NIE-PDB: **Advanced Database Systems**

http://www.ksi.mff.cuni.cz/~svoboda/courses/241-NIE-PDB/

Lecture 7

Key-Value Stores: RiakKV

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Lecture Outline

Key-value stores

- Introduction

RiakKV

- Data model
- HTTP interface
- **CRUD operations**
- **Data types**
- **Search 2.0**
- Internal details

Key-Value Stores

Data model

- The most simple NoSQL database type
  - Works as a simple hash table (mapping)
- **Key-value pairs**
  - Key (id, identifier, primary key)
  - Value: binary object, black box for the database system

Query patterns

- Create, update or remove value for a given key
- **Get value** for a given key

Characteristics

- Simple model ⇒ **great performance, easily scaled, …**
- Simple model ⇒ **not for complex queries nor complex data**

Key Management

How the keys should actually be designed?

- **Real-world** identifiers
  - E.g. e-mail addresses, login names, …
- **Automatically generated** values
  - Auto-increment integers
    - Not suitable in peer-to-peer architectures!
  - Complex keys
    - Multiple components / combinations of time stamps, cluster node identifiers, …
    - Used in practice instead

Query Patterns

Basic **CRUD operations**

- Only when a key is provided
- $\Rightarrow$ knowledge of the keys is essential
  - It might even be difficult for a particular database system to provide a list of all the available keys!

Accessing the contents of the value part is not possible in general

- But we could instruct the database how to **parse the values**
- … so that we can **index** them based on certain **search criteria**

Batch / sequential processing

- **MapReduce**

Other Functionality

Expiration of key-value pairs

- Objects are **automatically removed** from the database **after a certain interval of time**
- Useful for user sessions, shopping carts etc.

Links between key-value pairs

- Values can be mutually interconnected via links
- These links can be traversed when querying

Collections of values

- Not only ordinary values can be stored, but also their collections (e.g. **ordered lists**, **unordered sets**, …)

Particular functionality always depends on the store we use!

Riak Key-Value Store

RiakKV

Key-value store

- https://www.tiot.jp/en/solutions/riak/
- Features
  - Open source, incremental scalability, automatic **sharding**, **peer-to-peer replication**, high availability, fault tolerance, …
- Originally developed by **Basho Technologies**
- Implemented in **Erlang**
  - General-purpose functional programming language and runtime system with garbage collection
    - Its main strength is concurrency and distribution
- Operating systems: **Linux**, Mac OS X, … (not Windows)
- Initial release in 2009
  - Version we cover is 3.0.10 (May 2022)

Data Model

Dataspace structure

Instance $(\rightarrow$ **bucket types**$) \rightarrow$ **buckets** $\rightarrow$ **objects**

- **Bucket type**
  - Optional logical **collection of buckets**
    - When not stated explicitly, the `default` type is assumed
  - Primarily allows for shared **configuration of buckets**
    - But also forms a **namespace for buckets**
    - As well as allows to define **user permissions**
- **Bucket**
  - Logical **collection of key-value objects**
  - Allows to override inherited bucket type properties
    - E.g., replication factor, read / write quora, …

Data Model

Dataspace structure (cont'd)

- **Object** = one **key-value pair**
  - **Key**: Unicode string **unique within a bucket**
  - **Value**: basically anything (text, binary object, image, …)
- Each object is also associated with additional **metadata**
  - Especially **content type**
    - I.e., data format of the value part
    - **Media types** (MIME types) are used for this purpose
    - E.g.: `text/plain`, `application/json`, `image/jpeg`, …
  - But also certain **internal metadata**
    - Causal context (vector clock), timestamp of the last modification, …

Data Model: Design Questions

Possible data modeling strategies

- **Multiple buckets**
  - Each for objects of just a **single entity type**
    - E.g., one bucket for actors, one for movies, each actor and movie has its own object
  - Allows for easier key management
- **Single bucket**
  - Serves for objects of **various entity types**
    - E.g., one bucket for both actors and movies, each actor and movie still has its own object
  - **Structured keys** might thus help
    - Distinct prefix can be used for each entity type
    - E.g., `actor_trojan`, `movie_medvidek`

