MI-PDB, MIE-PDB: **Advanced Database Systems**

http://www.ksi.mff.cuni.cz/~svoboda/courses/2015-2-MIE-PDB/

Lecture 12:

Key-Value Databases, Riak, Redis

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Key-value store

Basic characteristics

- The simplest NoSQL data store
  - A hash table (map)
  - When all access to the database is via primary key
- Like a table in RDBMS with two columns:
  - ID = key
  - NAME = value
    - BLOB with any data
- Basic operations:
  - get the value for the key
  - put a value for a key
    - If the value exists, it is overwritten
  - delete a key from the data store
- simple → great performance, easily scaled
- simple → not for complex queries, aggregation needs, …

Key-value store

Representatives

MemcachedDB

riak ✓

redis ✓

ORACLE

BERKELEY DB

HAMSTER DB
embedded database

not open-source

Project Voldemort

open-source version

Key-value store

Suitable Use Cases

Storing Session Information

- Every web session is assigned a unique session_id value
- Everything about the session can be stored by a single PUT request or retrieved using a single GET
- Fast, everything is stored in a single object

User Profiles, Preferences

- Every user has a unique user_id, user_name + preferences (e.g., language, colour, time zone, which products the user has access to, …)
- As in the previous case:
  - Fast, single object, single GET/PUT

Shopping Cart Data

- Similar to the previous cases

Key-value store

When Not to Use

Relationships among Data

- Relationships between different sets of data
- Some key-value stores provide link-walking features
  - Not usual

Multioperation Transactions

- Saving multiple keys
  - Failure to save any one of them → revert or roll back the rest of the operations

Query by Data

- Search the keys based on something found in the value part

Operations by Sets

- Operations are limited to one key at a time
- No way to operate upon multiple keys at the same time

Key-value store

Query

- We can query by the key
- To query using some attribute of the value column is (typically) not possible
  - We need to read the value to figure out if the attribute meets the conditions
- What if we do not know the key?
  - Some systems enable to retrieve the list of all keys
    - Expensive
  - Some support searching inside the value
    - Using, e.g., a kind of full text index
      - The data must be indexed first
      - Riak search (see later)

Key-value store

Query

- How to design the key?
  - Generated by some algorithm
  - Provided by the user
    - e.g., userID, e-mail
  - Derived from time-stamps (or other data)
- Typical candidates for storage: session data (with the session ID as the key), shopping cart data (user ID), user profiles (user ID), …
- Expiration of keys
  - After a certain time interval
  - Useful for session/shopping cart objects

RIAK

Key-value store

Riak

- Open source, distributed database
  - First release: 2009
  - Implementing principles from Amazon's Dynamo
- OS: Linux, BSD, Mac OS X, Solaris
- Language: Erlang, C, C++, some parts in JavaScript
- Built-in MapReduce support
- Stores keys into buckets = a namespace for keys
  - Like tables in a RDBMS, directories in a file system, …
  - Have set of common properties for its contents
    - e.g., number of replicas

