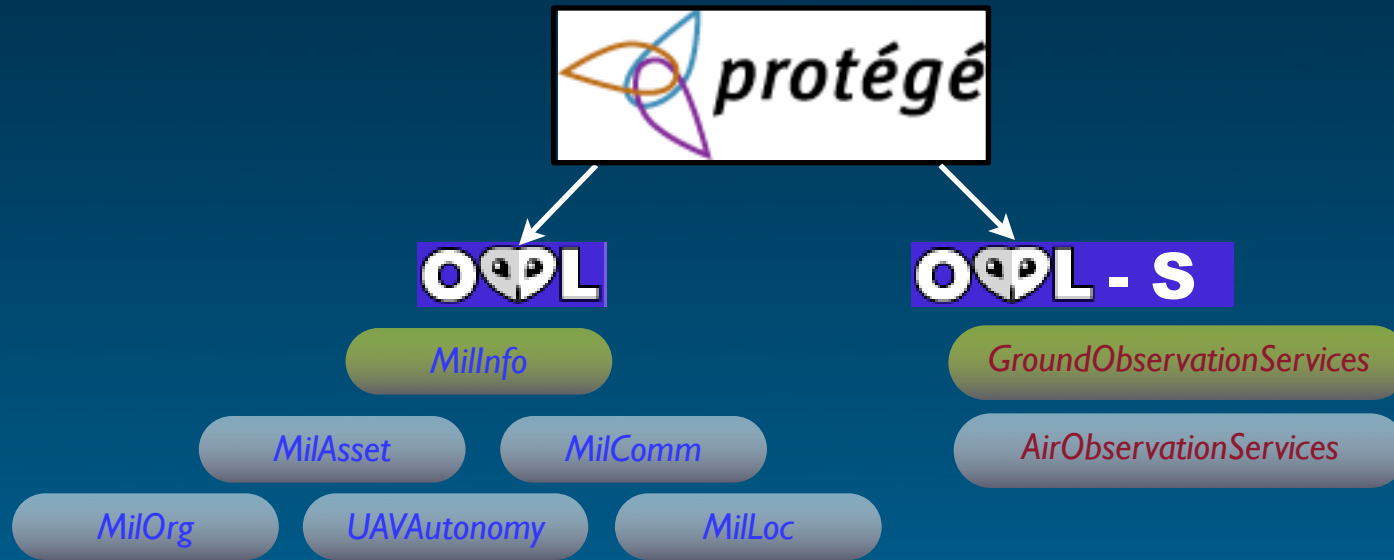# *Using Ontologies to Build a Web Service-based Architecture for Aerospace Systems*

Andre Valente (Knowledge Systems Ventures)
Doug Holmes (Java Professionals)
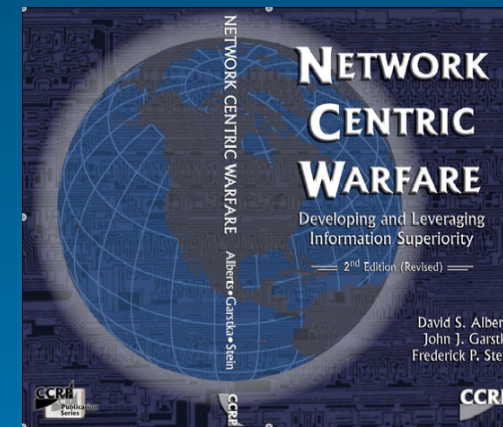*Frank Alvidrez (Lockheed Martin Aeronautics)*

Applying the MilInfo Ontology with Service Descriptions

protégé

OWL

MilInfo

MilAsset   MilComm

MilOrg   UAVAutonomy   MilLoc

OWL - S

GroundObservationServices

AirObservationServices

- *Motivation*
- *The Project: Ilium*
- *The Ontology: MilInfo, an Ontology of Military Information*
- *The Application: Semantic Web Services Powering a Network Centric UAV Architecture*
- *Conclusions*

Trends

- **Organizational trends mirror technical trends**

- **Evident in the influence of the Internet on organizations**
  - *centralized, homogenous => distributed, ad hoc*
  - *synchronized processes => asynchronous and parallel processes*
  - *limited access to data => widely shared data*
  - *strict control hierarchy => emergent control*
  - *optimized and rigid => satisfactory and flexible*

- **Inspired a revolution in military affairs known as "Network Centric Operations"**

- **Reflected in terms such as:**
  - *"shared awareness"*
  - *"agility"*
  - *"self-synchronization*
  - *"power to the edge"*

NETWORK CENTRIC WARFARE

NETWORK CENTRIC WARFARE

Developing and Leveraging
Information Superiority

2nd Edition (Revised)

David S. Alberts
John J. Garstka
Frederick P. Stein

CCRP

"NCW focuses on the combat power that can be generated from the effective linking or networking of the warfighting enterprise. It is characterized by the ability of geographically dispersed forces (consisting of entities) to create a high level of shared battlespace awareness that can be exploited via self-synchronization and other network-centric operations to achieve commanders' intent."
Dave Alberts

A Network-Centric View of Military Air Operations

- **Aircraft are more than mechanical devices designed to accomplish a specific task**
- **They are part of a broader solution to military problems e.g. intelligence acquisition, force application and other tasks**
- **That solution includes:**
  - *A network of other types of nodes (human operators, ground stations, other aircraft, etc.) and associated capabilities*
  - *Specialized sub-networks of nodes with a particular set of common interests*
- **In other words, aircraft are components of a <u>distributed</u> and <u>collaborative</u> (computing & operational) architecture**
- **In that light, we consider the capabilities of:**

Advanced Fighters

&

Unmanned Air Vehicles (UAVs)

