Cloud-based Geospatial open systems for mitigating climate change: research directions, challenges, and future perspectives

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Outline

- Overview & motivating scenario
- Challenges in exploitation open-source geospatial systems climate change
- Novel Cloud-based architectures for spatial-meteorological integrity
- Future research frontiers and recommendations

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Background & Motivating Scenario

Motivating Application Scenario

Promoting the health of lightweight dwellers:

- Relationships between mobility and meteorological data
  - How vehicle emissions affect health of people
- Interactive visualization
  - Interactive heatmaps showing pollution and mobility
- Green pathfinder
  - Origin-destination health-aware paths

➢ Primitive geospatial queries
- Proximity queries
- Spatial join
- Spatial clustering
- Spatial geo-statistics (e.g., sampling)
- k-Nearest Neighborhoods

QoS goals include
- ✓ Low latency
- ✓ High throughput
- ✓ Maximum resource utilization
- ✓ Maximum accuracy

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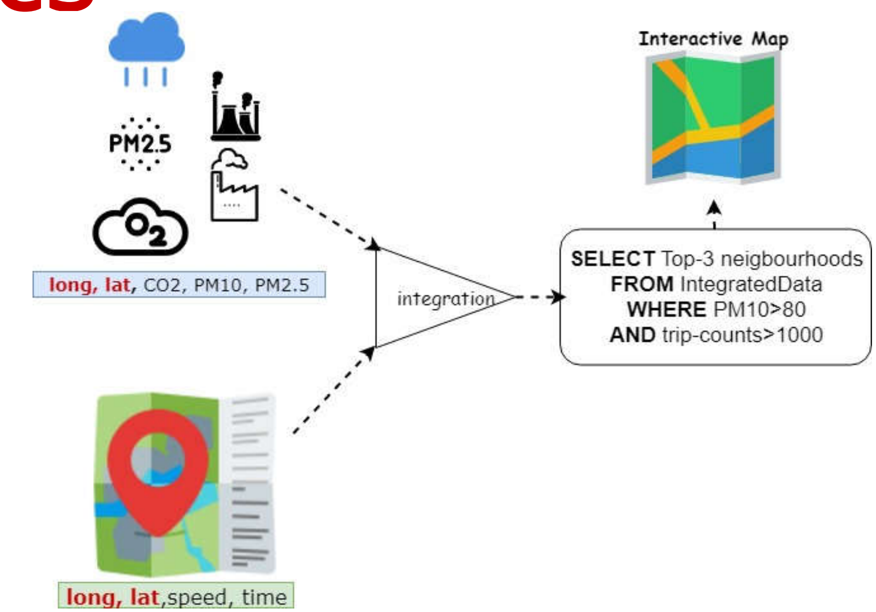
Shared meteorological and mobility analytics

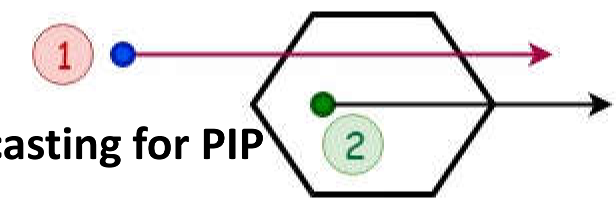
- Spatial join between **mobility & meteorological data**
- Enables new interesting interactive queries



Geospatial Queries

- Proximity query:
  - Data sorted on distance to a POI criteria (optionally specifying a range of distance)
  - Can be solved by applying Point-in-Polygon (PIP) test, by transforming the problem into an inclusion (**Containment)** query

- Containment query:
  - Requests all points contained within the premises of a polygonal shape (regularly or arbitrarily shaped)
  - Requires PIP test