Riak Usage: Querying

Basic **CRUD operations**

- Create, Read, Update, and Delete
  - All based on a **key look-up**

Extended functionality

- **Links** – relationships between objects and their traversal
- **Search 2.0** – full-text queries accessing values of objects
- **MapReduce**
- …

Riak Usage: Interfaces

Application interfaces

- **HTTP API**
  - Requests are submitted as **HTTP requests** with appropriately selected / constructed **methods**, **URLs**, **headers**, and **data**
- **Protocol Buffers API**
- **Erlang API**

Client libraries for a variety of programming languages

- Official: Java, Ruby, Python, C#, PHP, …
- Community: C, C++, Haskell, Perl, Python, Scala, …

HTTP API

cURL = tool for **sending requests and receiving responses** via **HTTP**

- `-u user:password` (alternatively also `--user`)
  - **User credentials** to be used for **server authentication**
- `-X command` (`--request`)
  - **Request method** to be used (GET, PUT, …)
- `-H header` (`--header`)
  - **Extra headers** to be included when sending the request
- `-d data` (`--data`)
  - **Data to be sent** to the server
- `-i` (`--include`)
  - Whether response headers should also be printed

Basic Operations

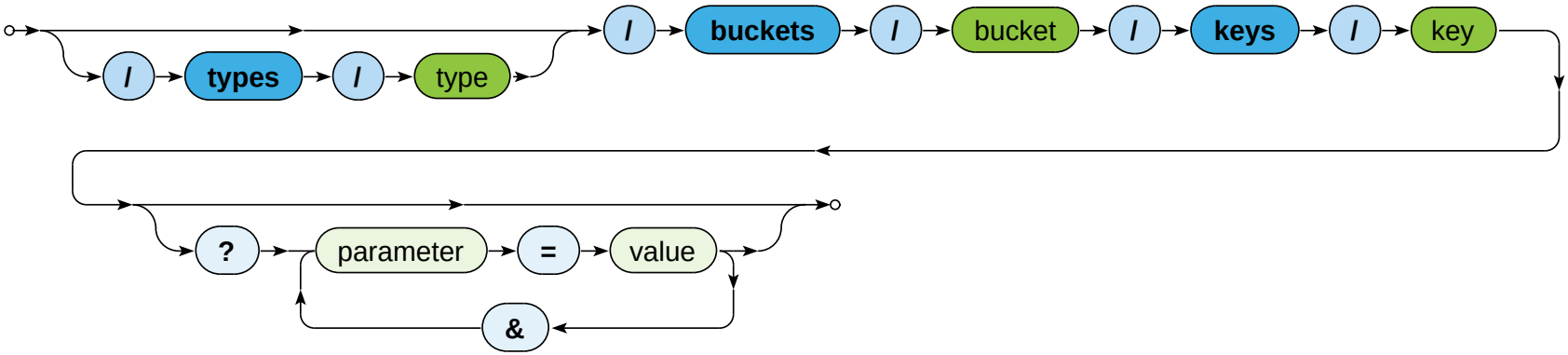
CRUD Operations

Basic object operations

- Create: `POST` or `PUT` methods
  - **Inserts** a key-value pair into a given bucket
- Read: `GET` method
  - **Retrieves** a key-value pair from a given bucket
- Update: `PUT` method
  - **Updates** a key-value pair in a given bucket
- Delete: `DELETE` method
  - **Removes** a key-value pair from a given bucket

CRUD Operations

Generic **URL pattern** for all basic object operations



Optional parameters

- Allow to override bucket-level properties for a given request
  - `r`, `w`: read / write quorum to be attained
  - …
- Permitted parameters depend on the particular operation

