DATASTAX
DEVELOPERS

CASSANDRA SUMMIT
MARCH 13-14, 2023 • SAN JOSE, CA

TRAINING DAY

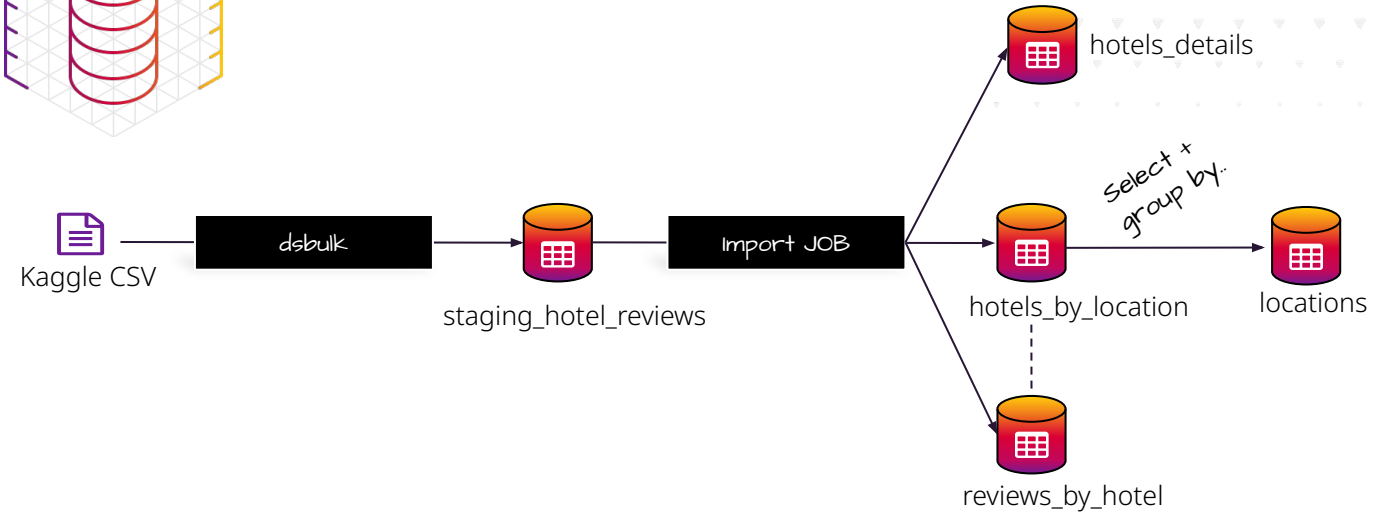
CASSANDRA SUMMIT
MARCH 13-14, 2023 • SAN JOSE, CA

APACHE CASSANDRA® FOR ARCHITECTS AND DATA ENGINEERS:

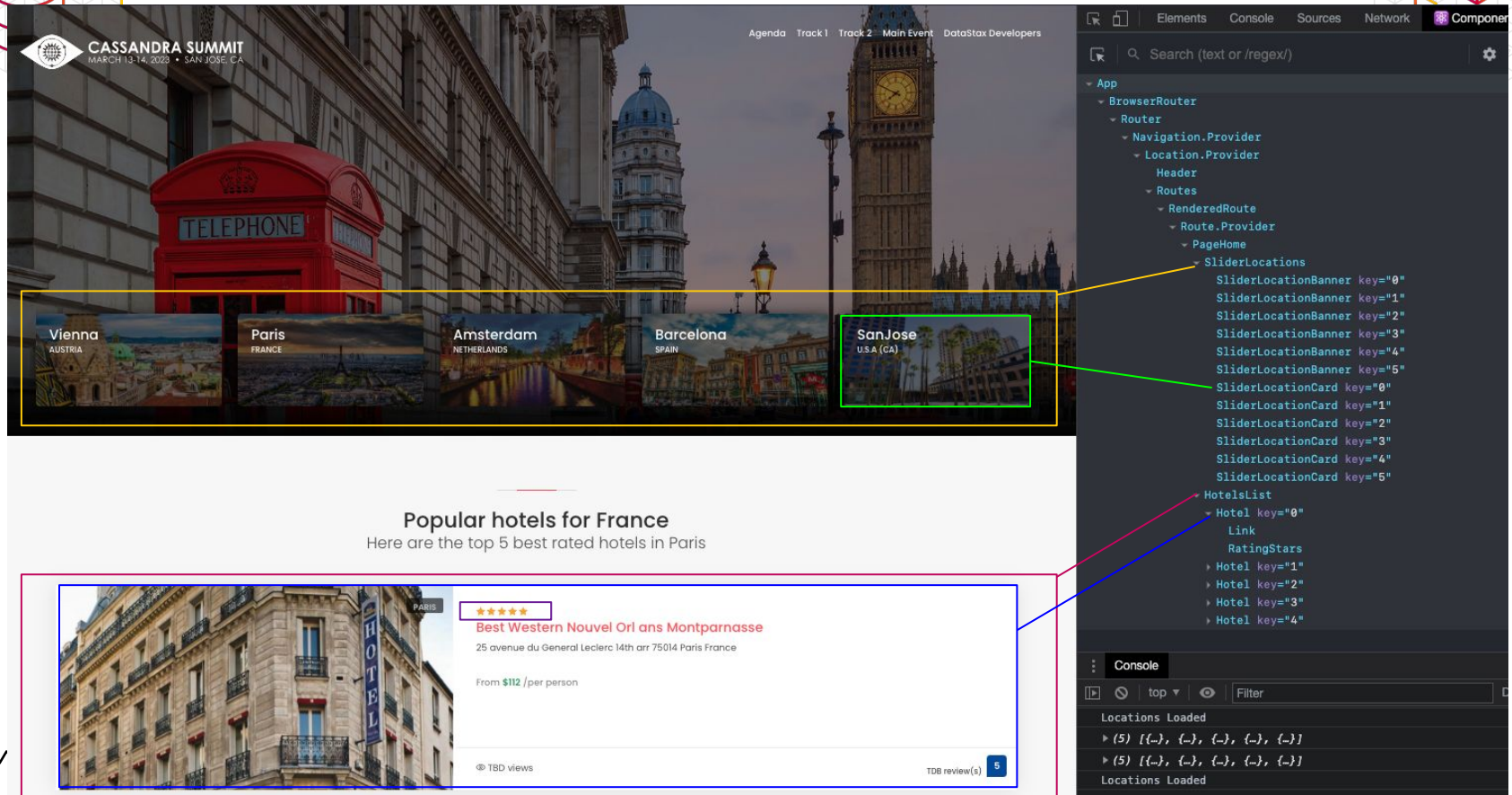
2 - Storage in Cassandra

DRAFTS SLIDES

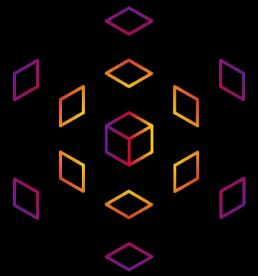
Data Preparation



❯ React Components

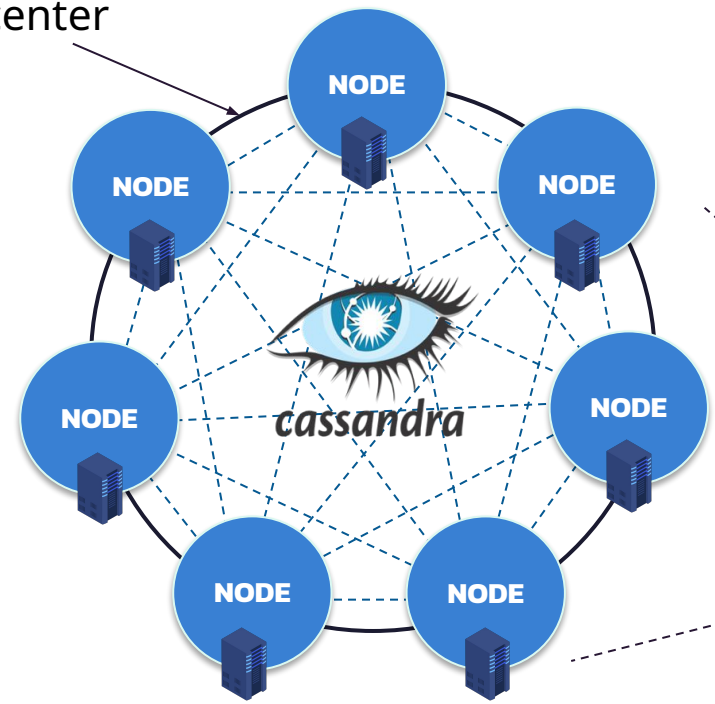


Data Distribution

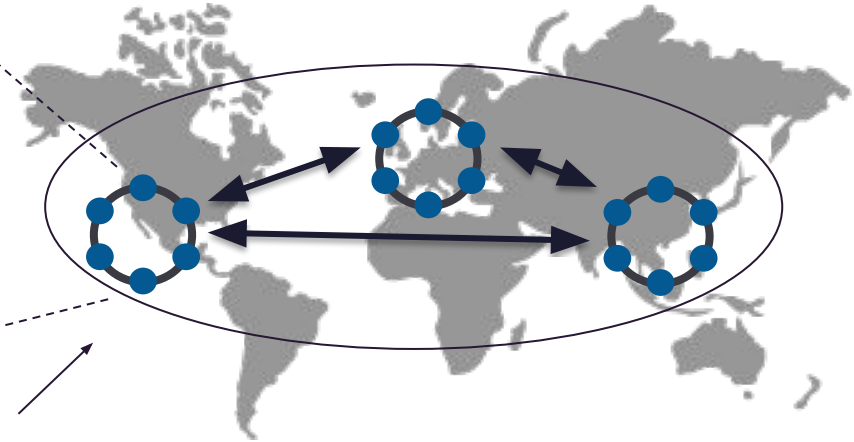


❯ Architecture: cluster and datacenters

Datacenter

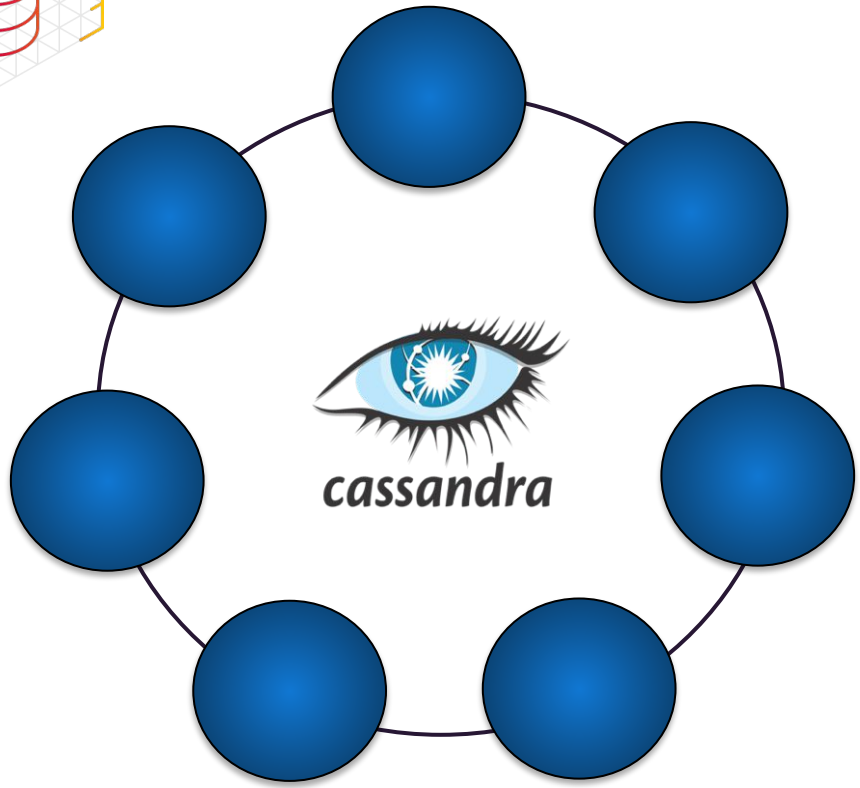


1. **NO** Single Point of Failure (masterless)
2. Scales for writes and reads
3. Application can contact any node
   (in case of failure - just contact next one)



