Scalable Spatio-temporal Indexing and Querying over a Document-oriented NoSQL Store

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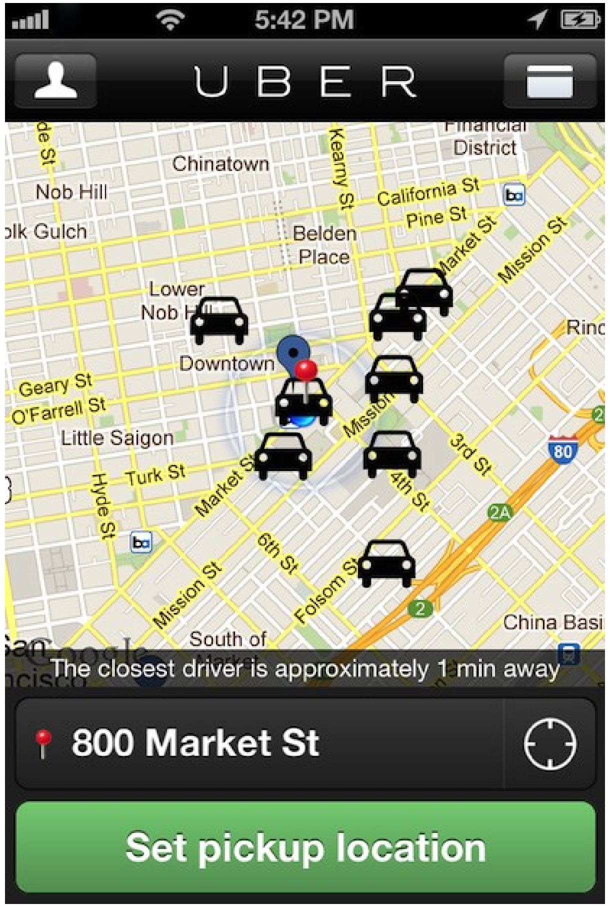
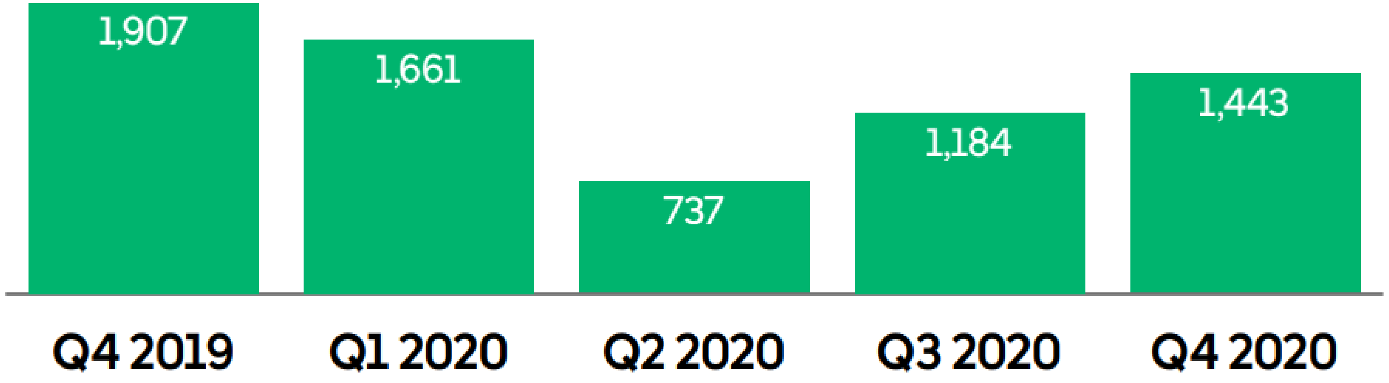
Introduction/Motivation (1/2)

- In recent years the increasing size of the spatio-temporal data requires new approaches for their storage and retrieval
- Scalable querying of spatio-temporal data management is a challenging topic
- Uber reports Millions of trips per quarter year;



Uber Technologies, Inc. Q4 2020 Earnings, Supplemental Data



Introduction/Motivation (2/2)

- NoSQL stores are exploited by modern applications for data storage and querying, providing scalability and availability

- Despite the popularity of NoSQL systems, they are not optimized for spatial data

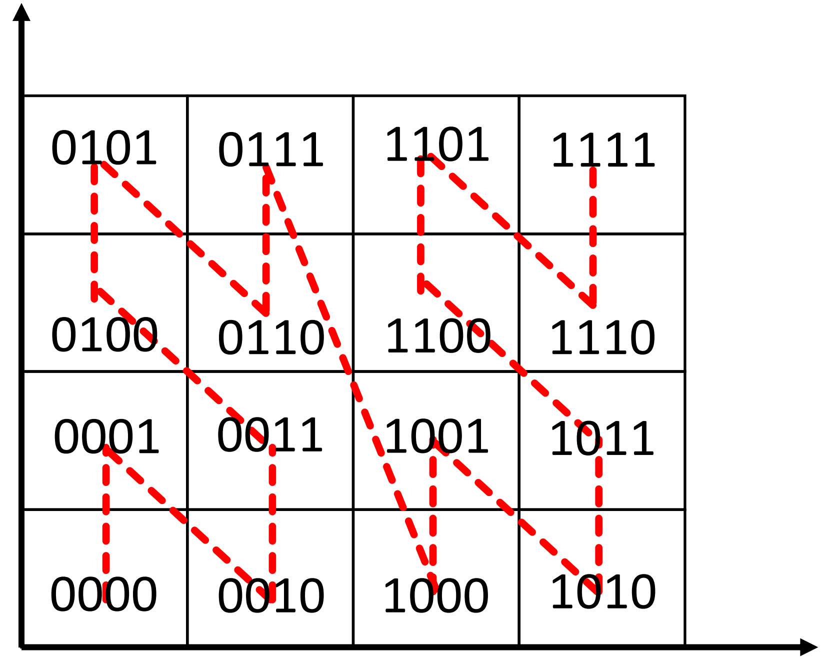
- In this work we opt for MongoDB store to support efficient spatio-temporal querying, as it embeds geospatial features