CRUD Operations: Create and Update

Inserts / updates a key-value pair in a given bucket

- **Key is specified** ⇒ **PUT** method
  - Transparently **inserts / updates** (**replaces**) a given object
    - I.e., when updating, everything really must be specified again
- **Key is missing** ⇒ **POST** method (insertion only)
  - Key will be generated automatically and returned via a header
    - E.g.: `4zmJhCNhM4h6mUJVw35CkOuNZ28`
- Buckets as such are created transparently, bucket types not

Example

```
curl -i -X PUT \
  -H 'Content-Type: text/plain' \
  -d 'Ivan Trojan, 1964' \
  http://localhost:8098/buckets/actors/keys/trojan
```

CRUD Operations: Read

Retrieves a key-value pair from a given bucket

- Method: **GET**

Example

```
curl -i -X GET \
  http://localhost:8098/buckets/actors/keys/trojan
```

```
...
Content-Type: text/plain
Content-Length: 17
X-Riak-Vclock: a85hYGBgzGDKBVI8XxWO2dii9T4wMKgLZjAlMuWxMti+WXKHLwsA
Last-Modified: Sun, 25 Sep 2022 15:14:05 GMT
...
```

```
Ivan Trojan, 1964
```

CRUD Operations: Delete

Removes a key-value pair from a given bucket

- Method: **DELETE**
- When a given object does not exist, it does not matter

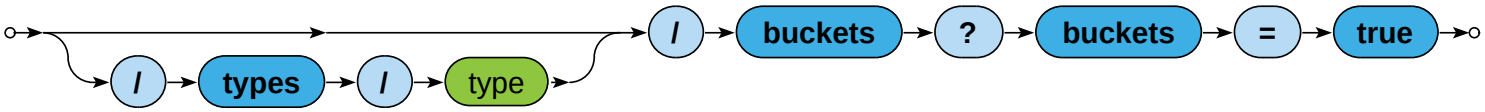
Example

```
curl -i -X DELETE \
  http://localhost:8098/buckets/actors/keys/trojan
```

Bucket Operations

List of all existing buckets

- I.e., buckets with at least one existing object
- Should not be used in production environments
  - Because of inefficiency, every cluster node needs to be involved



Example

```
curl -i -X GET http://localhost:8098/buckets?buckets=true
```

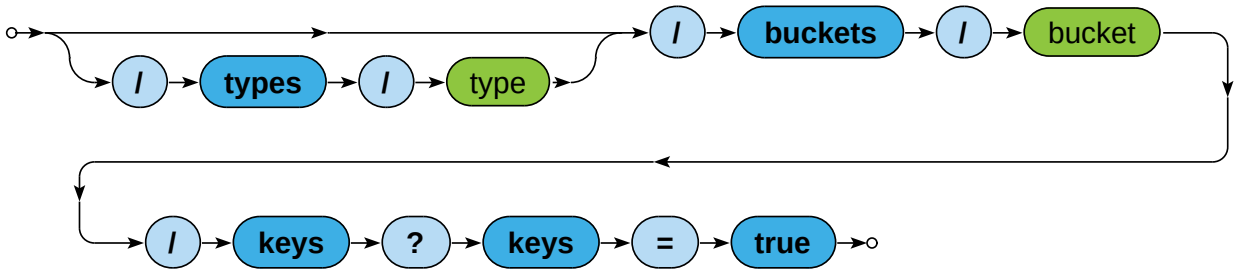
```
Content-Type: application/json
```

```
{ "buckets" : [ "actors", "movies" ] }
```

Bucket Operations

List of all existing keys in a given bucket

- Should not be used in production environments, once again



Example

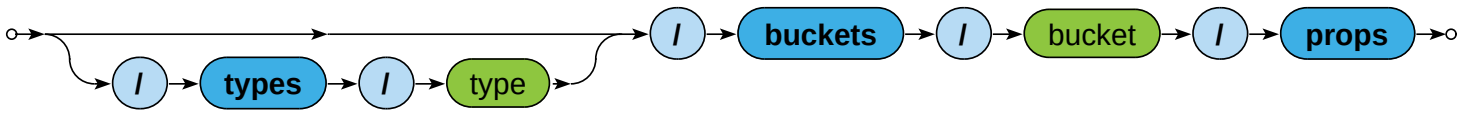
```
curl -i -X GET http://localhost:8098/buckets/actors/keys?keys=true
```

```
Content-Type: application/json
```

```
{ "keys" : [ "trojan", "machacek", "schneiderova", "sverak" ] }
```

