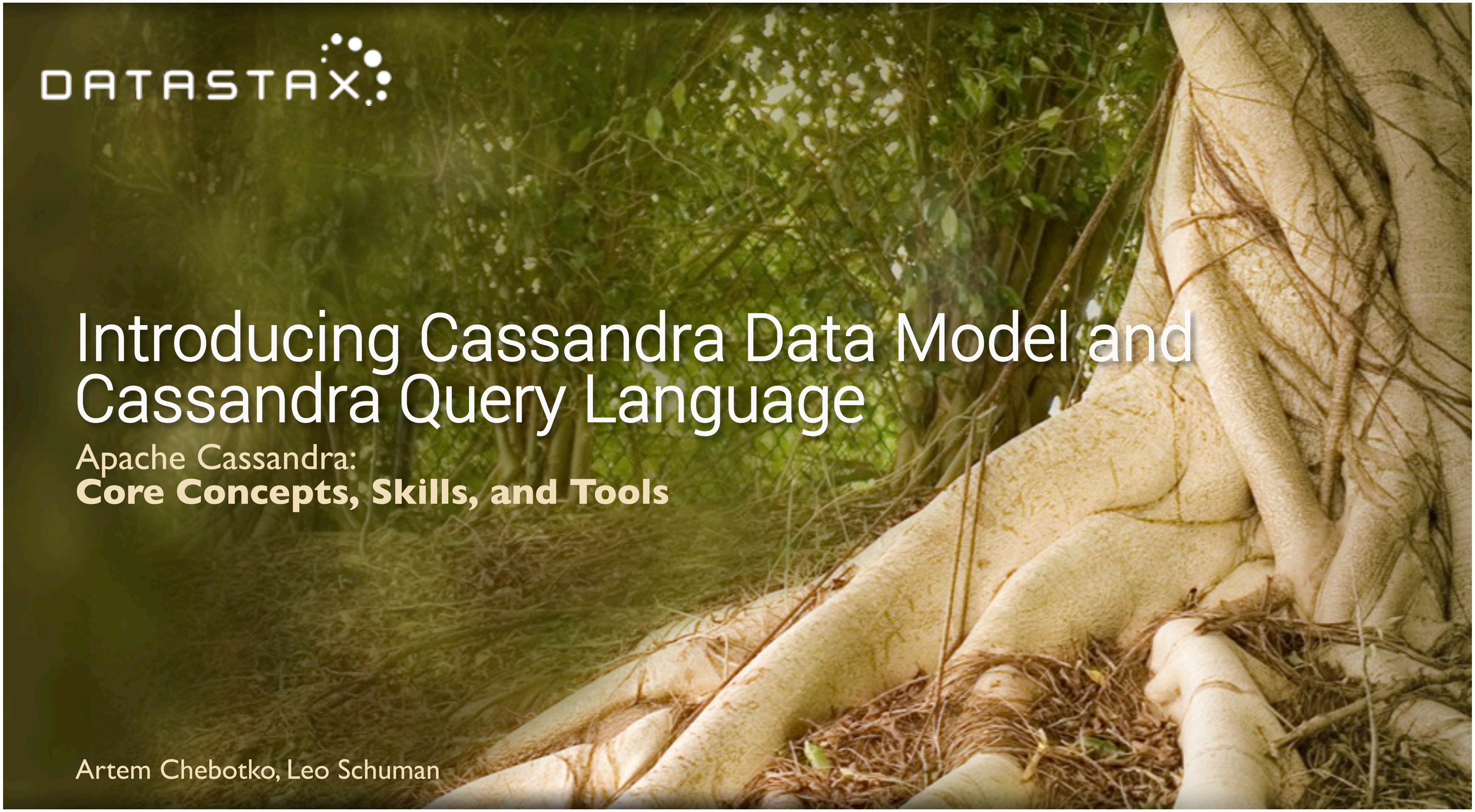


Introducing Cassandra Data Model and Cassandra Query Language

Apache Cassandra:
Core Concepts, Skills, and Tools

Artem Chebotko, Leo Schuman

April 8, 2014

Learning Objectives

- **Understand the Cassandra data model**
- Introduce *cqlsh* (optional)
- Understand and use the DDL subset of CQL
- Introduce *DevCenter*
- Understand and use the DML subset of CQL
- Understand basics of data modeling (optional)

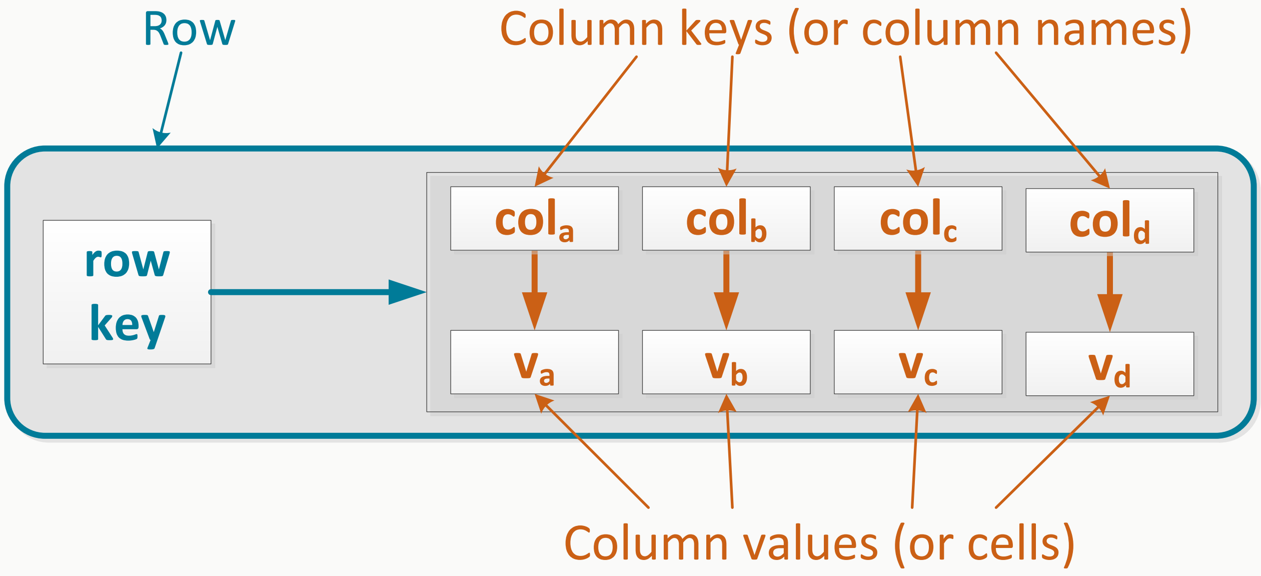
What are the essential constituents of the Cassandra data model?

- The Cassandra data model defines
  1. *Column family* as a way to store and organize data
  2. *Table* as a two-dimensional view of a multi-dimensional *column family*
  3. Operations on tables using the Cassandra Query Language (CQL)

- We cover these three constituents in the order they are listed
  - Understanding *column families* is a prerequisite to understanding *tables*
  - Understanding *tables* is a prerequisite to understanding operations

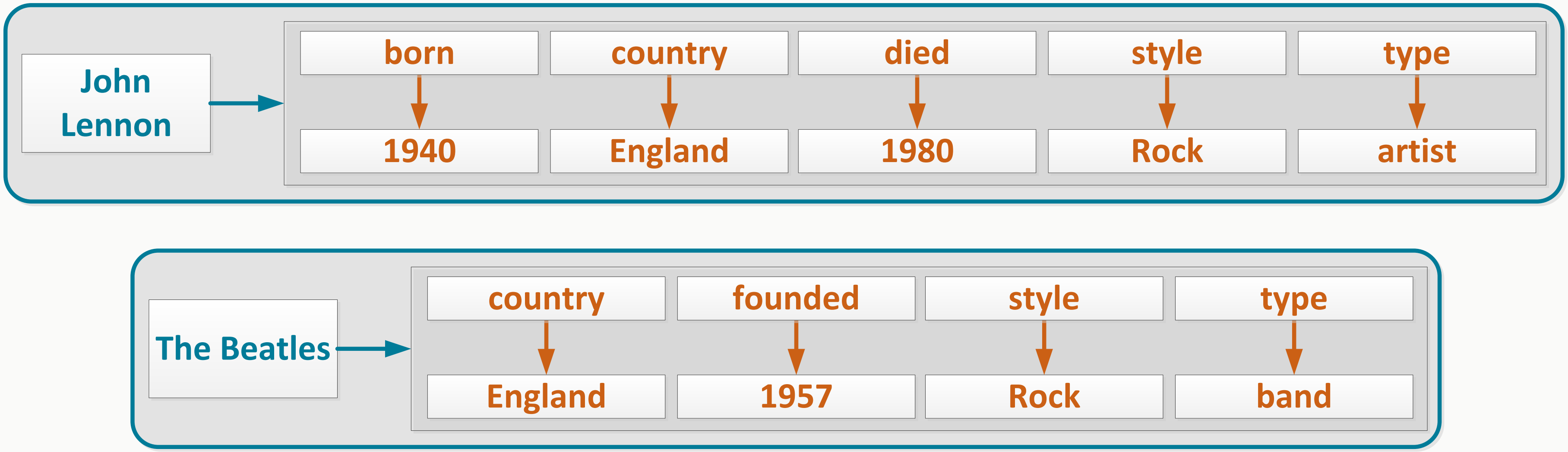
What are row, row key, column key, and column value?

- *Row* is the smallest unit that stores related data in Cassandra
  - Rows – individual rows constitute a *column family*
  - Row key – uniquely identifies a *row* in a *column family*
  - Row – stores pairs of *column keys* and *column values*
  - Column key – uniquely identifies a *column value* in a *row*
  - Column value – stores one value or a *collection* of values



What are row, row key, column key, and column value?

- Sample rows that describe an artist and a band
  - *Column keys* are inherently sorted



John Lennon

born	country	died	style	type
1940	England	1980	Rock	artist

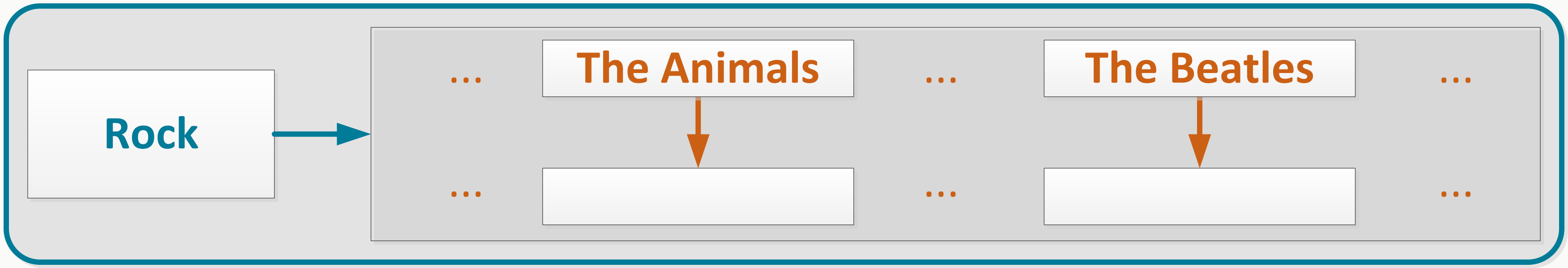
The Beatles

country	founded	style	type
England	1957	Rock	band

- A *row* can be retrieved if its *row key* is known
- A *column value* can be retrieved if its *row key* and *column key* are known

What is a wide row?

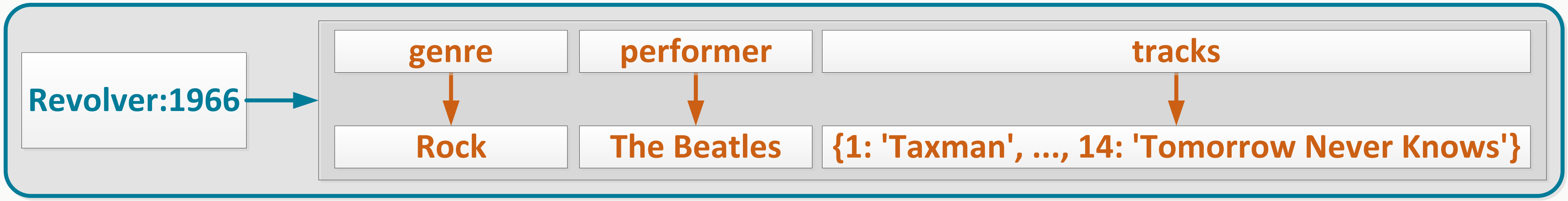
- Rows may be described as "skinny" or "wide"
  - Skinny row – has a fixed, relatively small number of *column keys*
    - Previous examples were skinny rows
  - Wide row – has a relatively large number of *column keys* (hundreds or thousands); this number may increase as new data values are inserted
    - For example, a row that stores all bands of the same style
    - The number of such bands will increase as new bands are formed



- Note that column values do not exist in this example
  - The column key – in this case a band name – stores all the data desired
  - Could have stored the number of albums, or year founded, etc., as column values

What are composite row key and composite column key?

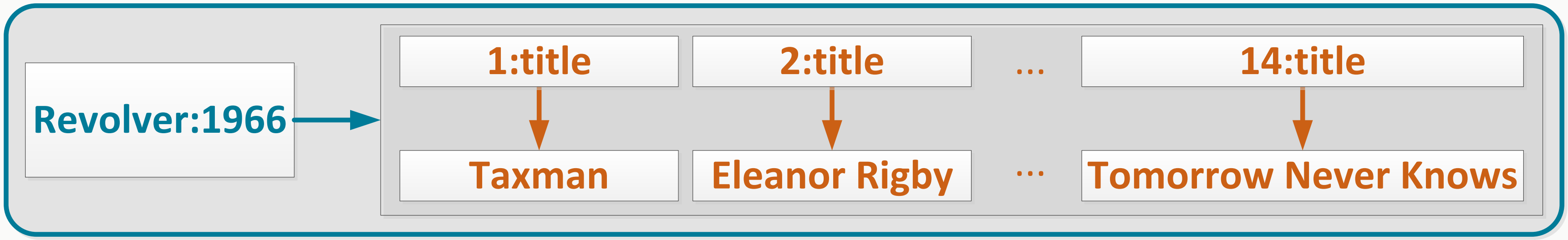
- Composite row key – multiple components separated by colon



Revolver:1966

genre	performer	tracks
Rock	The Beatles	{1: 'Taxman', ..., 14: 'Tomorrow Never Knows'}

  - 'Revolver' and 1966 are the album title and year
  - 'tracks' value is a collection (map)
- Composite column key – multiple components separated by colon
  - Composite column keys are sorted by each component



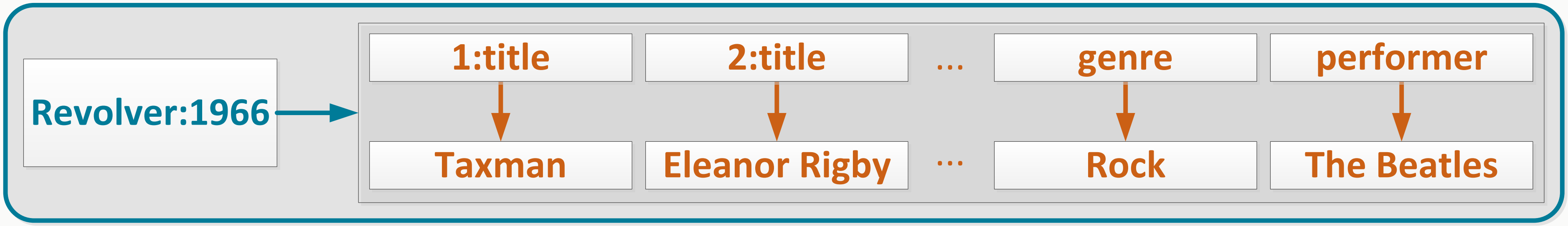
Revolver:1966

1:title	2:title	…	14:title
Taxman	Eleanor Rigby	…	Tomorrow Never Knows

  - 1,2, …, 14 are track numbers; 'title' is metadata
    - We could have stored actual title as components of composite column keys: 1:Taxman, 2:Eleanor Rigby, …, 14:Tomorrow Never Knows

Can simple and composite column keys co-exist in the same row?

- Row can contain both simple and composite column keys

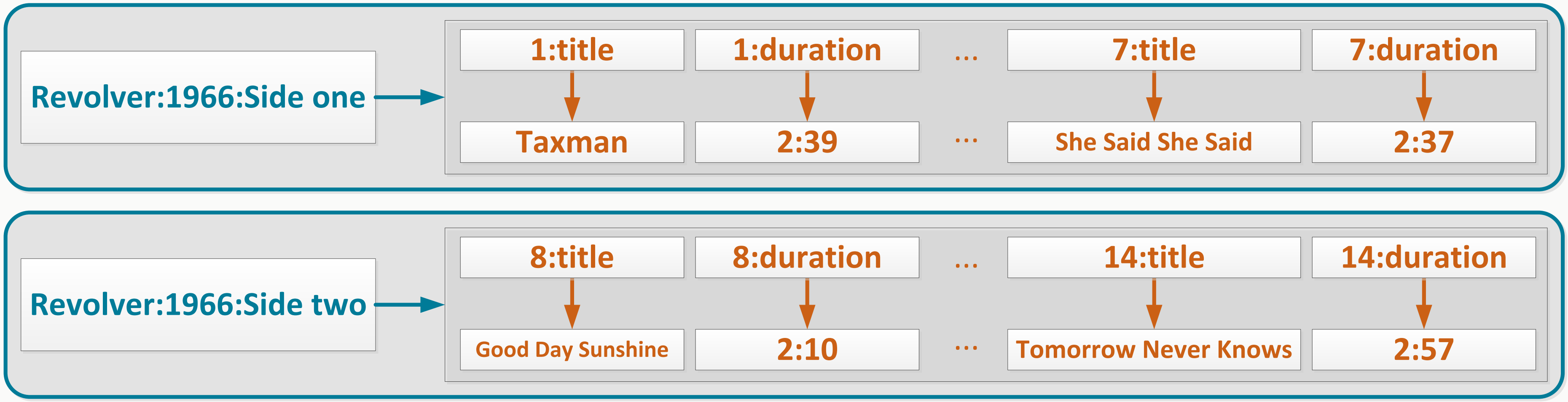


Revolver:1966	1:title	2:title	…	genre	performer
	Taxman	Eleanor Rigby	…	Rock	The Beatles

  - 'genre' and 'performer' are simple column keys
  - '1:title', '2:title', … are composite column keys

What components of a row can store useful values?