Raw casting for PIP

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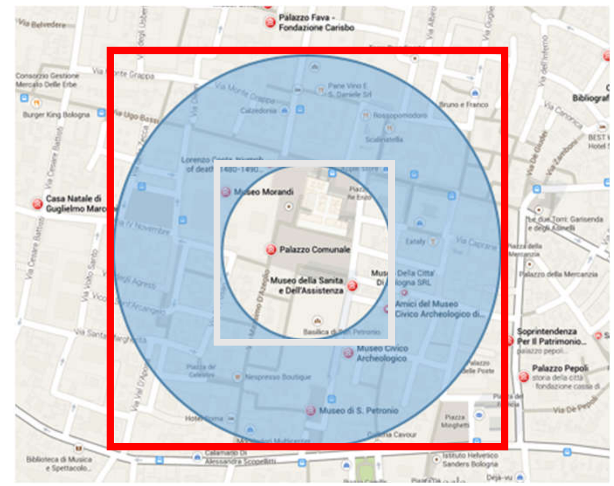
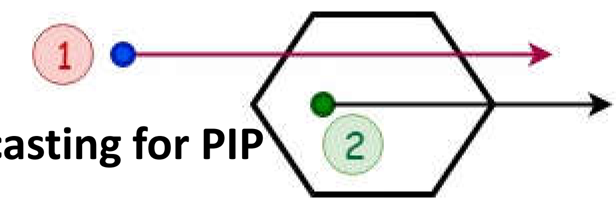
Solving proximity queries by spatial join



- Transforming proximity query into a containment:
  - Calculate the embedding area (rectangular areas)
  - Apply a PIP algorithm to retrieve points within the embedding space. (join op., filter)
  - Calculate distance between all points from the previous list and retrieve points that fall within the range specified. (refine)



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Partial landscape of Cloud-based geospatial systems

Desired features include:

- Filter-and-refinement approach. For spatial join.
- SQL-alike support. For spatial queries
- Spatial Approximate Query Processing. e.g., Spatial sampling

spatial join	queries	SQL	
others	join, range, containment, clustering (MR-DBSCAN), KNN	×	Stark
Broadcast , partition	join, range	×	SpatialSpark
others	join, range, KNN	×	locaionSpark
distance join	join, range, KNN	✓	simba
filter-and-refine	join, range	✓	Spark Magellan
filter-and-refine	join, range, KNN, sampling	✓	Sedona
filter-and-refine	join, range, KNN	✗	SpatialHadoop
filter-and-refine	join, range, KNN, ...	✓	geomesa
filter-and-refine	join, range, KNN	✗	GeoFlink
			Spark, Flink, Hadoop

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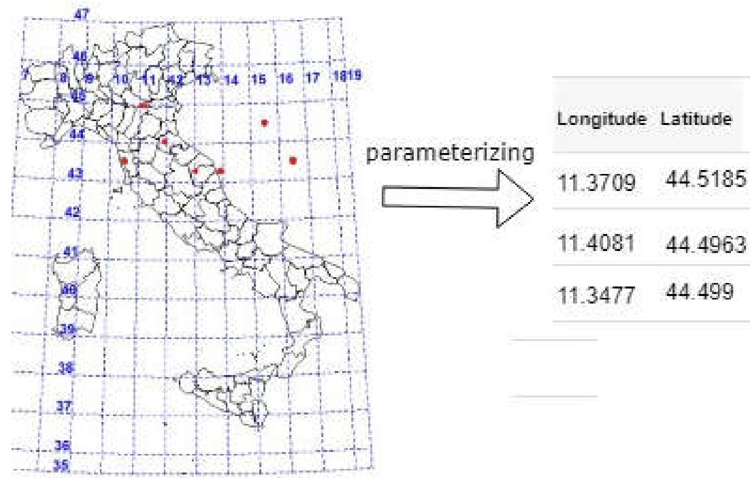
challenges

Geospatial data transformation

- Big geospatial data management is challenging
  - geospatial records are parametrized (longitudes and latitudes)
  - GPS is rarely 100% accurate,
    - susceptible to acceptable error-bounds
  - Real geometries are lost by this kind of transformation
  - Reconstructing into real geometries is **expensive**