Cluster

❯ Data is organized as tables



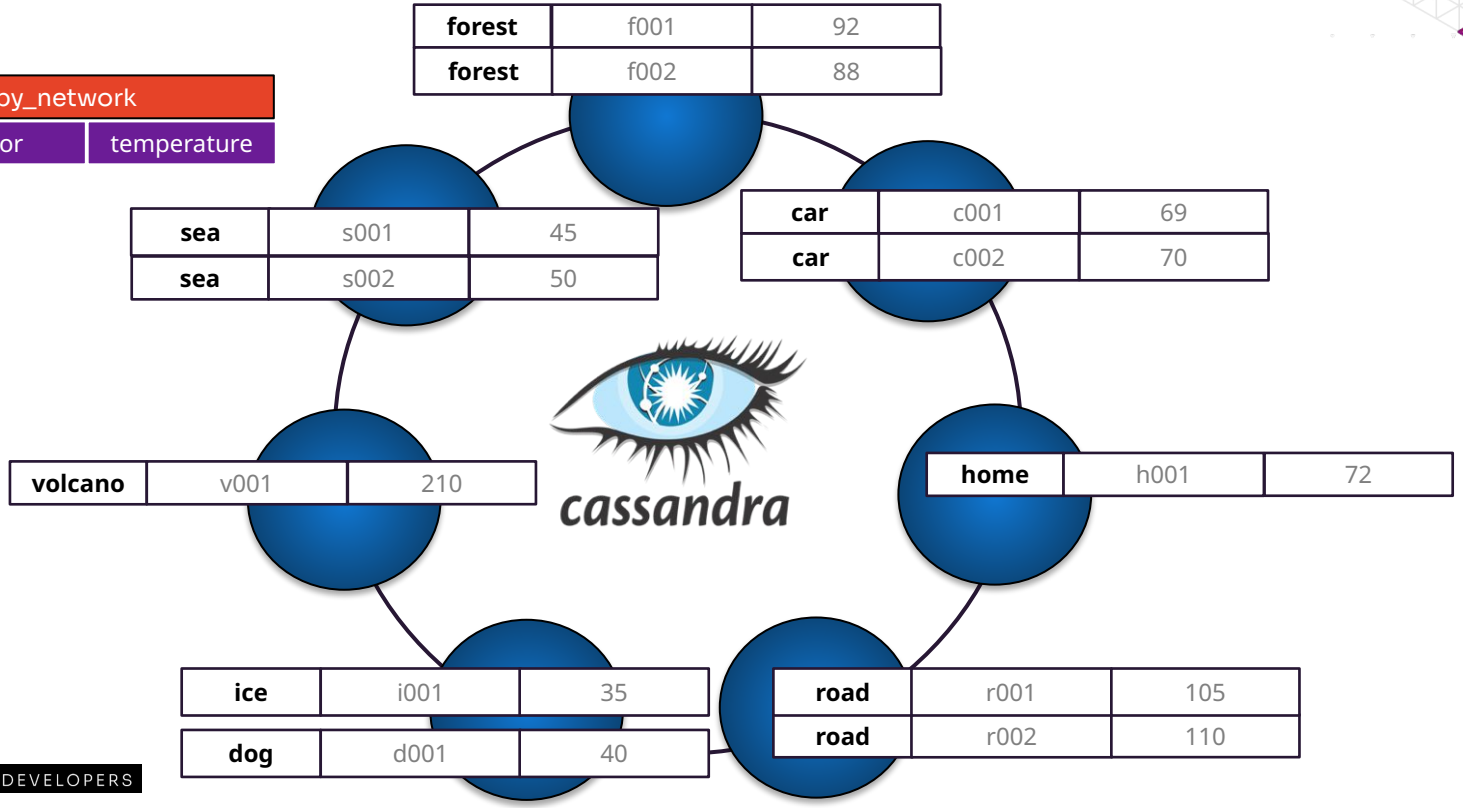
sensors_by_network		
network	sensor	temperature
forest	f001	92
forest	f002	88
volcano	v001	210
sea	s001	45
sea	s002	50
home	h001	72
car	c001	69
car	c002	70
dog	d001	40
road	r001	105
road	r002	110
ice	i001	35

Partition Key

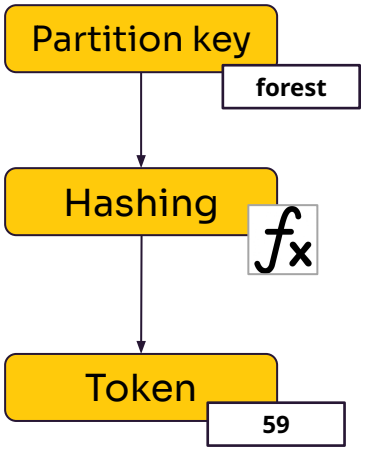
Primary Key

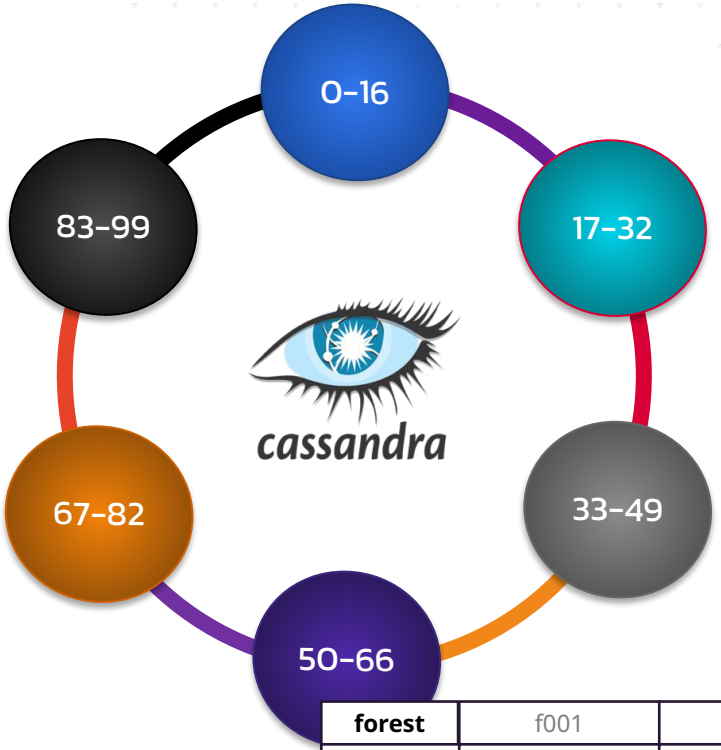
❯ Data is organized as distributed tables