- Any component of a row can store *data* or *metadata*
  - Simple or composite row keys
  - Simple or composite column keys
  - Atomic or set-valued (collection) column values



Revolver:1966:Side one →

1:title	1:duration	…	7:title	7:duration
Taxman	2:39	…	She Said She Said	2:37

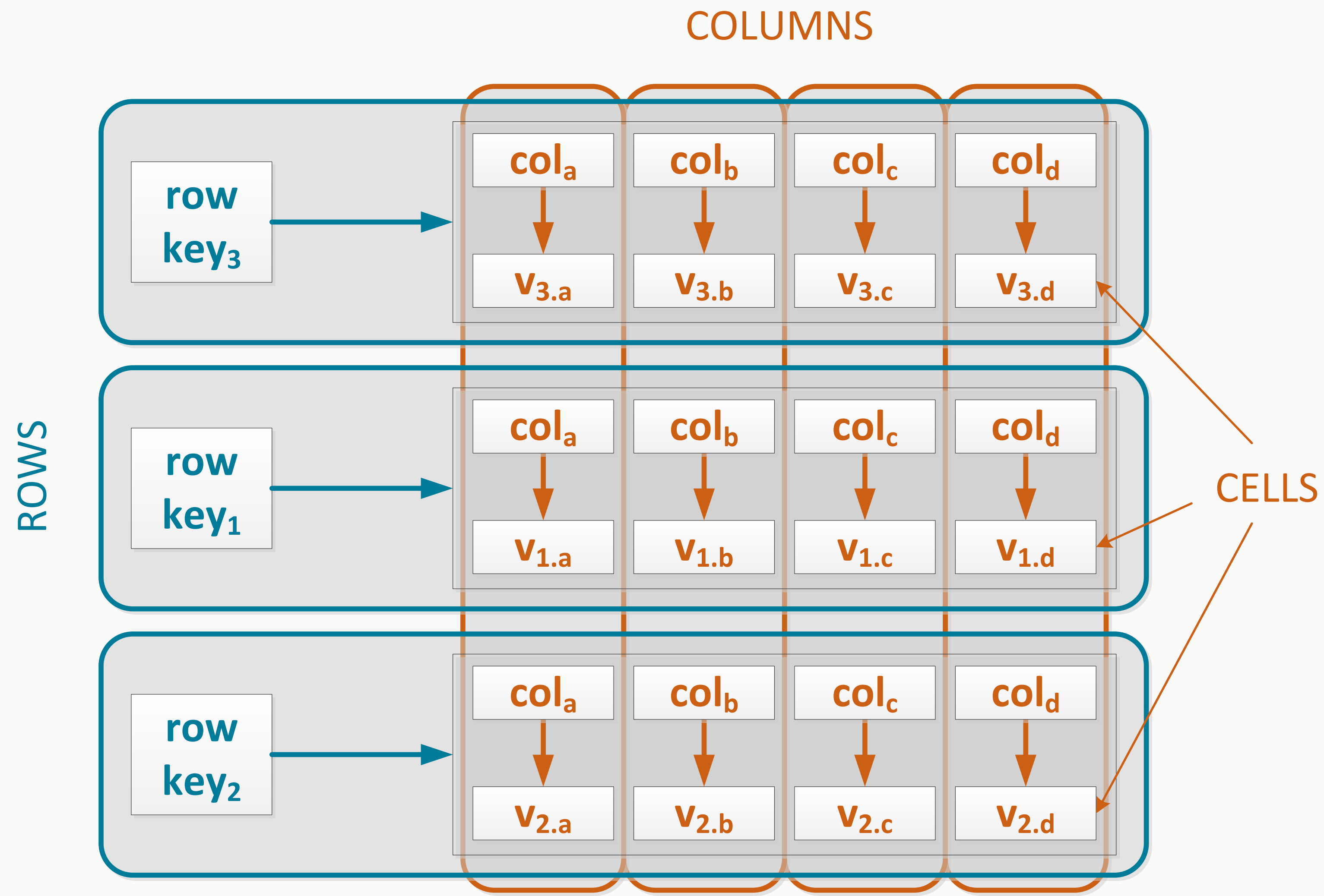
Revolver:1966:Side two →

8:title	8:duration	…	14:title	14:duration
Good Day Sunshine	2:10	…	Tomorrow Never Knows	2:57

- Metadata: 'Side one', 'Side two', 'title', 'duration'
- Data: everything else ('Revolver', '1966', 'She Said She Said', etc.)

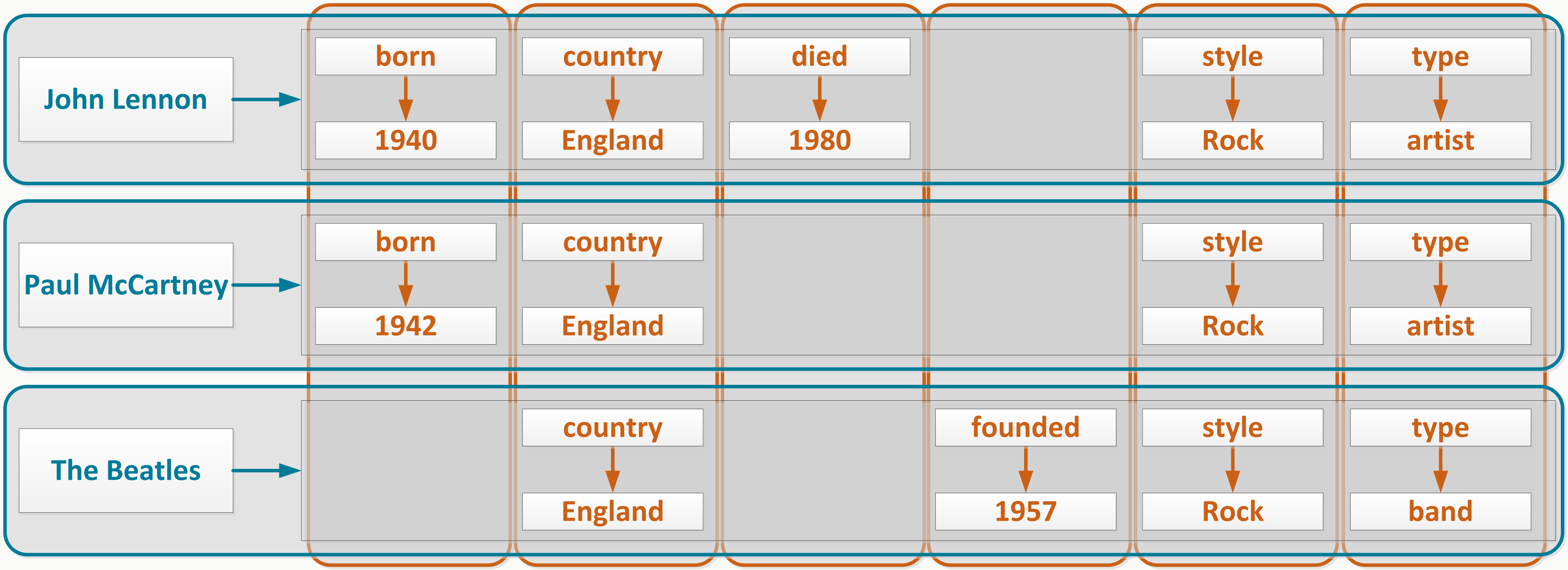
What is a column family?

- Column family – set of rows with a similar structure


COLUMNS
ROWS
row key$_3$
col$_a$ col$_b$ col$_c$ col$_d$
v$_{3.a}$ v$_{3.b}$ v$_{3.c}$ v$_{3.d}$
row key$_1$
col$_a$ col$_b$ col$_c$ col$_d$
v$_{1.a}$ v$_{1.b}$ v$_{1.c}$ v$_{1.d}$
row key$_2$
col$_a$ col$_b$ col$_c$ col$_d$
v$_{2.a}$ v$_{2.b}$ v$_{2.c}$ v$_{2.d}$
CELLS

What is a column family?

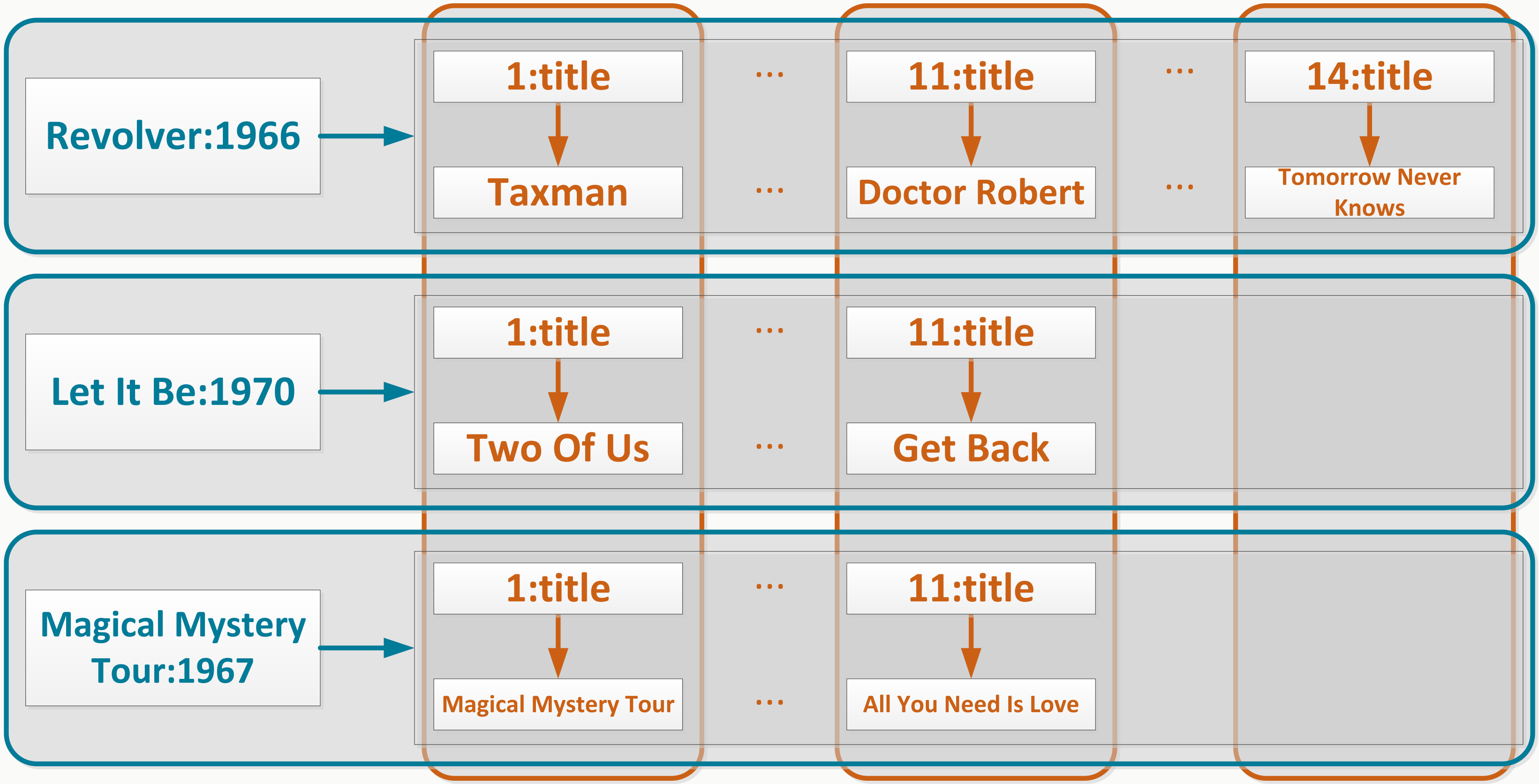
- Distributed
- Sparse
  - Column family that stores data about artists and bands



John Lennon	→	born → 1940	country → England	died → 1980		style → Rock	type → artist
Paul McCartney	→	born → 1942	country → England			style → Rock	type → artist
The Beatles	→		country → England		founded → 1957	style → Rock	type → band

What is a column family?

- Sorted columns
- Multidimensional
  - Column family that stores albums and their tracks



Revolver:1966

1:title

Taxman

…

11:title

Doctor Robert

…

14:title

Tomorrow Never Knows

Let It Be:1970

1:title

Two Of Us

…

11:title

Get Back

Magical Mystery Tour:1967

1:title

Magical Mystery Tour

…

11:title

All You Need Is Love

What are the size limitations for a column family?

- Size of a *column family* is only limited to the size of a *cluster*
  - Linear scalability
  - *Rows* are distributed among the *nodes* in a *cluster*

- *Column family* component size considerations
  - Data from a one row must fit on one node
    - Data from any given row never spans multiple nodes
  - Maximum columns per row is 2 billion
    - In practice – Up to 100 thousand
  - Maximum data size per cell (column value) is 2 GB
    - In practice – Up to 100 MB

Exercise 1: Model sample data as column families

DATASTAX

What is a CQL table and how is it related to a column family?

- A *CQL table* is a *column family*
  - CQL tables provide two-dimensional views of a column family, which contains potentially multi-dimensional data, due to composite keys and collections
- *CQL table* and *column family* are largely interchangeable terms
  - Not surprising when you recall *tables* and *relations*, *columns* and *attributes*, *rows* and *tuples* in relational databases
- Supported by declarative language Cassandra Query Language
  - Data Definition Language, subset of CQL
  - SQL-like syntax, but with somewhat different semantics
  - Convenient for defining and expressing Cassandra database schemas

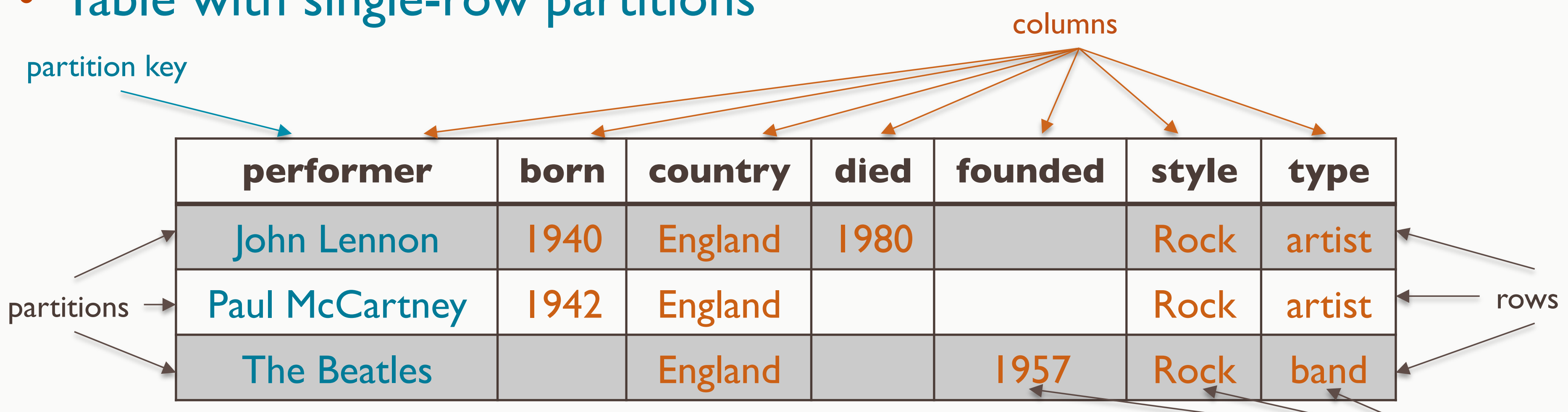
What is CQL table and how is it related to column family?

- Cassandra 1.2+ relies on CQL schema, concepts, and terminology, though the older Thrift API remains available
  - Recall that CQL provides a two dimensional view of potentially multi-dimensional data

Table (CQL API terms)	**Column Family** (Thrift API terms)
Table is a set of *partitions*	*Column family* is a *set of rows*
Partition may be single or multiple row	*Row* may be skinny or wide
Partition key uniquely identifies a partition, and may be simple or composite	*Row key* uniquely identifies a row, and may be simple or composite
Column uniquely identifies a cell in a partition, and may be regular or clustering	*Column key* uniquely identies a cell in a row, and may be simple or composite
Primary key is comprised of a partition key plus clustering columns, if any, and uniquely identifies a row in both its partition and table	

What are partition, partition key, row, column, and cell?

