

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

<http://www.ksi.mff.cuni.cz/~svoboda/courses/191-MIE-PDB/>

Lecture 10

Wide Column Stores: Cassandra

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26. 11. 2019

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Lecture Outline

Wide column stores

- Introduction

Apache Cassandra

- Data model
- Cassandra query language
 - DDL statements
 - DML statements

Wide Column Stores

Data model

- Column family
 - Table is a collection of **similar rows** (not necessarily identical)
- Row
 - Row is a collection of **columns**
 - Should encompass a group of data that is accessed together
 - Associated with a unique **row key**
- Column
 - Column consists of a **column name** and **column value** (and possibly other metadata records)
 - Scalar values, but also **flat sets, lists or maps** may be allowed

Apache Cassandra



Apache Cassandra

Column-family database

- <http://cassandra.apache.org/>
- Features
 - Open-source, high availability, linear scalability, sharding (spanning multiple datacenters), peer-to-peer configurable replication, tunable consistency, MapReduce support
- Developed by **Apache Software Foundation**
 - Originally at Facebook
- Implemented in Java
- Operating systems: cross-platform
- Initial release in 2008

Data Model

Database system structure

Instance → **keyspaces** → **tables** → **rows** → **columns**

- Keyspace
- Table (column family)
 - **Collection of (similar) rows**
 - Table schema must be specified, yet can be modified later on
- Row
 - **Collection of columns**
 - Rows in a table do not need to have the same columns
 - Each row is **uniquely identified** by a **primary key**
- Column
 - **Name-value pair** + additional data

Data Model

Column values

- Empty value
 - `null`
- Atomic values
 - **Native data types** such as texts, integers, dates, ...
 - **Tuples**
 - Tuple of anonymous fields, each of any type (even different)
 - **User defined types** (UDT)
 - Set of named fields of any type
- Collections
 - **Lists, sets, and maps**
 - Nested tuples, UDTs, or collections are also allowed, but currently only in a **frozen mode**, i.e. individual embedded elements cannot be accessed directly

Data Model

Collections

- **List**
 - **Ordered collection of non-unique values**
 - Order based on positions
 - Certain limitations and performance issues unfortunately exist
 - Internal read-before-write operations must be executed
- **Set**
 - **Ordered collection of unique values**
 - Order based on values
- **Map**
 - **Ordered collection of key-value pairs**
 - Order based on keys
 - Keys must be unique

Sample Data

Table of **actors**

id									
trojan	<table><tr><th>name</th></tr><tr><td>(Ivan, Trojan)</td></tr></table>	name	(Ivan, Trojan)	<table><tr><th>year</th></tr><tr><td>1964</td></tr></table>	year	1964	<table><tr><th>movies</th></tr><tr><td>{ samotari, medvidek }</td></tr></table>	movies	{ samotari, medvidek }
name									
(Ivan, Trojan)									
year									
1964									
movies									
{ samotari, medvidek }									
machacek	<table><tr><th>name</th></tr><tr><td>(Jiří, Macháček)</td></tr></table>	name	(Jiří, Macháček)	<table><tr><th>year</th></tr><tr><td>1966</td></tr></table>	year	1966			
	name								
	(Jiří, Macháček)								
year									
1966									
	<table><tr><th>movies</th></tr><tr><td>{ medvidek, vratnelahve, samotari }</td></tr></table>			movies	{ medvidek, vratnelahve, samotari }				
movies									
{ medvidek, vratnelahve, samotari }									
schneiderova	<table><tr><th>name</th></tr><tr><td>(Jitka, Schneiderová)</td></tr></table>	name	(Jitka, Schneiderová)	<table><tr><th>year</th></tr><tr><td>1973</td></tr></table>	year	1973	<table><tr><th>movies</th></tr><tr><td>{ samotari }</td></tr></table>	movies	{ samotari }
name									
(Jitka, Schneiderová)									
year									
1973									
movies									
{ samotari }									
sverak	<table><tr><th>name</th></tr><tr><td>(Zdeněk, Svěrák)</td></tr></table>	name	(Zdeněk, Svěrák)	<table><tr><th>year</th></tr><tr><td>1936</td></tr></table>	year	1936	<table><tr><th>movies</th></tr><tr><td>{ vratnelahve }</td></tr></table>	movies	{ vratnelahve }
name									
(Zdeněk, Svěrák)									
year									
1936									
movies									
{ vratnelahve }									

