Global Information Management

NASA’s ATM Ontology: Semantic Integration and Querying across NAS Data Sources

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Long Term Vision:
A Global Airspace Question-Answering System

current

“Identify all sectors within which any A320 aircraft is currently operating in US airspace”

historical

“Which US carrier had the largest number of flights rerouted due to weather during the month of August 2010?”

Airspace Oracle

UAL

ZTL sector 2
ZTL sector 10
ZOA sector 45
...
Many Challenges!

• Question understanding
• Automated reasoning
• Information retrieval
• Natural language generation

• **Data exchange & integration**
  – **Data exchange**: How do you facilitate aviation data sharing and system interoperability?
    • Using *standards*: AIXM, FIXM, WXXM
  – **Data integration**: How do you take heterogeneous data from multiple sources and weave together a harmonized picture of global airspace operations?
    • Using *semantics*!
Some Small Steps Toward the Vision

NASA has developed a *semantics-based* data integration prototype capable of answering a limited set of queries about airspace operations.
Outline

• Background and Motivation
• Semantic Integration Approach
• Prototype: Integrating and querying data for airspace operations at KATL on 2012/09/08
NASA Project Background

• NASA researchers need historical ATM data
  – NASA Ames conducts research on future ATM concepts
  – Researchers require data for analysis and concept validation

• NASA Ames’ **ATM Data Warehouse** archives data collected from FAA, NASA, NOAA, DOT, industry
  – Warehouse captures:
    • live streamed data
    • published periodic data
  – Data holdings available back to 2009
A Sampling of Archived Data Warehouse Holdings

- ATCSCC Advisories
- Airline Situation Display to Industry (ASDI)*
- Air Route Traffic Control Center (flight plans & tracks)
- Corridor Integrated Weather Service (CIWS)
- Center-TRACON Automation System (CTAS)
- Exelis Commercial Track Feed

- METAR
- AIREP, PIREP
- Rapid Refresh (RR) Weather Forecast
- Terminal Aerodrome Forecast (TAF)
- Time-based Flow Management (TBFM)
- TRACON (flight plans & tracks)

*SWIM conversion underway for available sources

ATM Data Warehouse: A microcosm of the NAS data environment
Problem: Non-integrated Data

- ATM Warehouse data is replicated & archived in its original format
- Data sets lack standardization
  - data formats
  - nomenclature
  - conceptual structure
- To analyze and mine data, researchers must write special-purpose code to integrate data for each new task
  ➔ Huge time sink!

• Possible cross-dataset mismatches:
  - terminology
  - scientific units
  - temporal alignment
  - spatial alignment
  - conceptualization organization
Proposed Solution

Relieve users of responsibility for integration!

‘Pre-integrate’ the Warehouse data sources using Semantic Integration

1. Develop an integrated data repository based on a common semantic data model ("an ontology")
2. Write translators to transform data from the original sources into an integrated common data repository
3. Expose integrated repository, not individual sources, to users for query and access
Semantic Integration Approach:

ATM Warehouse
- ASDI
- METAR
- TFM Advisories

Other Data Sources
- ERAM
- Airline, Aircraft, Airport Info
- ASPM

1. Common Cross-ATM Ontology
2. Translators
3. Integrated ATM Semantic Data Store

Query & Access Service
What is an Ontology??

- **Ontology** = data model + database

  - **data model**: provides a unified framework for describing, interrelating, and reasoning about different types of ATM data

    The data model provides a basis for integrating heterogeneous ATM data from multiple sources

  - **database**: contains integrated air traffic management information from multiple sources, stored as per data model

    This database can be queried like a conventional database. But it can also draw inferences from the data and generate new data using inference rules.

  - Plays similar role as UML, but adds inference and reasoning
What is modeled by the NASA ATM Ontology?

