NIE-PDB: **Advanced Database Systems**

http://www.ksi.mff.cuni.cz/~svoboda/courses/221-NIE-PDB/

Lecture 8

Wide Column Stores: Cassandra

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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
  - Version we cover is 4.0.6 (August 2022)

Data Model

Database system structure

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

- Keyspace
- Table (column family)
  - **Collection of (similar) rows**
    - Rows do not need to have exactly the same columns
  - Table schema must be specified, yet can be modified later on
- Row
  - **Collection of columns**
  - Each row is **uniquely identified** by a compulsory 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 permitted, however, currently only in a frozen mode

Data Model

Collections

- **List** = **ordered collection of values**
  - This order is based on positions
  - Values do not need to be unique
- **Set** = **collection of unique values**
  - Values are internally ordered
- **Map** = **collection of key-value pairs**
  - Keys must be unique
  - Pairs are internally ordered based on keys

Sample Data

Table of **actors**

id	
'trojan'	name: ('Ivan', 'Trojan') | year: 1964 | movies: { 'samotari', 'medvidek' }
'machacek'	name: ('Jiří', 'Macháček') | year: 1966 | movies: { 'medvidek', 'vratnelahve', 'samotari' }
'schneiderova'	name: ('Jitka', 'Schneiderová') | year: 1973 | movies: { 'samotari' }
'sverak'	name: ('Zdeněk', 'Svěrák') | year: 1936 | movies: { 'vratnelahve' }

Sample Data

Table of **movies**

id	
'samotari'	title: 'Samotáři' | year: 2000 | actors: null | genres: ['comedy', 'drama']
'medvidek'	title: 'Medvídek' | director: ('Jan', 'Hřebejk') | year: 2007 | properties: { length: 100 } | actors: { 'trojan': 'Ivan', 'machacek': 'Jirka' }
'vratnelahve'	title: 'Vratné lahve' | year: 2006
'zelary'	title: 'Želary' | year: 2003 | actors: {} | genres: ['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

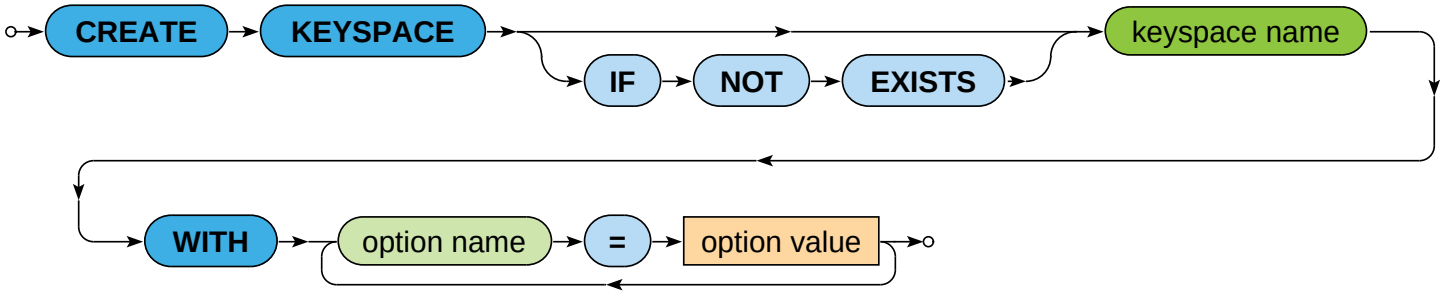
CQL = **Cassandra Query Language**

- 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



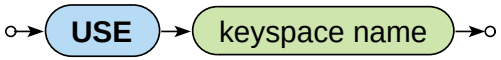
- **Creates a new keyspace**
- **Replication option** is mandatory
  - `SimpleStrategy` (only one replication factor)
  - `NetworkTopologyStrategy`
    (individual replication factor for each data center)

