# Denormalization

## Big Data Systems

Dr. Rubi Boim

# Motivation (for this course)

- The basics of wide column data modeling

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# Denormalization

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**Denormalization** is a strategy used on a previously-normalized 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 or by grouping data.[1][2] It is often motivated by performance or scalability in relational database software needing to carry out very large numbers of read operations. Denormalization differs from the unnormalized form in that denormalization benefits can only be fully realized on a data model that is otherwise normalized.

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**Also applied to Relational Databases**


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What is normalized?

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# Functional dependency

- A constraint between two sets of attributes
  **X—>Y**

For example

- {country} —> {continent}
  if we know the country is France, we know the continent is Europe
- {user_id} —> {user_name}
  if we know the user id is 123 we know it is “Rubi"

# Relational DB & Normalization

- “requires” the data to be normalized in order to
  - Reduce data redundancy
  - Improve data integrity

# Relational DB & Normalization

- “requires” the data to be normalized in order to
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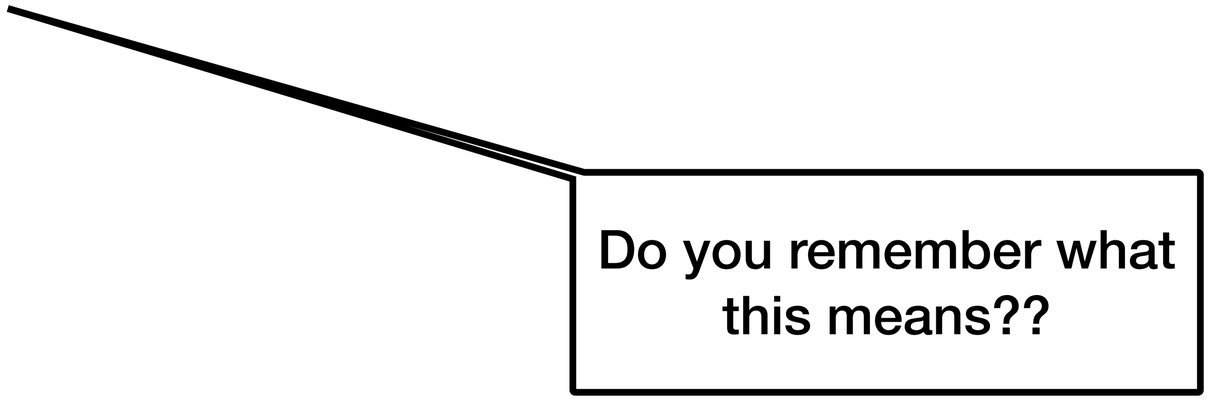
  - Improve data integrity



# Relational DB & Normalization

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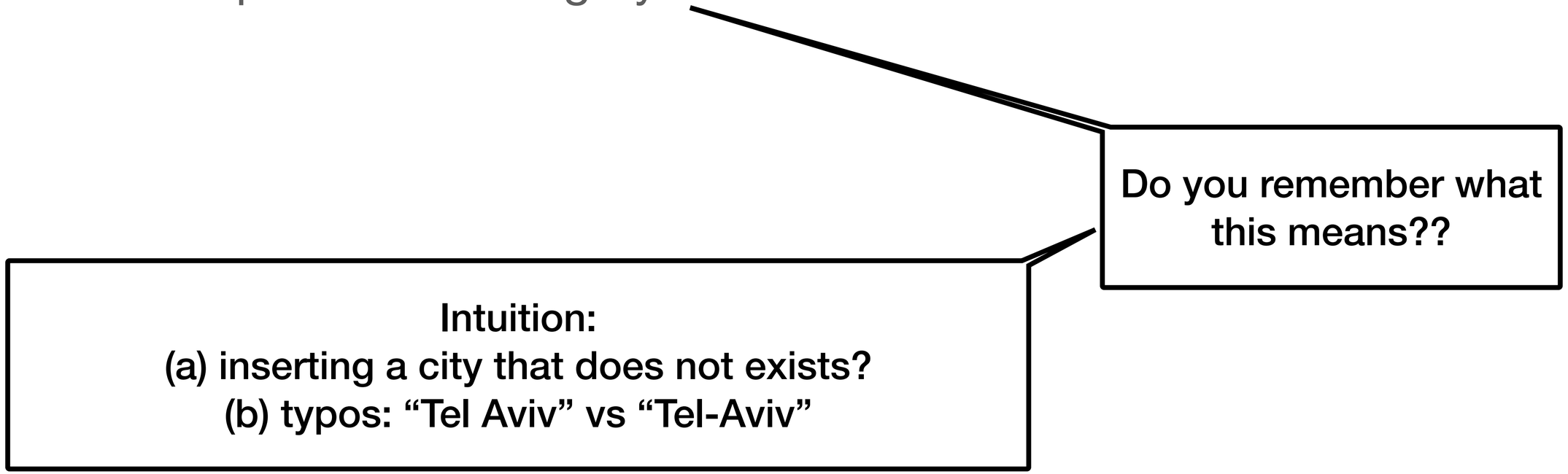
  - Reduce data redundancy
  - Improve data integrity



# Relational DB & Normalization

- “requires” the data to be normalized in order to
  - Reduce data redundancy
  - Improve data integrity

**A relation R is in 3rd normal form if:**

**Whenever there is a nontrivial dependency A1,A2,…,An —>B for R, then {A1, A2, …, An} a super key for R,**
**or B is part of a key**

(See “Database Systems” course for more info)

# Normalization - Example

**users-ver1**

| user_id | fname | lname | city | country |
|---|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv | Israel |
| 102 | Tova | Milo | Tel Aviv | Israel |
| 103 | Lebron | James | Los Angeles | USA |

What are the functional dependencies?

# Normalization - Example

**users-ver1**

| user_id | fname | lname | city | country |
|---|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv | Israel |
| 102 | Tova | Milo | Tel Aviv | Israel |
| 103 | Lebron | James | Los Angeles | USA |

**What are the functional dependencies?**

**{user_id} —> {fname,lname,city,country}**
**user_id is a key 👍🏻**

# Normalization - Example

**users-ver1**

| user_id | fname | lname | city | country |
|---|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv | Israel |
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**What are the functional dependencies?**

**{city} —> {country}**
**city is not part of the key ❌**

# Normalization - Example

**users-ver1**

| user_id | fname | lname | city | country |
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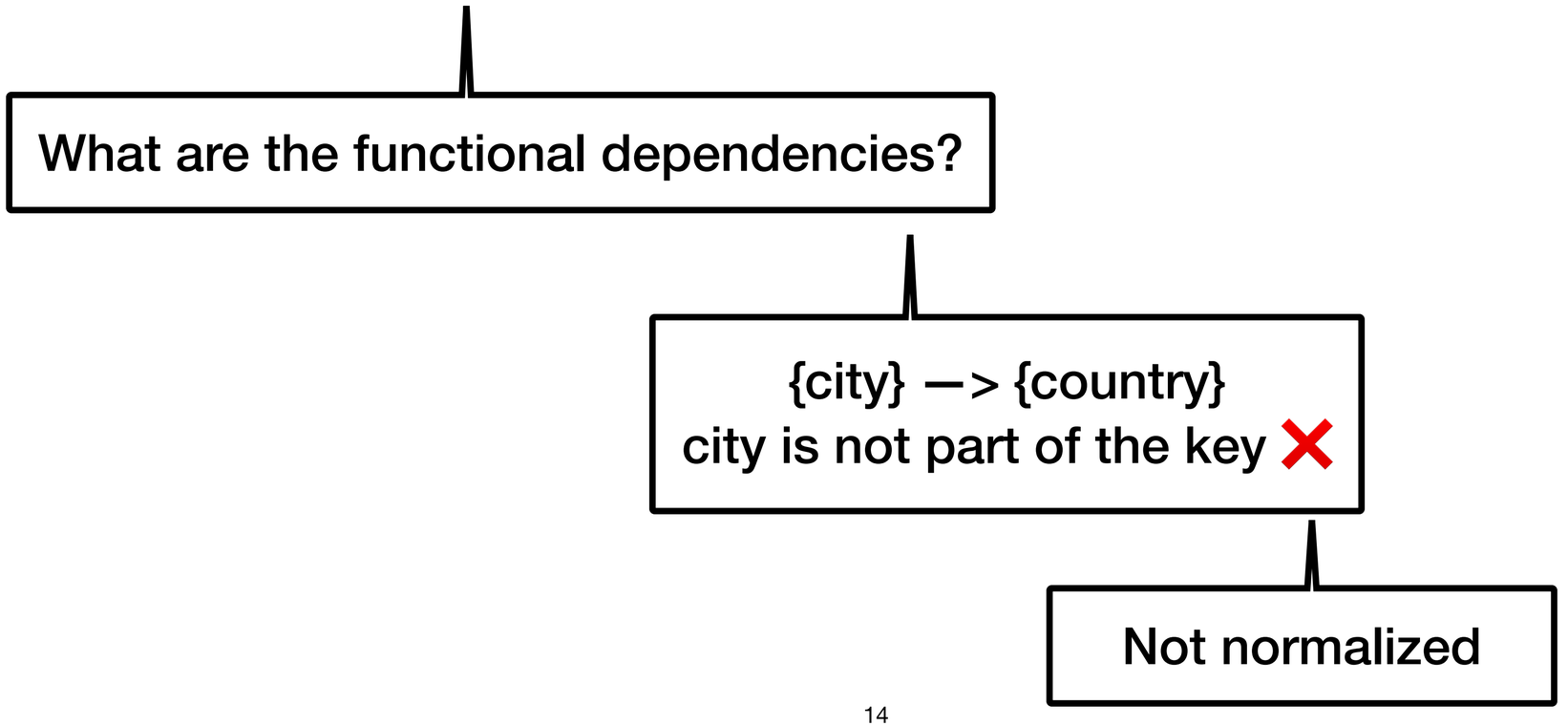

# Normalization - Example

**users-ver1**

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|---|---|---|---|---|
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What are the functional dependencies?

{city} —> {country}
city is not part of the key ❌

Not normalized

So how can you normalize it?

# Normalization - Example

**users-ver1**

| user_id | fname | lname | city | country |
|---|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv | Israel |
| 102 | Tova | Milo | Tel Aviv | Israel |
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**users-ver2**

| user_id | fname | lname | city |
|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv |
| 102 | Tova | Milo | Tel Aviv |
| 103 | Lebron | James | Los Angeles |

**cities**

| city | country |
|---|---|
| Tel Aviv | Israel |
| Los Angeles | USA |

# Normalization - Example

**users-ver1**

| user_id | fname | lname | city | country |
|---|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv | Israel |
| 102 | Tova | Milo | Tel Aviv | Israel |
| 103 | Lebron | James | Los Angeles | USA |

We assume users will be much bigger than cities —> reduced storage

What is the difference? Data integrity? Storage?

**users-ver2**

| user_id | fname | lname | city |
|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv |
| 102 | Tova | Milo | Tel Aviv |
| 103 | Lebron | James | Los Angeles |

**cities**

| city | country |
|---|---|
| Tel Aviv | Israel |
| Los Angeles | USA |

# Normalized DB

- Data integrity ✔
- Reduced Storage ✔
- JOINS are used to retrieve data

```
SELECT users.*, cities.country
FROM users, cities
WHERE users.city = cities.city
```

**users**

| user_id | fname | lname | city |
|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv |
| 102 | Tova | Milo | Tel Aviv |
| 103 | Lebron | James | Los Angeles |

**cities**

| city | country |
|---|---|
| Tel Aviv | Israel |
| Los Angeles | USA |

# Normalized DB

So whats the problem in Big Data?