Advanced Fighter Aircraft Can Play Many Roles

- **A modern single-seat fighter aircraft has**
  - *a very capable, electronically scanned, multi-mode radar and other sensors*
    - **air-air (search, track, identify, attack, etc.)**
    - **air-ground (ground map, GMTI, ATR, SAR, etc.)**
  - *an ability to quickly go to almost any "interesting" place*
    - **very fast**
    - **survivable**
    - **flexible**
  - *an ability to "operate on" the environment in a variety of ways*
    - **physical force with precision weapons**
    - **physical force with area weapons**
    - **electronic influence with jamming devices**
  - *a human in charge*
    - **judgement, intuition, etc..**
    - **command and control capabilities**
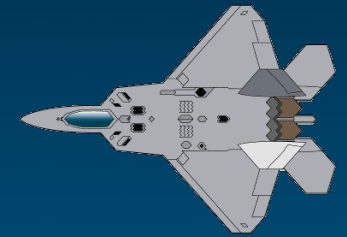
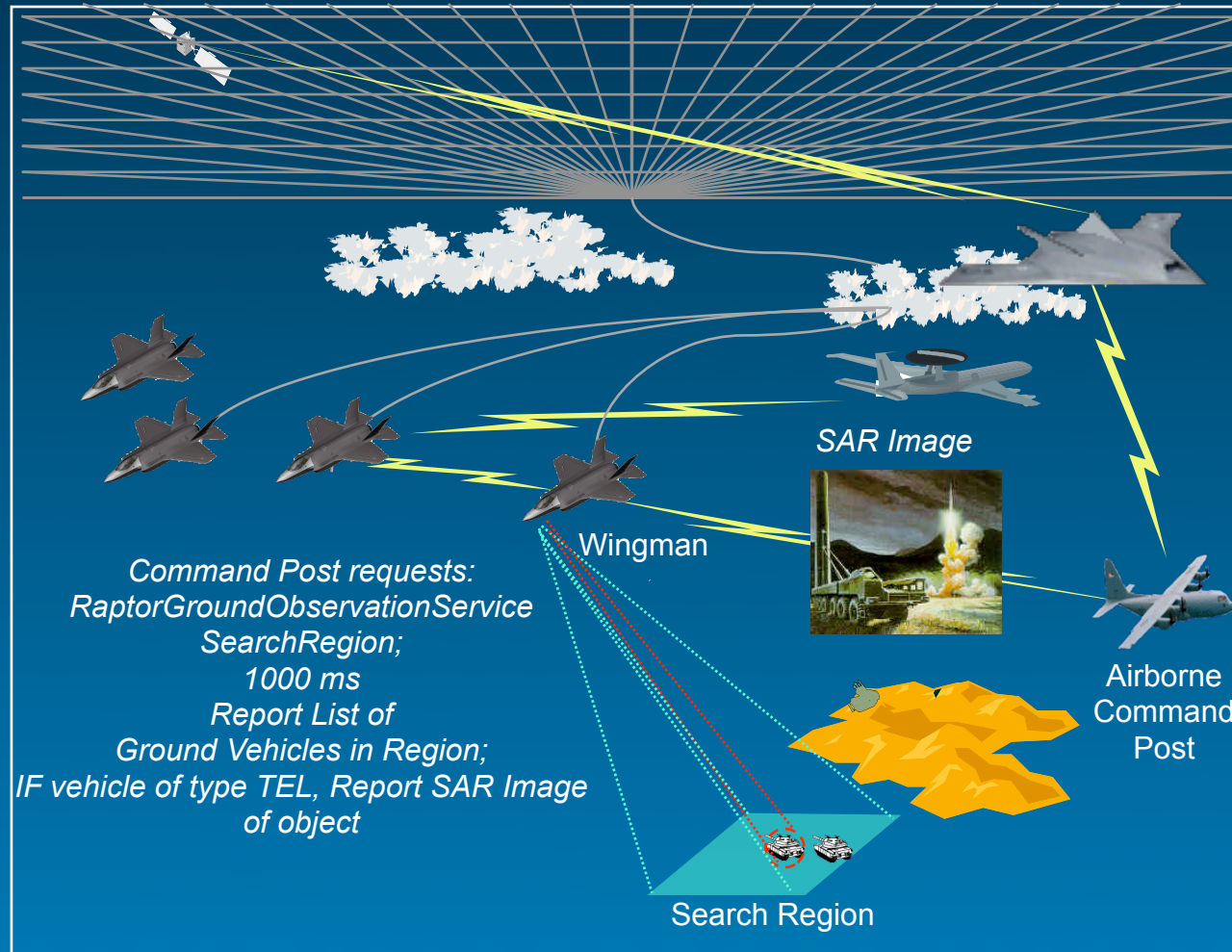# Unmanned Air Vehicles (UAV) Can (Also) Play Many Roles

- **An Unmanned Air Vehicle can have**
  - **the capabilities of a sensor & EW platform**
    - **a very capable, electronically scanned, multi-mode radar, electro-optical and other sensors**
    - **electronic influence with jamming devices**
  - **the capabilities of an aircraft**
    - **ability to quickly go to almost any "interesting" place**
    - **ability to observe from altitude**
    - **employ a wide range of precision weapons**
  - **the capabilities of a robot**
    - **risk reduction**
    - **endurance, persistence, un-distracted attention**
    - **"non-human" performance**
    - **economy (sometimes...)**
  - **the capabilities of an information system**
    - **information processing and distribution**
    - **intelligent communications relay**

# Potential Manned Aircraft and UAV Synergy in Network Centric Military Air Operations

- **Modern Aircraft that are:**
  - *"Nodes" in a Network*
  - *Members of an Operational "Community of Interest"*

- **A Community of Interest that shares:**
  - *Goals (Military Objectives)*
  - *Constraints (Rules of Engagement)*
  - *Policy (business rules)*
  - *Semantics*
  - *Services*

- **Allows any "Node" with a need (e.g. Command Post Duty Officer, Other Aircraft, Ground Unit, etc.) to:**
  - *find an appropriate, available resource to meet the need*
  - *maximize the use all available resources to resolve critical situations*

UAV Node reports: ALERT: high interest object detected in Search Region

SAR Image

Wingman

Command Post requests:
RaptorGroundObservationService
SearchRegion;
1000 ms
Report List of
Ground Vehicles in Region;
IF vehicle of type TEL, Report SAR Image
of object

Airborne Command Post

Search Region

The Project: Ilium Framework

- *The Ilium Framework is a prototype Distributed, Modeling, Simulation and Engineering Environment*

- *Intended to support Architecture-Driven, Distributed, Collaboration among Project Stakeholders and a Multi-Disciplinary Team*

- *Centered on Department of Defense Architecture Framework (DoDAF) enterprise models*
  - *UML Profile*

- *Implemented in Java*

- *Supports multiple communications protocols*
  - *JXTA P2, Sockets, HLA, DIS, HTTP*

- *Supports multiple M&S Plug-ins*
  - *EADSIM, JSAF, etc.*
  - *Configured with a DoDAF Model*
  - *Consistent with, and traceable to, the DoDAF Model*

- *Supports multiple engineering tool Plug-ins*
  - *RF and IR Signature Analysis, CADS, NCO Analysis Tools*
  - *KB Analysis Tools (TBD)*

- *Supports a software engineering testbed for prototype Plug-ins*
  - *Multi-ship Coordination System*
  - *UAV Route Planning System*

- *Configurable COI objects*

- *Depends on RDF and OWL ontologies*
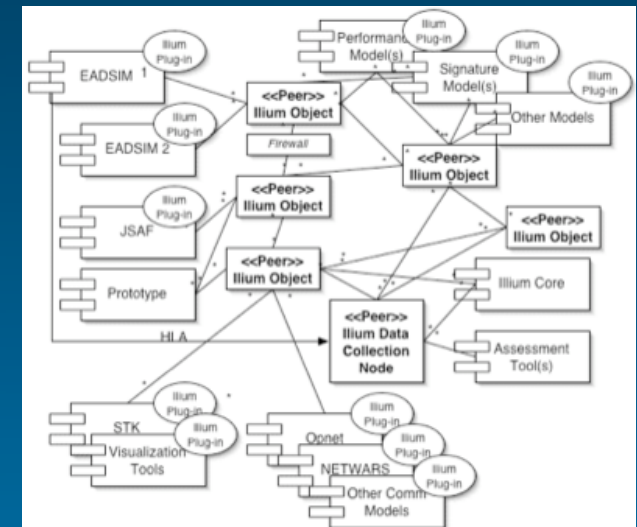
Current Goals