Baseline (1/3)

- MongoDB offers spatial indexes (2d/2dsphere)
- The geospatial **2dsphere** index is based on geohashing

{location: “2dsphere”}

- The geohash values are indexed by *B-trees*

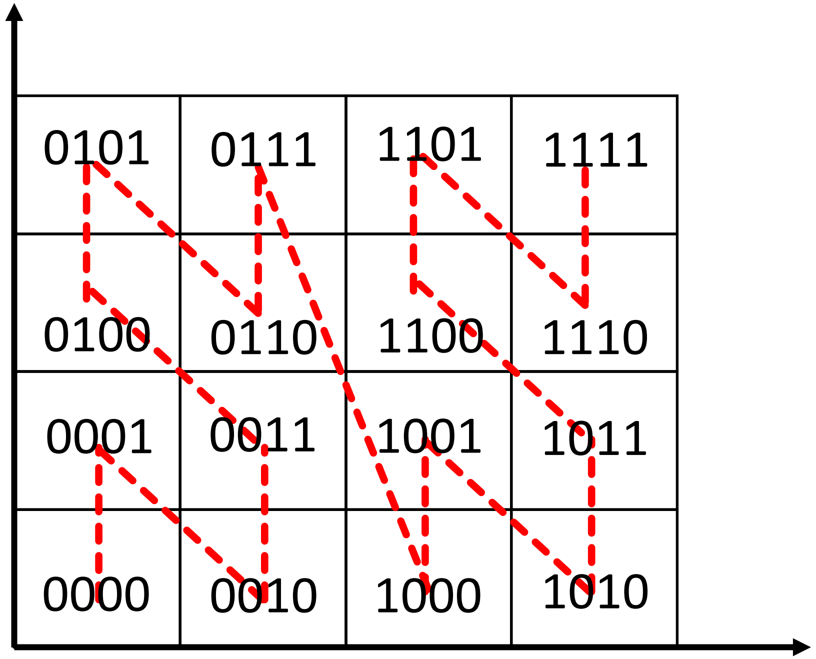


Z-order curve

```
{
 _id: 1,
 location: {"type": Point, coordinates: [37.983810, 23.727539]},
        ...
}
```

Baseline (2/3)

- MongoDB also offers compound indexes for indexing two or more fields in a single structure
- A spatio-temporal index in MongoDB is created in the two following ways:
  - `{ location: “2dsphere”, date: 1 }`
  - `{ date: 1, location: “2dsphere” }`



Z-order curve

```
{
 _id: 1,
 location: {"type": Point, coordinates: [37.983810, 23.727539]},
 date: ISODate("2018-09-12T12:15:17.777Z"),
       ...
}
```

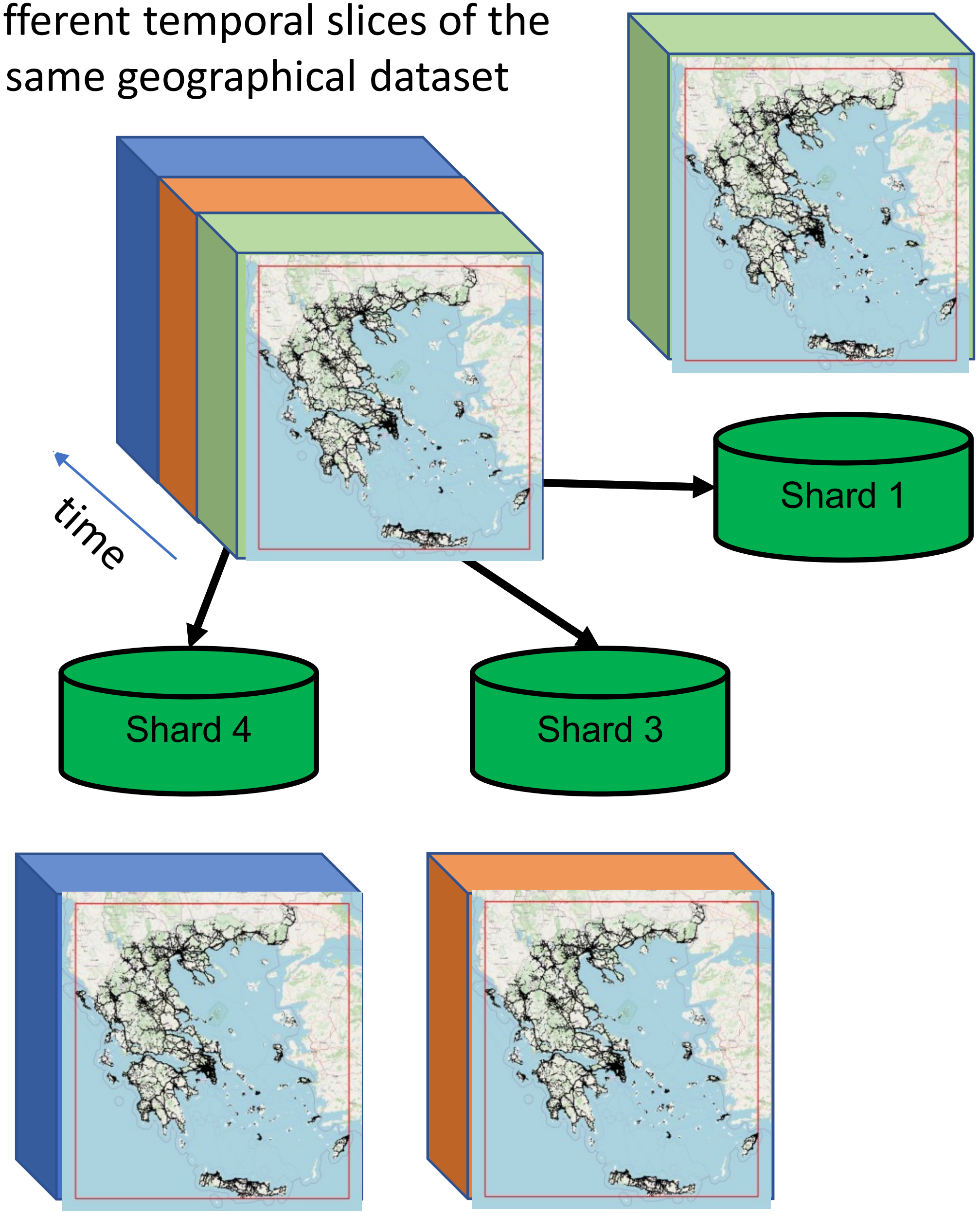
Baseline (3/3)