- Data integrity ✔
- Reduced Storage ✔
- JOINS are used to retrieve data

```
SELECT users.*, cities.country
FROM users, cities
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**users**

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| 101 | Rubi | Boim | Tel Aviv |
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**cities**

| city | country |
|---|---|
| Tel Aviv | Israel |
| Los Angeles | USA |

# Normalized DB

So whats the problem in Big Data?

- Data integrity ✓ — do not scale
- Reduced Storage ✓ — cheap today
- JOINS are used to retrieve data — do not scale

```
SELECT users.*, cities.country
FROM users, cities
WHERE users.city = cities.city
```

**users**

| user_id | fname | lname | city |
|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv |
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**cities**

| city | country |
|---|---|
| Tel Aviv | Israel |
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# Denormalization

- No 3NF
- Improve reads / writes performance dramatically
  - At the expense of data integrity and storage
  - Requires more writes
- Also applied on relational DBs
- “Workaround” when joins are unavailable (wide columns DBs)

# Example (continue)

cities

| city | country |
|---|---|
| Tel Aviv | Israel |
| Los Angeles | USA |

```
SELECT users.*, cities.country
FROM users, cities
WHERE users.city = cities.city
```

users

| user_id | fname | lname | city |
|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv |
| 102 | Tova | Milo | Tel Aviv |
| 103 | Lebron | James | Los Angeles |

```
SELECT * FROM users-deno
```

users-deno

| user_id | fname | lname | city | country |
|---|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv | Israel |
| 102 | Tova | Milo | Tel Aviv | Israel |
| 103 | Lebron | James | Los Angeles | USA |

# Example (continue)

cities

| city | country |
|---|---|
| Tel Aviv | Israel |
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```
SELECT users.*, cities.country
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users

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users-deno

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Which version is faster?

# Example (continue)

cities

| city | country |
|---|---|
| Tel Aviv | Israel |
| Los Angeles | USA |

```
SELECT users.*, cities.country
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users

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users-deno

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Which version is faster?

# Example (continue)

cities

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users-deno

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Which version is faster?

If we have 10k queries per second, which will be (much) faster?

# Moving to Cassandra

| user_id | fname | lname | city | country |
|---|---|---|---|---|
| 101 | Rubi | Boim | Tel Aviv | Israel |
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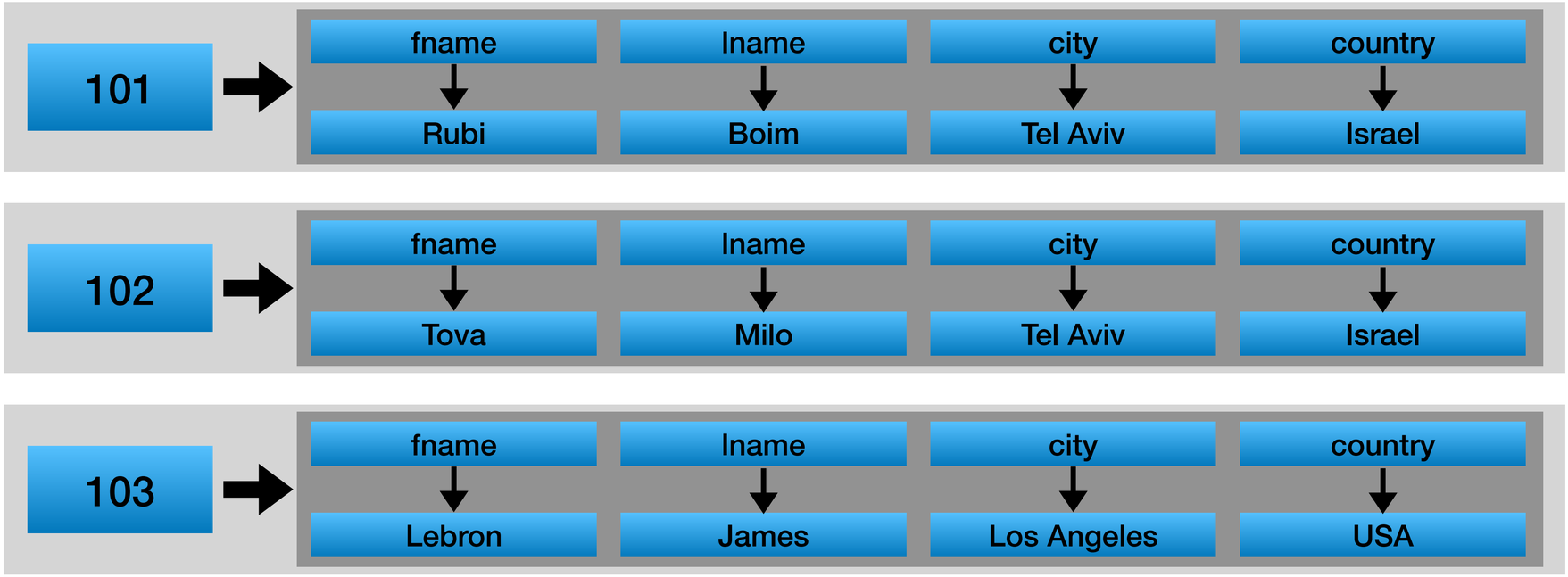
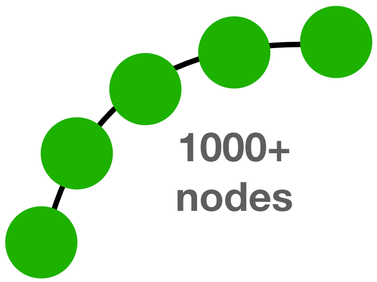



**What about this query**

```
SELECT * FROM users
WHERE country = "Israel"
```

Is this an efficient query?



# Moving to Cassandra

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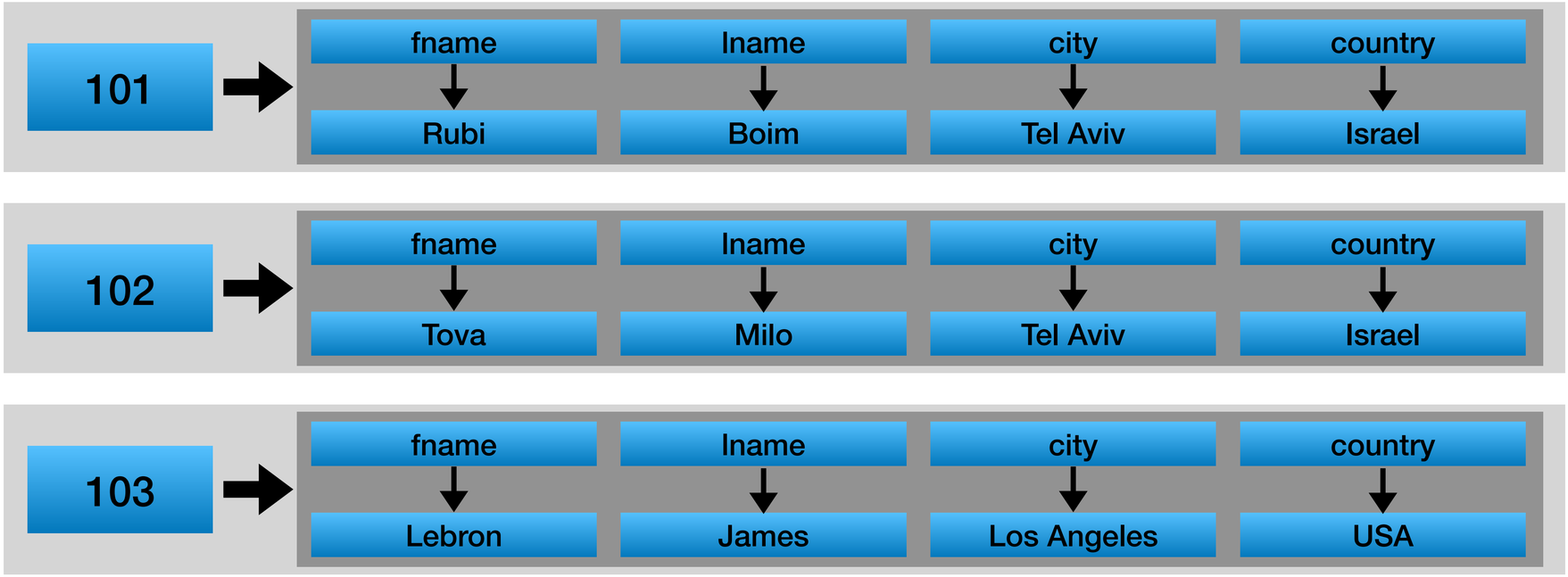
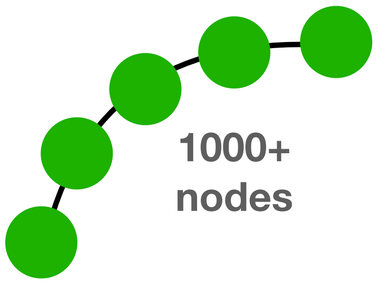



**What about this query**

```
SELECT * FROM users
WHERE country = "Israel"
```

Is this an efficient query?

No




Error! It is not even a valid query…

# Moving to Cassandra

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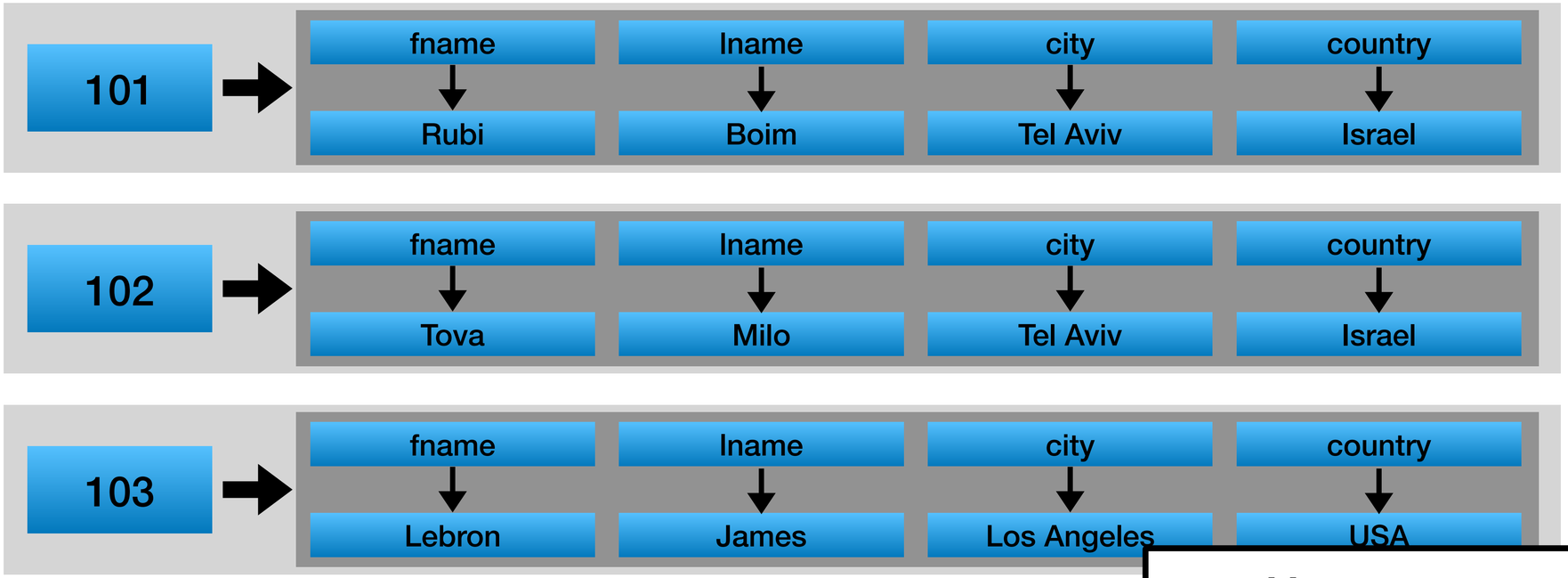


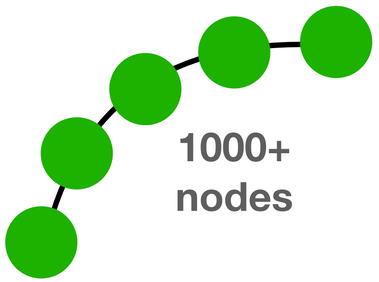

How can we solve this?

