Ontologies: Weather and Flight Information

Kajal Claypool

Kelly Moran

MIT Lincoln Laboratory

This work was sponsored by the Federal Aviation Administration under Air Force Contract No. FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.
Interactions between FAA Facilities and Airlines for Newark Congestion Problems

Next Generation Air Transportation System Operational Concept
Semantic Interoperability Framework must be able to support

- Mediation for systems that will never switch over
- Transition of legacy systems to net-centric systems
- New systems
Outline

• Background

• Ontology Engineering (Kajal)
  – NNEW Weather Ontology
  – Flight Object Ontology

• Ontology Alignment (Kelly)
  – Ontology Alignment
  – Semantic Discovery in NextGen Network Enabled Weather (NNEW)

• Summary
NNEW Ontology Development Methodology – “Green” Engineering

- **Ontology-level method:**
  - Spiral development methodology
  - **Specification:** Define the domain and scope of the ontology
NNEW Ontology Development Methodology

- Ontology-level method:
  - Focus Area Evaluation:
    Segment the overall domain and scope of ontology into smaller focus areas. Prioritize the focus area.
• **Prototype implementation:**
  - **Conceptualize:** Enumerate important concepts
  - **Reuse:** Identify reuse opportunities at upper/mid/low ontologies for straight reuse or as starting point
  - **Implement:** Define the classes, class hierarchy, and properties for the concept
  - **Validate:** Validate the ontology focus area
Design Principles

• Design principles:

  – Expressive representation
    Model concepts with hierarchies and relationships, not with flat term concatenation

  – Internal concept reuse
    Reusing concepts within an ontology ensures consistency and reduces ambiguity

  – Consistent scoping
    Converge on a common granularity for each sub-domain
NNEW Weather Ontology

Layered Approach to Ontology Design

1. General weather concepts

2. Aviation specific weather concepts derived from general weather ontology

3. FAA specific weather concepts derived from aviation concepts

Legend:
- subClassOf
- Constrained Concepts
Example: Wind Ontology

Legend
- SWEET 2.0
- JMBL derived
- WordNet derived
- Weather Ontology

Diagram:
- Transport
- Atmosphere
- Circulation
- Motion
- Air
- Wind
- Speed
- Direction
- Gust
- breeze
- tailwind
- maximum_spread
- Jetstream
- Wind Phenomena
- EarthSciencePhenomena
- AssociatedQuantity
- AssociatedPhenomenon
- AssociatedDate
- Scale
- HazardnessLevel
- AssociatedSubstance
- AssociatedRealm

- windUComponent
- windVComponent
- windComponent
- componentValue
- Mean
- Error
- GridIncrement
- Increment
- Coefficient
- (ObjectProperty)

- JMBL derived
- WordNet derived
- Weather Ontology
Flight Information Ontology: Data Dictionary to Ontology
Flight Information & Modeling Process

Key Issue:
• DD - human readable not machine readable
Ontology: Capturing Knowledge

- Machine readable: Semi-automate generation of data model
- Machine process-able:
  - Can be reasoned over
  - Can support mediation for transition systems
- Searchable/indexable
- Basis of capturing agreement, and of applying knowledge
### Ontology Example

**Text**

#### 7.24 ASSIGNED_RTE

<table>
<thead>
<tr>
<th>Name</th>
<th>Taxonomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASSIGNED_RTE</td>
<td>[TBD]</td>
</tr>
</tbody>
</table>

**Synonyms**

<table>
<thead>
<tr>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route</td>
</tr>
<tr>
<td>Assigned</td>
</tr>
<tr>
<td>RTE</td>
</tr>
</tbody>
</table>

**Description**

A route assigned to a flight as part of a reroute traffic management initiative. A flight can have more than one assigned route.

**Has Parts**

<table>
<thead>
<tr>
<th>Route elements (flights, airways etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
</tr>
</tbody>
</table>

**Is Part Of**

<table>
<thead>
<tr>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFMS</td>
</tr>
</tbody>
</table>

**Creator**

<table>
<thead>
<tr>
<th>TFMS</th>
</tr>
</thead>
</table>

**Contribution**

<table>
<thead>
<tr>
<th>TFMS</th>
</tr>
</thead>
</table>

**Affecting Events**

<table>
<thead>
<tr>
<th>Traffic Manager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Created when a reroute is issued for a flight. Can be modified by the traffic manager if the reroute is edited.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Audience</th>
<th>Data Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFMS users (airlines etc.)</td>
<td></td>
</tr>
<tr>
<td>Traffic Managers</td>
<td></td>
</tr>
</tbody>
</table>

**Identification**

| Identifies an assigned route. Users are supposed to file and follow assigned routes. |

| Reroute monitor compares assigned routes to current flight routes to determine reroute conformance. |

| Traffic managers of the TMU monitor reroute conformance and put flights on their assigned routes if the users do not file them. |

**Example**

`<CTR:ASSIGNED_RTE=COD-MEX-SHM-TARNL1>/CTR:ASSIGNED_RTE`  

<table>
<thead>
<tr>
<th>Access Restriction</th>
<th>Maturity</th>
<th>Accuracy Method</th>
<th>Accuracy Periodicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>assigned</td>
<td>rarely</td>
<td></td>
</tr>
</tbody>
</table>