- **Improve Autonomy and Flexibility of Network-Centric UAV Platforms**
  - **For UAVs increasing autonomy implies flexibility**
    - **Arbitrary interactions with humans and other systems**
    - **Authority to specify goals (including related Actions)**
    - **Significant goals for UAV's occur at Mission and Task levels**
  - **Ensure flexibility in network configuration**
    - **Nodes must be able to task each other dynamically**
    - **Nodes may join and leave at any time**
    - **There may be a centralized plan, but the execution is decentralized**
- **Apply Semantic Web technologies to the analysis, design and development of network-centric UAV platforms**
- **Improve communications with - and between - machines**
  - **Develop a useful collection of Middle Ontologies to support design - and possibly implementation - of intelligent systems**
  - **anchor these with an ontology of Military Information**

Why We Focus on Information

- *...it seems like everybody in the military is talking about "Information"*
- *War and Anti-War (a book)*
  - *"...the foundations of information war can be found in a book by Alvin and Heidi Toffler's War and Anti-War: Survival at the Dawn of the Twenty-first Century"*
- *Information Operations (a mission)*
  - *"Actions taken to affect adversary information and information systems while defending one's own information and information systems" DoD Dictionary of Military Terms*
- *Network-Centric Operations and Warfare (a doctrine)*
  - *"...the theory of war for the Information Age..." David Alberts, Power to the Edge*
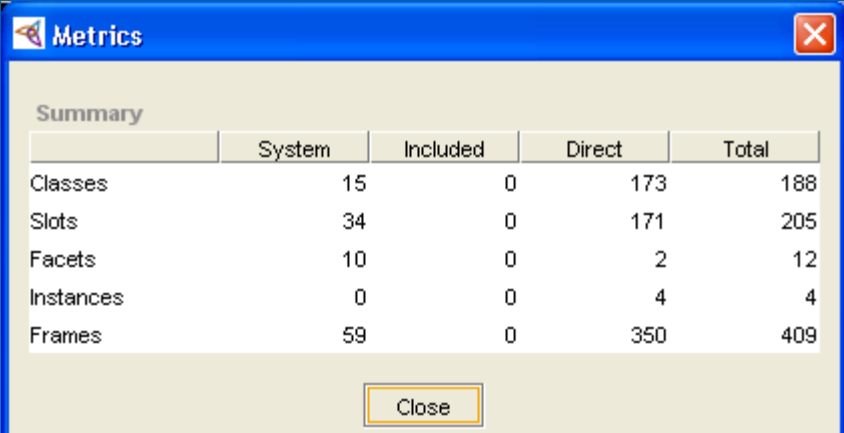
But… What is Information?

- *When "Information" is both an End and, perhaps, the Means of Military Operations, we had better know exactly what It Is.*

- *The U. S. DoD Dictionary says Information is:*
  - *1. Facts, data, or instructions in any medium or form.*
  - *2. The meaning that a human assigns to data by means of the known conventions used in their representation.*

- *Is That a Document? Or is it an Interpretation of a Document? Or the contents of a Document? What about some signal being transmitted (e.g., by a Radar)?*

- *What are the "parts" of Information? Which are significant and useful? How are they used to achieve our goals?*

- *What evidence supports which inference? How is the evidence evaluated?*

MilInfo Ontology Goals

- *Provide a Mid-level Ontology to support the development of formal models and knowledge bases for:*
  - *Enterprise Systems Architecture Models (e.g. DoDAF)*
  - *Knowledge-based design and development environments*
  - *Knowledge-based, Network-Centric Systems*

- *Anchor a family of ontologies that will also serve as domain models for software development*
  - *MilInfo: "Core" - Information*
  - *MilComm: Communications*
  - *MilOrg : Organizations*
  - *MilAsset: Physical Resources*
  - *MilService: Service Descriptions*
  - *Etc.*

Basic Design Choices for MilInfo

- *MilInfo was developed in OWL using Protégé*
- *Intended to make it as standards-compliant as possible.*
- *Use of OWL brings added expressiveness (compared to, say, RDF or UML)*
- *Allows use of openly available reasoners (e.g., RACER)*
- *We also want to use OWL-S to specify, compose and reason about Semantic Web Services*
  - *Part of dynamic configuration of network-centric architectures*
- *Current status*
  - *Relatively small*
    - *188 concepts, 205 slots*

Metrics

Summary

	System	Included	Direct	Total
Classes	15	0	173	188
Slots	34	0	171	205
Facets	10	0	2	12
Instances	0	0	4	4
Frames	59	0	350	409

Close

MilInfo Scope

- *Support specification and querying of the following facets of military information:*

  - *Content (e.g., to what topic does the information pertain?)*
  - *Significance (e.g., who needs/ uses the information?)*
  - *Composition (e.g., of what "parts" is the information composed?)*
  - *Source (what agency or system is the source of the information?)*
  - *Quality (e.g., how accurate is the information?)*
  - *Analysis (e.g., is the information inspectable?)*
  - *Constraints (e.g., which agents are permitted to have access to the information)*

Borrowing the Wheel: OpenCyc

- *Several top ontologies available*
- *Decided to use portions of OpenCyc as a top Ontology*
  - *We will use only what we need*
  - *OpenCyc addresses some fundamental modeling questions*
- *What worked*
  - *Reuse => Jump-start*
  - *Got some good wheels (it would have been hard to reinvent)*
- *What didn't work*
  - *Hard to untangle OpenCyc pieces*
  - *Protégé/OWL could not load OpenCyc!*
  - *Import into Protégé made manually (we would have loved to use PROMPT!)*

Some Key Concepts Borrowed From OpenCyc

- *AbstractInformation*
  - *"The collection of all instances of abstract information stored or transmitted in some manner, and representing (to someone potentially at least) something."*
- *InformationBearingThing (IBT)*
  - *"Each element of #$InformationBearingThing is an item that carries information, for an interpreter who understands its conventions."*
- *InformationTransferEvent*
  - *"An event in which information is transferred from a source (informationOrigin) to a destination (informationDestination), both of which are either intelligent agents or InformationBearingThings"*
- *IBTGeneration*
  - *"A type of InformationTransferEvent which creates some information-bearing thing --- thus, an event in which some idea or information is expressed."*

id of air object:: image of object

Ontologies Should Create
Iluminating Distinctions

id of air object:: type and affiliation of object

- *Ontology needs to prove its power by making distinctions that illuminate*

- *OpenCyc's difference between AbstractInformation and InformationBearingObject*
  - *AbstractInformation is the content and information*
  - *InformationBearingObject is a physical manifestation (e.g. a document)*
  - *An InformationBearingObject contains information but is not per se information.*

- *Enables to distinguish between*
  - *Database-AbstractContent = abstract repositories of information*
  - *Database-Physical = an Information Bearing Object (IBO) that stores many pieces of information, organized for easy scanning and access, i.e. some particular, tangible copy of a database.*

Ontologies Should Enable Useful Classifications

need ::id of air object ⊂ id_image of object

- *For example, how should we define military plans, orders, requests, pictures and reports?*

- *Military plans, orders, and requests are clearly abstract information*
  - *Can be realized into many different InformationBearingObjects (e.g. electronic and printed versions)*

