ACID or BASE? – the case of NoSQL

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“***What’s next?***”

ACID or BASE?
– the case of NoSQL

ACID or BASE? – the case of NoSQL

Summary :

- an alternative to relational databases -- why?
- availability versus consistency: replication, distributed, ...
- key-value stores, columnar databases, document stores, ...
- commercial NoSQL implementations: a few examples

NoSQL - what's in a name

Wikipedia:

A NoSQL or Not Only SQL database provides a mechanism for

- storage and retrieval of data
- modelled otherwise than in relational database tables & relations
- motivations for this approach include:
  simplicity of design,
  horizontal scaling,
  finer control over availability,
  faster than in some RDBMS

NoSQL databases are finding significant, growing industry use in *big data* and *real-time web* applications.

Many NoSQL stores *compromise consistency* in favour of *availability* and *partition tolerance* ("CAP theorem")

Most NoSQL stores lack true *ACID transactions*

Term introduced 1998 by Carlo Strozzi (really meaning *no SQL*);

reintroduced 2009 by Eric Evans in the context of distributed DBs

NoSQL and Big Data

Big Data:

- ***3V*** **(Gartner): high-Volume, high-Velocity data with high Variety**
- **enables decision making, insight discovery, process optimization**

  ==> data *analysis* is central: data mining; statistical techniques

  ==> *distributed* analysis starts to make sense
- **insight:**
  - **keep *all* data (sensor data, website clicks, blogs, ...)**
  - **in their *original* format (no Data Warehouse style ETL)**
  - **for potential later use (not yet decided)**

    (pre-formatting destroys / biases information)
- **as a consequence:**
  - **unstructured (or semi-structured, non-flat) data**
  - **no (or less) quality control or semantics during load**
  - **interpretation & value judgement: done by ad-hoc analysis step**

What's the problem with relational databases? 1.2

P#1: must convert information from their natural representation into table(s)

P#2: must later reconstruct information from tabular representation

P#3: data must be modelled (semantics!) before storing it

P#4: a table column can only store similar data ("schema" is fixed)

P#5: relational systems may not scale well

P#6: joins between different systems (different identifiers): difficult

P#7: SQL dialects vary => difficult to port applications between databases

P#8: complex business rules are not easily expressible in SQL

P#9: approximate terms and fuzzy searches: not performing well

P#10: RDBMS don't store & validate complex documents efficiently

What's the problem with relational databases? (cont'd)

Hey, that rings a bell ...

"*Store your DB2 data as XML*":

- no need to convert back/forth to/from tabular representation
- no need to (re)interpret the XML structure when loading
- no need for predefined schema (columns & data types)
- let the reading application do the difficult work:

```
SELECT  coname, XMLQUERY('count($E//function[.="analyst"])'
                         PASSING b.employees as E        )
FROM    companies b
WHERE   XMLEXISTS('$E/employees/person[function="analyst"]'
                         PASSING employees AS E          )
```

where the content of XML column "employees" could be something like:

```
<?xml version="1.0" encoding="UTF-8"?>
<employees cono="32"><person><lname>Janssen</lname><fname>D.</fname>
    <address><street>Kortestraat</street><city>Leuven</city></address>
    <function>analyst</function></person>
<person>....<function>programmer</function></person></employees>
```

What's the problem with relational databases? (cont'd)

XML: still too rigid / too limited

How can we *store anything whatsoever*

and yet easily *find it back* and/or

aggregate on it (count/sum/avg/rank/top10/...)

"*In search of a middle ground between file system & database*"
(Robert Greene, 2012)

Solutions (?) ==> **NoSQL !**

- *schema-less* storage (=> dynamically add new attributes)
- but with *keys* & values (tuple store, ...) & possibly indexes
- using a *distributed* storage model (autonomous nodes; TCP/IP)
- with *replication* for fault-tolerance (redundancy across nodes)

  ==> hence can afford "commodity hardware"; scales linearly
- **BUT** which *guarantees* can such a setup provide us?

NoSQL database architecture 2

schema-less storage 2.1

most NoSQL databases offer the possibility to work

- without a “schema”, i.e., a predefined structure
- or with dynamically changing schema’s

distributed (partitioned) 2.2

***scaling out* instead of scaling up:**

- “shared nothing” architecture: no common disk/memory/processor
- each participant is a cluster *node* (identity; network topology)
- node = both data and *analysis* jobs: work can be “threaded”

sharding, *replication*, fault-tolerance 2.3

a *shard* is a table partition, but isolated on a cluster node

- multiple nodes store the same partition (& allows read parallelism)

data (row) *versioning* 2.4

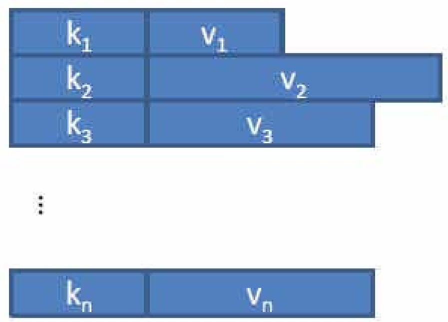
- may become crucial because of replication!

NoSQL database types 3

Key/Value Databases 3.1

- **values (data) stored based on programmer-defined** keys [hash table approach]
- **system is agnostic as to the semantics of the value**
- **requests are expressed in terms of keys**

  put(key, value)
  get(key): value
- **indexes are defined over keys**
  [some systems support secondary indexes over (part of) the value]



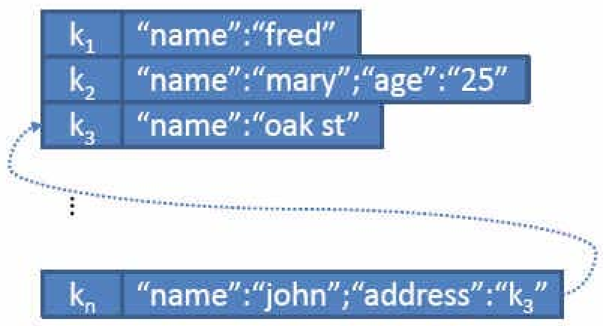
Examples: Berkeley DB, Oracle NoSQL, LevelDB, Dynamo, Memcached

NoSQL database types (cont'd)

Document Data Model

3.2

- **documents are stored based on a programmer-defined key** [a key-value store]
- **system is aware of the arbitrary document structure**
- **support for lists, pointers and nested documents**
- **requests expressed in terms of key (or attribute, if index exists)**
- **support for key-based indexes and secondary indexes**



Examples: MongoDB, CouchDB, RaptorDB, Riak, *IBM Lotus Notes*

NoSQL database types (cont'd)

Columnar Databases

3.3

[wide column store - 'Big Table' clones - cf. DB2 LUW with BLU]

- **stores data tables as sections of columns of data**
  [rather than as rows of data] [hybrid row/column structure]
- **data stored together with meta-data ('a map')**
  [typically including row id, attribute name & value, timestamp]
- **most often sparse storage**
- **"like just storing indexes, one per column"**

Peter	2013	75
Peter	2014	11
Peter		3
Eliza	2014	70
Eliza	2014	1
	2012	472
	2011	11
...		
	...	
		...

