Moving Objects Database Technology for Ad-Hoc Querying and Satellite Data Retrieval of Dynamic Atmospheric Events

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Presentation Outline

• Motivations and Objectives
  • Application
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• Review: Moving Objects Database Concepts
• System Overview and Status
  • Software Architecture
  • Demo I – Web-based Trajectory Query
  • Demo II – Matlab-based Satellite Data Retrieval
• Future Work
Motivations and Objectives
Application Objectives (I)

- Provide the NASA workforce with previously unavailable data(base) management, analysis, and query capabilities that will advance the research and understanding of dynamic weather events based on data derived from the NASA mission sensor measurements.

- Focus on tropical cyclone events.

- Our technology will provide both Earth Science researchers and non-scientist decision makers with the capability to:
  - Ad-hoc query for dynamic atmospheric events and their related information, and
  - Easily retrieve satellite data for scientific analysis.
Application Objectives (II)

Ad-hoc Trajectory Query

```
List all tropical cyclones that starts from Windsor, Ontario, to St. John’s, Newfoundland from 1979 to 2005. Retrieve NCEP-NCAR global reanalysis data and the NCEP NARR data” and data from 40 tropical cyclones were collected.

```

A visualization for the query “List the best tracks of the hurricane passing within 75 nautical miles of mid-Florida Bay from 1886 to 1996” (http://www.aoml.noaa.gov/hrd/Storm_pages/fl_track_red.html)

Radial distributions of mean rain rates (derived from (a) PR and (b) TMI) at the "mature" stage. (Chie Yokoyama and Yukari N. Takayabu, "A Statistical Study on Rain Characteristics of Tropical Cyclones using TRMM Satellite Data", Monthly Weather Review, vol. 136, pp. 3848--3862, Oct. 2008.)


“Retrieve QuikSCAT wind vectors and TRMM precipitation data for all tropical cyclones with translation speed faster than 15 meter/second”.

**Application Objectives (IV)**
The tangential component is near symmetric for slow-moving storms. The left-right asymmetry induced by and becomes stronger for fast-moving storms. Asymmetry increases with translation speed and is associated with the weakening of tropical cyclones.
System Objectives (I)

Non-scientist Decision Makers, Earth Science Researchers

Web-based spatiotemporal query/request system

DBMS_k

Spatiotemporal query model/engine for STQL

Moving Objects Software Library (MOSL)

Moving Objects Database

Satellite image representation

Historical satellite data product

Near real-time satellite data product

Retrieve information from relevant agencies/centers
System Objectives (II)

Moving Objects Database (MOD)
- keeps tropical cyclone and hurricane data provided by public sources and web sites in a centralized repository.
- is a full-fledged database with additional support for spatial and spatiotemporal data in its data model and query language.
- requires an extensible database system.

Moving Objects Software Library (MOSL)
- provides the functionality (in terms of types, operations, predicates) that can be deployed by users/scientists in ad hoc queries and in database application programs (C++, Java, Matlab, etc.) to retrieve and derive tropical cyclone data.
- provides a spatiotemporal data type system together with a large number of operations (e.g., Intersection, Union, Difference) and predicates (Inside, Meet, Disjoint, Overlaps; Enters, Leaves, Crosses, Bypasses).
- provides historical spatiotemporal data types like hmpoint, hmline, andhmregion.
- can be integrated into extensible databases.
- is database-independent and application-neutral.
System Objectives (III)

Spatiotemporal Query Language (STQL)
- provides the communication interface between the moving objects database for tropical cyclone data and the user/scientist
- enables users to pose ad hoc spatiotemporal queries on moving objects in general and tropical cyclone data in particular
- allows users to obtain immediate response

Satellite Data Retrieval (SDR)
- takes output trajectory information from user queries as input for satellite data retrieval
- Enable users to manipulate satellite data for future data analysis
Review: Moving Objects Database Concepts
A moving object represents the continuous evolution of a spatial object over time.

Classification of moving objects

- Category 1: Moving points
  - Only time-dependent location is of interest
  - Examples: cell phone users, cars, terrorists, whales

- Category 2: Moving region
  - Also the time-dependent shape and/or areal extent is of interest
  - Examples: hurricanes, forest fires, oil spills, diseases, glaciers

- Category 3: Moving line
  - the time-dependent shape and/or linear extent is of interest
  - Examples: traffic jam, front of an army; boundary of any moving region
Review: Moving Objects Database Concepts (II)

- Formally: Let \{point, line, region\}. Then a moving object \( m \) is a function of a spatiotemporal data type \( \mathbb{M}(\mathbb{X}) = time \mathbb{X} \mathbb{X} \).
  - \( m_{\text{point}} = \mathbb{M}({\text{point}}) = time {\text{point}} \)
  - \( m_{\text{line}} = \mathbb{M}({\text{line}}) = time {\text{line}} \)
  - \( m_{\text{region}} = \mathbb{M}({\text{region}}) = time {\text{region}} \)
Review: Moving Objects Database Concepts (III)

- Spatiotemporal operations and spatiotemporal predicates embedded into a Spatiotemporal Query Language called STQL.