- Table with single-row partitions



partition key

columns

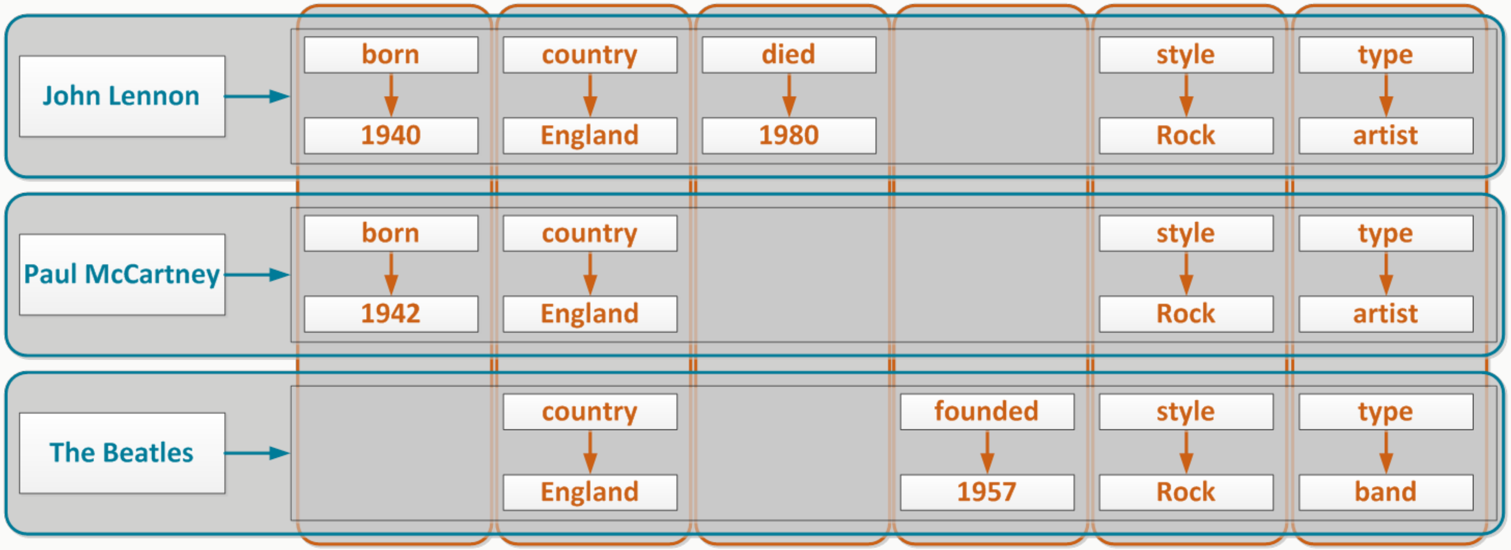
partitions

rows

cells

performer	born	country	died	founded	style	type
John Lennon	1940	England	1980		Rock	artist
Paul McCartney	1942	England			Rock	artist
The Beatles		England		1957	Rock	band

- Column family view



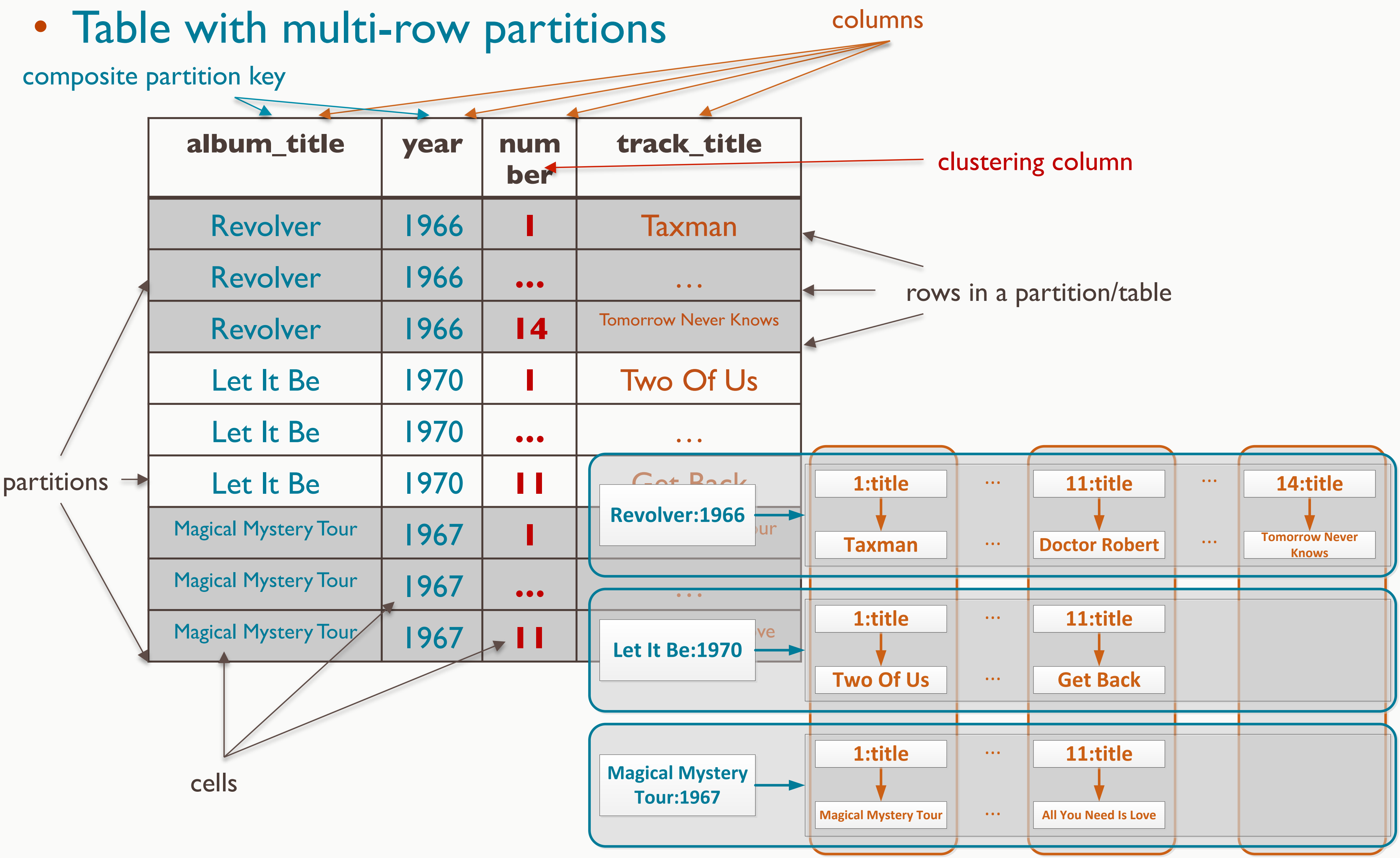
John Lennon →
born → 1940
country → England
died → 1980
style → Rock
type → artist

Paul McCartney →
born → 1942
country → England
style → Rock
type → artist

The Beatles →
country → England
founded → 1957
style → Rock
type → band

What are composite partition key and clustering column?

- Table with multi-row partitions



columns

composite partition key

clustering column

rows in a partition/table

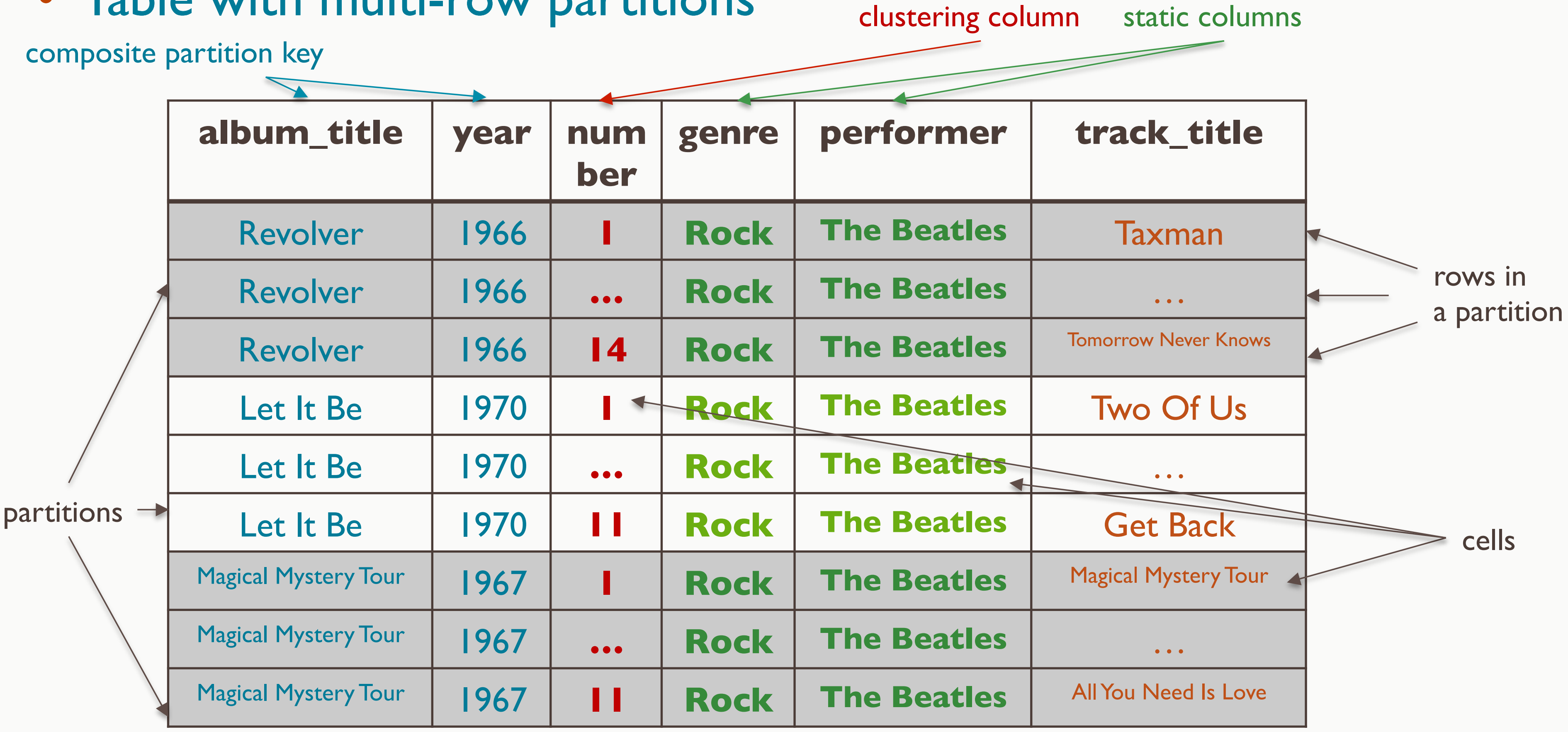
partitions

cells

album_title	year	number	track_title
Revolver	1966	1	Taxman
Revolver	1966	...	. . .
Revolver	1966	14	Tomorrow Never Knows
Let It Be	1970	1	Two Of Us
Let It Be	1970	...	. . .
Let It Be	1970	11	Get Back
Magical Mystery Tour	1967	1	ur
Magical Mystery Tour	1967	...	. . .
Magical Mystery Tour	1967	11	ve

What are static columns?

- Table with multi-row partitions



composite partition key

clustering column

static columns

rows in a partition

partitions

cells

album_title	year	number	genre	performer	track_title
Revolver	1966	1	Rock	The Beatles	Taxman
Revolver	1966	...	Rock	The Beatles	...
Revolver	1966	14	Rock	The Beatles	Tomorrow Never Knows
Let It Be	1970	1	Rock	The Beatles	Two Of Us
Let It Be	1970	...	Rock	The Beatles	...
Let It Be	1970	11	Rock	The Beatles	Get Back
Magical Mystery Tour	1967	1	Rock	The Beatles	Magical Mystery Tour
Magical Mystery Tour	1967	...	Rock	The Beatles	...
Magical Mystery Tour	1967	11	Rock	The Beatles	All You Need Is Love

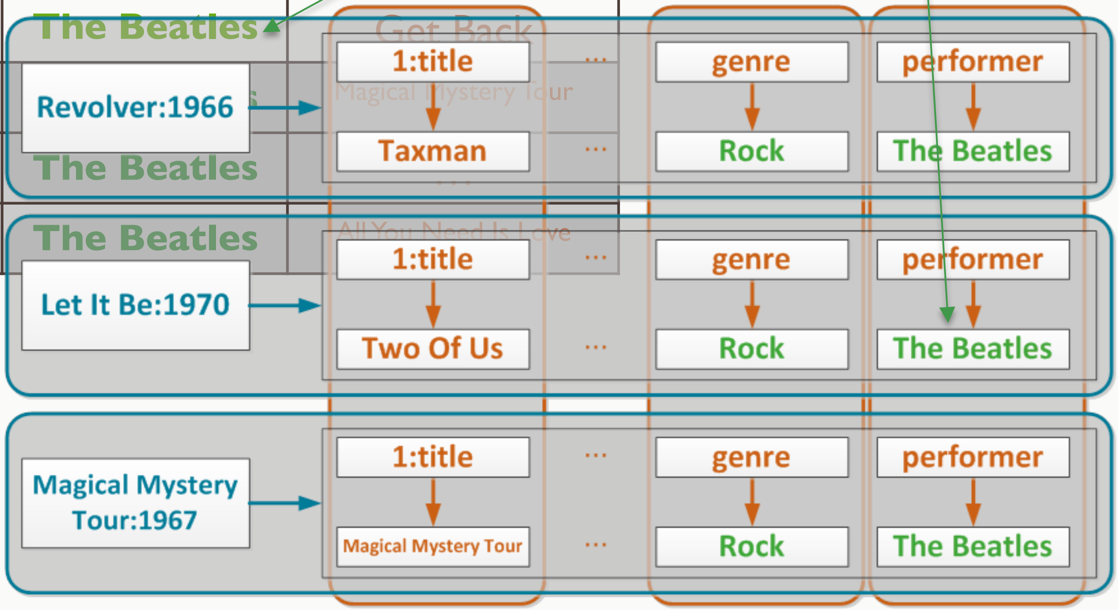
- Static column values are shared for all rows in a multi-row partition

What are static columns?

- Table with multi-row partitions

album_title	year	number	genre	performer	track_title
Revolver	1966	1	Rock	The Beatles	Taxman
Revolver	1966	...	Rock	The Beatles	...
Revolver	1966	14	Rock	The Beatles	Tomorrow Never Knows
Let It Be	1970	1	Rock	The Beatles	Two Of Us
Let It Be	1970	...	Rock	The Beatles	...
Let It Be	1970	11	Rock	The Beatles	Get Back
Magical Mystery Tour	1967	1	Rock	The Beatles	Magical Mystery Tour
Magical Mystery Tour	1967	...	Rock	The Beatles	...
Magical Mystery Tour	1967	11	Rock	The Beatles	All You Need Is Love

static column value



What is a primary key?

- Primary key uniquely identifies a row in a table
  - Simple or composite partition key and all clustering columns (if present)

performer	born	country	died	founded	style	type
John Lennon	1940	England	1980		Rock	artist
Paul McCartney	1942	England			Rock	artist
The Beatles		England		1957	Rock	band

- Primary key (table above)
  - performer
- Primary key (table below)
  - album, year, number
- Static columns cannot be part of a primary key

album_title	year	number	track_title
Revolver	1966	1	Taxman
Revolver	1966	...	…
Revolver	1966	14	Tomorrow Never Knows
Let It Be	1970	1	Two Of Us
Let It Be	1970	...	…
Let It Be	1970	11	Get Back
Magical Mystery Tour	1967	1	Magical Mystery Tour

What are collection columns?

- Multiple values can be stored in a column
  - Set – typed collection of unique values (e.g., genres)

```
{"Blues", "Jazz", "Rock"}
```

    - Ordered by values
    - No duplicates
  - List – typed collection of non-unique values (e.g., artists)

```
["Lennon", "Lennon", "McCartney"]
```

    - Ordered by position
    - Duplicates are allowed
  - Map – typed collection of key-value pairs (e.g., tracks)

```
{1:"Taxman", 2:"Eleanor Rigby", 3:"I'm Only Sleeping"}
```

    - Ordered by keys
    - Unique keys but not values

What are collection columns?

- Map example
  - Collection column *tracks* holds a *map* of album tracks

title	year	genre	performer	tracks
Revolver	1966	Rock	The Beatles	{1: 'Taxman', 2: 'Eleanor Rigby', 3: 'I'm Only Sleeping', 4: 'Love You To', …, 14: 'Tomorrow Never Knows'}
Let It Be	1970	Rock	The Beatles	{1: 'Two Of Us', 2: 'I Dig A Pony', 3: 'Across The Universe', 4: 'Let It Be', 5: 'Maggie Mae', …, 11: 'Get Back'}
Magical Mystery Tour	1967	Rock	The Beatles	{1: 'Magical Mystery Tour', 2: 'The Fool On The Hill', 3: 'Flying', 4: 'Blue Jay Way', …, 11: 'All You Need Is Love'}

Exercise 2: Represent column families as tables

Learning Objectives

- Understand the Cassandra data model
- **Introduce *cqlsh* (optional)**
- Understand and use the DDL subset of CQL
- Introduce *DevCenter*
- Understand and use the DML subset of CQL
- Understand basics of data modeling (optional)

What is *cqlsh* and how do you launch it?

- Cassandra client with the command-line interface
  - Supports Cassandra Query Language statements
  - Supports *cqlsh* shell commands

- Launching on Linux

```
$ ./cqlsh [options] [host [port]]
```

- Launching on Windows

```
python cqlsh [options] [host [port]]
```

- Examples

```
$ ./cqlsh
```

```
$ ./cqlsh -u student -p cassandra 127.0.0.1 9160
```

What shell commands does *cqlsh* support?

Command	Description
`CAPTURE`	Captures command output and appends it to a file
`CONSISTENCY`	Shows the current consistency level, or given a level, sets it
`COPY`	Imports and exports CSV (comma-separated values) data
`DESCRIBE`	Provides information about a Cassandra cluster or data objects
`EXPAND`	Formats the output of a query vertically
`EXIT or QUIT`	Terminates cqlsh
`SHOW`	Shows the Cassandra version, host, or data type assumptions
`SOURCE`	Executes a file containing CQL statements
`TRACING`	Enables or disables request tracing

What shell commands does *cqlsh* support?

- CQL commands must be terminated with semi-colon
- SOURCE

```
SOURCE 'file'
```

```
SOURCE './myscript.cql';
```

- COPY

```
COPY table_name ( column, ...)
FROM ( 'file_name' | STDIN )
WITH option = 'value' AND ... ;
```

```
COPY table_name ( column , ... )
TO ( 'file_name' | STDOUT )
WITH option = 'value' AND ... ;
```

```
COPY performers_by_style (style, name)
FROM ‘./performers_by_style.csv'
WITH HEADER = 'true';
```

What shell commands does *cqlsh* support?

