Global Information Management

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

Presented By: Rich Keller, Ph.D.
Date: August 27, 2015
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

- ZTL sector 2
- ZTL sector 10
- ZOA sector 45...

UAL
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*!
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)

**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

**METAR report**
- 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 301852Z 11004KT...
- meteorological condition status = observed
- surface pressure = 1010.1
- surface temperature = 22

**Flight DAL1512**
- actual arrival time = 2012-09-08T20:35:00
- actual departure time = 2012-08-19T03:00
- call sign = DAL1512
- flight route string = KATL>CADIT6>CADIT>..
- 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

**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
- model code = 50742752
- number of engines = 2
- number of seats = 145
- registration number = N342NB

**A319**
- Aircraft type code = A319
- manufacturer = Airbus

**Flight Track for DAL1512**
- Track Position #1
  - ground speed = 461
  - reporting time = 2012-09-08T19:03:00
  - sequence number = 1
- Aircraft Fix #1
  - altitude = 3700.0
  - latitude = 33.657222222
  - longitude = -84.4955555556

- Track Position #2
  - ground speed = 184
  - reporting time = 2012-09-08T19:03:32
  - sequence number = 2
- Aircraft Fix #2
  - altitude = 3600.0
  - latitude = 33.65
  - longitude = -84.481333333

**Rway 09R/27L**
- runway

**Aircraft Fix #1**
- has fix

**Aircraft Fix #2**
- has fix

**Flight DAL1512**
- arrival airport
- departure airport
- has runway
- has flight Path
- has aircraft flown
- has aircraft manufacturer
- has aircraft model
Ontology crosses AIXM, FIXM, WXXM boundaries

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

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,CADIT,G... 
- user category = COMMERCIAL

Rway 09R/27L

Flight Track for DAL1512
- has runway
- has METAR report

Track Position #1
- ground speed = 461
- reporting time = 2012-09-08T19:03:00
- sequenceNumber = 1

Aircraft Fix #1
- altitude = 3700.0
- latitude = 33.6597222222
- longitude = -84.4855555556

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

Airframe N342NB
- aircraft registrant = DELTA AIR LINES INC
- serial number = 1746
- certificate issue date = 2009-12-31
- manufacture year = 2002
- model SCode = 50742575
- number of engines = 2
- number of seats = 145
- registration number = N342NB

A319
- Aircraft type code = A319
- model ID = generic

Airbus

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 301822 11004KT...
- metar station has precipitation sensor = true
- meteorological condition status = observed
- surface pressure = 1010.1
- surface temperature = 22

METAR report

Federal Aviation Administration
EUROCONTROL
Semantic Integration Approach:

ATM Warehouse

- ASDI
- METAR
- TFM Advisories

Other Data Sources

- ERAM
- Airline, Aircraft, Airport Info
- ASPM

Common Cross-ATM Ontology

Integrated ATM Semantic Data Store

Query & Access Service

1. ATM Warehouse
2. Translators
3. Query & Access Service
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
- Actual arrival time: 2012-09-08T20:35:00
- Actual departure time: 2012-09-08T19:03:00
- Call sign: DAL1512
- Flight route string: KATL.CAD175.CAD176.GCI
- 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

Delta Air Lines
- Air carrier name: Delta Air Lines
- Airline call sign: DELTA
- Country of registry: United States
- IATA Carrier Code: DL
- ICAO Air Carrier Code: DAL

A319
- Aircraft type code: A319
- Model ID: generic

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

Rway 09R/27L

KATL METAR @18:52
- Dewpoint: 19
- Met condition end time: 2012-09-08T18:52:00
- Met condition probability: 1.0
- Met condition start time: 2012-09-08T18:52:00
- METAR report string: KATL 3018322 11004KT...
- Metar station has precipitation sensor: true
- Meteorological condition status: observed
- Surface pressure: 1010.1
- Surface temperature: 22
- Altitude: 3700.0

Flight Track for DAL1512

Message-Time-UTC | AC-ID | Departure-Time-UTC | Departure-Named-Fix | Arrival-Named-Fix | AC-Type
--- | --- | --- | --- | --- | ---
2012-09-08 19:02:35 | DAL1512 | 2012-09-08 19:03:00 | KATL | KORD | 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 / TMIs**
  - 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

Rich Keller  Mei Wei
Intelligent Systems Division

Shubha Ranjan  Michelle Eshow
ATM Data Warehouse Group
Aviation Systems Division

NASA Ames Research Center
Contact: rich.keller@nasa.gov

Funded by NASA Aeronautics Research Mission Directorate
Aviation Operations & Safety Program
Questions

Comments