→

Eliza : [4, 5]
Peter: [1, 2, 3]
...

2011 : [7, ...]
2012 : [6, ...]
2013 : [1]
2014 : [2, 4, 5]

1 : [5]
3 : [3]
11 : [2, 7]
70 : [4]
75 : [1]
472 : [6]
...

or

(name, Eliza, v1, 4)
(name, Eliza, v1, 5)
(name, Peter, v1, 1)
(name, Peter, v1, 2)
(name, Peter, v1, 3)
(date, 2011, v1, 7)
...
(date, 2012, v1, 6)
...
(date, 2013, v1, 1)
(date, 2014, v1, 2)
(date, 2014, v1, 4)
(date, 2014, v1, 5)
(amount, 1, v1, 5)
(amount, 3, v1, 3)
(amount, 4, v1, 2) *
(amount, 11, v1, 7)
(amount, 11, v2, 2)
(amount, ...)

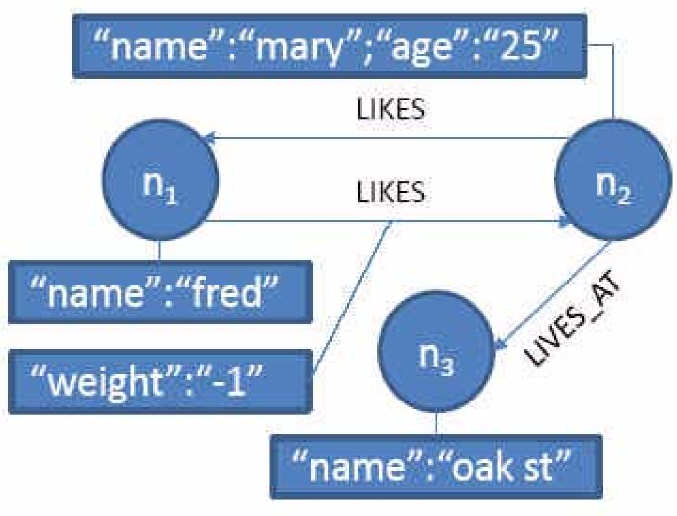
Examples: Google Bigtable (2006), HBase, Hypertable, Cassandra

NoSQL database types (cont'd)

Graph Data Model

3.4

- **data is stored in terms of nodes and links**
  both can have (arbitrary) attributes
- **requests are expressed based on system id's (if no indexes exist)**
  secondary indexes for nodes and links are supported
- **SPARQL query language:** retrieve nodes by attributes and links by type, start and/or end node, and/or attributes



Examples: Neo4j, InfoGrid, IMS

Vendors are embracing NoSQL

... as they did with MDM, XML, OO, ... ??

(or is this different?)

- **Oracle [key value] :** BerkeleyDB, NoSQL DB
- **IBM:**

  [key value, columnar] : BigInsights / HBase (Linux; uses Hadoop)

  IBM DB2 LUW + BLU accelerator (ACID!)

  BlueRunner (Cassandra): email in the cloud

  [document] : IBM DB2 + MongoDB support ("*DB2 JSON*")

  [graph] : IBM DB2 + Triple-Graph Store option
- **Microsoft :** Azure [SaaS]
- **...**

ACID or BASE?

Transactions, consistency and availability

- **In a 'shared something' environment, ACID is wanted:**

  Pessimistic behaviour: force consistency at end of transaction!
  - **Atomicity:** all or nothing (of the *n* actions): commit or rollback
  - **Consistency:** transactions never observe or cause inconsistent data
  - **Isolation:** transactions are not aware of concurrent transactions
  - **Durability:** acknowledged transactions persist in all events
- **In a 'shared nothing' environment, BASE is implemented:**

  Optimistic behaviour: accept temporary database inconsistencies
  - **Basically Available** [guaranteed thanks to replication]
  - **Soft state** [it's the user's (application's) task to guarantee consistency]
  - **Eventually consistent (weakly consistent)**
    [database will be consistent in the longer run; 'stale' data is OK]

Why not have both? => consistency & availability & speed (through sharding)?

The CAP theorem

Brewer's Conjecture (2000; proved in 2002; refined in 2012):

Real world data storage systems like to have three properties:

- [data] **Consistency** [all clients see the same data at the same time]
- [data] **Availability** [guaranteed server response: success or failure]
- **Partition tolerance** [nodes/messages may fail/get lost/unreachable]

Conjecture:

in a multi server/node/rac shared nothing environment
it is only possible to satisfy at most two of these requirements

C+A ~ "ACID": this needs a single, central server (with replication ?)

C+P: either "write N, read 1" or "write 1, read N" (maybe too slow ?)

A+P = "BASE": no strong consistency guarantees ...

(in reality: C, A, P are continuum; choices can be "ad hoc" !)