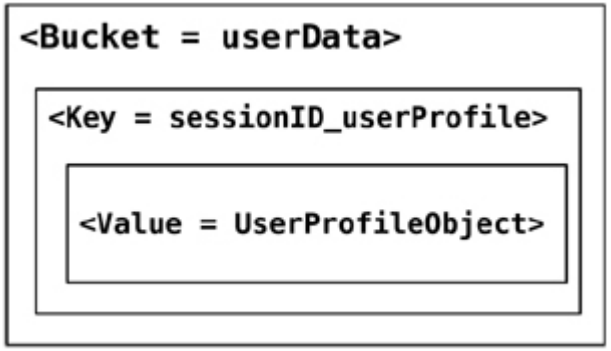
http://basho.com/riak/

Riak Buckets

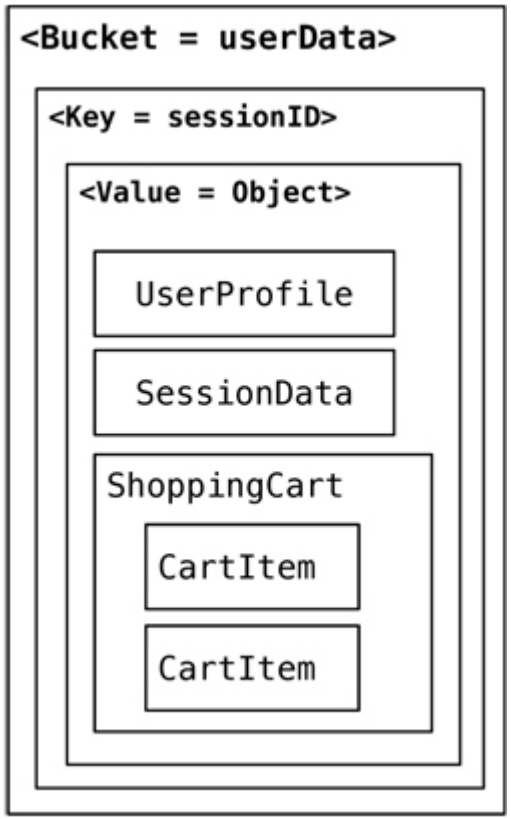
Oracle	Riak
database instance	Riak cluster
table	bucket
row	key-value
rowid	key

namespace for keys

Terminology in Oracle vs. Riak



Adding type of data to the key, still everything in a single bucket



Single object for all data, everything in a single bucket

Separate buckets for different types of data

Key-value store

Example


```
Bucket bucket = getBucket(bucketName);
IRiakObject riakObject =
 bucket.store(key, value).execute();
```

```
Bucket bucket = getBucket(bucketName);
IRiakObject riakObject =
 bucket.fetch(key).execute();
byte[] bytes = riakObject.getValue();
String value = new String(bytes);
```

Riak Usage

- HTTP – default interface
  - GET (retrieve), PUT (update), POST (create), DELETE (delete)
  - Other interfaces: Protocol Buffers, Erlang interface
  - We will use curl (**`curl --help`**)
    - Ccommand-line tool for transferring data using various protocols
- Keys and buckets in Riak:
  - Keys are stored in buckets (= namespaces) with common properties
    - `n_val` – replication factor
    - `allow_mult` – allowing concurrent updates
    - ...
  - If a key is stored into non-existing bucket, it is created
  - Keys may be user-specified or generated by Riak
- Paths:
  - `/riak/<bucket>`
  - `/riak/<bucket>/<key>`

a particular bucket

key in a bucket

Riak Usage – Examples

Working with Buckets

- List all the buckets:

```
curl http://localhost:10002/riak?buckets=true
```

- Get properties of bucket `foo`:

```
curl http://localhost:10002/riak/foo/
```

- Get all keys in bucket `foo`:

```
curl http://localhost:10002/riak/foo?keys=true
```

- Change properties of bucket `foo`:

```
curl -X PUT http://localhost:10002/riak/foo -H
   "Content-Type: application/json" -d '{"props" : {
   "n_val" : 2 } }'
```

Riak Usage – Examples

Working with Data

- Storing a plain text into bucket `foo` using a generated key:

```
curl -i -H "Content-Type: plain/text" -d "My text"
   http://localhost:10002/riak/foo/
```

HTTP POST

- Storing a JSON file into bucket `artist` with key `Bruce`:

```
curl -i -H "Content-Type: application/json" -d
   '{"name":"Bruce"}'
   http://localhost:10002/riak/artists/Bruce
```

HTTP GET

- Getting an object:

```
curl http://localhost:10002/riak/artists/Bruce
```

Riak Usage – Examples

Working with Data

- Updating an object:

HTTP PUT

```
curl -i -X PUT -H "Content-Type: application/json" -
  d '{"name":"Bruce", "nickname":"The Boss"}'
  http://localhost:10002/riak/artists/Bruce

curl http://localhost:10002/riak/artists/Bruce
```

check the value

- Deleting an object:

HTTP DELETE

```
curl -i -X DELETE
  http://localhost:10002/riak/artists/Bruce

curl http://localhost:10002/riak/artists/Bruce
```

Riak Links

- Allow to create relationships between objects
  - Like, e.g., foreign keys in relational databases, or associations in UML
- Attached to objects via Link header

