

**MIE-PDB.16: Advanced Database Systems**

<http://www.ksi.mff.cuni.cz/~svoboda/courses/181-MIE-PDB/>

Lecture 9

# **Key-Value Stores: RiakKV**

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# Lecture Outline

## Key-value stores

- Introduction

## RiakKV

- Data model
- HTTP interface
- **CRUD operations**
- **Links and Link walking**
- 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

**Prefixes** describing entity types are often used as well

- E.g. `movie_medvidek`, `movie_223123`, ...

# 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

- <http://basho.com/products/riak-kv/>
- Features
  - Open source, incremental scalability, high availability, operational simplicity, decentralized design, automatic data distribution, advanced replication, fault tolerance, ...
- Developed by **Basho Technologies**
- Implemented in **Erlang**
  - General-purpose, concurrent, garbage-collected programming language and runtime system
- Operating system: **Linux**, Mac OS X, ... (not Windows)
- Initial release in 2009



# Data Model

## Riak database system structure

Instance (→ bucket types) → **buckets** → **objects**

- **Bucket** = **collection of objects** (logical, not physical collection)
  - Various properties are set at the level of buckets
    - E.g. default replication factor, read / write quora, ...
- **Object** = **key-value pair**
  - **Key** is a Unicode string
    - **Unique within a bucket**
  - **Value** can be anything (text, binary object, image, ...)
  - Each object is also associated with **metadata**
    - E.g. its **content type** (text/plain, image/jpeg, ...),
    - and other internal metadata as well

# Data Model

## Design Questions

How buckets and objects should be modeled?

- **Buckets with objects of a single entity type**
  - E.g. one bucket for actors, one for movies, each actor and movie has its own object
- **Buckets with objects of various entity types**
  - E.g. one bucket for both actors and movies, each actor and movie has its own object once again
  - Structured keys might then help
    - E.g. actor\_trojan, movie\_medvidek
- Buckets with complex objects containing various data
  - E.g. one object for all the actors, one for all the movies

# Riak Usage: Querying

## Basic **CRUD** operations

- Create, Read, Uppdate, and Delete
- 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: API

## Application interfaces

- **HTTP API**
  - All the user 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, ...

# Riak Usage: HTTP API

## cURL tool

- Allows to **transfer data from / to a server using HTTP** (or other supported protocols)

## Options

- `-X command, --request command`
  - **HTTP request method to be used** (GET, ...)
- `-d data, --data data`
  - **Data to be sent** to the server (implies the **POST method**)
- `-H header, --header header`
  - **Extra headers** to be included when sending the request
- `-i, --include`
  - Prints both headers and (not just) body of a response

# Basic Operations

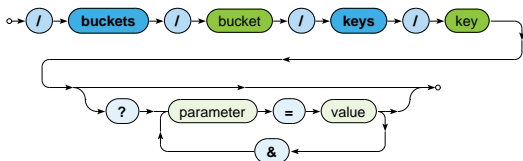
# CRUD Operations

## Basic operations on objects

- **Create**: POST or PUT methods
  - **Inserts a key-value pair** into a given bucket
  - Key is specified manually, or will be generated automatically
- **Read**: GET method
  - **Retrieves a key-value pair** from a given bucket
- **Uppdate**: 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

URL **pattern** of HTTP requests for all the CRUD operations



**Optional parameters** (depending on the operation)

- $r, w$ : read / write quorum to be attained
- ...



# CRUD Operations

## Create and Update

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

- **PUT** method
  - Should be used when a **key is specified explicitly**
  - Transparently **inserts / updates** (replaces) a given object
- **POST** method
  - When a **key is to be generated automatically**
  - Always **inserts** a new object
- Buckets are created transparently whenever needed

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

### Request

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

### Response

```
...
Content-Type: text/plain
...
```

```
Ivan Trojan, 1964
```

# CRUD Operations

## Delete

**Removes a key-value pair** from a given bucket

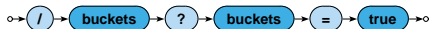
- Method: **DELETE**
- If a given object does not exist, it does not matter

## Example

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

# Bucket Operations

**Lists all the buckets** (buckets with at least one object)



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

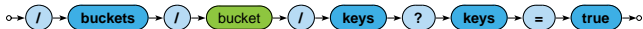
```
Content-Type: application/json
```

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

# Bucket Operations

**Lists all the keys** within a given bucket

- Not recommended to be used in production environments since it is a very expensive operation