sensors_by_network		
network	sensor	temperature



❯ Each node owns a range of tokens

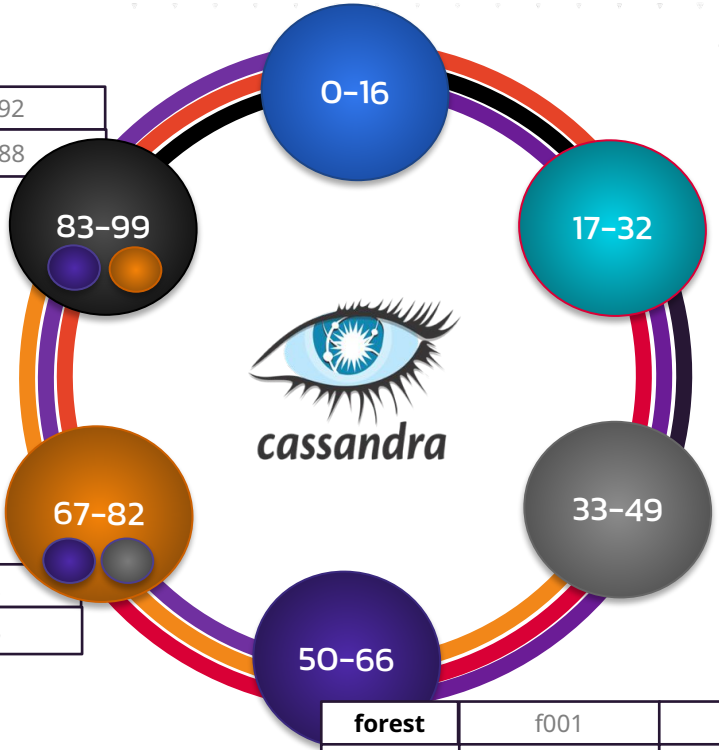




forest	f001	92
forest	f002	88

Data is replicated according to a replication factor

RF = 3

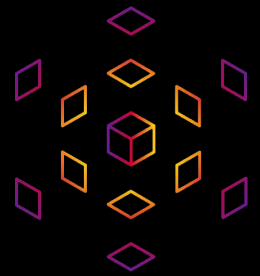


forest	f001	92
forest	f002	88

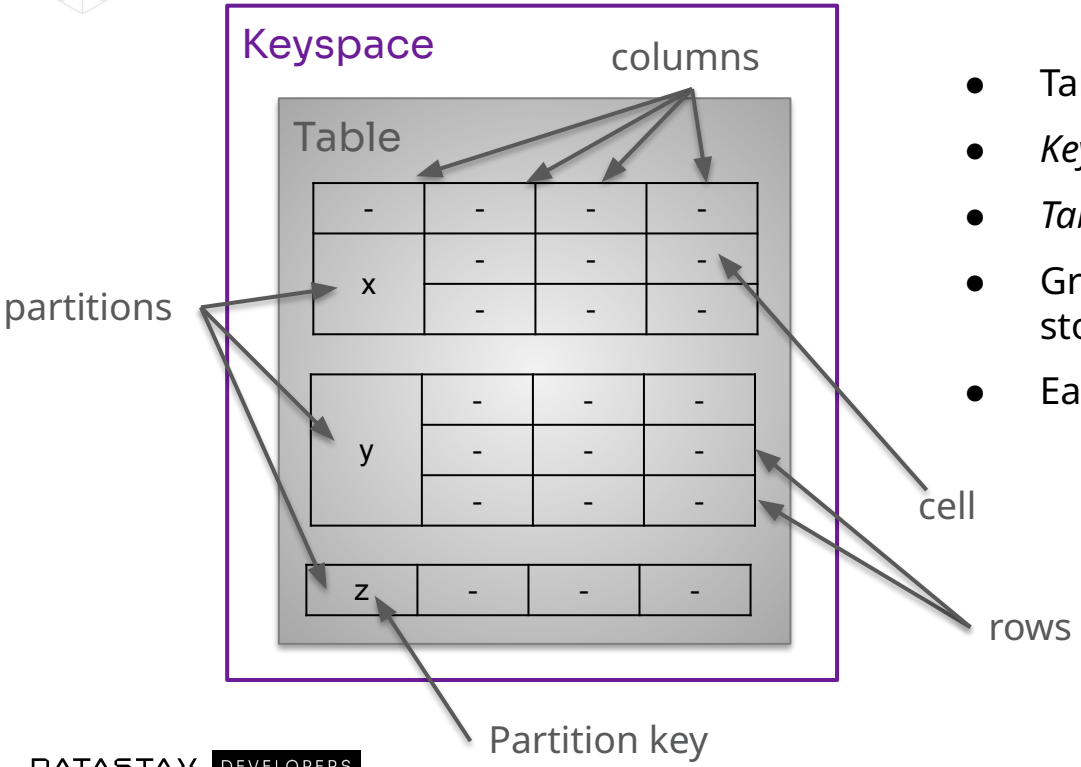
forest	f001	92
forest	f002	88

forest	f001	92
forest	f002	88

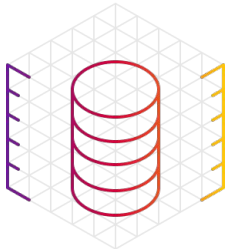
Data Organization



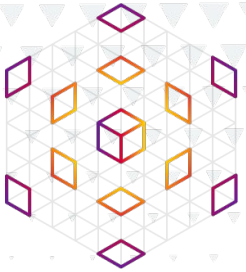
❯Cell ∈ Row ∈ Partition ∈ Table ∈ Keyspace



- Tabular data model, with one twist
- *Keyspaces* contain *tables*
- *Tables* have *rows* and *columns*
- Groups of related rows called *partitions* are stored together on the same node (or nodes)
- Each row has a *partition key*



❯ Create a keyspace

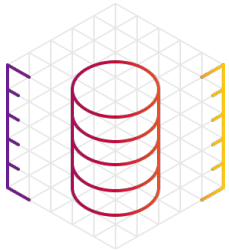


Keyspace

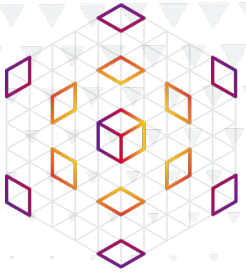
Replication strategy

```
CREATE KEYSPACE sensor_data
WITH REPLICATION = {
    'class' : 'NetworkTopologyStrategy',
    'us-west-1' :    3,
    'eu-central-1' : 5
};
```

Replication factor by data center



❯ Create a table



Keyspace

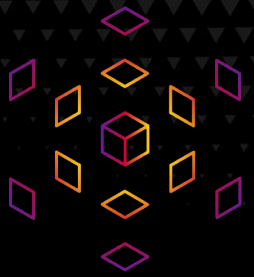
Table

```
CREATE TABLE sensor_data.sensors_by_network (
    network     text,
    sensor      text,
    temperature integer,
    PRIMARY KEY ((network), sensor)
);
```

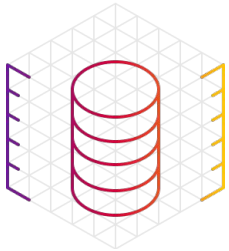
Primary key

Partition key

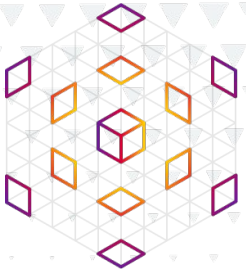
Clustering key



Key Definition



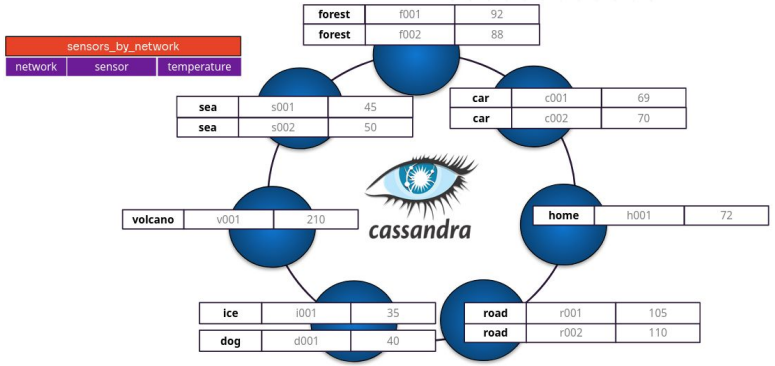
Primary key defines how data is **stored**



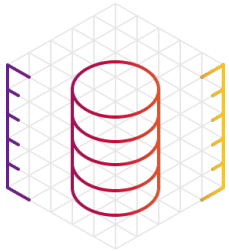
Primary Key = Partition Key + Clustering Key

Partition Key (mandatory)
Defines data partitioning and distribution over the cluster

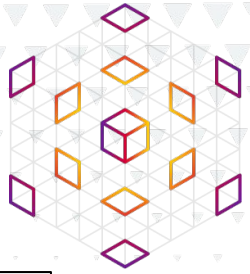
Clustering Key (optional)
Defines data uniqueness and ordering within a partition




```
CREATE TABLE sensor_data.temperatures_by_sensor (
  sensor      TEXT,
  date        DATE,
  timestamp   TIMESTAMP,
  value       FLOAT,
  PRIMARY KEY ((sensor, date), timestamp)
) WITH CLUSTERING ORDER BY (timestamp DESC);
```

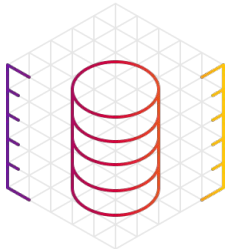


Primary key defines how data is **retrieved**

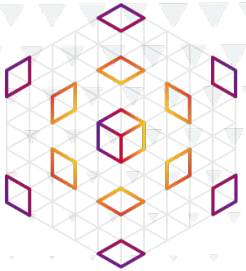


```
PRIMARY KEY ((sensor, date), timestamp);
```

```
SELECT * FROM temperatures_by_sensor ...

    WHERE sensor = ?;

    WHERE sensor > ?;

    WHERE sensor = ? AND date > ?:

    WHERE sensor = ? AND date = ? AND timestamp > ?;
```



Primary key definition cannot be **changed**

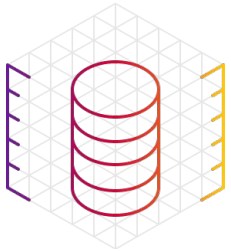


Important:

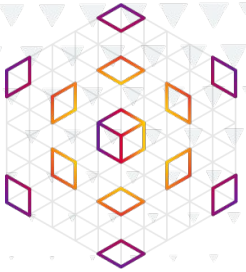
Once created, a primary key cannot be changed! You will need new tables and migration. Stay lazy, design it right in advance!

```
ALTER TABLE temperatures_by_sensor
ADD season TEXT;
```

```
ALTER TABLE temperatures_by_sensor
DROP PRIMARY KEY
ADD PRIMARY KEY (sensor, timestamp)
```

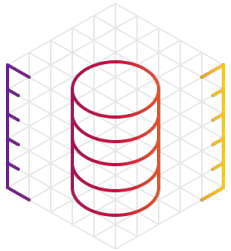


❯ Tables with single-row partitions

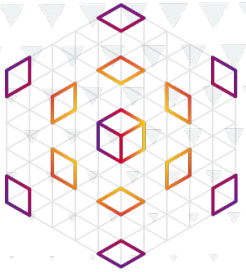


```
CREATE TABLE users (
  email       TEXT,
  name        TEXT,
  age         INT,
  date_joined DATE,
  PRIMARY KEY ((email))
);
```

```
CREATE TABLE movies (
  title       TEXT,
  year        INT,
  duration    INT,
  avg_rating  FLOAT,
  PRIMARY KEY ((title, year))
);
```

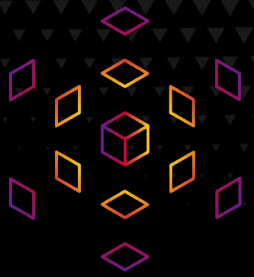


❯ Tables with multi-row partitions

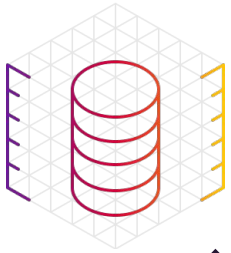


```
CREATE TABLE ratings_by_user (
  email   TEXT,
  year    INT,
  title   TEXT,
  rating  INT,
  PRIMARY KEY ((email), year, title)
) WITH CLUSTERING ORDER BY
       (year DESC, title ASC);
```

```
CREATE TABLE ratings_by_movie (
  title   TEXT,
  year    INT,
  email   TEXT,
  rating  INT,
  PRIMARY KEY ((title, year), email)
);
```



Rules for good partitioning



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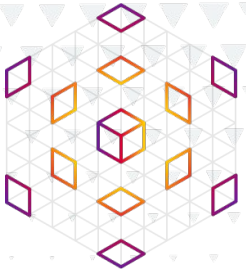
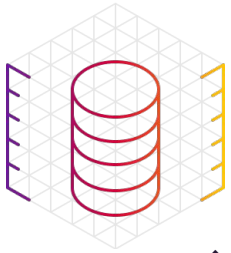


- **Store together what you retrieve together**
- Avoid big partitions
- Avoid hot partitions

Q: Show temperature evolution over time for **sensor X** on **july 6th 2022**

```
PRIMARY KEY ((sensor, timestamp));
```

```
PRIMARY KEY ((sensor), timestamp);
```



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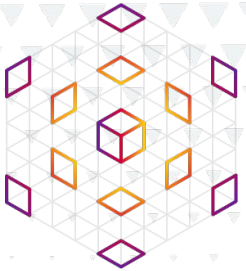


