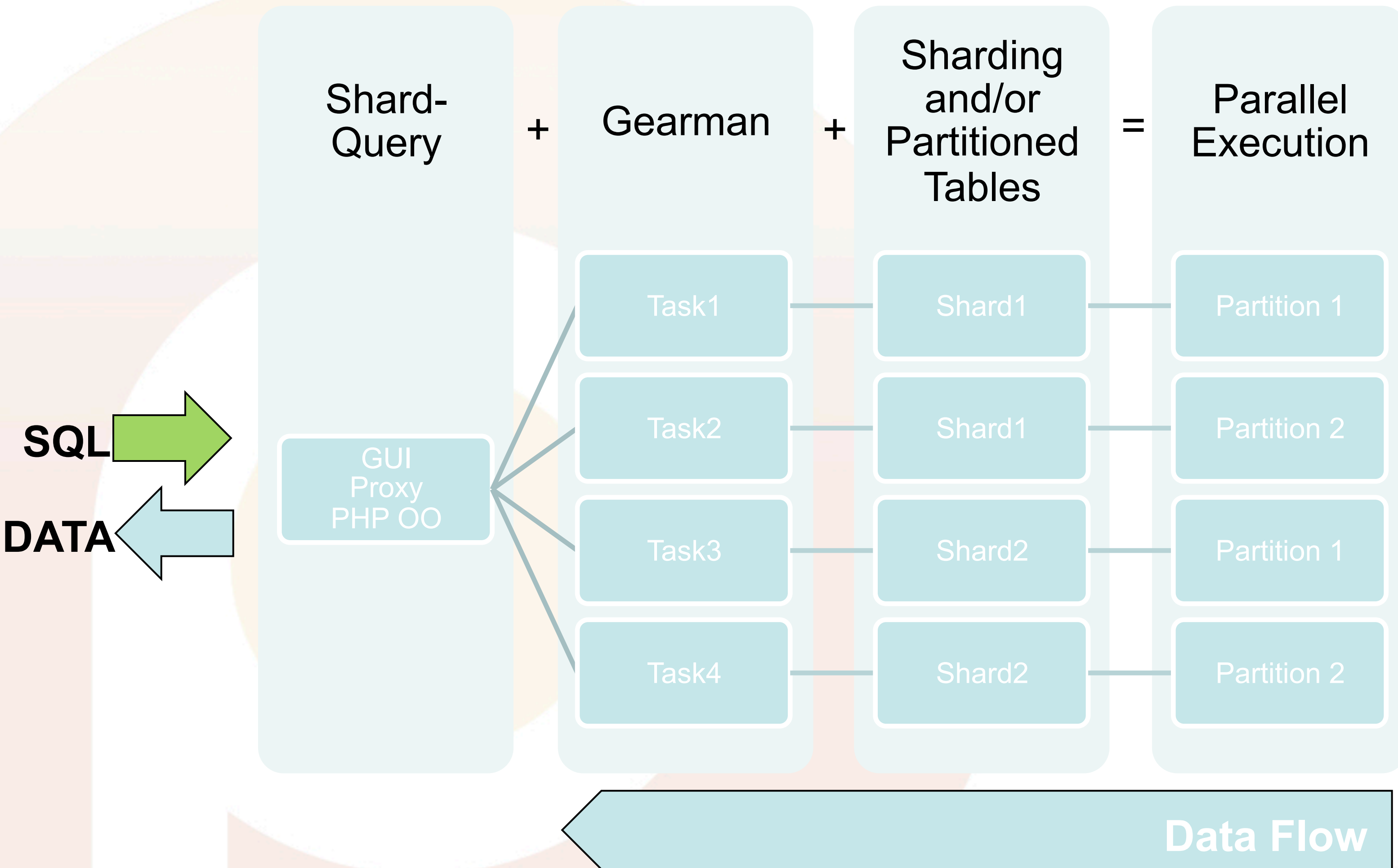
Shard-Query 2.0



Code Maturity

- **Revision 1, May 22, 2010 0.0.1**
  - 270 lines of PHP code checked into Google Code
  - Limited select support, no aggregation pushdown
  - One developer (me) – only suited for limited audience as a POC
  - Not object oriented, or a framework, just a simple CLI PHP app
- **Revision 447, Jan 28, 2013 – Shard Query *beta* 2.0.0**
  - Over 9700 lines of PHP code
  - Full coverage of SELECT statement plus custom aggregate function support
  - Support for all almost DML and DDL operations (except create/drop database)
  - Two additional developers
    - Special thanks to Alex Hurd who is a **production** tester and contributor of the REST interface
    - And Andre Rothe, who contributes to the SQL parser
  - REST web interface, MySQL proxy Lua script, OO PHP library framework
  - Feature complete and stable to a level fit for community use