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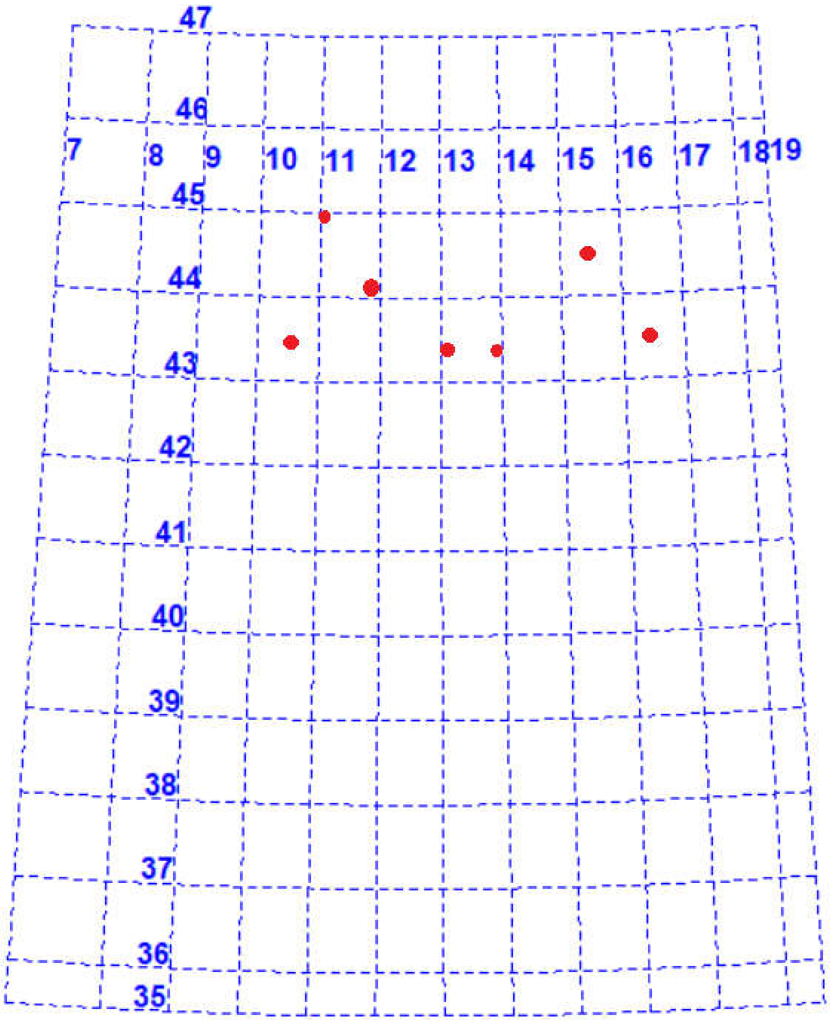

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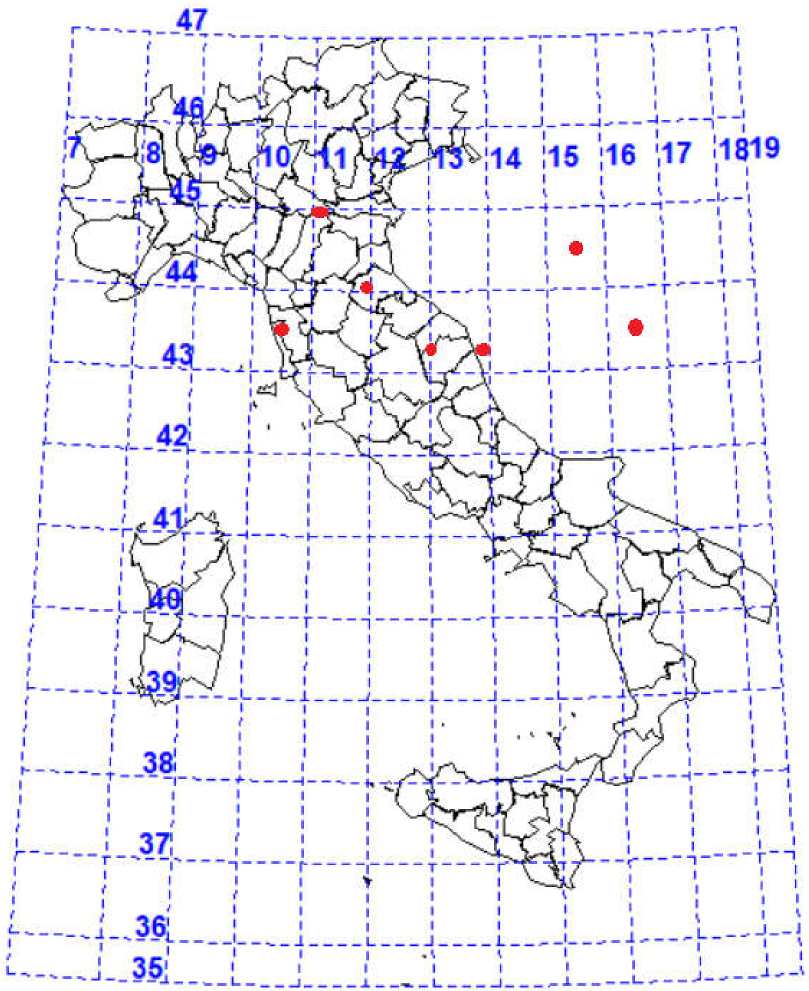
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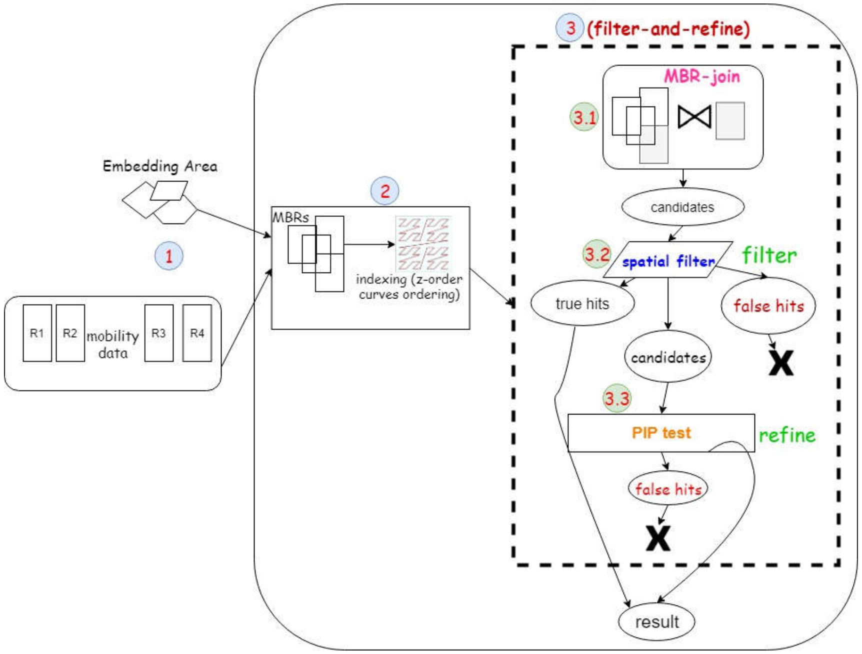
Filter-and-refine