- *Military pictures are better defined as InformationBearingObjects*
  - *We normally refer to a physical realization (e.g,. the picture file acquired by a UAV) rather than the abstract picture it contains*

- *Reports (and manuals, etc.) have a dual character*
  - *Sometimes we mean the physical printed copy distributed (an IBO), sometimes the report content (AbstractInformation).*
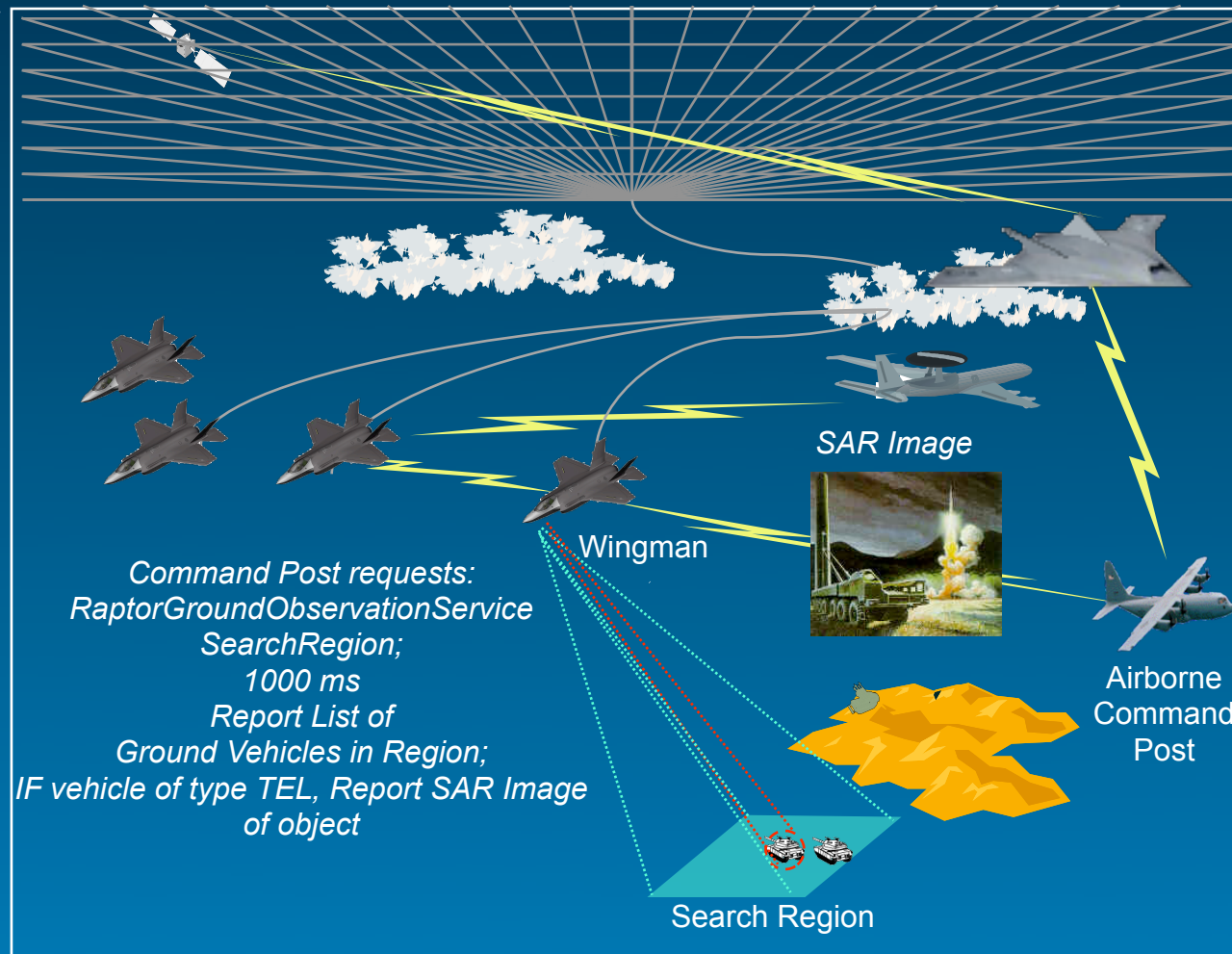
The Extended Application:
Self Synchronization with Semantic Web Technologies and Tools

- **Apply the Ontology to an Important Network Centric Operations Concept:**
  - **Support Self Synchronization of Forces**
    - **rapid composition of resources to resolve unexpected problems and obtain maximum benefit from available resources**
    - **A form of "emergent" Command and Control**
    - **controversial in the abstract**
    - **a working example to address doubts and questions**

- **Use OWL-S Service Descriptions to Support Automatic and Mixed Initiative Planning and Response**
  - **analogous to the current Command Post "human" response**
    - **should be "faster"**
    - **could be "better"**
  - **presumes a notional automated planning system**
    - **multiple candidates exist**

# An Example of Self Synchronization in Military Air Operations

- **Rapid composition of resources**
  - *e.g. airborne Fighters and UAV's in a particular sector)*
- **Resolve unexpected problems**
  - *an urgent report of enemy preparations for missile activities in a particular region)*
- **Obtain maximum benefit from available Resources (e.g. a flight of Advanced Fighter's with:**
  - *an important primary mission*
    - *e.g. air defense of an assigned sector*
    - *demands full attention of the pilot*
  - *three other aircraft with the same mission*
    - *a lot of "un-used" computing and sensing capability)*
- **A Community of Interest**
  - **Theater Air Operations**
  - **Supported at Airborne Command Post**
- **Allows a "Node" with a need to:**
  - *find an appropriate, available Service*
  - *specify the parameters of a search and the desired result*
  - *obtain the information without pilot intervention*
  - *"borrow" an appropriate Service from a Fighter*