**What about this query**

```
SELECT * FROM users
WHERE country = "Israel"
```

Is this an efficient query?

No



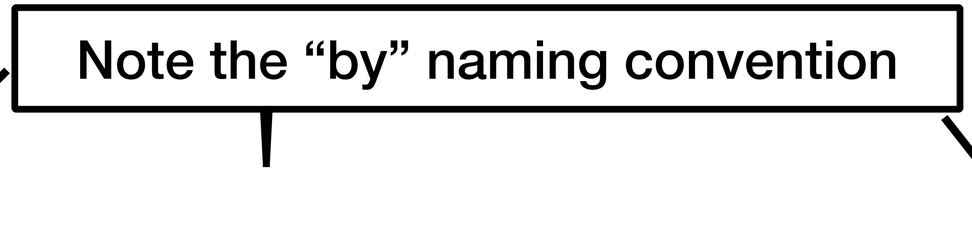

Error! It is not even a valid query…

# Denormalization by 2 tables

```
CREATE TABLE users_by_id (
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   country      TEXT,
   PRIMARY KEY (user_id)
);
```

```
CREATE TABLE users_by_country (
   country      TEXT,
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   PRIMARY KEY (country)
);
```

# Denormalization by 2 tables




```
CREATE TABLE users_by_id (
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   country      TEXT,
   PRIMARY KEY (user_id)
);
```

```
CREATE TABLE users_by_country (
   country      TEXT,
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   PRIMARY KEY (country)
);
```

# Denormalization by 2 tables

Note the “by” naming convention

```
CREATE TABLE users_by_id (
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   country      TEXT,
   PRIMARY KEY (user_id)
);
```

```
CREATE TABLE users_by_country (
   country      TEXT,
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   PRIMARY KEY (country)
);
```

Would this work?

# Denormalization by 2 tables

Note the “by” naming convention

```
CREATE TABLE users_by_id (
   user_id      BIGINT,
   fname        TEXT,
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   city         TEXT,
   country      TEXT,
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```

```
CREATE TABLE users_by_country (
   country      TEXT,
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   PRIMARY KEY (country)
);
```

Would this work?

How many rows would do we have here?

# Denormalization by 2 tables

Note the “by” naming convention

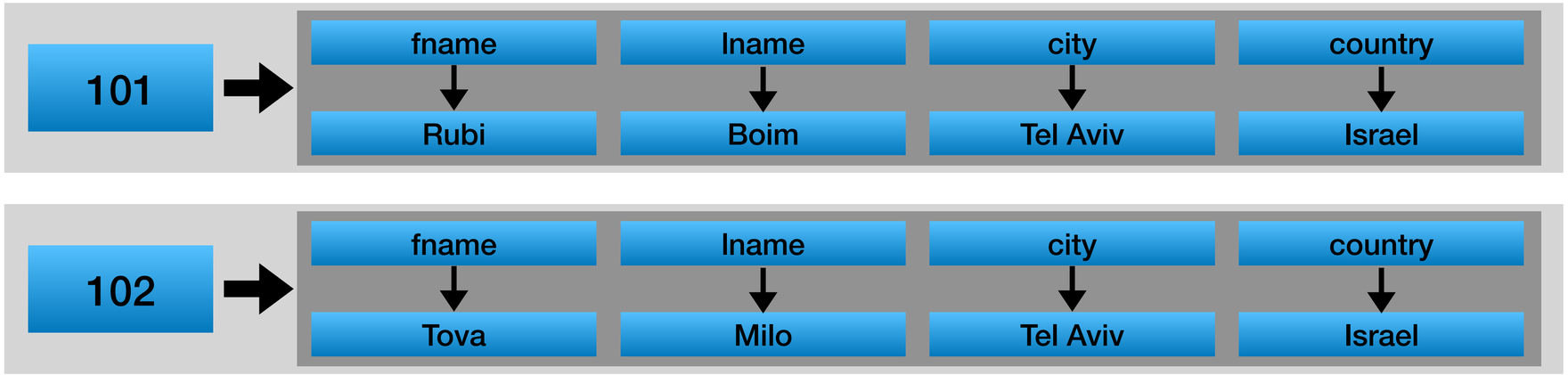
```
CREATE TABLE users_by_id (
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   country      TEXT,
   PRIMARY KEY (user_id)
);
```

```
CREATE TABLE users_by_country (
   country      TEXT,
   user_id      BIGINT,
   fname        TEXT,
   lname        TEXT,
   city         TEXT,
   PRIMARY KEY (country, user_id)
);
```

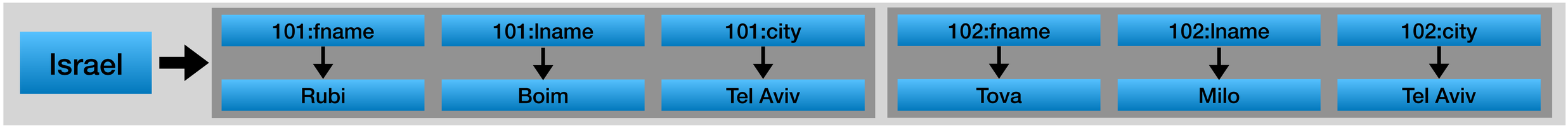
Now it is ok :)

# Denormalization by 2 tables

`users_by_id`

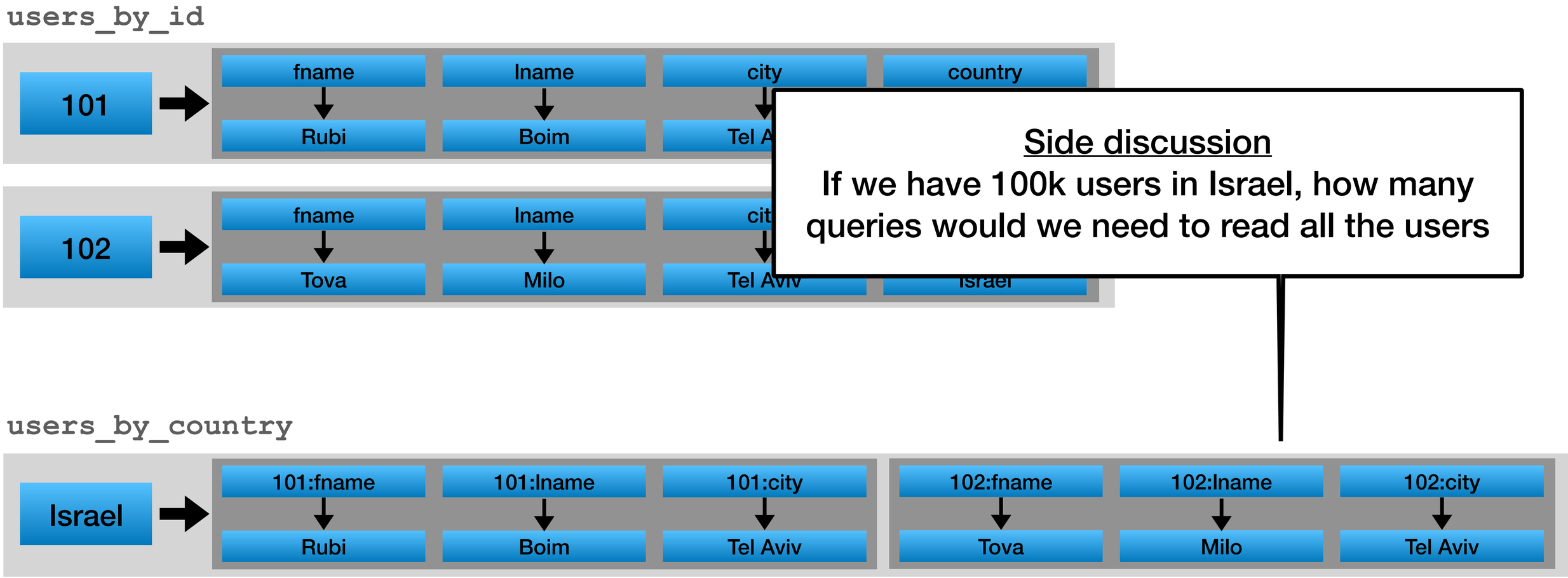



`users_by_country`




