
Ontologies: Weather and Flight Information

Kajal Claypool

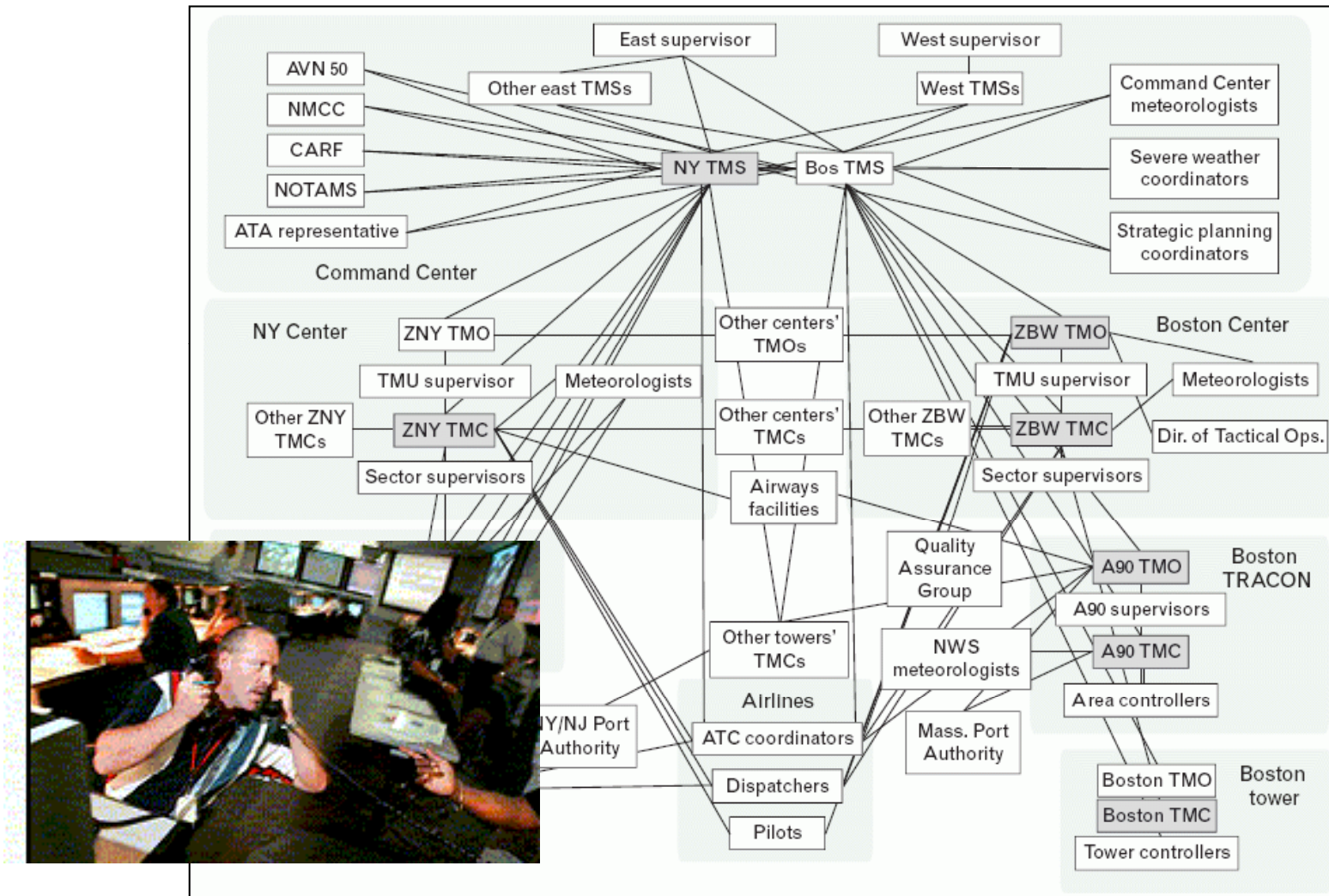
Kelly Moran

MIT Lincoln Laboratory





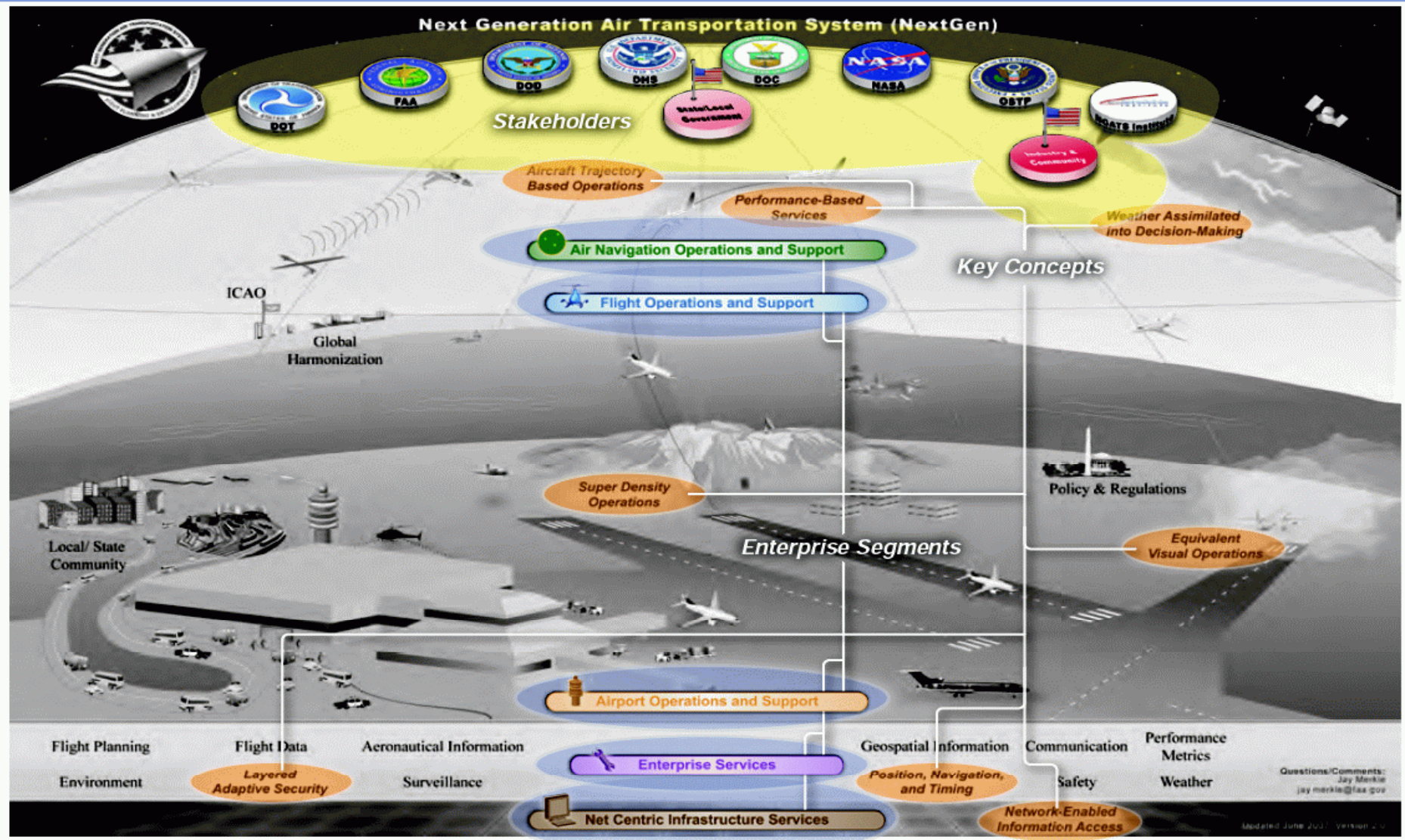
Interactions between FAA Facilities and Airlines for Newark Congestion Problems



Evans, J. Ducot, E., "Corridor Integrated Weather System, Lincoln Laboratory Journal, Volume 16, Number 1, 2006

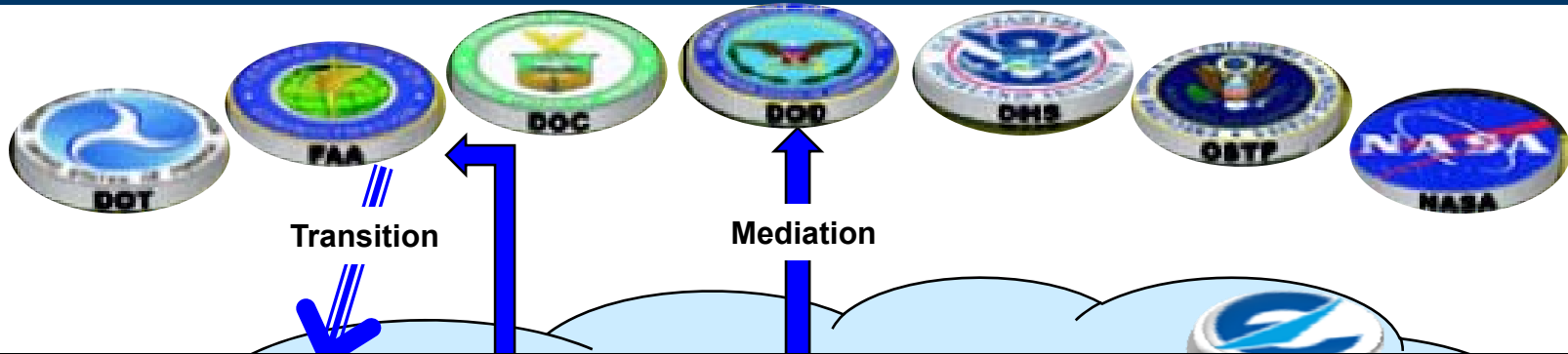


Next Generation Air Transportation System Operational Concept



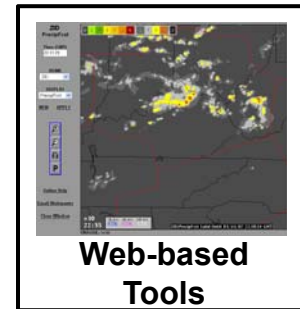
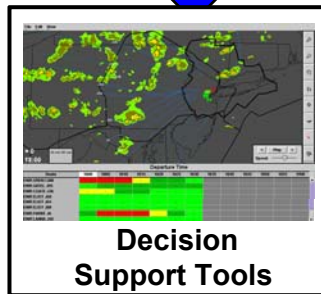
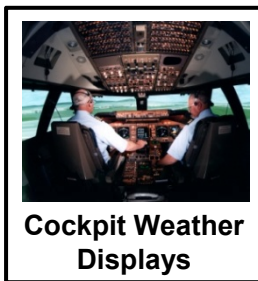