Sample Data

Table of **movies**

id				
samotari	title	year	actors	genres
	Samotáři	2000	null	[comedy, drama]
medvidek	title	director	year	
	Medvídek	(Jan, Hřebejk)	2007	
	actors		{ trojan: Ivan, machacek: Jirka }	
vratnelahve	title	year	actors	
	Vratné lahve	2006	{ machacek: Robert Landa }	
zelary	title	year	actors	genres
	Želary	2003	{ }	[romance, drama]

Data Model

Additional data associated with...

the whole column in case of atomic values, or
each individual element of a collection

- **Time-to-live (TTL)**
 - After a certain period of time (number of seconds) a given column / element is automatically deleted
- **Timestamp (writetime)**
 - Timestamp of the last modification
 - Assigned automatically or manually as well
- Both the records can be queried
 - Unfortunately not in case of collections and their elements

Cassandra API

CQLSH

- **Interactive command line shell**
- `bin/cqlsh`
- Uses **CQL** (*Cassandra Query Language*)

Client drivers

- Provided by the community
- Available for various languages
 - Java, Python, Ruby, PHP, C++, Scala, Erlang, ...

Query Language

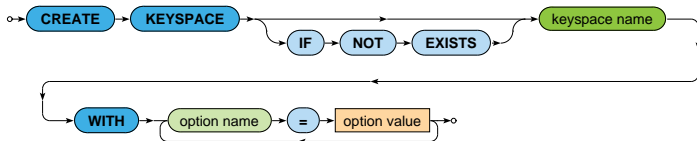
CQL = Cassandra Query Language

- Declarative query language
 - Inspired by SQL
- **DDL statements**
 - `CREATE KEYSPACE` – creates a new keyspace
 - `CREATE TABLE` – creates a new table
 - ...
- **DML statements**
 - `SELECT` – selects and projects rows from a single table
 - `INSERT` – inserts rows into a table
 - `UPDATE` – updates columns of rows in a table
 - `DELETE` – removes rows from a table
 - ...

DDL Statements

Keyspaces

CREATE KEYSPACE



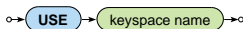
- **Creates a new keyspace**
- **Replication option** is mandatory
 - SimpleStrategy (only one replication factor)
 - NetworkTopologyStrategy (individual replication factor for each data center)

```
CREATE KEYSPACE moviedb
WITH replication = {'class': 'SimpleStrategy', 'replication_factor': 3}
```

Keyspaces

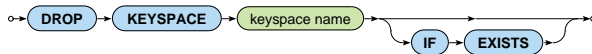
USE

- Changes the current keyspace



DROP KEYSPACE

- Removes a keyspace, all its tables, data etc.



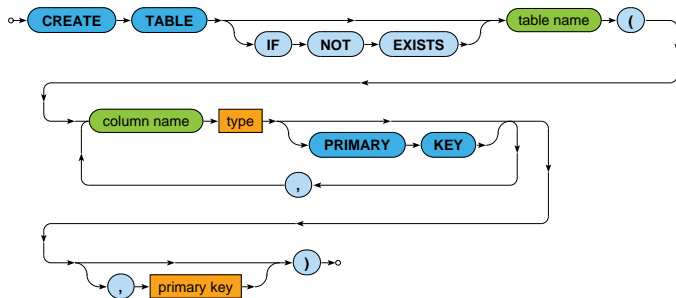
ALTER KEYSPACE

- Modifies options of an existing keyspace

Tables

CREATE TABLE

- **Creates a new table** within the current keyspace
- Each table must have exactly one **primary key** specified



Tables

Examples: tables for **actors** and **movies**

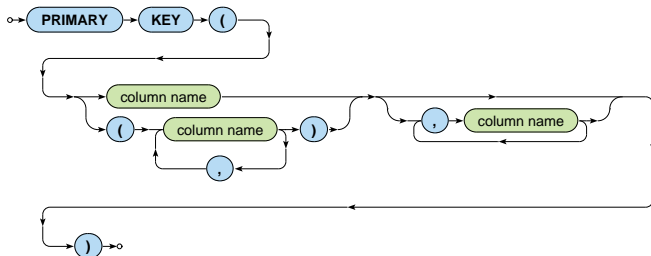
```
CREATE TABLE actors (  
  id TEXT PRIMARY KEY,  
  name TUPLE<TEXT, TEXT>,  
  year SMALLINT,  
  movies SET<TEXT>  
)
```

```
CREATE TABLE movies (  
  id TEXT,  
  title TEXT,  
  director TUPLE<TEXT, TEXT>,  
  year SMALLINT,  
  actors MAP<TEXT, TEXT>,  
  genres LIST<TEXT>,  
  countries SET<TEXT>,  
  PRIMARY KEY (id)  
)
```