Bucket Properties

Setting and retrieval of **bucket properties**



- **Retrieval** ⇒ **GET** method
  - Lists current values of all bucket properties
- **Update** ⇒ **PUT** method
  - Updates values of selected bucket properties
    - I.e., values of not mentioned properties are preserved intact
- **Reset** ⇒ **DELETE** method
  - Resets all or just selected bucket properties
    - I.e., removes them or replaces them with bucket type defaults

Bucket Properties: Examples

Update of selected properties

```
curl -i -X PUT \
  -H 'Content-Type: application/json' \
  -d '{ "props" : { "n_val" : 3, "w" : "all", "r" : 1 } }' \
  http://localhost:8098/buckets/actors/props
```

Reset of selected properties

```
curl -i -X DELETE \
  -H 'Content-Type: application/json' \
  -d '{ "props" : { "search_index" : "" } }' \
  http://localhost:8098/buckets/actors/props
```

Reset of all properties

```
curl -i -X DELETE \
  http://localhost:8098/buckets/actors/props
```

Bucket Properties

Important properties

- `n_val`: **replication factor**
- `r` / `w`: **read** / **write quorum**
  - Particular value, `all` (all replicas), `quorum` ($\texttt{n\_val}/2 + 1$)
- `search_index`
  - Name of the associated **search index**, if any
- `datatype`
  - Name of the associated **data type**, if any
  - E.g.: `counter`, `set`, `map`, …
- `allow_mult`
  - Whether to allow **sibling objects** to be created

Data Types

Motivation

Replica conflict

- Situation when **not all replicas** of a given object are **identical**
  - I.e., two or even more of them are mutually inconsistent

Riak is an **AP system** $\Rightarrow$ such **conflicts are unavoidable**

- And so they need to be **resolved** somehow…
  - Either automatically or manually
- Until now we only worked with **ordinary objects**
  - With atomic values only
  - And both resolution strategies possible
- But we also have an alternative in a form of **data type objects**
  - Inspired by the concept of **CRDTs**

CRDTs

Convergent Replicated Data Types

- **Generic concept** introducing a couple of data types
  - Each useful for a different real-world use case
    - G-Counter (Grow-only Counter), PN-Counter (Positive-Negative Counter), G-Set (Grow-only Set), …
- Particular **CRDT definition** involves a description of…
  - Permitted **content** – can be atomic as well as structured
  - Permitted **operations**
  - **Convergence rule**
    - Specifically tailored mechanism used for **conflict resolution**

CRDTs implemented in Riak

- **Counter**, **set**, **map**, **register**, **flag**, …
  - Not all of them can be used at the top level, though

Data Types: Counters

Counter

- **Integer counter**
  - Both positive and negative values are permitted
  - When a new counter is first used, its value is **initialized to 0**
- Operations
  - **Increment** / **decrement** by a given value
    - I.e., it is not possible to set the counter to a particular value
    - Just relative changes are permitted
- Convergence rule
  - **All requested increments / decrements are eventually applied**

Data Types: Sets

Set

- **Unordered collection of unique binary values**
  - E.g., strings
  - When a new set is first used, it is **initialized as an empty set**
- Operations
  - **Addition** / **removal** of one or more elements
- Convergence rule
  - **Addition wins over removal**
    - At the level of individual elements

Data Types: Maps

Map

- **Unordered collection of embedded name-value pairs**
  - **Names** are strings
  - **Values** can be anything
    - I.e., registers, flags, but also counters, sets and even maps
    - **Complex data structures** can therefore be easily created
  - Names must be suffixed according to the types of values
    - E.g., `field_register`, `field_flag`, …
- Operations
  - **Addition** / **update** / **removal** of a given element
- Convergence rule
  - **Addition / update wins over removal**
  - Values themselves are treated recursively based on their types