- DESCRIBE

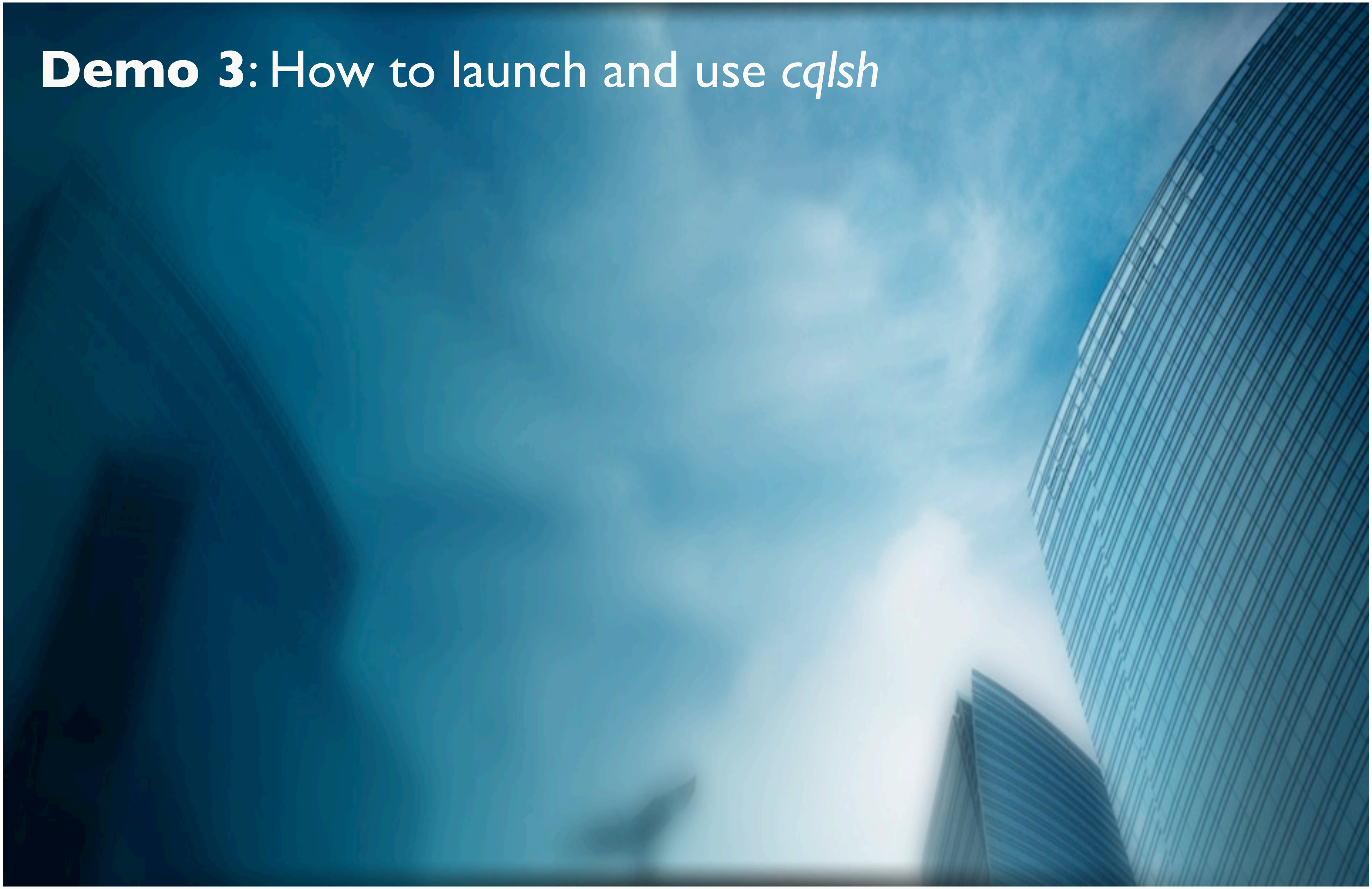
```
DESCRIBE CLUSTER | SCHEMA | KEYSPACES |
KEYSPACE keyspace_name | TABLES | TABLE table_name
```

```
DESCRIBE TABLE album;
```

- EXIT

```
EXIT | QUIT;
```

Demo 3: How to launch and use *cqlsh*



DATASTAX

Learning Objectives

- Understand the Cassandra data model
- Introduce *cqlsh* (optional)
- **Understand and use the DDL subset of CQL**
- Introduce *DevCenter*
- Understand and use the DML subset of CQL
- Understand basics of data modeling (optional)

What is a keyspace or schema?

- Keyspace – a top-level namespace for a CQL table schema
  - Defines the replication strategy for a set of tables
    - Keyspace per application is a good idea
  - Data objects (e.g., tables) belong to a single keyspace

- Replication strategy – the number and pattern by which partitions are copied among nodes in a cluster
  - Two strategies available
    - Simple Strategy (used for prototyping)
    - Network Topology Strategy (production)

How to create, use and drop keyspaces/schemas?

- To create a keyspace

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

- To assign the working default keyspace for a *cqlsh* session

```
USE musicdb;
```

- To delete a keyspace and all internal data objects

```
DROP KEYSPACE musicdb;
```

What is the syntax of the CREATE TABLE statement?

- The CQL below creates a table in the current keyspace

Primary key declared inline

```
CREATE TABLE performer (
  name VARCHAR PRIMARY KEY,
  type VARCHAR,
  country VARCHAR,
  style VARCHAR,
  founded INT,
  born INT,
  died INT
);
```

Primary key declared in separate clause

```
CREATE TABLE performer (
  name VARCHAR,
  type VARCHAR,
  country VARCHAR,
  style VARCHAR,
  founded INT,
  born INT,
  died INT,
  PRIMARY KEY (name)
);
```

How are primary key, partition key, and clustering columns defined?

- Simple partition key, no clustering columns

```
PRIMARY KEY ( partition_key_column )
```

- Composite partition key, no clustering columns

```
PRIMARY KEY ( ( partition_key_col1, …, partition_key_colN ) )
```

- Simple partition key and clustering columns

```
PRIMARY KEY ( partition_key_column,
              clustering_column1, …, clustering_columnM )
```

- Composite partition key and clustering columns

```
PRIMARY KEY ( ( partition_key_col1, …, partition_key_colN ),
               clustering_column1, …, clustering_columnM )
```

How are primary key, partition key, static and clustering columns defined?

- Example

Can find all performers and albums for a given track title

```
CREATE TABLE albums_by_track (
  track_title VARCHAR,
  performer VARCHAR,
  year INT,
  album_title VARCHAR,
  PRIMARY KEY
  (track_title, performer,
   year, album_title)
);
```

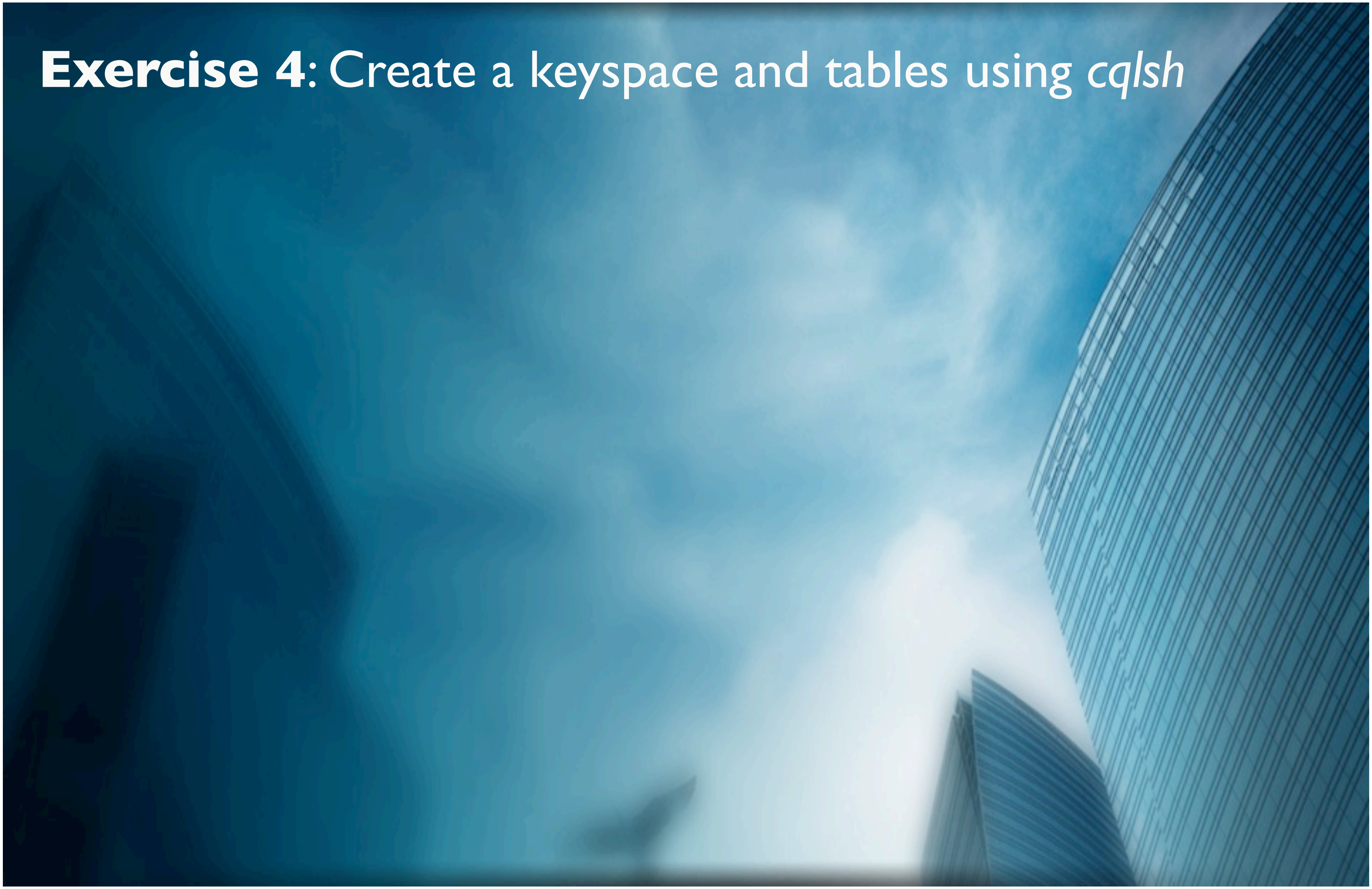
Can find a performer, genre, and all track numbers and titles for a given album title and year

```
CREATE TABLE tracks_by_album (
  album_title VARCHAR,
  year INT,
  performer VARCHAR STATIC,
  genre VARCHAR STATIC,
  number INT,
  track_title VARCHAR,
  PRIMARY KEY
  ((album_title, year),
    number)
);
```

What CQL data types are available?

CQL Type	Constants	Description
ASCII	strings	US-ASCII character string
BIGINT	integers	64-bit signed long
BLOB	blobs	Arbitrary bytes (no validation), expressed as hexadecimal
BOOLEAN	booleans	true or false
COUNTER	integers	Distributed counter value (64-bit long)
DECIMAL	integers, floats	Variable-precision decimal
DOUBLE	integers	64-bit IEEE-754 floating point
FLOAT	integers, floats	32-bit IEEE-754 floating point
INET	strings	IP address string in IPv4 or IPv6 format*
INT	integers	32-bit signed integer
LIST	n/a	A collection of one or more ordered elements
MAP	n/a	A JSON-style array of literals: { literal : literal, literal : literal ... }
SET	n/a	A collection of one or more elements
TEXT	strings	UTF-8 encoded string
TIMESTAMP	integers, strings	Date plus time, encoded as 8 bytes since epoch
TUPLE	n/a	Up to 32k fields
UUID	uuids	A UUID in standard UUID format
TIMEUUID	uuids	Type 1 UUID only (CQL 3)
VARCHAR	strings	UTF-8 encoded string
VARINT	integers	Arbitrary-precision integer

Exercise 4: Create a keyspace and tables using *cqlsh*



What are UUID and TIMEUUID for?

- UUID and TIMEUUID are universally unique identifiers
  - Generated programmatically
  - Format

    ```
    hex{8}-hex{4}-hex{4}-hex{4}-hex{12}
    52b11d6d-16e2-4ee2-b2a9-5ef1e9589328
    ```

  - Used to assign conflict-free (unique) identifiers to data objects
  - Numeric range so vast that duplication is statistically all but impossible
- UUID data type supports Version 4 UUIDs
  - Randomly generated sequence of 32 hex digits separated by dashes
  - 52b11d6d-16e2-4ee2-b2a9-5ef1e9589328

What are UUID and TIMEUUID for?

- TIMEUUID data type supports Version 1 UUIDs
  - Embeds a time value within a UUID
  - Generated using time (60 bits), a clock sequence number (14 bits), and MAC address (48 bits)

    `1be43390-9fe4-11e3-8d05-425861b86ab6`

    - CQL function `now()` generates a new TIMEUUID
  - Time can be extracted from TIMEUUID
    - CQL function `dateOf()` extracts the embedded timestamp as a date
  - TIMEUUID values in clustering columns or in column names are ordered based on time
    - DESC order on TIMEUUID lists most recent data first

What are UUID and TIMEUUID for?

- Example
  - Users are identified by UUID
  - User activities (i.e., rating a track) are identified by TIMEUUID
    - A user may rate the same track multiple times
    - Activities are ordered by the time component of TIMEUUID

```
CREATE TABLE track_ratings_by_user (
  user UUID,
  activity TIMEUUID,
  rating INT,
  album_title VARCHAR,
  album_year INT,
  track_title VARCHAR,
  PRIMARY KEY (user, activity)
) WITH CLUSTERING ORDER BY (activity DESC);
```

What is TIMESTAMP for?

- TIMESTAMP holds date and time
  - 64-bit integer representing a number of milliseconds since January 1 1970 at 00:00:00 GMT
  - Entered as
    - 64-bit integer
    - String literal in the ISO 8601 format
      - 1979-12-18 08:12:51-0400
      - 2014-02-27
      - Other variations are allowed
  - Displayed in *cqlsh* as
    - yyyy-mm-dd HH:mm:ssZ

What are special properties of the COUNTER data type?

- Cassandra supports distributed counters
  - Useful for tracking a count
  - Counter column stores a number that can only be updated
    - Incremented or decremented
    - Cannot assign an initial value to a counter (initial value is 0)
  - Counter column cannot be part of a primary key
  - If a table has a counter column, all non-counter columns must be part of a primary key

```
CREATE TABLE ratings_by_track (
  album_title VARCHAR,  album_year INT,  track_title VARCHAR,
  num_ratings COUNTER,
  sum_ratings COUNTER,
  PRIMARY KEY (album_title, album_year, track_title)
);
```

What are special properties of the COUNTER data type?

- Performance considerations
  - Read is as efficient as for non-counter columns
  - Update is fast but slightly slower than an update for non-counter columns
    - A read is required before a write can be performed
- Accuracy considerations
  - If a counter update is timed out, a client application cannot simply retry a "failed" counter update as the timed-out update may have been persisted
    - Counter update is not an idempotent operation
    - Running an increment twice is not the same as running it once

What is the purpose of the CLUSTERING ORDER BY clause?

- CLUSTERING ORDER BY defines how data values in clustering columns are ordered (ASC or DESC) in a table
  - ASC is the default order for all clustering columns
  - When retrieving data, the default order or the order specified by a CLUSTERING ORDER BY clause is used
    - The order can be reversed in a query using the ORDER BY clause

```
CREATE TABLE albums_by_genre (
  genre VARCHAR,
  performer VARCHAR,
  year INT,
  title VARCHAR,
  PRIMARY KEY (genre, performer, year, title)
) WITH CLUSTERING ORDER BY
  (performer ASC, year DESC, title ASC);
```

Exercise 5: Create tables using UUID, TIMEUUID, and COUNTER columns

What is the syntax of the ALTER TABLE statement?

- ALTER TABLE manipulates the table metadata
  - Adding a column

```
ALTER TABLE album ADD cover_image VARCHAR;
```

  - Changing a column data type

```
ALTER TABLE album ALTER cover_image TYPE BLOB;
```

    - Types must be compatible
    - Clustering and indexed columns are not supported

  - Dropping a column

```
ALTER TABLE album DROP cover_image;
```

    - PRIMARY KEY columns are not supported

What is the syntax of the DROP TABLE statement?

- DROP TABLE removes a table (all data in the table is lost)

```
DROP TABLE album;
```

What are collection columns for?

- Collection columns are multi-valued columns
  - Designed to store discrete sets of data (e.g., tags for a blog post)
    - A collection is retrieved in its entirety
  - 64,000 - maximum number of elements in a collection
    - In practice – dozens or hundreds
  - 64 KB - maximum size of each collection element
    - In practice – much smaller
  - Collection columns
    - cannot be part of a primary key
    - cannot be part of a partition key
    - cannot be used as a clustering column
    - cannot nest inside of another collection

How are collection columns defined?

- Set – typed collection of unique values

```
keywords SET<VARCHAR>
```

  - Ordered by values
  - No duplicates

- List – typed collection of non-unique values

```
songwriters LIST<VARCHAR>
```

  - Ordered by position
  - Duplicates are allowed

- Map – typed collection of key-value pairs

```
tracks MAP<INT,VARCHAR>
```

  - Ordered by keys
  - Unique keys but not values

What is a user-defined type?

- User-defined types group related fields of information
    - Represents related data in a single table, instead of multiple, separate tables
    - Uses any data type, including collections and other user-defined types
    - Reserved words cannot be used as a name for a user-defined type
        - byte
        - smallint
        - complex
        - enum
        - date
        - interval
        - macaddr
        - bitstring

```
CREATE TYPE track (
  album_title VARCHAR,
  album_year INT,
  track_title VARCHAR,
);
```

What is a user-defined type?