- Query 1: “Determine the total size of the forest areas destroyed by the fire called “The Big Fire”.

  ```plaintext
  forest(forestname:string, Territory:hmregion)
  forest_fire(firename:string, Extent:hmregion)
  
  SELECT sum(size) FROM
  (SELECT size AS area(traversed(Intersection(Territory, Extent)))
  FROM   forest fire, forest
  WHERE  firename = "The Big Fire" AND
         Ever(Intersects(Territory, Extent)))
  
  In database terms: spatiotemporal join
  ```
Query 2: “Find all planes that ran into a hurricane.”

```
flights(id:string, Route:hmpoint)
weather(kind:string, Extent:hmregion)

SELECT id
FROM flights, weather
WHERE kind = "hurricane" AND
    Route Disjoint>>meet>>Inside Extent
```
Why Moving Objects Database?

- Representing and storing moving entities in (standard) database system using spatiotemporal data types
- A collection of comprehensive spatiotemporal operations and predicates to query moving entities.
- Efficient ad-hoc query on moving entities.
System Overview and Status
Exploration of database systems with extensibility features appropriate and needed for implementing MOSL

- Needed features
  - BLOB (Binary Large Object) data type for representing values/objects of arbitrary length
  - UDTs and UDFs for the specification and external binding of user-defined data types and functions implemented in MOSL
- Appropriate DBS: Oracle, Informix; PostgreSQL

**BLOB data type**

- is a built-in data type in SQL and represents arbitrarily long, finite byte strings (4GB)
- is used for representing complex application objects of large and/or varying length (e.g., spatial, image, DNA, video, multimedia objects)
Generic BLOB Interface Implementation in Oracle

Generic BLOB Interface Implementation in Informix

Generic BLOB Interface Implementation in PostgreSQL

iBLOB Interface

iBLOB Implementation

partially implemented

implemented
System Overview and Status (III) - Software Architecture

- Generic BLOB Interface
  - is database system independent
  - makes all components built on top of it database system independent

- User-defined data type iBLOB
  - iBLOB = Intelligent Binary Large Object
  - implemented on top of the generic BLOB interface
  - enables *random read access* to the conceptual components of a *complex application object* without understanding their meaning
  - enables *random updates* of application objects
  - Not necessary to load a complex application object completely into main memory
  - Two main parts
    - *Structure index* represents the hierarchical structure of the application object
    - *Sequence index* maintains the logical sequential order of components stored in the structure index and supports updates
• **Moving Objects Software Library (MOSL)**
  o provides a first implementation of the data type `hmpoint` for historical moving point objects
  o offers a few spatiotemporal operations on historical moving point objects

• **Spatiotemporal Query Language (STQL)**
  o enables the embedding of spatiotemporal operations and predicates into an extension of SQL
  o allows the execution of spatiotemporal queries

• **Simple Query Tool and Visualization Tool**
  o Query tool for posing STQL queries
  o Web-based and Google Map-based visualization tool
    ▶ for showing the results of STQL queries (trajectories) with Google maps as background
    ▶ providing the full functionality of Google maps like zooming, tagging, etc.
System Overview and Status (V) - Demo I

Step 1: User Input STQL query

```
SELECT tv, name, m.name, m.track 
FROM poogup1, test moving m 
WHERE m.name = 'POYZER1' AND 
  is_cross(m.track, t.geom) = 1
```

Submit Query

Step 2: Push “Submit Query” button and result plotted.

Data Table

8 rows retrieved.
Moving Object Database GUI
for weather event analysis and tracking

m.name: CINDY
r.id: 18

Map Visualization

Data Table
3 rows retrieved.
System Overview and Status (VII) - Demo I
Partition Tree Files

Input (Trajectory, User-defined Region Size [Radius=R])

HDF satellite data files

Retrieve satellite data partition from HDF files

Select measurements less than R degree from event centre

Search Partition Tree Files

Statistical Analysis

System Overview and Status (VIII) - Demo II
System Overview and Status (IX) - Demo II

GUI DEMO Snapshots

Step 1: 2009 Tropical Cyclone Selection

Tropical Cyclone Best Track Plotted after Selection in Step 1
Step 2: User Specifies Radius in degree

Step 3: User Specifies Mission (Satellite)

Step 4: Push “Retrieve Data” Button to retrieve data based on user-defined tropical cyclone trajectory and radius parameter

Satellite Data (HDF format) stored in local file systems

Filenames corresponding to retrieved data.

Data based on user-defined trajectory and radius parameters retrieved on-demand from local file system
Step 5: User selects filename(s)

Step 6: Push “Plot” button to plot retrieved measurements.

Step 7: Select Statistical Analysis Options of measurements and Plot Results

System Overview and Status (XI) - Demo II
System Overview and Status (XII) - Demo II

QuikSCAT Data Retrieved for Hurricane Bill 2009 and R = 3
Future Work

- Populating the Moving Objects Database with global tropical cyclone trajectories from 2000-2009, QuikSCAT and TRMM trajectory data
- Integrating/Connecting Satellite Data Retrieval on Matlab to Oracle-based moving objects database.
- Exploration of other integration alternatives
- Continuation of MOSL and STQL development
- Implementation of a protot

• Shen-Shyang Ho, Wenqing Tang, and W. Timothy Liu. Tropical Cyclone Event Sequence Similarity Search via Dimensionality Reduction and Metric Learning, *16th ACM SIGKDD Int. Conf. on Knowledge Discovery and Data Mining (KDD)*, Washington, DC, July 25-28, 2010.