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

Keyspaces

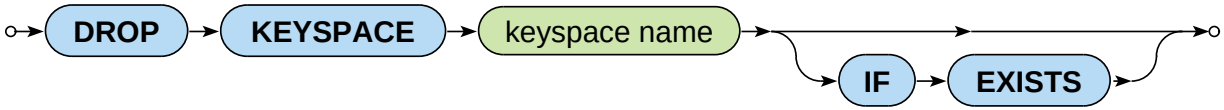
USE

- Changes the current keyspace



DROP KEYSPACE

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



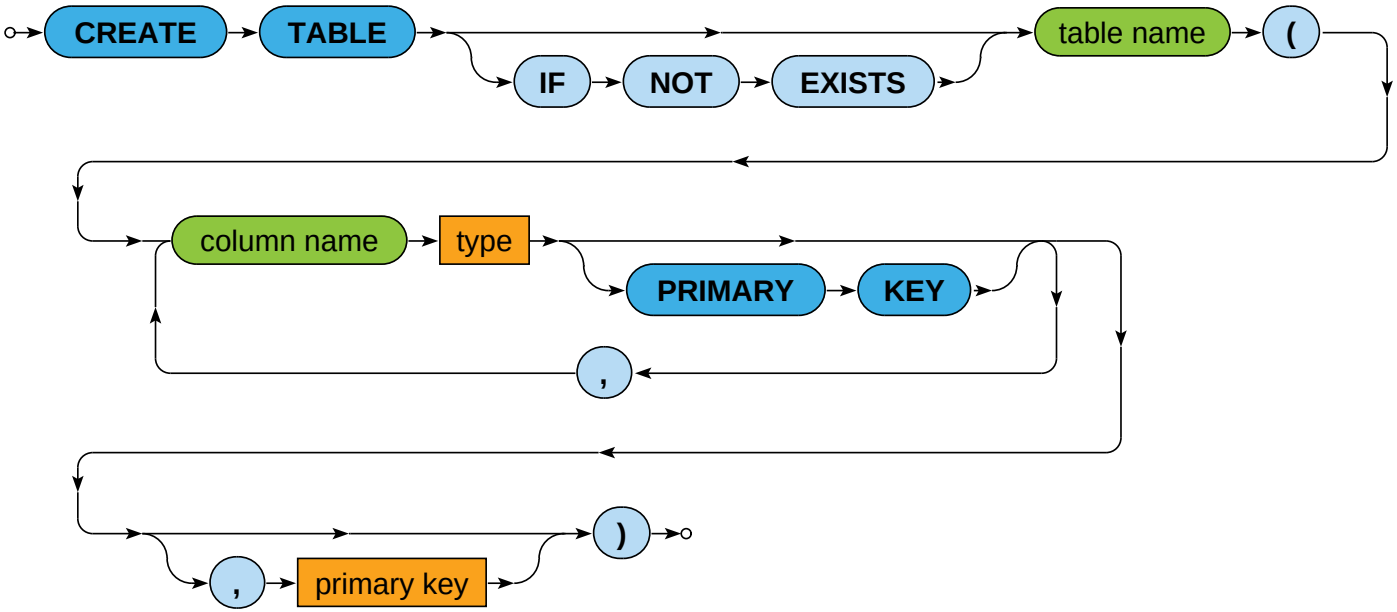
ALTER KEYSPACE

- 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



- None of the columns is compulsory (except the primary key)