Semantic Interoperability Framework



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



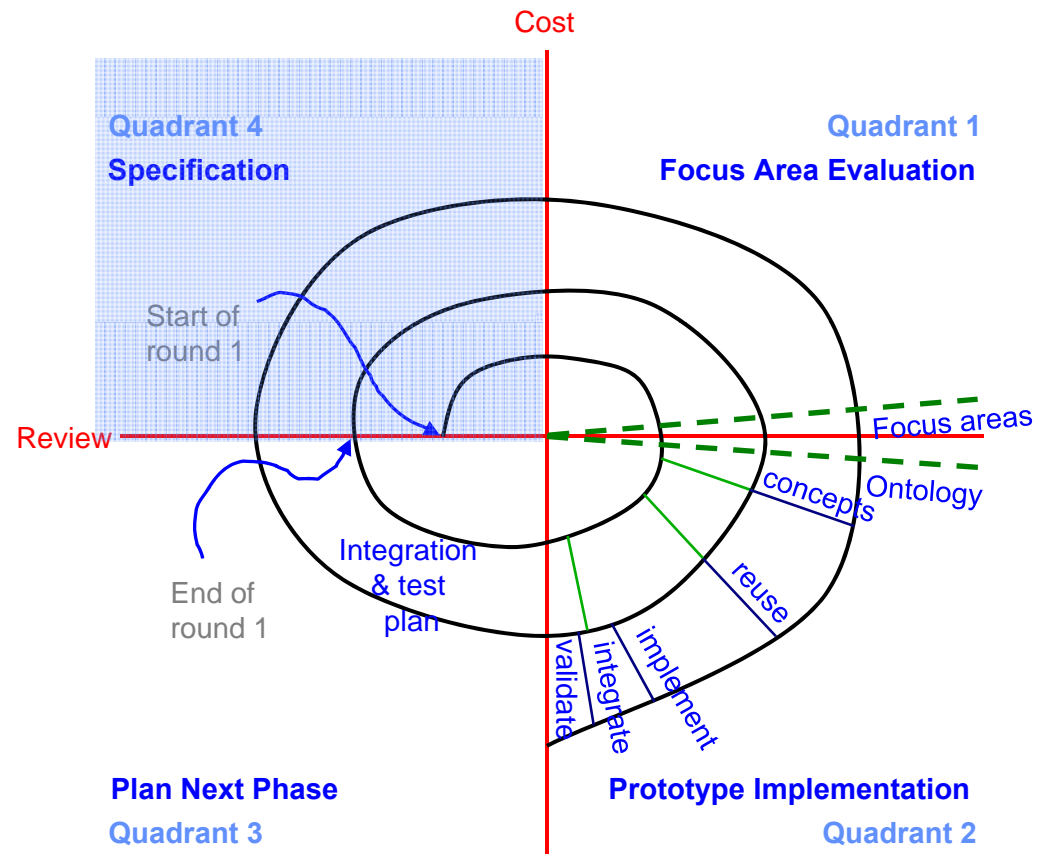
- **Ontology Engineering (Kajal)**
 - **NEW Weather Ontology**
 - **Flight Object Ontology**
- **Ontology Alignment (Kelly)**
 - **Ontology Alignment**
 - **Semantic Discovery in NextGen Network Enabled Weather (NEW)**
- **Summary**



NNEW Ontology Development Methodology – “Green” Engineering

- **Ontology-level method:**

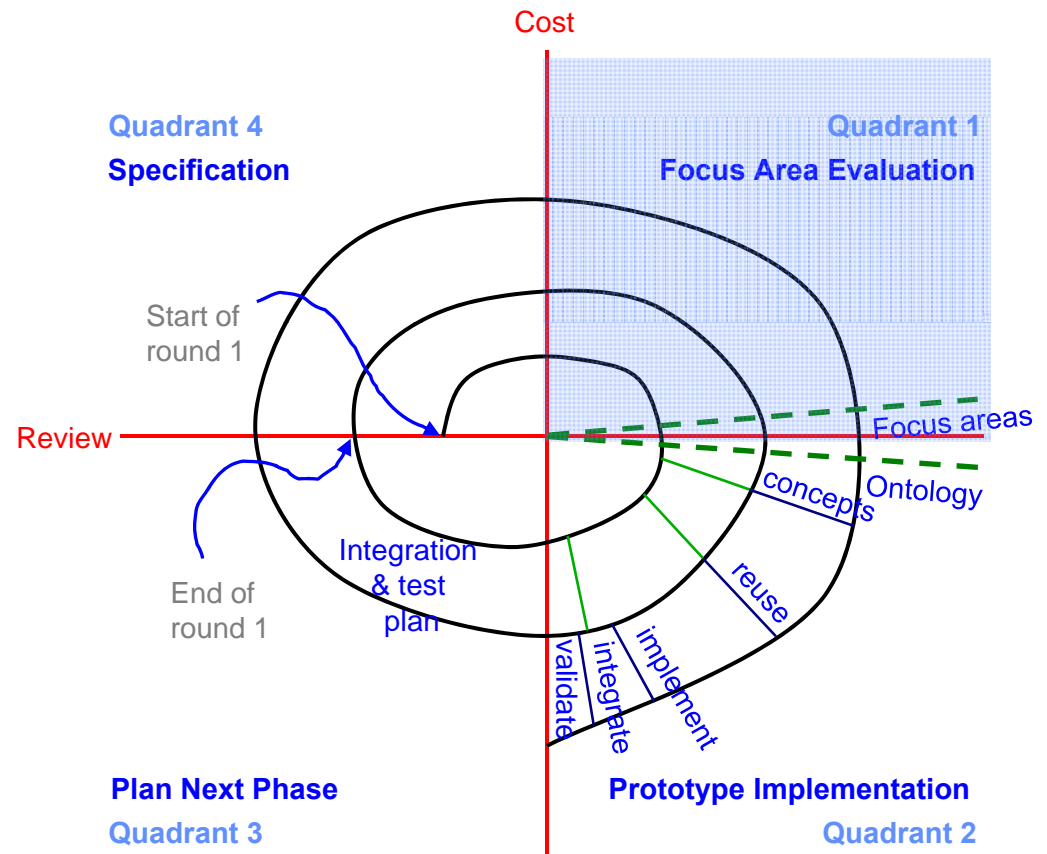
- Spiral development methodology
- **Specification:** Define the domain and scope of the ontology





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.

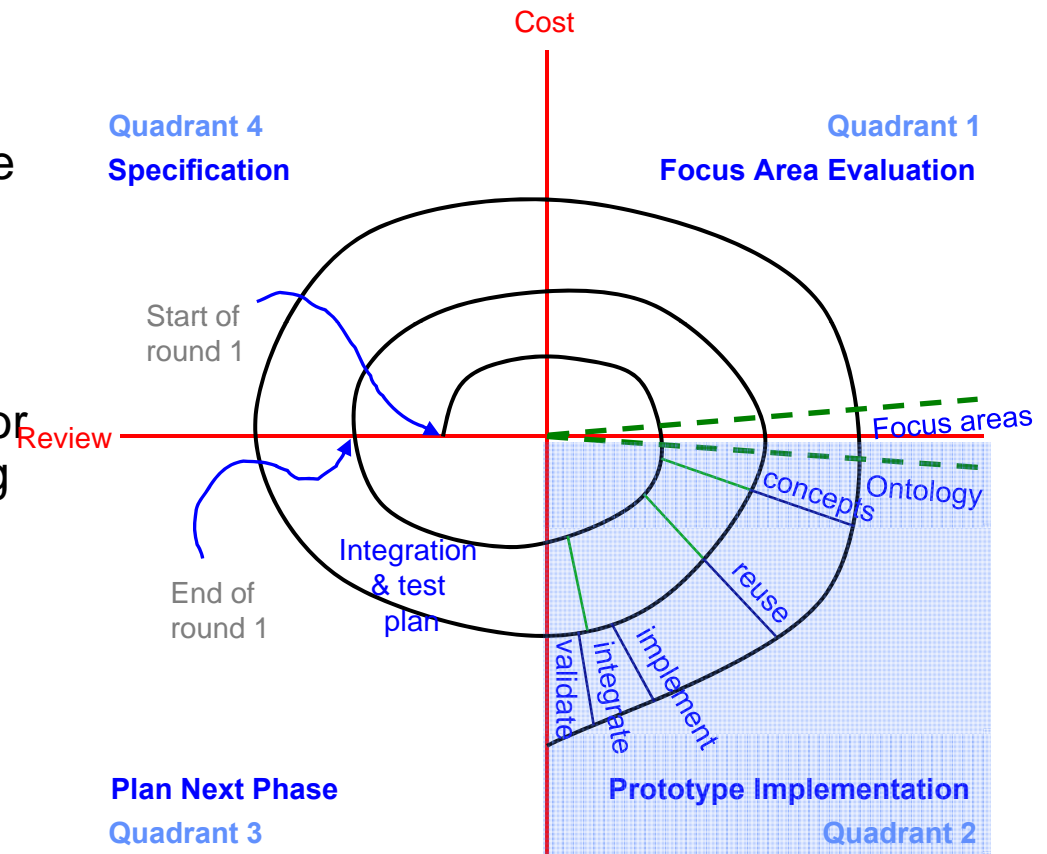




NNEW Ontology Development Methodology

- **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



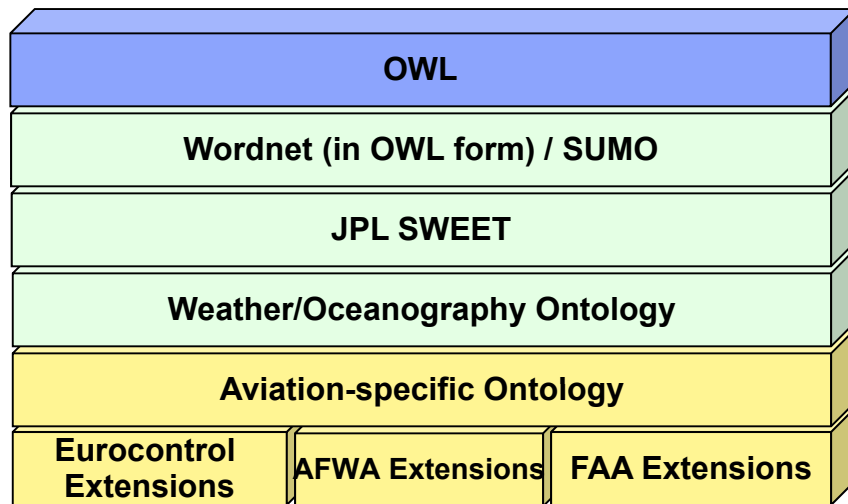


Design Principles

- **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

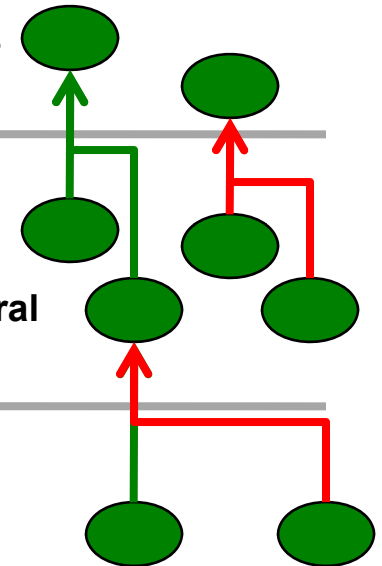


Layered Approach to Ontology Design

1. General weather concepts

2. Aviation specific weather concepts derived from general weather ontology

3. FAA specific weather concepts derived from aviation concepts



Legend:



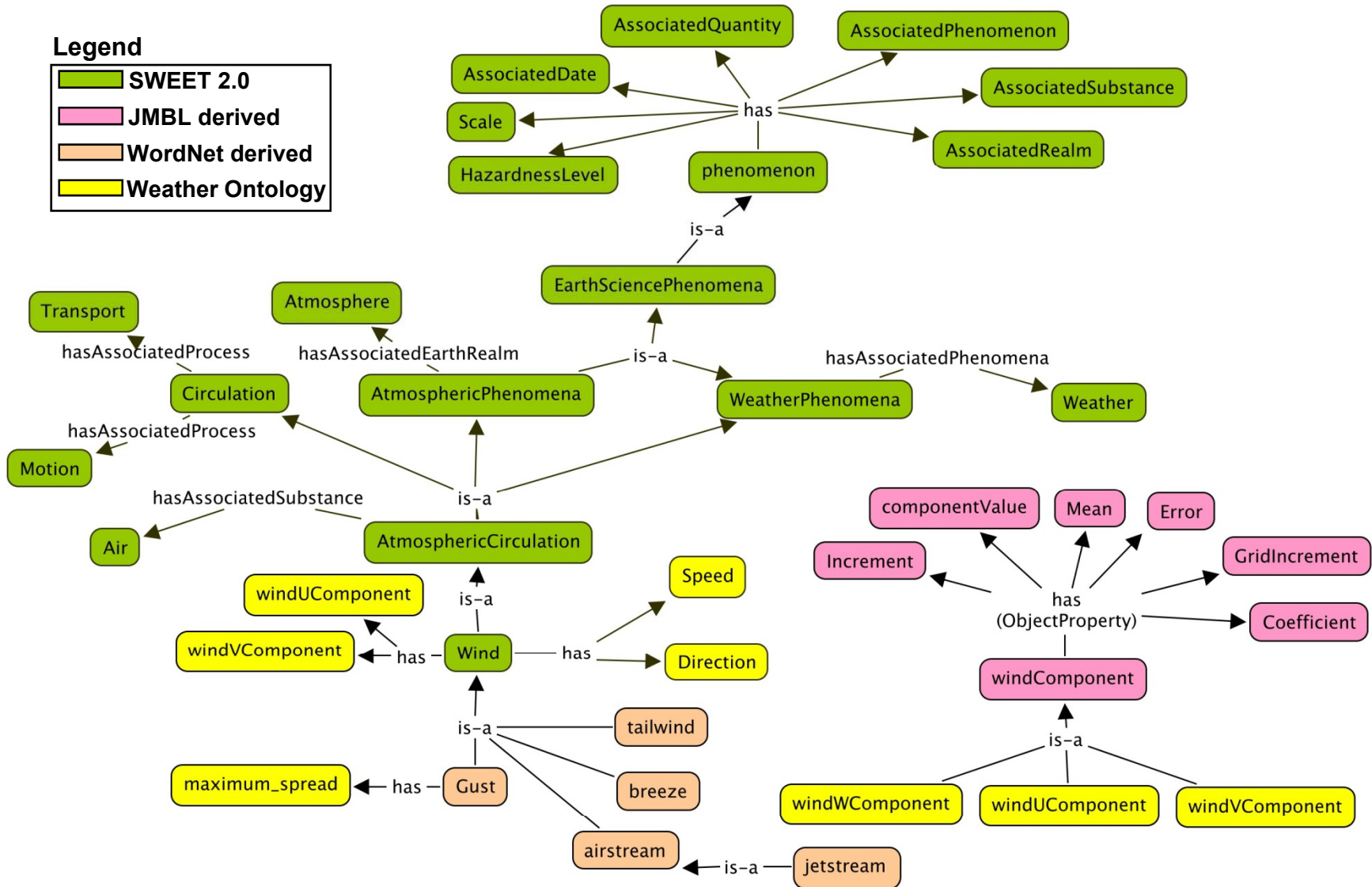
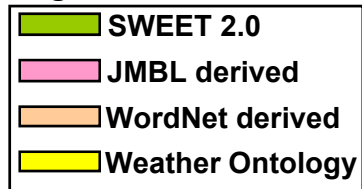
subClassOf

Constrained Concepts



Example: Wind Ontology

Legend

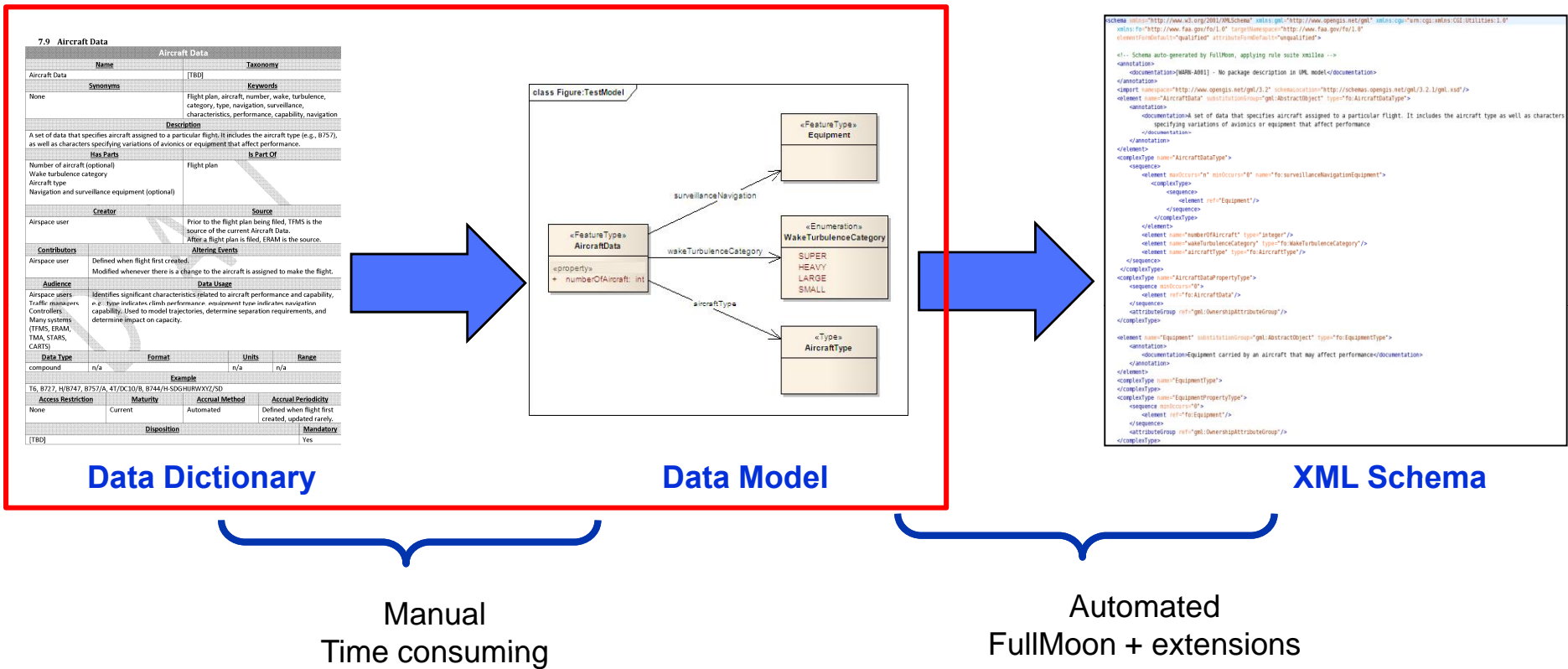




Flight Information Ontology: Data Dictionary to Ontology



Flight Information & Modeling Process

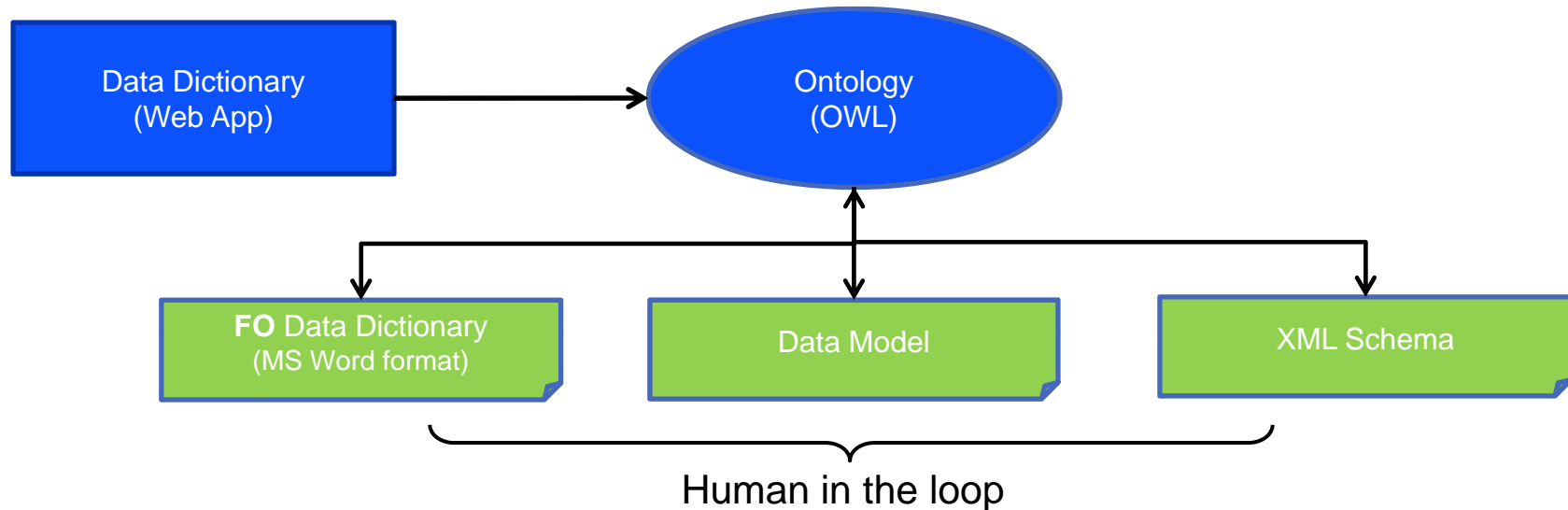


Key Issue:

- 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**



An Ontology Embedded in Word Template !