==> sacrifice consistency to gain faster responses in a more scalable manner

CAP theorem: consequences

5.1

ACID (RDBMS)	BASE (NoSQL)
strong consistency	weak consistency (=> allow stale data)
isolation	last write wins
transaction	program managed
robust database	simple database
simple code (SQL)	complex code
available & consistent	available & partition-tolerant
scale-up (limited)	scale-out (unlimited)
shared-something (disk, mem, proc)	shared-nothing (parallellizable)

The NRW notation:

where N = # replica's per item,
R = # reads (before declaring "success"),
W = # writes (before declaring "success"):

NRW=n1n: read-optimized strong consistency

cf DB2's logging mechanism

NRW=nn1: write-optimized strong consistency

cf DB2's buffer pool reading mechanism; recovery mechanisms

weak eventual consistency: when e.g. R+W <= N

suppose N=3, R=1, W=1:

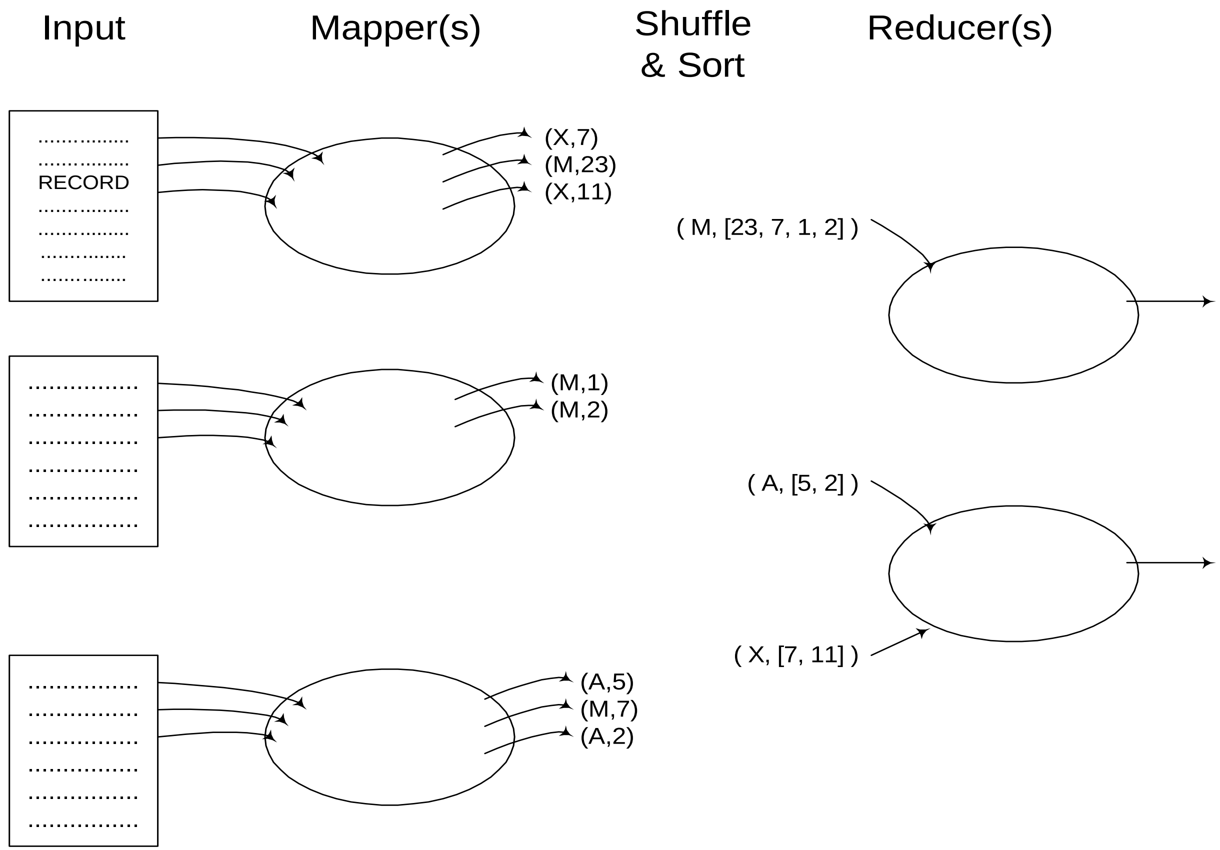
- a certain data item is stored on nodes A, B and C
- client1 modifies the item through node A (& receives success msg)
- "eventually", nodes B and C will be updated
- client2 reads & modifies same item through node B (& success)
  BUT before node B got updated!
- conflict resolution ==> timestamps (versioning) needed
- clients *could* later be notified of the occurrence of this conflict

Framework example: MapReduce design patterns

Not just *data* is distributed, also the *application logic* must be

==> "*bring the program close to the data it is reading/writing*"

A **MapReduce** *framework* simplifies implementing parallel algorithms:



MapReduce design patterns (cont’d)

- Filtering (“WHERE”): done in the mappers
- Top-N filtering: needs ranking: pre-filtering in the mappers
- Distinct filter: use combiners; whole record as key, no value
- Summarization (count, sum, average, ...): combiners & reducer(s)

  with “GROUP BY”: multiple reducers are possible
- Total-order sorting: is often not needed!
- Reduce-side join (is essentially a merge-scan join)
- Meta-patterns: job chaining

Further reading: see e.g.

“MapReduce Design Patterns”, Donald Miner & Adam Shook, 2013

SQL vs NoSQL

5.4

	SQL	NoSQL
types	one 'logical' database, with somewhat distinct 'physical' impl.	many different types [columnar, key/value, document, ..]
history	1970	2000
storage	table/row/column a.k.a. file/record/field storage	it depends: records, documents ++ unstructured ++
schema	'static' schema's structure is pre-determined	'dynamic' or no schema ++ schema-free ++
scaling	vertical	horizontal ++ easier, cheaper ++
dvlpmnt model	initially: proprietary; later: open source	open source ++ agile ++
trans-actions	consistency: ACID ++ yes ++	consistency: BASE -- not always --
DML	++SQL++	OO; also SQL-like -- infancy --
other concerns: security & access control; optimizer; check constraints; ...		

Hive 6.1

- **Not really a database: rather "data warehouse software"**
  - **file based storage**
  - **maintains a "metastore"**
- **Built on top of Hadoop (Apache)**
  - **files are actually HDFS (distributed & replicated) fragments**

    ==> **optimized for retrieve & for append**; update not supported
- **Is itself an Apache project: free, open-source** `http://hive.apache.org/`
- **HiveQL:**
  - **SQL-style language**
  - **optimizer creates MapReduce source code (in Java)**
- **Command-line interface:**

  hive -f file.hive ==> run script

  hive -e 'cmd' ==> execute a single Hive command

  hive ==> interactive mode

HiveQL - statements

CREATE TABLE *tablename* (*col1* type, *col2* type) [PARTITIONED BY (col3 type)]
[ROW FORMAT DELIMITED FIELDS TERMINATED BY '\t']
[STORED AS TEXTFILE] ;

SHOW TABLES ;

DESCRIBE *tablename* ;

LOAD DATA [LOCAL] INPATH 'filename' [OVERWRITE] INTO TABLE *tablename* ;

-- input data must already be in the correct format (incl. delimiters) for the table!