- Add albums and links to the performer:

```
curl -H "Content-Type: text/plain" -H 'Link:
  </riak/artists/Bruce>; riaktag="performer"' -d
  "The River"
  http://localhost:10002/riak/albums/TheRiver

curl -H "Content-Type: text/plain" -H 'Link:
  </riak/artists/Bruce>; riaktag="performer"' -d
  "Born To Run"
  http://localhost:10002/riak/albums/BornToRun
```

Riak Links

- Find the artist who performed the album The River

```
curl -i
  http://localhost:10002/riak/albums/TheRiver/artists,performer,1
```

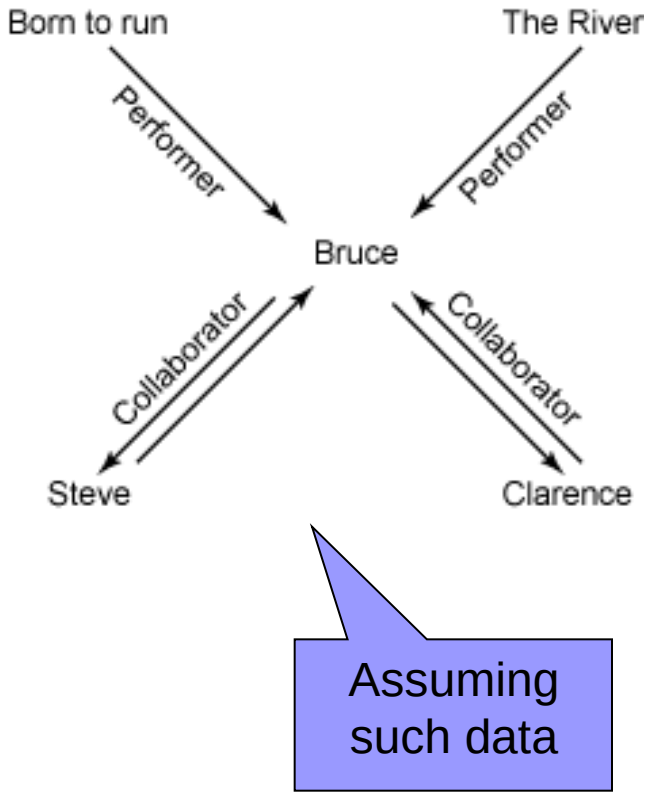
  - Restrict to bucket `artists`
  - Restrict to tag `performer`
  - `1` = include this step to the result

Riak Links

- Which artists collaborated with the artist who performed The River

```
curl -i
  http://localhost:10002/
  riak/albums/TheRiver/ar
  tists,_,0/artists,colla
  borator,1
```

  - `_` = wildcard (any relationship)
  - `0` = do not include this step to the result



Riak Search

- A distributed, full-text search engine
- Provides the most advanced query capability next to MapReduce
- Key features:
  - Support for various mime types
    - JSON, XML, plain text, …
  - Support for various analyzers (to break text into tokens)
    - A white space analyzer, an integer analyzer, a no-op analyzer, …
  - Exact match queries
  - Scoring and ranking for most relevant results
  - …

Riak Search

- First the data must be indexed:
  1. Reading a document
  2. Splitting the document into one or more fields
  3. Splitting the fields into one or more terms
  4. Normalizing the terms in each field
  5. Writing `{Field, Term, DocumentID}` to an index
- Indexing: `index <INDEX> <PATH>`
- Searching: `search <INDEX> <QUERY>`

Riak Search

- Queries:
  - Wildcards: `Bus*`, `Bus?`
  - Range queries:
    - `[red TO rum]` = documents with words containing “red” and “rum”, plus any words in between
    - `{red TO rum}` = documents with words in between “red” and “rum”
  - AND/OR/NOT and grouping: `(red OR blue) AND NOT yellow`
  - Prefix matching
  - Proximity searches
    - `"See spot run"~20` = documents with words within a block of 20 words