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>,
  properties details,
  PRIMARY KEY (id)
)
```

Primary Keys

Primary keys have two parts

- Compulsory **partition key**
  - At least one column
  - Defines how individual rows are distributed between shards
- Optional **clustering columns**
  - Defines the order in which individual rows are locally stored by each shard

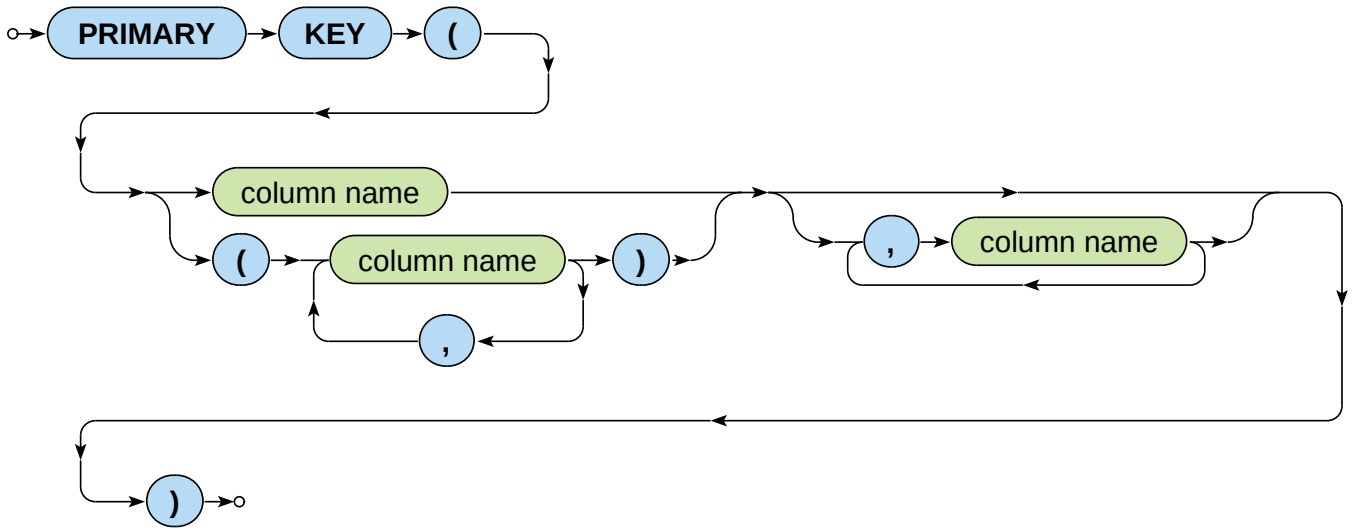
Column-level primary key definition

- A given column (the only one) becomes the partition key
- There are no clustering columns

Primary Keys

Table-level primary key definition

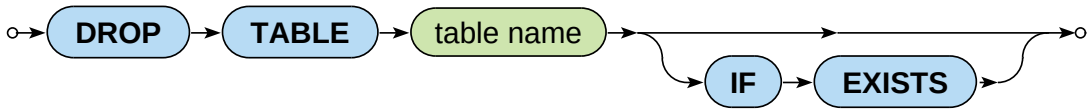
- The first column / all columns in the embedded parentheses become the partition key
- All the remaining ones (if any) form the clustering columns



Tables

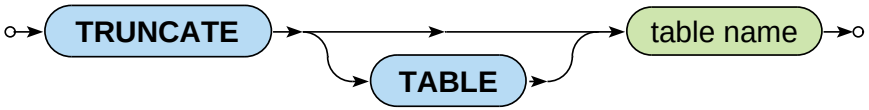
DROP TABLE

- Removes a table together with all data it contains