```
SELECT * FROM users_by_country WHERE country = "Israel"
```

# Denormalization by 2 tables

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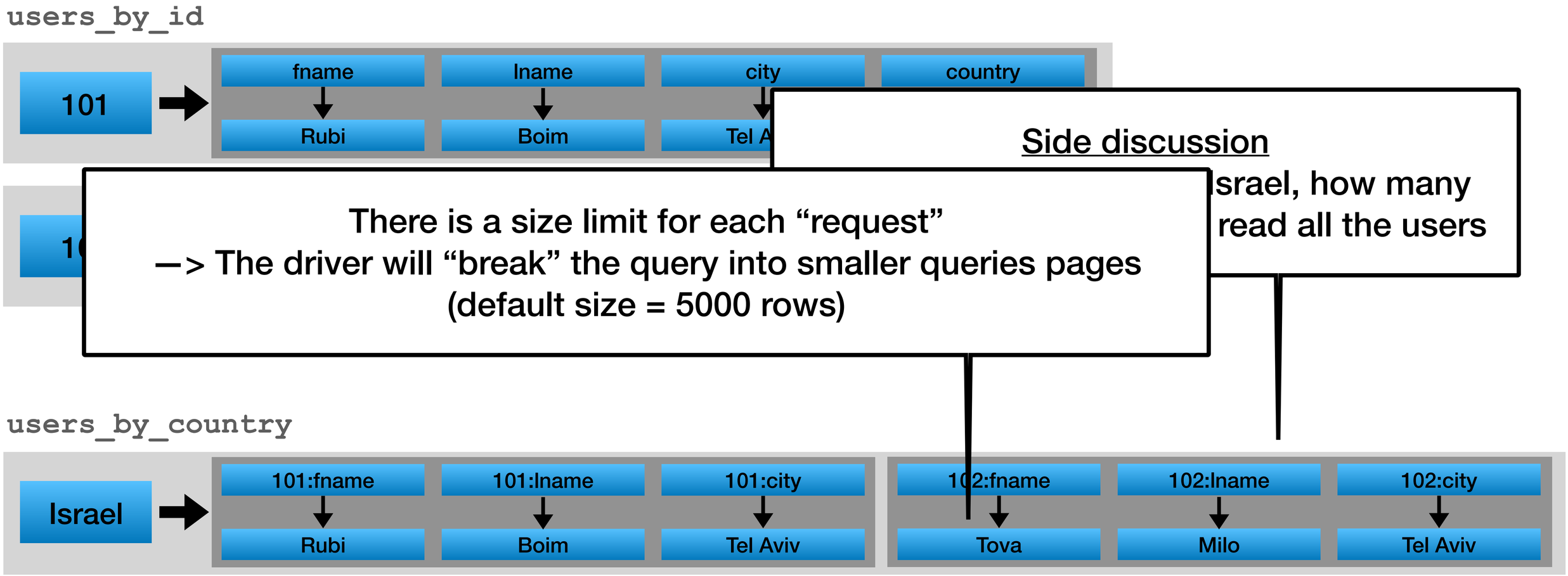
# Denormalization by 2 tables



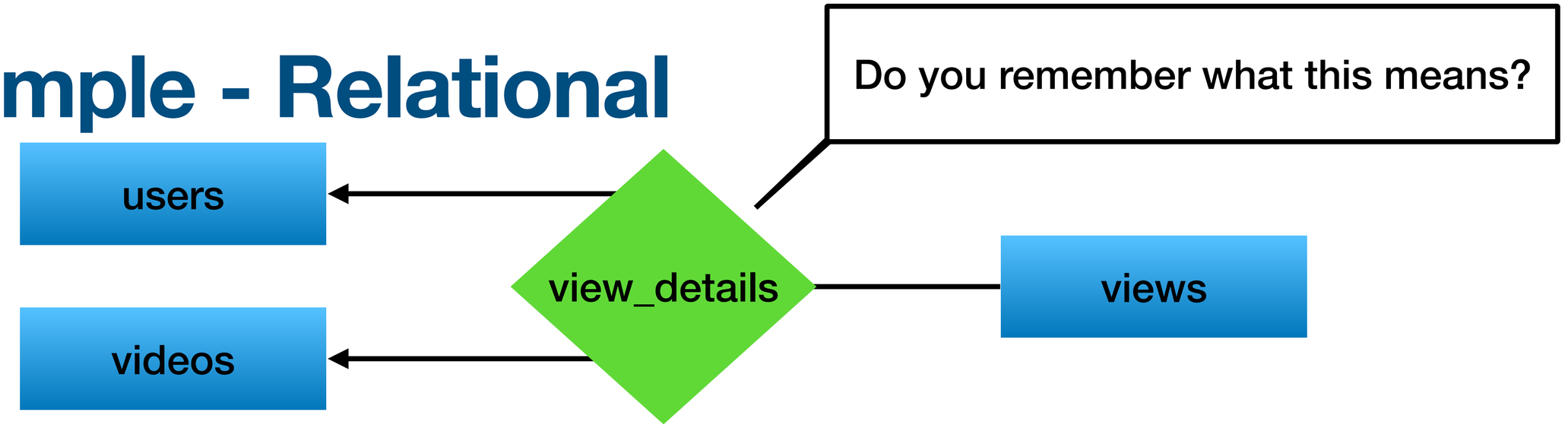

```
SELECT * FROM users_by_country WHERE country = “Israel”
```

# Interesting .

- We saw 2 different ways to denormalize:
  - Merging 2 tables into 1 table
  - Splitting 1 table into 2 tables

- Denormalization is crucial for “correct” data modeling in Big Data

# Example - Relational




**users**

| user_id | name | city | … |
|---|---|---|---|
| 101 | Rubi Boim | Tel Aviv | |
| 102 | Tova Milo | Tel Aviv | |
| 103 | Lebron James | Los Angeles | |

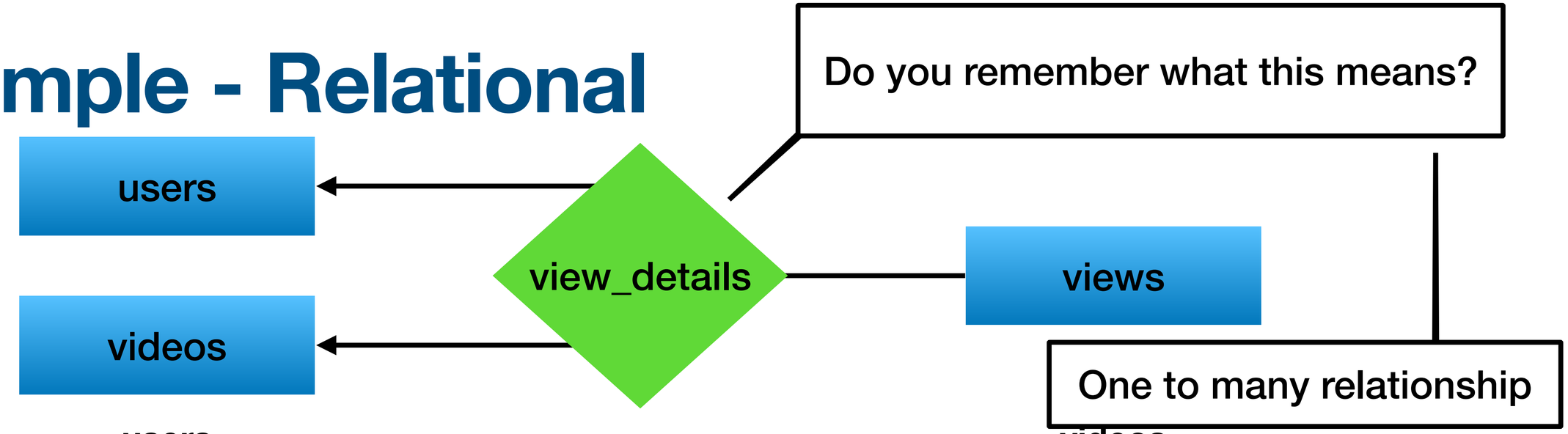
**videos**

| video_id | title | year | … |
|---|---|---|---|
| 1 | Bad Boys | 1995 | |
| 2 | Top Gun | 1986 | |
| 3 | American Pie | 1999 | |

**views**

| view_id | user_id | video_id | device | … |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |

# Example - Relational

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**videos**

| video_id | title | year | … |
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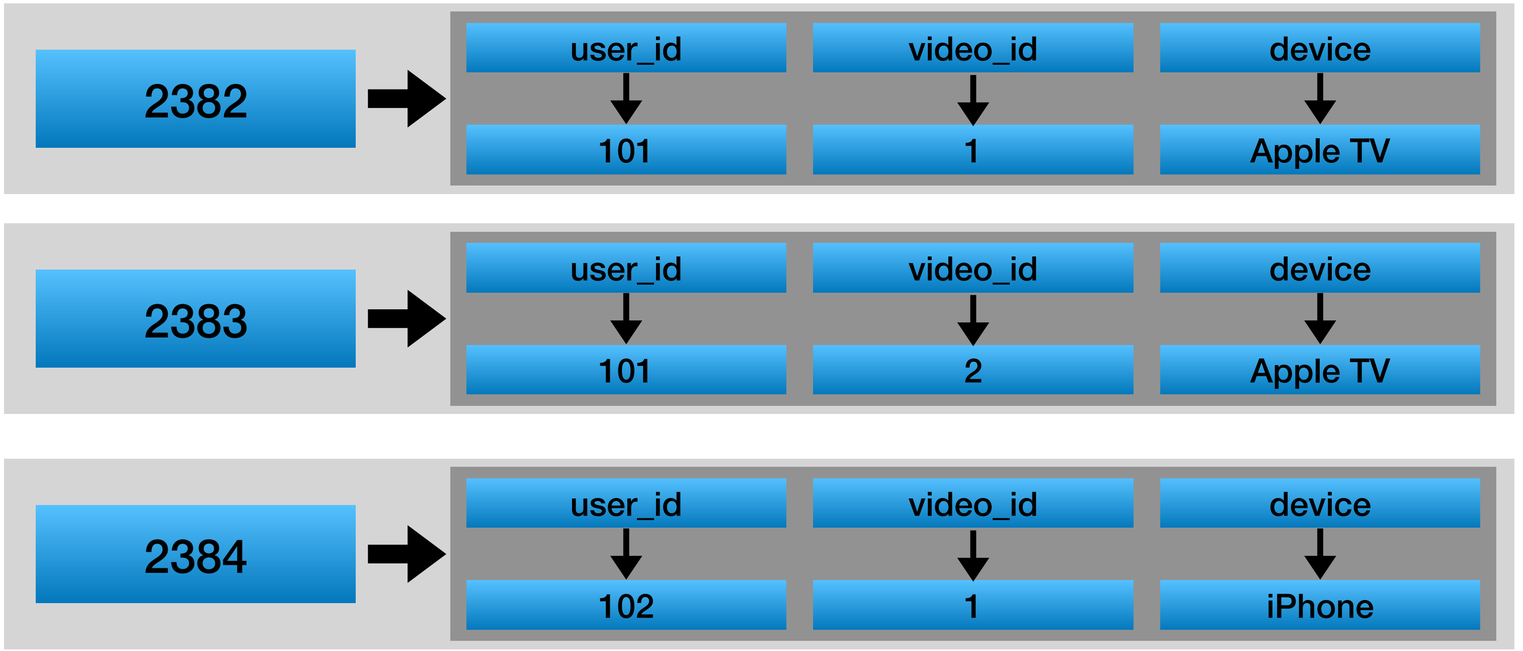
| 3 | American Pie | 1999 | |

**views**

| view_id | user_id | video_id | device | … |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |

# Example - Cassandra