Key-value store

Transactions in Riak

W > N/2

R + W > N

- BASE (**B**asically **A**vailable, **S**oft state, **E**ventually consistent)
- Uses the concept of quorums
  - N = replication factor
    - Default N = 3
  - Data must be written at least at W nodes
  - Data must be found at least at R nodes
- Values W and R:
  - Can be set by the user for every single operation
  - `all` / `one` / `quorum` / `default` / an integer value
- Example:
  - A Riak cluster with N = 5, W = 3
  - Write is reported as successful ↔ reported as a success on > 3 nodes
  - Cluster can tolerate N – W = 2 nodes being down for write operations
- dw = durable write
  - More reliable write, not just “promised” that started
- rw = for deletes (read and delete)

```
{
  "props": {
    ...
    "dw": "quorum",
    "n_val": 5,
    "name": "cart",
    "postcommit": [],
    "pr": 0,
    "precommit": [],
    "pw": 0,
    "r": "quorum",
    "rw": "quorum",
    "w": "quorum",
    ...
  }
}
```

Key-value store

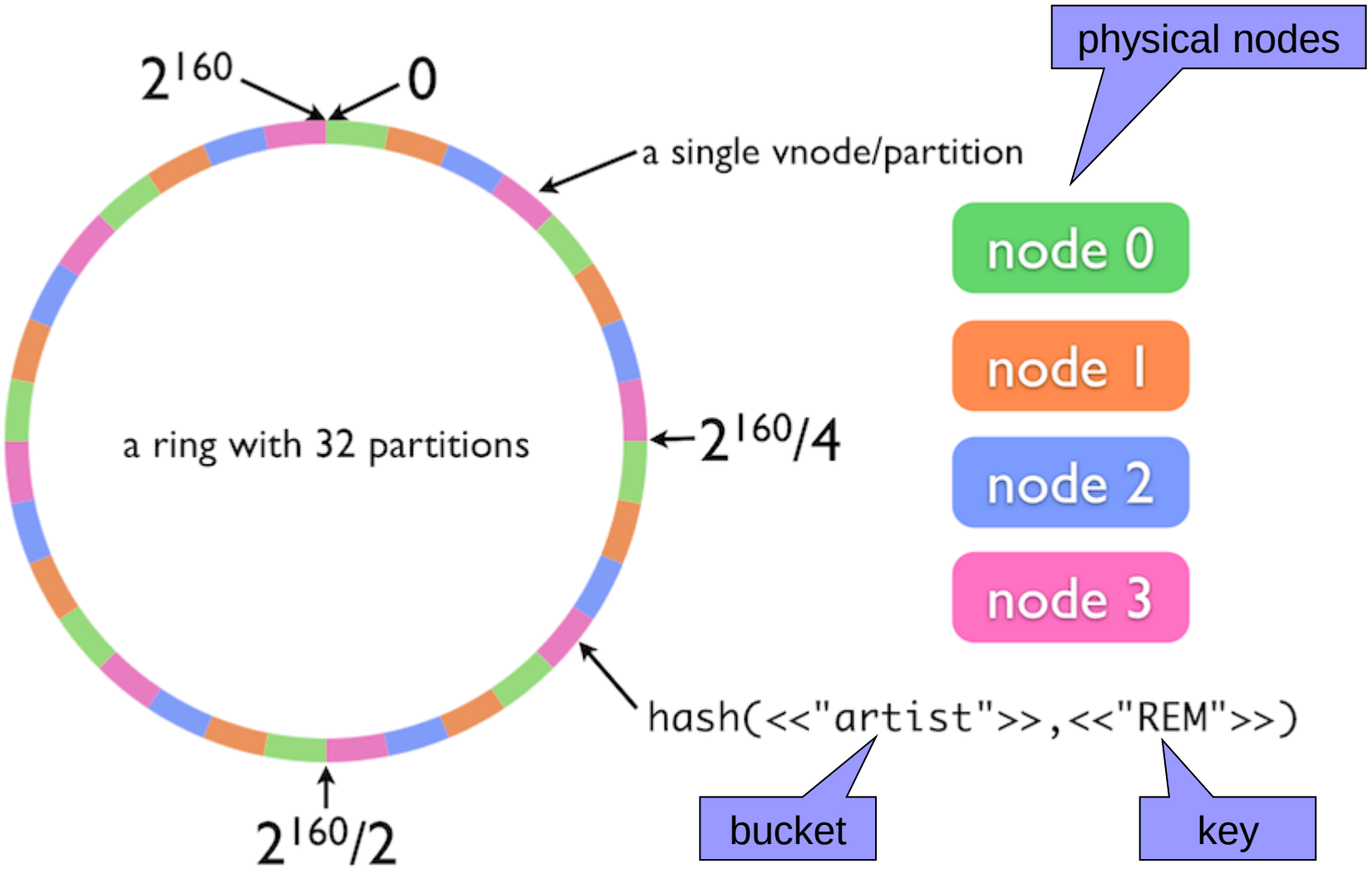
Clustering in Riak

- Center of any cluster: 160-bit integer space (Riak ring) which is divided into equally-sized partitions
- Physical nodes run virtual nodes (vnodes)
  - Each physical node in the cluster is responsible for:

    `1/(total number of physical nodes)`

    of the ring
  - Number of vnodes on each node:

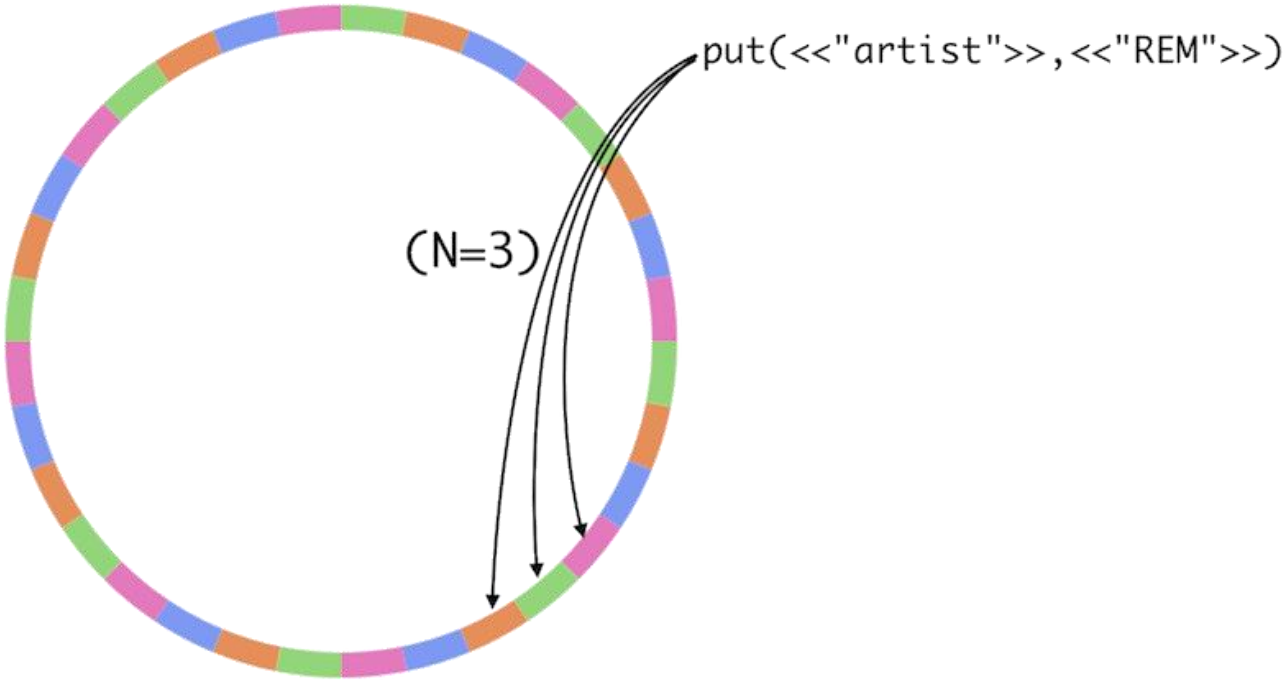
    `(number of partitions)/(number of physical nodes)`
- Nodes can be added and removed from the cluster dynamically
  - Riak will redistribute the data accordingly
- Example:
  - A ring with 32 partitions
  - 4 physical nodes
  - 8 vnodes per node


physical nodes
2^{160}
0
a single vnode/partition
node 0
node 1
node 2
node 3
a ring with 32 partitions
$2^{160}/4$
hash(<<"artist">>,<<"REM">>)
bucket
key
$2^{160}/2$