❖ 150+ object types

- Flights
- Aircraft and manufacturers
- Airlines
- Airports and physical infrastructure
- NAS facilities
- Air traffic management initiatives
- Surface weather conditions and forecasts
- Airspace sectors, fixes, routes, airways
- Flight plans and paths

❖ 150+ object properties

- actualDepartureTime
- actualArrivalTime
- airportArrivalRate
- cloudType
- dewpoint
- EDCTarrivalHold
- equipmentCode
- groundSpeed
- heading
- hourlyPrecipitation
- IATAcarrierCode
- issuedTime
- manufactureYear
- maxVisibility

❖ 100+ relationship types

- hasRampTower
- hasRunway
- operatedBy
- locatedInSector
- manufacturedBy
- hasSurfaceWindCondition
- hasLOAwith
- exemptedAFP
- departureScope
- ADLday
- adjacentSector
- aircraftFix
- aircraftFlown
- arrivalRunway
- reRouteConstraint

❖ Object/property/relationship instances also stored in ontology

Covers selection of concepts found in the AIXM, FIXM, WXXM conceptual models
Ontology Representation of a Flight (viewed as graph)

**Properties**
- object
- relationship

**Objects**
- KATL Airport
- KORD Airport
- Delta Air Lines
- Aircraft N342NB

**Relationships**
- departure airport
- arrival airport
- has flight Path
- has runway
- has fix

**KATL METAR @18:52**
- dewpoint = 19
- met condition end time = 2012-09-30T18:52:00
- met condition probability = 1.0
- met condition start time = 2012-09-30T18:52:00
- METAR report string = KATL 3018522 1100KT...
- metar station has precipitation sensor = true
- meteorological condition status = observed
- surface pressure = 1010.1
- surface temperature = -22

**Flight DAL1512**
- actual arrival time = 2012-09-30T20:35:00
- actual departure time = 2012-09-30T19:03:00
- call sign = DAL1512
- flight route string = KATL,CADIT6,CADIT,G...
- user category = COMMERCIAL

**KORD Airport**
- airport name = CHICAGO O HARE INTL
- FAA airport code = ORD
- hours offset from UTC = -6
- ICAO airport code = KORD
- Located in State = IL
- within timezone = America/Chicago

**Aircraft N342NB**
- aircraft registrant = DELTA AIR LINES INC
- serial number = 1746
- certificate issue date = 2009-12-31
- manufacturer year = 2002
- model SCode = 50742752
- number of engines = 2
- number of seats = 145
- registration number = N342NB

**Track Position #1**
- ground speed = 461
- reporting time = 2012-09-30T19:03:00
- sequenceNumber = 1

**Track Position #2**
- ground speed = 184
- reporting time = 2012-09-30T19:03:32
- sequenceNumber = 2

**Aircraft Fix #1**
- altitude = 3700.0
- latitude = 33.6507222222
- longitude = -84.4955555556

**Aircraft Fix #2**
- altitude = 3600.0
- latitude = 33.65
- longitude = -84.4833333333

**Flight Track for DAL1512**
Ontology crosses AIXM, FIXM, WXXM boundaries

Aeronautical | Flight | Weather | Equipment | Industry

KATL Airport
- airport name = HARTSFIELD - JACKSON...
- FAA airport code = ATL
- hours offset from UTC = -5
- ICAO airport code = KATL
- within timezone = America/New York

Flight DAL1512
- actual arrival time = 2012-09-08T20:35:00
- actual departure time = 2012-09-08T19:03:00
- call sign = DAL1512
- flight route string = KATL, CADIT6, CADIT, G...
- user category = COMMERCIAL

Flight Track for DAL1512
- Track Position #1
  - ground speed = 461
  - reporting time = 2012-09-08T19:03:32
  - sequenceNumber = 1

Aircraft Fix #1
- Position of DAL1512 at 2012-09-08 19:03:32
  - ground speed = 184
  - reporting time = 2012-09-08T19:03:32
  - sequenceNumber = 2

Track Position #1
- Fix for DAL1512 at 2012-09-08 19:03:32
  - altitude = 3600.0
  - latitude = 33.65
  - longitude = -84.4833333333

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- airport name = CHICAGO O HARE INTL
- FAA airport code = ORD
- hours offset from UTC = -6
- ICAO airport code = KORD
- Located in State = IL
- within timezone = America/Chicago

Delta Air Lines
- Air carrier name = Delta Air Lines
- airline callsign = DELTA
- country of registry = United States
- IATA Carrier Code = DL
- ICAO Air Carrier Code = DAL