- However, MongoDB cannot distribute documents on a shards based on their spatial information
- Thus, we are restricted to the integration of the temporal field only as a shard key for spatio-temporal querying:

  `{date: 1}` **(bsl)**

- On each shard we create one of the following compound indexes (co-existing with a local single index based on the date field)
  - `{ location: “2dsphere”, date: 1 }` **(BslST)**
  - `{ date: 1, location: “2dsphere” }` **(BslTS)**

Different temporal slices of the same geographical dataset



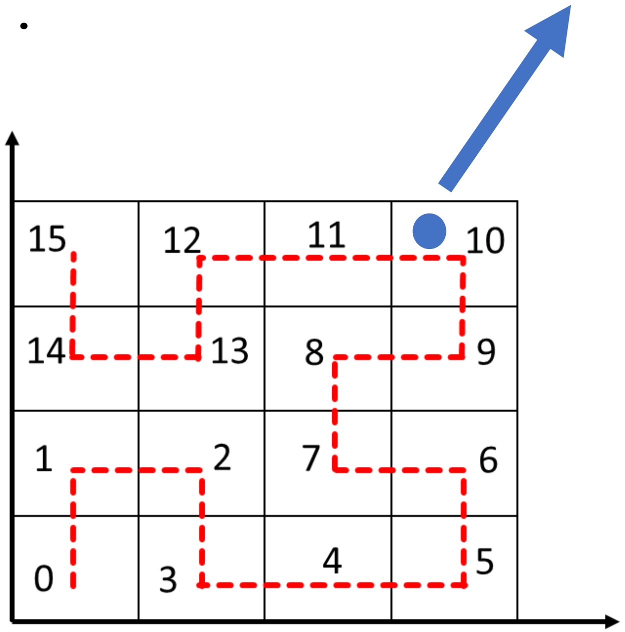
Our approach (1/2)

- We exploit the Hilbert space-filling curve and integrate the 1D numeric value in a new field in each document

- We form the compound indexes based on the fields:

  {hilbertIndex: 1, date: 1}

```
{
 _id: 1,
 location: {"type": Point,
        coordinates: [37.983810, 23.727539]},
 date: ISODate("2018-09-12T12:15:17.777Z"),
 hilbertIndex: NumberLong(10),
 ...
}
```