- Table columns can be user-defined types
  - Requires the use of the *frozen* keyword in C* 2.1
  - A user-defined type can be used as a data type for a collection

```
CREATE TABLE musicdb.track_ratings_by_user (
  user UUID,
  activity TIMEUUID,
  rating INT,
  song frozen <track>,
PRIMARY KEY (user, activity)
) WITH CLUSTERING ORDER BY (activity DESC);
```

What is the syntax of the ALTER TYPE statement?

- ALTER TYPE can change a user-defined type
  - Change the type of a field
    - Types must be compatible

```
ALTER TYPE track ALTER album_title TYPE BLOB;
```

  - Add a field to a type

```
ALTER TYPE track ADD track_number INT;
```

  - Rename a field of a type

```
ALTER TYPE track RENAME album_year TO year;
```

  - Rename a user-defined type

```
ALTER TYPE track RENAME TO song;
```

What is the syntax of the DROP TYPE statement?

- DROP TYPE removes a user-defined type
  - Cannot drop a user-defined type that is in use by a table or another type

```
DROP TYPE track;
```

What is a tuple?

- Tuples hold fixed-length sets of typed positional fields
  - Convenient alternative to creating a user-defined type
  - Accommodates up to 32768 fields, but generally only use a few
  - Useful when prototyping
  - Must use the frozen keyword in C* 2.1
  - Tuples can be nested in other tuples

```
CREATE TABLE user (
  id UUID PRIMARY KEY,
  email text,
  equalizer frozen<tuple<float,float,float,float,float,
                         float,float,float,float,float>>,
  name text,
  preferences set<text>
);
```

What is a secondary index?

- Tables are indexed on columns in a primary key
  - Search on a partition key is very efficient
  - Search on a partition key and clustering columns is very efficient
  - Search on other columns is not supported

- Secondary indexes
  - Can index additional columns to enable searching by those columns
    - one column per index
  - Cannot be created for
    - counter columns
    - static columns

How do you create and drop secondary indexes?

- To create a secondary index

```
CREATE TABLE performer (
  name VARCHAR,
  type VARCHAR,
  country VARCHAR,
  style VARCHAR,
  founded INT,
  born INT,
  died INT,
  PRIMARY KEY (name)
);

CREATE INDEX performer_style_key ON performer (style);
```

- To drop a secondary index

```
DROP INDEX performer_style_key;
```

When do you want to use a secondary index?

- Secondary indexes are for searching convenience
  - Use with low-cardinality columns
    - Columns that may contain a relatively small set of distinct values
      - For example, there are many artists but only a few dozen music styles
      - Allows searching for all artists for a specified style (a potentially expensive query because it may return a large result set)
  - Use with smaller datasets or when prototyping
- Do not use
  - On high-cardinality columns
  - On counter column tables
  - On a frequently updated or deleted columns
  - To look for a row in a large partition <u>unless</u> narrowly queried
    - e.g., search on both a partition key and an indexed column

Exercise 6: Add user-defined type, alter tables, add collection column, and add secondary indexes

Learning Objectives

- Understand the Cassandra data model
- Introduce *cqlsh* (optional)
- Understand and use the DDL subset of CQL
- **Introduce *DevCenter***
- Understand and use the DML subset of CQL
- Understand basics of data modeling (optional)

What is *DevCenter* and how do you launch it?

- Cassandra client with the GUI interface
  - IDE for developers and administrators
  - Supports Cassandra Query Language statements
  - Does not support *cqlsh* commands
    - SOURCE, COPY, DESCRIBE, etc.
- Launching on Linux

```
$ ./DevCenter
```

- Launching on Windows

```
DevCenter.exe
```

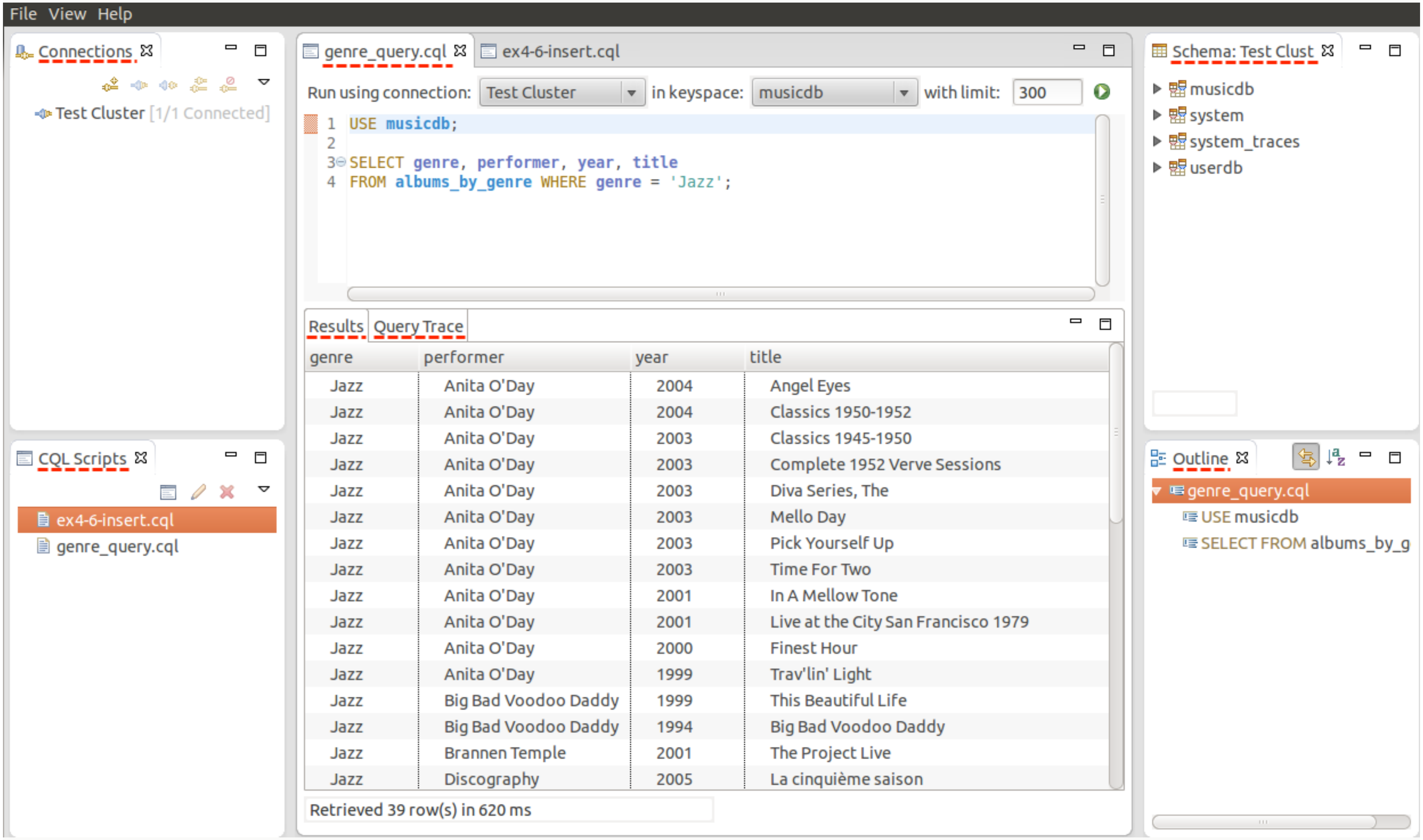
- Launching on Mac OS

```
DevCenter.app
```

What are the main features of *DevCenter*?

- Main features
  - Create and manage Cassandra connections
  - Create, edit, and execute CQL scripts
    - syntax highlighting
    - code auto-completion
    - real-time script validation against the current connection
  - Explore database objects via the Schema explorer
  - Navigate long CQL scripts via the Outline view
  - Execute CQL queries and view results and query trace

What are the main features of *DevCenter?*



Run using connection: Test Cluster in keyspace: musicdb with limit: 300

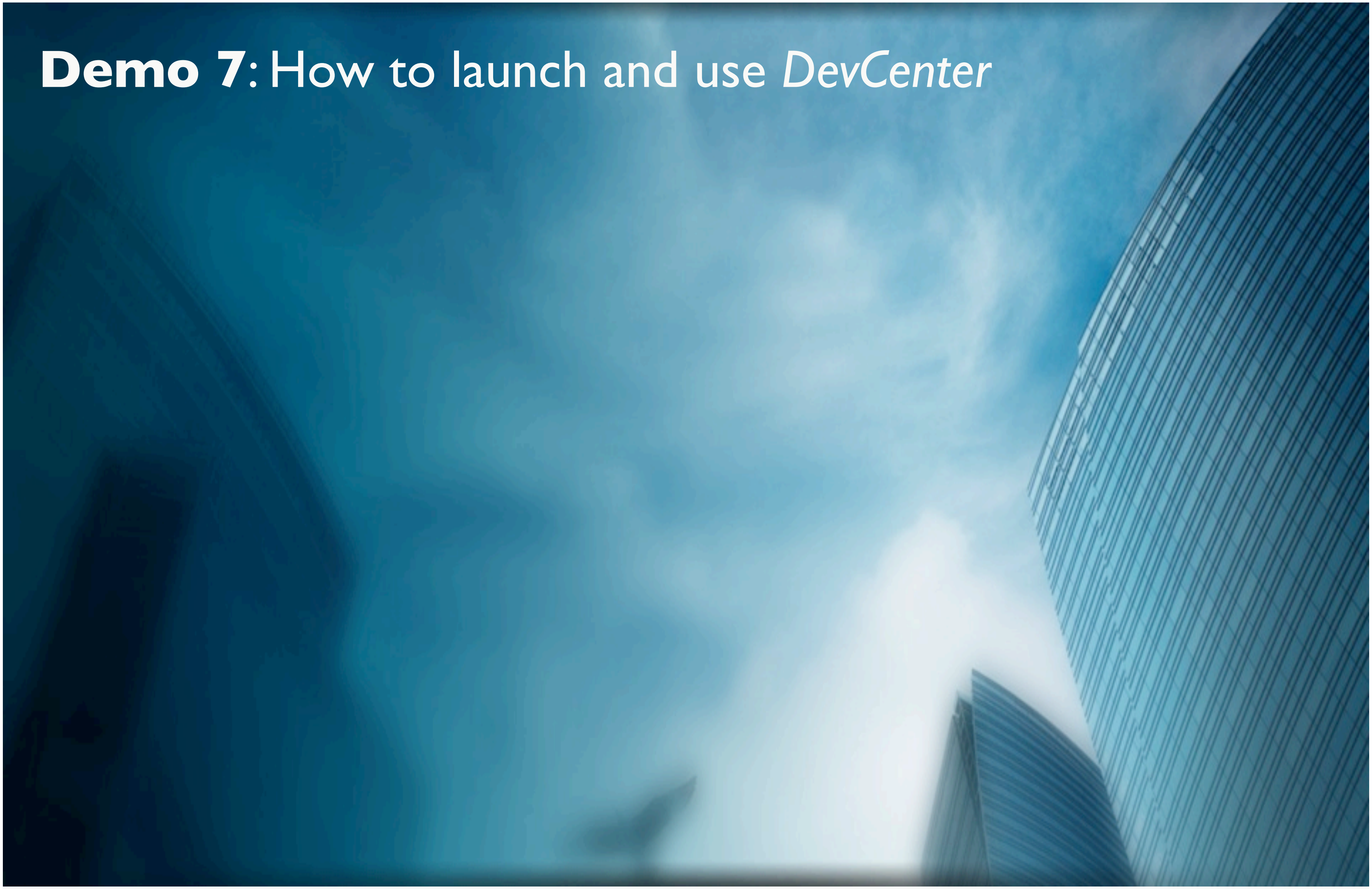
```
USE musicdb;

SELECT genre, performer, year, title
FROM albums_by_genre WHERE genre = 'Jazz';
```

genre	performer	year	title
Jazz	Anita O'Day	2004	Angel Eyes
Jazz	Anita O'Day	2004	Classics 1950-1952
Jazz	Anita O'Day	2003	Classics 1945-1950
Jazz	Anita O'Day	2003	Complete 1952 Verve Sessions
Jazz	Anita O'Day	2003	Diva Series, The
Jazz	Anita O'Day	2003	Mello Day
Jazz	Anita O'Day	2003	Pick Yourself Up
Jazz	Anita O'Day	2003	Time For Two
Jazz	Anita O'Day	2001	In A Mellow Tone
Jazz	Anita O'Day	2001	Live at the City San Francisco 1979
Jazz	Anita O'Day	2000	Finest Hour
Jazz	Anita O'Day	1999	Trav'lin' Light
Jazz	Big Bad Voodoo Daddy	1999	This Beautiful Life
Jazz	Big Bad Voodoo Daddy	1994	Big Bad Voodoo Daddy
Jazz	Brannen Temple	2001	The Project Live
Jazz	Discography	2005	La cinquième saison

Retrieved 39 row(s) in 620 ms

Demo 7: How to launch and use *DevCenter*



Learning Objectives

- Understand the Cassandra data model
- Introduce *cqlsh* (optional)
- Understand and use the DDL subset of CQL
- Introduce *DevCenter*
- **Understand and use the DML subset of CQL**
- Understand basics of data modeling (optional)

What is the syntax of the INSERT statement?

```
INSERT INTO table_name (column1, column2 ...)
VALUES (value1, value2 ...)
```

- Inserts a row into a table
  - Must specify columns to insert values into
    - Primary key columns are mandatory (identify the row)
    - Other columns do not have to have values
      - Non-existent ‘values’ do not take up space
- Atomicity and isolation
  - Inserts are atomic
    - All values of a row are inserted or none
  - Inserts are isolated
    - Two inserts with the same values in primary key columns will not interfere – executed one after another

What is the syntax of the INSERT statement?

- To insert a row into a table

```
CREATE TABLE albums_by_performer (
  performer VARCHAR,
  year INT,
  title VARCHAR,
  genre VARCHAR,
  PRIMARY KEY (performer, year, title)
) WITH CLUSTERING ORDER BY (year DESC, title ASC);
```

```
INSERT INTO albums_by_performer (performer,year,title,genre)
VALUES ('The Beatles', 1966, 'Revolver', 'Rock');
```

```
INSERT INTO albums_by_performer (performer, year, title)
VALUES ('The Beatles', 1995, 'Beatlemania');
```

performer	year	title	Genre
The Beatles	1995	Beatlemania	
The Beatles	1966	Revolver	Rock

What is the syntax of the INSERT statement?

- To insert a row into a table with UUID and TIMEUUID columns

```
CREATE TABLE track_ratings_by_user (
   user UUID,
   activity TIMEUUID,
   rating INT,
   album_title VARCHAR,
   album_year INT,
   track_title VARCHAR,
   PRIMARY KEY (user, activity)
) WITH CLUSTERING ORDER BY (activity DESC);
```

```
INSERT INTO track_ratings_by_user
(user,activity,rating,album_title,album_year,track_title)
VALUES (52b11d6d-16e2-4ee2b2a9-5ef1e9589328,
dbf3fbfc-9fe4-11e3-8d05-425861b86ab6, 5,'Revolver',1966,'Yellow
Submarine');
```

user	activity	album_title	album_year	rating	track_title
52b11d6d-16e2- …	dbf3fbfc-9fe4- …	Revolver	1966	5	Yellow Submarine

What is the syntax of the UPDATE statement?

```
UPDATE <keyspace>.<table>
SET column_name1 = value, column_name2 = value,
WHERE primary_key_column = value;
```

- Updates columns in an existing row
    - Row must be identified by values in primary key columns
    - Primary key columns cannot be updated
    - An existing value is replaced with a new value
    - A new value is added if a value for a column did not exist before
- Atomicity and isolation
    - Updates are atomic
        - All values of a row are updated or none
    - Updates are isolated
        - Two updates with the same values in primary key columns will not interfere – executed one after another

What is the syntax of the UPDATE statement?

- To update a row in a table

```
UPDATE albums_by_performer
SET genre = 'Rock'
WHERE performer = 'The Beatles' AND
                  year = 1995 AND
                  title = 'Beatlemania';
```

- Before update

performer	year	title	Genre
The Beatles	1995	Beatlemania	
The Beatles	1966	Revolver	Rock

- After update

performer	year	title	Genre
The Beatles	1995	Beatlemania	Rock
The Beatles	1966	Revolver	Rock

What is an "upsert"?

- UPdate + inSERT
  - Both UPDATE and INSERT are write operations
  - No reading before writing
- Term “upsert” denotes the following behavior
  - INSERT updates or overwrites an existing row
    - When inserting a row in a table that already has another row with the same values in primary key columns
  - UPDATE inserts a new row
    - When a to-be-updated row, identified by values in primary key columns, does not exist
  - Upserts are legal and do not result in error or warning messages

What are lightweight transactions or ‘compare and set’?

- Introduces a new clause IF NOT EXISTS for inserts
  - Insert operation executes if a row with the same primary key does not exist
  - Uses a consensus algorithm called Paxos to ensure inserts are done serially
  - Multiple messages are passed between coordinator and replicas with a large performance penalty
  - [applied] column returns true if row does not exist and insert executes
  - [applied] column is false if row exists and the existing row will be returned

```
INSERT INTO albums_by_performer (performer,year,title)
VALUES ('The Beatles', 1966, 'Revolver’) IF NOT EXISTS;
```

[applied]
true

```
INSERT INTO albums_by_performer (performer, year, title)
VALUES ('The Beatles', 1995, 'Beatlemania’) IF NOT EXISTS;
```

[applied]	performer	year
false	The Beatles	1966

What are lightweight transactions or Compare and Set?

- Update uses IF to verify the value for column(s) before execution
  - [applied] column returns true if condition(s) matches and update written
  - [applied] column is false if condition(s) do not match and the current row will be returned

```
UPDATE albums_by_performer SET year = 1968 WHERE performer =
'The Beatles' IF title = 'Revolver';
```

[applied]
true

```
UPDATE albums_by_performer SET year = 1968 WHERE performer =
'The Beatles' IF title = 'Revolver’ AND year = 1967;
```

[applied]	performer	year
false	The Beatles	1966

What is the purpose of the TTL option?