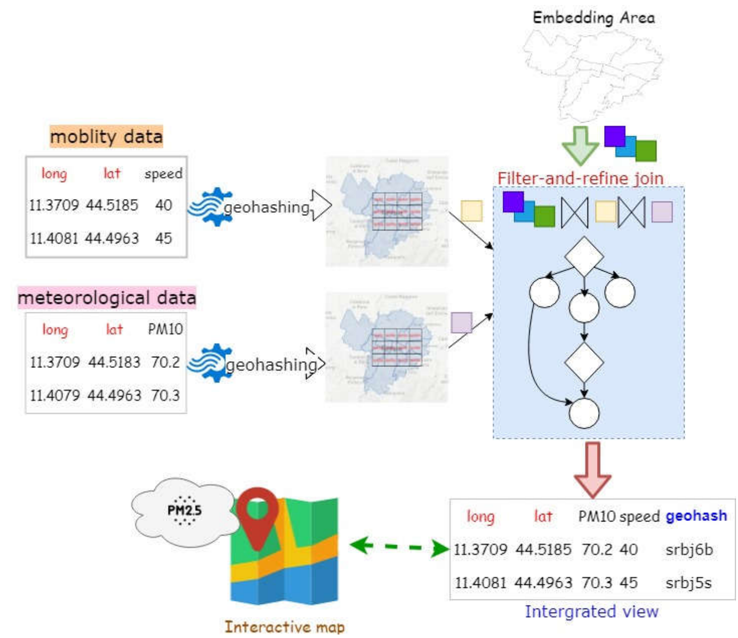
- Based on dimensionality reduction
  - Compute geohash for every point
  - Compute geohash covering of the embedding area
  - Perform a cheap equi-join to find which points fall within the embedding area (filter)
  - Use the ray casting algorithm to exclude false positives (refine)
- Adopted by Spark's Magellan and Geomesa



Architectures

Proposed Architecture

- Generate geohashes of mobility and meteorological
- Apply the filter-and-refine spatial join
  - The results contain a unified view
- Generate interactive maps (e.g., heatmaps)