TRUNCATE TABLE

- Preserves a table but removes all data it contains



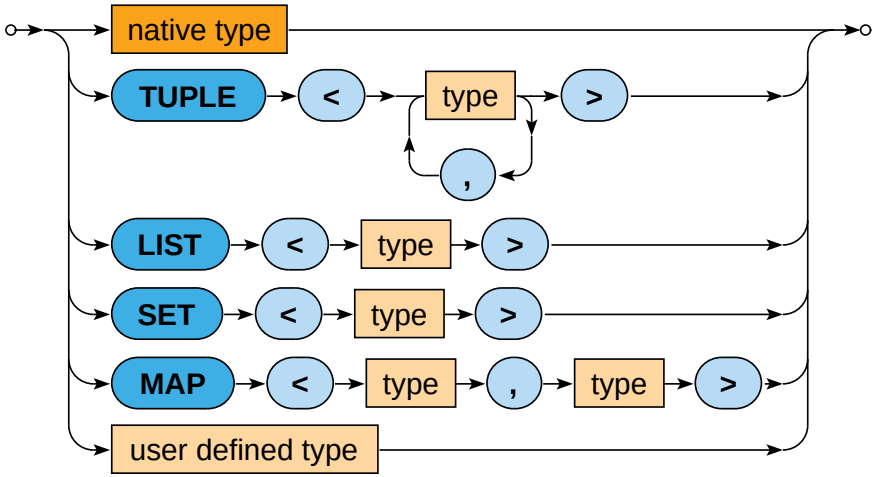
ALTER TABLE

- 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

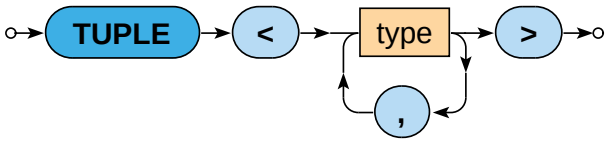
Native types

- `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)
- …

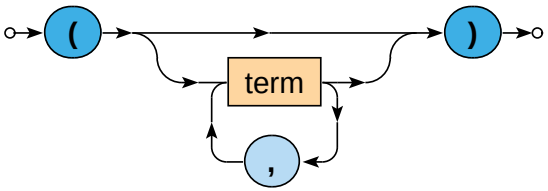
Tuple Data Types

Tuples

- Declaration



- Literals

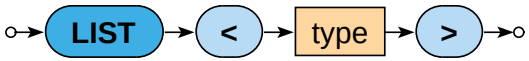


  - E.g. `( 'Jiří', 'Macháček' )`

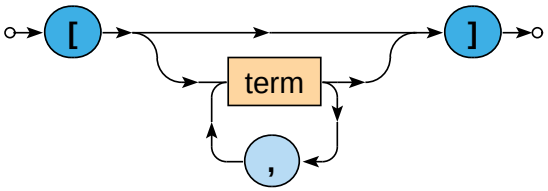
Collection Data Types

Lists

- Declaration



- Literals

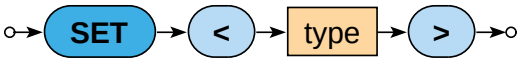


  - E.g. `[ 'comedy', 'drama' ]`

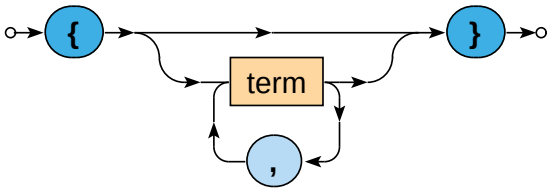
Collection Data Types

Sets

- Declaration



- Literals

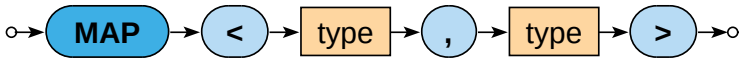


  - E.g. `{ 'medvidek', 'vratnelahve', 'samotari' }`

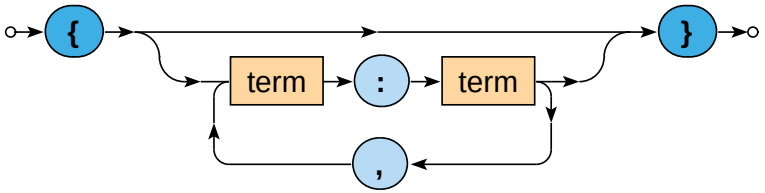