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

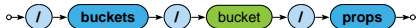
```
Content-Type: application/json
```

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

# Bucket Operations

## Setting and retrieval of **bucket properties**

- Properties
  - `n_val`: replication factor
  - `r, w, ...`: read / write quora and their alternatives
  - ...
- Requests
  - GET / PUT method: **retrieve** / **set** bucket properties



## Example

```
{  
  "props" : { "n_val" : 3, "w" : "all", "r" : 1 }  
}
```

# Links and Link Walking

# Links and Link Walking

## Links

- **Links** are metadata that establish **one-way relationships** between pairs of objects
  - Act as lightweight pointers between individual key-value pairs
  - I.e. represent and **extension to the pure key-value data model**
- Each link...
  - is defined within the source object
  - is associated with a **tag** (sort of link type)
  - can be traversed in a given direction only
  - may connect objects even from different buckets
- Multiple links can lead from / to a given object

## Link walking

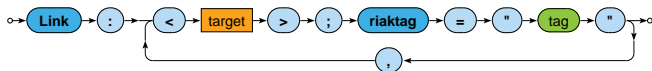
- New way of querying – navigation between objects using links



# Links

How are links defined?

- **Special Link header** is used for this purpose
- Multiple link headers can be provided, or equivalently multiple links within one header



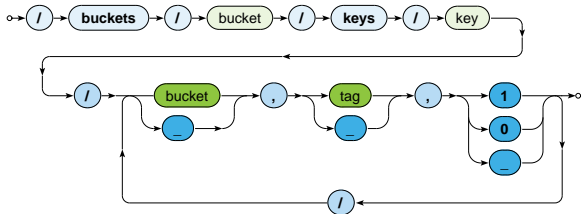
Example

```
curl -i -X PUT
-H 'Content-Type: text/plain'
-H 'Link: </buckets/actors/keys/trojan>; riaktag="tactor"'
-H 'Link: </buckets/actors/keys/machacek>; riaktag="tactor"'
-d 'Medvídek, 2007'
http://localhost:8098/buckets/movies/keys/medvidek
```

# Link Walking

How can links be traversed?

- Standard **GET requests** with **link traversal description**
  - Exactly one object where the traversal is initiated
    - Accessed in a standard way
  - Single or multiple **navigational steps** then follow



# Link Walking

## Parameters of navigation steps

- *Bucket*
  - Only objects from a certain **target bucket** are selected
  - `_` when not limited to any particular bucket
- *Tag*
  - Only links of a given **tag** are considered
  - `_` when not limited to any particular tag
- *Keep*
  - 1 when the discovered objects should be **included in the result**
  - 0 otherwise
  - `_` means 1 for the very last step, 0 for all the other preceding

# Link Walking

## Examples

Actors who played in *Medvídek* movie

```
curl -i -X GET
  http://localhost:8098/buckets/movies/keys/medvidek
    /actors,tactor,1
```

```
Content-Type: multipart/mixed; boundary=...
```

Movies in which appeared actors from *Medvídek* movie  
(assuming that the corresponding actor → movie links also exist)

```
curl -i -X GET
  http://localhost:8098/buckets/movies/keys/medvidek
    /actors,tactor,0/movies,tmovie,1
```

# Data Types

# Data Types

## Motivation

- Riak began as a **pure key-value store**
  - I.e. was completely agnostic toward the contents of values
- However, if **availability is preferred to consistency**, mutually conflicting replicas might exist
  - Such **conflicts can be resolved at the application level**,
  - but this is often (only too) difficult for the developers
- And so the concept of **Riak Data Types** was introduced
  - When used (it is not compulsory), **Riak is able to resolve conflicts automatically**

# Data Types

## Convergent Replicated Data Types (CRDT)

- Generic concept
- Various **types** for several common scenarios
- Specific **conflict resolution rules** (convergence rules)

## Available **data types**

- Register, flag
  - Can only be used embedded in maps
- Counter, set, and map
  - Can be used embedded in maps as well as directly at the bucket level

# Data Types

## Register

- Allows to store **any binary value** (e.g. string, ...)
- Convergence rule: **the most chronologically recent value wins**