INSERT INTO dest [PARTITION col3=...] SELECT cols FROM src WHERE ...

SELECT *colnames*, expr FROM *tablename* WHERE cond ORDER BY expr LIMIT 10 ;

SELECT *colname*, SUM(expr) FROM *tablename* WHERE cond GROUP BY *colname* ;

FROM src INSERT OVERWRITE TABLE dest SELECT cols WHERE cond ;

FROM src INSERT OVERWRITE [LOCAL] DIRECTORY 'dirname' SELECT * WHERE ... ;

FROM tbl1 JOIN tbl2 ON (col1=col2) INSERT OVERWRITE TABLE t3 SELECT col1,col3 ;

Supported datatypes:

string int double decimal timestamp date ...

Examples:

SELECT * FROM t WHERE col < 7; -- filtering in parallel by the mappers

SELECT * FROM t ORDER BY col DESC LIMIT 10; -- pre-filtering; no global sorting!

SELECT col, MIN(val), COUNT(1) FROM t GROUP BY col; -- combiners & reducers

SELECT * FROM t1 LEFT OUTER JOIN t2 ON (t1.fkcol = t2.fkcol);

Hive - Interacting with Java

- **The Hive cli should be used as the principal user interface**
- **Hive allows calling Java Hadoop programs by writing and using Hive User Defined Functions (UDFs) in Java**
- **Additionally, there exists a JDBC interface to Hive**

All cluster behaviour is managed by HDFS

- **data nodes (3-fold replication)**
- **single name node, "master" (for metadata)**
- **clients transparently communicate with the cluster** through Java API
- **files are automatically split in blocks of 128 MB**
- **file compression on-the-fly**
- **supports *streaming* data access ("write-once, read-many")**
- **nodes run Linux; access through TCP/IP**

HBase

- Built on top of Hadoop (Apache) just like Hive
  - written in Java
  - files are actually HDFS (distributed & replicated) fragments
- Is itself an Apache project: free, open-source `http://hbase.apache.org/`
- Only uses HDFS, not MapReduce
- **Columnar** NoSQL database
- columns grouped in *families* which are are stored together
- For random read+write access to large datasets
  - "strongly consistent" writes: CP, not AP
  - still non-ACID: e.g. no rollbacks: each action is a transaction
- By design: no datatypes, no foreign keys, no indexes, no triggers
- table cells are just byte sequences (non-typed)
- keys: column name, row pointer, timestamp (=version)
- a table is essentially a **sorted** *map*, keyed by these three

HBase: an example

The “canonical” example: the *web table*

- table of crawled web pages (with attributes); row key = URL
- continuously accessed (globally) by analytics (MapReduce) jobs
- continuously accessed (randomly) to update content & attributes
- a webtable could contain 2 column *families*: `contents` & `anchor`
  - 1 column in the `contents` family: `contents:html`
  - several in `anchor`, e.g. `anchor:lang`, `anchor: www.apache.org`

```
{   "anchor:www.apache.org" : {
        "http://www.abis.be/html/index.html" : {
            "v1" : "<a href=\"http://www.apache.org/\">Apache</a>" ,
            "v2" : .....       } ,
        .....                              } ,
    "content:html" : {
        "http://www.abis.be/html/index.html" : {
            "v1" : "<html><head> .........."         }
```

(etc.)

HBase in practice

- **command line interface: example:**

```
$ hbase master start
$ hbase shell
    hbase> list
        TABLE
        0 row(s) in 0.6830 seconds
    hbase> create 't1', 'f1'                    -- creates table t1 with one column family f1
    hbase> list
        TABLE
        t1
        1 row(s) in 0.0480 seconds
    hbase> put 't1', 'row1', 'f1:a', 'val1'     -- puts value "val1" in cell  (row1,f1:a)
    hbase> scan 't1'
        ROW      COLUMN+CELL
        row1     column=f1:a, timestamp=1396745613547, value=val1
    hbase> get 't1', 'row1'
        COLUMN       CELL
        f1:a         timestamp=1396745613547, value=val1
    hbase> quit
```

- **The "real" HBase use is through a Java program (API)**

Cassandra

- **Columnar NoSQL database**
- **originally developed by Facebook (2007)**
  - **but Facebook moved to HBase for its messaging platform (2010)**
- **became an Apache incubator project in 2009**
  - **written in Java**
  - **v 2.0 : May 2014**
- **free, open-source** `http://cassandra.apache.org/`
- **commercial add-ons & support ("enterprise edition")**
  by Datastax `http://www.datastax.com/`
- **CQL:**
  - **SQL-style language**
  - **but no joins, no subqueries, no GROUP BY**
  - **only since v 2.0 there is built-in cursor support**
    for a plain "SELECT col1, col2 FROM t [WHERE cond]

Cassandra - architecture

- **nodes form a cluster (called a “ring”, but any topology allowed)**
- **peer-to-peer network**
- **meta-data is exchanged once a second, using “*gossip*” protocol**
- **meta-data: SSTables (in-memory)**
  - **contains topology info and table “catalog” info**
  - **needs regular *compaction* (cf. REORG)**

    to ensure durability of transactions
- **partitioner**
  - **distributes data cells over nodes, based on *partition key* & hash**
- **the *client* is responsible for deciding the *consistency level***
  - **in NRW terminology: R & W decided by the user**

    ==> user chooses whether Cassandra is CP or AP
- **primary key updates not allowed; no foreign keys**
- **no transactions ==> no rollbacks**

Cassandra - table layout

- **columnar database:**
  - **each cell (called a "*column*") is a (name,value,timestamp) tuple**
  - **a *row* is a collection of columns, stored in alphabetic order**
    stored together on a single node
  - **a *column family* (or a *table*) is a collection of rows**
  - **a *key space* is a group of column families**
- ***indexes* are user-defined column families**

Used by:

- **Spotify (for their playlist data)**
- **eBay (for their fraud detection implementation)**
- **(earlier) Facebook (inbox search)**
- **IBM: BlueRumor (email system in the cloud; Jun Rao)**
- **Twitter**

MongoDB

- **JSON-style documents (BSON)** [document-based queries]
- **schema-free**
  - written in C++ for high performance
  - full index support
  - memory mapped files
  - no transactions (but supports atomic operations)
  - not relational
- **scalability**

  replication - sharding
- **MongoDB = CP, optionally AP** [on top of CP]
- **'utilities' available:**
  - mongo<u>export</u> ; mongo<u>import</u> ; ...
- **language drivers available:** C, C++, Java, JavaScript, perl, PHP, Python, Ruby, C#, Erlang, Delphi, ... [*community supported*]
- **OS:** OS X, Linux, Windows, Solaris
- **Opens source, free -** commercial edition available

