STRUCTURED STORAGE IN ATLAS DISTRIBUTED DATA MANAGEMENT

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Overview

- Structured storage
  - Concepts
  - Technologies
- ATLAS DDM use cases
  - Storage facility
  - Data-intensive analytics
- Operational experiences
  - Software
  - Hardware
- Conclusions
Is this about NoSQL? Yes, but...
- NoSQL is a buzzword term to annoy RDBMS people
- Correct CS term: (distributed) structured storage
- Many products support SQL or SQL-derivatives anyway

So what is NoSQL, pardon, structured storage about?
- 1. **Non-relational modelling and storage of data**
  - Use the native data layout of an application
- 2. **Linear scalability of data processing**
  - Scalability ≠ Performance

**Performance:** Capability of a system to provide a certain response time
- e.g., *generate a valid analysis of a sample within three seconds*

**Scalability:** Dependency characteristics between resources and performance
- e.g., *maintain the three seconds when the number of samples increase*
Structured Storage :: Concepts

- Relational database management systems
  - Vertical scalability (“scale up”)
  - Few powerful nodes
  - Shared state
  - Explicit partitioning
  - Resistant hardware
  - ACID
  - Implicit queries (WHAT)

- Structured storage
  - Horizontal scalability (“scale out”)
  - Lots of interconnected low cost nodes
  - Shared nothing architecture
  - Implicit partitioning
  - Reliability in software
  - BASE
  - Explicit data pipeline (HOW)
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Main problems addressed:

1. There is an upper limit of processing power you can put in a single node
2. Explicit partitioning can be cumbersome
3. Relaxation of ACID properties can be necessary
4. Query plans need information about the data contents
Structured Storage :: Technologies

- Three technologies evaluated
  - MongoDB (10gen, Inc.)
  - Cassandra (Apache Software Foundation, formerly Facebook)
  - Hadoop with HBase (Apache Software Foundation, formerly Yahoo)

- Many more available, but these were chosen with the following things in mind
  - Large community available and widely installed
  - In production use at several larger companies with respectable data sizes
  - Potential commercial support

- 12 node cluster to evaluate technologies
  - Nodes located in CERN IT data centre
  - Nodes managed by Puppet
    - Data centre automation framework
    - Implicit service and configuration definition
    - One-button push update on all nodes

<table>
<thead>
<tr>
<th>Cluster configuration</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes</td>
<td>12</td>
</tr>
<tr>
<td>Architecture</td>
<td>Linux x86_64</td>
</tr>
<tr>
<td>CPU Cores</td>
<td>96 (Intel Xeon 2.26 GHz, 8/node)</td>
</tr>
<tr>
<td>RAM</td>
<td>288 GB (24/node)</td>
</tr>
<tr>
<td>Storage</td>
<td>–</td>
</tr>
<tr>
<td>Storage Network</td>
<td>–</td>
</tr>
<tr>
<td>Disk</td>
<td>24 SATA (1TB each, 2/node)</td>
</tr>
<tr>
<td>Cache</td>
<td>–</td>
</tr>
<tr>
<td>Network</td>
<td>1 GigE</td>
</tr>
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Hadoop is a framework for distributed data processing. It is not a database like MongoDB or Cassandra.

Many components:
- **HDFS**: distributed filesystem
- **MapReduce**: distributed processing of large data sets
- **HBase**: distributed data base for structured storage
- **Hive**: SQL frontend and warehouse
- **Pig**: data-flow language for parallel execution
- **ZooKeeper**: coordination service
- ... many more
Structured Storage :: Technologies :: Data Models

mongoDB

{  
  _id: 'Main Account User',  
  groups: ['group_a', 'group_b', 'group_c'],  
  selections: {    
    'select_a': 123,    
    'select_b': abc  
  }  
}

Cassandra

'Groups': {  
  'Main Account User': {    
    'groups': ['group_a', 'group_b', 'group_c']  
  }  
}

'HBase'

'Main Account User': {  
  'Groups': {    
    'groups': ['group_a', 'group_b', 'group_c']  
  },  
  'Selections': {    
    'select_a': 123,    
    'select_b': abc  
  }  
}

- Explicit row-key
- Native datatypes
- Everything indexable
- Implicit row-keys
- Data is byte streams
- Column Families group row-keys
- Implicit row-key
- Data is byte streams
- Row-keys group Column Families
- Row-keys are sorted
Structured Storage :: Technologies :: Data Bases

**mongoDB**
- Master/Slave
  - Smart client implements failover
- Write-ahead log
- Limited MapReduce
  - interleaved
  - bound to single thread
- Keyed binary storage
- Indexes
- Table locking
- Replica sets
- Explicit partitioning

**Cassandra**
- No single point of failure
  - ring of nodes
  - forwarding of requests
- Write-ahead log
- No MapReduce
  - can use Hadoop
- No file storage
- Bloom filter
- Row locking
- Snapshotting
- Implicit partitioning

**Apache HBase**
- No single point of failure
  - multiple masters
- Write-ahead log
- MapReduce
- File storage
  - Data on HDFS
  - Can be used as a source and sink within Hadoop
- Bloom filter
- Row locking
- HDFS-backed redundancy
- Implicit partitioning
## Structured Storage :: Technology Selection

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<td>Distribution, Complex config</td>
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<td><strong>Buffered read 256</strong></td>
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Use cases :: Log file aggregation