Tables

Primary key has two parts:

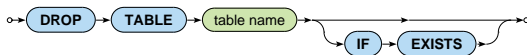
- Compulsory **partition key**
 - Single column or multiple columns
 - Determines how rows are distributed in a cluster
- Optional **clustering columns**
 - Defines the clustering order, i.e. how table rows are locally stored within a given shard



Tables

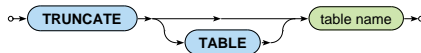
DROP TABLE

- Removes a table together with all data it contains



TRUNCATE TABLE

- Preserves a table but removes all data it contains



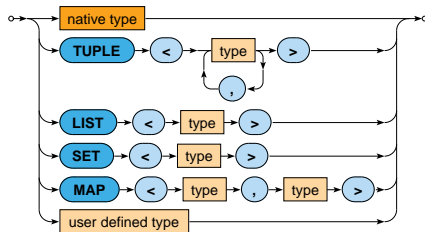
ALTER TABLE

- Allows to alter, add or drop table columns

Data Types

Types of columns

- Native types
- **Tuples**
- Collection types: **lists**, **sets**, and **maps**
- **User-defined types**



Native Data Types

Native types

- `tinyint`, `smallint`, `int`, `bigint`
 - Signed integers (1B, 2B, 4B, 8B)
- `varint`
 - Arbitrary-precision integer
- `decimal`
 - Variable-precision decimal
- `float`, `double`
 - Floating point numbers (4B, 8B)
- `boolean`
 - Boolean values `true` and `false`

Native Data Types

Native types

- `text`, `varchar`
 - UTF8 encoded string
 - Enclosed in single quotes (not double quotes)
 - Escaping sequence: `' '`
- `ascii`
 - ASCII encoded string
- `date`, `time`, `timestamp`
 - Dates, times and timestamps
 - E.g. `'2016-12-05'`, `'2016-12-05 09:15:00'`, `1480929300`

Native Data Types

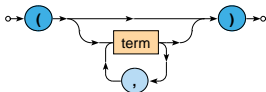
Native types

- `counter` – 8B signed integer
 - Only 2 operations supported: incrementing and decrementing
 - I.e. value of a counter cannot be set to a particular number
 - Restrictions in usage
 - Counters cannot be a part of a primary key
 - Either all table columns (outside the primary key) are counters, or none of them
 - TTL is not supported
 - ...
- `blob` – arbitrary bytes
- `inet` – IP address (both IPv4 and IPv6)
- ...

Tuple Data Types

Tuple types

- Literals for tuples

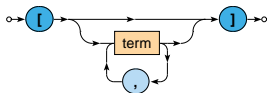


- E.g. ('Jiří', 'Macháček')

Collection Data Types

List types

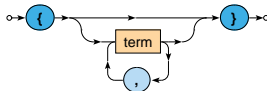
- Literals for lists



- E.g. ['comedy', 'drama']

Set types

- Literals for sets

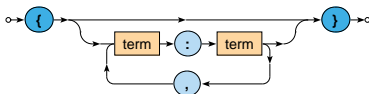


- E.g. {'medvidek', 'vratnelahve', 'samotari'}

Collection Data Types

Map types

- Literals for maps

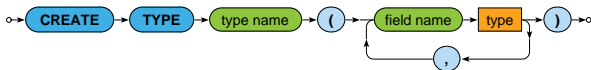


- E.g. `{'machacek': 'Robert Landa'}`

User-Defined Data Types

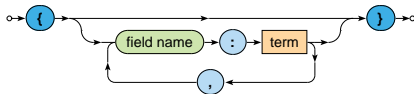
User-defined types (UDT)

- Creation of a new type



- E.g. `CREATE TYPE name (first TEXT, last TEXT)`

- Literals for UDTs



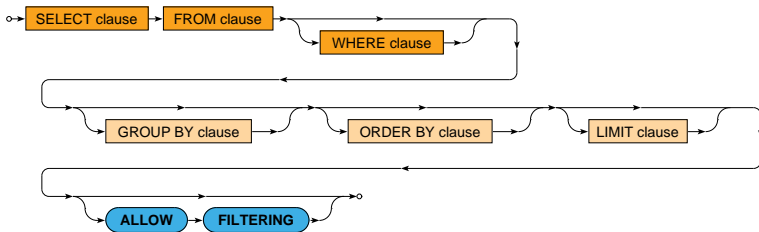
- E.g. `{first: 'Ivan', last: 'Trojan'}`