MongoDB - Concepts and Structures

- **A Mongo deployment (<u>server</u> or <u>instance</u>) holds a set of <u>databases</u>**
  - a <u>database</u> holds a set of <u>collections</u>
  - a <u>collection</u> holds a set of <u>documents</u>
  - a <u>document</u> is a set of fields: <u>key-value pairs</u> (JSON - BSON)
  - key-value-pairs:
    a *key* is a name (string)
    a *value* is a basic type like string, integer, float, timestamp, binary, etc., an embedded document, or an array of values
  - a '*special pair*': _objectid - default artificial key

  'Lazy' - [most]
  - collections & databases created when first document inserted

- **collections can be '<u>capped</u>'**

  need to be created before **they can be used!**

  [no deletes, limited updates tolerated]

  have a 'fixed' size

  db.createcollection('courseColCapped', ..., ...)

MongoDB - Concepts and Structures (cont'd)

Document-oriented : collections **store** documents **in BSON format** [collection=?= table]

- **JSON-style documents: BSON (Binary JSON)**
- **support for 'non-traditional' data types:** Date **type and a** BinData **type**
  - can reference other documents
  - lightweight (*minimal spatial overhead*), traversable (*find data quickly*), efficient (*linked to C/C++ data types*) - VERY FAST
- **all documents belonging to one and the same collection** can have **heterogeneous data structures!** [remember: no schema's]
- **typically** [check version]**: 4MB document limit**

MongoDB - Concepts and Structures - JSON

Let's first introduce JSON...

JavaScript Object Notation

°) a collection of (nested) key-value pairs

°) supporting ordered lists

°) record oriented

... and then talk about BSON [Binary JSON]

- **an 'efficient' implementation of JSON**
- **efficient use of storage space**
- **increased scan-speed**
  [large elements in a BSON document are prefixed with a length field]
- **array indices explicitly stored**

MongoDB - Concepts and Structures - JSON

```
{
   "glossary": {
      "title": "example glossary",
         "GlossDiv": {
          "title": "S",
              "GlossList": {
              "GlossEntry": {
                 "ID": "SGML",
                       "SortAs": "SGML",
                       "GlossTerm": "Standard Generalized Markup Language",
                       "Acronym": "SGML",
                       "Abbrev": "ISO 8879:1986",
                       "GlossDef": {
                    "para": "A meta-markup language, used to create DocBook.",
                            "GlossSeeAlso": ["GML", "XML"]
                 },
                       "GlossSee": "markup"
              }
          }
      }
   }
}
```

ACID or BASE?
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MongoDB - startup

- **Installation**

  download, unzip, create data directory, create default config file, and get started!

- **Start the MongoDB 'server'**

./bin/mongod

[***bin\mongod.exe***]

- **Start MongoDB 'client' -** interactive JavaScript shell

./bin/mongo

[***bin\mongo.exe***]

[root@everest bin]# ./mongod --dbpath /data/db **--port** 27017 **--config** /etc/mongod.conf

MongoDB - basics

Basic commands - examples

use [db name]

show dbs
show collections

Basic operations

- **Insert operations** [sample]

```
> use coursedb
switched to db coursedb
> db.courseCol.insert({"Coursename":"DB2","Coursedur":3})
> db.courseCol.insert({"Coursename":"Oracle","Coursedur":5})
> db.courseCol.insert({"Coursename":"SQLServer","Coursedur":2})
> show collections
courseCol
system.indexes
```

MongoDB - basics (cont'd)

- **Select operations** [sample]

```
> db.courseCol.find({"Coursename":"Oracle"})

{ "_id" : ObjectId("51a089ad17338b27674af7a2"), "Coursename" : "Oracle", "Coursedur" : "5" }

> db.courseCol.find({"Coursename":"Oracle"},{"Coursedur":1});

{ "_id" : ObjectId("51a089ad17338b27674af7a2"), "Coursedur" : "5" }

> db.courseCol.find({Coursedur:{"$gt":2}});

{ "_id" : ObjectId("51a08fc295ce664a0e633cfb"), "Coursename" : "Oracle", "Coursedur" : 5 }
{ "_id" : ObjectId("51a08fd795ce664a0e633cfd"), "Coursename" : "DB2", "Coursedur" : 3 }
```

conditional ops: $gt, $gte, ..., $and, $in, $or, $nor, ...
$limit, $offset, ..., $sort, ...

MongoDB - basics (cont'd)

- **...** [sample]

```
> db.courseCol.insert({"Coursename":"DB2","Coursedur":3, "Instructor" : "Kris"})

> db.courseCol.find({"Coursename":"DB2"});
{ "_id" : ObjectId("51a08fd795ce664a0e633cfd"), "Coursename" : "DB2", "Coursedur" : 3 }
{ "_id" : ObjectId("51a090dd95ce664a0e633cfe"), "Coursename" : "DB2", "Coursedur" : 3,
"Instructor" : "Kris" }

> db.courseCol.find({"Coursename":"DB2"},{"Instructor":1});
{ "_id" : ObjectId("51a08fd795ce664a0e633cfd") }
{ "_id" : ObjectId("51a090dd95ce664a0e633cfe"), "Instructor" : "Kris" }

> db.courseCol.find({"Instructor":"Kris"});
{ "_id" : ObjectId("51a090dd95ce664a0e633cfe"), "Coursename" : "DB2", "Coursedur" : 3,
"Instructor" : "Kris" }
>
```

MongoDB - basics (cont'd)

- **Update** [sample] - !! default !! - only the first doc is updated

```
> db.courseCol.insert({"Coursename":"DB2","Coursedur":3, "Instructor" : "Kris"})

> db.courseCol.find({"Coursename":"DB2"});
{ "_id" : ObjectId("51a09e6595ce664a0e633cff"), "Coursename" : "DB2", "Coursedur" : 3,
"Instructor" : "Kris" }

> db.courseCol.update({"Coursename":"DB2"},{$set : {"Coursedur":6}})
> db.courseCol.find({"Coursename":"DB2"});
{ "_id" : ObjectId("51a09e6595ce664a0e633cff"), "Coursename" : "DB2", "Coursedur" : 6,
"Instructor" : "Kris" }

> db.courseCol.update({"Coursename":"DB2"},{$set : {"CoursedurUSA":8}})
> db.courseCol.find({"Coursename":"DB2"});
{ "Coursedur" : 6, "CoursedurUSA" : 8, "Coursename" : "DB2", "Instructor" : "Kris", "_id" :
ObjectId("51a09e6595ce664a0e633cff") }
```

alternatives: $inc, $set, $push, $pushall, ...