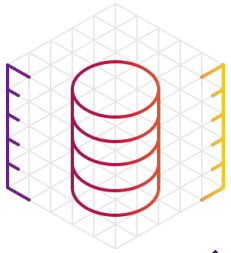
- Store together what you retrieve together
- **Avoid big partitions**
- Avoid hot partitions

```
PRIMARY KEY ((sensor), timestamp);
```

```
PRIMARY KEY ((sensor, date), timestamp);
```

BUCKETING

- Up to 2 billion cells per partition
- Up to ~100k values in a partition
- Up to ~100MB in a Partition



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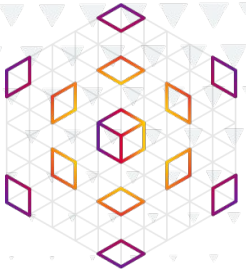
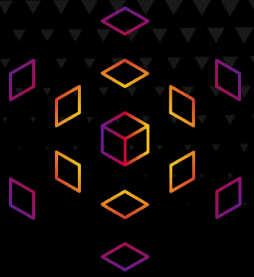


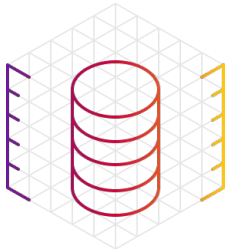
- Store together what you retrieve together
- Avoid big partitions
- **Avoid hot partitions**

```
PRIMARY KEY ((date), sensor, timestamp);
```

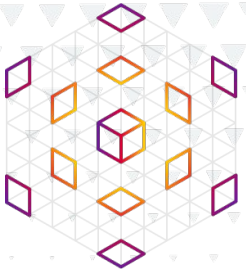
```
PRIMARY KEY ((date, sensor), timestamp);
```



Normalization vs Denormalization



Normalization



“Database normalization is the process of structuring a relational database in accordance with a series of so-called normal forms in order to reduce data redundancy and improve data integrity. It was first proposed by Edgar F. Codd as part of his relational model.”

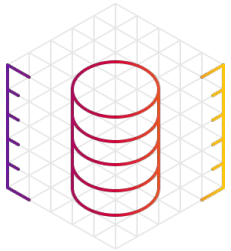
PROS: Simple write, Data Integrity **CONS:** Slow read, Complex Queries

Employees

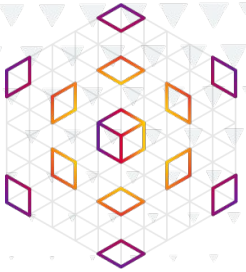
id	f_name	l_name	dept_id
1	Edgar	Codd	1
2	Raymond	Boyce	1
3	Alan	Turing	2

Departments

dept_id	department
1	Engineering
2	Math



Denormalization



“Denormalization is a strategy used on a database to increase performance. In computing, denormalization is the process of trying to improve the read performance of a database, at the expense of losing some write performance, by adding redundant copies of data”

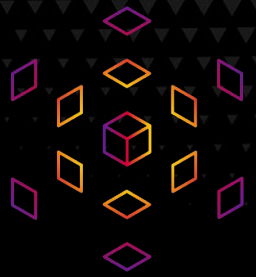
PROS: Quick Read, Simple Queries **CONS:** Multiple Writes, Manual Integrity

Employees

id	f_name	l_name	dept_id	department
1	Edgar	Codd	1	Engineering
2	Raymond	Boyce	1	Engineering
3	Alan	Turing	2	Math

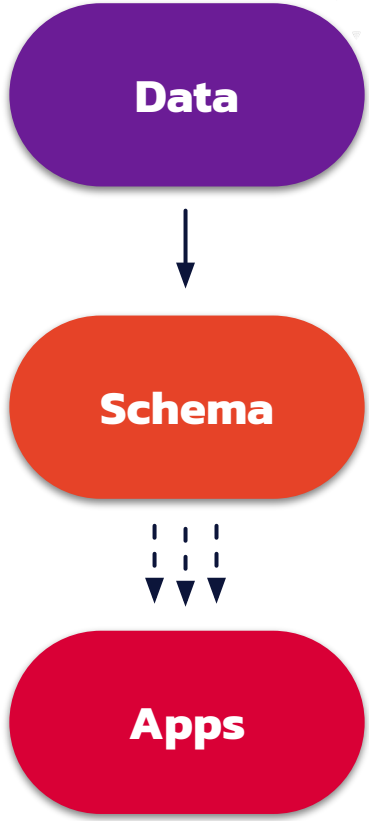
Departments

dept_id	department
1	Engineering
2	Math

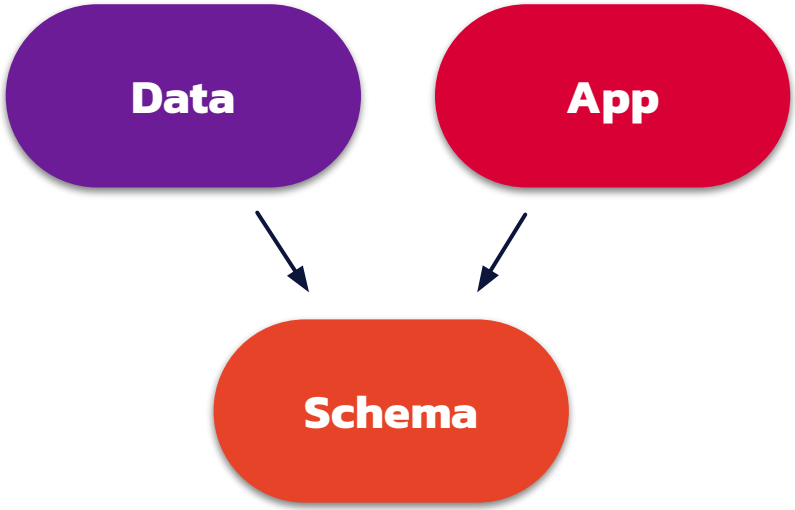


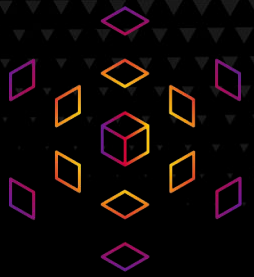
Relational vs NoSQL Schema

❯ Relational Database =Integration Database

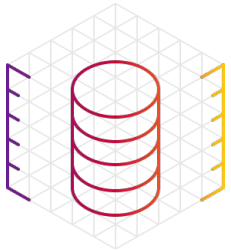


❯ NoSQL Database = Application Database

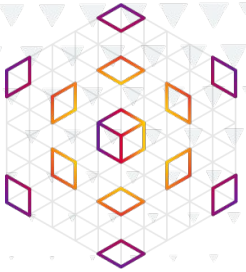




Data Modeling Methodology

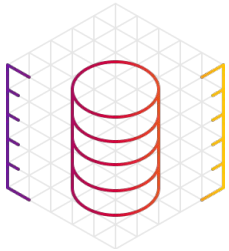


What is Data Modeling ?

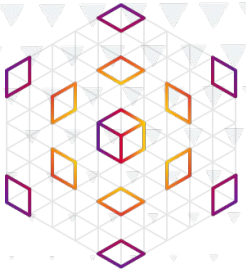


- Collection and analysis of data requirements
- Identification of participating entities and relationships
- Identification of data access patterns
- A particular way of organizing and structuring data
- Design and specification of a database schema
- Schema optimization and data indexing techniques

Data Quality: completeness consistency accuracy
Data Access: queryability efficiency scalability



Cassandra Data Modeling Principles



Modeling principle 1: "**Know your data**"

- Key and cardinality constraints are fundamental to schema design

Modeling principle 2: "**Know your queries**"

- Queries drive schema design

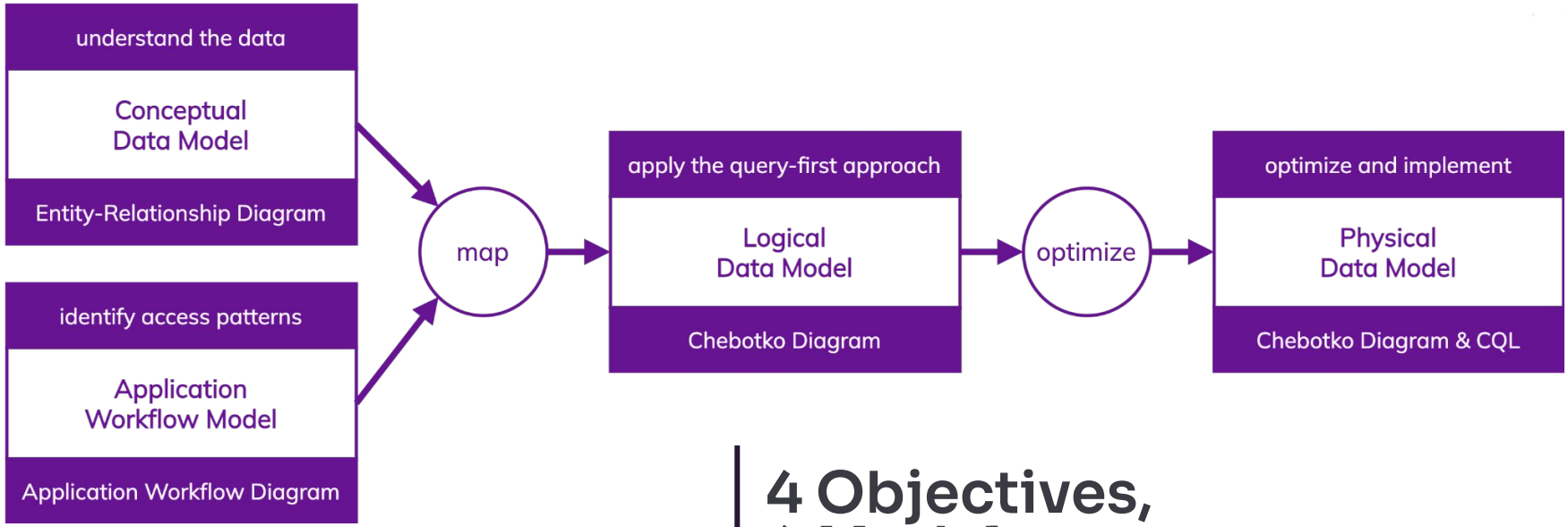
Modeling principle 3: "**Nest data**"

- Data nesting is the main data modeling technique

Modeling principle 4: "**Duplicate data**"

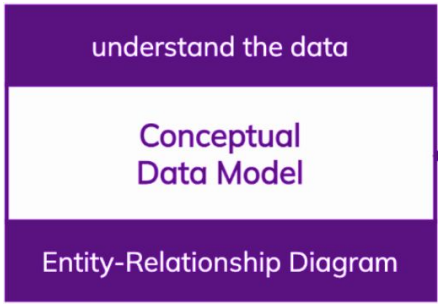
- Better to duplicate than to join

❯ 4/4/2 Like in soccer (= *real* football)