Data Types: Registers & Flags

Register

- Allows to store **any binary value** (e.g., string)
- Convergence rule
  - **The most chronologically recent value wins**
- Registers can only be stored within maps
  - I.e., not at the top level for entire objects

Flag

- **Boolean value**
  - `enable` (true), and `disable` (false)
- Convergence rule: **enable wins over disable**
- Flags can only be stored within maps, too

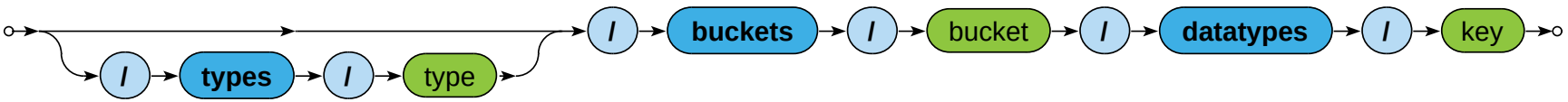
Usage of Data Types

Activation

- Via **bucket type properties** (i.e., not individual buckets)
  - Property `datatype` is set to the desired data type
    - Possible values: `counter`, `set`, `map`, …
  - Property `allow_mult` must be enabled

Usage

- Different URL pattern for requests is assumed
  - Keyword `datatypes` is expected instead of `keys`



Example: Counters

Initialization / update

- Operations `increment` and `decrement` can be used
  - Both actually with positive / negative values

```
curl -i -X POST \
  -H 'Content-Type: application/json' \
  -d '{ "increment" : 0 }' \
  http://localhost:8098/types/counters/buckets/movies/datatypes/en
```

Retrieval

```
curl -i -X GET \
  http://localhost:8098/types/counters/buckets/movies/datatypes/cs
```

```
Content-Type: application/json
```

```
{ "type" : "counter", "value" : 4 }
```

Search 2.0

Search 2.0

Riak **Search 2.0** (**Yokozuna**)

- **Full-text search** over object values
- Uses **Apache Solr**
  - Distributed, scalable, failure tolerant, real-time search platform

Mechanisms

- **Indexation**
  - Triggered whenever Riak object is changed (inserted, …)
  - **Riak object** $\xrightarrow{\text{extractor}}$ **Solr document** $\xrightarrow{\text{schema}}$ **Solr index**
- **Querying**
  - Riak **search query** $\rightarrow$ Solr search query $\rightarrow$ Solr response
    - List of matching Solr **documents with scores**
    - Each providing identification of the associated **source object**

Extractors

Extractor = parser for object values

- **Produces fields to be indexed**
- Chosen automatically based on a **content type**
  - E.g.: `application/json` ⇒ JSON extractor

Available extractors

- For common data formats…
  - Plain text, XML, JSON, *noop* (unknown content type)
- For Riak **data types**…
  - Counter (`application/riak_counter`)
  - Set (`application/riak_set`)
  - Map (`application/riak_map`)

User-defined custom extractors (implemented in Erlang)

Extractors: Plain Text

Plain text extractor (`text/plain`)

- Single field with the whole value content is extracted

Example

```
Dira u Hanusovic, 2014
```

```
[
  { <<"text">>, <<"Dira u Hanusovic, 2014">> }
]
```

Extractors: XML

XML extractor (`text/xml`, `application/xml`)

- One field is extracted for each simple **element** or **attribute**
  - But only when enabled, i.e., its name contains a **type suffix**
- Available type suffixes
  - **Single-value**
    - `_s` (string), `_i` (integer), `_f` (float), `_b` (boolean), …
  - **Multi-value**
    - When multiple values are expected
    - E.g., for several sibling elements of the same name
    - `_ss` (strings), `_is` (integers), `_fs` (floats), `_bs` (booleans), …
- **Dot notation** is used for flattened names of extracted fields
  - `.` for embedded elements (e.g., `movie.title_s`)
  - `@` for attributes (e.g., `movie@year_i`)