Collection Data Types

Maps

- Declaration



- Literals

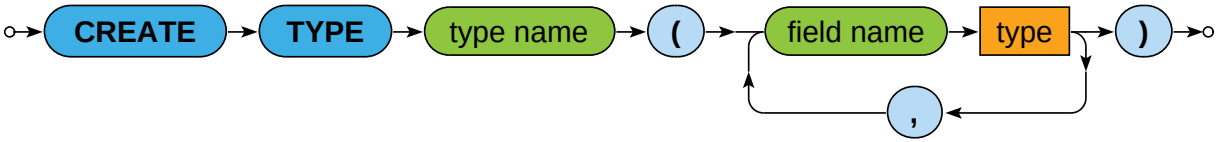


  - E.g. `{ 'machacek': 'Robert Landa' }`

User-Defined Data Types

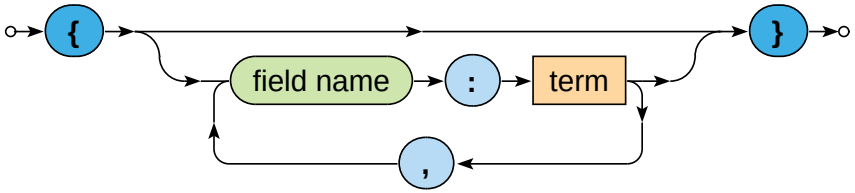
User-defined types (UDT)

- Definition



  - E.g. `CREATE TYPE details ( length SMALLINT, annotation TEXT )`

- Literals



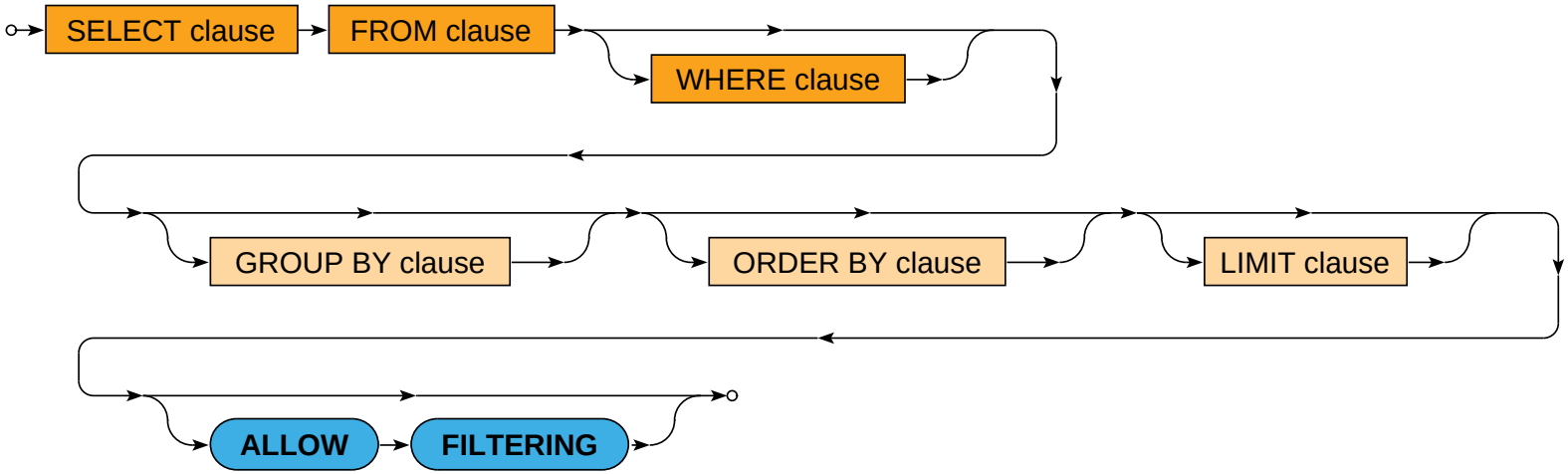
  - E.g. `{ length: 100 }`

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

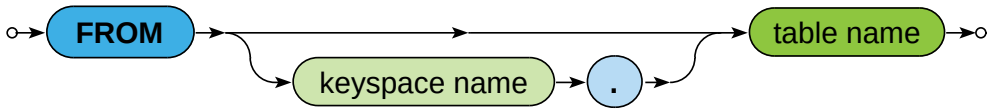
Example

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

Selection

FROM clause

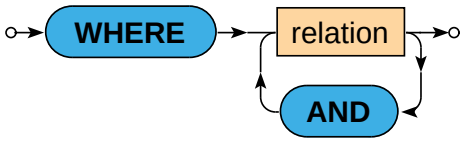
- Defines a **single table to be queried**
  - From the current / selected keyspace
- I.e. joining of multiple tables is not possible



Selection

WHERE clause

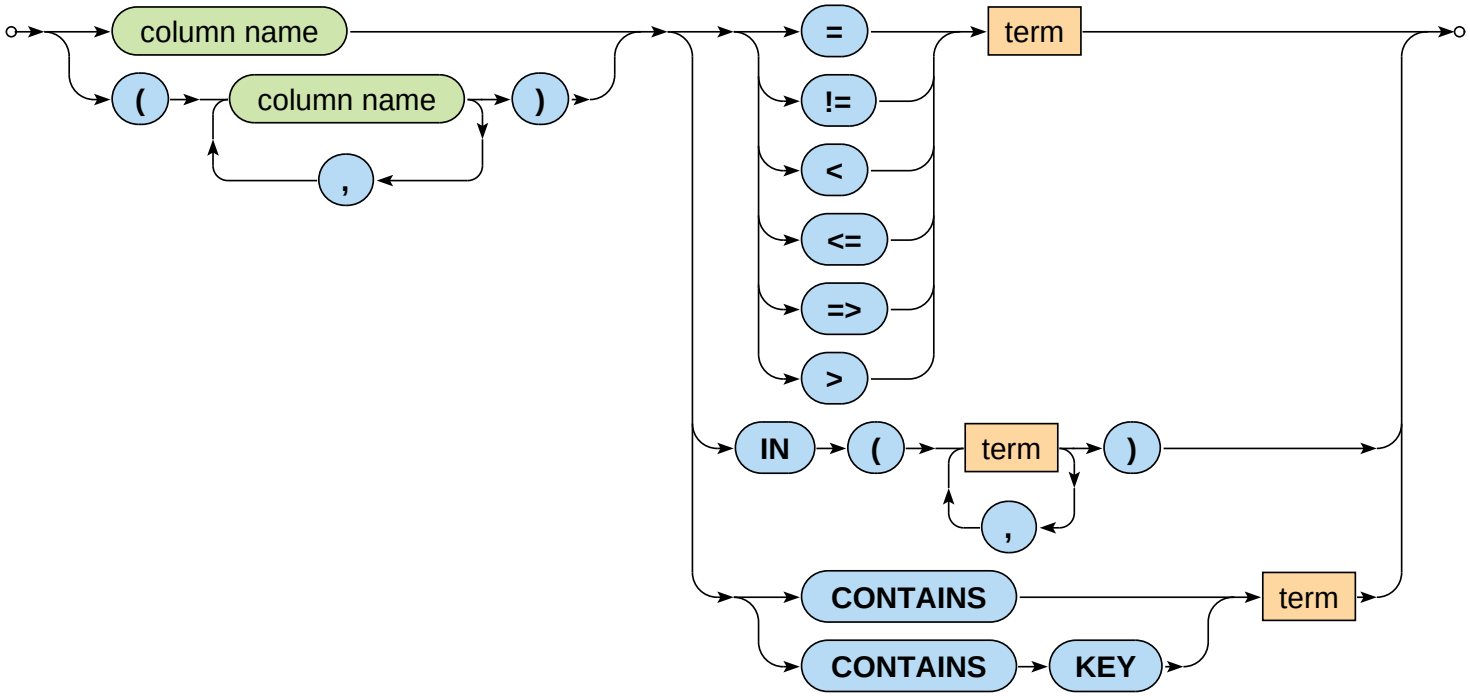
- **One or more relations a row must satisfy** in order to be included in the query result