Aircraft N342NB
- aircraft registrant = DELTA AIR LINES INC
- serial number = 1746
- certificate issue date = 2009-12-31
- manufacture year = 2002
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Flight DAL1512
- has flight Path
  - Airbus
  - has model
    - A319
    - has manufacturer
      - Airbus

Aeronautical Flight Weather Equipment Industry
Semantic Integration Approach:

1. Common Cross-ATM Ontology
2. Translators
3. Query & Access Service

ATM Warehouse
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- METAR
- TFM Advisories

Other Data Sources
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- Airline, Aircraft, Airport Info
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Data Translators

• How is data mapped from the source schemas into the ontology schema?
  – custom translator is written for each data source

  – similar in spirit to data warehouse ETL tools
Example: Mapping an ASDI Departure Message

<table>
<thead>
<tr>
<th>Message-Time-UTC</th>
<th>AC-ID</th>
<th>Departure-Time-UTC</th>
<th>Departure-Named-Fix</th>
<th>Arrival-Named-Fix</th>
<th>AC-Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-09-08 19:02:35</td>
<td>DAL1512</td>
<td>2012-09-08 19:03:00</td>
<td>KATL</td>
<td>KORD</td>
<td>A319</td>
</tr>
</tbody>
</table>
Example: Mapping an ASDI Departure Message

**Flight DAL1512**
- **AC-ID**: DAL1512
- **Departure-Time-UTC**: 2012-09-08 19:02:35
- **Departure-Named-Fix**: KATL
- **Arrival-Named-Fix**: KORD
- **AC-Type**: A319

**KATL Airport**
- **airport name**: HARTSFIELD - JACKSON...
- **FAA airport code**: ATL
- **hours offset from UTC**: -5
- **ICAO airport code**: KATL
- **Located in State**: GA
- **within timezone**: America/New_York

**KORD Airport**
- **airport name**: CHICAGO O HARE INTL
- **FAA airport code**: ORD
- **hours offset from UTC**: -6
- **ICAO airport code**: KORD
- **Located in State**: IL
- **within timezone**: America/Chicago

**Delta Air Lines**
- **Air carrier name**: Delta Air Lines
- **airline callsign**: DELTA
- **country of registry**: United States
- **IATA Carrier Code**: DL
- **ICAO Air Carrier Code**: DAL

**ASDI Departure Message**
- **Message-Time-UTC**: 2012-09-08 19:02:35
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- **Departure-Named-Fix**: KATL
- **Arrival-Named-Fix**: KORD
- **AC-Type**: A319
Querying the Ontology

• **Querying = graph-matching:**
  – Each query represents a graph pattern
  – The pattern is matched against the ontology network and all possible matches are returned

• **SPARQL: W3C standard ontology query language**
  (uses SQL-like syntactic constructs)

• **Benchmark Queries:**
  – Set of 17 queries developed to evaluate query performance as ontology scales up
  – Query solutions all require integrated data; none can be answered using a single data source alone
Representative Queries
(restricted to flights on 9/8/12, arriving/departing KATL)

- **Flight Demographics:**
  - F1: Find Delta flights using A319s departing ZTL airports
  - F3: Find flights with rainy departures from ATL

- **Sector Capacity:**
  - S4: Find which sector controlled the most flights during a given hour
  - S6: Find the busiest sectors in the NAS on a given day, aggregating hourly

- **FAA Advisories / TMI:**
  - T1: Find flights that were subject to GDP Advisories

- **Weather-Impacted Traffic (WITI) Calculation**
  - W1: Calculate hourly WITI values (High Wind, Low Ceiling, Low Visibility)

- **ASPM (Flight Delay) Data**
  - A3: Compare ASPM AAR with Arrival Demand on an hourly basis at an airport
Status

• Right now, ATM Ontology is just a prototype
  – Includes over 380K instances of ATM objects/properties
• Working to deploy a test version @ NASA
• Initial results promising, but scale-up will be challenging
• Key tasks ahead:
  – Increase scale
  – Increase scope
  – Develop query interface
Collaborators and Funding

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Questions

Comments