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EC2 Instance Sizes

Instance Sizes Compared				
Instance Size	***Feature***	***Measure***		***Price Per hour***
m2.xlarge The Pawn	**cores**	**2**		**0.41 USD**
	ecu	6.5		
	ecu/core	**3.25**		
	storage	420		
	memory	17.1		
hs1.8xlarge The King	**cores**	**16**		**3.1 USD**
	ecu	35		
	ecu/core	**2.25**		
	storage	2048		
	memory	60.5		

Scale Out				
Instance Size	***Feature***	***1x Machine***	***8x Machines***	***8X Price Per hour***
m2.xlarge The Pawn	**cores**	2	16	**3.28 USD**
	ecu	6.5	**52**	
	ecu/core	**3.25**	**3.25**	
	storage	420	3360	
	memory	17.1	**136.8**	
hs1.8xlarge The King	**cores**	16	128	
	ecu	**35**	280	
	ecu/core	**2.25**	**2.25**	
	storage	2048	16384	
	memory	60.5	484	

For a few cents more we get much more CPU power in aggregate if
eight smaller machines are used

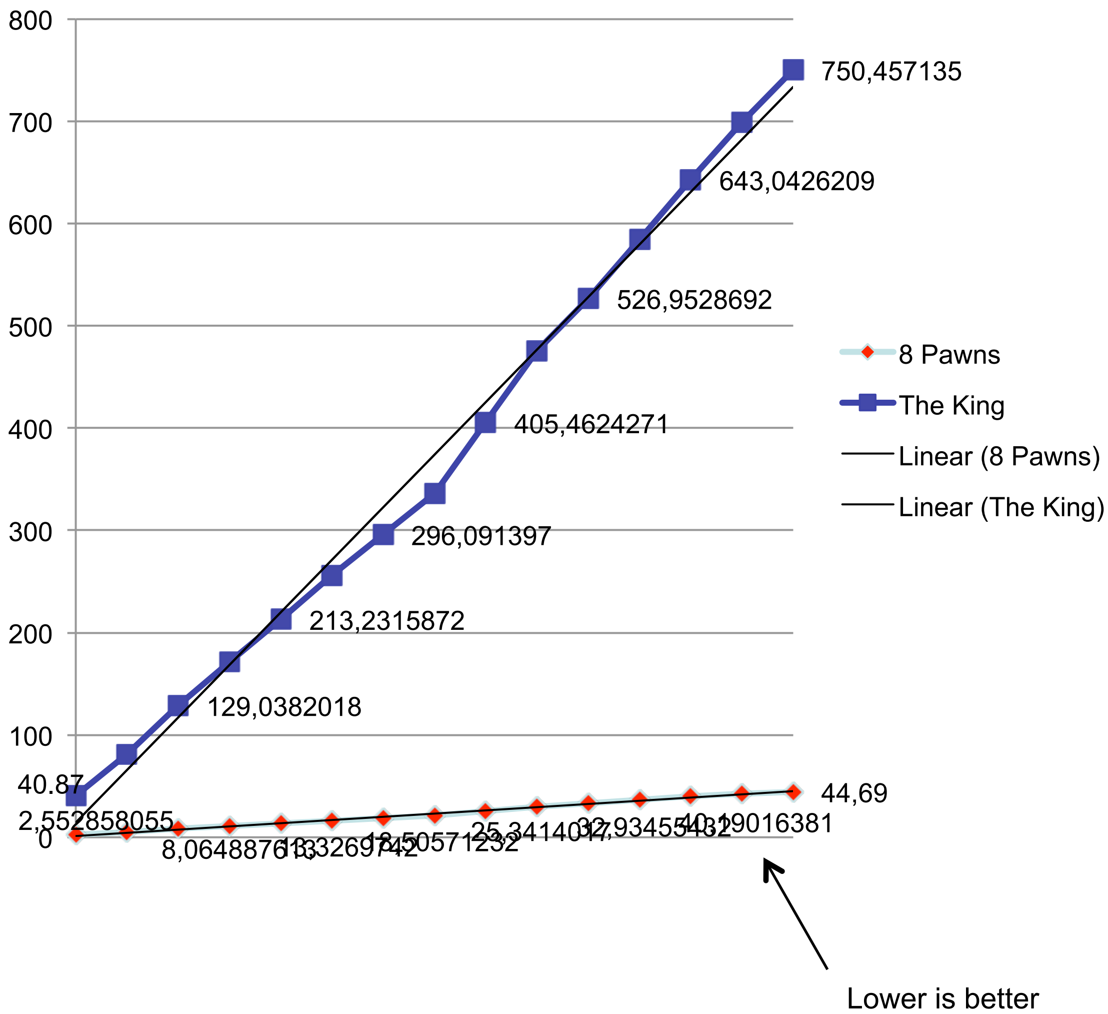
Distributed row store w/ Galera

- Each shard is an Percona XtraDB Cluster
  - HA sharding solution with simple Xtrabackup backup
  - Support massive ingestion rates via MPP loader
  - real time ad-hoc complex querying (sub second)
  - For OLTP access to the same data, use Shard-Key-Mapper