Key-value store

Replication in Riak

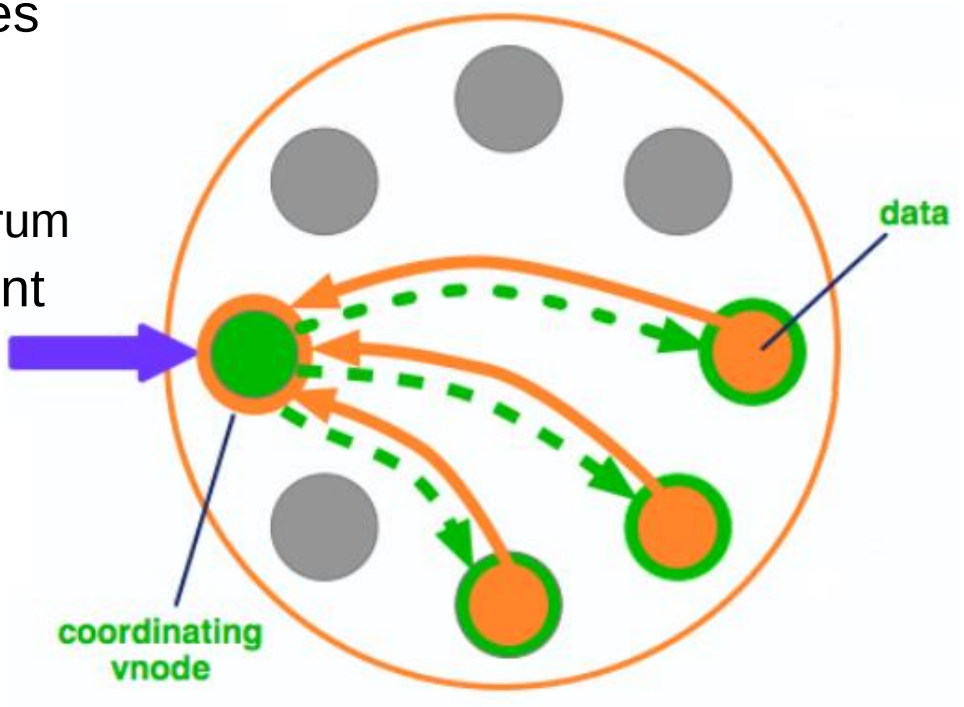
- Setting called N value
  - Default: N=3
- Riak objects inherit the N value from their bucket



Key-value store

Riak Request Anatomy

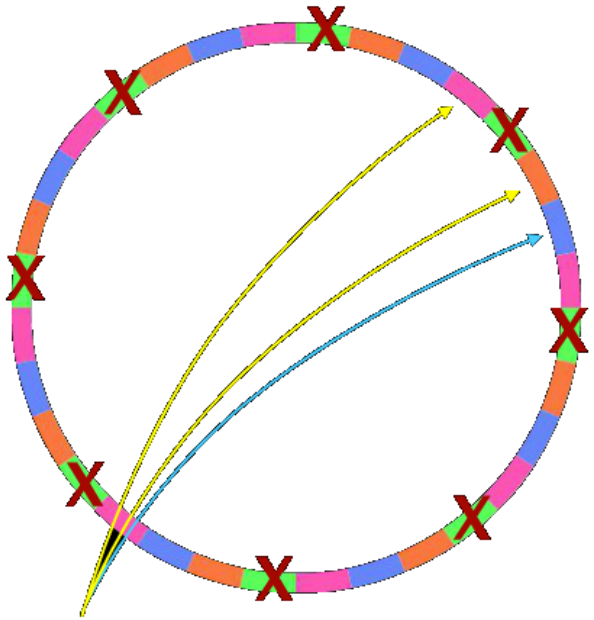
- Each node can be a coordinating vnode = node responsible for a request
  1. Finds the vnode for the key according to hash
  2. Finds vnodes where other replicas are stored – next N-1 nodes
  3. Sends a request to all vnodes
  4. Waits until enough requests returned the data
     - To fulfill the read/write quorum
  5. Returns the result to the client