**Disposition**

| Exists until reroute expires or is canceled or flight is displaced. |

<table>
<thead>
<tr>
<th>Requires</th>
<th>Is Required By</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASSIGNED_RTE_TYPE</td>
<td>none</td>
</tr>
</tbody>
</table>

**References**

<table>
<thead>
<tr>
<th>Data Transactions or Interfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFMS data exchanges</td>
</tr>
</tbody>
</table>

**Notes**

| n/a |

**Version**

| 1.0 | 6 August 2010 | Michael Harris (Voipe) | Initial version for review. |

---

**Ontology**

- **FlightObjectComponent**
- **ASSIGNED_RTE_TYPE**
- **TFMS**
- **RouteElement**
- **AssignedRoute**
- **createdBy**
- **hasContributor**
- **references**
  - **TrafficManager**
  - **TrafficManager**
  - **[TBD]** (literal)
  - **FlightObj**
Outline

• Background

• Semantic Interoperability Framework
  – NNEW Weather Ontology
  – Ontology/Vocabulary Alignment
  – Semantic Discovery in NextGen Network Enabled Weather (NNEW)

• Summary
Interoperability Challenges

National Weather Service Vocabulary
(Climat and Forecast)

aerosol_angstrom_exponent
age_of_stratospheric_air
air_density
air_potential_temperature
air_pressure
air_pressure_anomaly
air_pressure_at_cloud_base
air_pressure_at_cloud_top
air_pressure_at_convective_cloud_base
air_pressure_at_convective_cloud_top
air_pressure_at_freezing_level
air_pressure_at_sea_level
air_temperature
air_temperature_anomaly
air_temperature_at_cloud_top
air_temperature_lapse_rate
adiabatic_lapse_rate
alimeter_range
altitude_at_top_of_dry_convection
direction_of_rotation_from_east_to_x
direction_of_rotation_from_east_to_y
angstrom_exponent_of_ambient_aerosol_in_air

Department of Defense Vocabulary
(Joint METOC Broker Language – JMBL)

temperature_AdiabaticLapseRate
temperature_Air
temperature_AirDifferenceStandard
temperature_AirError
temperature_AirErrorEstimate
temperature_AirIncrement
temperature_AirMean
temperature_AirAnomaly
temperature_AirError

air_temperature

atmosphere__absolute_vorticity

vorticity_Absolute

1046

1270
Ontologies in NNEW

![Diagram showing the integration of ontologies and web services for NextGen Weather and JMBL Imagery systems.](image-url)
### Ontology Alignment Process

**Result is “alignment files”: searchable ontologies themselves!**

- Active area of research
- Several classes of algorithms exist: Simple, Hybrid, Composite
Ontology Alignment in the Weather Domain

• Most algorithms are developed to map between expressive ontologies\(^1,\ 2\)
  – Leverage the semantics encapsulated within the ontologies

• Weather domain often includes less expressive ontologies that contain long concatenations of terms
  – Often mapped to more modular central ontologies (NextGen)

  \[
  \text{tendency_of_atmosphere_mass_content_of_particulate_organic_matter_dry_aerosol_due_to_net_production_and_emission}
  \]


• Typical alignment algorithms are not suited to this problem
  – Can only detect 1:1 matches

• Need an algorithm that can detect n-ary matches (n:1, 1:n)
CompositeMatch Algorithm

- Lincoln-developed alignment algorithm identifies both 1:1 and n-ary (or “composite”) matches

- Hybrid algorithm
  - Uses four scoring methods to determine *what is a match*
    - Lexical
    - Linguistic
    - Context
    - Metadata
Lexical

• Compares two concept names based on their syntax
  - String and substring comparison (reordering)
  - Tokenization
  - Acronym detection
  - Abbreviation detection
  - Plural detection

VeritcallyIntegratedLiquid ≈ Liquid_Integrated_Vertically ≈ VIL
Linguistic

- Compares two concept names based on their *semantics*
  - WordNet: Large English database of terms grouped into synonyms, linked by semantic relations
  - Performs WordNet lookup to get semantic similarity

\[ \text{WaterVapor} \approx \text{AqueousVapor} \]
Context

- Compares the “context” of two concepts
  - Compares two concepts’ weighted subgraphs to a given depth $d$
Metadata

• Compares the comments of two concepts
  - Comments contain descriptions of concepts
  - Lexical comparison of comments renders a metadata similarity score

```
```
```
```
```
```
```
```
```
```
CompositeMatch Process

- Three-pass algorithm

Simple match identification

N-ary match identification

Post-processing
CompositeMatch Process

1. **Simple match identification**
   - Score every concept \( c \) from \( O \) with every concept \( c' \) from \( O' \)
   - Sort pairs into “buckets”

2. **N-ary match identification**
   - Generate composites from “conflict sets” using subsetting
   - Sort pairs into “buckets”

3. **Post-processing**
   - Optionally reduce to single best match per concept (“best match only” option)