```
CREATE TABLE views (
    view_id         TIMEUUID,
    user_id         BIGINT,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((view_id))
);
```




**Which queries can we efficiently return?**

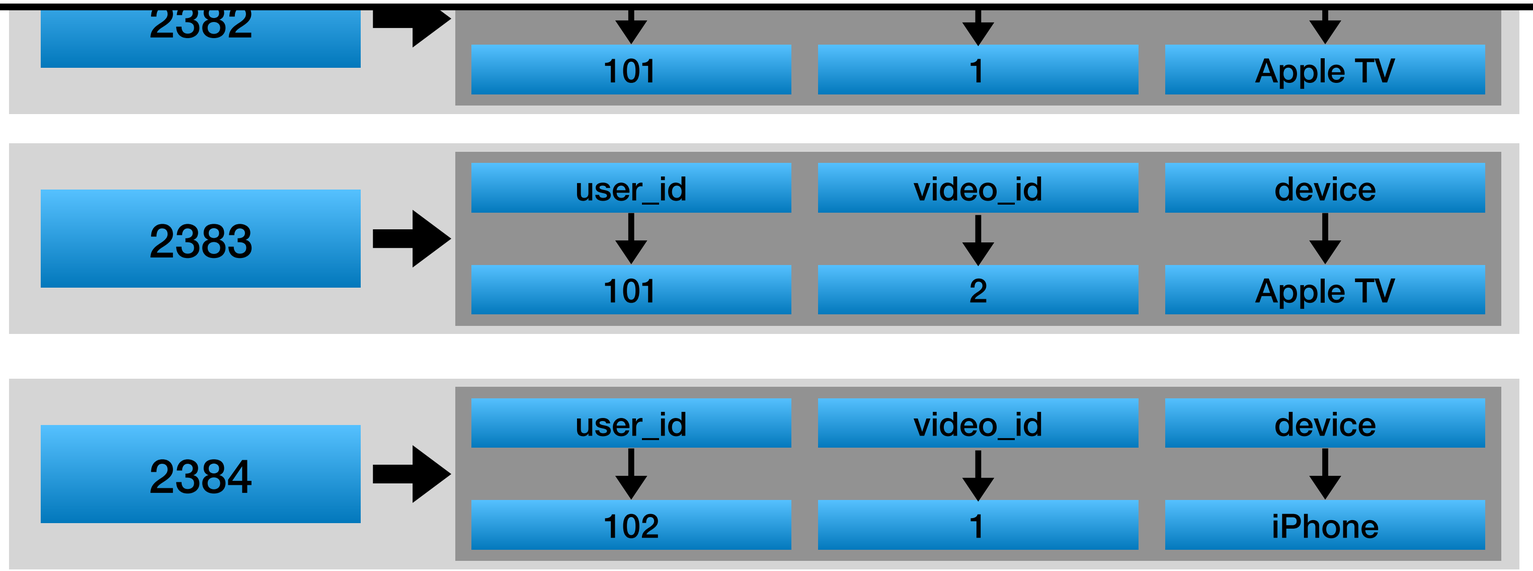
**views**

| view_id | user_id | video_id | device | ... |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |

# Example - Cassandra

Side discussion - why did we switch to TIMEUUID instead of Integer?

```
CREATE TABLE views (
    view_id         TIMEUUID,
    user_id         BIGINT,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((view_id))
);
```




**Which queries can we efficiently return?**

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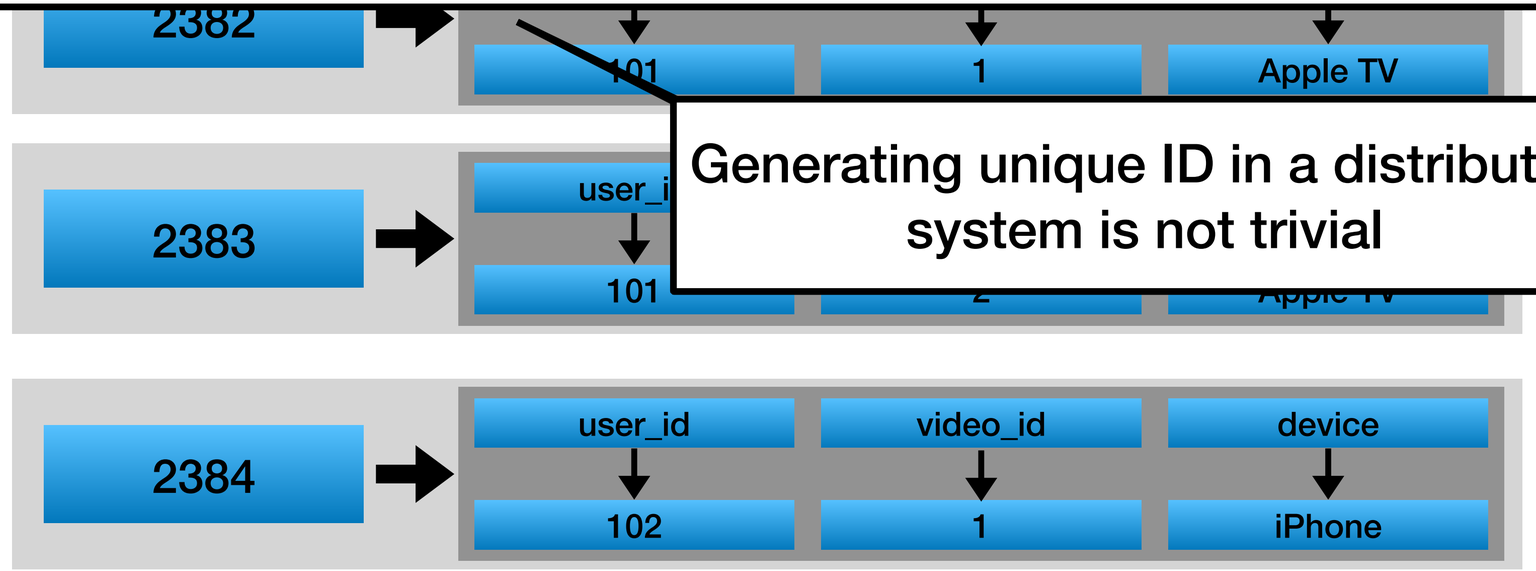
# Example - Cassandra

```
CREATE TABLE views (
    view_id         TIMEUUID,
    user_id         BIGINT,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((view_id))
);
```

Side discussion - why did we switch to TIMEUUID instead of Integer?

Generating unique ID in a distributed system is not trivial



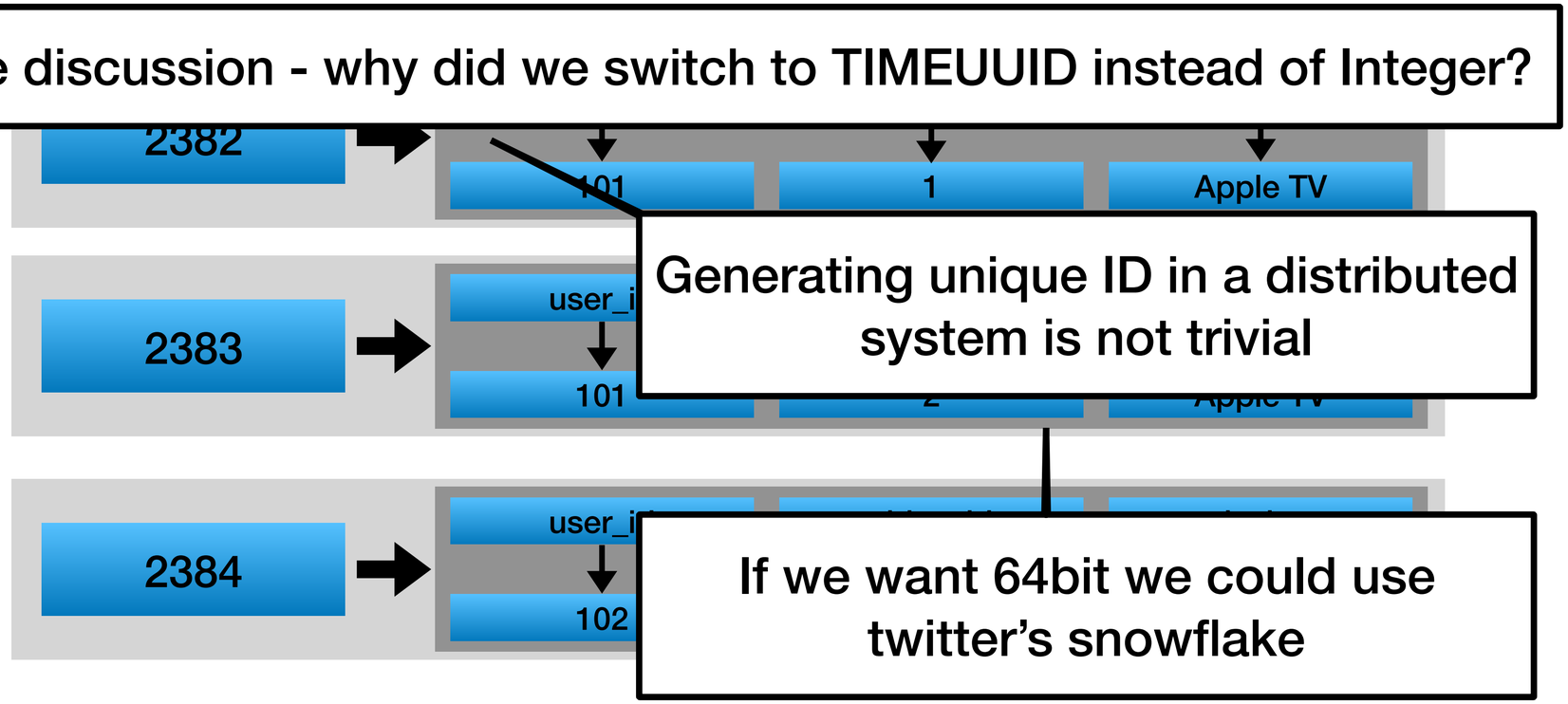

**Which queries can we efficiently return?**

**views**

| view_id | user_id | video_id | device | … |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |

# Example - Cassandra

```
CREATE TABLE views (
    view_id         TIMEUUID,
    user_id         BIGINT,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((view_id))
);
```



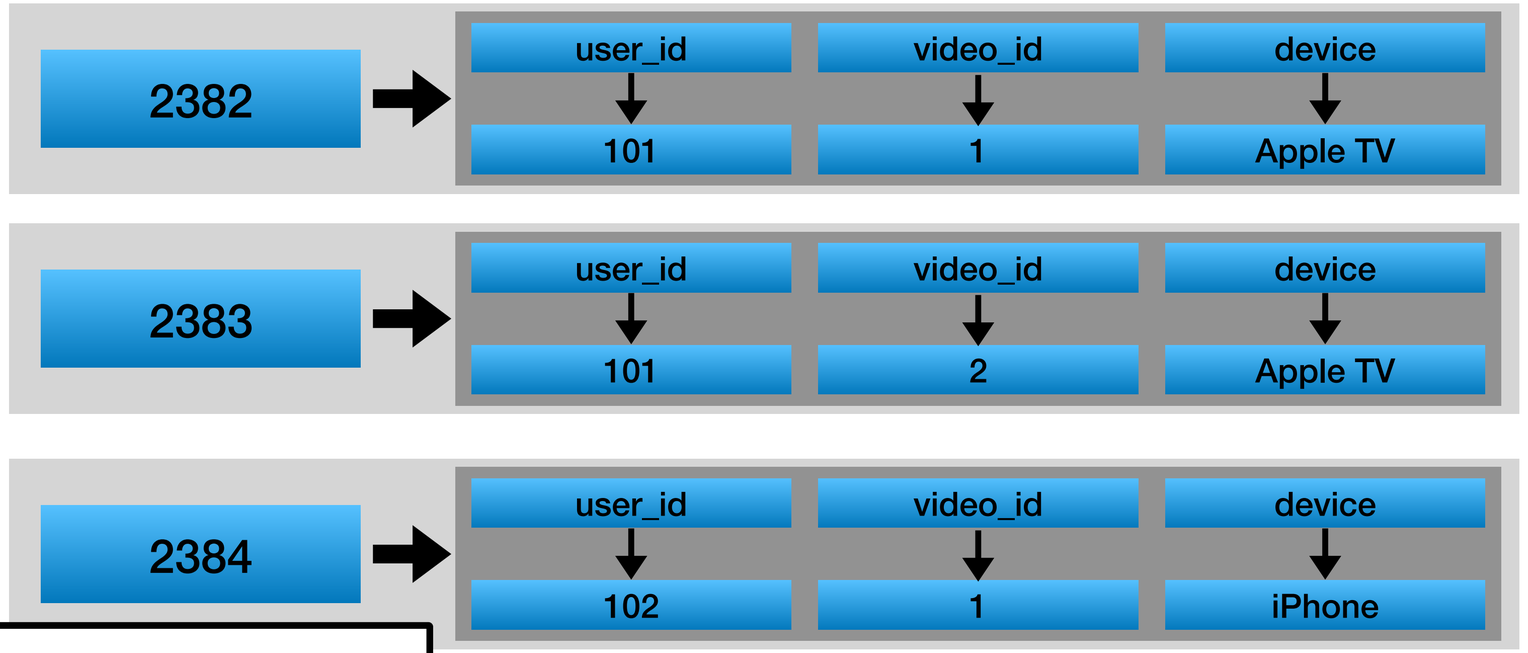

**Which queries can we efficiently return?**

**views**

| view_id | user_id | video_id | device | … |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |

# Example - Cassandra