Key-value store

Replication in Riak

- Riak's key feature: high availability
- Hinted handoff
  1. Node failure
  2. Neighboring nodes temporarily take over storage operations
  3. When the failed node returns, the updates received by the neighboring nodes are handed off to it



```
put(<<"artist">>,<<"REM">>)
```

Key-value store

Clustering in Riak

- No master node
  - Each node is fully capable of serving any client request
  - Uses consistent hashing to distribute data around the cluster
    - Minimizes reshuffling of keys when a hash-table data structure is rebalanced
    - Only `k/n` keys need to be remapped on average
      - `k` = number of keys
      - `n` = number of slots
- Gossip protocol
  - To share and communicate ring state and bucket properties around the cluster
  - Each node „gossips“:
    - Whenever it changes its claim on the ring
      - Announces its change
    - Periodically sends its current view of the ring state
      - To a randomly-selected peer
      - For the case a node missed previous updates

Key-value store

Riak Vector Clocks

- Problem:
  - Any node is able to receive any request
  - Not all nodes need to participate in each request

  → We need to know which version of a value is current

non human readable

a85hYGBgzGDKBVIcR4M2cgczH7HPYEpkzGNlsP/VfYYvCwA=

- When a value is stored in Riak, it is tagged with a vector clock
  - A part of object's header
- For each update it is updated to determine:
  - Whether one object is a direct descendant of the other
  - Whether the objects are direct descendants of a common parent
  - Whether the objects are unrelated in recent heritage

REDIS

Key-value store

Redis

- Open-source database
  - First release: 2009
  - Development sponsored by WMware
- OS: most POSIX systems like Linux, *BSD, OS X, …
  - Win32-64 experimental version
- Language: ANSI C
  - Clients in many languages: C, PHP, Java, Ruby, Perl, ...
- Not standard key-value features (rather a kind of document database):
  - Keys are binary safe = any binary sequence can be a key
  - The stored value can be any object → “data structure server”
    - strings, hashes, lists, sets and sorted sets
  - Can do range, diff, union, intersection, … operations
    - Atomic operations
    - Not usual, not required for key-value stores

http://redis.io/

Key-value store

Redis

- In-Memory Data Set
  - Good performance
    - For datasets not larger than memory → distribution
  - Persistence: dumping the dataset to disk periodically / appending each command to a log
- Pipelining
  - Allows to send multiple commands to the server without waiting for the replies + finally read the replies in a single step
- Publish/subscribe
  - Published messages are sent into channels and subscribers express interest in one or more channels
  - e.g., one user subscribes to a channel
    - e.g., `subscribe warnings`

    another sends messages
    - e.g., `publish warnings "it's over 9000!"`
- Cache-like behavior
  - Key can have assigned a time to live, then it is deleted

Redis Cache-like Behaviour

Example

```
> SET cookie:google hello
OK
> EXPIRE cookie:google 30
(integer) 1
> TTL cookie:google          // time to live
(integer) 23
> GET cookie:google
„hello“                      // still some time to live
> TTL cookie:google
(integer) -1                 // key has expired
> GET cookie:google
(nil)                        // and was deleted
```

Redis Data Types

Strings

- Binary safe = any binary sequence
  - e.g., a JPEG image
- Max length: 512 MB
- Operations:
  - Set/get the string value of a key: GET/SET, SETNX (set if not set yet)
  - String-operation: APPEND, STRLEN, GETRANGE (get a substring), SETRANGE (change a substring)
  - Integer-operation: INCR, INCRBY, DECR, DECRBY
    - When the stored value can be interpreted as an integer
  - Bit-operation: GETBIT, BITCOUNT, SETBIT

Redis Data Types

Strings – Example

```
> SET count 10
OK
> GET count
„10“
> INCR count
(integer) 11
> DECRBY count 10
(integer) 1
> DEL count
(integer) 1          // returns the number of keys removed
```

Redis Data Types

List

- Lists of strings, sorted by insertion order
- Possible to push new elements on the head (on the left) or on the tail (on the right)
- A key is removed from the key space if a list operation will empty the list (= value for the key)
- Max length: $2^{32} - 1$ elements
  - 4,294,967,295 = more than 4 billion of elements per list
- Accessing elements
  - Very fast near the extremes of the list (head, tail)
  - Slow accessing the middle of a very big list
    - *O(N)* operation