- 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

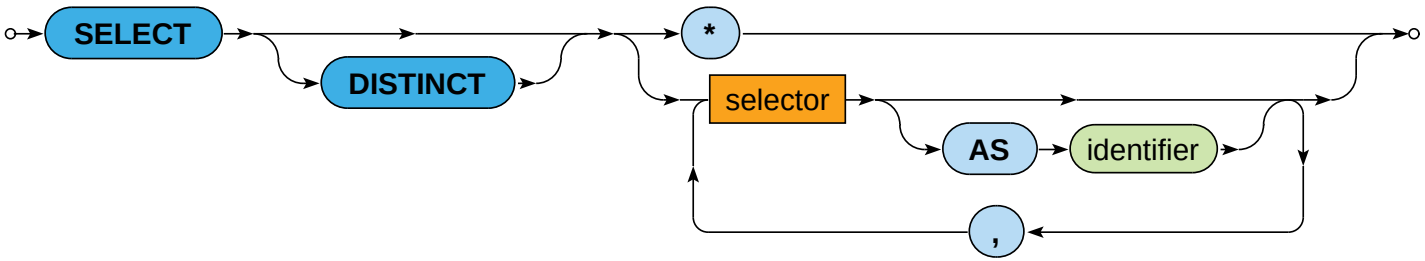
WHERE clause: **relations**

- **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

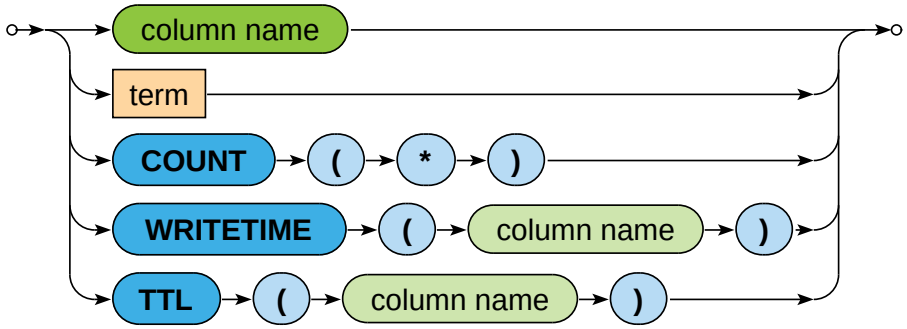
- Defines **columns or values to be included in the result**
  - ∗ = all the table columns
  - Aliases can be defined using `AS`



- **DISTINCT** – duplicate rows are removed

Selection

SELECT clause: **selectors**

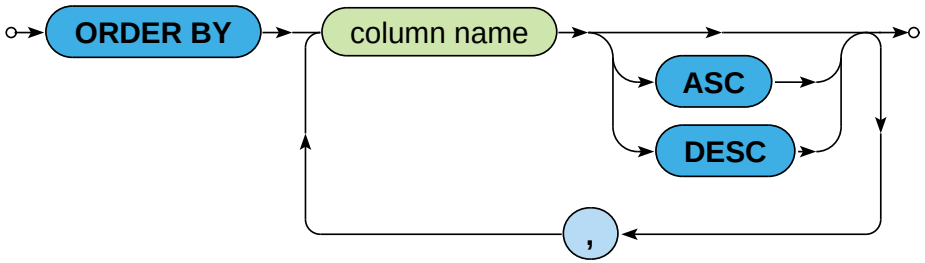


- **COUNT(*)**
  - Number of all the rows in a group (see aggregation)
- **WRITETIME** and **TTL**
  - Selects modification timestamp / remaining time-to-live of a given column
  - Cannot be used on collections and their elements
  - Cannot be used in other clauses (e.g. WHERE)

Selection

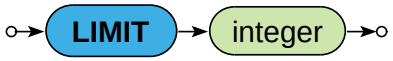
ORDER BY clause

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