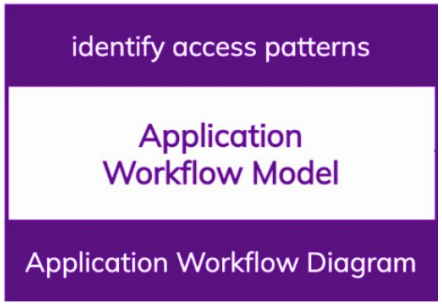


4 Objectives,
4 Models
2 Transitions

Data Modeling Methodology: Step I

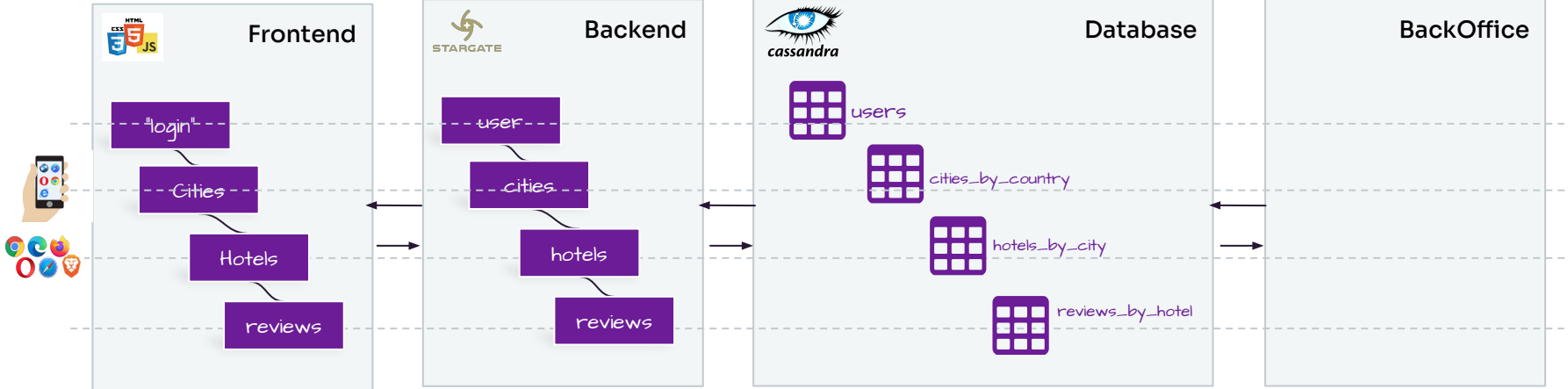


Analyze the Domain

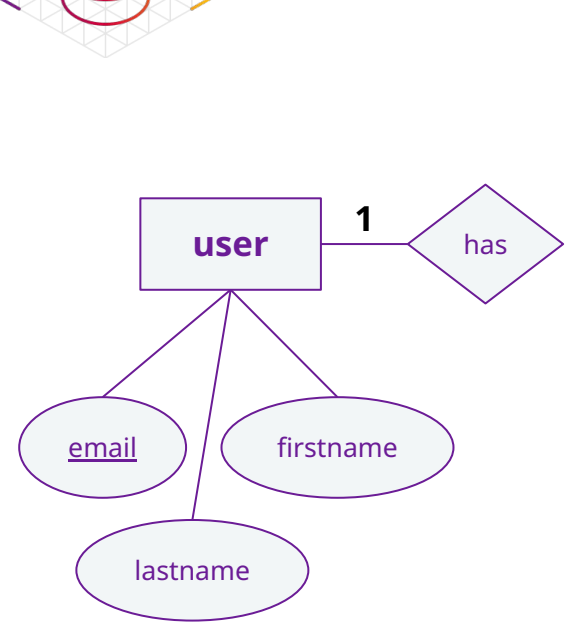


Analyze Customer Workflows

Applied Methodology

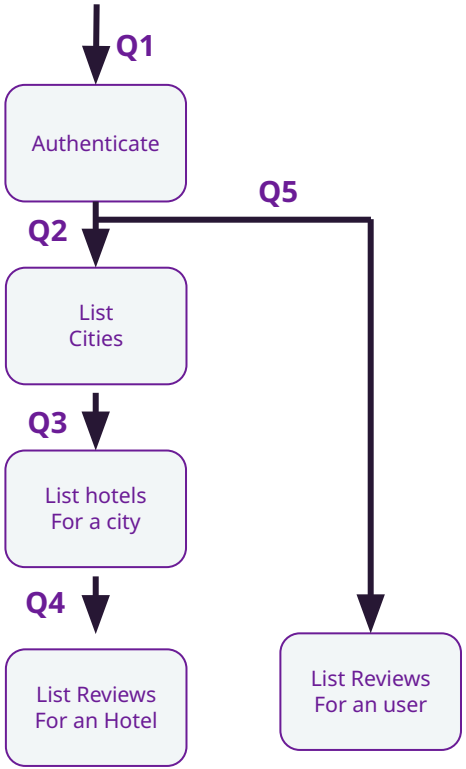


Entity-Relationship Diagram

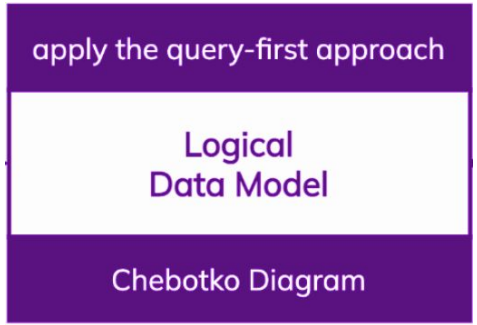


TODO

Application Workflow Diagram

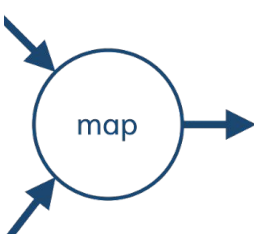


Data Modeling Methodology: Step II



Design queries and build tables based on the queries

Mapping Rules



Mapping rule 1: "**Entities and relationships**"
- Entity and relationship types map to tables

Based on a conceptual data model

Mapping rule 2: "**Equality search attributes**"
- Equality search attributes map to the beginning columns of a primary key

Mapping rule 3: "**Inequality search attributes**"
- Inequality search attributes map to clustering columns

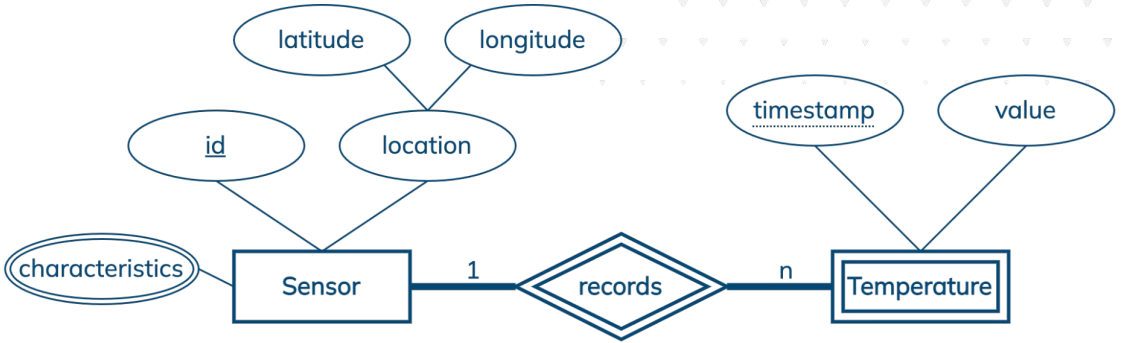
Mapping rule 4: "**Ordering attributes**"
- Ordering attributes map to clustering columns

Based on a query

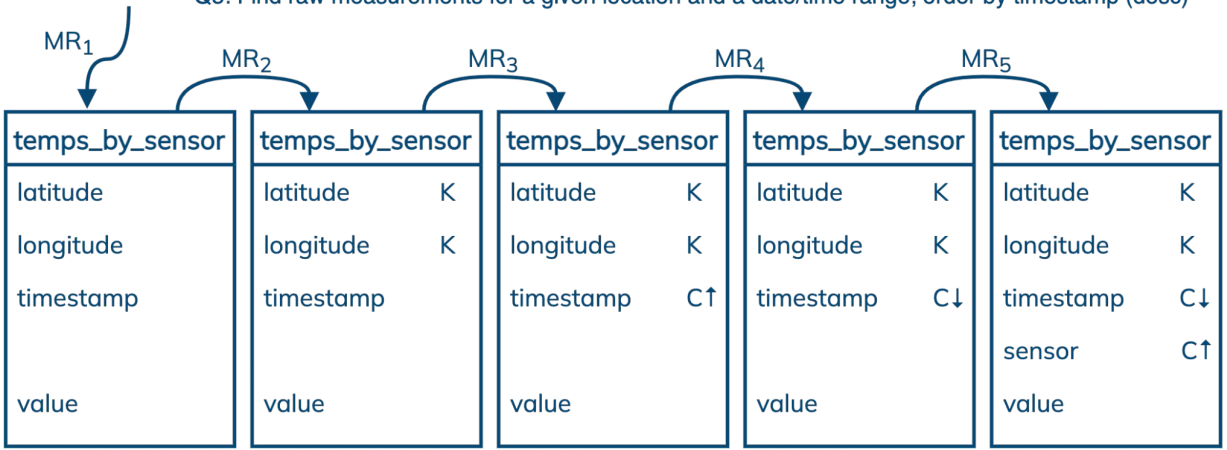
Mapping rule 5: "**Key attributes**"
- Key attributes map to primary key columns

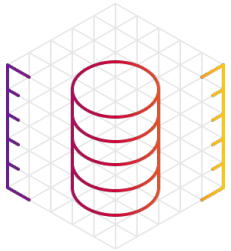
Based on a conceptual data model

Example: Applying Mapping Rules

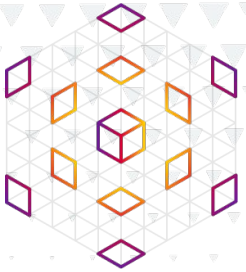


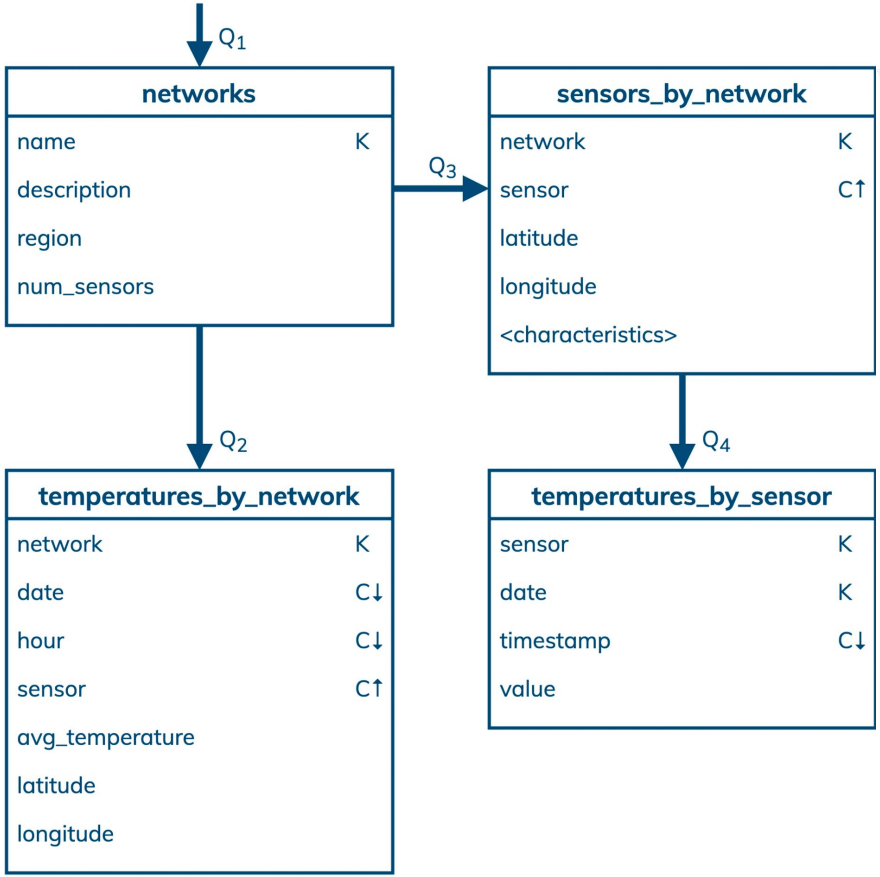
Q5: Find raw measurements for a given location and a date/time range; order by timestamp (desc)