## Flag

- **Boolean values:** enable (true), and disable (false)
- Convergence rule: **enable wins over disable**

## Counter

- Operations: increment / decrement by a given integer value
- Convergence rule: **all requested increments and decrements are eventually applied**



# Data Types

## Set

- **Collection of unique binary values**
- Operations: addition / removal of one / multiple elements
- Convergence rule: **addition wins over removal** of elements

## Map

- **Collection of fields with embedded elements** of any data type (including other nested maps)
- Operations: addition / removal of an element
- Convergence rule: **addition / update wins over removal**

# 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

## How does it work?

- Indexation
  - **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 **bucket-key pairs**  $\rightarrow$  Riak response: list of **objects**

# Search 2.0: Extractors

## Extractor

- **Parses the object value and produces fields to be indexed**
- Chosen automatically based on a MIME type

## Available extractors

- **Common predefined extractors**
  - Plain text, XML, JSON, *noop* (unknown content type)
- **Built-in extractors for Riak Data Types**
  - Counter, map, set
- **User-defined custom extractors**
  - Implemented in Erlang, registered with Riak

# Search 2.0: Extractors

## Plain text extractor (text/plain)

- Single field with the whole content is extracted

## Example

Input Riak object

```
Ivan Trojan, 1964
```

Output Solr document

```
[  
  { text, <<"Ivan Trojan, 1964">> }  
]
```

# Search 2.0: Extractors

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

- One field is created for each element and attribute
  - Only fields with type suffixes are considered
  - E.g. `_s` for string, `_i` for integer, `_b` for boolean, ...
  - Dot notation is used to compose flatten names of nested items

## Example

Input Riak object / Output Solr document

```
<?xml version="1.0" encoding="UTF-8" ?>
<actor year_i="1964">
  <name_s>Ivan Trojan</name_s>
</actor>
```

```
[
  { <<"actor.name_s">>, <<"Ivan Trojan">> },
  { <<"actor.@year_i">>, <<"1964">> }
]
```

# Search 2.0: Extractors

## JSON extractor (application/json)

- Similar principles as for XML documents are applied

### Example

#### Input Riak object

```
{  
  name_s : "Ivan Trojan",  
  year_i : 1964  
}
```

#### Output Solr document

```
[  
  { <<"name_s">>, <<"Ivan Trojan">> },  
  { <<"year_i">>, <<"1964">> }  
]
```

# Search 2.0: Indexation

## Solr document

- Automatically **extracted fields** + a few **auxiliary fields** such as:
  - `_yz_rb` (bucket name), `_yz_rk` (key), ...

## Solr schema

- **Describes how fields are indexed within Solr**
  - Values of fields are analyzed and split into terms
  - Terms are normalized, stop words removed
  - ...
  - **Triples** (`token`, `field`, `document`) are produced and **indexed**
- Default schema available (`_yz_default`)
  - Suitable for debugging,  
but custom schemas should be used in production



# Search 2.0: Index Creation

## How is index created?

- Index must be created first, then associated with a single bucket

## Example

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

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

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

# Search 2.0: Index Usage

## Search queries

- Parameters
  - q – **search query** (correctly encoded)
    - Individual search criteria
  - wt – response write
    - Query result format
  - start / rows – **pagination** of matching objects
  - ...



# Search 2.0: Index Usage

## Available search functionality

- **Wildcards**
  - E.g. `name:Iva*`, `name:Iva?`
- **Range queries**
  - E.g. `year:[2010 TO *]`
- **Logical connectives** and parentheses
  - AND, OR, NOT
- **Proximity searches**
- ...

# 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
- **Gossip protocol**
  - Each node periodically sends its current view of the cluster, its state and changes, bucket properties, ...

## CAP properties

- AP system: availability + **partition tolerance**

# Consistency

## BASE principles

- **Availability is preferred to consistency**
- Default properties of buckets
  - `n_val`: replication factor
  - `r`: read quorum
  - `w`: write quorum (node participation is sufficient)
  - `dw`: write quorum (write to durable storage is required)
- Specific options of requests override the bucket properties

## Strong consistency can be achieved

- When quora set carefully, i.e.:
  - $w > n\_val/2$  for write quorum
  - $r > n\_val - w$  for read quorum

# Causal Context

**Conflicting replicas are unavoidable** (with eventual consistency)

⇒ how are they resolved?

