Towards Fast SQL Query Processing in DB2 BLU Using GPUs
A Technology Demonstration

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Outline

- DB2 BLU Acceleration
- Hardware Acceleration
- Nvidia GPU
- Key Analytic Database Operators
- Our Acceleration Design
- Live Technology Demonstration
DB2 with BLU Acceleration

Next generation database
- Super Fast (query performance)
- Super Simple (load-and-go)
- Super Small (storage savings)

Seamlessly integrated
- Built seamlessly into DB2
- Consistent SQL, language interfaces, administration
- Dramatic simplification

Hardware optimized
- Memory optimized
- CPU-optimized
- I/O optimized
Risk system injects 1/2 TB per night from **25 different source systems.**

“**Impressive load times.**”

Some queries achieved an almost 100x speed up with literally no tuning.

**6 hours!**

Installing BLU to query results

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One of the world’s most profitable and secure rated banks.
DB2 with BLU Acceleration: The 7 Big Ideas

1. Simple to Implement and Use
2. Extreme Compression
3. Deep HW Instruction Exploitation (SIMD)
4. Core-Friendly Parallelism
5. Optimal Memory Caching
6. Data Skipping
7. Column Store

Analytics Super Fast Super Easy

Extreme Performance

Lower Operating Cost

Hardware Optimized

OpenPOWER™
Hardware Acceleration

- Use specific hardware to execute software functions faster

- Popular accelerator technology
  - SIMD
    - Present in every CPU
  - GPUs
    - Easy to program
  - FPGA
    - Hard to program
Nvidia GPU

NVIDIA Tesla K40

- Kepler technology
- Peak double precession performance: 1.66 TFLOPs
- Peak single precession performance: 5 TFLOPs
- High Memory Bandwidth: up to 288 GB/Sec
- Memory Size: 12GB
- Number of cores: 2880
Key Analytic Database Operators

- **GROUP BY / Aggregation**
  - `SELECT column_name, aggregate_function(column_name)
    FROM table_name
    WHERE column_name operator value
    GROUP BY column_name;`

- **Join**
  - `SELECT column_name(s)
    FROM table1
    JOIN table2
    ON table1.column_name=table2.column_name;`

- **Sort**
  - `SELECT column_name
    FROM table_name
    ORDER BY column_name;`
Hardware Configuration

- **POWER8 S824L**
  - 2 sockets, 12 cores per socket, SMT-8, 512GB
  - Ubuntu LE 14.04.02 LTS

- **GPU:**
  - 2 NVIDIA Tesla K40
Infrastructure

- Adding the support for Nvidia GPU
  - CUDA (Compute Unified Device Architecture) is a parallel computing platform and programming model created by NVIDIA

- Memory Management
  - Pin/Unpin memory
  - To run on GPU, threads asks for pinned memory
  - This is for fast transfers to/from GPU
    - PCI-E Gen3
  - Will be improved in 2016 with Nylink on POWER
GPU Scheduler

- Each CPU thread can submit tasks to GPU scheduler
  - Should submit memory requirement on GPU
- The scheduler checks all the GPUs on the system
  - Reserve the memory on the GPU
  - Create a stream
  - Return to the CPU thread with GPU number and stream Id
Our Acceleration Design

- Use parallel POWER8 threads for reading/pre-processing data
- Transfer data to GPU
- Have the GPU to process the query
- Transfer the result back to host machine
Hybrid Design: Use Both POWER8 and GPU for Query Processing

- Decide where to execute the query dynamically at runtime
  - Use GPU only
  - Use CPU only
  - Use both

```
Input from optimizer
```

```
Moderator
```

```
Number of rows < T1 or Number of Groups < T2
Use DB2-BLU chain
```

```
T1 < Number of rows < T3 & Number of Groups > T2
Use the Accelerator chain
```

```
Number of rows > T3
Partition data, use both DB2-BLU and accelerator chains
```
GPU Kernels

- Design and develop our own GPU runtime
- Developed fast kernels
  - e.g. GROUP BY, aggregation
- Use Nvidia CUDA calls
  - e.g. Atomic operations
- Use Nvidia fast kernels
  - e.g. sort
Group By/Aggregation

- What does it do?
- SELECT C1, \textbf{SUM(C2)} FROM simple_table
  GROUP BY C1

\textbf{Simple_Table}

<table>
<thead>
<tr>
<th>C1</th>
<th>C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>98</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>9</td>
<td>92</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
</tr>
<tr>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
</tr>
</tbody>
</table>