LIMIT clause

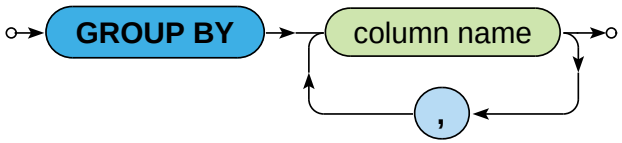
- **Limits the number of rows** returned in the query result



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

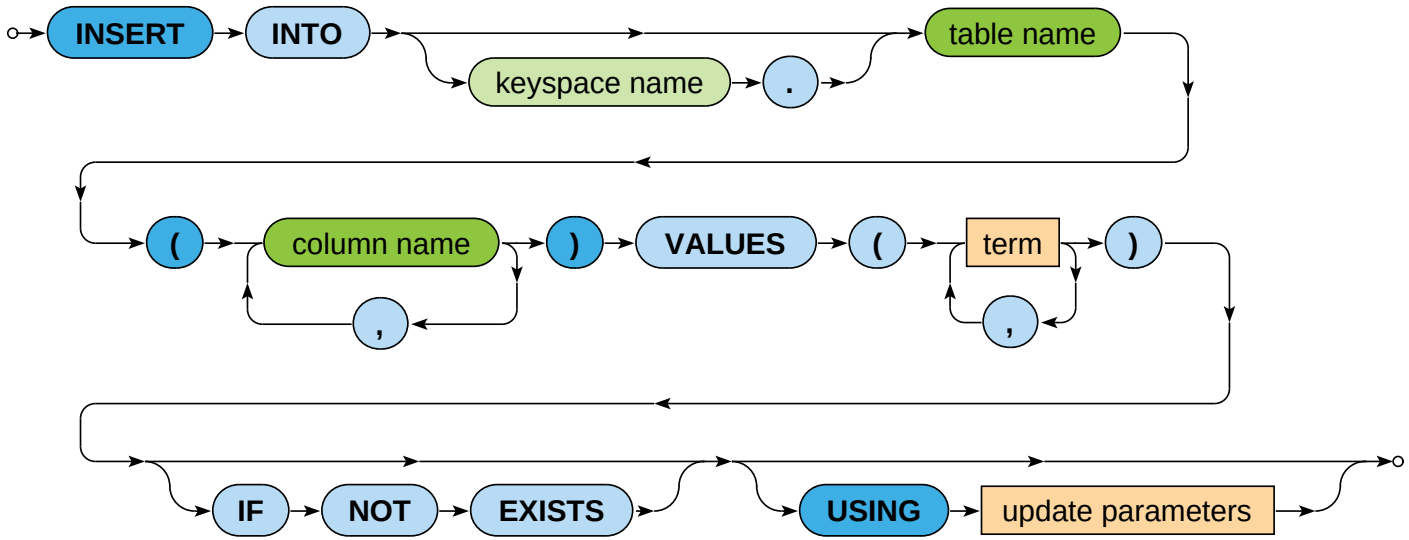
ALLOW FILTERING modifier

- 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

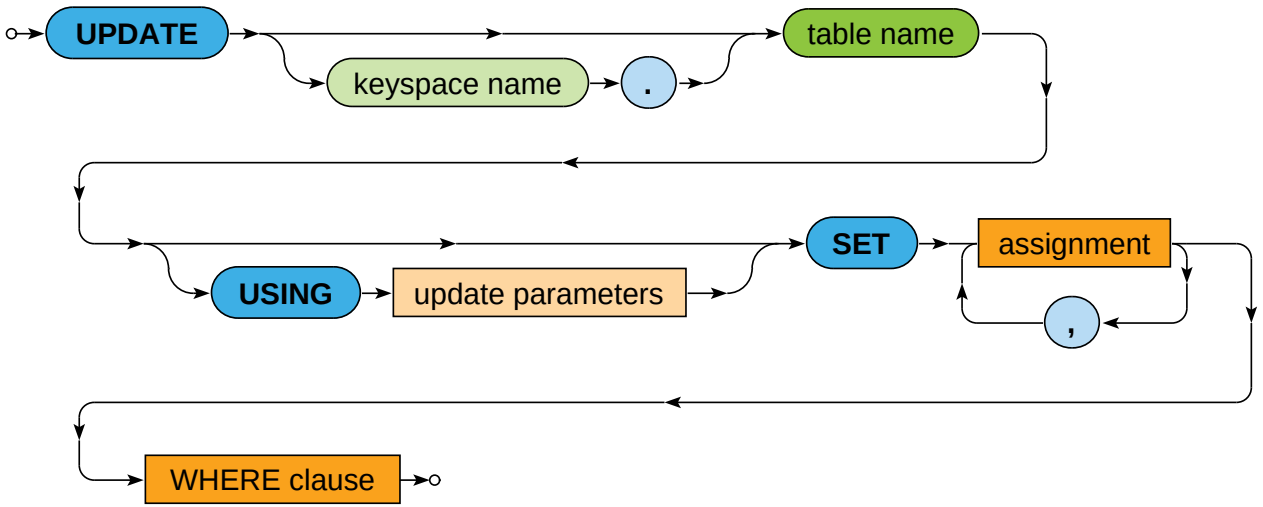
Example

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

Updates

UPDATE statement

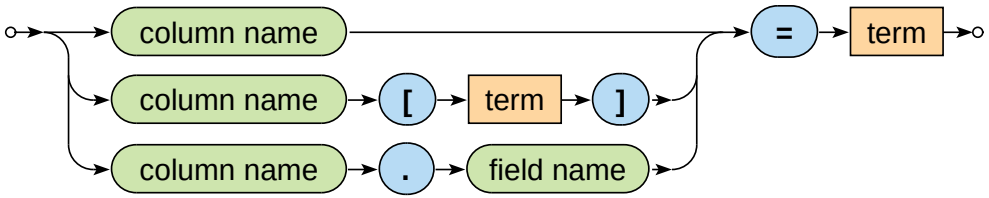
- **Updates existing rows** within a given table
  - When a row with a given primary key does not yet exist, it is inserted
- At least all primary key columns must be specified in the WHERE clause



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
    - Items of lists are numbered starting with 0
  - 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',
  properties.length = 99
WHERE id = 'vratnelahve'
```