- **Causal context** = auxiliary data and mechanisms that are necessary in order to resolve the conflicts
- **Low-level techniques**
  - Timestamps, vectors clocks, dotted version vectors
  - They can be used to resolve conflicts **automatically**
    - Might fail, then we must make the choice by ourselves
  - Or we can resolve the conflicts **manually**
    - Siblings then need to be enabled (`allow_mult`)  
= multiple versions of object values
- User-friendly **CRDT data types** with built in resolution
  - Register, flag, counter, set, map

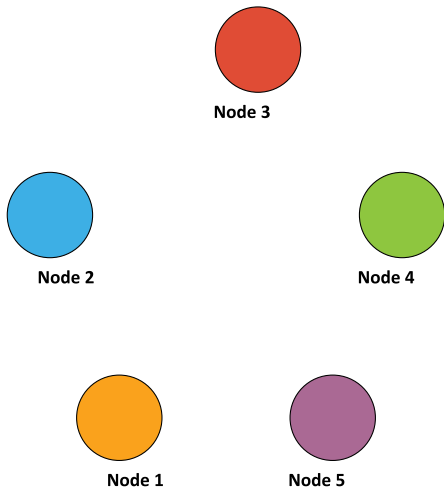
# Causal Context

## Vector clocks

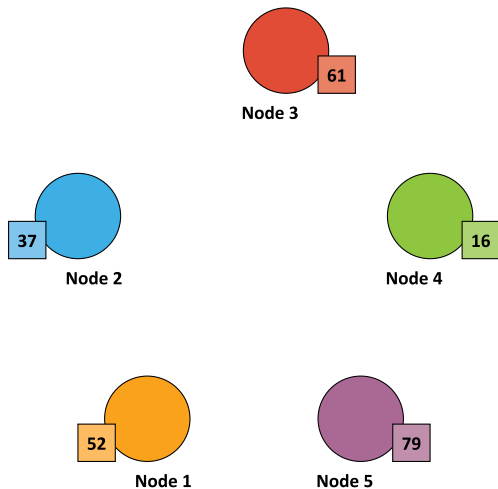
- Mechanism for **tracking object update causality** in terms of logical time (not chronological time)
- **Each node has its own logical clock** (integer counter)
  - Initially equal to 0
  - Incremented by 1 whenever any event takes place
- **Vector clock = vector of logical clocks of all the nodes**
  - Each node maintains its local copy of this vector
  - **Whenever a message is sent, the local vector is sent as well**
  - **Whenever a message is received, the local vector is updated**
    - Maximal value for each individual node clock is taken



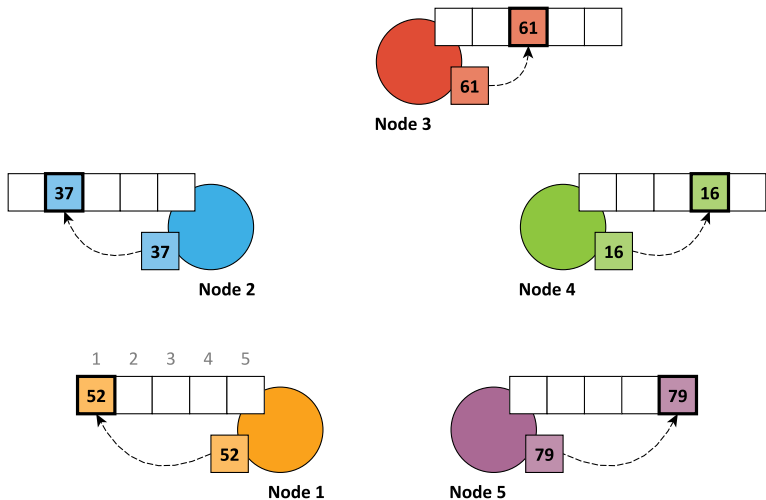
# Vector Clocks



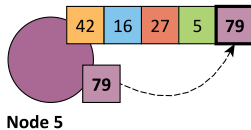
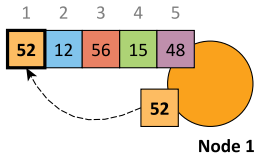
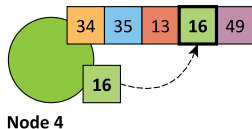
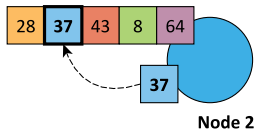
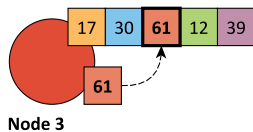
# Vector Clocks