Redis Data Types

List

- Operations:
  - Add element(s) to the list:
    - LPUSH (to the head)
    - RPUSH (to the tail)
    - LINSERT (inserts before or after a specified element)
    - LPUSHX (push only if the list exists, do not create if not)
  - Remove element(s): LPOP, RPOP, LREM (remove elements specified by a value)
  - LRANGE (get a range of elements), LLEN (get length), LINDEX (get an element at index)
  - BLPOP, BRPOP remove an element or block until one is available
    - Blocking version of LPOP/RPOP

Redis Data Types

List – Example

```
> LPUSH animals dog
(integer) 1      // number of elements in the list
> LPUSH animals cat
(integer) 2
> RPUSH animals horse
(integer) 3
> LRANGE animals 0 -1 // -1 = the end
1) „cat"
2) „dog"
3) „horse"
> RPOP animals
„horse"
> LLEN animals
(integer) 2
```

Redis Data Types

Set

- Unordered collection of non-repeating strings
- Possible to add, remove, and test for existence of members in *O(1)*
- Max number of members: $2^{32} - 1$
- Operations:
  - Add element: SADD, remove element: SREM
  - Classical set operations: SISMEMBER, SDIFF, SUNION, SINTER
  - The result of a set operation can be stored at a specified key (SDIFFSTORE, SINTERSTORE, ...)
  - SCARD (element count), SMEMBER (get all elements)
  - Operations with a random element: SPOP (remove and return random element), SRANDMEMBER (get a random element)
  - SMOVE (move element from one set to another)

Redis Data Types

Set – Example

```
> SADD friends:Lisa Anna
(integer) 1
> SADD friends:Dora Anna Lisa
(integer) 2
> SINTER friends:Lisa friends:Dora
1) „Anna"
> SUNION friends:Lisa friends:Dora
1) „Lisa"
2) „Anna"
> SISMEMBER friends:Lisa Dora
(integer) 0
> SREM friends:Dora Lisa
(integer) 1
```

Redis Data Types

Sorted Set

- Non-repeating collection of strings
- Every member is associated with a score
  - Used in order to make the set ordered
    - From the smallest to the greatest
  - May have repeated values
    - Then lexicographical order
- Possible to add, remove, or update elements in *O(log N)*
- Operations:
  - Add element(s): ZADD, remove element(s): ZREM, increment the score of a member: ZINCRBY
  - Number of elements in a set: ZCARD
  - Elements with a score in a specified range: ZCOUNT (count), ZRANGEBYSCORE (get the elements)
  - Set operations (store result at a specified key): ZINTERSTORE, ZUNIONSTORE , …

Redis Data Types

Sorted Set – Example

```
> ZADD articles 1 Anna 2 John 5 Tom
(integer 3)
> ZCARD articles
(integer) 3
> ZCOUNT articles 3 10 // members with score 3-10
(integer) 1
> ZINCRBY articles 1 John
„3“                    // returns new John's score
> ZRANGE articles 0 -1 // outputs all members
1) „Anna“    // sorted according score
2) „John“
3) „Tom“
```

Redis Data Types

Hash

- Maps between string fields and string values
- Max number of field-value pairs: $2^{32} - 1$
- Optimal data type to represent objects
  - e.g., a user with fields name, surname, age, …
- Operations:
  - HSET key field value (set a value to the field of a specified key), HMSET (set multiple fields)
  - HGET (get the value of a hash field), HMGET, HGETALL (get all fields and values in a hash)
  - HKEYS (get all fields), HVALS (get all values)
  - HDEL (delete one or more hash fields), HEXISTS, HLEN (number of fields in a hash)

Redis Data Types

Hash – Example

```
> HSET users:sara id 3
(integer) 1
> HGET users:sara id
„3“
> HMSET users:sara login sara group students
OK
> HMGET users:sara login id
1) „sara“
2) „3“
> HDEL users:sara group
(integer) 1
> HGETALL users:sara
1) „id“
2) „3“
3) „login“
4) „sara“
```