Extractors: XML

Example

```
<?xml version="1.1" encoding="UTF-8"?>
<movie year_i="2014" language="cs">
  <title_s>Dira u Hanusovic</title_s>
  <details>
    <length>102</length>
    <rating_s>**</rating_s>
  </details>
  <genre_ss>comedy</genre_ss>
  <genre_ss>drama</genre_ss>
<movie>
```

```
[
  { <<"movie@year_i">>, <<"2014">> },
  { <<"movie.title_s">>, <<"Dira u Hanusovic">> },
  { <<"movie.details.rating_s">>, <<"**">> },
  { <<"movie.genre_ss">>, [ <<"comedy">>, <<"drama">> ] }
]
```

Extractors: JSON

JSON extractor (`application/json`)

- Similar principles as the XML extractor applies

Example

```
{
  "title_s" : "Dira u Hanusovic",
  "language" : "cs",
  "year_i" : 2014,
  "details" : { "length" : 102, "rating_s" : "**" },
  "genre_ss" : [ "comedy", "drama" ]
}
```

```
[
  { <<"title_s">>, <<"Dira u Hanusovic">> },
  { <<"year_i">>, <<"2014">> },
  { <<"details.rating_s">>, <<"**">> },
  { <<"genre_ss">>, [ <<"comedy">>, <<"drama">> ] }
]
```

Indexing Schema

Solr document

- Extracted fields + **auxiliary fields**
  - `_yz_rt` (**bucket type**), `_yz_rb` (**bucket**), `_yz_rk` (**key**), …
    - Allow for the identification of the source Riak object

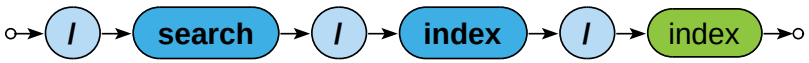
Solr schema

- Describes how values of fields are indexed within Solr
  - Values are **analyzed**, **tokenized**, and **filtered**
    - E.g., stop words removed, stemmers applied, …
  - **Triples** (token value, field name, document id) are **indexed**
- `_yz_default` = default predefined schema
  - Suitable for debugging
    - Does not support specific national characters, …
  - **Custom schemas** can also be created

Index Initialization

Step 1: **index creation**

- Default (`_yz_default`) schema is assumed when not specified



Example

```
curl -i -X PUT \
  -H 'Content-Type: application/json' \
  -d '{ "schema" : "_yz_default" }' \
  http://localhost:8098/search/index/imovies
```

```
curl -i -X PUT \
  http://localhost:8098/search/index/imovies
```

Index Initialization

Step 2: **index association**

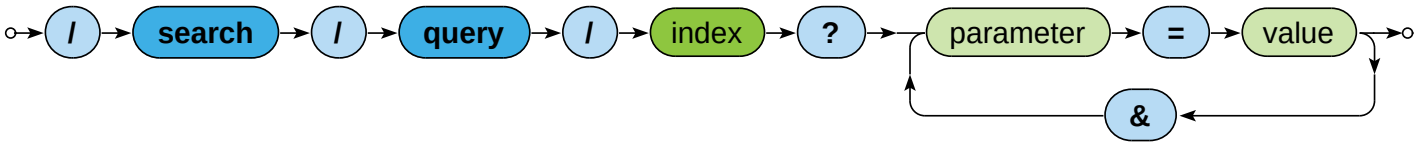
- Index must then be associated with particular buckets
  - Via `search_index` **bucket property**
- Note that the already existing objects will not be indexed

Example

```
curl -i -X PUT \
  -H 'Content-Type: application/json' \
  -d '{ "props" : { "search_index" : "imovies" } }' \
  http://localhost:8098/buckets/actors/props
```

Search Requests

Search queries



- Parameters
  - `q`: **search query conditions** to be satisfied
  - `wt`: **response writer** to be used, i.e., **data format** of the result
    - E.g.: `json`, `csv`, `xml`, `php`, …
  - `sort`: **ordering criteria**
    - Document **scores** or both single-/multi-value **fields** can be used
    - By default (when not specified), `score desc` is assumed
    - Multiple criteria are separated by commas
    - E.g.: `year_i desc,title_s asc`
  - `start` / `rows`: **pagination** of matching documents