7.24 ASSIGNED RTE

Concept

Concept label

Axiom: Equivalent class

Annotation: dc:description

Object property: hasPart

Object property: createdBy

Object property: hasContributor

Object property: hasAudience

Datatype property:
hasFormat [range: string]

Datatype property:
hasMaturity [range: string]

Object property: hasAccess

Datatype property:
hasDisposition [range: string]

Object property: requires

Annotation: references (custom)

Datatype property:
hasDataTransaction [range:
string]

Annotation: dc:date [type:date]

ASSIGNED RTE			
Name	Taxonomy		
ASSIGNED RTE	[TBD]		
Synonyms	Keywords		
Assigned Route	TFMDI, TFMS		
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	Is Part Of		
Route elements (fixes, airways etc.)	none		
Creator	Source		
Traffic Manager	TFMS		
Contributors	Altering Events		
Traffic Manager	Created when a reroute is issued for a flight. Can be modified by the traffic manager if the reroute is edited.		
Audience	Data Usage		
TFMDI users (airlines etc.)	Identifies an assigned route. Users are supposed to file and follow assigned routes. Reroute monitor compares assigned routes to current field routes to determine reroute conformance.		
Traffic Managers	Traffic managers at the TMUs monitor reroute conformance and put flights on their assigned routes if the users do not file them.		
Data Type	Format	Units	Range
string	A list of route elements (fixes, airways etc.) separated by spaces.	n/a	Up to 1024 characters.
Example			
<CTR_ASSIGNED RTE>RQD MIE SHM TARNE1</CTR_ASSIGNED RTE>			
Access Restriction	Maturity	Accrual Method	Accrual Periodicity
[TBD]	current	assigned	rarely
Disposition			Mandatory
Exists until reroute expires or is cancelled or flight is disposed of.			No
Requires	Is Required By		
ASSIGNED RTE_TYPE	none		
References			
[TBD]			
Data Transactions or Interfaces			
TFMDI data exchanges.			
Notes			
n/a			
Version	Date	Author	Description of Changes
1.0	6 August 2010	Michael Harris (Volpe)	Initial version for review.

Datatype property: hasKeyword
[range: string]

Axiom: Inverse properties

Object property: hasSource

Object property:
hasAlteringEvent
[range: string]

Datatype property:
hasDataUsage
[range: string]

Object property:
measurement.owl#hasUnit

Instance data

Datatype property:
hasAccrualMethod [range: string]

Datatype property:
hasAccrualPeriodicity [range:
string]

Datatype property: isMandatory
[range: boolean]

Axiom: Inverse properties

Annotation: rdf:comment

Annotation: dc:creator

Annotation: dc:versionInfo



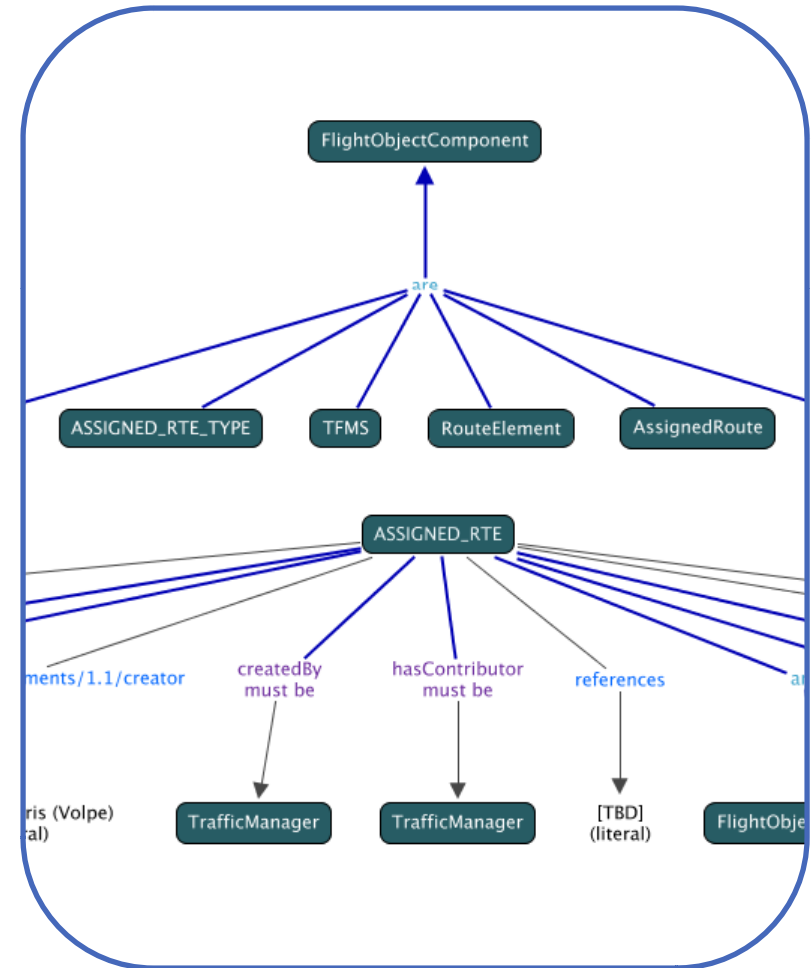
Ontology Example Text

7.24 ASSIGNED_RTE

Name		Taxonomy	
ASSIGNED_RTE	[TBD]		
Synonyms		Keywords	
Assigned Route	TFMDI, TFMS		
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		Is Part Of	
Route elements (fixes, airways etc.)		none	
Creator		Source	
Traffic Manager		TFMS	
Contributors		Altering Events	
Traffic Manager	Created when a reroute is issued for a flight. Can be modified by the traffic manager if the reroute is edited.		
Audience		Data Usage	
TFMDI users (airlines etc.)	Identifies an assigned route. Users are supposed to file and follow assigned routes.		
Traffic Managers	Reroute monitor compares assigned routes to current field routes to determine reroute conformance.		
	Traffic managers at the TMUs monitor reroute conformance and put flights on their assigned routes if the users do not file them.		
Data Type	Format	Units	Range
string	A list of route elements (fixes, airways etc.) separated by spaces.	n/a	Up to 1024 characters.
Example			
<CTR_ASSIGNED_RTE>ROD MIE SHM TARNE1</CTR_ASSIGNED_RTE>			
Access Restriction	Maturity	Accrual Method	Accrual Periodicity
[TBD]	current	assigned	rarely
Disposition			Mandatory
Exists until reroute expires or is cancelled or flight is disposed of.			No
Requires		Is Required By	
ASSIGNED_RTE_TYPE		none	
References			
[TBD]			
Data Transactions or Interfaces			
TFMDI data exchanges.			
Notes			
n/a			
Version	Date	Author	Description of Changes
1.0	6 August 2010	Michael Harris (Volpe)	Initial version for review.



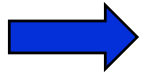
Ontology





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 (Climate and Forecast)



aerosol_angstrom_exponent
 age_of_stratospheric_air
 air_density
 air_potential_temperature
 air_pressure
air_temperature
 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
atmosphere_
 air_temperature_threshold
 altimeter_range
absolute_
 altimeter_range_correction_due_to_dry_troposphere
 altimeter_range_correction_due_to_ionosphere
 altimeter_range_correction_due_to_wet_troposphere
vorticity
 altitude
 altitude_at_top_of_dry_convection
 angle_of_emergence
 angle_of_incidence
 angle_of_rotation_from_east_to_x
 angle_of_rotation_from_east_to_y
 angstrom_exponent_of_ambient_aerosol_in_air



1046

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



temperatureAdiabaticLapseRate temperatureAir
 temperatureAirDifferenceStandard
 temperatureAirError temperatureAirErrorEstimate
 temperatureAirIncrement temperatureAirMean
temperatureAir
 temperatureAnomaly temperatureAtmospheric
 temperatureSecondary temperatureBrightness
 temperatureBrightnessCorrected
 temperatureBrightnessCount
 temperatureBrightnessOccurrence
 temperatureBrightnessStandardDeviation
 temperatureDewpoint
 temperatureDewpointDepression
 temperatureDewpointDepressionCoefficient
 temperatureDewpointDepressionErrorEstimate
 temperatureDewpointDepressionIncrement
atmosphere
 temperatureDewpointDepressionMinimum
 temperatureDewpointMaximum
 temperatureDewpointMaximumMean
 temperatureDewpointMaximumStandardDeviation
 temperatureDewpointMean
 temperatureDewpointMinimum
vorticityAbsolute
 temperatureDewpointMinimumStandardDeviation
 temperatureDewpointStandardDeviation
 temperatureDifference temperatureEarthSkin
 temperatureFrequency temperatureGradient
 temperatureHeatIndex
 temperatureInfraredStandardDeviation



1270



But What If...