Hilbert curve

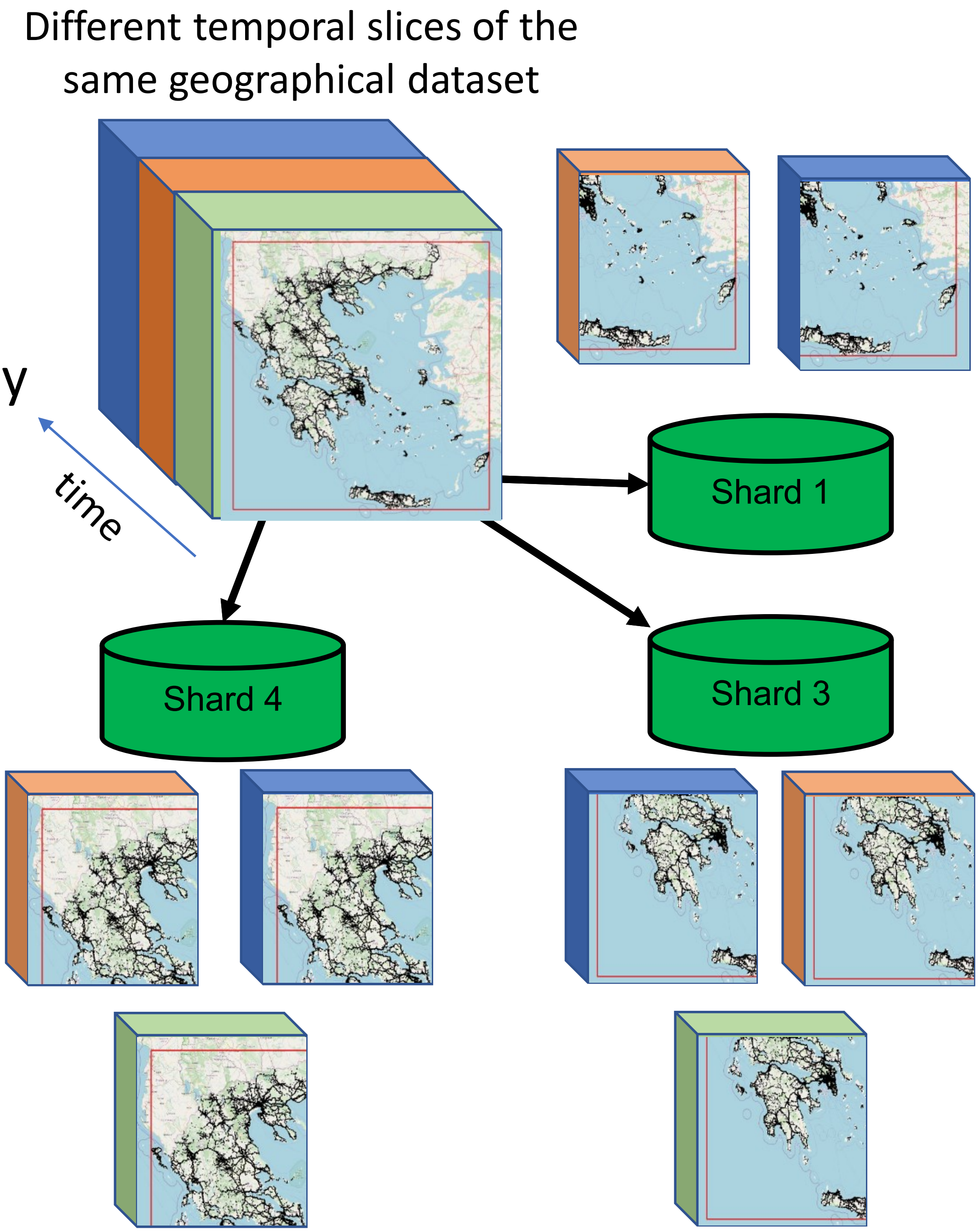
Our approach (2/2)

- Since the spatial information is embedded in every document as a numeric field, we use the shard key:

  `{hilbertIndex: 1, date: 1}` <u>(hil)</u>

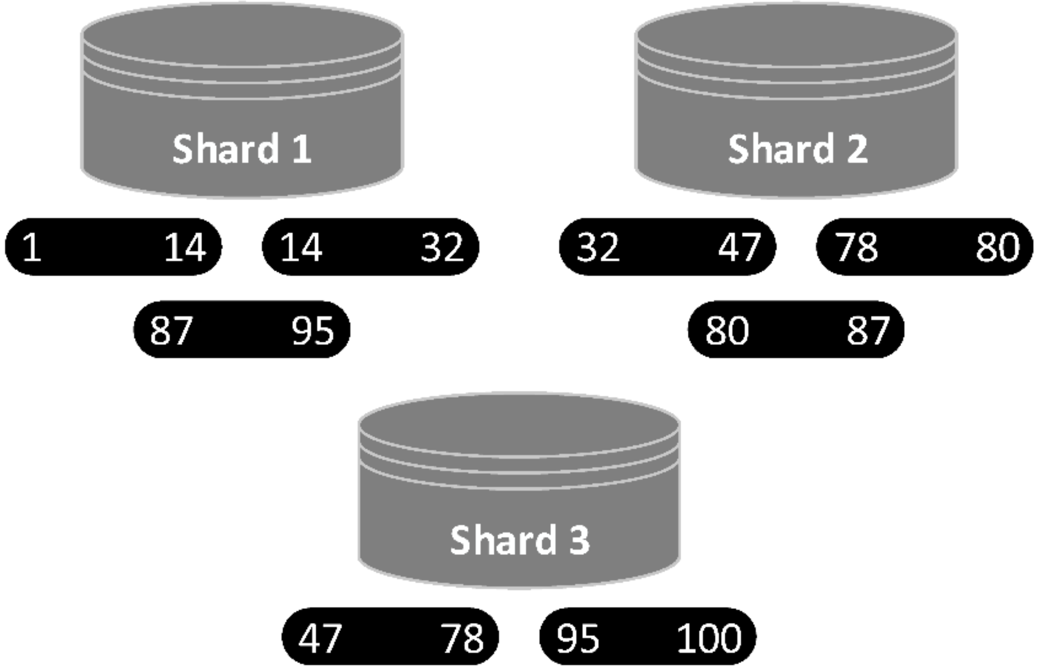
- By default, each shard has compound indexes based on the declared fields in the shard key

- Shard overloading is unlikely to occur in case of spatial/spatio-temporal skewness