UAV Node reports: ALERT: high interest object detected in Search Region

SAR Image

Wingman

Command Post requests:
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SearchRegion;
1000 ms
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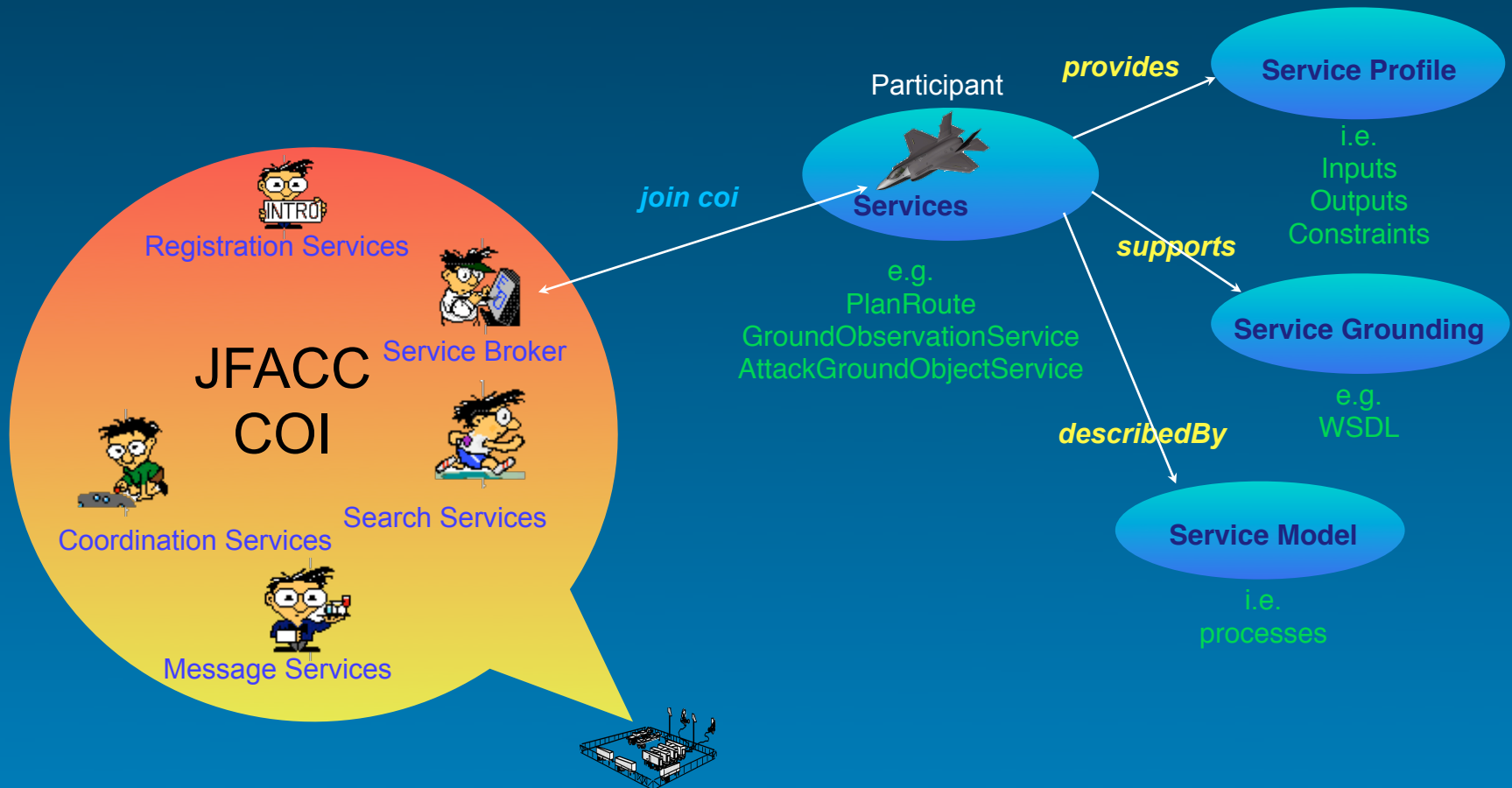*Airborne Command Post*

Search Region

Ilium Communities of Interest (ICOI)

- *Specialized "Communities of Interest" [COI] are created at key nodes (e.g. CAOC, SOF Task Force, Mission Commander, or any authorized node); any [arbitrary] node may join the COI as a participant*

- *Ilium emulates [implements] the COI and Services*
- *COI's provide a set of Services and brokering facilities to any/all participants*
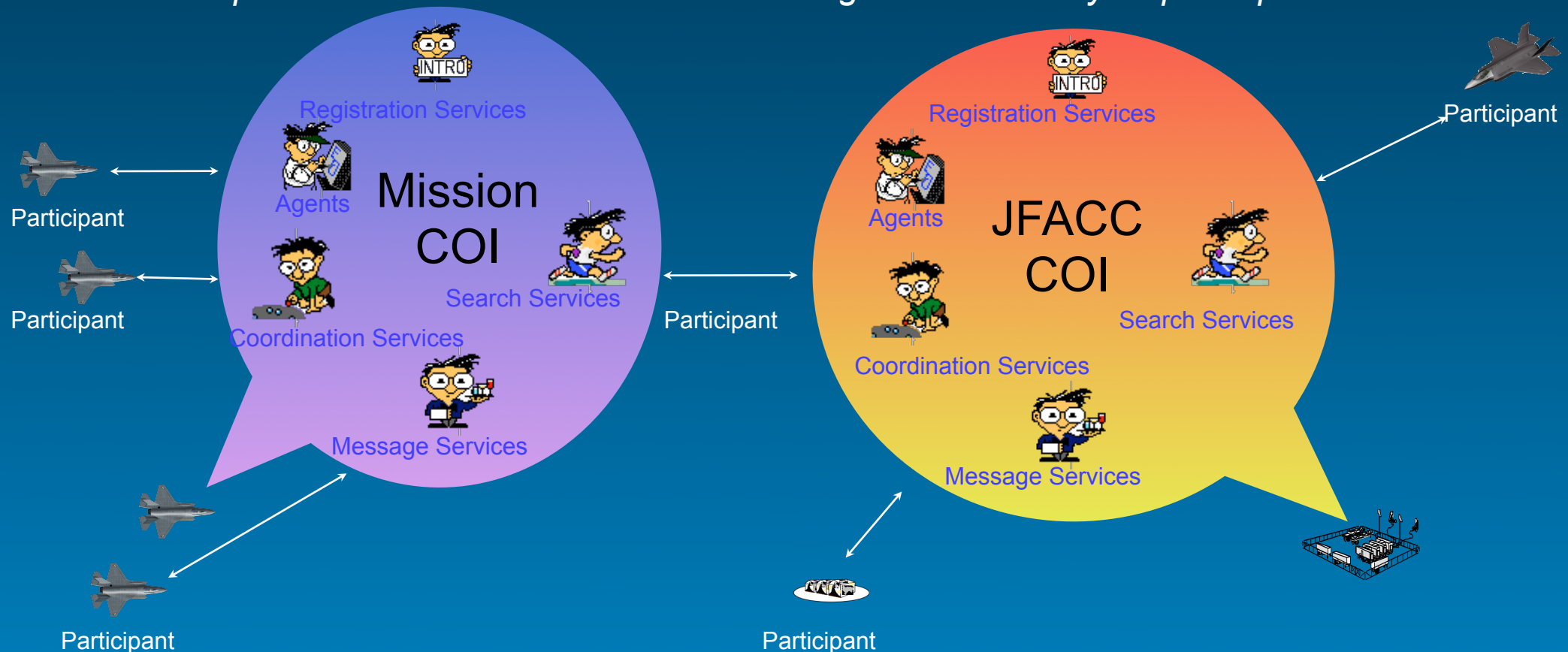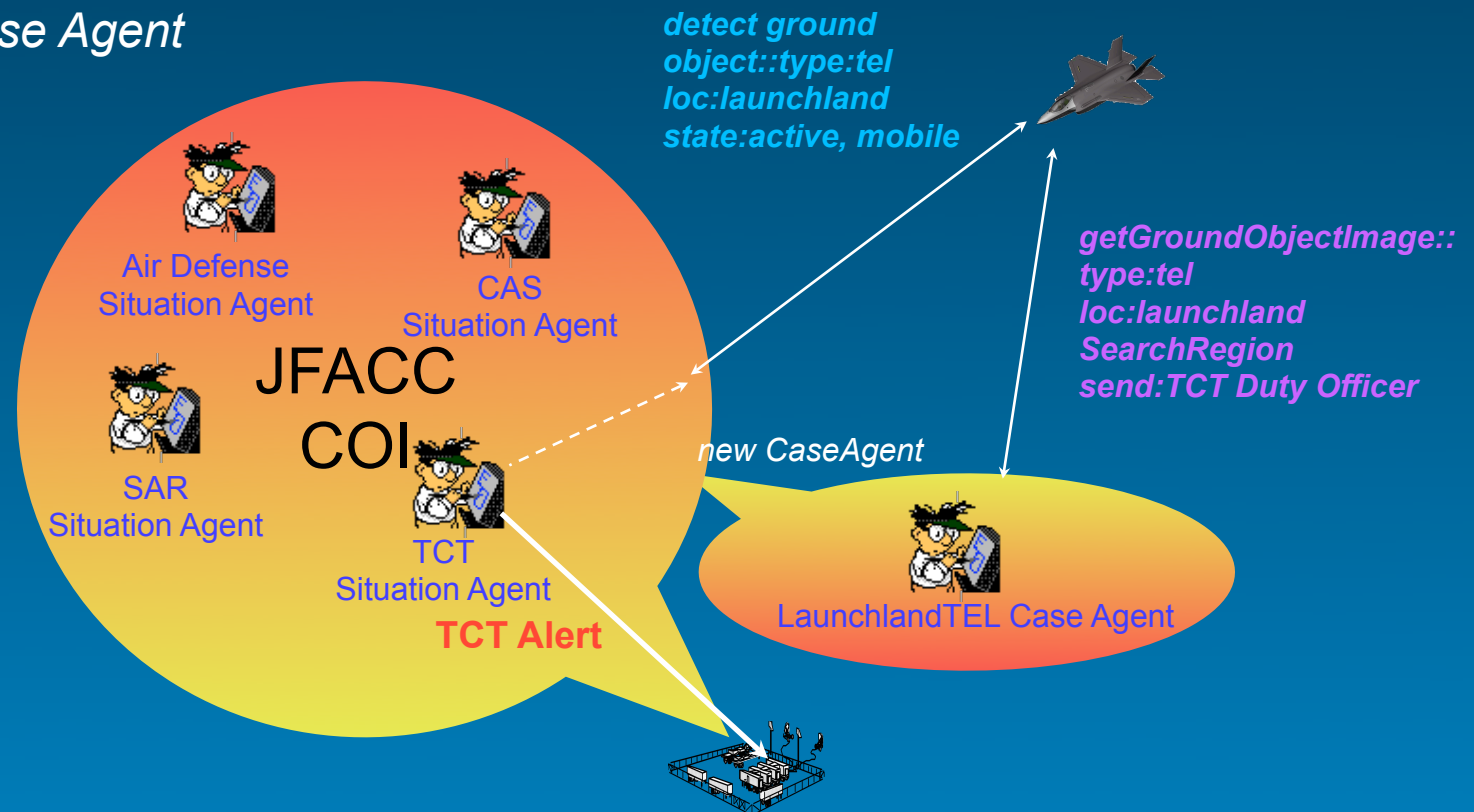
Service Descriptions in OWL-S