DML Statements

Selection

SELECT statement

- **Selects matching rows** from a single table



Selection

Clauses of SELECT statements

- SELECT – columns or values to appear in the result
- FROM – single table to be queried
- WHERE – filtering conditions to be applied on table rows
- GROUP BY – columns to be used for grouping of rows
- ORDER BY – criteria defining the order of rows in the result
- LIMIT – number of rows to be included in the result

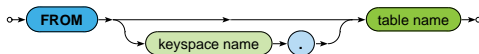
Example

```
SELECT id, title, actors
FROM movies
WHERE year = 2000 AND genres CONTAINS 'comedy'
```

Selection

FROM clause

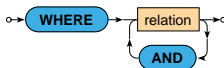
- Defines a **single table to be queried**
 - From the current / selected keyspace
- I.e. joining of multiple tables is not possible



Selection

WHERE clause

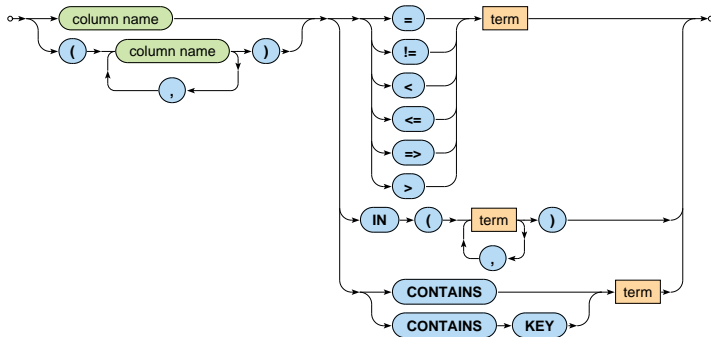
- **One or more relations a row must satisfy** in order to be included in the query result



- Only simple conditions can be expressed and **not all relations are allowed**, e.g.:
 - only primary key columns can be involved unless secondary index structures exist
 - non-equal relations on partition keys are not supported
 - ...

Selection

WHERE clause: relations



Selection

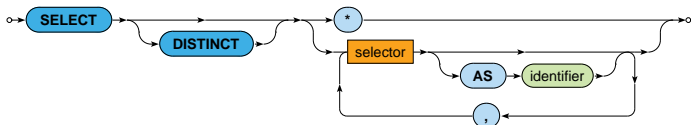
WHERE clause: relations

- **Comparisons**
 - =, !=, <, <=, >=, >
- **IN**
 - Returns true when the actual value is one of the enumerated
- **CONTAINS**
 - May only be used on collections (lists, sets, and maps)
 - Returns true when a collection contains a given element
- **CONTAINS KEY**
 - May only be used on maps
 - Returns true when a map contains a given key

Selection

SELECT clause

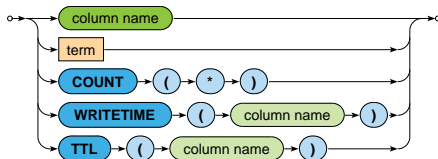
- Defines **columns or values to be included in the result**
 - * = all the table columns
 - Aliases can be defined using AS



- **DISTINCT** – duplicate rows are removed

Selection

SELECT clause: **selectors**

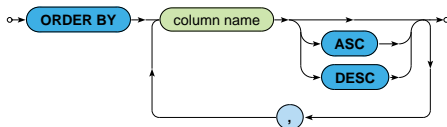


- **COUNT(*)**
 - Number of all the rows in a group (see aggregation)
- **WRITETIME** and **TTL**
 - Selects modification timestamp / remaining time-to-live of a given column
 - Cannot be used on collections and their elements
 - Cannot be used in other clauses (e.g. WHERE)

Selection

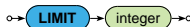
ORDER BY clause

- Defines the **order of rows returned in the query result**
- Only orderings induced by clustering columns are allowed!



LIMIT clause

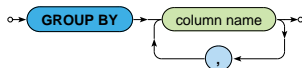
- **Limits the number of rows** returned in the query result



Selection

GROUP BY clause

- **Groups rows of a table** according to certain columns
- Only groupings induced by primary key columns are allowed!