Scientific Community Vocabulary (Climate and Forecast)

aerosol_angstrom_exponent
 age_of_stratospheric_air
 air_density
 air_potential_temperature
 air_pressure
 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
 air_temperature_threshold
 altimeter_range
 altimeter_range_correction_due_to_dry_troposphere
 altimeter_range_correction_due_to_ionosphere
 altimeter_range_correction_due_to_wet_troposphere
 altitude
 altitude_at_top_of_dry_convection
 angle_of_emergence
 angle_of_incidence
 angle_of_rotation_from_east_to_x
 angle_of_rotation_from_east_to_y
 angstrom_exponent_of_ambient_aerosol_in_air

air temperature

atmosphere_

absolute_

vorticity



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

temperatureAdiabaticLapseRate temperatureAir
 temperatureAirDifferenceStandard
 temperatureAirError temperatureAirErrorEstimate
 temperatureAirIncrement temperatureAirMean
 temperatureAnomaly temperatureAtmospheric
 temperatureBrightness temperatureBrightness
 temperatureBrightnessCorrected
 temperatureBrightnessCount
 temperatureBrightnessOccurrence
 temperatureBrightnessStandardDeviation
 temperatureDewpoint
 temperatureDewpointDepression
 temperatureDewpointDepressionCoefficient
 temperatureDewpointDepressionErrorEstimate
 temperatureDewpointDepressionIncrement
 temperatureDewpointDepressionMinimum
 temperatureDewpointMaximum
 temperatureDewpointMaximumMean
 temperatureDewpointMaximumStandardDeviation
 temperatureDewpointMean
 temperatureDewpointMinimum
 temperatureDewpointMinimumMean
 temperatureDewpointMinimumStandardDeviation
 temperatureDewpointStandardDeviation
 temperatureDifference temperatureEarthSkin
 temperatureFrequency temperatureGradient
 temperatureHeatIndex
 temperatureInfraredStandardDeviation

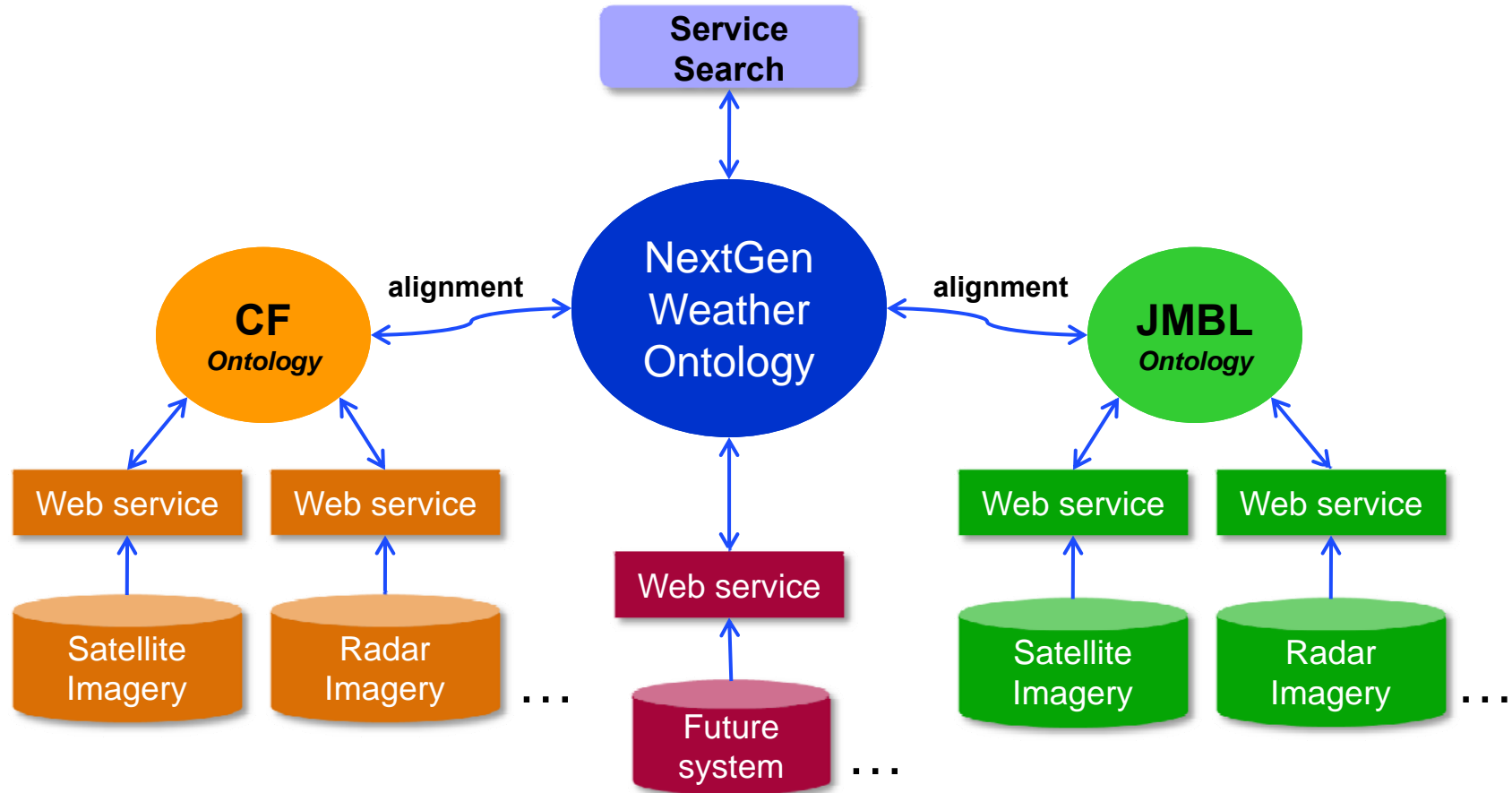
temperatureAir

atmosphere

vorticityAbsolute

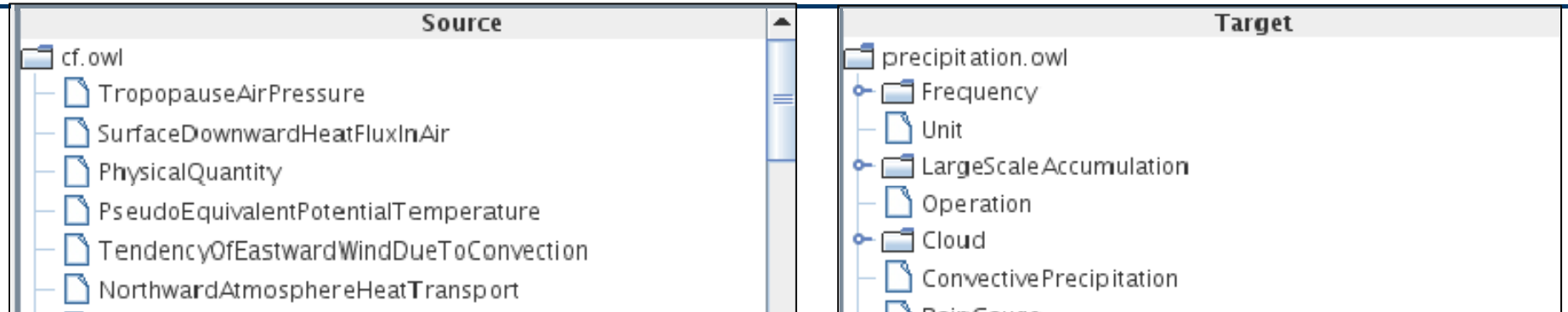


Ontologies in NNEW

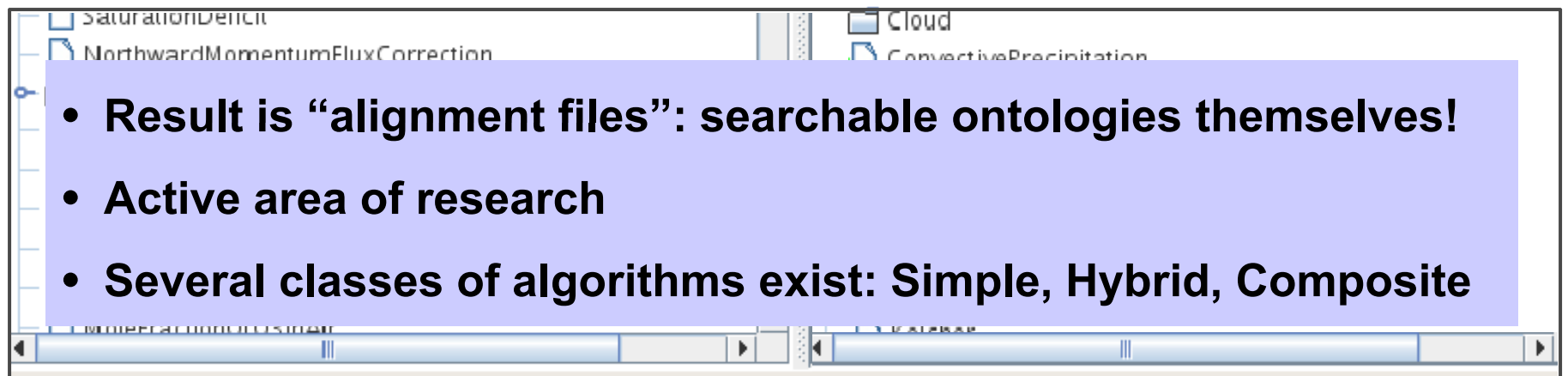




Ontology Alignment Process



Alignment Algorithm





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)



tendency_of_atmosphere_mass_content_of_particulate_organic_matter_dry_aerosol_due_to_net_production_and_emission



Tendency? Atmosphere? MassContent? Particulate? OrganicSubstance?