Search Conditions

Term searches

- Value of a given field must be equal to the provided term
  - In case of a multi-value field, at least one of its values
- E.g.: `title_s:Samotari`

Phrase searches

- Group of more terms needs to be wrapped by double quotes
- E.g.: `title_s:"Dira u Hanusovic"`

Wildcard searches

- Available wildcards
  - `?` matches exactly one arbitrary character
  - `*` matches zero ore more arbitrary characters
- E.g.: `title_s:*Bob?le` matching `Bobule`, `2Bobule`, …

Search Conditions

Range searches

- Range of values between a pair of bounds
  - `[` and `]` denote **inclusive** bounds, `{` and `}` **exclusive** bounds
  - `*` denotes positive / negative infinity
- E.g.: `year_i:[2015 TO *}`

Logical expressions

- Logical connectives can be used for more complex queries
  - `AND` for **conjunction**, `OR` **disjunction** and `NOT` **negation**
  - Auxiliary **parentheses** `()` can also be utilised
- E.g.: `genre_ss:action OR genre_ss:fantasy`

Search Requests

URL encoding issues

- Step 1: preparing the intended **search condition**
  - E.g.: `title_s:*Bobule OR (year_i:[2020 TO *} AND stars_s:\*\*)`
  - Undesired **Solr metacharacters** are deactivated by escaping
    - E.g.: `:`, `*`, `?`, `(`, `)`, `[`, `]`, `{`, `}`, …
- Step 2: encoding **unsafe and reserved URL characters**
  - Each needs to be replaced with the corresponding code
  - At least those necessary…
    - E.g.: space `%20`, `"` `%22`, `\` `%5C`, `:` `%3A`, `*` `%2A`, `?` `%3F`, `(` `%28`, `)` `%29`, `[` `%5B`, `]` `%5D`, `{` `%7B`, `}` `%7D`, …
  - E.g.: `title_s%3A%2ABobule%20OR%20%28year_i%3A%5B2020%20TO%20%2A%7D%20AND%20stars_s%3A%5C%2A%5C%2A%29`

Search Requests

URL encoding issues (cont'd)

- Step 3: preparing curl request
  - Undesired **shell metacharacters** also need to be suppressed
    - E.g.: &, ?, …
  - E.g.: …\&q=… instead of …&q=…

Example

```
curl -i -X GET \
  http://localhost:8098/search/query/imovies\?wt=json\&q=year_i%3A2020
```

Internal Details

Architecture

Sharding + peer-to-peer replication architecture

- Any node can serve any read or write user request
- **Physical nodes** run (several) **virtual nodes** (vnodes)
  - Nodes can be added and removed from the cluster dynamically

CAP properties

- **AP system**: **availability + partition tolerance**
  - I.e., availability is preferred to consistency
- Strong consistency can also be achieved
  - When activated within the whole cluster
  - And appropriate quora are set:
    - $\texttt{w} > \texttt{n\_val}/2$ for write quorum
    - $\texttt{r} > \texttt{n\_val} - \texttt{w}$ for read quorum
  - However, such an approach is deprecated

Riak Ring

Replica placement strategy

- Consistent hashing function
  - Consistent = does not change when cluster changes
  - Domain: pairs of a **bucket name and object key**
  - Range: **160-bit integer space** = Riak Ring