- **When a non-grouping column would be accessed directly** in the SELECT clause (i.e. without being wrapped by an aggregate function), the first value encountered will always be returned

Selection

GROUP BY clause: **aggregates**

- Native aggregates
 - **COUNT**(column)
 - Number of all the values in a given column
 - `null` values are ignored
 - **MIN**(column), **MAX**(column)
 - Minimal / maximal value in a given column
 - **SUM**(column)
 - Sum of all the values in a given column
 - **AVG**(column)
 - Average of all the values in a given column
- User-defined aggregates

Selection

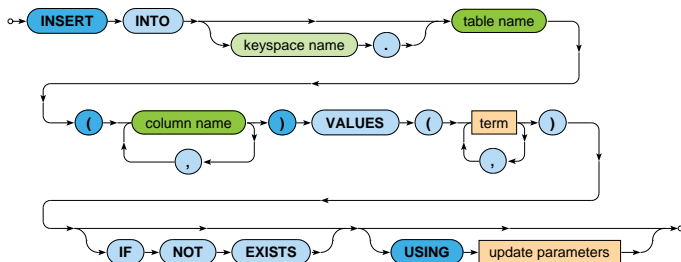
ALLOW FILTERING modifier

- By default, **only non-filtering queries are allowed**
 - I.e. queries where
the number of rows read \sim the number of rows returned
 - Such queries have predictable performance
 - They will execute in a time that is proportional to the amount of data returned
- ALLOW FILTERING **enables (some) filtering queries**

Insertions

INSERT statement

- **Inserts a new row** into a given table
 - When a row with a given primary key already exists, it is updated
- Values of at least primary key columns must be set
- Names of columns must always be explicitly enumerated



Insertions

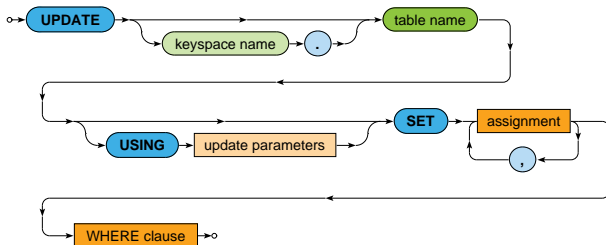
Example

```
INSERT INTO movies (id, title, director, year, actors, genres)
VALUES (
    'stesti',
    'Štěstí',
    ('Bohdan', 'Sláma'),
    2005,
    { 'vilhelmová': 'Monika', 'liska': 'Toník' },
    [ 'comedy', 'drama' ]
)
USING TTL 86400
```

Updates

UPDATE statement

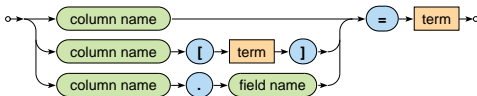
- **Updates existing rows** within a given table
 - When a row with a given primary key does not yet exist, it is inserted
- At least all primary key columns must be specified in the WHERE clause



Updates

UPDATE statement: **assignments**

- Describe modifications to be applied
- Allowed assignments:
 - Value of a whole column is replaced
 - Value of a list or map element is replaced
 - Value of a user-defined type field is replaced



Updates

Examples

```
UPDATE movies
SET
  year = 2006,
  director = ('Jan', 'Svěrák'),
  actors = { 'machacek': 'Robert Landa', 'sverak': 'Josef Tkaloun' },
  genres = [ 'comedy' ],
  countries = { 'CZ' }
WHERE id = 'vratnelahve'
```

```
UPDATE movies
SET
  actors['vilhelmova'] = 'Helenka',
  genres[1] = 'comedy'
WHERE id = 'vratnelahve'
```

Updates

Examples

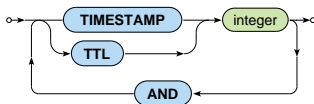
```
UPDATE movies
SET
  actors = actors + { 'vilhelmova': 'Helenka' },
  genres = [ 'drama' ] + genres,
  countries = countries + { 'SK' }
WHERE id = 'vratnelahve'
```

```
UPDATE movies
SET
  actors = actors - { 'vilhelmova', 'landovsky' },
  genres = genres - [ 'drama', 'sci-fi' ],
  countries = countries - { 'SK' }
WHERE id = 'vratnelahve'
```

Insertions and Updates

Update parameters

- **TTL**: time-to-live
 - 0, null or simply missing for persistent values
- **TIMESTAMP**: writetime

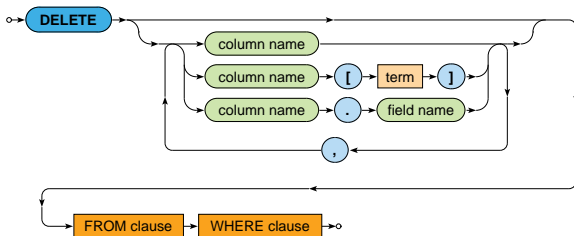


- Only newly inserted / updated values are really affected

Deletions

DELETE statement

- Removes existing rows / columns / elements of collections from a given table



Lecture Conclusion

Cassandra

- **Wide column store**

Cassandra query language

- DDL statements
- DML statements
 - **SELECT, INSERT, UPDATE, DELETE**