- Time-to-live (TTL) defines expiring columns
    - INSERT and UPDATE can optionally assign data values a time-to-live
        - TTL is specified in seconds
        - Expired columns/values are eventually deleted
        - With no TTL specified, columns/values never expire

- TTL is useful for automatic deletion
    - When data gets outdated after some time
    - When only most recent data is needed
        - Older data may be archived elsewhere by a background process
        - Helps keep the size of a table and its partitions manageable
        - Restricts the data view to most recent data

What is the purpose of the TTL option?

- To store a row for 86400 seconds (1 day)

```
INSERT INTO track_ratings_by_user
(user,activity,rating,album_title,album_year,track_title)
VALUES (52b11d6d-16e2-4ee2-b2a9-5ef1e9589328,
dbf3fbfc-9fe4-11e3-8d05-25861b86ab6,5,'Revolver',1966,'Yellow
Submarine')
USING TTL 86400;
```

  - Re-inserting the same row before it expires will overwrite TTL

- To store a column value for 30 seconds

```
UPDATE track_ratings_by_user
USING TTL 30
SET rating = 0
WHERE user = 52b11d6d-16e2-4ee2-b2a9-5ef1e9589328 AND
             activity = dbf3fbfc-9fe4-11e3-8d05-425861b86ab6;
```

  - Only column 'rating' for this row is affected by TTL

What is the syntax of the DELETE statement?

- Deletes a partition, a row or specified columns in a row
  - Row must be identified by values in primary key columns
  - Primary key columns cannot be deleted without deleting the whole row
- To delete a partition from a table

```
DELETE FROM track_ratings_by_user
WHERE user = 52b11d6d-16e2-4ee2-b2a9-5ef1e9589328;
```

- To delete a row from a table

```
DELETE FROM track_ratings_by_user
WHERE user = 52b11d6d-16e2-4ee2-b2a9-5ef1e9589328 AND
      activity = dbf3fbfc-9fe4-11e3-8d05-425861b86ab6;
```

- To delete a column from a table row

```
DELETE rating FROM track_ratings_by_user
WHERE user = 52b11d6d-16e2-4ee2-b2a9-5ef1e9589328 AND
      activity = dbf3fbfc-9fe4-11e3-8d05-425861b86ab6;
```

What is the syntax of the TRUNCATE statement?

- TRUNCATE removes all rows in a table
  - The table definition (schema) is not affected

```
TRUNCATE track_ratings_by_user;
```

Exercise 8: Inserting and updating values using DevCenter

How do you manipulate counters?

- COUNTER – defining and updating
    - INSERT is not allowed
    - Initial counter value is 0

```
CREATE TABLE stats (
  performer VARCHAR,
  albums COUNTER,
  concerts COUNTER,
  PRIMARY KEY (performer)
);
```

```
UPDATE stats
SET albums = albums + 1, concerts = concerts + 10
WHERE performer = 'The Beatles';
```

performer	albums	concerts
The Beatles	1	10

How do you manipulate collections?

- CQL set – defining and inserting
  - Collection column cannot be part of a primary key

```
CREATE TABLE band (
  name VARCHAR PRIMARY KEY,
  members SET<VARCHAR>
);
```

```
INSERT INTO band (name, members)
VALUES ('The Beatles', {'Paul', 'John', 'George', 'Ringo'});
```

name	members
The Beatles	{'George', 'John', 'Paul', 'Ringo'}

How do you manipulate collections?

- CQL set – performing union, difference and deletion

```
UPDATE band SET members = members +
{'Pete', 'Stuart', 'Paul', 'Jonathan'}
WHERE name = 'The Beatles';
```

name	members
The Beatles	{'George', 'John', 'Jonathan', 'Paul', 'Pete', 'Ringo', 'Stuart'}

```
UPDATE band SET members = members - {'Jonathan'}
WHERE name = 'The Beatles';
```

name	members
The Beatles	{'George', 'John', 'Paul', 'Pete', 'Ringo', 'Stuart'}

```
DELETE members FROM band WHERE name = 'The Beatles';
```

name	members
The Beatles	

How do you manipulate collections?

- CQL list – defining and inserting
  - Collection column cannot be part of a primary key

```
CREATE TABLE song (
  id UUID PRIMARY KEY,
  title VARCHAR,
  songwriters LIST<VARCHAR>
);
```

```
INSERT INTO song (id, title, songwriters)
VALUES (252608cb-0f56-4cf3-82ee-b7fe00f3920f,
        'I Want to Hold Your Hand', ['John', 'Paul']);
```

id	songwriters	title
252608cb-0f56-4cf3-82ee-b7fe00f3920f	['John', 'Paul']	I Want to Hold Your Hand

How do you manipulate collections?

- CQL list – appending and prepending

```
UPDATE song SET songwriters = songwriters +
['Paul', 'Jonathan']
WHERE id = 252608cb-0f56-4cf3-82ee-b7fe00f3920f;
```

id	songwriters	title
252608cb-0f56-4cf3-82ee-b7fe00f3920f	['John', 'Paul', 'Paul', 'Jonathan']	I Want to Hold Your Hand

```
UPDATE song SET songwriters = ['Patrick'] + songwriters
WHERE id = 252608cb-0f56-4cf3-82ee-b7fe00f3920f;
```

id	songwriters	title
252608cb-0f56-4cf3-82ee-b7fe00f3920f	['Patrick', 'John', 'Paul', 'Paul', 'Jonathan']	I Want to Hold Your Hand

How do you manipulate collections?

- CQL list – updating, subtracting and deleting

```
UPDATE song SET songwriters[3] = 'Ringo'
WHERE id = 252608cb-0f56-4cf3-82ee-b7fe00f3920f;
```

id	songwriters	title
252608cb-0f56-4cf3-82ee-b7fe00f3920f	['Patrick', 'John', 'Paul', 'Ringo', 'Jonathan']	I Want to Hold Your Hand

```
UPDATE song SET songwriters = songwriters -
['Patrick', 'Jonathan', 'Ringo']
WHERE id = 252608cb-0f56-4cf3-82ee-b7fe00f3920f;
```

id	songwriters	title
252608cb-0f56- …	['John', 'Paul']	I Want to Hold Your Hand

```
DELETE songwriters[0], songwriters[1] FROM song
WHERE id = 252608cb-0f56-4cf3-82ee-b7fe00f3920f;
```

id	songwriters	title
252608cb-0f56- …		I Want to Hold Your Hand

How do you manipulate collections?

- CQL map – defining and inserting
  - Collection column cannot be part of a primary key

```
CREATE TABLE album (
  title VARCHAR,
  year INT,
  tracks MAP<INT,VARCHAR>,
  PRIMARY KEY ((title, year))
);
```

```
INSERT INTO album (title, year, tracks)
VALUES ('Revolver', 1966, {1: 'Taxman', 2: 'Eleanor Rigby'});
```

title	year	tracks
Revolver	1966	{1: 'Taxman', 2: 'Eleanor Rigby'}

How do you manipulate collections?

- CQL map – updating

```
UPDATE album SET tracks[14] = 'Yellow Submarine'
WHERE title = 'Revolver' AND year = 1966;
```

title	year	tracks
Revolver	1966	{1: 'Taxman', 2: 'Eleanor Rigby', 14: 'Yellow Submarine'}

```
UPDATE album SET tracks[14] = 'Tomorrow Never Knows'
WHERE title = 'Revolver' AND year = 1966;
```

title	year	tracks
Revolver	1966	{1: 'Taxman', 2: 'Eleanor Rigby', 14: 'Tomorrow Never Knows'}

How do you manipulate collections?

- CQL map – deleting

```
DELETE tracks[14] FROM album
WHERE title = 'Revolver' AND year = 1966;
```

title	year	tracks
Revolver	1966	{1: 'Taxman', 2: 'Eleanor Rigby'}

```
DELETE tracks FROM album
WHERE title = 'Revolver' AND year = 1966;
```

title	year	tracks
Revolver	1966	

How do you manipulate user-defined types and tuples?

- User-defined type - Defining and inserting

```
CREATE TYPE track (
   album_title text,
   album_year int,
   track_title text
);

CREATE TABLE track_ratings_by_user (
   user UUID,
   activity TIMEUUID,
   rating INT,
   song frozen <track>,
   PRIMARY KEY (user, activity)
) WITH CLUSTERING ORDER BY (activity desc));
```

```
INSERT INTO track_ratings_by_user (user, activity, rating,
song ) VALUES (6ed4f220-5361-11e4-8d89-c971d060d947,
779a96e0-6eea-11e4-9803-0900200c9a66, 10,
{album_title: 'Let It Be', album_year: 1970,
 track_title: 'Let It Be'});
```

user	activity	rating	song
62d4f220-5361-…	779a96e0-6eea-…	10	{album_title: 'Let It Be', album_year: 1970, track_title: 'Let It Be'}

How do you manipulate user-defined types and tuples?

- User-defined type - Updating

```
UPDATE track_ratings_by_user
SET song = {album_title: 'Let It Be', album_year: 1970,
            track_title: 'Two of Us'}
WHERE user = 6ed4f220-5361-11e4-8d89-c971d060d947 AND
activity = 779a96e0-6eea-11e4-9803-0900200c9a66;
```

user	activity	rating	song
62d4f220-5361-…	779a96e0-6eea-…	10	{album_title: 'Let It Be', album_year: 1970, track_title: 'Two of Us'}

- User-defined type - Deleting

```
DELETE song from track_ratings_by_user WHERE user =
6ed4f220-5361-11e4-8d89-c971d060d947 AND activity =
779a96e0-6eea-11e4-9803-0900200c9a66;
```

user	activity	rating	song
62d4f220-5361-…	779a96e0-6eea-…	10	

How do you manipulate user-defined types and tuples?

- Tuple - Defining and inserting

```
CREATE TABLE user (
  id UUID PRIMARY KEY,
  email text,
  name text,
  preferences set<text>,
  equalizer frozen<tuple<float,float,float,float,float,
                       float,float,float,float,float>>
);

INSERT INTO user (id, equalizer)
VALUES (6ed4f220-5361-11e4-8d89-c971d060d947,
(3.0, 6.0, 9.0, 7.0, 6.0, 5.0, 7.0, 9.0, 11.0, 8.0));
```

id	equalizer
62d4f220-5361-…	(3.0, 6.0, 9.0, 7.0, 6.0, 5.0, 7.0, 9.0, 11.0, 8.0)

How do you manipulate user-defined types and tuples?

- Tuple - Updating

```
UPDATE user SET equalizer =
(4.0, 1.6, -1.8, -5.6, -0.7, 0.9, 2.9, 4.3, 4.3, 4.3)
WHERE id = 6ed4f220-5361-11e4-8d89-c971d060d947;
```

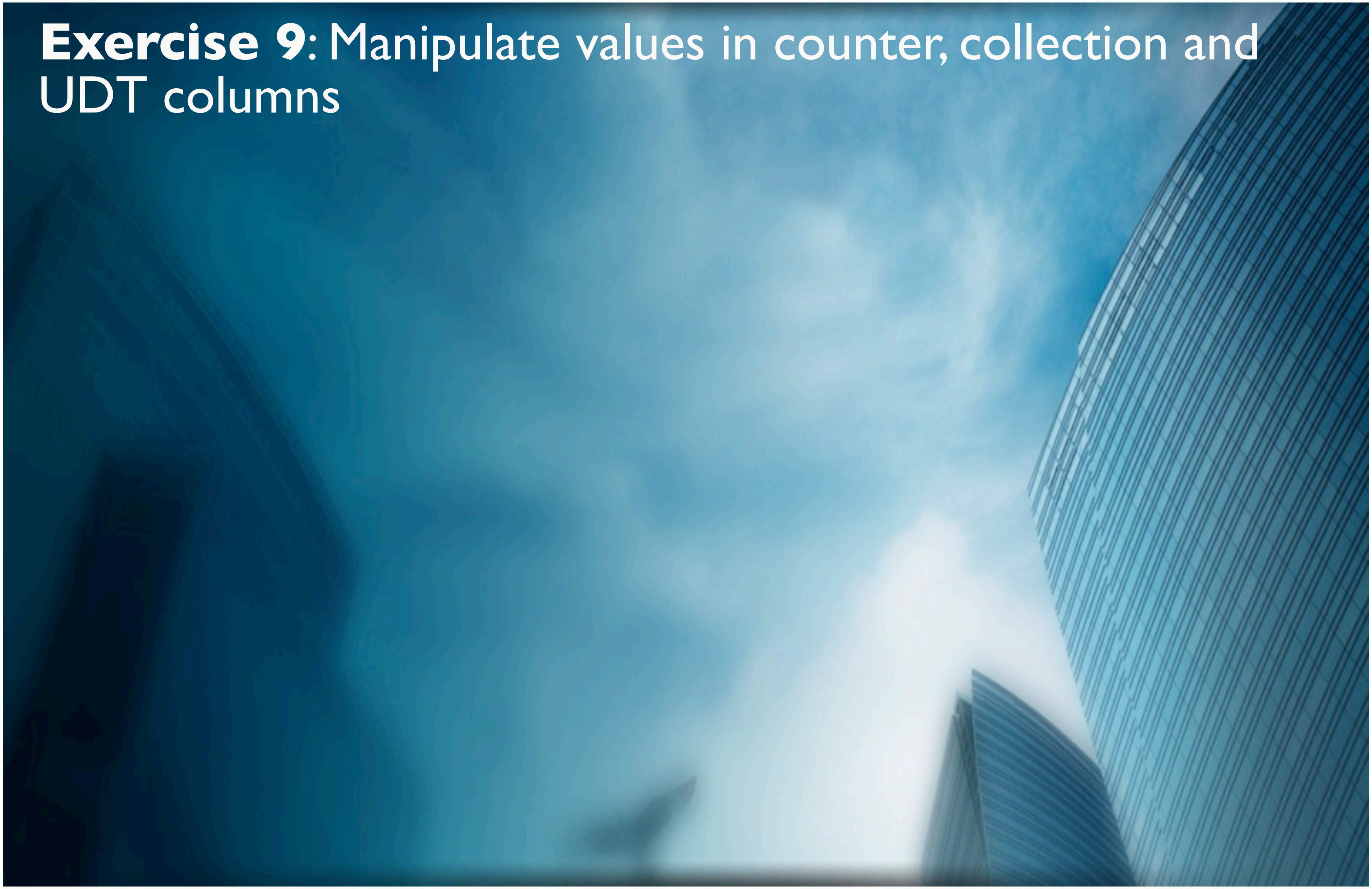
id	equalizer
62d4f220-5361-…	(4.0, 1.6, -1.8, -5.6, -0.7, 0.9, 2.9, 4.3, 4.3, 4.3)

- Tuple - Deleting

```
DELETE equalizer from user
WHERE id = 6ed4f220-5361-11e4-8d89-c971d060d947
```

id	equalizer
62d4f220-5361-…	

Exercise 9: Manipulate values in counter, collection and UDT columns



What is the purpose of the BATCH statement?

- BATCH statement combines multiple INSERT, UPDATE, and DELETE statements into a single logical operation
  - Saves on client-server and coordinator-replica communication
  - Atomic operation
    - If any statement in the batch succeeds, all will
  - No batch isolation
    - Other “transactions” can read and write data being affected by a partially executed batch

What is the purpose of the BATCH statement?

- Example

```
BEGIN BATCH
   DELETE FROM albums_by_performer
   WHERE performer = 'The Beatles' AND
                    year = 1966 AND title = 'Revolver';
   INSERT INTO albums_by_performer (performer, year, title,
                                   genre)
   VALUES ('The Beatles', 1966, 'Revolver', 'Rock');
APPLY BATCH;
```

- `BEGIN UNLOGGED BATCH`
  - Does not write to the batchlog
  - Saves time but no longer atomic
  - Allows operations on counter columns

What is the purpose of the BATCH statement?

- Lightweight transactions in batch
  - Batch will execute only if conditions for all lightweight transactions are met
  - All operations in batch will execute serially with the increased performance overhead

```
BEGIN BATCH
   UPDATE user SET lock = true IF lock = false;
   WHERE performer = 'The Beatles' AND
                     year = 1966 AND title = 'Revolver';
   INSERT INTO albums_by_performer (performer, year, title,
                                   genre)
   VALUES ('The Beatles', 1966, 'Revolver', 'Rock');
   UPDATE user SET lock = false;
APPLY BATCH;
```

What is the syntax of the SELECT statement?

- Retrieves rows from a table that satisfy an optional condition
  - SELECT – Which columns to retrieve?
  - FROM – Which table to retrieve from?
  - WHERE – What condition must rows satisfy?
  - ORDER BY – How to sort a result set?
  - LIMIT – How many rows to return?
  - ALLOW FILTERING – Is scanning over all partitions allowed?

```
SELECT select_expression
FROM keyspace_name.table_name
WHERE relation AND relation ...
ORDER BY ( clustering_column ( ASC | DESC )...)
LIMIT n
ALLOW FILTERING
```

What is the syntax of the SELECT statement?

- To retrieve all rows

```
SELECT *
FROM album;
```

- To retrieve specific columns of all rows

```
SELECT performer, title, year
FROM album;
```

- To retrieve a specific field from a user-defined type column

```
SELECT performer.lastname
FROM album;
```

- To compute the number of rows in a table

```
SELECT COUNT(*)
FROM album;
```

What predicates are allowed in the WHERE clause?

- Equality search – one partition
  - To retrieve one partition, values for all partition key columns must be specified
    - In a single-row partition, row = partition

```
CREATE TABLE tracks_by_album ( …
PRIMARY KEY ((album_title, year), number));
```

```
SELECT album_title, year, number, track_title
FROM tracks_by_album
WHERE album_title = 'Revolver' AND year = 1966;
```

album_title	year	number	track_title
Revolver	1966	1	Taxman
Revolver	1966	2	Eleanor Rigby
…	…	…	…
Revolver	1966	14	Tomorrow Never Knows

What predicates are allowed in the WHERE clause?