```
CREATE TABLE views (
    view_id         TIMEUUID,
    user_id         BIGINT,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((view_id))
);
```




SELECT * FROM views WHERE view_id = ?

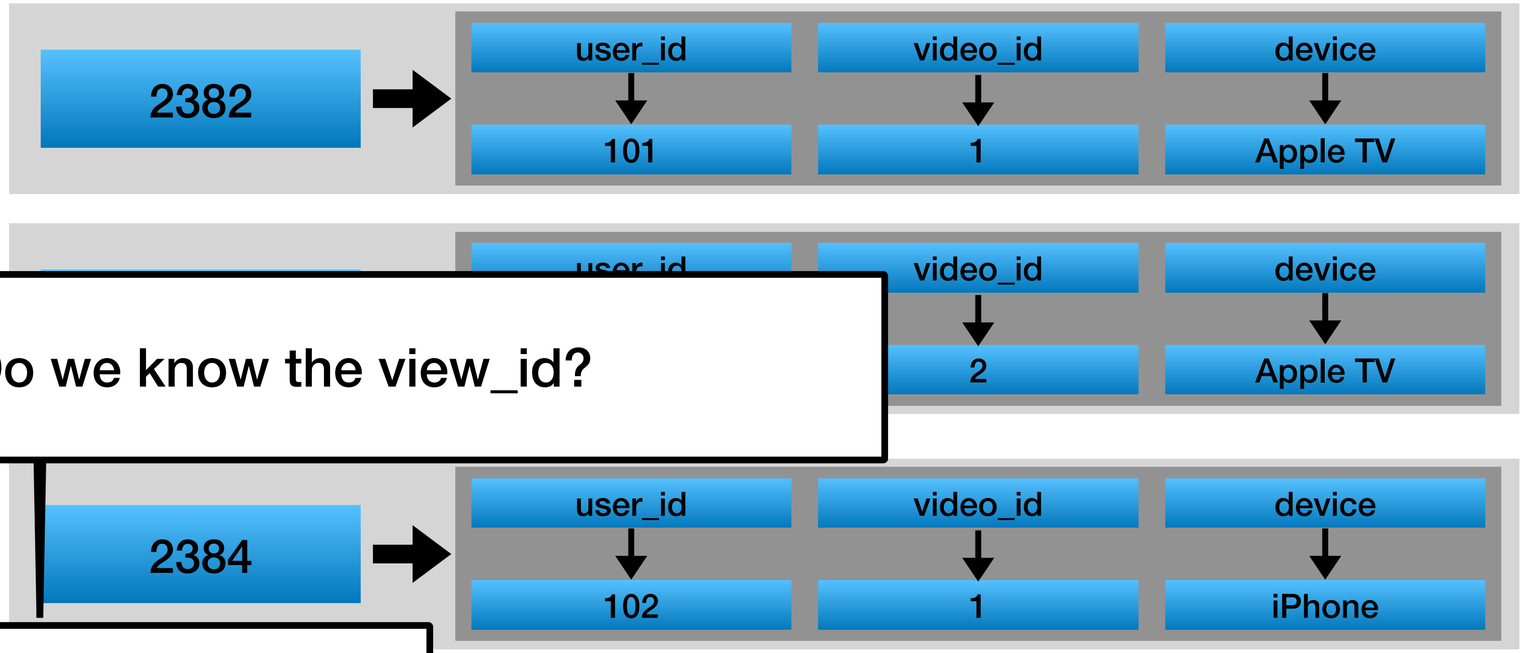
**Which queries can we efficiently return?**

**views**

| view_id | user_id | video_id | device | ... |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |

# Example - Cassandra

```
CREATE TABLE views (
    view_id         TIMEUUID,
    user_id         BIGINT
    video_id
    device
    PRIMARY KEY ((
);
```




Do we know the view_id?

SELECT * FROM views WHERE view_id = ?

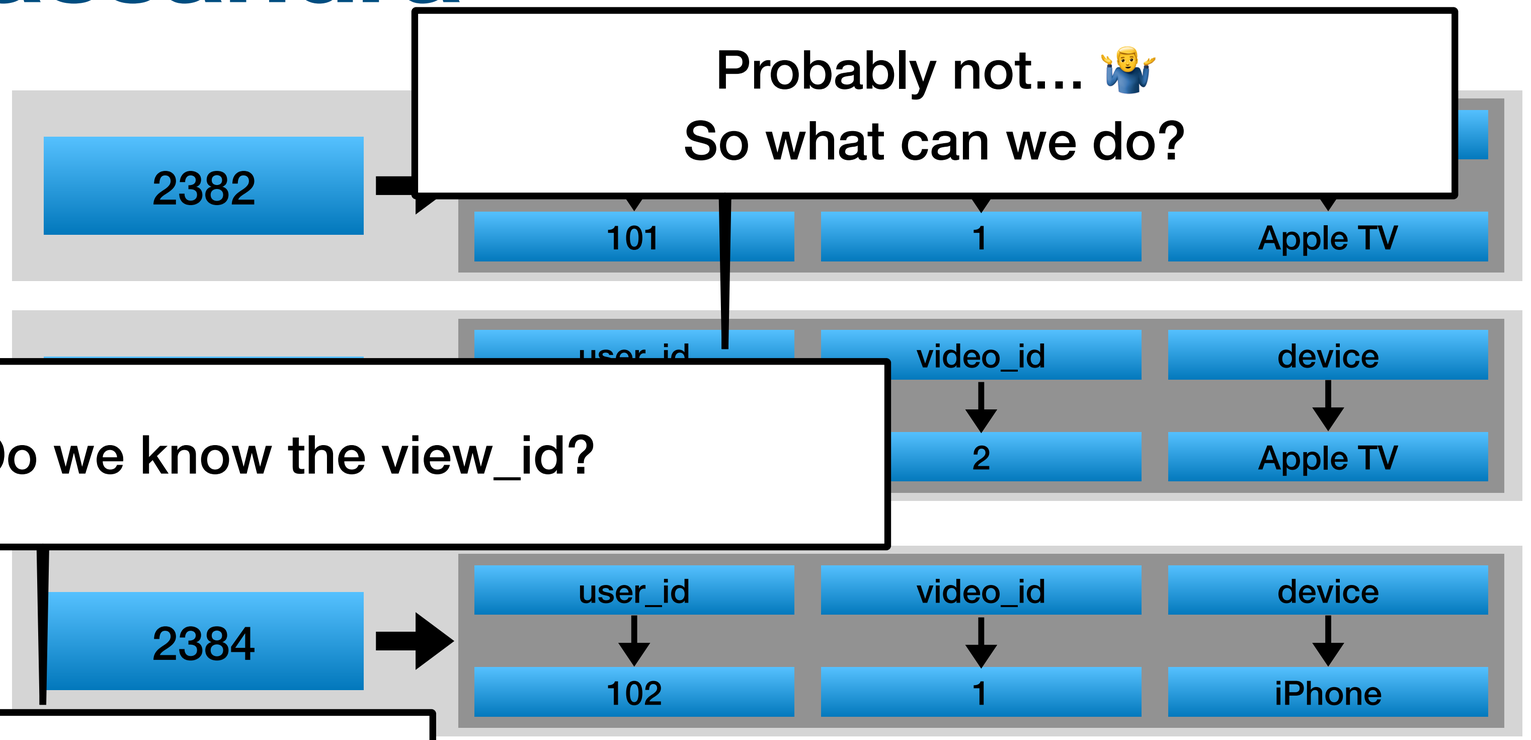
Which queries can we efficiently return?

**views**

| view_id | user_id | video_id | device | … |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |

# Example - Cassandra

```
CREATE TABLE views (
    view_id         TIMEUUID,
    user_id         BIGINT
    video_id
    device
    PRIMARY KEY ((
);
```




SELECT * FROM views WHERE view_id = ?

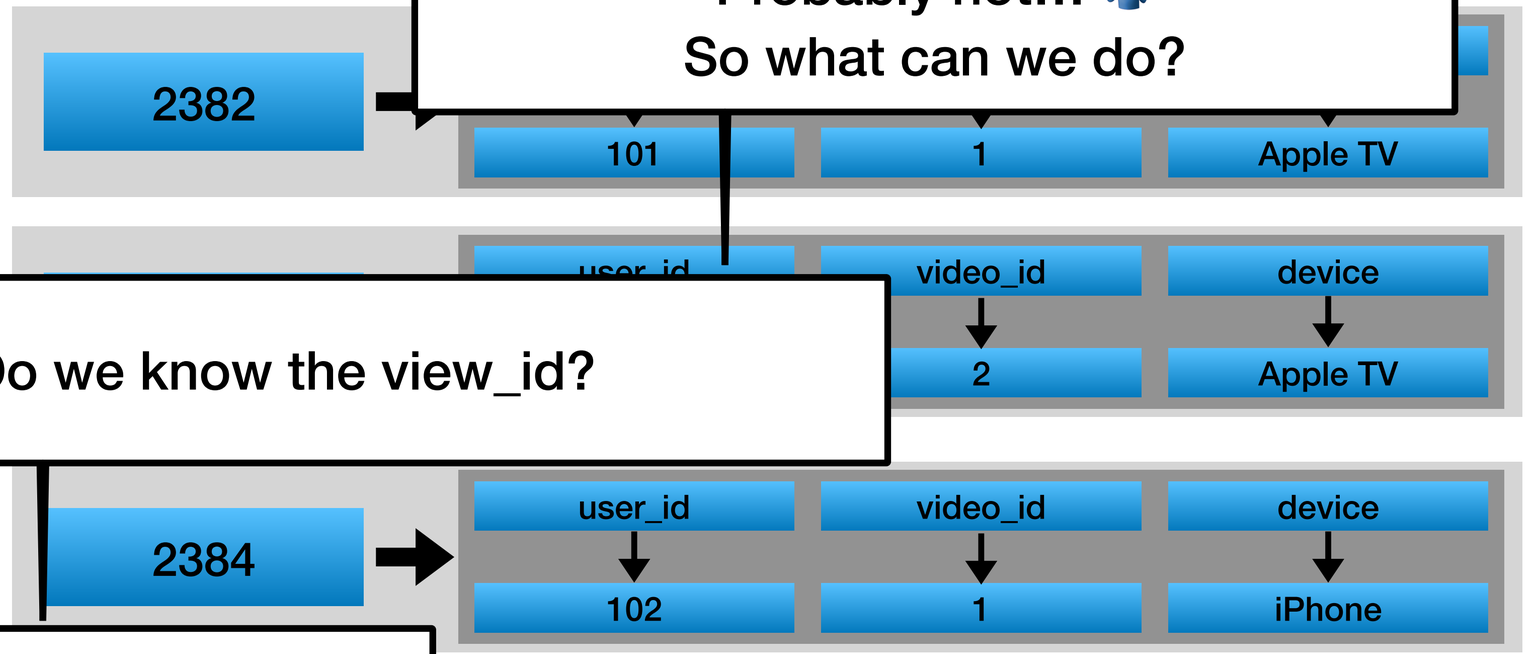
**Which queries can we efficiently return?**

**views**

| view_id | user_id | video_id | device | … |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |

# Example - Cassandra