\textbf{C1} \quad \textbf{SUM(C2)}

<table>
<thead>
<tr>
<th>C1</th>
<th>SUM(C2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>280</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
</tr>
<tr>
<td>2</td>
<td>43</td>
</tr>
</tbody>
</table>
Group by/Acgregate Operation in GPU

- Hash based algorithm
- Use grouping keys and a hash function to insert keys to a hash table

- Aggregation
  - Use Nvidia Atomic CUDA calls for some data types (INT32, INT64, etc)
  - Use Locks for other data types (Double, FixedString, etc)

- Three main steps
  - Initialize the hash table
  - Grouping/Aggregation in a global hash table
  - Scanning the global hash table to retrieve groups
Initialization kernel

- Create/initialize the hash table in device memory
- Data needs to be aligned → May need Padding
  - Grouping key can be anywhere in the hash table based on alignment requirements
- Initialization happens in parallel using parallel GPU threads
- Select \( \text{SUM}(C1), \text{MIN}(C2), \text{MAX}(C3) \) from table1 Group by\( (C1) \)
  - Int 64: C1, C2
  - Int 32: C3

<table>
<thead>
<tr>
<th>C1(64bit)</th>
<th>SUM(C1) (64bit)</th>
<th>MAX(C2)(64bit)</th>
<th>MIN(C3)(64bit)</th>
<th>Padding(32 bit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFFFFFFFFFFFFFFF</td>
<td>0</td>
<td>-9223372036854775808</td>
<td>2147483647</td>
<td>0</td>
</tr>
<tr>
<td>FFFFFFFFFFFFFFFF</td>
<td>0</td>
<td>-9223372036854775808</td>
<td>2147483647</td>
<td>0</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>FFFFFFFFFFFFFFFF</td>
<td>0</td>
<td>-9223372036854775808</td>
<td>2147483647</td>
<td>0</td>
</tr>
</tbody>
</table>
Hash based Group by/Aggregate

• Group by:
  – Parallel threads read keys/payloads from table and insert keys to HT
  – Use a hash function to hash keys
    – Murmur hashing: Wide keys(larger than 64bit)
    – Mod hashing: short keys(smaller than 64bit)
  – If collision happens, we check the next empty slot in hash table

• Aggregation:
  – If thread key matches an entry in HT we need to perform the Agg function

<table>
<thead>
<tr>
<th>Thread i</th>
<th>HT(before Aggregation)</th>
<th>HT(After Aggregation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key</td>
<td>Sum</td>
<td>Min</td>
</tr>
<tr>
<td>ABFGH</td>
<td>13</td>
<td>21.2</td>
</tr>
<tr>
<td>……</td>
<td>……</td>
<td>……</td>
</tr>
<tr>
<td>……</td>
<td>……</td>
<td>……</td>
</tr>
</tbody>
</table>
Aggregation

• CUDA atomic operations for
  – Implemented in hardware (very fast)
  – Use for both global and shared memory
  – Specific data types (INT32, INT64, etc)

• Use AtomicCAS for specific data types e.g. Double
  – Specific Agg functions/data types
    __device__ double atomicAdd(double* address, double val) {
      unsigned long long int* address_as_ull = (unsigned long long int*)address;
      unsigned long long int old = *address_as_ull, assumed;
      do {
        assumed = old;
        old = atomicCAS(address_as_ull, assumed, __double_as_longlong(val + _longlong_as_double(assumed)));
      } while(assumed != old);
      return __longlong_as_double(old);
    }

Check Nvidia docs for more details: http://docs.nvidia.com/cuda/cuda-c-programming-guide/#atomic-functions
Aggregation (Continued)

• Locks
  – For datatypes that are larger than 64 bits
    – Decimal, FixedString
  – Each thread needs to perform following
    – Acquire a lock which is associated with the corresponding entry in hash table
    – Apply the AGG function
    – Release the lock
  – Costly operation
Hash-Based Group By/Aggregate

- `SELECT C1, SUM(C2) FROM Simple_Table GROUP BY C1`

Simple_Table

<table>
<thead>
<tr>
<th>KEY</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>5</td>
</tr>
<tr>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>93</td>
<td>1</td>
</tr>
<tr>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>93</td>
<td>0</td>
</tr>
<tr>
<td>93</td>
<td>1000</td>
</tr>
</tbody>
</table>