Updates

Examples: modification of collection elements

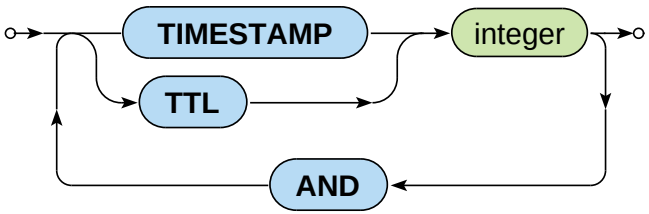
```
UPDATE movies
SET
  actors = actors + { 'vilhelmova': 'Helenka' },
  genres = [ 'drama' ] + genres,
  countries = countries + { 'SK' }
WHERE id = 'vratnelahve'
```

```
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

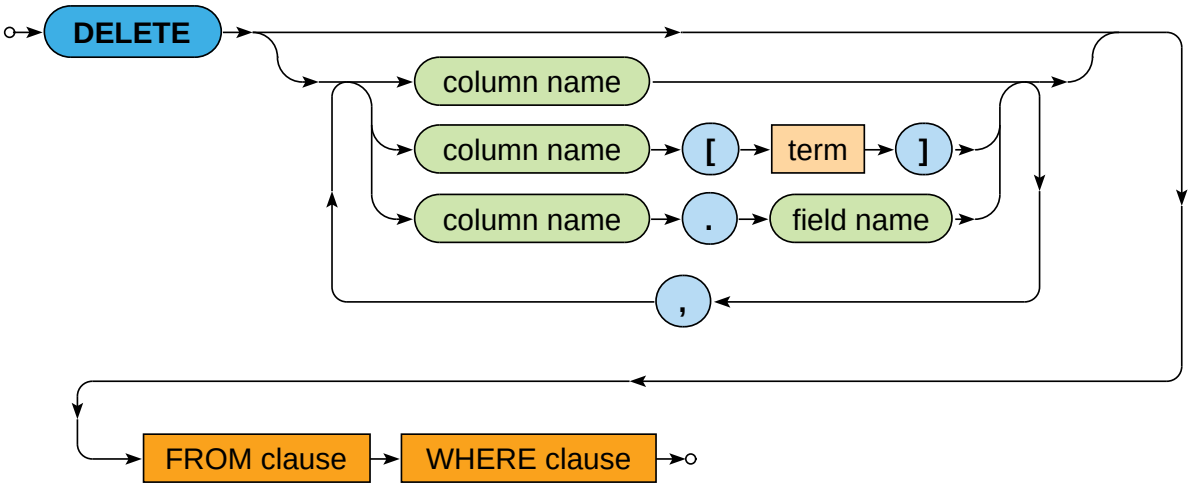


- Only newly inserted / updated values are really affected

Deletions

DELETE statement

- **Removes the matching rows** /
  Preserves these rows but **removes the selected columns** /
  Preserves these columns but **removes elements of collections** or **fields of UDT values**



Lecture Conclusion

Cassandra

- **Wide column store**

Cassandra query language

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