Chebotko Diagram

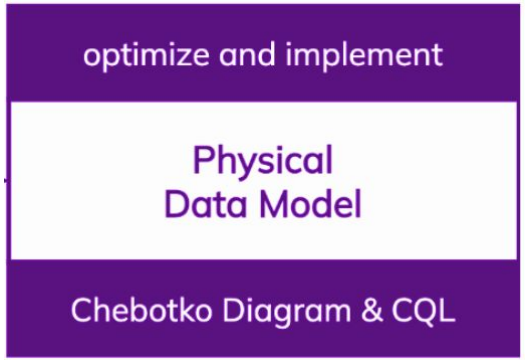




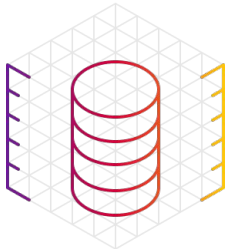
Data access patterns

Q_1: Find information about all networks; order by name (asc)
Q_2: Find hourly average temperatures for every sensor in a specified network for a given date range; order by date (desc) and hour (desc)
Q_3: Find information about all sensors in a specified network
Q_4: Find raw measurements for a particular sensor on a specified date; order by timestamp (desc)

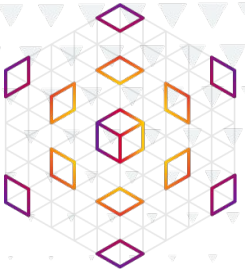
Data Modeling Methodology: Step III



Optimize and Create



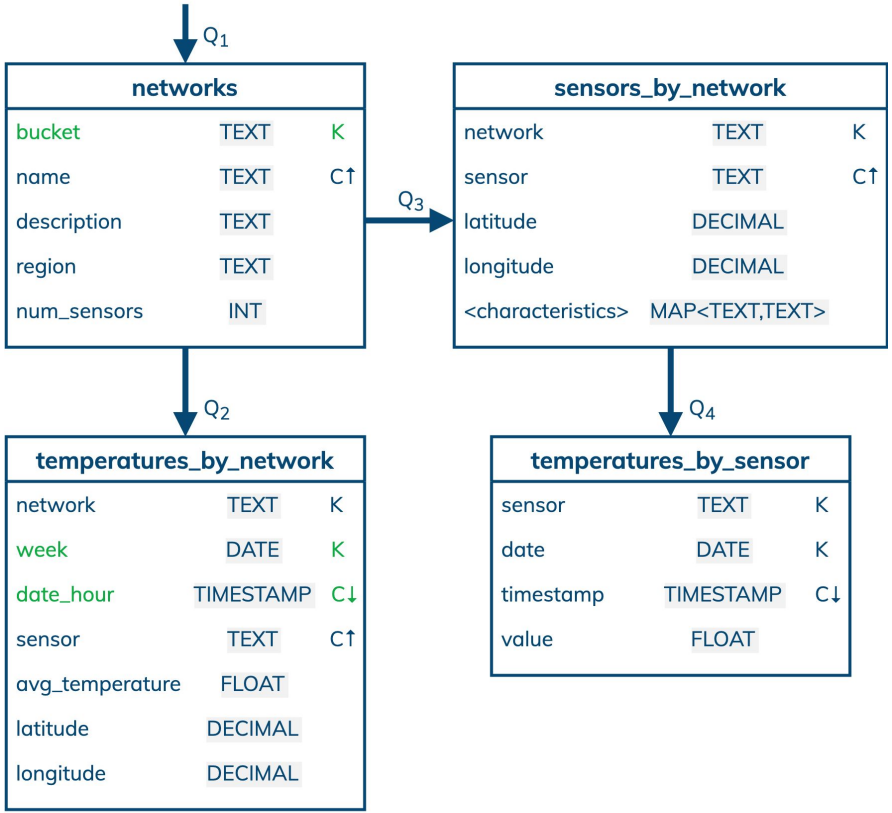
Optimization Techniques

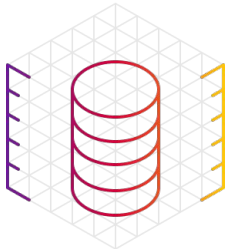


- Partition size limits and splitting large partitions
- Data duplication and batches
- Indexes and materialized views*
- Concurrent data access and lightweight transactions*
- Dealing with tombstones*

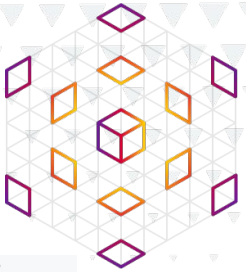
* Explained in details at our free DS220 course at academy.datastax.com

Physical Data Model: Chebotko Diagram





❯ Cassandra Query Language



Q1

```
CREATE TABLE networks (
  bucket TEXT,
  name TEXT,
  description TEXT,
  region TEXT,
  num_sensors INT,
  PRIMARY KEY ((bucket),name)
);
```

Q2

```
CREATE TABLE temperatures_by_network (
  network TEXT,
  week DATE,
  date_hour TIMESTAMP,
  sensor TEXT,
  avg_temperature FLOAT,
  latitude DECIMAL,
  longitude DECIMAL,
  PRIMARY KEY ((network,week),date_hour,sensor)
) WITH CLUSTERING ORDER BY (date_hour DESC, sensor ASC);
```

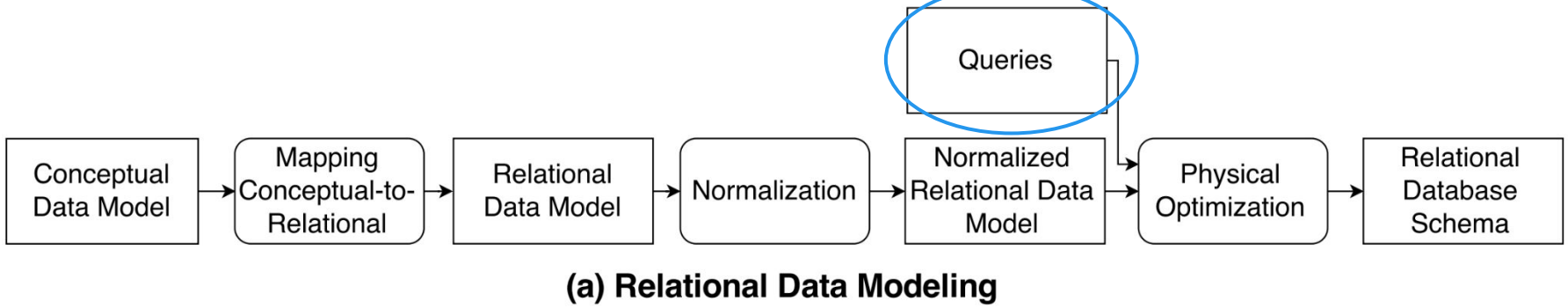
Q3

```
CREATE TABLE sensors_by_network (
  network TEXT,
  sensor TEXT,
  latitude DECIMAL,
  longitude DECIMAL,
  characteristics MAP<TEXT,TEXT>,
  PRIMARY KEY ((network),sensor)
);
```

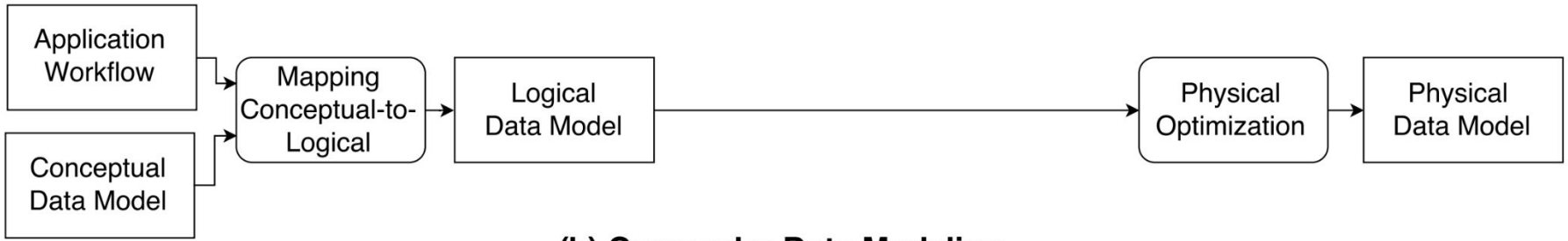
Q4

```
CREATE TABLE temperatures_by_sensor (
  sensor TEXT,
  date DATE,
  timestamp TIMESTAMP,
  value FLOAT,
  PRIMARY KEY ((sensor,date),timestamp)
) WITH CLUSTERING ORDER BY (timestamp DESC);
```

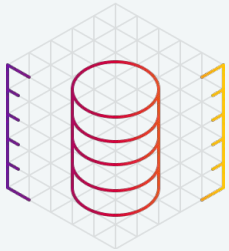
Relational vs Cassandra Modeling Process