- HDFS is mounted as a POSIX filesystem via FUSE
  - Daily copies of all the ATLAS DDM log files are aggregated in a single place
  - 8 months of logs accumulated, already using 3 TB of space on HDFS
- Python MapReduce jobs analyse the log files
  - Streaming API: read from stdin, write to stdout
- Processing the data takes about 70 minutes
  - Average IO at 70MB/s
  - Potential for 15% performance increase if re-written in pure Java
    - Better read patterns and reducing temporary network usage
Client interaction with ATLAS DDM generates traces
- E.g., downloading a dataset/file from a remote site
- Lots of information (25 attributes), time-based
- One month of traces uncompressed 80GB, compressed 25GB
  - Can be mapreduced in under 2 minutes

Implemented in HBase as distributed atomic counters
- Previously developed in Cassandra
- At various granularities (minutes, hours, days)
- Size of HBase tables negligible
- Average rate at 300 insertions/s

Migrated from Cassandra within 2 days
- Almost the same column-based data model
- Get extra Hadoop benefits for free (mature ecosystem with many tools)
- The single Cassandra benefit, HA, was implemented in Hadoop recently
Use cases :: DQ2Share

- HTTP cache for dataset/file downloads
  - Downloads via ATLAS DDM tools to HDFS, serves via Apache
  - Get all the features of HDFS for free, i.e., one large reliable disk pool
Use cases :: Wildcard search

- List contents of ATLAS DDM based on a pattern
  - e.g., all data11 datasets (query: data11*)
  - RDBMS: Index range scan (~2 seconds, in memory)

- This becomes more expensive on sub-selections
  - e.g., all data11 datasets with a RAW datatype (query: data11*RAW*)
  - RDBMS: Index full scan (~10 seconds, in memory)

- And worst if only later parts of the pattern are used
  - e.g., all datasets with a RAW datatype (query: *RAW*)
  - RDBMS: Full table scan (~30 seconds in memory, ~60 seconds on disk)

- Asynchronous wildcard search in Hadoop HDFS
  - Periodic dump of the necessary columns from RDBMS to a flat file
  - MapReduce with distributed grep (~30 seconds)
  - Prime example for RDBMS offloading
Use cases :: Accounting

- Break down usage of ATLAS data contents
  - Historical free-form meta data queries
    \[
    \{\text{site}, \text{nbfiles}, \text{bytes}\} := \{\text{project=\text{data10*}}, \text{datatype=ESD}, \text{location=CERN*}\}
    \]
  - Non-relational periodic summaries
  - A full accounting run takes about 8 minutes
    - Pig data pipeline creates MapReduce jobs
    - 7 GB of input data, 100 MB of output data

- (come and see the poster)
Operational experiences :: Software

- **MongoDB**
  - Easiest to install *(download tarball, unpack, run)*
  - One line of configuration to change to create the cluster

- **Cassandra**
  - Packages from ASF
  - Straightforward installation and configuration via Puppet/tarball
  - However, nodes need special hardware configuration (two disks for commitlog and data)

- **Hadoop**
  - Cloudera distribution
    - Tests and packages the Hadoop ecosystem
  - Straightforward installation via Puppet/YUM
  - But the configuration was ... not so obvious
    - Many parameters, extensive documentation, but bad default performance
      - Cluster IO throughput maxing at 30MB/sec, network not saturated
    - But guidelines on how to set parameters properly only exist for large installations
    - Tweaked a lot, but most of the time it got worse and never better
    - Left it defaults *(next slide please...)*
Operational experiences :: Software

- SLC5?
  - But the throughput problem didn’t come from Hadoop
  - Instead the 8-year-old kernel of SLC5 was the problem
    - No `epoll` (non-blocking-IO) support

- SLC6!
  - Migrated the whole cluster in-flight to SLC6
    - Original reason for migration was because of a SLC5 kernel bug that broke Puppet
  - Procedure
    - 1. Drain one node (not exactly mandatory)
    - 2. Wipe and reinstall node with SLC6 + puppet template
    - 3. There is no step three (automatic resynchronisation of node into cluster)
    - 4. Goto 1
  - Just a few minutes downtime while Hadoop headnode was migrated
    - Could have possibly averted downtime by manually assigning another headnode
    - (Latest Hadoop release can do it automatically now with high-availability headnode)
  - Performance increase of IO remarkable
    - Random read/write performance per node improved by factor 4
    - Cluster IO throughput now maxing at 80MB/sec, network saturated

- Backups
  - Hourly encrypted backups of the HDFS image
  - Cluster state can be restored within 3 minutes (including downloading and unpacking the backup)
Operational experiences :: Hardware

- Disk failure is common and cannot be ignored
- Data centre annual disk replacement rate up to 13% (Google & CMU, 2011)

- Within one year we had
  - 5 disk failures
    - 20% failure rate!
    - Out of which 3 happened at the same time
  - 1 Mainboard failure
    - Together with the disk failure, but another node

- Worst case scenario experienced up to now
  - 4 nodes out of 12 dead within a few minutes
  - Hadoop
    - Reported erroneous nodes
    - Blacklisted them
    - And resynced the remaining ones
  - No manual intervention necessary
  - Nothing was lost
Conclusions

- Structured storage systems are too useful to be ignored
- Hadoop proved to be the correct choice and an excellent platform for our analytical workloads
  - Stable – reliable – fast – easy to work with
  - Survived disastrous hardware failures
- DDM use cases well covered
  - Storage facility (log aggregation, traces, web sharing)
  - Data processing (trace mining, accounting, searching)
- Miscellaneous
  - All three evaluated products provide full durability, and transactions were not missed
  - We see Hadoop complementary to RDBMS, not as a replacement

- Future work
  - WAN replication as Hadoop is location aware
  - Generic RDBMS-to-HBase synchronisation framework
  - Improved data mining framework for generic analytics
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