Distributed row store w/ Galera

- All the components support HA
  - Galera, Gearman, Apache, PHP, MySQL proxy
  - Redundancy can be fully geographically distributed
  - Use partitioning at the table level too
  - Use InnoDB compression

Simple In-Memory COUNT(*) query performance



Days	8 Pawns	The King
1	2.552858	40.84573
2	5.090356	81.4457
3	8.064888	129.0382
4	10.74412	171.9059
5	13.32697	213.2316
6	16.0227	256.3633
7	18.50571	296.0914
8	21.02053	336.3285
9	25.3414	405.4624
10	29.69324	475.0918
11	32.93455	526.9529
12	36.5517	584.8272
13	40.19016	643.0426
14	42.75	699.1011
15	44.69	750.4571

Distributed column store

- Each shard is a Infobright database
  - Pros
    - Hash joins, small data footprint, no indexes
  - Cons
    - Single threaded loading (one thread per shard, can't take advantage of MPP loader)
    - Append only (LOAD DATA INFILE)
    - No partitions

Distributed column store

- There is a bug in Infobright Community Edition that is currently preventing Shard-Query from working properly
- I’m working on a workaround for the bug.
- I expect to have the fix released by the end of next week.

Distributed document store

- The "schema" is simply

```
CREATE TABLE document_type (
    document_id bigint auto_increment primary
    key,
    doc longtext
);
```

JSON document

- Unfortunately, finding rows by anything other than the document_id is not possible without using LIKE ☹

- Or is it?

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Need to extract/index the data

- We could create a function that extracts a key from a JSON document
- Use the function in SQL to extract the data
- Find a way to create a "function index" for the extraction

Create a function to extract data

```
create function json_extract (
   v_doc longtext charset utf8,
   v_key longtext charset utf8
) returns int unsigned
comment 'Extracts JSON value'
language SQL
deterministic
modifies sql data
sql security invoker
begin
        declare v_start int default 0;
        declare v_end int default 0;
        declare v_search text charset utf8 default "";

        set v_search := concat('"', v_key, '":');
        set v_start := instr(v_doc, v_search);
        if v_start = 0 or v_start is null then
                return null;
        end if;

        set v_start := v_start + length(v_search);
        if(substr(v_doc, v_start,1) = '"') then
                set v_start := v_start + 1;
        end if;

        set v_end := locate('"',v_doc);
        if (v_end = 0) then
                set v_end := locate(",", v_doc);
                if v_end = 0 then
                        set v_end := locate("}", v_doc);
                end if;
        end if;

        if v_end = 0 then
                return null;
        end if;

        return cast(substr(v_doc, v_start, v_end + if(substr(v_doc, v_start+1,1) = '"', -1,0)) as UNSIGNED);

end;
```

Stored function

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Distributed document store

- Flexviews allows the creation of “materialized views” which are cached views that can be updated efficiently when rows are changed.
- But the view is updated asynchronously
- You can refresh the view periodically.
- You can index the view

Create SQL to extract data

```
-- SQL to extract the data
SELECT
order_id as order_id,
document_store.json_extract(doc,"customer_id") as customer_id,
document_store.json_extract(doc,"order_id") as order_total,
document_store.json_extract(doc,"order_date") as order_date
FROM  document_store.orders as orders;
```

That SQL as Flexviews SQL API

```
call flexviews.create_mvlog('document_store','orders');

call flexviews.create('document_store','orders_idx', 'INCREMENTAL');
set @mvid := last_insert_id();

call flexviews.add_table(@mvid, 'document_store', 'orders', 'orders',NULL);

call flexviews.add_expr(@mvid, 'COLUMN', 'order_id', 'order_id');

call flexviews.add_expr(@mvid, 'COLUMN',        'document_store.json_extract
(doc,"customer_id")', 'customer_id');

call flexviews.add_expr(@mvid, 'COLUMN',        'document_store.json_extract
(doc,"order_id")', 'order_total');

call flexviews.add_expr(@mvid, 'COLUMN',        'document_store.json_extract
(doc,"order_date")', 'order_date');
```

Enable and use the "view"

```
call flexviews.enable(@mvid);
Query OK, 0 rows affected (34 min 33.23 sec)

-- build btree indexes
alter table orders_idx
add key(order_id),
add key(customer_id),
add key(order_date);
Query OK, 0 rows affected (4 min 33.23 sec)

--use the "index"
mysql> select count(*)  from document_store.orders_idx where customer_id = 36\G
*************************** 1. row ***************************
count(*): 28416
1 row in set (0.16 sec)
```

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