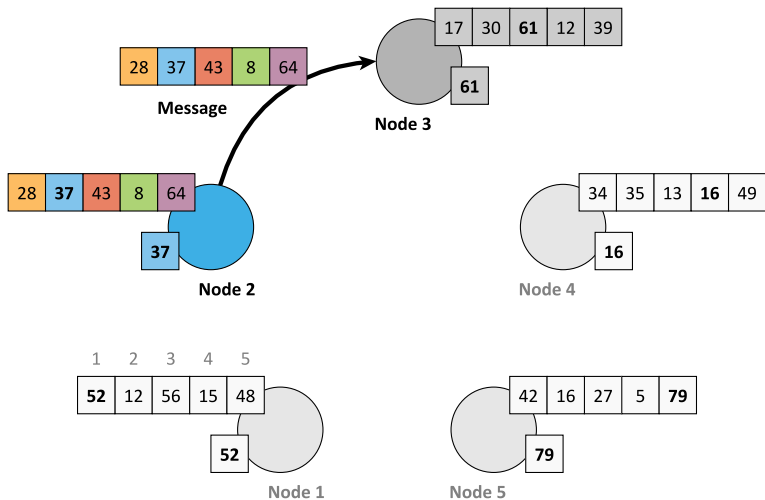
# Vector Clocks



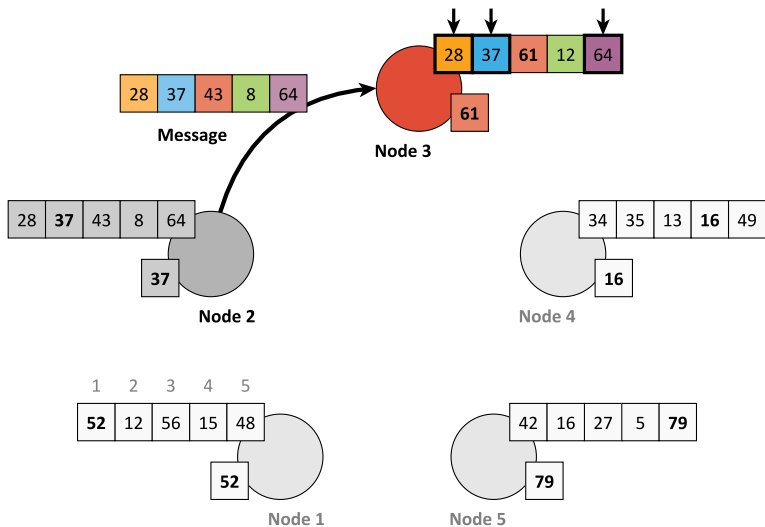
# Vector Clocks



# Vector Clocks



# Vector Clocks



# 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

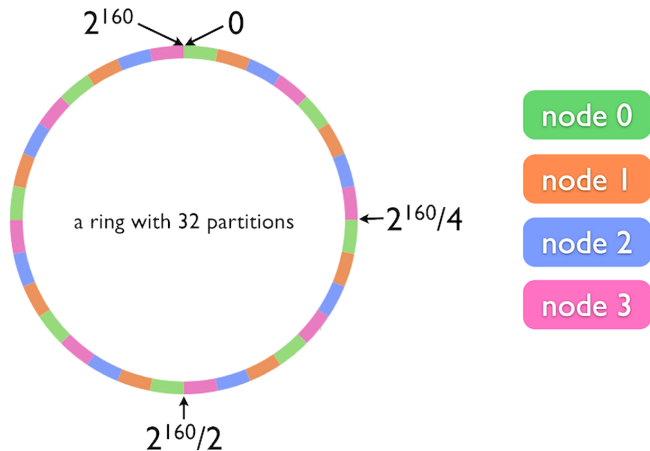
## Riak Ring

- The whole ring is split into equally-sized disjoint partitions
  - Physical nodes are mutually interleaved
    - ⇒ 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**
- **Link walking**
- **Search 2.0** full-text based on Apache Solr