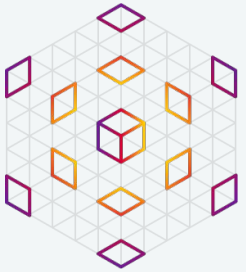
(a) Relational Data Modeling



(b) Cassandra Data Modeling



Key Takeaways



Data Modeling Principles

- Know your data
- Know your queries
- Nest data
- Duplicate data

The Most Efficient Access Pattern

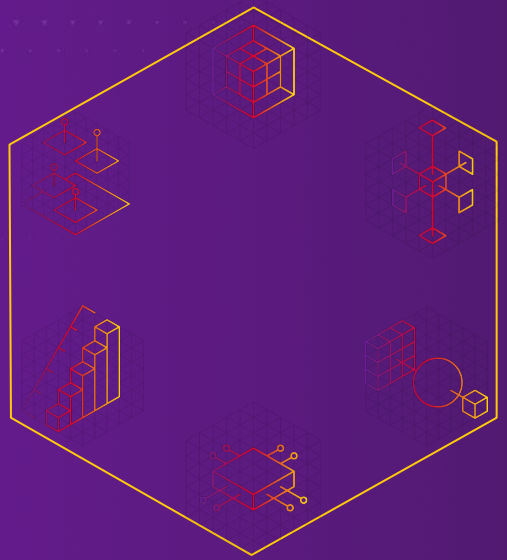
A query is satisfied by accessing one partition

Primary Key

- Data uniqueness
- Data distribution
- Data queryability

The Cassandra Data Modeling Methodology

It is not more complex than the relational data modeling methodology



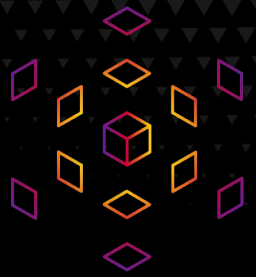
Labs 2.a and 2.b

Create your Cassandra Cluster

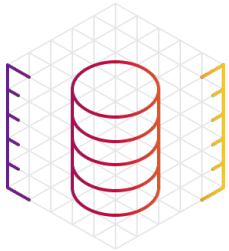
Initialize your data model

Start the user interface

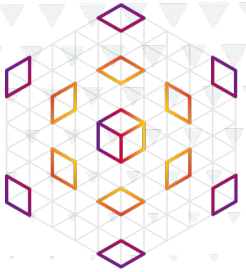
github.com/DataStax-Academy/cassandra-for-data-engineers



Partition size limits and splitting large partitions

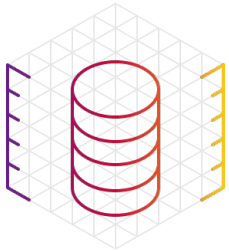


❯ Partition Size Limits

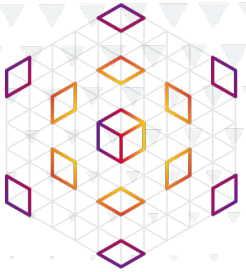


- Theoretical:
  - 2 billion values
  - Node disk size
- Practical:

Cassandra 2	**Cassandra 3 and 4**
100,000 values	10 x 100,000 values
100 MB	10 x 100 MB



❯ Splitting Large Partitions

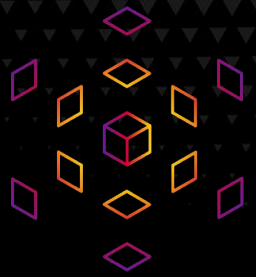


- **Solution**: introduce an additional column to a partition key
  - Use an existing or derived column – convenience
  - Use an artificial “bucket” column – more control

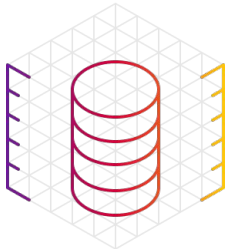
- **Cons**: supported access patterns may change

```
PRIMARY KEY ((sensor), timestamp);
```

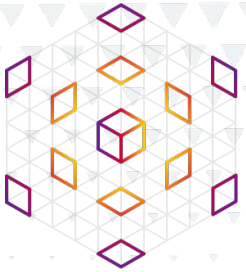
```
PRIMARY KEY ((sensor, date), timestamp);
```



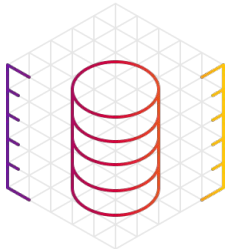
Data duplication and batches



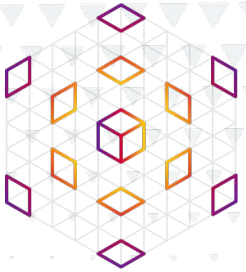
❯ Data Duplication



- Types of data duplication
  - Duplication across tables
  - Duplication across partitions of the same table
  - Duplication across rows of the same partition
- Duplication factor: constant ✔ vs non-constant ✖

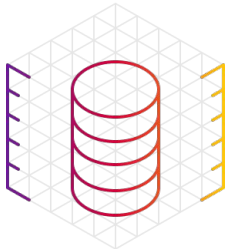


Keeping Duplicated Data Consistent with **Batches**

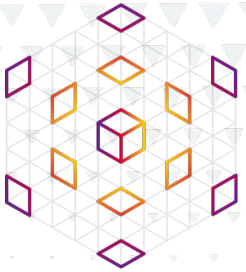


- Logged, single-partition batches
  - Efficient and atomic
  - Use whenever possible
- Logged, multi-partition batches
  - Somewhat efficient and pseudo-atomic
  - Use selectively
- Unlogged and counter batches
  - Do not use

```
BEGIN BATCH
  INSERT INTO ...;
  INSERT INTO ...;
  ...
APPLY BATCH;
BEGIN BATCH
  UPDATE ...;
  UPDATE ...;
  ...
APPLY BATCH;
```

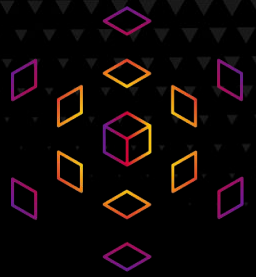


Keeping Duplicated Data Consistent with **MVs**



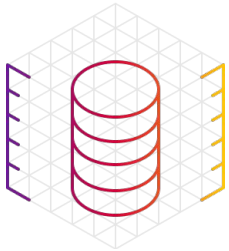
- **Experimental** feature
- Not always applicable
- May become inconsistent
- 10% write penalty to a base table

```
CREATE MATERIALIZED VIEW
networks_by_region AS
  SELECT * FROM networks
  WHERE region IS NOT NULL
    AND name IS NOT NULL
PRIMARY KEY ((region), name);
```

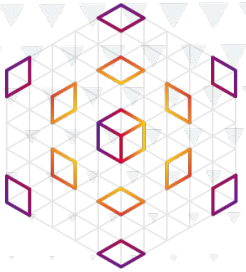


Indexes and materialized views

(+ `allow filtering`)



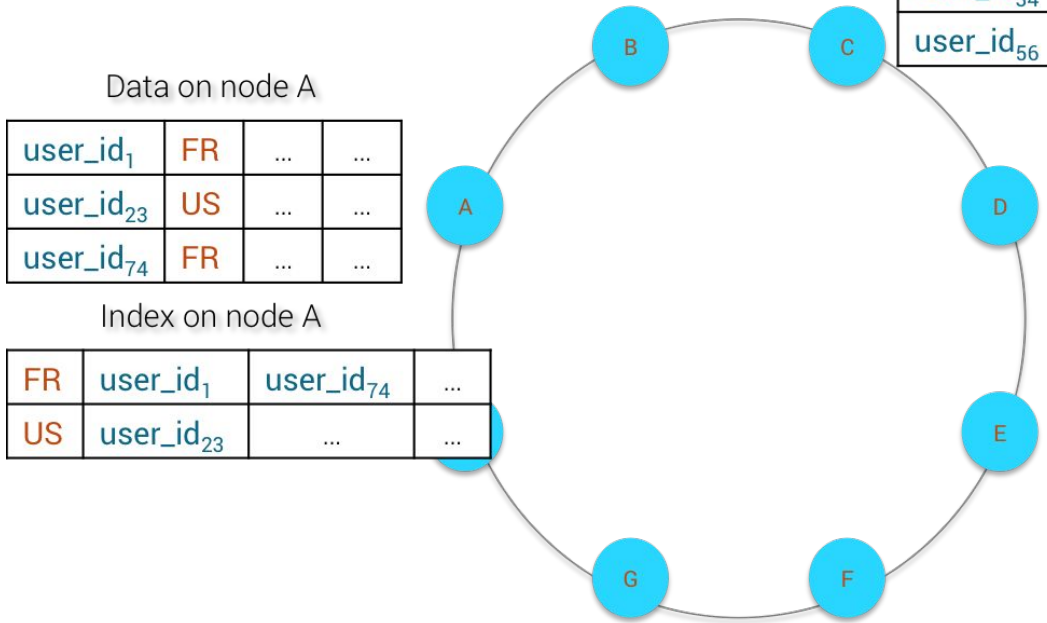
❯ Indexing Mechanisms



- Distributed indexes: highly scalable
  - Tables ← the best solution available
  - Materialized views (experimental)

- Local indexes: not highly scalable
  - Secondary indexes (2i)
  - SSTable-attached secondary indexes (SASI)
  - Storage-Attached Indexes (SAI)

How Secondary Indexes Work



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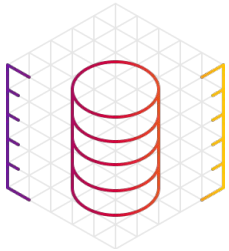
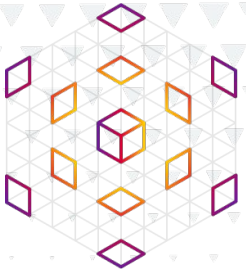
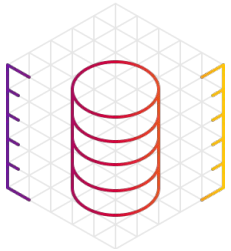


❯ Storage-Attached Indexes (SAI)

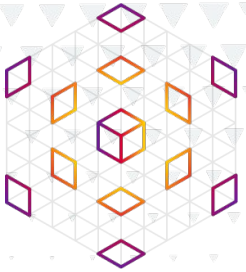


- The best index available
  - Faster writes
  - Less disk space
  - Multiple indexes can be used in one query
  - Reads can be expensive (similar limitations to 2is and SASIs)
- Convenience, not performance

```
CREATE CUSTOM INDEX users_by_name_sai
ON users (name)
USING 'org.apache.cassandra.index.sai.StorageAttachedIndex';
```

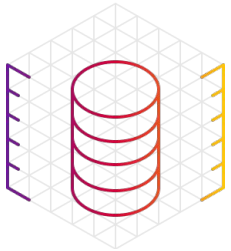


When to use secondary index (1 of 2)

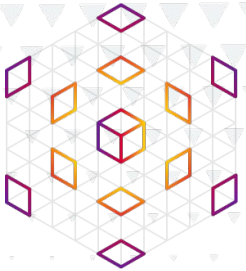


- **Real-time transactional query**: retrieving rows from a large multi-row partition, when both a **partition key** and an indexed column are used in a query.

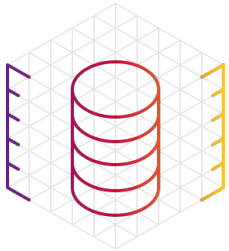
- **Expensive analytical query**: retrieving a large number of rows from potentially many partitions, when only an indexed **low-cardinality** column is used in a query.