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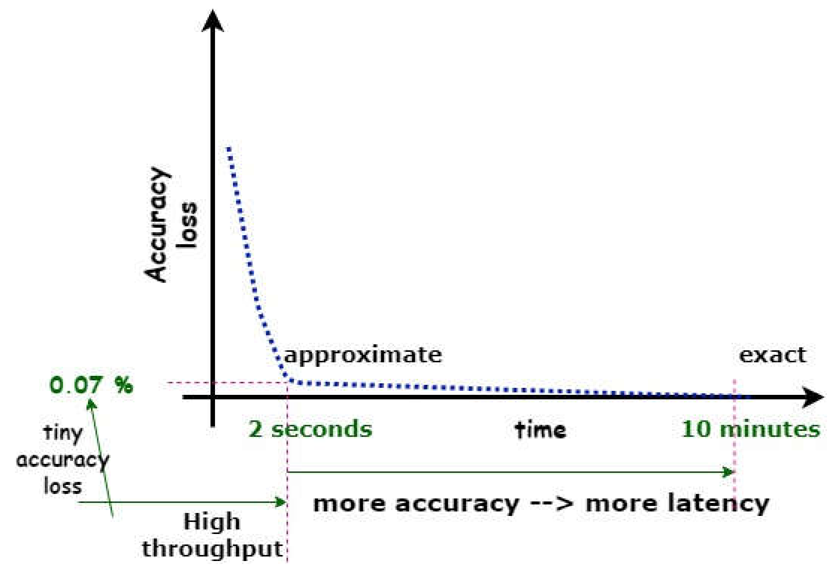
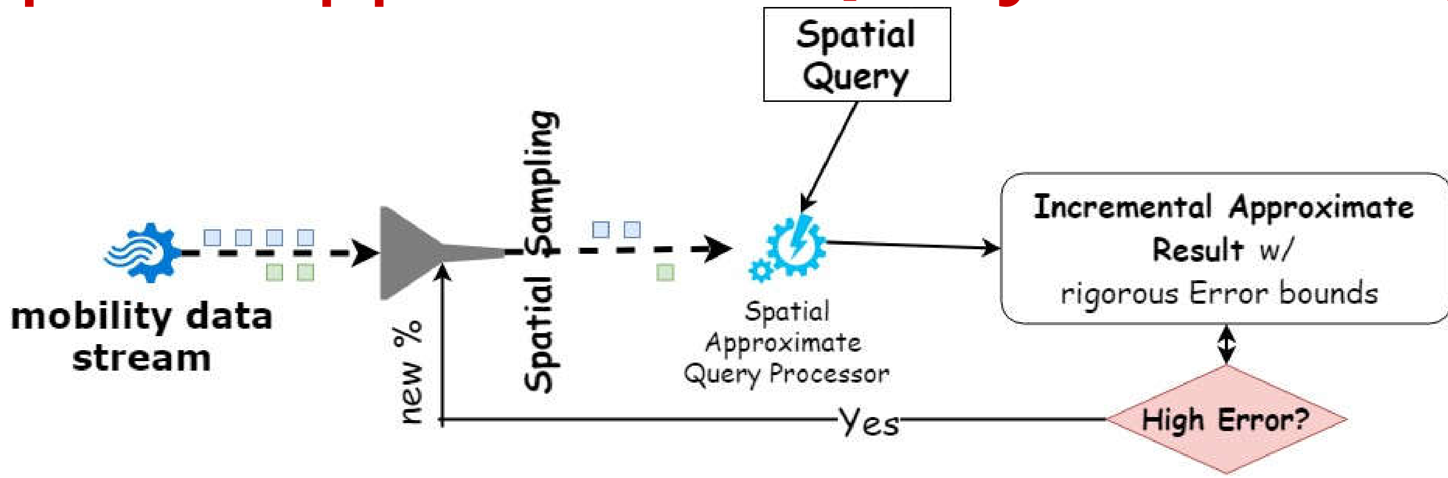
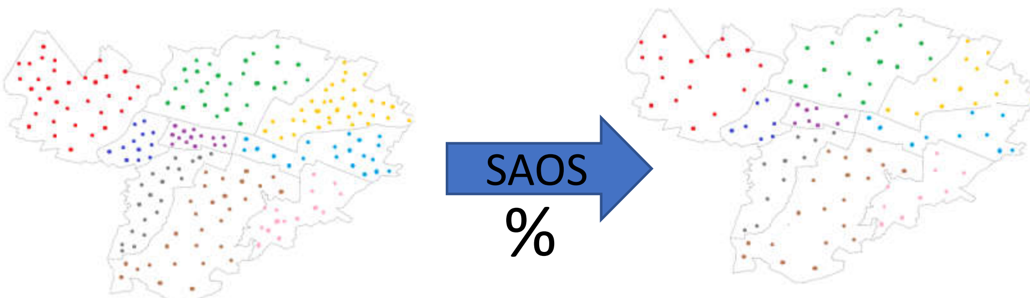
Spatial Approximate Query Processing