Hash Table

<table>
<thead>
<tr>
<th>Key</th>
<th>Aggregated Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>7</td>
</tr>
<tr>
<td>93</td>
<td>1006</td>
</tr>
</tbody>
</table>

Result

<table>
<thead>
<tr>
<th>23</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>1006</td>
</tr>
</tbody>
</table>
### Supported Data Types & AGG functions

<table>
<thead>
<tr>
<th>SQL--</th>
<th>MAX</th>
<th>MIN</th>
<th>SUM</th>
<th>COUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINT8</td>
<td>Cast to SINT32</td>
<td>Cast to SINT32</td>
<td>Cast to SINT 32</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>SINT16</td>
<td>Cast to SINT32</td>
<td>Cast to SINT32</td>
<td>Cast to SINT32</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>SINT32</td>
<td>AtomicMax</td>
<td>AtomicMin</td>
<td>AtomicAdd</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>SINT64</td>
<td>AtomicMax</td>
<td>AtomicMin</td>
<td>AtomicAdd</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>REAL</td>
<td>Use AtomicCAS</td>
<td>Use AtomicCAS</td>
<td>AtomicAdd</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>DOUBLE</td>
<td>Use AtomicCAS</td>
<td>Use AtomicCAS</td>
<td>Use AtomicCAS</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>DECIMAL</td>
<td>Lock</td>
<td>Lock</td>
<td>Use AtomicADD(2-3 steps)</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>DATE</td>
<td>CAST to SINT32</td>
<td>CAST to SINT32</td>
<td>N/A</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>TIME</td>
<td>CAST to SINT32</td>
<td>CAST to SINT32</td>
<td>N/A</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>TIMESTAMP(64bit)</td>
<td>AtomicMax</td>
<td>AtomicMin</td>
<td>N/A</td>
<td>AtomicCount</td>
</tr>
<tr>
<td>FixedString</td>
<td>Lock</td>
<td>Lock</td>
<td>N/A</td>
<td>AtomicCount</td>
</tr>
</tbody>
</table>
GPU SORT

• Reduced the amount of data transferred between host and GPU device
  – Use Nvidia Fast sort kernel
  – Copy key and data to GPU memory, use 4-byte key and 4-byte payload
  – Skip the copying back of the sorted keys
  – Skip the copying of payload data into GPU memory on subsequent sorts to resolve duplicates.
  – Use the same data format between DB2 and GPU sort routines

• Handling multiple small sort jobs concurrently in the GPU
  – Handle multiple small sort jobs in the GPU
  – Each thread works on sort data range
  – there are more sort key bytes to process
GPU SORT

• Where GPU performs BEST:
  – Up to 750M rows when all sort data fit within GPU device memory
  – Sort on single integer column of size 4-byte or less. i.e. only one trip to the GPU is required
Acceleration Demonstration

- Accelerating DB2 BLU Query Processing with Nvidia GPUs on POWER8 Servers
  - A Hardware/Software Innovation Preview

- Compare query acceleration of DB2 BLU with GPU vs. non-GPU baseline
- Show CPU offload by demonstrating increased multi-user throughput with DB2 BLU with GPU
BLU Analytic Workload

- A set of Queries from existing BLU Analytic workloads
  - TPC-DS database schema
    - Based on a retail database with in-store, on-line, and catalog sales of merchandise
  - 15% of queries use GPU heavily
  - 50% of queries use GPU moderately
  - 35% of queries do not use GPU at all

- Benchmark Configuration
  - 100 GB (raw) Data set
  - 10 concurrent users
Performance Result

- ~2x improvement in workload throughput
- CPU Offload + improved query runtimes are the main factors

Most individual queries improve in end-to-end run time
The DB2 BLU GPU demo technology will attempt to balance GPU operations across the available GPU devices.

These measurements are taken from the Demo Workload running in continuous mode.
Summary

- Hardware/Software Innovation Preview demonstrated GPU Acceleration
- Improved DB2 BLU query throughput
  - Use both POWER8 processor and Nvidia GPUs
  - Design and develop fast GPU kernels
  - Use Nvidia kernels, function calls, etc
- Hardware Acceleration shows potential for
  - Faster execution time
  - CPU off-loading