```
CREATE TABLE views (
    view_id         TIMEUUID,
    user_id         BIGINT
    video_id
    device
    PRIMARY KEY ((
);
```




SELECT * FROM views WHERE view_id = ?

Which queries can we efficiently return?

views

| view_id | user_id | video_id | device | … |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |

Probably the queries will be by the user/movie
How can we support this?

# Denormalization by 2 tables

```
CREATE TABLE views_by_user (
    user_id         BIGINT,
    view_id         TIMEUUID,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((user_id), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

```
CREATE TABLE views_by_video (
    video_id        BIGINT,
    view_id         TIMEUUID,
    user_id         BIGINT,
    device          TEXT,
    PRIMARY KEY ((video_id), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

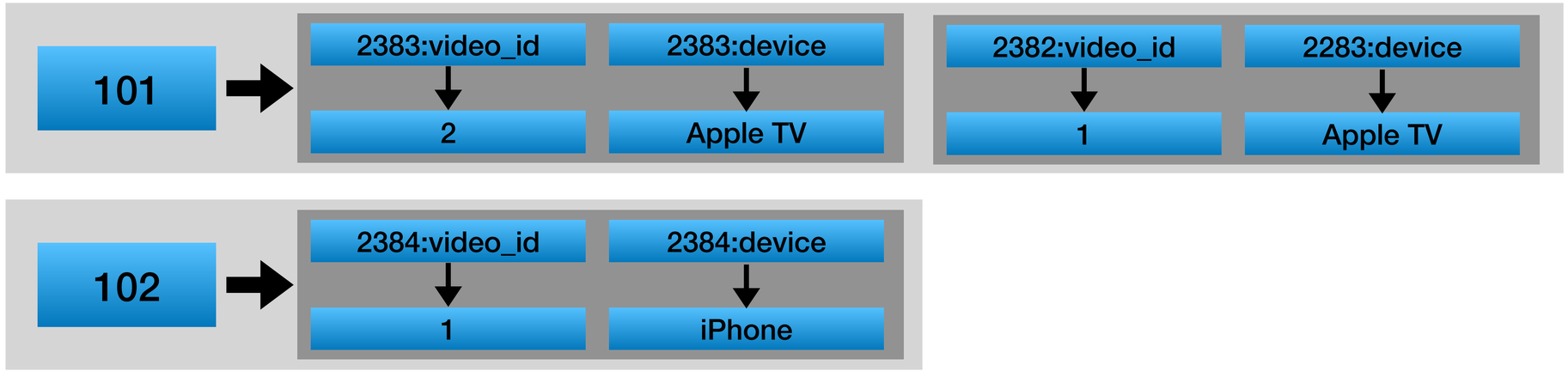
**Efficient queries:**

get all recent views of a user

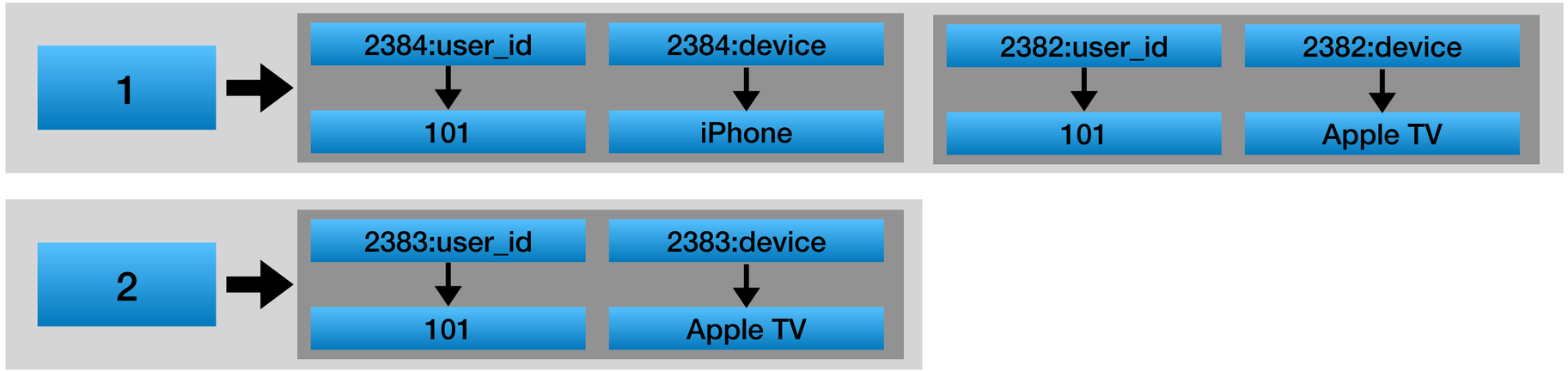
get all recent views of a video

# Denormalization by 2 tables

views_by_user




views_by_video



# Example continue

Why do we care?

**How can we return all the views for a specific day?**

```
CREATE TABLE views_by_user (
    user_id         BIGINT,
    view_id         TIMEUUID,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((user_id), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

```
CREATE TABLE views_by_video (
    video_id        BIGINT,
    view_id         TIMEUUID,
    user_id         BIGINT,
    device          TEXT,
    PRIMARY KEY ((video_id), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

# Example continue

Why do we care?

Calculating trending videos for example

**How can we return all the views for a specific day?**