- **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”) matches³
- Hybrid algorithm
 - Uses four scoring methods to determine *what is a match*

Lexical

Linguistic

Context

Metadata



CompositeMatch Scoring Methods

Lexical

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

VeritcallyIntegratedLiquid \approx Liquid_Integrated_Vertically \approx VIL



CompositeMatch Scoring Methods

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

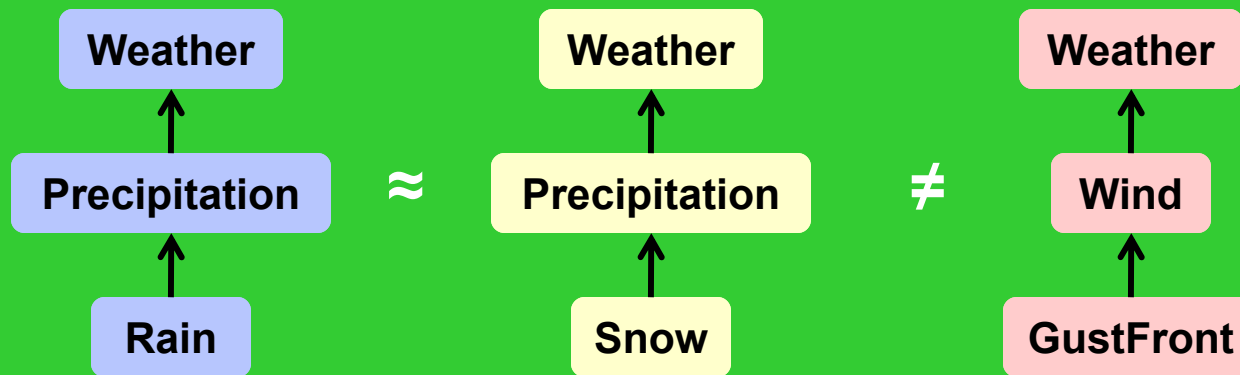
WaterVapor

≈

AqueousVapor

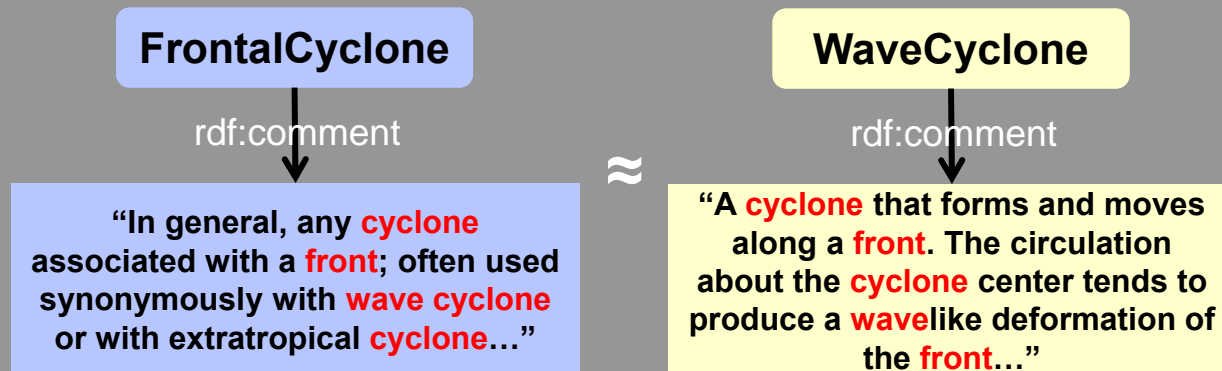
Context

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



Metadata

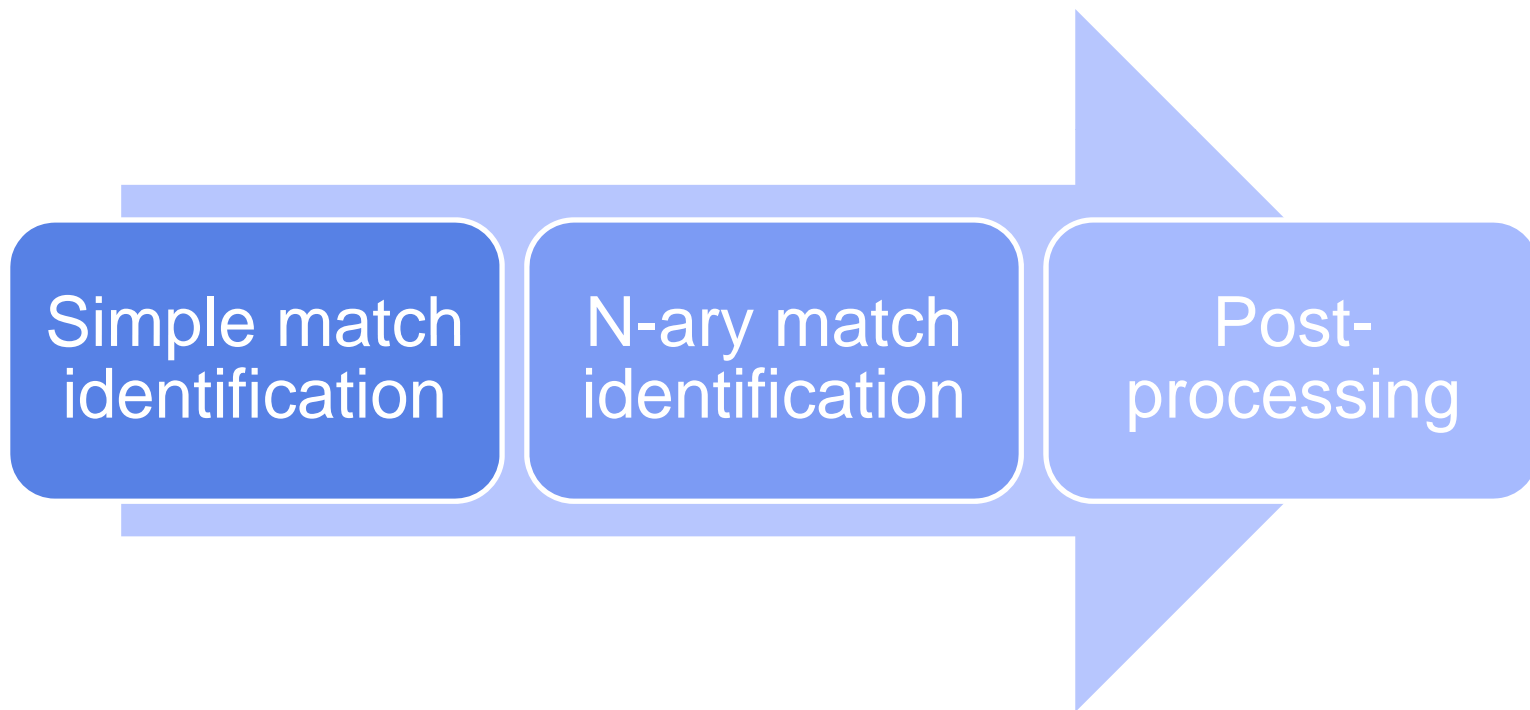
- Compares the comments of two concepts
 - Comments contain descriptions of concepts
 - Lexical comparison of comments renders a metadata similarity score