- Equality search – one row
  - To retrieve one row, values for all primary key columns must be specified
    - In a single-row partition, primary key = partition key

```
CREATE TABLE tracks_by_album ( …
PRIMARY KEY ((album_title, year), number));
```

```
SELECT album_title, year, number, track_title
FROM tracks_by_album
WHERE album_title = 'Revolver' AND year = 1966 AND
      number = 6;
```

album_title	year	number	track_title
Revolver	1966	6	Yellow Submarine

What predicates are allowed in the WHERE clause?

- Equality search – subset of rows
  - To retrieve a subset of rows in a partition, values for all partition key columns and all clustering columns must be specified with the last clustering column value being a set
    - IN is only allowed on the last clustering column of a primary key

```
CREATE TABLE tracks_by_album ( …
PRIMARY KEY ((album_title, year), number));
```

```
SELECT album_title, year, number, track_title
FROM tracks_by_album
WHERE album_title = 'Revolver' AND year = 1966 AND
      number IN (2,6,7,14);
```

album_title	year	number	track_title
Revolver	1966	2	Eleanor Rigby
Revolver	1966	6	Yellow Submarine
Revolver	1966	7	She Said She Said
Revolver	1966	14	Tomorrow Never Knows

What predicates are allowed in the WHERE clause?

- Equality search – subset of rows
  - To retrieve a subset of rows in a partition, values for all partition key columns and one or more but not all clustering columns must be specified
    - Clustering columns in a predicate must constitute a prefix of clustering columns specified in the primary key definition

```
CREATE TABLE albums_by_performer ( …
   PRIMARY KEY (performer, year, title));
```

```
SELECT title, year
FROM albums_by_performer
WHERE performer = 'The Beatles' AND year = 1970;
```

title	year
At The Hollywood Bowl	1970
Let It Be	1970
The Beatles Christmas Album	1970

What predicates are allowed in the WHERE clause?

- Equality search – multiple partitions
  - To retrieve multiple partitions, a set of values for a partition key must be specified using IN
    - IN is only allowed on the last column of a partition key

```
CREATE TABLE albums_by_performer ( …
   PRIMARY KEY (performer, year, title));
```

```
SELECT performer, title, year
FROM albums_by_performer
WHERE performer IN ('The Beatles', 'Deep Purple');
```

performer	title	year
The Beatles	Let It Be...Naked	2003
…	…	…
The Beatles	With The Beatles	1963
Deep Purple	Abandon	1998
…	…	…

What predicates are allowed in the WHERE clause?

- Range search
  - >, >=, <, <=
  - Can only a range search on a partition key using the `token()` function

```
WHERE token(key) >= token(?) AND token(key) < token(?)
```

    - Results are not meaningful for *RandomPartitioner* and *Murmur3Partitioner*

  - Allowed on only one clustering column in a predicate
    - This column should be defined later in the PRIMARY KEY clause than any other clustering column used in a predicate

What predicates are allowed in the WHERE clause?

- Range search – subset of rows

```
CREATE TABLE tracks_by_album ( …
PRIMARY KEY ((album_title, year), number));
```

```
SELECT album_title, year, number, track_title
FROM tracks_by_album
WHERE album_title = 'Revolver' AND year = 1966 AND
              number >= 6 AND number < 8;
```

album_title	year	number	track_title
Revolver	1966	6	Yellow Submarine
Revolver	1966	7	She Said She Said

What predicates are allowed in the WHERE clause?

- Range search – slice of a partition

```
CREATE TABLE track_by_duration ( …
PRIMARY KEY (track_title, minutes, seconds));
```

```
SELECT album_title, year, number, track_title
FROM tracks_by_duration
WHERE album_title = 'Revolver' AND year = 1966 AND
              (minutes, seconds) >= (2, 30) AND
              (minutes, seconds) < (6, 0);
```

album_title	year	number	track_title
Revolver	1966	6	Yellow Submarine
Revolver	1966	7	She Said She Said

What is the purpose of the LIMIT clause?

- LIMIT restricts the number of returned rows
  - Default value is 10,000 (cqlsh)

- To retrieve less rows

```
SELECT * FROM performer LIMIT 10;
```

- To retrieve more rows

```
SELECT * FROM performer LIMIT 100000;
```

What is the purpose of the ALLOW FILTERING clause?

- Allows scanning over all partitions
  - Predicate does not specify values for partition key columns
    - Relaxes the requirement that a partition key must be specified
    - Potentially expensive queries that may return large results
      - Use with caution
      - LIMIT clause is recommended
  - Predicate can have equality or inequality relations on clustering columns
    - Return 7th tracks for the first 10 albums in the table

```
SELECT * FROM tracks_by_album
WHERE number = 7 LIMIT 10 ALLOW FILTERING;
```

- Return the number of albums with 30 or more tracks

```
SELECT COUNT(*) FROM tracks_by_album
WHERE number = 30 LIMIT 100000 ALLOW FILTERING;
```

How are indexed columns used in a query?

- A predicate may involve only an indexed column

```
CREATE INDEX performer_country_key ON performer (country);
```

```
SELECT name FROM performer WHERE country = 'Iceland';
```

- A predicate may involve primary key and indexed columns
  - Useful to narrow a search in a large multi-row partition

- A predicate may involve multiple indexed columns
  - ALLOW FILTERING must be used

```
CREATE INDEX performer_country_key ON performer (country);
CREATE INDEX performer_style_key ON performer (style);
```

```
SELECT name FROM performer
WHERE country = 'Iceland' AND style = 'Rock' ALLOW FILTERING;
```

How are indexed collection columns queried?

- Searches on indexed collections uses the *CONTAINS* keyword

- Set, List, Map – Search for a value

```
CREATE INDEX ON user (preferences);
```

```
SELECT id FROM user
WHERE preferences CONTAINS 'Rock';
```

- Map – Search for a key

```
CREATE INDEX ON album (tracks);
```

```
SELECT title, tracks FROM album
WHERE tracks CONTAINS KEY 20;
```

How are indexed UDT and tuple columns queried?

- The column is treated as a blob and must search on all fields

- User-defined type – Search all fields

```
CREATE INDEX ON track_ratings_by_user (song);
```

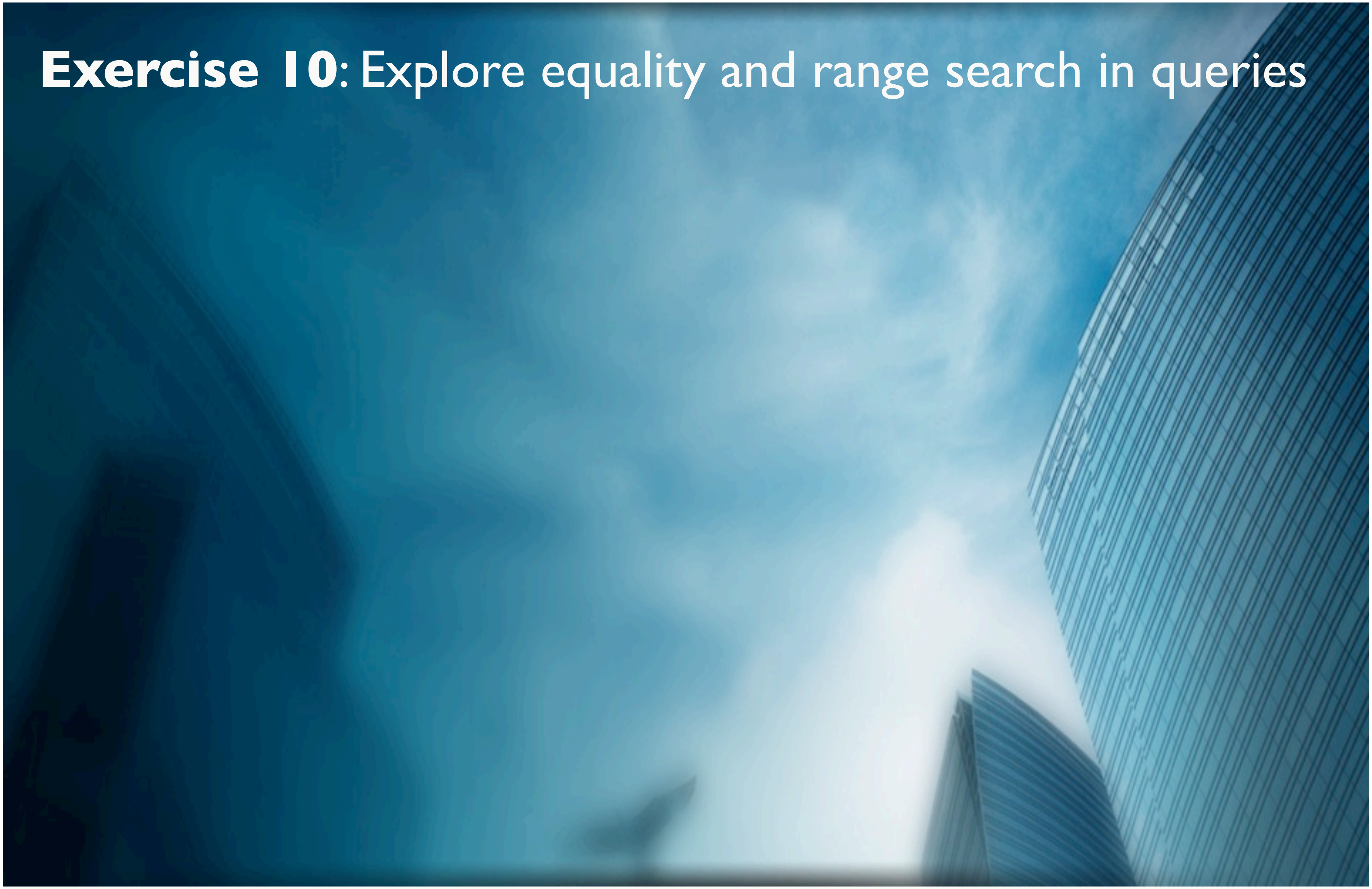
```
SELECT * FROM track_ratings_by_user
WHERE song = {album_title: 'Beatles For Sale',
              album_year: 1964,
              track_title: 'Cant Buy Me Love'};
```

- Tuple – Search all fields

```
CREATE INDEX ON user (equalizer);
```

```
SELECT * FROM user
WHERE equalizer = (1.0, 2.0, 3.0, 4.0, 5.0,
                   6.0, 7.0, 8.0, 9.0, 10.0);
```

Exercise 10: Explore equality and range search in queries



DATASTAX

What is the purpose of the ORDER BY clause?

- ORDER BY specifies how query results must be sorted
  - Allowed only on clustering columns
  - Default order is ASC or as defined by WITH CLUSTERING ORDER
  - Default order can be reversed for all clustering columns at once

```
CREATE TABLE tracks_by_album ( …
PRIMARY KEY ((album_title, year), number));
```

```
SELECT album_title, year, number, track_title
FROM tracks_by_album
WHERE album_title = 'Revolver' AND year = 1966
ORDER BY number DESC;
```

album_title	year	number	track_title
Revolver	1966	14	Tomorrow Never Knows
Revolver	1966	13	Got to Get You Into My Life
…	…	…	…
Revolver	1966	1	Taxman

What functions are available in CQL?

- TIMEUUID functions
  - `dateOf()` – extracts the timestamp as a date of a timeuuid column

```
SELECT dateOf(timeuuid_column), … FROM …;
```

  - `now()` – generates a new unique timeuuid

```
INSERT INTO … (timeuuid_column, …) VALUES (now(), …);
```

  - `minTimeuuid()` and `maxTimeuuid()` – return a UUID-like result given a conditional time component as an argument

```
SELECT * FROM … WHERE … AND
timeuuid_column > maxTimeuuid('2014-01-01 00:00+0000') AND
timeuuid_column < minTimeuuid('2014-03-01 00:00+0000');
```

  - `unixTimestampOf()` – extracts the "raw" timestamp of a timeuuid column as a 64-bit integer

```
SELECT unixTimestampOf(timeuuid_column), … FROM …;
```

What functions are available in CQL?

- Blob conversion functions
  - Series of `typeAsBlob()` and `blobAsType()` functions

```
SELECT varcharAsBlob(varchar_column), … FROM …;
```

```
SELECT blobAsBigint(blob_column), … FROM …;
```

- Token access function
  - `token()` function

```
SELECT * FROM … WHERE token(partition_key) > token(2014);
```

Demo 11: Explore queries with various predicates (optional)

Learning Objectives

- Understand the Cassandra data model
- Introduce *cqlsh* (optional)
- Understand and use the DDL subset of CQL
- Introduce *DevCenter*
- Understand and use the DML subset of CQL
- **Understand basics of data modeling (optional)**

What is data modeling?

- Data modeling is a process that involves
  - Collection and analysis of data requirements in an information system
  - Identification of participating entities and relationships among them
  - Identification of data access patterns
  - A particular way of organizing and structuring data
  - Design and specification of a database schema
  - Schema optimization and data indexing techniques
- Data modeling = Science + Art

What are the key steps of data modeling?

- Key steps of data modeling for Cassandra

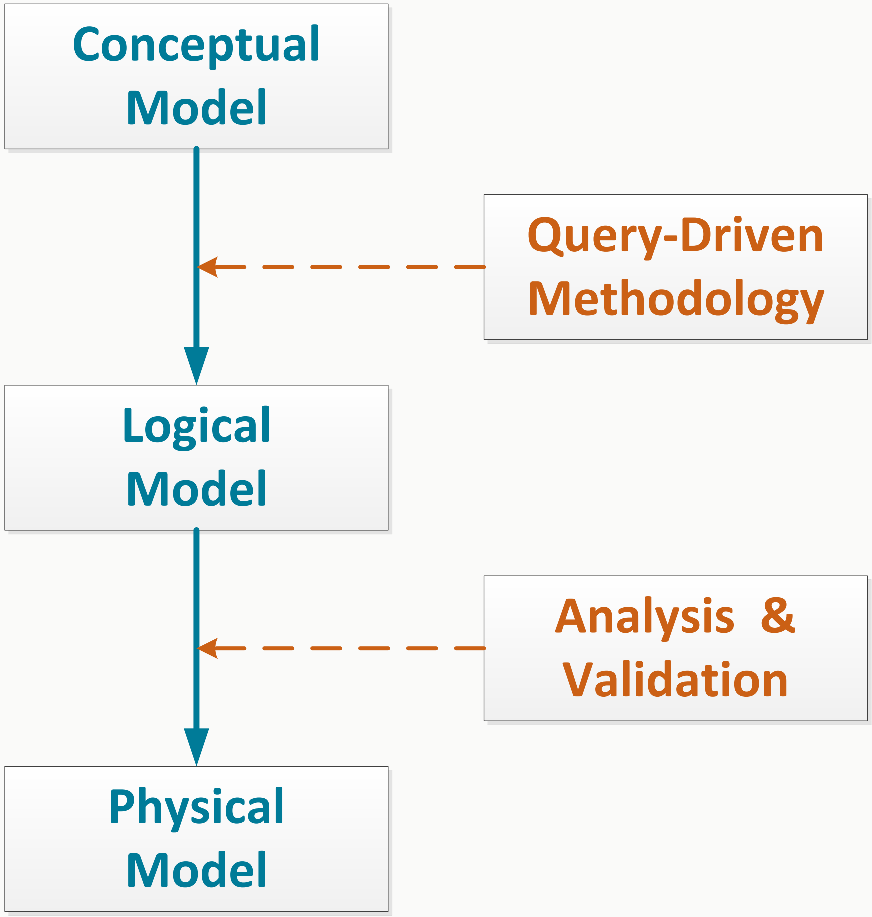
1. Understand data and application queries
   - Data may or may not exist in some format (RDBMS, XML, CSV, …)
   - Queries can be organized into a query graph
2. Design column families
   - Design is based on access patterns or queries over data
3. Implement the design using CQL
   - Optimizations concerning data types, keys, partition sizes, ordering

What are the key steps of data modeling?

- The products of the data modeling steps are documented as
  - Conceptual data model
    - Technology-independent, unified view of data
    - Entity-relationship model, dimensional model, etc.
  - Logical data model
    - Unique for Cassandra
    - Column family diagrams
  - Physical data model
    - Unique for Cassandra
    - CQL definitions

What is a data modeling framework?

- Defines transitions between models
  - Query-driven methodology
  - Formal analysis and validation
- Defines a scientific approach to data modeling
  - Modeling rules
  - Mapping patterns
  - Schema optimization techniques

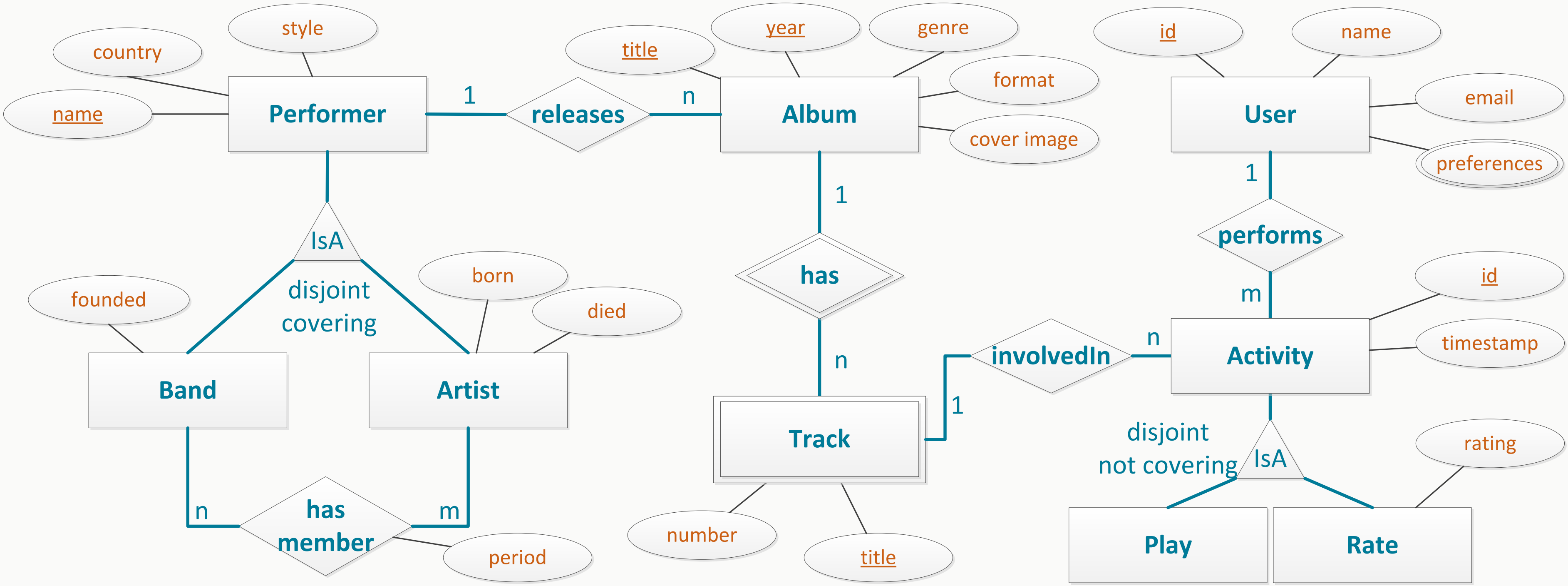


What is a conceptual data model?