- COI's provide a set of Services to any/all participants

- Participants provide - and use - Services to other participants in the COI

- Participants announce the Services they provide with OWL-S Profiles when they join the COI
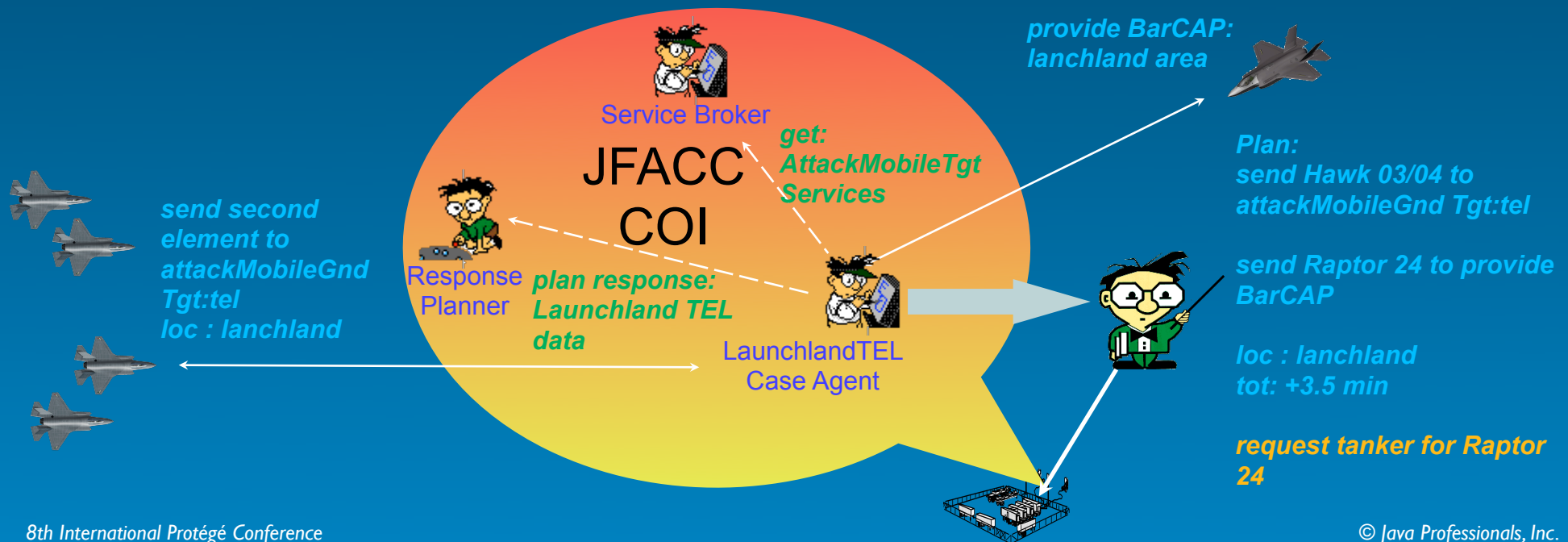
Registration Services

JFACC COI

Service Broker

Coordination Services

Search Services

Message Services

Participant

join coi

Services

e.g.
PlanRoute
GroundObservationService
AttackGroundObjectService

provides

Service Profile

i.e.
Inputs
Outputs
Constraints

supports

Service Grounding

e.g.
WSDL

describedBy

Service Model

i.e.
processes

COI Situation Agents

- *Specialized Situation Agents [of the COI] "listen" for evidence of particular situations [guided by SWRL Rules]*