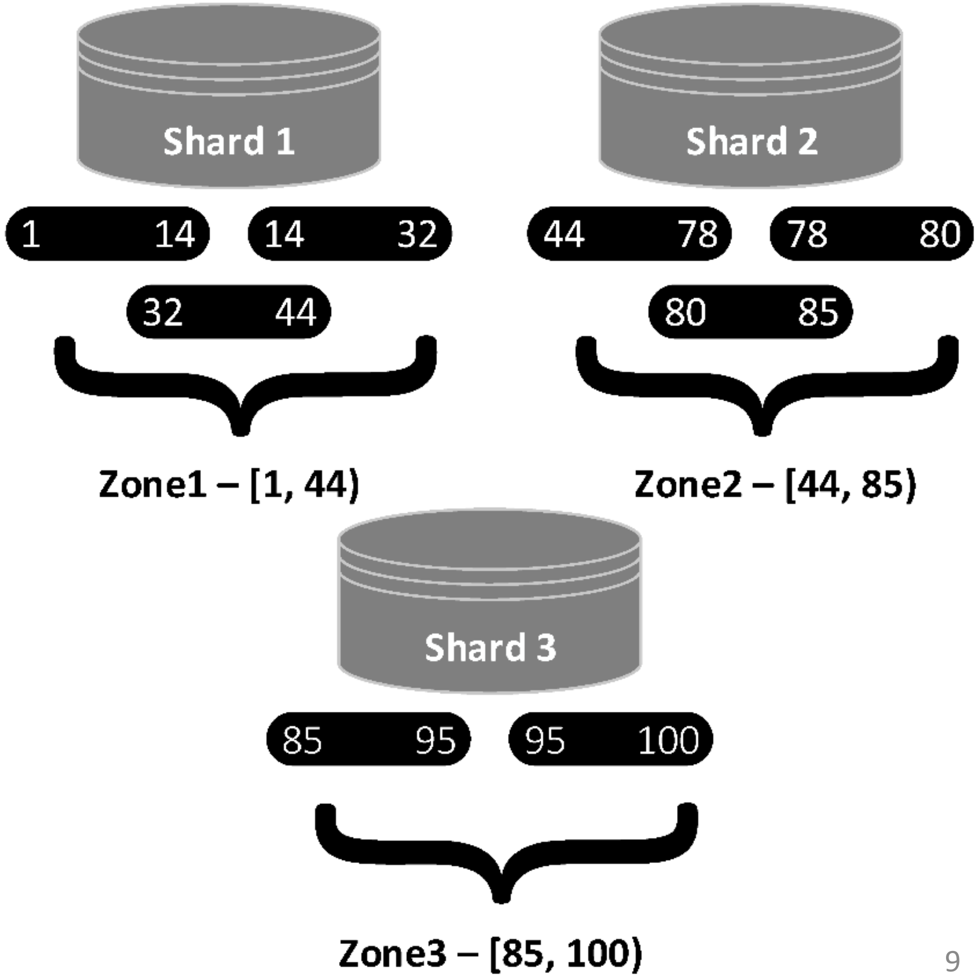
Usage of zones

Default distribution



Continuous ranges of shard keys (*chunks*) are distributed evenly in the cluster

Zone usage

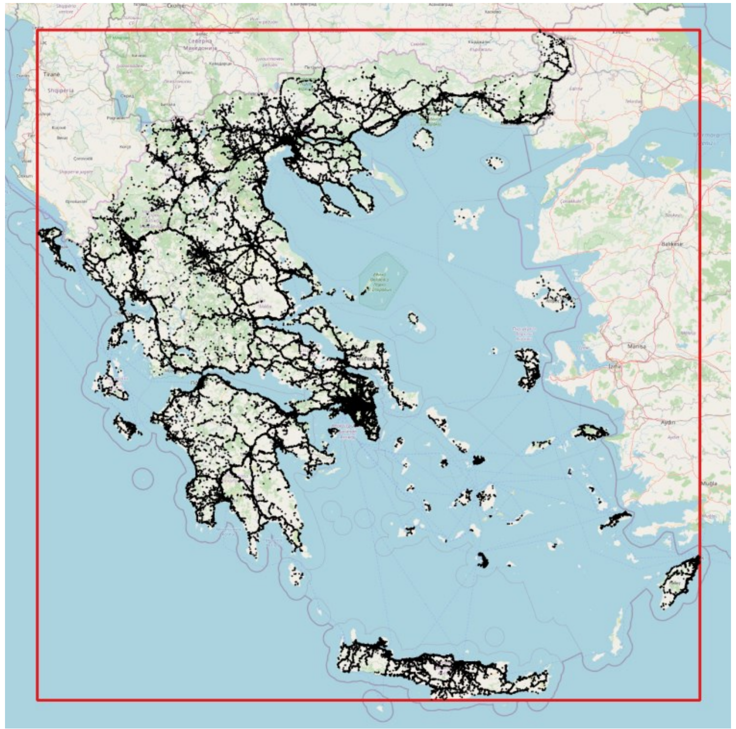


Experiments (1/5) – Setup

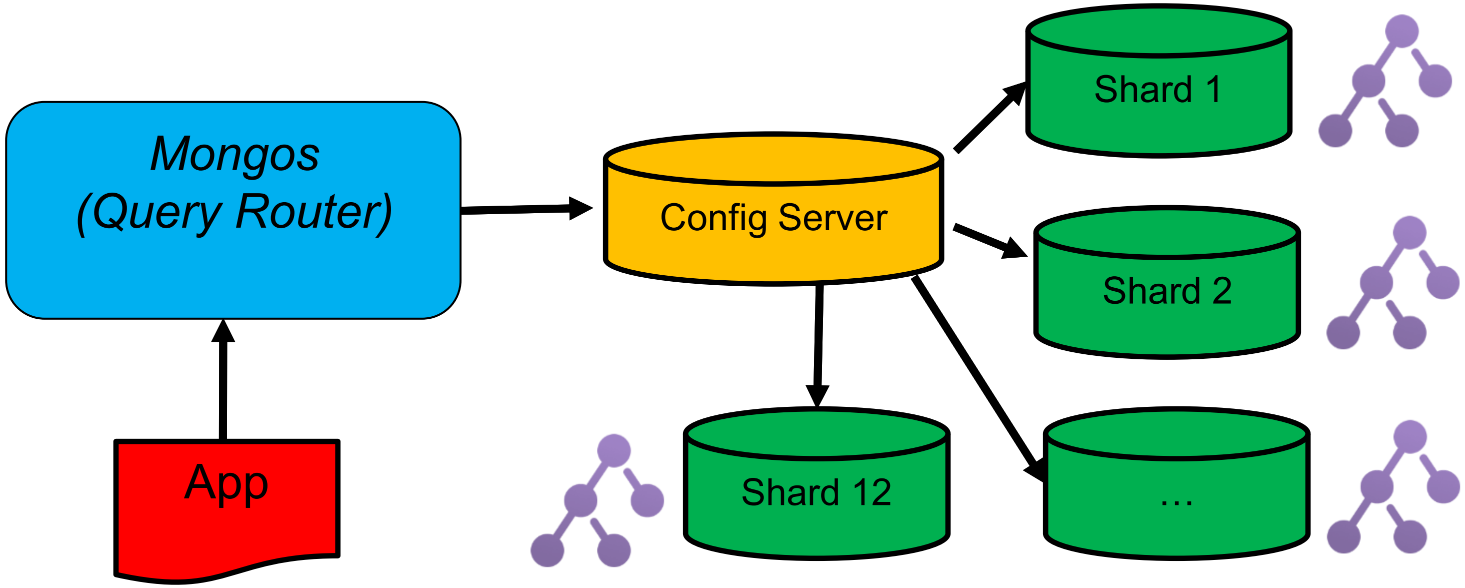
Real data set	
Size in MongoDB	*#points*
~40GB	**15.2M**

- Assess the efficiency of the proposed Hilbert-based approach against the baseline on a MongoDB Cluster
- We consider two types of spatio-temporal queries; the “spatially small” ($\boldsymbol{Q_x^s}$) and the “spatially big” ($\boldsymbol{Q_x^b}$)

Time periods
$\boldsymbol{Q_1^x}$ **–** One hour
$\boldsymbol{Q_2^x}$ **–** One day
$\boldsymbol{Q_3^x}$ **–** One week
$\boldsymbol{Q_4^x}$ **–** One month