- Challenges
  - ➢ Data streams arrive very fast
  - ➢ Skewness and arrival rates fluctuate
- Decision makers accept tiny loss in accuracy in exchange for a throughput gain



Spatial Approximate Query Processing





Future Research

Conclusion and Open research

- **Current** Cloud-based open-source geospatial systems are limited in their capacity
  - However, they are good springboards!
- Offloading jobs to Edge devices
  - Port some processing to Edge devices,
  - reducing time-to-insight.
    - e.g., pushing spatial sampler to Edge devices upstream (near the data sources).

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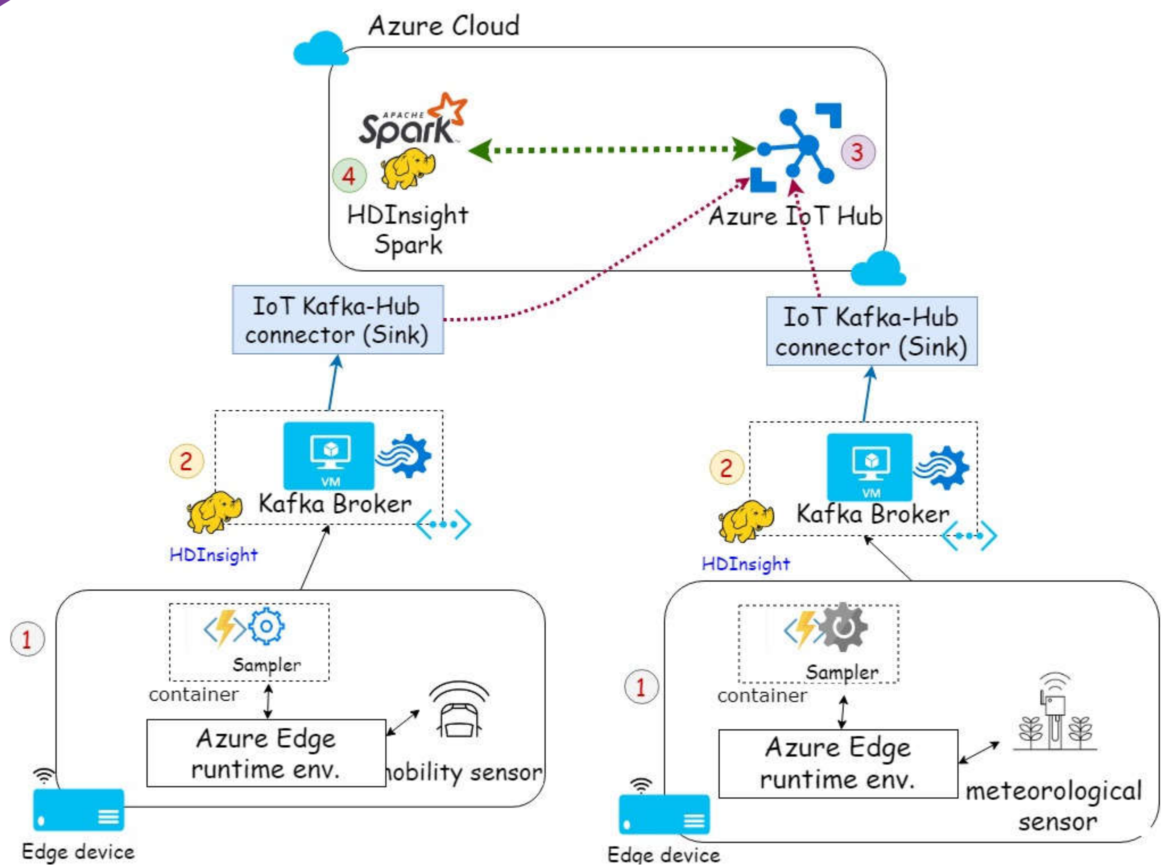