- *When a Situation is detected, the Agent:*
  - *Defines the Situation [i.e. name, type, urgency, criticality, etc.]*
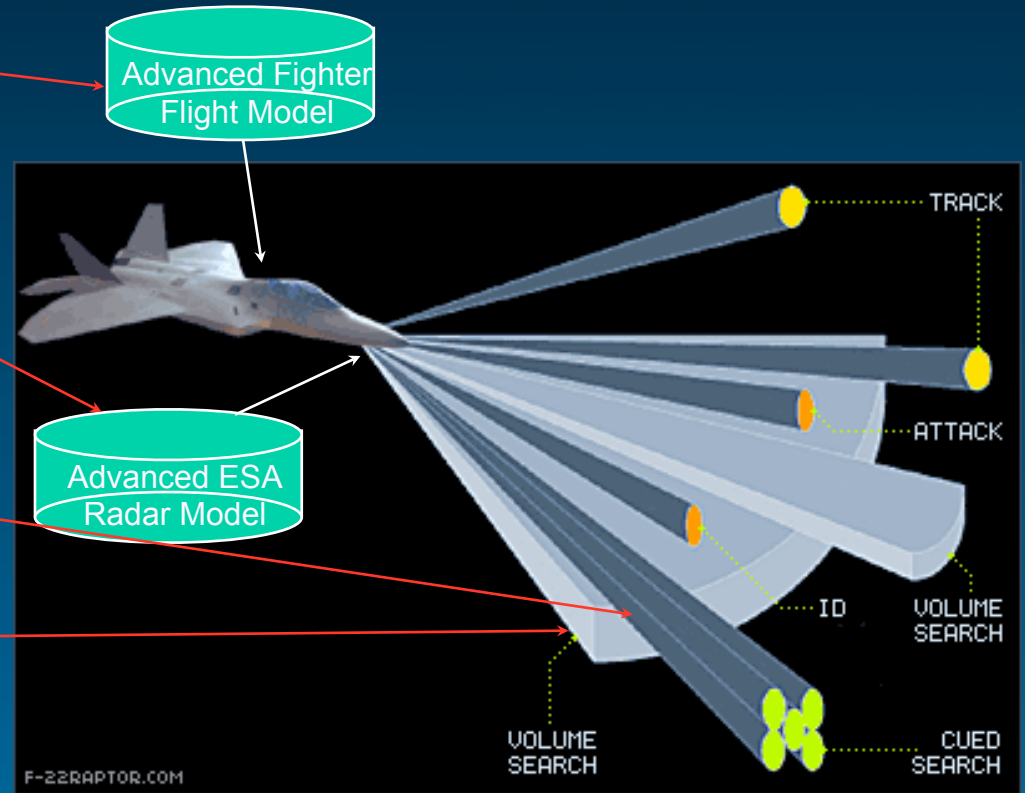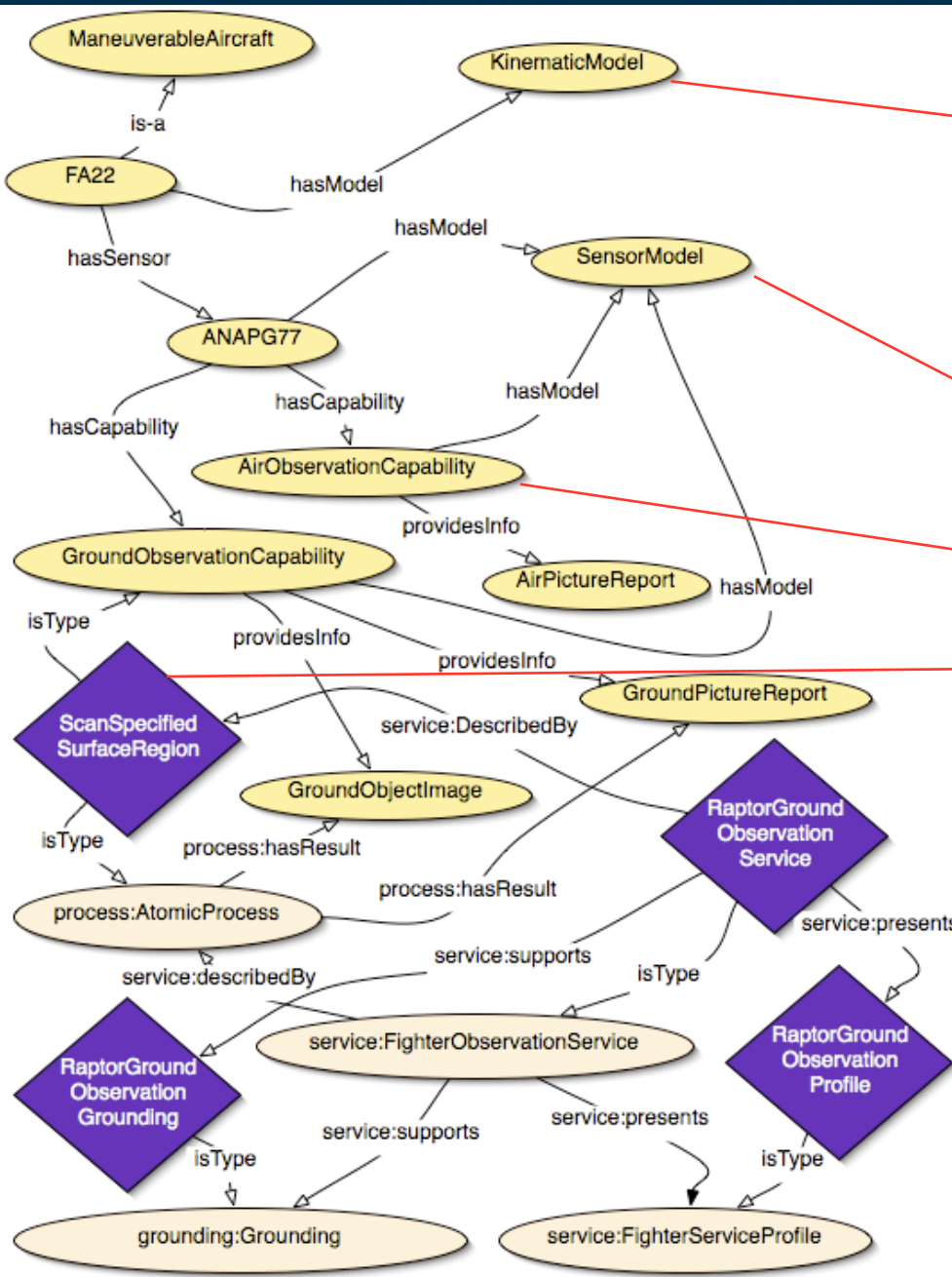 - *Alerts some/all participants [depending on C2 Rules]*
  - *Creates a Case Agent*

detect ground object::type:tel loc:launchland state:active, mobile

getGroundObjectImage:: type:tel loc:launchland SearchRegion send:TCT Duty Officer

Air Defense Situation Agent

CAS Situation Agent

JFACC COI

SAR Situation Agent

TCT Situation Agent

TCT Alert

new CaseAgent

LaunchlandTEL Case Agent

Situation Case Agent

- *The Case Agent [guided by SWRL Rules]*

  - *Analyzes [characterizes] the situation*
  - *Determines the availability of Resources [i.e. "nodes"] with Services [from OWL-S Profiles]*
  - *Makes a plan - or multiple plans*
  - *Proposes the plan to [Duty Officer, Mission Commander, Flight Lead, participants, all of the above depending on C2 Rules]*
  - *Supports execution of the plan*
  - *Requests additional resources when needed*
  - *Notifies Participants when the Situation is resolved*