MongoDB - basics (cont'd)

- **Remove** [sample]

```
> db.courseCol.remove()

db.courseCol.remove({"Coursedur" : {$lt : 7}})
> db.courseCol.find({"Coursename":"DB2"});
```

MongoDB - Indexes

- **full index support**
  [index on any attribute (including multiple, list/arrays, nested)]
  [blocking by default]
- **increase query performance**
- **indexes are implemented as “B-Tree” indexes**
  [unique or not] [asc, desc]
  [missing keys: null by default - sparse index]
- **as always: data overhead for inserts and deletes**
- **document TTL in index can be specified**
- **implementation:**

```
> db.courseCol.ensureIndex( {"Coursename" : 1 })
> db.courseCol.getIndexes()
[    {},
     {
          "v" : 1,
          "key" : {
               "Coursename" : 1
          },
          "ns" : "test.courseCol",
          "name" : "Coursename_1"
     }
]
```

MongoDB - Indexes (cont’d)

Limitations:

- **collections : max 64 indexes**
- **index key length max 1024 bytes**
- **queries can only use 1 index**
  [careful with concatenated indexes, careful with negation,
  careful with regexp]
- **indexes have storage requirements, and impact the performance of writes**
- **in memory sort (no-index) limited to 32 MB**

MongoDB - Indexes - explain, caching

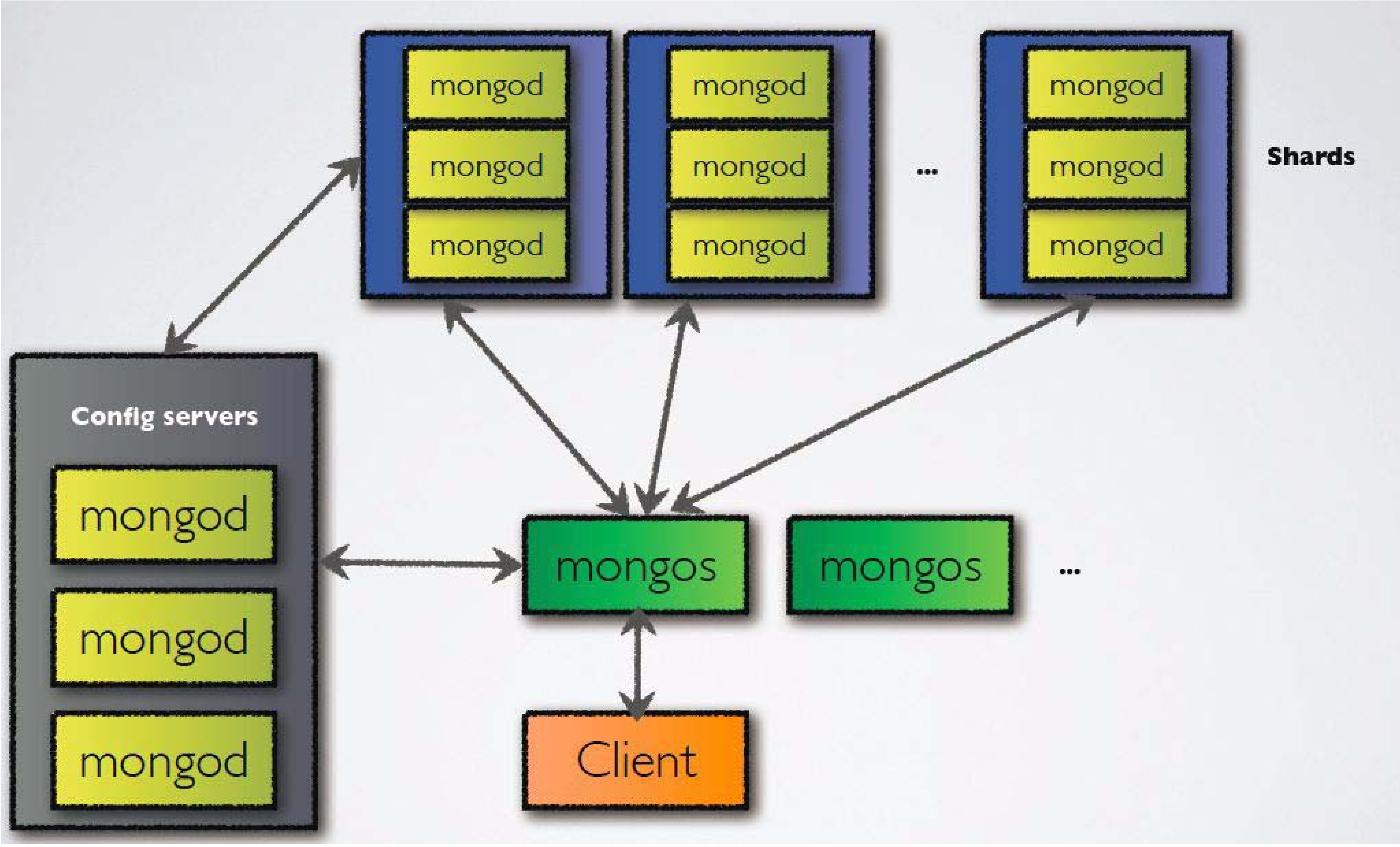
```
> db.courseCol.find({"Coursename":"Oracle"}).explain()
{
    "cursor" : "BtreeCursor Coursename_1",
    "isMultiKey" : false,
    "n" : 1,
    "nscannedObjects" : 1,             "nscanned" : 1,
    "nscannedObjectsAllPlans" : 1,   "nscannedAllPlans" : 1,
    "scanAndOrder" : false,            "indexOnly" : false,
    "nYields" : 0,                      "nChunkSkips" : 0,
    "millis" : 0,                       "indexBounds" : {
        "Coursename" : [
            [
                "Oracle",
                "Oracle"
            ]
        ]
    },
    "server" : "everest.abis.be:27017"
}
```

The Query Optimizer:

- **for each query "type", MongoDB periodically tries all useful idxes**
- **aborts the rest as soon as one plan wins**
- **the 'winning plan' is temporarily cached for each "type" of query**

Hints are supported.