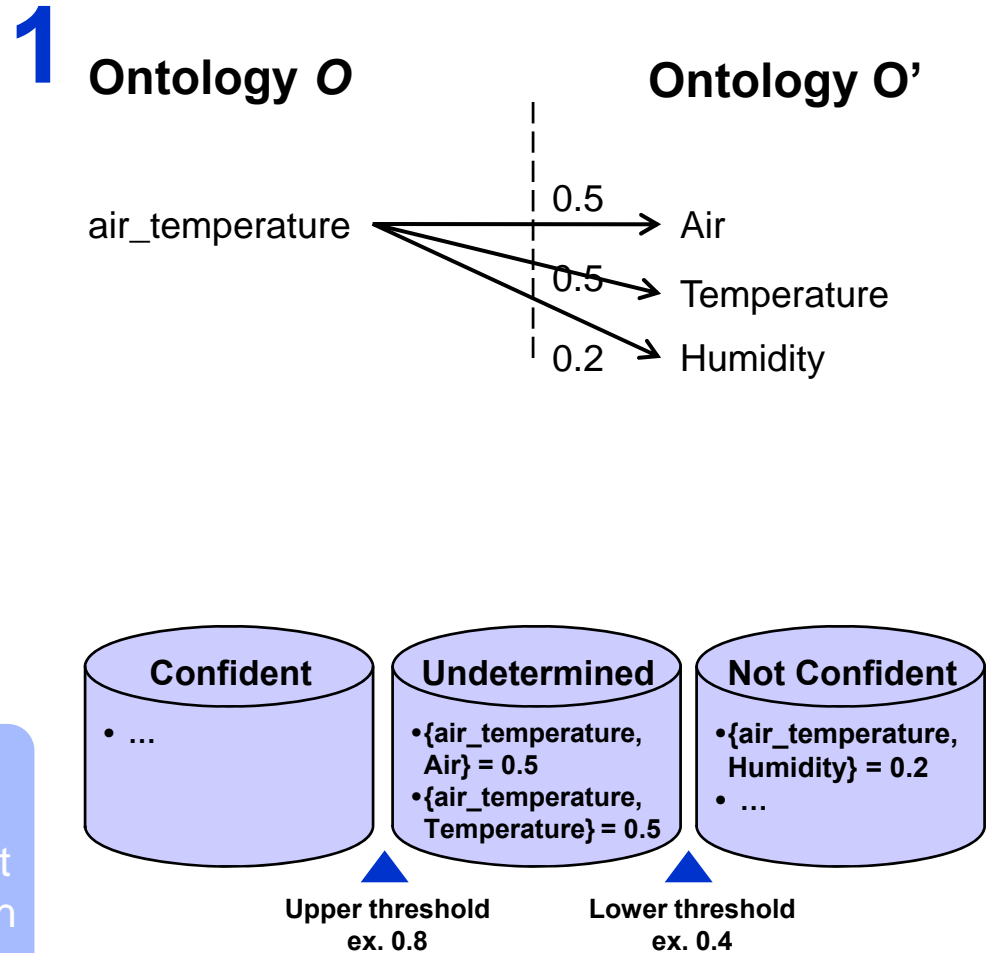
CompositeMatch Process

- Three-pass algorithm



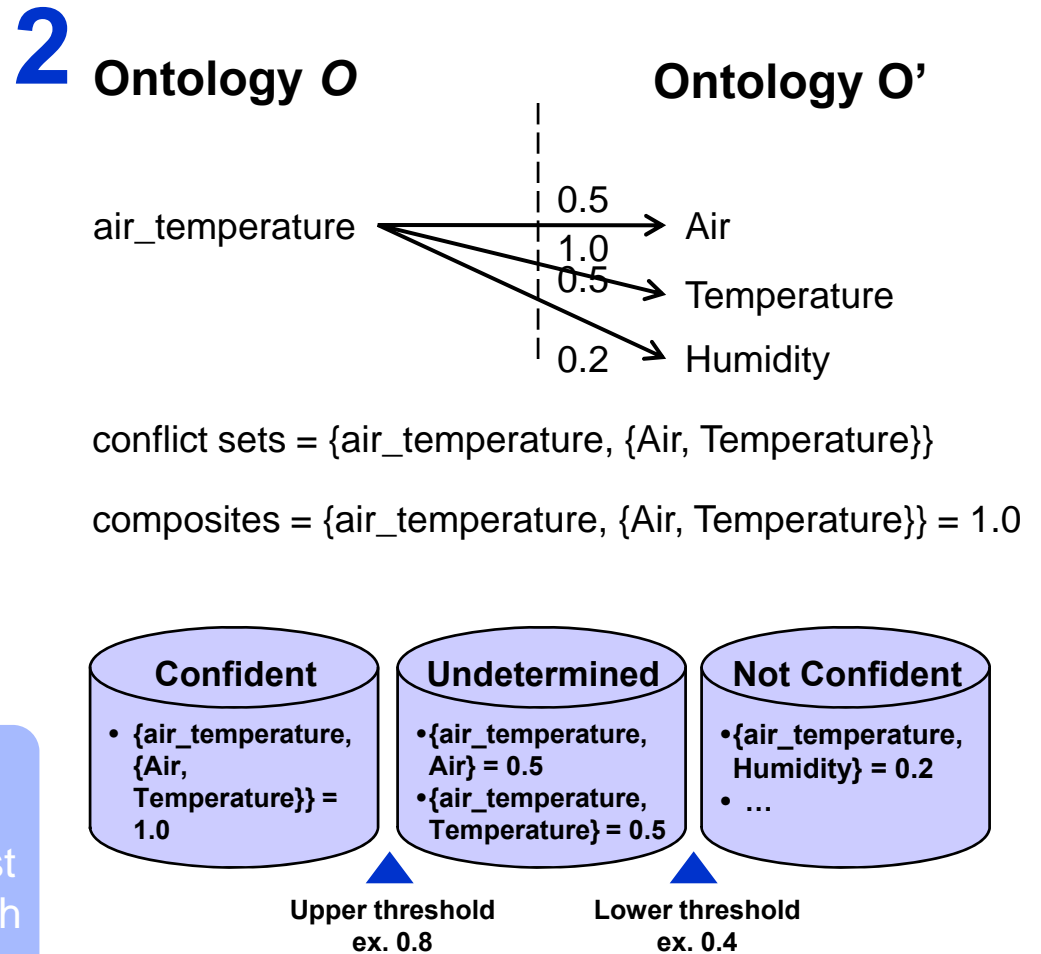
CompositeMatch Process

- 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)



CompositeMatch Process

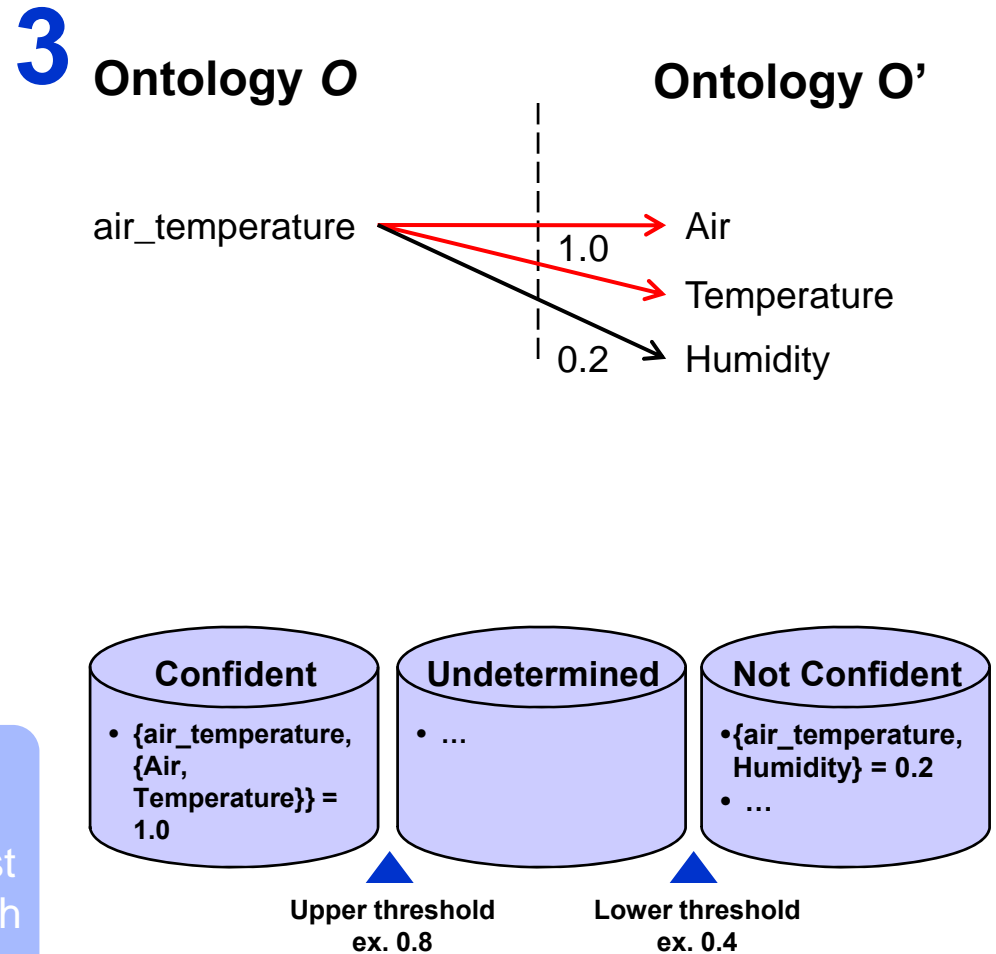
- 1 Simple match identification**
 - Score every concept c from O with every concept c' from O'
 - Sort pairs into "buckets"
- 2 N-ary match identification**
 - Generate composites from "conflict sets" using subsetting
 - Sort pairs into "buckets"
- 3 Post-processing**
 - Optionally reduce to single best match per concept ("best match only" option)





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)

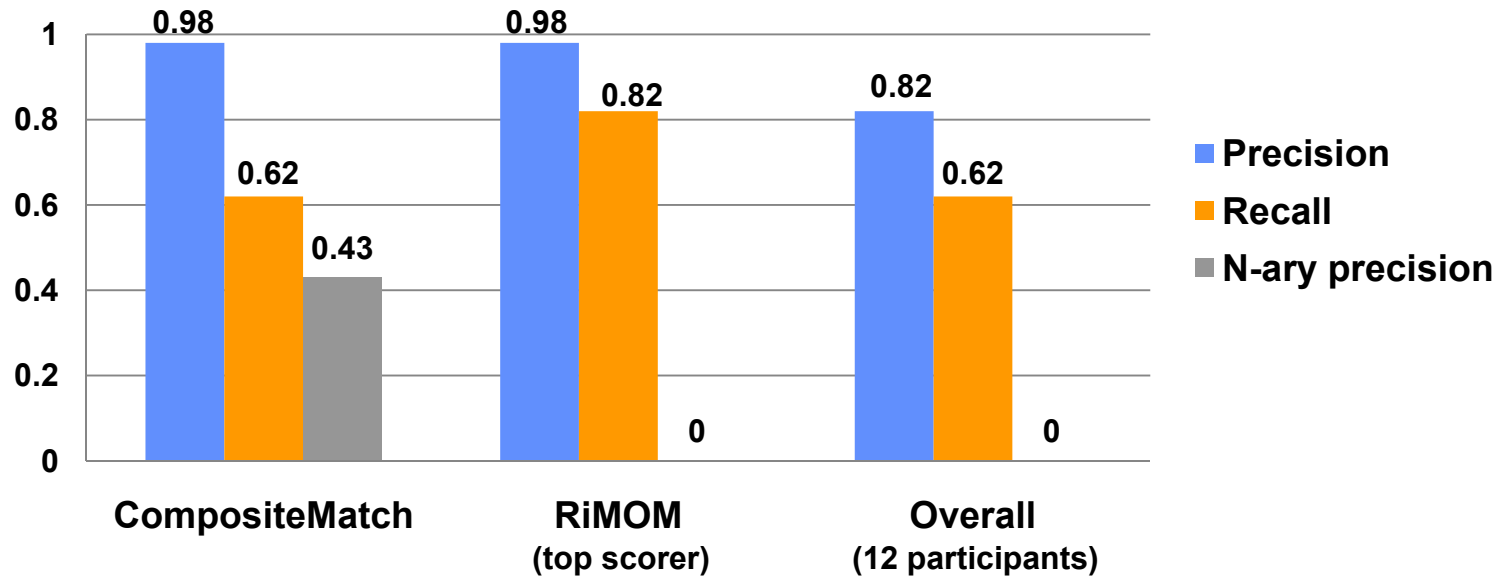




Evaluation Results

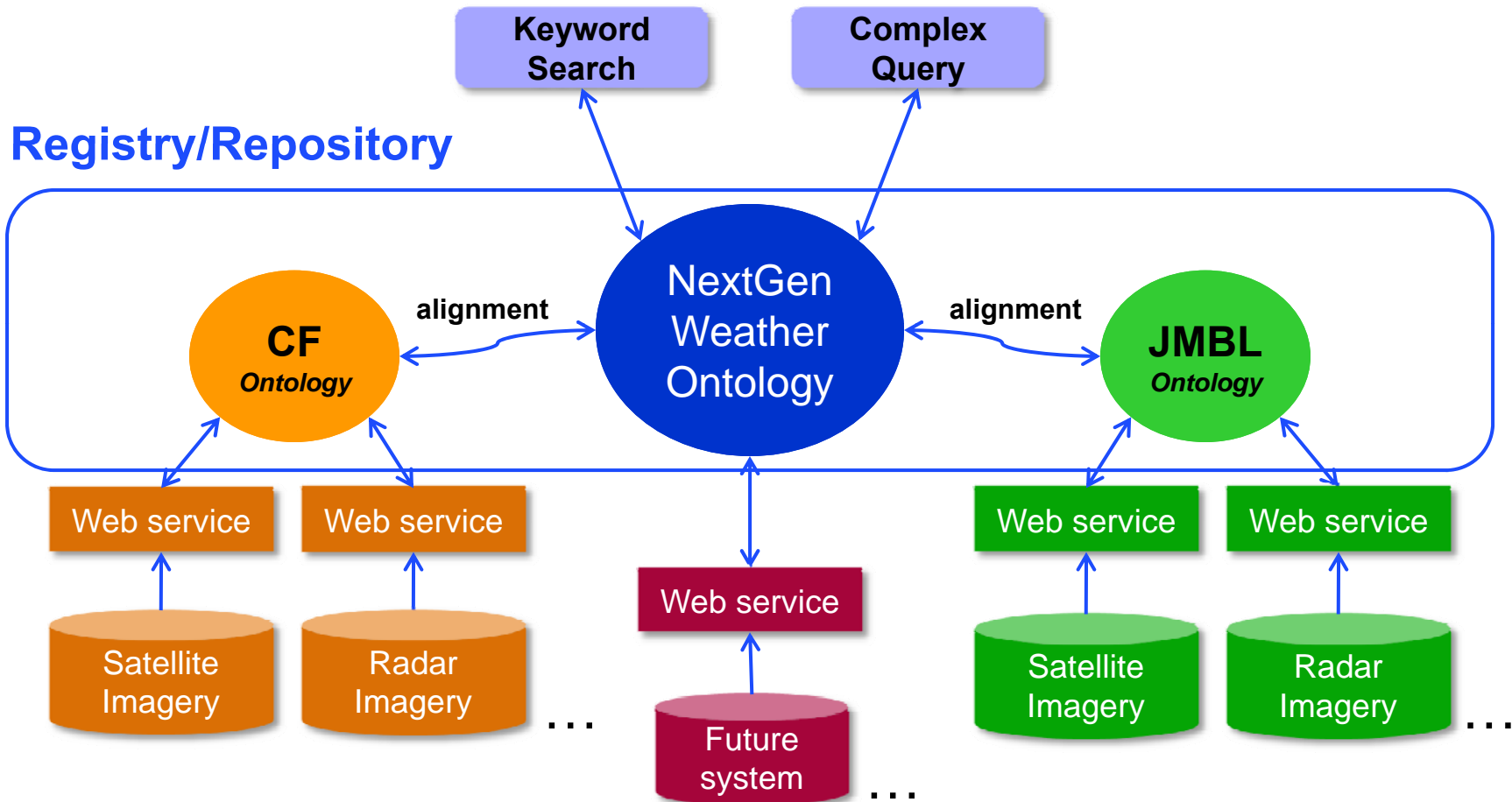
- Test suite: OAEI 2010 Benchmark⁴
 - 12 participants total
 - Top scorer: Risk Minimization-Based Ontology Mapping (RiMOM)⁵