Service Broker

JFACC COI

get: AttackMobileTgt Services

Response Planner

plan response: Launchland TEL data

LaunchlandTEL Case Agent

provide BarCAP: lanchland area

Plan:
send Hawk 03/04 to attackMobileGnd Tgt:tel

send Raptor 24 to provide BarCAP

loc : lanchland
tot: +3.5 min

request tanker for Raptor 24

send second element to attackMobileGnd Tgt:tel
loc : lanchland

Example Ontology Segment

- *Portions of 3 ontologies configure a simulation scenario*
  - *Military Information*
  - *Military Assets*
  - *OWL-S*
- *Capabilities may be viewed as Services*

OWL-S Ontology Segment

- *Input*
- *Output*
- *PreConditions*
- *Results/Effects*

Raptor24::GMTI Search Report
2247GMT
SearchRegionAlpha
GT1234::typeTEL22::NN456780::52kph
GT1235::typeSA99::NN4567778;:50 kph
GT1236::typeCivTruck::NN4556456::93kph

Search Region
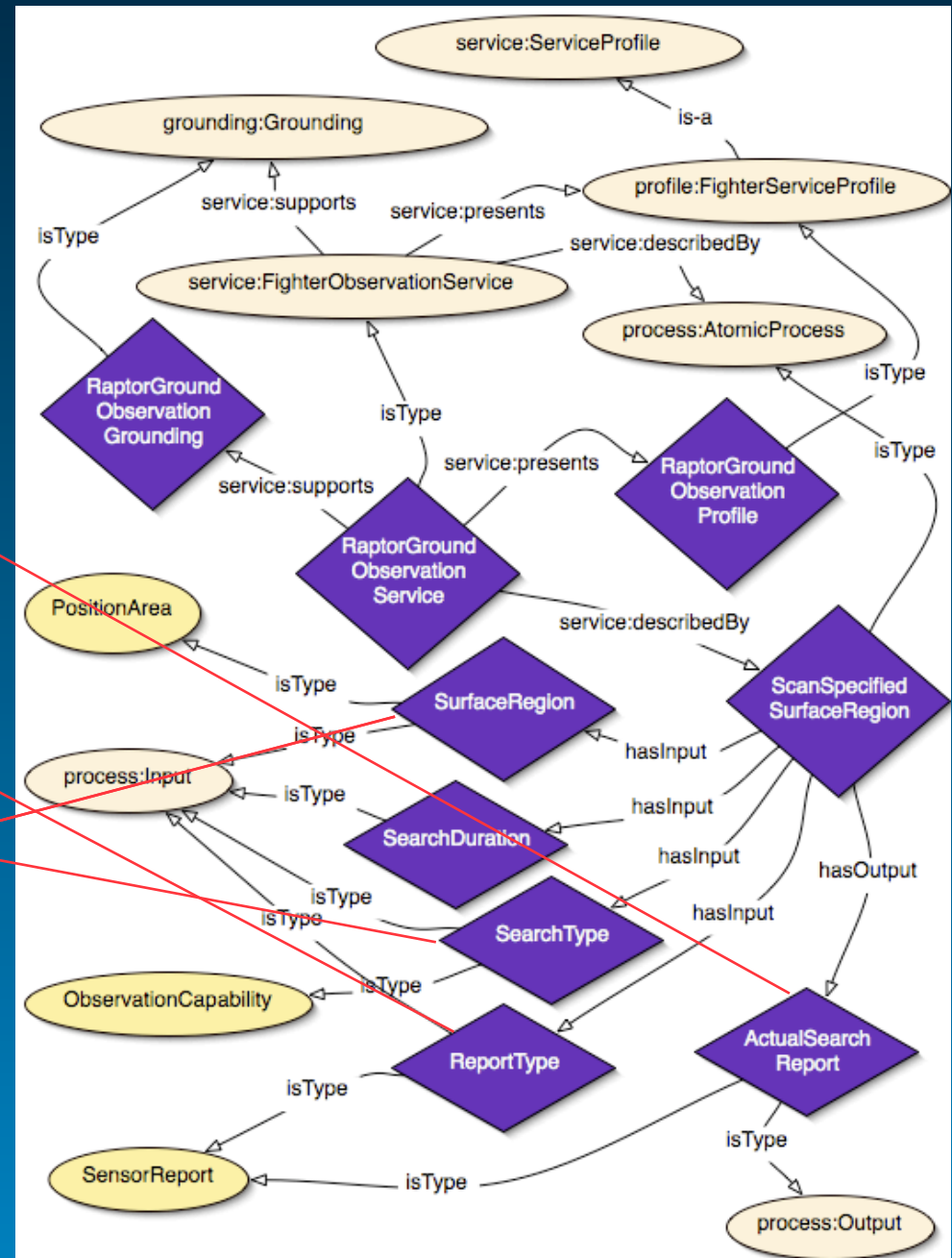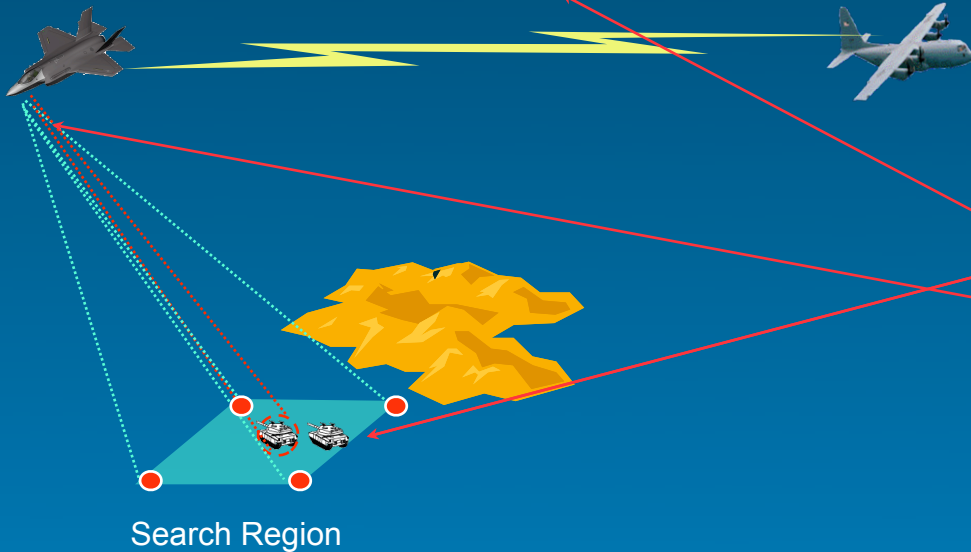
Conclusions

- **Modern military systems are network-centric**
  - *Aircraft are more than equipment – they are nodes in a network*
  - *Broad opportunity to apply Semantic Web tools and concepts*
- **Ilium Project aims to implement this concept**
  - *Uses Semantic Web technologies (OWL, OWL-S)*
  - *Bridge the gap to OO implementation technologies (UML, MDA)*
  - *Example benefit: Increase autonomy of Unmanned Air Vehicles (UAVs)*
- **Military Information Ontology is foundation for representing network-centric components in Ilium**
  - *Provides key distinctions, overall framework*
  - *Family of interconnected ontologies*
  - *Created in Protégé/OWL, reuses OpenCyc elements*
- **Current application focus**
  - *Implement Semantic Communities of Interest using OWL-S*