```
CREATE TABLE views_by_user (
    user_id         BIGINT,
    view_id         TIMEUUID,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((user_id), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

```
CREATE TABLE views_by_video (
    video_id        BIGINT,
    view_id         TIMEUUID,
    user_id         BIGINT,
    device          TEXT,
    PRIMARY KEY ((video_id), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

# Example continue

**How can we return all the views for a specific day?**

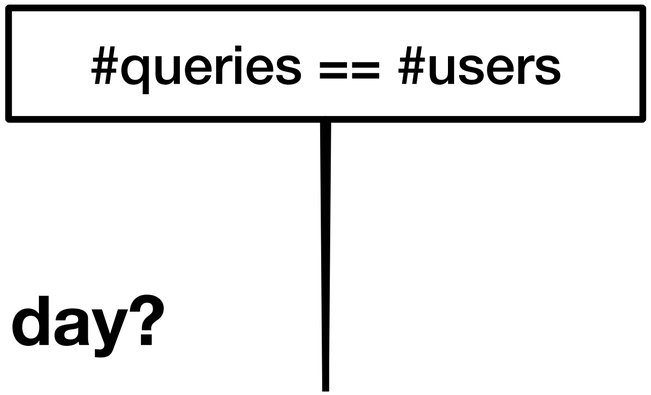
- Create a job (Spark?) that reads all the views from views_by_user and filter the result

- Create a job (Spark?) that reads all the views from views_by_video and filter the result

- Denormalize to another table

What is the difference between the options (time / IO)?

# Example continue




**How can we return all the views for a specific day?**

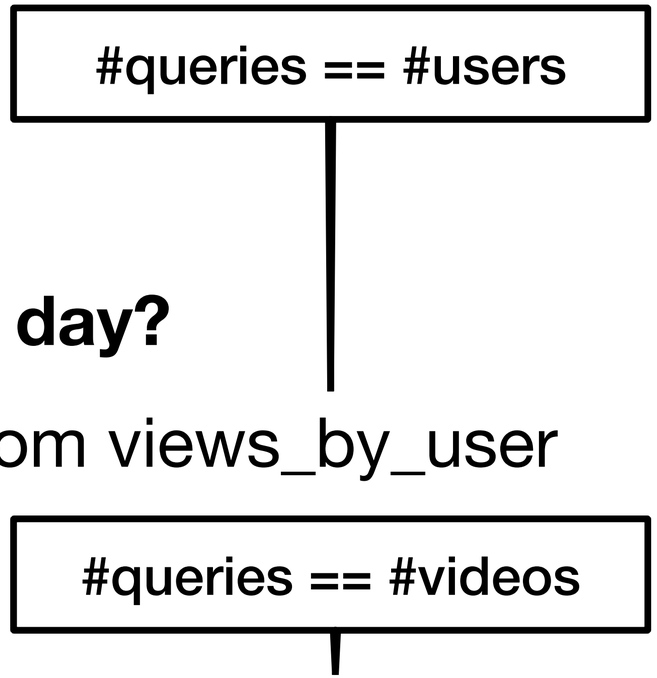
- Create a job (Spark?) that reads all the views from views_by_user and filter the result

- Create a job (Spark?) that reads all the views from views_by_video and filter the result

- Denormalize to another table

What is the difference between the options (time / IO)?

# Example continue




**How can we return all the views for a specific day?**

- Create a job (Spark?) that reads all the views from views_by_user and filter the result
- Create a job (Spark?) that reads all the views from views_by_video and filter the result
- Denormalize to another table

What is the difference between the options (time / IO)?

# Example continue

**How can we return all the views for a specific day?**

- Create a job (Spark?) that reads all the views from views_by_user and filter the result

#queries == #users

- Create a job (Spark?) that reads all the views from views_by_video and filter the result

#queries == #videos

- Denormalize to another table

#queries == “1”

What is the difference between the options (time / IO)?

# Example continue

**How can we return all the views for a specific day?**

- Create a job (Spark?) that reads all the views from views_by_user and filter the result

#queries == #users

- Create a job (Spark?) that reads all the views from views_by_video and filter the result

#queries == #videos

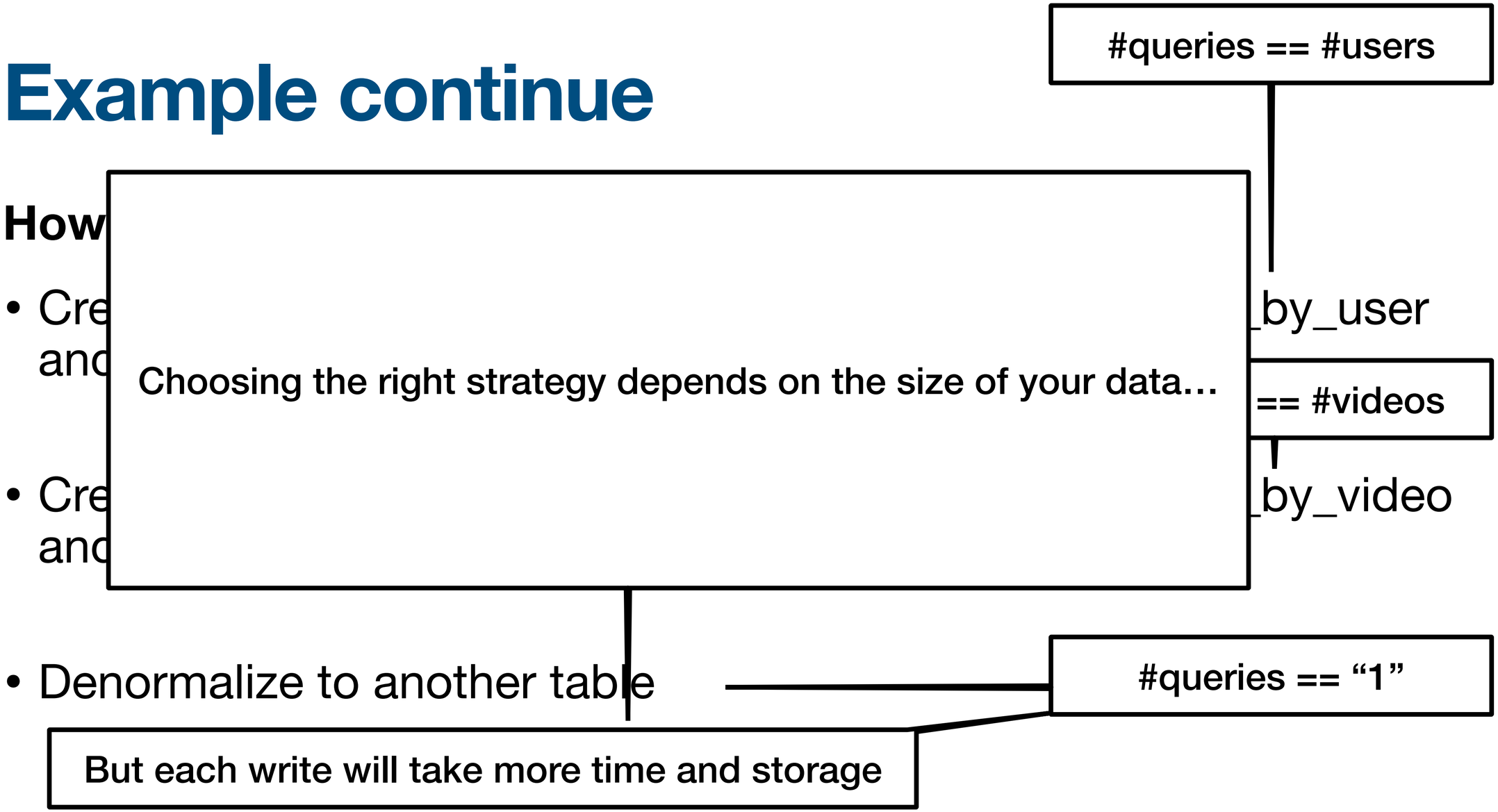
- Denormalize to another table

#queries == “1”

But each write will take more time and storage

What is the difference between the options (time / IO)?

# Example continue




What is the difference between the options (time / IO)?

# 3rd denormalization

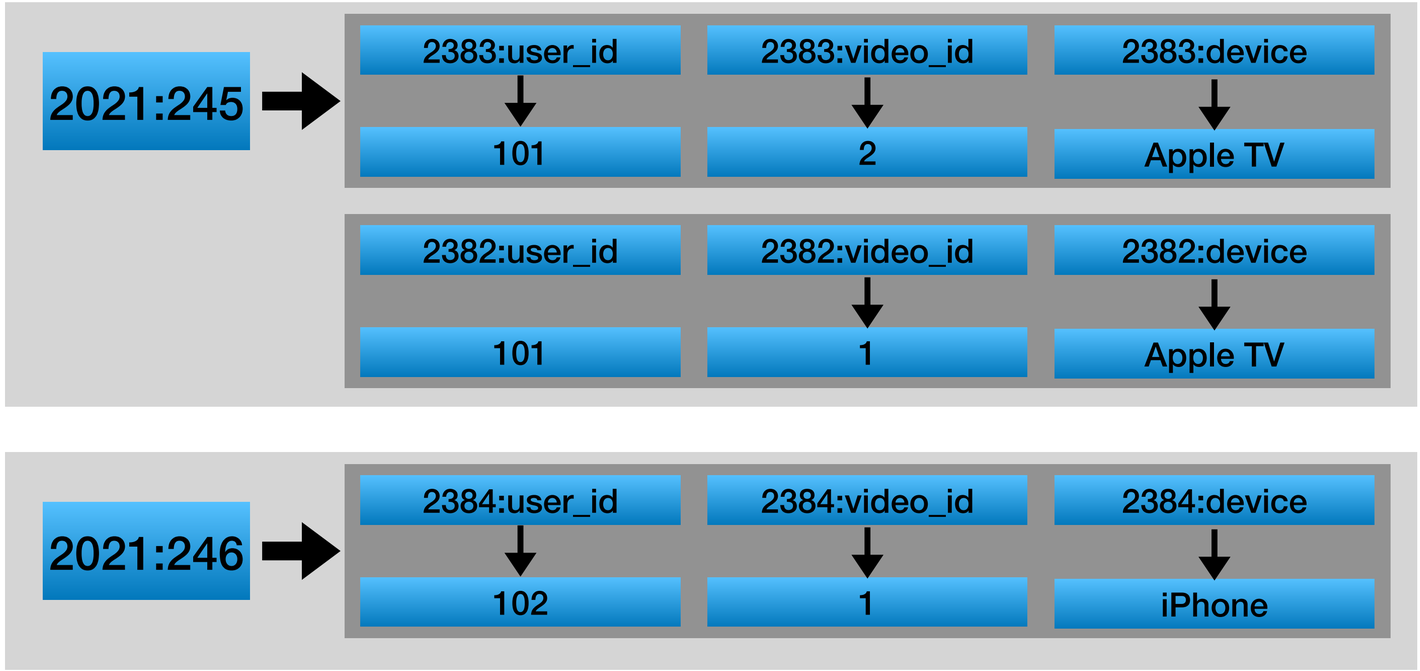
```
CREATE TABLE views_by_user (
    user_id         BIGINT,
    view_id         TIMEUUID,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((user_id), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

```
CREATE TABLE views_by_video (
    video_id        BIGINT,
    view_id         TIMEUUID,
    user_id         BIGINT,
    device          TEXT,
    PRIMARY KEY ((video_id), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

```
CREATE TABLE views_by_day (
    year            INT,
    day             INT,
    view_id         TIMEUUID,
    user_id         BIGINT,
    video_id        BIGINT,
    device          TEXT,
    PRIMARY KEY ((year, day), view_id)
) WITH CLUSTERING ORDER BY
  (view_id DESC);
```

# 3rd denormalization

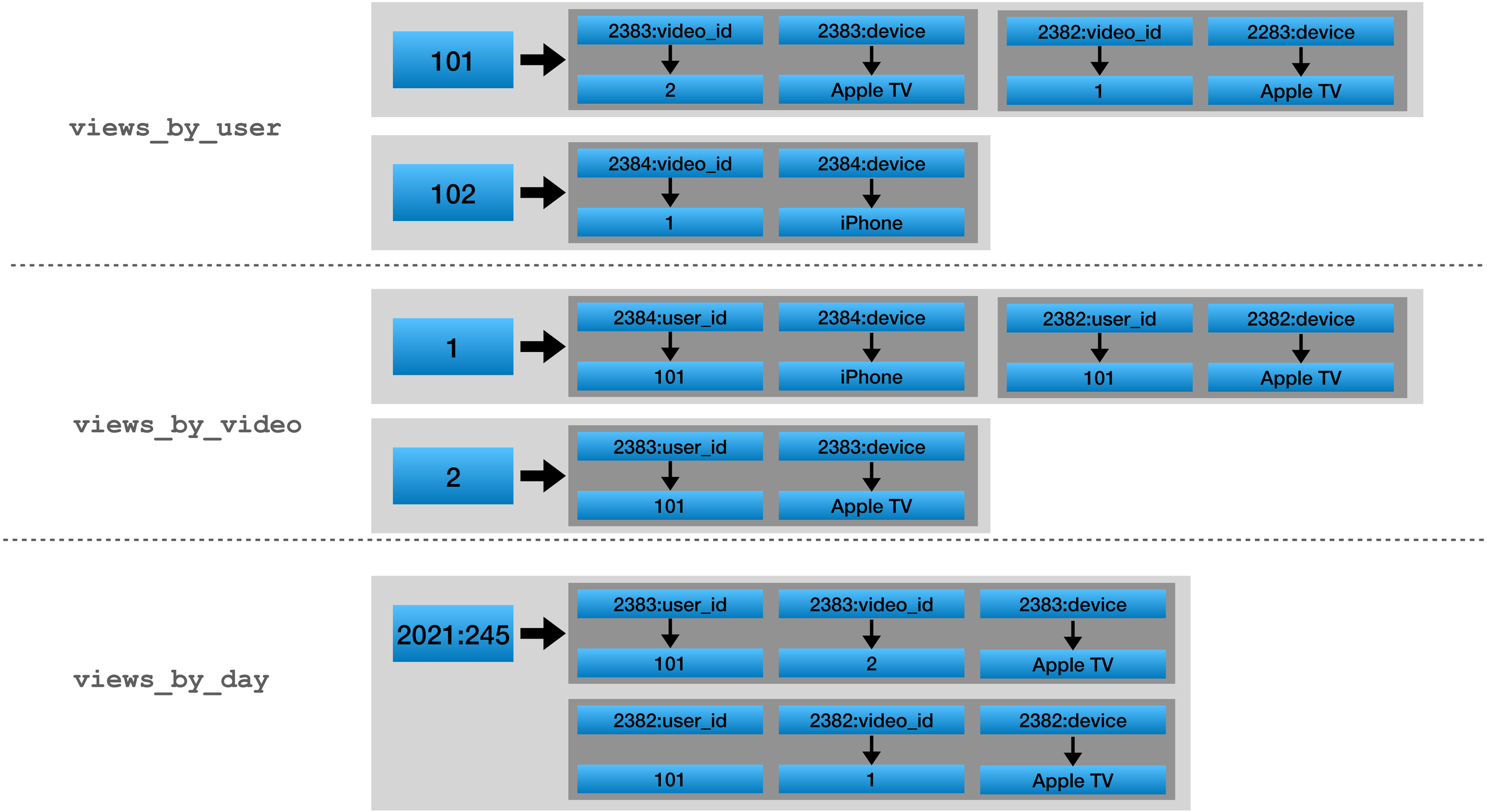
`views_by_day`




assuming:
- views 2382 and 2383 are on day 245 (2021)
- view 2384 is on day 246 (2021)

**views**

| view_id | user_id | video_id | device | ... |
|---|---|---|---|---|
| 2382 | 101 | 1 | Apple TV | |
| 2383 | 101 | 2 | Apple TV | |
| 2384 | 102 | 1 | iPhone | |


views_by_user
101
2383:video_id
2
2383:device
Apple TV
2382:video_id
1
2283:device
Apple TV
102
2384:video_id
1
2384:device
iPhone
views_by_video
1
2384:user_id
101
2384:device
iPhone
2382:user_id
101
2382:device
Apple TV
2
2383:user_id
101
2383:device
Apple TV
views_by_day
2021:245
2383:user_id
101
2383:video_id
2
2383:device
Apple TV
2382:user_id
101
2382:video_id
1
2382:device
Apple TV

# Interesting questions

What happens if

- Barkuni releases new video?
- Taylor Swift releases new song?
- Elon Musk wakes up?
- We have +100m views per day?

* image from YouTube