- Unified view of data
  - Captures understanding of data entities and relationships
- Technology-independent
  - Has nothing to do with existing database models
- Graphical representations
  - Entity-relationship diagrams
    - Chen notation recommended
  - Dimensional modeling diagrams
  - UML diagrams

What is a conceptual data model?

- Conceptual data model for music data
  - ER diagram (Chen notation)
  - Describes entities, relationships, roles, keys, cardinalities
    - What is possible and what is not in existing or future data



What is the Cassandra data modeling methodology?

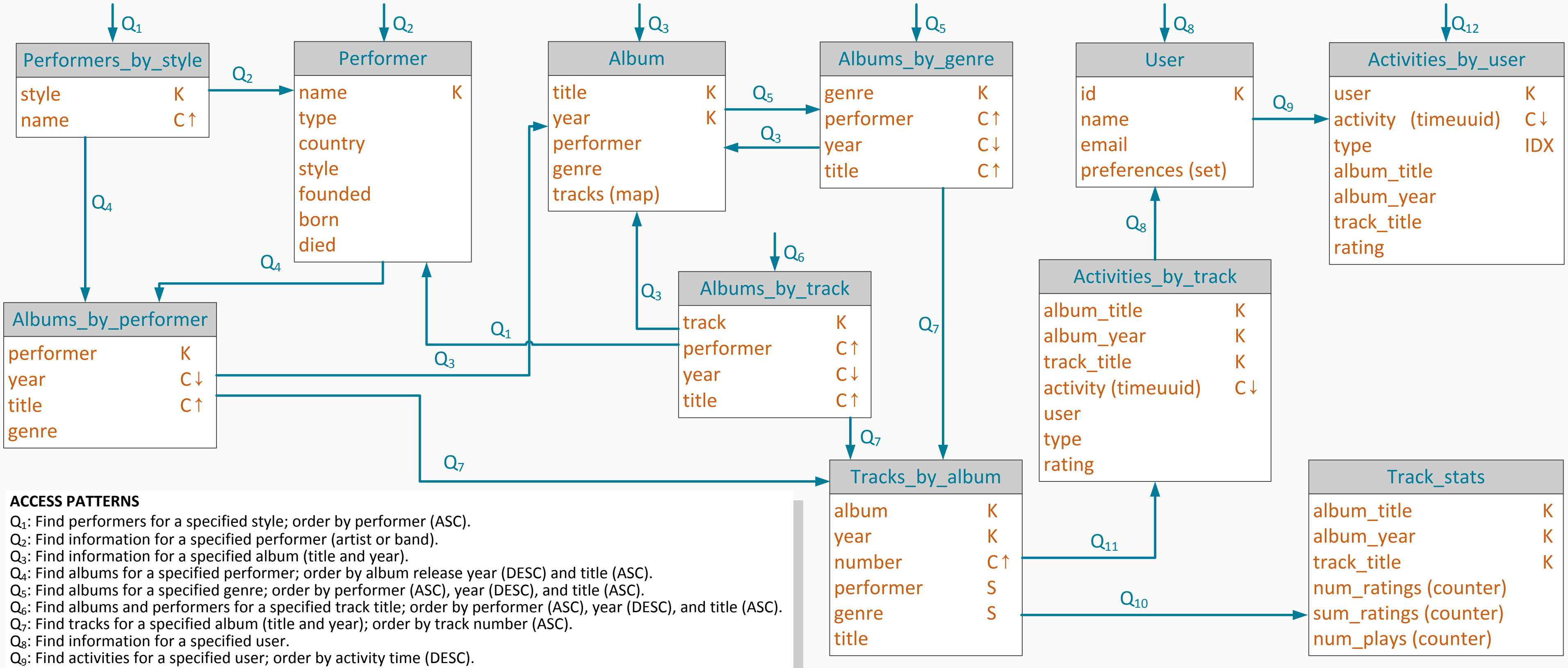
- Defines how a conceptual DM maps to a logical DM
  - Modeling rules
    - Ensure that a query is efficiently supported by a column family
  - Mapping patterns
    - Pattern input: one or more components of a conceptual DM
    - Pattern input: a query
    - Pattern output: a column family or several alternative solutions

- Enables an algorithmic approach to Cassandra data modeling
  - For each query
    - Identify a subset of the conceptual DM that describes query data
    - Apply a suitable mapping pattern on the subset and the query

What is a logical data model?

- Data is viewed and organized into column families or tables
  - Both column families and tables can be used at the logical level
    - Table is a two-dimensional view of a multi-dimensional column family
- Chebotko Diagram
  - Graphical representation of a logical data model
  - A column family is represented by a rectangle
    - Column family name
    - Columns that may optionally be designated as *K* (partition key), *C* (clustering column), *S* (static column), and *IDX* (indexed column)
  - Access patterns are represented by links between column families
    - Labeled with queries

What is a logical data model?



Performers_by_style	
style	K
name	C↑

Performer	
name	K
type	
country	
style	
founded	
born	
died	

Album	
title	K
year	K
performer	
genre	
tracks (map)	

Albums_by_genre	
genre	K
performer	C↑
year	C↓
title	C↑

User	
id	K
name	
email	
preferences (set)	

Activities_by_user	
user	K
activity (timeuuid)	C↓
type	IDX
album_title	
album_year	
track_title	
rating	

Albums_by_performer	
performer	K
year	C↓
title	C↑
genre	

Albums_by_track	
track	K
performer	C↑
year	C↓
title	C↑

Activities_by_track	
album_title	K
album_year	K
track_title	K
activity (timeuuid)	C↓
user	
type	
rating	

Tracks_by_album	
album	K
year	K
number	C↑
performer	S
genre	S
title	

Track_stats	
album_title	K
album_year	K
track_title	K
num_ratings (counter)	
sum_ratings (counter)	
num_plays (counter)	

ACCESS PATTERNS

Q_1: Find performers for a specified style; order by performer (ASC).
Q_2: Find information for a specified performer (artist or band).
Q_3: Find information for a specified album (title and year).
Q_4: Find albums for a specified performer; order by album release year (DESC) and title (ASC).
Q_5: Find albums for a specified genre; order by performer (ASC), year (DESC), and title (ASC).
Q_6: Find albums and performers for a specified track title; order by performer (ASC), year (DESC), and title (ASC).
Q_7: Find tracks for a specified album (title and year); order by track number (ASC).
Q_8: Find information for a specified user.
Q_9: Find activities for a specified user; order by activity time (DESC).
Q_{10}: Find statistics for a specified track.
Q_{11}: Find user activities for a specified track; order by activity time (DESC).
Q_{12}: Find user activities for a specified activity type.
...

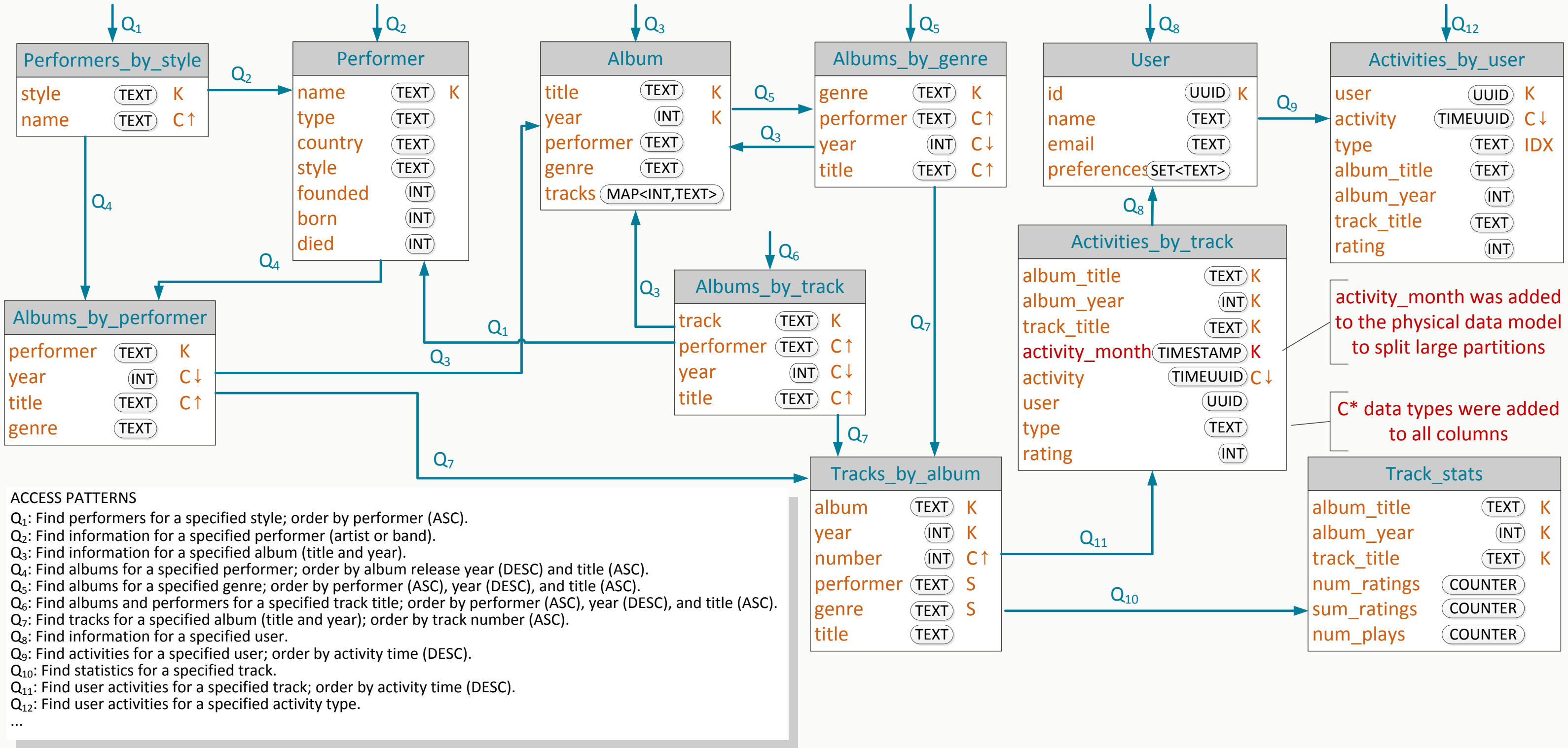
How do you analyse and validate a logical design?

- Important considerations
  - Natural or surrogate keys?
  - Are write conflicts (overwrites) possible?
  - What data types to use?
  - How large are partitions?
  - How much data duplication is required?
  - Are client-side joins required and at what cost?
  - Are data consistency anomalies possible?
  - How to enable transactions and data aggregation?
  - …

- Various optimization techniques are defined and applied
  - Result in a physical data model

What is a physical data model?

- Final blueprint of database schema design
  - CQL script that instantiates a database schema in Cassandra
  - Chetbotko Diagrams can be used at the physical level to visualize the design
    - When there are significant differences from the logical design
    - A physical-level Chetbotko Diagram should show column data types



Performers_by_style		
style	TEXT	K
name	TEXT	C↑

Performer		
name	TEXT	K
type	TEXT	
country	TEXT	
style	TEXT	
founded	INT	
born	INT	
died	INT	

Album		
title	TEXT	K
year	INT	K
performer	TEXT	
genre	TEXT	
tracks	MAP<INT,TEXT>	

Albums_by_genre		
genre	TEXT	K
performer	TEXT	C↑
year	INT	C↓
title	TEXT	C↑

User		
id	UUID	K
name	TEXT	
email	TEXT	
preferences	SET<TEXT>	

Activities_by_user		
user	UUID	K
activity	TIMEUUID	C↓
type	TEXT	IDX
album_title	TEXT	
album_year	INT	
track_title	TEXT	
rating	INT	

Albums_by_performer		
performer	TEXT	K
year	INT	C↓
title	TEXT	C↑
genre	TEXT	

Albums_by_track		
track	TEXT	K
performer	TEXT	C↑
year	INT	C↓
title	TEXT	C↑

Activities_by_track		
album_title	TEXT	K
album_year	INT	K
track_title	TEXT	K
activity_month	TIMESTAMP	K
activity	TIMEUUID	C↓
user	UUID	
type	TEXT	
rating	INT	

activity_month was added to the physical data model to split large partitions

C* data types were added to all columns

Tracks_by_album		
album	TEXT	K
year	INT	K
number	INT	C↑
performer	TEXT	S
genre	TEXT	S
title	TEXT	

Track_stats		
album_title	TEXT	K
album_year	INT	K
track_title	TEXT	K
num_ratings	COUNTER	
sum_ratings	COUNTER	
num_plays	COUNTER	

ACCESS PATTERNS

Q_1: Find performers for a specified style; order by performer (ASC).
Q_2: Find information for a specified performer (artist or band).
Q_3: Find information for a specified album (title and year).
Q_4: Find albums for a specified performer; order by album release year (DESC) and title (ASC).
Q_5: Find albums for a specified genre; order by performer (ASC), year (DESC), and title (ASC).
Q_6: Find albums and performers for a specified track title; order by performer (ASC), year (DESC), and title (ASC).
Q_7: Find tracks for a specified album (title and year); order by track number (ASC).
Q_8: Find information for a specified user.
Q_9: Find activities for a specified user; order by activity time (DESC).
Q_{10}: Find statistics for a specified track.
Q_{11}: Find user activities for a specified track; order by activity time (DESC).
Q_{12}: Find user activities for a specified activity type.
...

Is relational database design similar to Cassandra database design?

No!

Cassandra

- Multi-dimensional column family
  - Equally good for simple and complex data
- All data required to answer a query must be nested in a column family
  - Referential integrity is a non-issue
- Data modeling methodology is driven by queries and data
  - Data duplication is considered normal (side effect of data nesting)

Relational

- Two-dimensional relation
  - Suited for simple data
  - Complex data requires many relations and "star" schemas
- Data from many relations is combined to answer a query
  - Referential integrity is important
- Data modeling is driven by data only
  - Data duplication is considered a problem (normalization theory)

How do you migrate from a relational database to Cassandra?

- The common ground
  - The conceptual data model is the same (technology-independent)
  - Application queries executed over data are the same
    - SQL and CQL are not
- General idea
  - Extract (reverse engineer) a conceptual data model from a relational database schema
  - Analyze queries
  - Perform logical and physical design for Cassandra as usual
  - Execute SQL queries and import their results into respective column families in Cassandra
  - Rewrite queries in CQL
- There can be many nuances

Where do you learn more about data modeling?

- A course specifically dedicated to data modeling
  - Apache Cassandra: Data Modeling
- datastax.com
- planetcassandra.org
- cassandra.apache.org

Demo 12: Explore CQL and data modeling resources

DATASTAX

Summary

- Data in Cassandra is stored in column families or tables
- Column family is a set of rows with unique row keys
- Table is a set of partitions with unique partition keys
- Table is a two-dimensional view of a multi-dimensional column family
- Table partitions and partition keys correspond to column family rows and row keys
- Table rows are different from column family rows
- Table partitions can be single-row or multi-row depending on the absence or presence of clustering columns, respectively
- Table primary key uniquely identifies a row and is formed by a partition key and clustering columns

Summary

- CQL keyspace-related statements: CREATE KEYSPACE, USE, DROP KEYSPACE
- CQL table-related statements: CREATE TABLE, ALTER TABLE, DROP TABLE
- CQL index-related statements: CREATE INDEX, DROP INDEX
- CQL data types: VARCHAR, TEXT, INT, UUID, TIMEUUID, TIMESTAMP, COUNTER, SET, LIST, MAP, etc.
- CQL data manipulation statements: INSERT, UPDATE, DELETE, TRUNCATE, BATCH, SELECT (INSERT and UPDATE have a TTL option)
- CQL query clauses: SELECT, FROM, WHERE, ORDER BY, LIMIT, ALLOW FILTERING

Summary

- Data modeling steps require to understand data and queries, design column families, optimize, and implement tables in CQL
- Conceptual data model is technology-independent
- Logical data model is captured using column family diagrams
- Physical data model is captured in CQL schema definitions
- Data modeling framework defines transitions between conceptual, logical and physical data models
- Data modeling methodology is query-driven

Review Questions

- What is the relationship between a column family and a CQL table?
- How are wide rows implemented in CQL?
- How are clustering columns ordered?
- What is the difference between UUID and TIMEUUID?
- When should secondary indexes be used?
- Are CQL counters 100% accurate?
- How does an upsert work?
- What predicates are allowed in a CQL query?
- When should the ALLOW FILTERING clause be used?
- How can data from two tables be combined in a CQL query?
- What are components of the data modeling framework?
- What is the purpose of Chetboko Diagrams?

DATASTAX