MongoDB - Architecture revisited



- **data is stored on a** shard **in** chunks **of a specific** size [by default 64M]
- **MongoDB automatically** splits **and** migrates **chunks as needed**

MongoDB - Config servers

- **stored meta data:**
  store cluster chunk ranges and locations
- **can have only 1 or 3**
  [production: use 3 if not ...]
- **2PC commit (not a replica set)**

[root@everest bin]# ./mongod --configsvr --port 27019

[root@zion bin]# ./mongod --configsvr --port 27019

[root@bryce bin]# ./mongod --configsvr --port 27019

MongoS

- **acts as a router / balancer**
  installed next to the application server
  routes application requests to the data
  balances chunks
- **no local data (persists to config database)**
- **can have 1 or many**

[root@thegrand bin]# ./mongos --configdb everest:27019, zion:27019, bryce:27019

Start, add, enable shard(ing)

- **start the shard database** [can be an already running, non-sharded db]

[root@th bin]# ./mongod --shardsvr --dbpath /data/db **--port** 27018 **--config** /etc/mongod.conf

- **add the shard definition on MongoS**

> sh.addShard('xenophon:27018')

> sh.addShard('socrates:27018')

- **enable sharding**

> sh.enableSharding("coursedb");

> sh.shardCollection("coursedb.courseCol", {"coursedur":1})

MongoDB Sharding - chunks

- **based on** range-partitioning**!**
- **a chunk is a** section **of a range**
  - **a chunk is** split **once it exceeds the maximum size**
    [configuration, default 64M]

    There is no split point if all documents have the same shard key
  - **chunk split is a logical operation**
    [no data is moved]
  - **if split creates too large of a discrepancy of #chunks across shards: rebalancing starts**
    [configuration parameter]

MongoDB Sharding - chunks (cont'd)

- **rebalancing:**
  - **balancer part of MongoS**
  - **migration - balancer lock:**
    - MongoS sends *moveChunk* to source shard
    - source shard notifies destination shard
    - destination shard claims the chunk shard-key range
    - destination shard pulls documents from source shard
    - destination shard updates config server - new location of copied chunks
  - **cleanup:**
    - **source shard deletes moved data**
      [waits for open cursors to either close or time out]
    - **MongoS releases balancer lock after old chunks are deleted**

MongoDB Sharding - chunks (cont'd)

Shard key:

- **use a field commonly used in queries**
- **shard key is immutable; shard key values are immutable**
- **shard key requires index on fields contained in key**
- **shard key limited to 512 bytes in size**
- **things to think about:**
  [use your RDBMS skills]
  - cardinality
  - write distribution
  - query isolation
  - data distribution

MongoDB - About Replication

- **Why?**
  - **high availability**
    - if a node fails, another node can step in
    - extra copies of data for recovery
  - **Scaling reads = applications with high read requirements can read from replicas**
- **a** *replica set* **- a set of mongod servers**
  - **minimum of 3**
  - **election of a primary (consensus)**
  - **writes go to primary; secondaries replicate from primary**
- **define and start the replica set -**’named’ **set**

mongod --replSet <name>

<name> uses a configuration file, listing the other servers in the set

MongoDB - About Replication - oplog

- **change operations are written to the** oplog **of the primary**
  - **a capped collection**
  - **must have enough space to allow new secondaries to catch up after copying from a primary**
  - **must have enough space to cope with any applicable** slaveDelay
  - **secondaries query the primary's oplog and apply what they find**

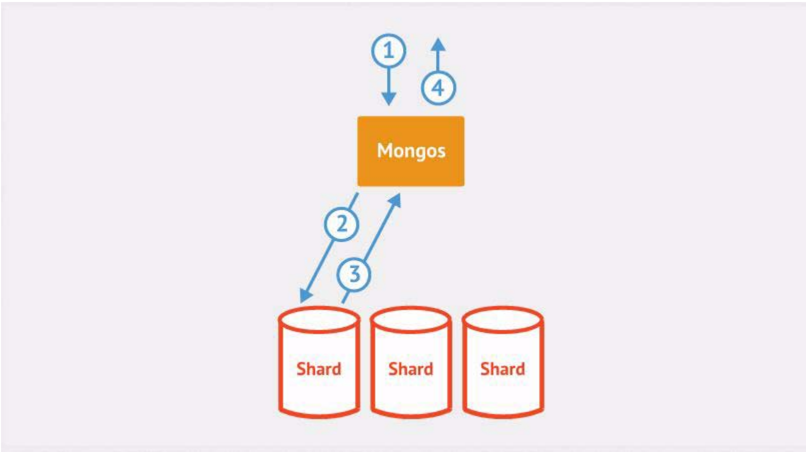
MongoDB - About Replication - failover

Failover:

- **replica set members monitor other set members [heartbeats]**
- **if primary not reachable, a new one is elected**
- **the secondary with the** most up-to-date oplog **is chosen**
  [priority can be set to influence election; secondaries can be banned from becoming primary]
- **if, after election, a secondary has changes not on the new primary, those are** undone**, and moved aside**
- **if you require a guarantee, ensure data is written to a majority of the replica set**

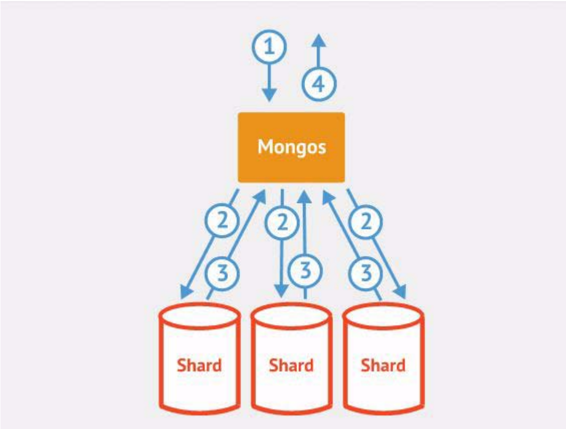
MongoDB - Request Routing

Targeted Queries

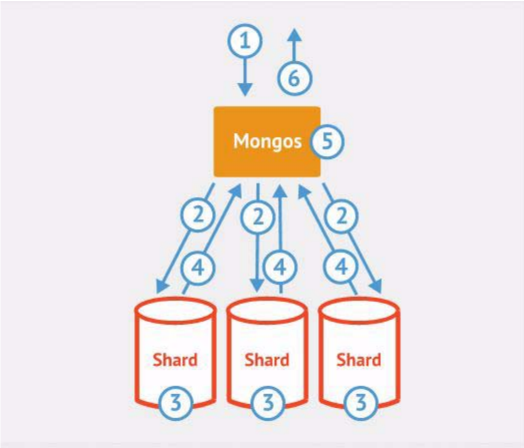


MongoDB - Request Routing (cont’d)