---

**Ontology \( O \)**
- `air_temperature`
- Score: 0.5

**Ontology \( O' \)**
- `Air`
- `Temperature`
- `Humidity`
- Scores: 0.5, 0.2

- **Confident**
  - \( \{\text{air_temperature}, \text{Temperature}\} = 0.5 \)

- **Undetermined**
  - \( \{\text{air_temperature}, \text{Air}\} = 0.5 \)
  - \( \{\text{air_temperature}, \text{Humidity}\} = 0.2 \)

- **Not Confident**
  - \( \{\text{air_temperature}\} \)

Upper threshold ex. 0.8
Lower threshold ex. 0.4
CompositeMatch Process

1. **Simple match identification**
   - Score every concept \( c \) from \( O \) with every concept \( c' \) from \( O' \)
   - Sort pairs into “buckets”

2. **N-ary match identification**
   - Generate composites from “conflict sets” using subsetting
   - Sort pairs into “buckets”

3. **Post-processing**
   - Optionally reduce to single best match per concept (“best match only” option)

**Ontology \( O \)**

- `air_temperature`
- `Temperature`
- `Humidity`

**Ontology \( O' \)**

- `Air`
- `Temperature`
- `Humidity`

**Conflict sets**

- \{`air_temperature`, `{Air, Temperature}`\}

**Composites**

- \{`air_temperature`, `{Air, Temperature}`\} = 1.0

**Post-processing**

- Optionally reduce to single best match per concept

**Upper threshold** ex. 0.8

**Lower threshold** ex. 0.4
CompositeMatch Process

1. Simple match identification
   - Score every concept $c$ from $O$ with every concept $c'$ from $O'$
   - Sort pairs into “buckets”

2. N-ary match identification
   - Generate composites from “conflict sets” using subsetting
   - Sort pairs into “buckets”

3. Post-processing
   - Optionally reduce to single best match per concept (“best match only” option)

Ontology $O$ with concepts:
- air_temperature
- Temperature
- Humidity

Ontology $O'$ with concepts:
- Air
- Temperature

Confident:
- $\{\text{air_temperature, } \{\text{Air, Temperature}\}\} = 1.0$

Undetermined:
- $\ldots$

Not Confident:
- $\{\text{air_temperature, Humidity}\} = 0.2$
- $\ldots$

Upper threshold: ex. 0.8
Lower threshold: ex. 0.4
Evaluation Results

- Test suite: OAEI 2010 Benchmark
  - 12 participants total
  - Top scorer: Risk Minimization-Based Ontology Mapping (RiMOM)

Average Performance on OAEI 2010 Tests

<table>
<thead>
<tr>
<th>Model</th>
<th>Precision</th>
<th>Recall</th>
<th>N-ary Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>CompositeMatch</td>
<td>0.98</td>
<td>0.62</td>
<td>0.43</td>
</tr>
<tr>
<td>RiMOM (top scorer)</td>
<td>0.98</td>
<td>0.82</td>
<td>0</td>
</tr>
<tr>
<td>Overall (12 participants)</td>
<td>0.82</td>
<td>0.62</td>
<td>0</td>
</tr>
</tbody>
</table>
Semantic Search

Registry/Repository

CF Ontology

JMBL Ontology

NextGen Weather Ontology

Web service

Web service

Web service

Web service

Satellite Imagery

Radar Imagery

Future system

Satellite Imagery

Radar Imagery

air_temperature ↔ \{\text{Air, Temperature}\} ↔ \text{TemperatureAir}
Semantic Search: Design Time

Registry/Repository

Alignments

CompositeMatch alignment algorithm

Ontologies

Ontology engineer

Ontology engineer
Semantic Search: Runtime

Registry/Repository

“Find the sources for air temperature information in the CONUS”

Clients

End user

OGC service-enabled display client

“Give me the air temperature grid for the entire CONUS from now until 2 days from now”

Service discovery

“Give me air temperature information as it becomes available within the CONUS”

Data Providers

Web Feature Service
Non-Gridded Data

Web Coverage Service
Gridded Data

NNEW Weather Ontology and Alignments

SPARQL Query

air_temperature

temperatureAir

CF

JMBL

Loaded at design time
Outline

• Background

• Semantic Interoperability Framework
  – NNEW Weather Ontology
  – Ontology/Vocabulary Alignment
  – Semantic Discovery in NextGen Network Enabled Weather (NNEW)

• Summary
Summary

• Future U.S. air transportation system (NextGen) requires large-scale integration of multiple systems

• Semantic services can do on-the-fly translation between information services
  – Early support for semantic functionality will save time and money in the future

• Lincoln is leveraging the semantic interoperability framework to lead FAA’s effort to provide net-centric connectivity across organizations (DoD, Eurocontrol)
Summary

- Ontologies can be used in conjunction with other data modeling methods to enhance semantic interoperability of WXXM producers and consumers
  - Provides semantics for otherwise context-free data
  - Converges on and enforces mutually agreed-upon terminology
  - Enables reuse of domain knowledge
  - Allows for cross-implementation interoperability

- Ontology alignment can realize the dream of runtime discovery of services using different vocabularies
  - Utility of ontology alignment demonstrated in ebXML registry/repository OWL profile demonstration