Experiments (2/5) - Setup

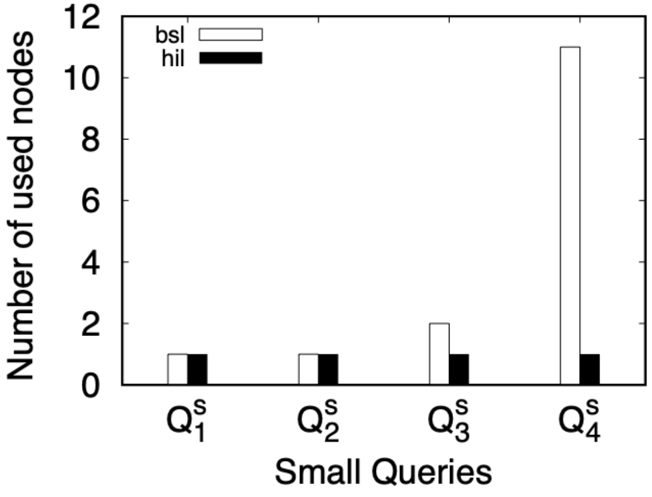


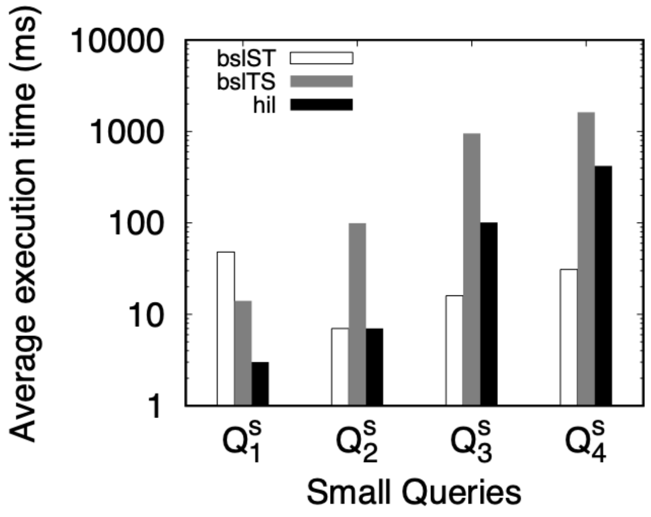
Execution of queries

17 nodes, 8GB RAM, x4 CPU cores,
12 nodes are used as shards with 100GB disk

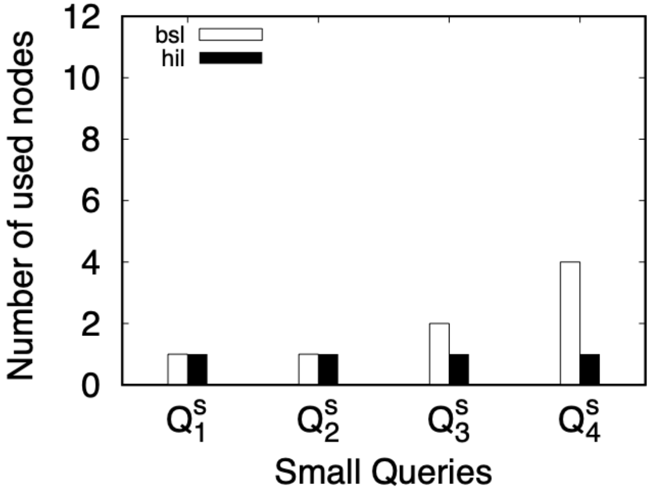
Experiments (3/5) - Performance of “spatially small” ST queries

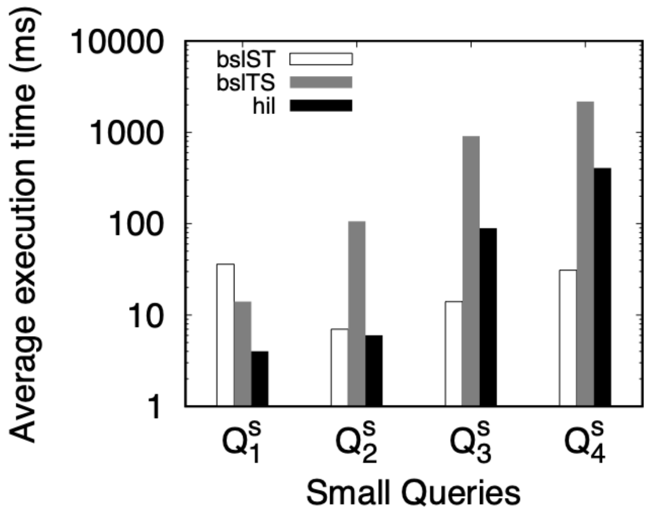
Default distribution





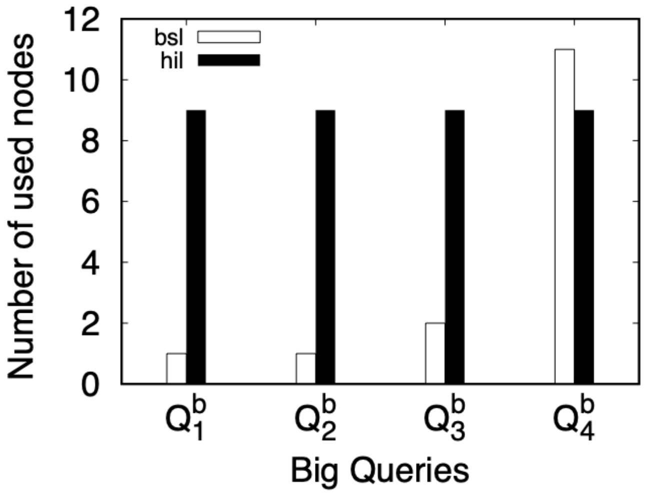
Zone usage

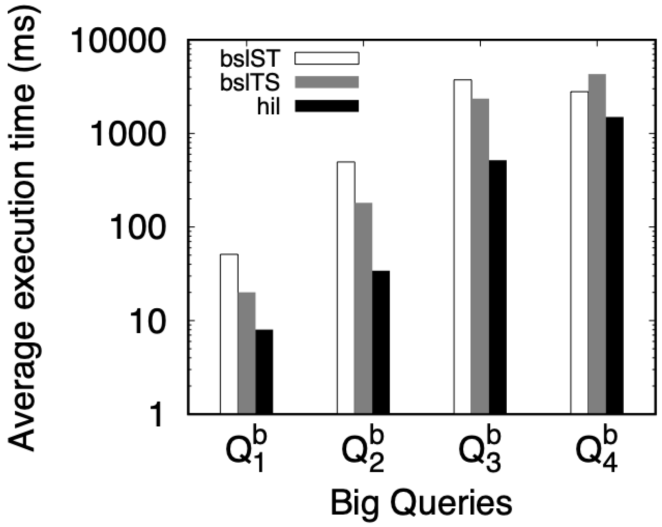




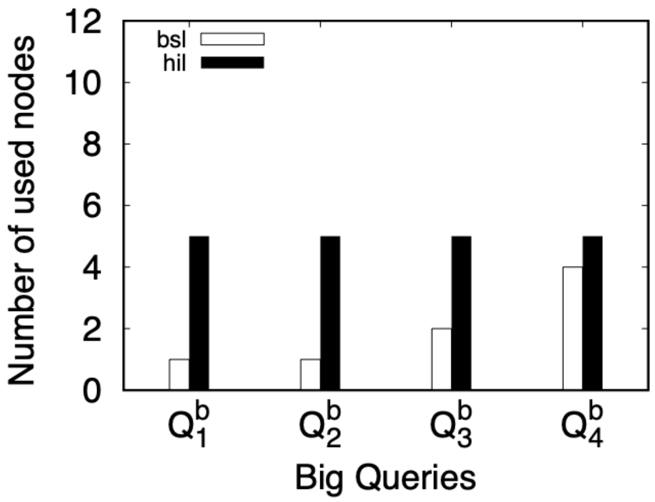
Experiments (4/5) - Performance of “spatially big” ST queries