Scatter Gather Queries



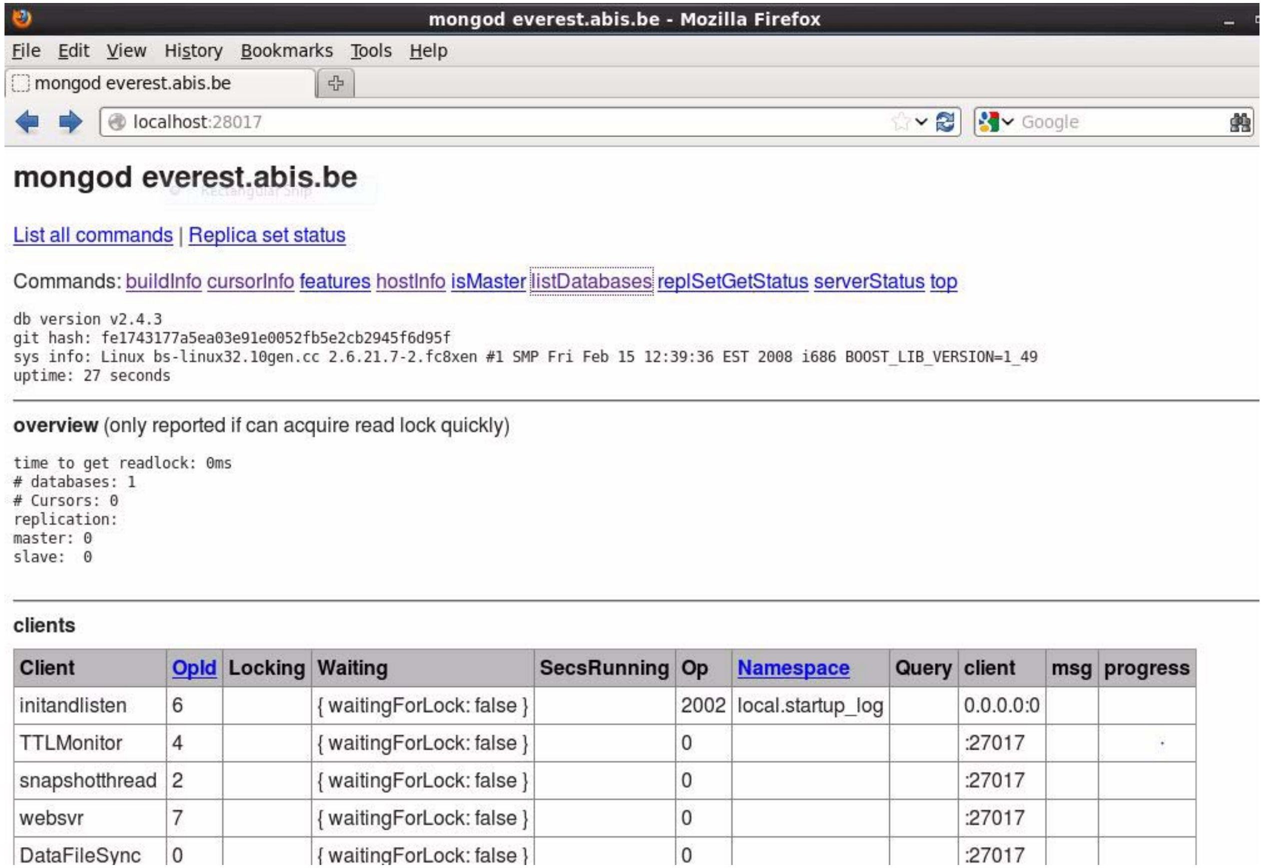
Scatter Gather Queries with Sort



MongoDB - REST interface

- **mongod provides a basic REST interface**
  [-- rest, default port 28017]

[root@everest bin]# ./mongod --dbpath /data/db --port 27017 --config /etc/mongod.conf --rest


mongod everest.abis.be - Mozilla Firefox

File Edit View History Bookmarks Tools Help

mongod everest.abis.be

localhost:28017

mongod everest.abis.be

List all commands | Replica set status

Commands: buildInfo cursorInfo features hostInfo isMaster listDatabases replSetGetStatus serverStatus top

```
db version v2.4.3
git hash: fe1743177a5ea03e91e0052fb5e2cb2945f6d95f
sys info: Linux bs-linux32.10gen.cc 2.6.21.7-2.fc8xen #1 SMP Fri Feb 15 12:39:36 EST 2008 i686 BOOST_LIB_VERSION=1_49
uptime: 27 seconds
```

overview (only reported if can acquire read lock quickly)

```
time to get readlock: 0ms
# databases: 1
# Cursors: 0
replication:
master: 0
slave:  0
```

clients

Client	OpId	Locking	Waiting	SecsRunning	Op	Namespace	Query	client	msg	progress
initandlisten	6		{ waitingForLock: false }		2002	local.startup_log		0.0.0.0:0		
TTLMonitor	4		{ waitingForLock: false }		0			:27017		
snapshotthread	2		{ waitingForLock: false }		0			:27017		
websvr	7		{ waitingForLock: false }		0			:27017		
DataFileSync	0		{ waitingForLock: false }		0			:27017		

MongoDB - Other features...

- **GridFS**
  - **store files of any size** (exceeding binary storage data max size)
  - **GridFS leverages existing** replication **or** autosharding **that has been set up**
- **Map Reduce**
  - **queries** [jscript function] **run in all shards parallel** [one thread per node]
  - **flexible aggregation and data processing**
  - **often used**
- **Geospatial Indexing**

  two-dimensional indexing for location-based queries
  [find objects based on location? Find closest n items to x]

```
db.map.insert({location : {longitude : -40, latitude : 78}})
db.map.find({location : {$near : [ -30, 70]}})
```

Questions, remarks, feedback, ... ?

Thank you!

Peter Vanroose

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