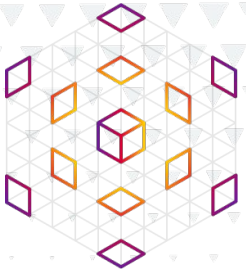
When to use secondary index (2 of 2)



- **Small clusters**: 3-10 nodes with RF=3
- **Infrequent queries**: may not affect the throughput much
- **Queries with LIMIT that can be quickly satisfied**: may not affect the throughput much
- **Convenience over performance**: simpler data modeling while potentially sacrificing throughput and query response time

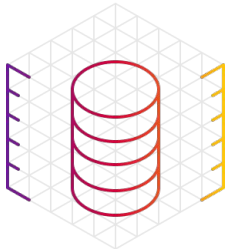


❯ Materialized Views

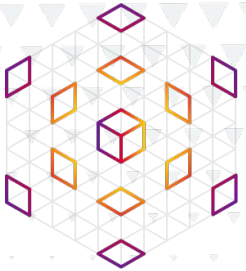


- **Experimental** feature
- Not always applicable
- May become inconsistent
- 10% write penalty to a base table

```
CREATE MATERIALIZED VIEW
networks_by_region AS
  SELECT * FROM networks
  WHERE region IS NOT NULL
    AND name IS NOT NULL
PRIMARY KEY ((region), name);
```

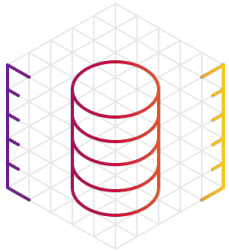


When to Use a Materialized View

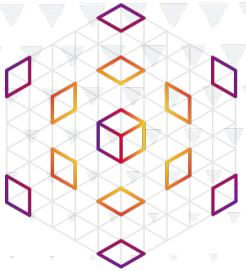


- Queries on higher-cardinality columns
  - Similar advantages as those of regular tables
  - Convenience of automatic view maintenance
  - Reads are as fast as for regular tables

- Important limitations
  - Restrictions on how PRIMARY KEY is constructed
  - 10% slower writes to the base table
  - Base-view inconsistencies
  - Use LOCAL_QUORUM and higher for base table writes
  - Disabled in Astra DB, experimental

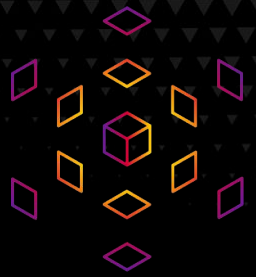


❯ Allow Filtering

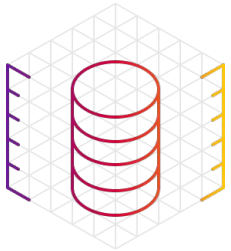


- Generally, using ALLOW FILTERING is not recommended

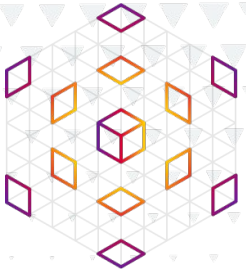
- But **scanning may be cheaper than indexing** in some cases
  - Scanning within a small partition
  - Scanning within a large partition based on a low-cardinality column
    (most rows from the partition will be returned)
  - Scanning a table based on a low-cardinality column for analytical purposes
    (most rows from the table will be returned)



Concurrent data access and lightweight transactions



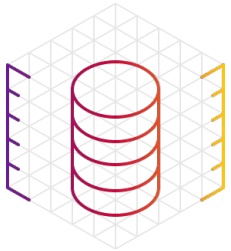
❯ Race conditions



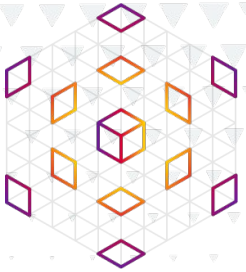
- Multiple transactions reading and writing the same piece of data concurrently, possibly leaving the data in a state **inconsistent with reality**

- Examples: registering a new username, counting votes, updating account balance, updating an order status, updating the highest bid

```
User 1: read(10)   10<20   write(20)
-------------------------------------------------> time
User 2:         read(10)   10<15   write(15)
```



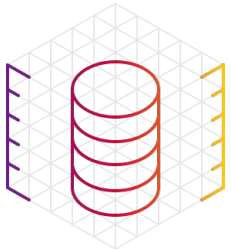
Linearizable Consistency



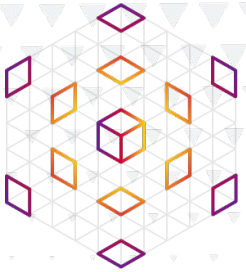
- Linearizable consistency ensures that concurrent transactions produce the same result as if they execute in a sequence, one after another
- Lightweight transactions (**LWTs**) in Cassandra and Astra DB

```
User 1: read(10) 10<20 write(20)
-------------------------------------------------> time
User 2:                          read(20) 20>15
```

```
User 1:                          read(15) 15<20 write(20)
-------------------------------------------------> time
User 2: read(10) 10<15 write(15)
```

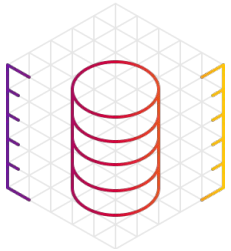


❯ Lightweight transactions (**LWTs**)

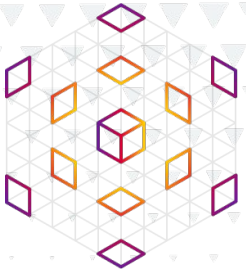


- Guarantee linearizable consistency
- Use with **race conditions and low data contention**
- Require 4 coordinator-replica round trips
- May become a bottleneck with high data contention

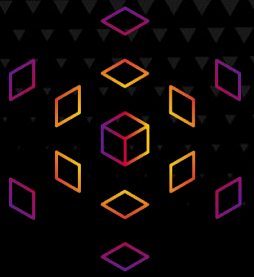
```
INSERT INTO ... VALUES ...
IF NOT EXISTS;

UPDATE ... SET ... WHERE ...
IF EXISTS | IF predicate [ AND ... ];

DELETE ... FROM ... WHERE ...
IF EXISTS | IF predicate [ AND ... ];
```



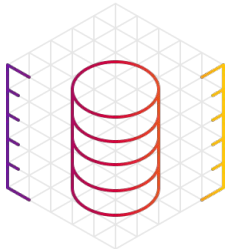
❯ Dealing with High Data Contention



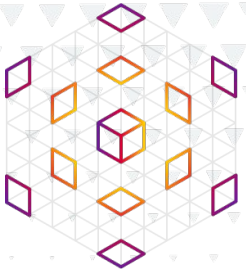
- Change a data model to eliminate race conditions
  - Isolate computation by isolating data
  - Record each transaction separately and aggregate data later
- Use a queue to control data contention
  - Astra Streaming



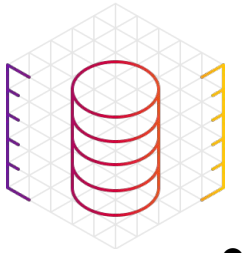
Tombstones



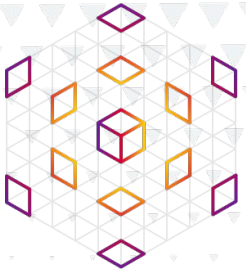
❯ Tombstones



- Written markers for deleted data
  - DELETEs
  - Data with TTL
  - UPDATEs and INSERTs with explicit NULL values
  - “Overwritten” collections
  - Multiple types: cell, row, range, partition, TTL tombstones for cells
  - Cleaned up during compaction after `gc_grace_seconds`

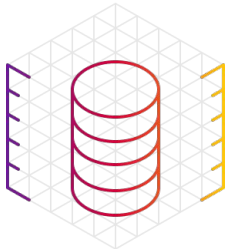


❯ Tombstone Issue 1: Large Partitions

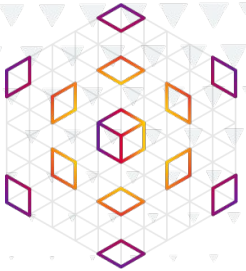


- Tombstone = additional data to store and read
- Query performance degrades, heap memory pressure increases
- `tombstone_warn_threshold`
  - Warning when more than 1,000 tombstones are scanned by a query
- `tombstone_failure_threshold`
  - Aborted query when more than 100,000 tombstones are scanned

- Consider **LCS** (leveled-compaction strategy + tuning) to ease read load
- Decrease `gc_grace_seconds` (default is 864000 or 10 days)
  - Deleted data and tombstones can be purged during compaction after `gc_grace_seconds`
  - Adjust repair frequency accordingly! (see next slide)

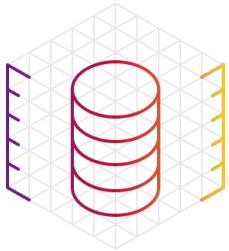


Tombstone Issue 2: Zombie or Resurrected Data

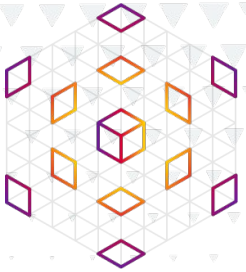


1. A replica node is unresponsive and receives no tombstone
2. Other replica nodes receive tombstones
3. The tombstones get purged after `gc_grace_seconds` and compaction
4. The unresponsive replica comes back online and resurrects data that was previously marked as deleted

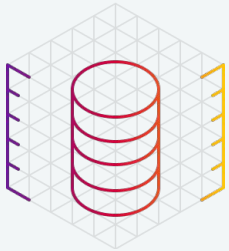
- Run repairs within the `gc_grace_seconds` and on a regular basis
- `nodetool repair` manually when needed
- Do not let a node rejoin the cluster after the `gc_grace_seconds`
  - but if you do, start it in `rebuild` mode after deleting `data/`



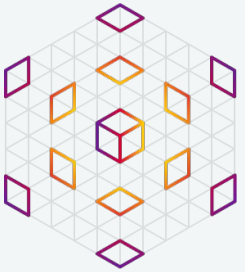
❯ Other Tombstones Considerations



- Design data models that avoid frequent deletes
- Use the most coarse-grained delete possible:
  (truncate) > partition > range > row > cell
  - Truncating/dropping a table is better
    than deleting each partition in the table
  - Deleting a partition is better
    than deleting each row in the partition
  - Deleting a row is better
    than deleting each value in the row



Key Takeaways



Partition Size

100K and 100MB

Bucketing

Data duplication and batches

Avoid non-constant duplication factors

Single-partition batches are efficient

Indexing

Materialized views are scalable but have other issues

Secondary indexes are good for searching within large partitions

LWTs

Linearizable consistency

Race conditions and low data contention

Design data models that eliminate race conditions

Tombstones

Design data models that avoid frequent deletions

Compact and repair to purge tombstones and avoid resurrected data