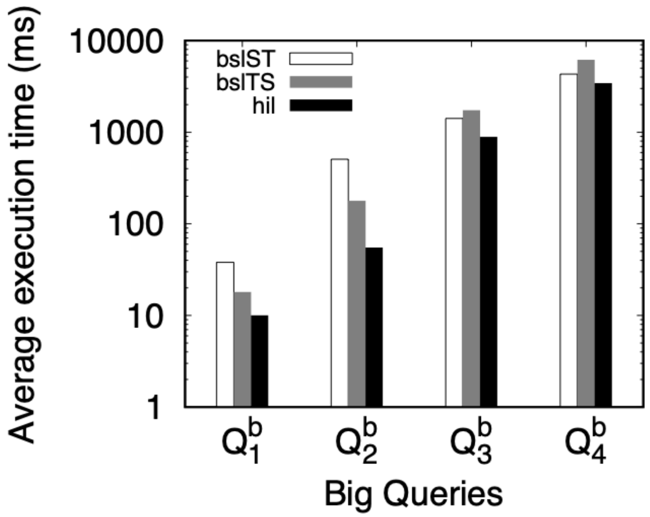
Default distribution





Zone usage

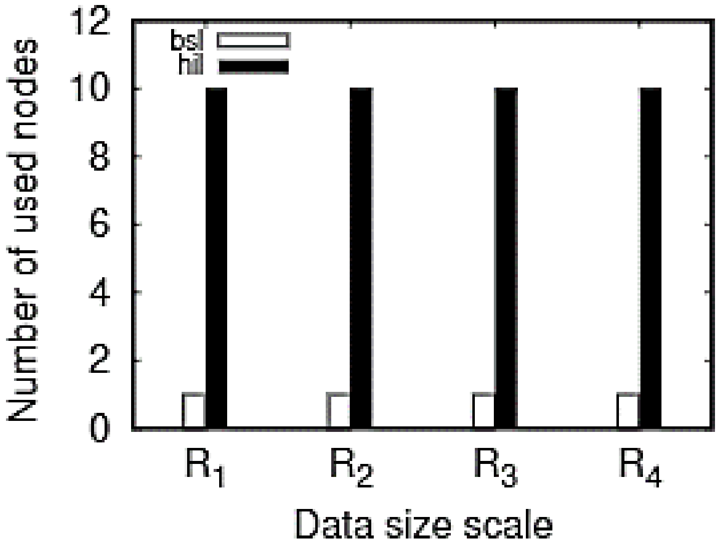


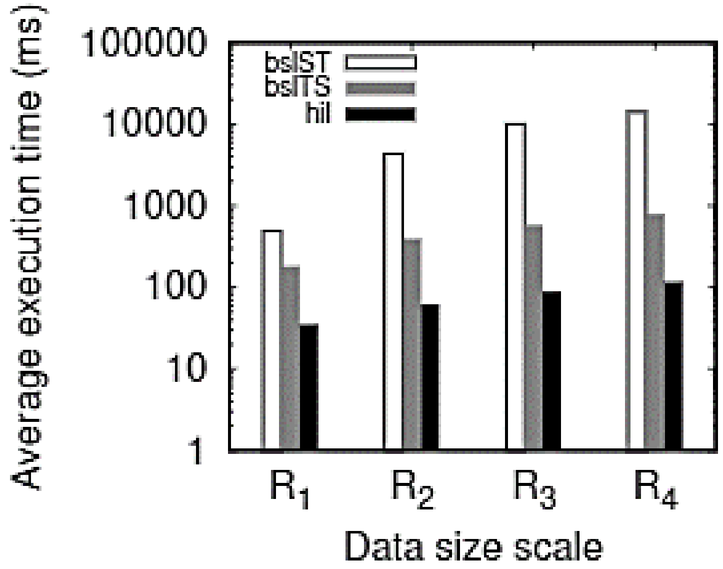


Experiments (5/5) - Scalability study

- We record the performance of $\boldsymbol{Q_2^b}$

	Real data set	
Size Factor	*Size (GB) in MongoDB*	*#points (M)*
x1 **(R_1)**	**~40**	**15.2**
x2**(R_2)**	**~83.87**	**31.4**
x3 **(R_3)**	**~127.21**	**47.7**
x4 **(R_4)**	**~171.39**	**63.9**





Conclusions

- We proposed a spatio-temporal approach for indexing and sharding on MongoDB
- The referred approaches were collated and evaluated on a MongoDB cluster
- Demonstrated the advantages of the proposed approach on specific queries
- Can be easily adopted as a solution on top of MongoDB

DATA STORIES

Thank you for your attention

More info:

our group: http://www.datastories.org/

project Track & Know: [*https://trackandknowproject.eu/*](https://trackandknowproject.eu/)

project Chorologos: [*https://www.ds.unipi.gr/chorologos/*](https://www.ds.unipi.gr/chorologos/)

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