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Spark
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HDInsight
Spark
3
Azure IoT Hub
IoT Kafka-Hub
connector (Sink)
IoT Kafka-Hub
connector (Sink)
2
VM
Kafka Broker
HDInsight
2
VM
Kafka Broker
HDInsight
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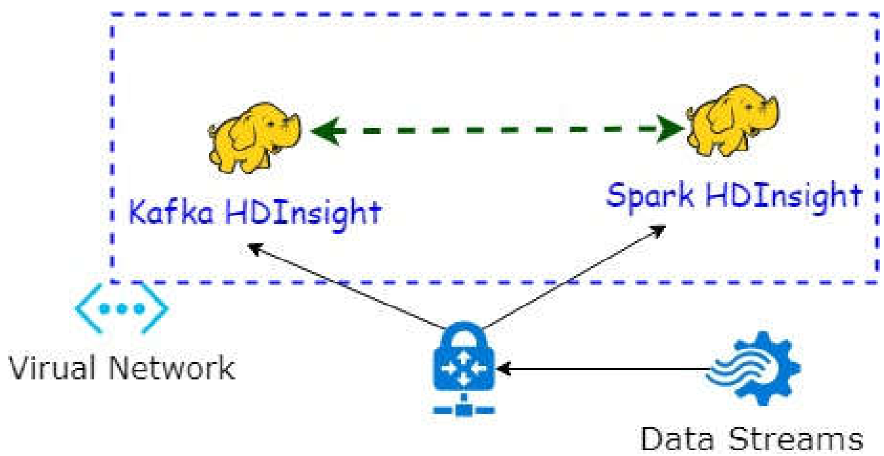
Sampler
container
Azure Edge
runtime env.
mobility sensor
Edge device
1
Sampler
container
Azure Edge
runtime env.
meteorological
sensor
Edge device

Open-source code

- My code for Cloud-based Spatial Approximate Query processing with instructions to deploy on **Microsoft Azure:**
  - https://isamaljawarneh.github.io/ApproximateStream/



Open for collaboration

- Our group (**Mobile Middleware Research Group**) at **University of Bologna**:

  http://www.middleware.unibo.it/

- Feel free to contact us:
  - Dr. **Isam Al Jawarneh** : isam.aljawarneh3@unibo.it
  - Prof. **Luca Foschini**: luca.foschini@unibo.it

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Relevant literature

[1] **I. M. Al Jawarneh**, P. Bellavista, L. Foschini and R. Montanari, **"Spatial-aware approximate big data stream processing,"** in 2019 IEEE Global Communications Conference (GLOBECOM), 2019, pp. 1-6.

[2] **I. M. Al Jawarneh**, P. Bellavista, A. Corradi, L. Foschini, R. Montanari and A. Zanotti, **"In-memory spatial-aware framework for processing proximity-alike queries in big spatial data,"** in 2018 IEEE 23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 2018, pp. 1-6.

[3] **Al Jawarneh, I. M.,** Bellavista, P., Corradi, A., Foschini, L., & Montanari, R. (2020). **Efficient QoS-Aware Spatial Join Processing for Scalable NoSQL Storage Frameworks.** IEEE Transactions on Network and Service Management, 18(2), 2437-2449.

[4] **Al Jawarneh, I. M.,** Bellavista, P., Corradi, A., Foschini, L., & Montanari, R. (2020). **Big spatial data management for the Internet of Things: a survey.** Journal of Network and Systems Management, 28(4), 990-1035.

Relevant literature

[5] **Al Jawarneh, I. M.,** Bellavista, P., Corradi, A., Foschini, L., & Montanari, R. (2020, September). **Spatially Representative Online Big Data Sampling for Smart Cities.** In 2020 IEEE 25th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD) (pp. 1-6). IEEE.

[6] **Al Jawarneh, I. M.,** Bellavista, P., Foschini, L., & Montanari, R. (2019, December). **Spatial-aware approximate big data stream processing.** In 2019 IEEE global communications conference (GLOBECOM) (pp. 1-6). IEEE.

[7] **Al Jawarneh, I. M.,** Bellavista, P., Corradi, A., Foschini, L., Montanari, R., & Zanotti, A. (2018, September). **In-memory spatial-aware framework for processing proximity-alike queries in big spatial data.** In 2018 IEEE 23rd international workshop on computer aided modeling and design of communication links and networks (CAMAD) (pp. 1-6). IEEE.

[8] **Al Jawarneh, I. M.,** Bellavista, P., Casimiro, F., Corradi, A., & Foschini, L. (2018, June). **Cost-effective strategies for provisioning NoSQL storage services in support for industry 4.0.** In 2018 IEEE symposium on computers and communications (ISCC) (pp. 01227-01232). IEEE.

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Thanks a lot!

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