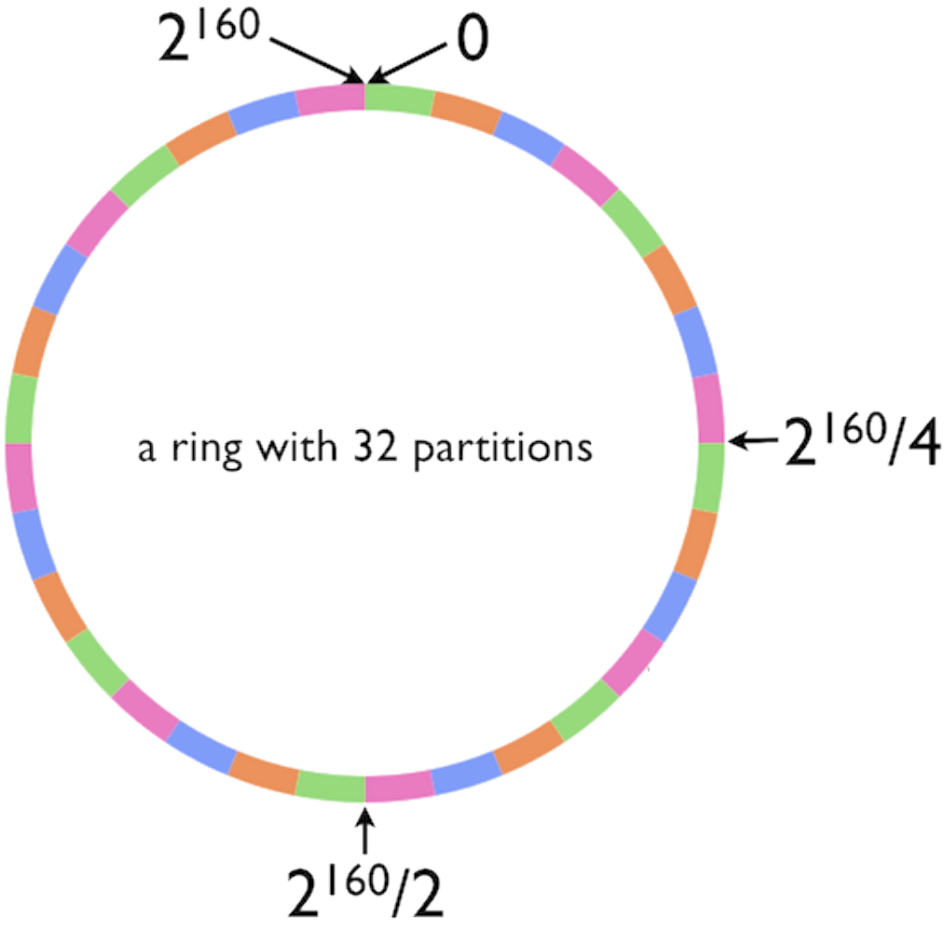
Riak Ring

- The whole ring is split into equally-sized disjoint partitions
  - Physical nodes are mutually interleaved
    $\Rightarrow$ reshuffling when cluster changes is less demanding
- **Each virtual node is responsible for exactly one partition**

Example

- Cluster with 4 physical nodes, each running 8 virtual nodes
  - I.e. 32 partitions altogether

Riak Ring



Source: http://docs.basho.com/

Riak Ring

Replica placement strategy

- The first replica…
  - Its location is **directly determined by the hash function**
- All the remaining replicas…
  - Placed to the **consecutive partitions in a clockwise direction**

What if a virtual node is failing?

- Hinted handoff
  - Failing nodes are simply skipped,
    neighboring nodes temporarily take responsibility
  - When resolved, replicas are handed off to the proper locations
- Motivation: high availability

Request Handling

Read and write requests can be submitted to any node

- This nodes is called a **coordinating node**
- Hash function is calculated, i.e. **replica locations determined**
- **Internal requests are sent** to all the corresponding nodes
- Then the coordinating node waits
  until sufficient number of responses is received
- **Result / failure is returned to the user**

But what if the cluster changes?

- The value of the hash function does not change,
  only the partitions and their mapping to virtual nodes change
- However, the Ring knowledge a given node has might be obsolete!

Lecture Conclusion

RiakKV

- **Highly available distributed key-value store**
- **Sharding with peer-to-peer replication architecture**
- **Riak Ring** with consistent hashing for replica placement

Query functionality

- Basic **CRUD operations**
- **Search 2.0** full-text based on Apache Solr