Average Performance on OAEI 2010 Tests





Semantic Search

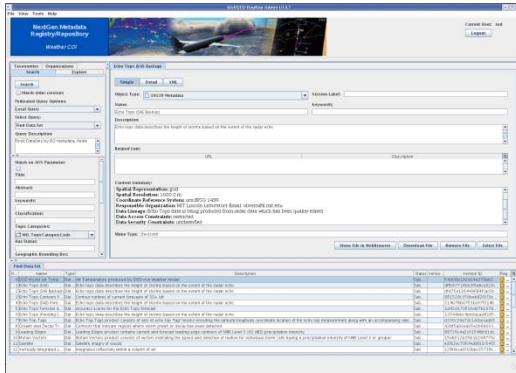


air_temperature ↔ {Air, Temperature} ↔ **TemperatureAir**

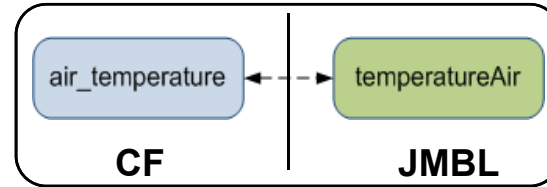


Semantic Search: Design Time

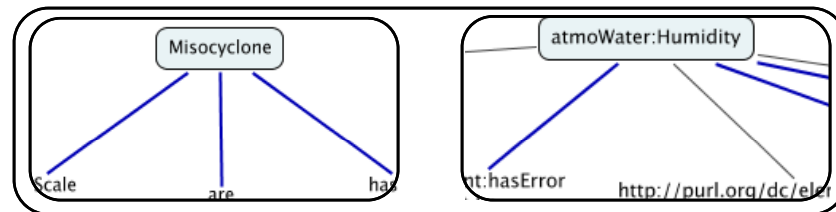
Registry/Repository



Alignments



Ontologies



Ontology engineer

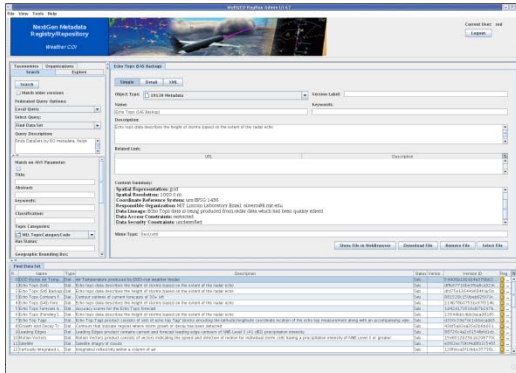


Ontology engineer

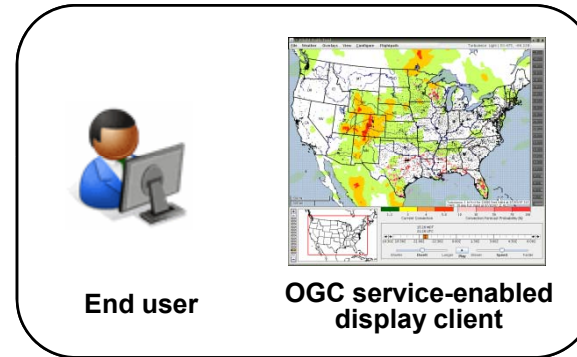


Semantic Search: Runtime

Registry/Repository



Clients



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



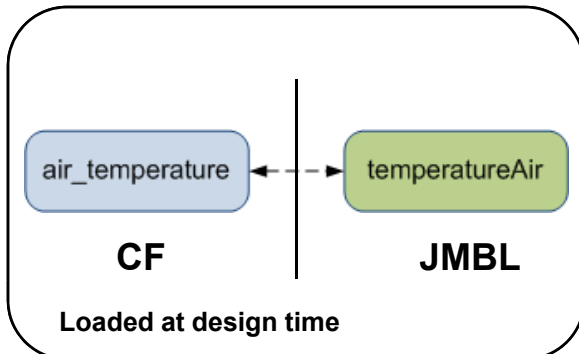
“Give me the air temperature grid for the entire CONUS from now until 2 days from now”



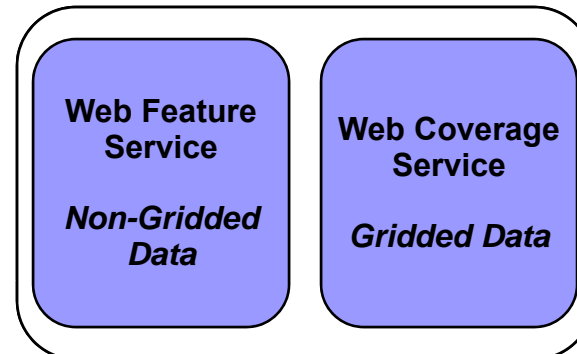
“Give me air temperature information as it becomes available within the CONUS”



NNEW Weather Ontology and Alignments



Data Providers





User ID':

Password':

Login

Taxonomies Organizations

Search Explore

Search

Match older versions

Federated Query Options:

Local Query

Select Query:

Find Data Set

Query Description:

Finds DataSets by ISO metadata, fields

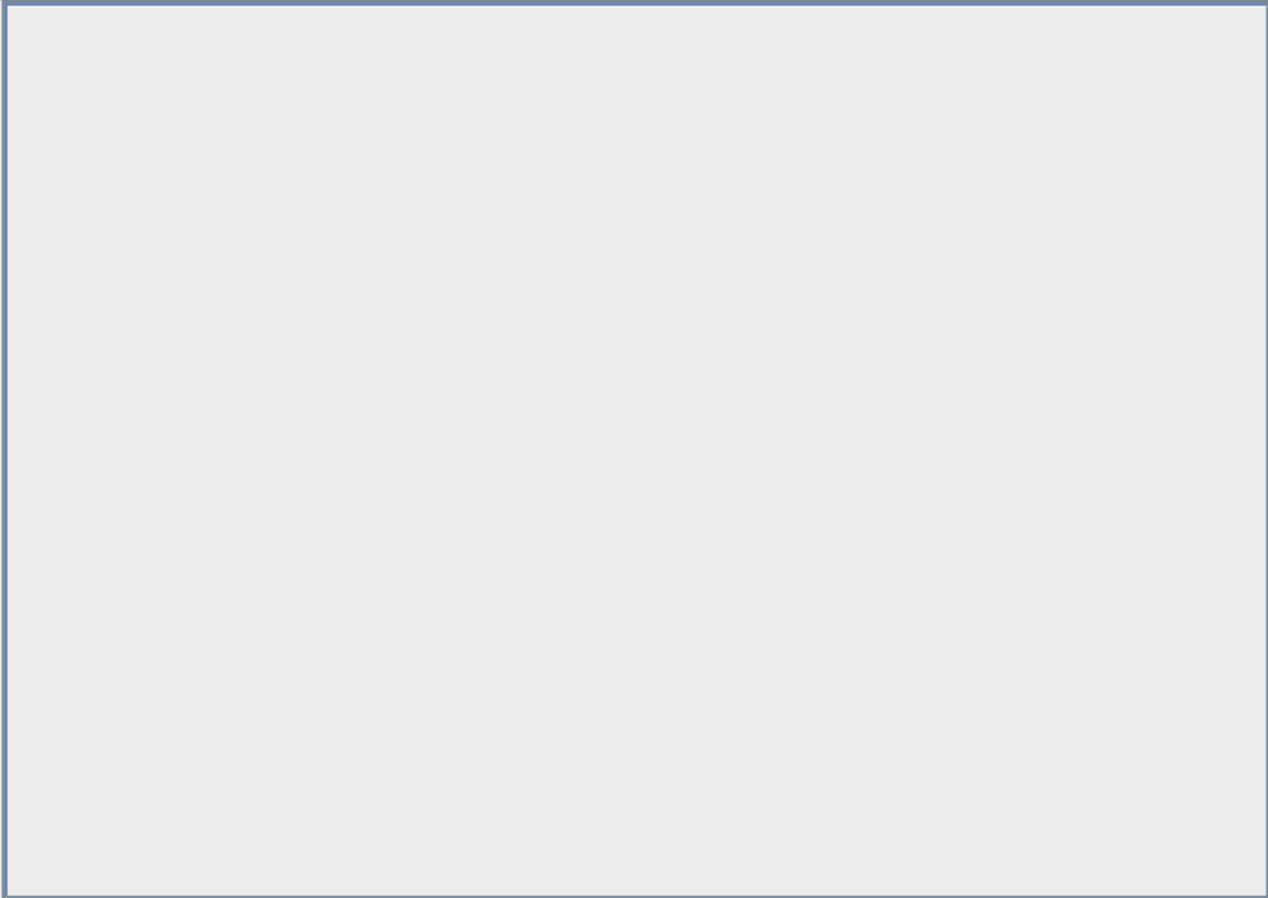
Match on ANY Parameter:

Title:

Abstract:


keywords:

Classification:





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