International Technology Alliance
In Network & Information Sciences

Sensors, Sources & Semantics

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Motivation

- "ISR* resources are typically in high demand and requirements usually exceed platform capabilities and inventory
- "The foremost challenge of collection management is to maximize the effectiveness of limited collection resources within the time constraints imposed by operational requirements"

*ISR = intelligence, surveillance and reconnaissance

JP 2-01 Joint and National Intelligence Support to Military Operations
http://www.dtic.mil/doctrine/jel/new_pubs/jp2_01print.pdf

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Task-Oriented Deployment of Sensor Data Infrastructures

- **Problem Addressed**: Optimal use of resources to get "best" and most important intelligence in a timely manner to the proper parties
- **Approach**: define a sufficiently-rich representation of a classification of sensors and sources to allow strategic planning, operational repurposing, and data delivery scheduling to meet the needs of multiple competing missions
- The representation is expected to be in the form of a ***Sensor Ontology*** which will:
  - Link to the representation of mission (task) requirements
  - Support the purposing and repurposing of sensors, at mission plan-time and run-time
  - Provide a schema for catalogues of sensor and source instances needed for our testbeds (especially IBM's sensor fabric)

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Ontologies? What and Why?

- Ontology: "formal specification of a (shared) conceptualization" [after Gruber 1993]
  - A set of logical axioms designed to account for the intended meaning of a vocabulary
- Why?
  - Facilitates communication and knowledge sharing by providing a unifying framework for "agents" with different viewpoints and terminologies:
    - Including combinations of people and software systems
  - Improves interoperation and cooperation by providing unambiguous semantics in a formal, machine-interpretable way
- Specific application examples:
  - Semantic matchmaking of sensors and sources to missions and tasks (ITA Project 8)
  - Semantically-mediated information fusion (ITA Project 9)
  - … building on Quality of Information models (ITA Project 7)

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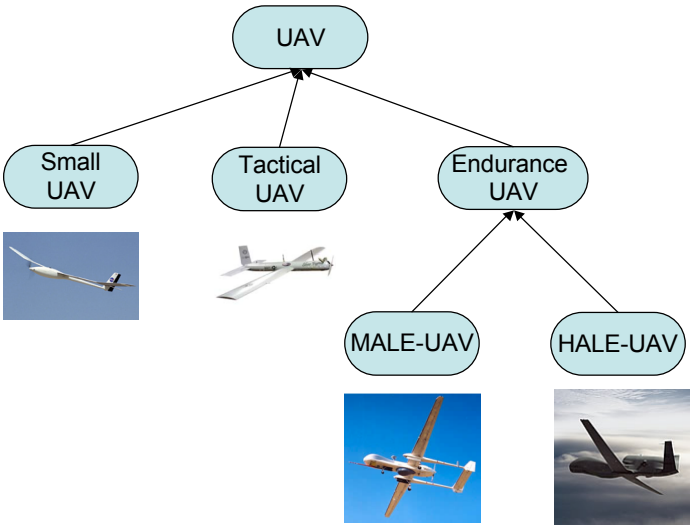
Motivating Example



NASA http://uav.wff.nasa.gov/Categories.cfm

Defense Update: http://www.defense-update.com/features/du-2-05/feature-uav.htm

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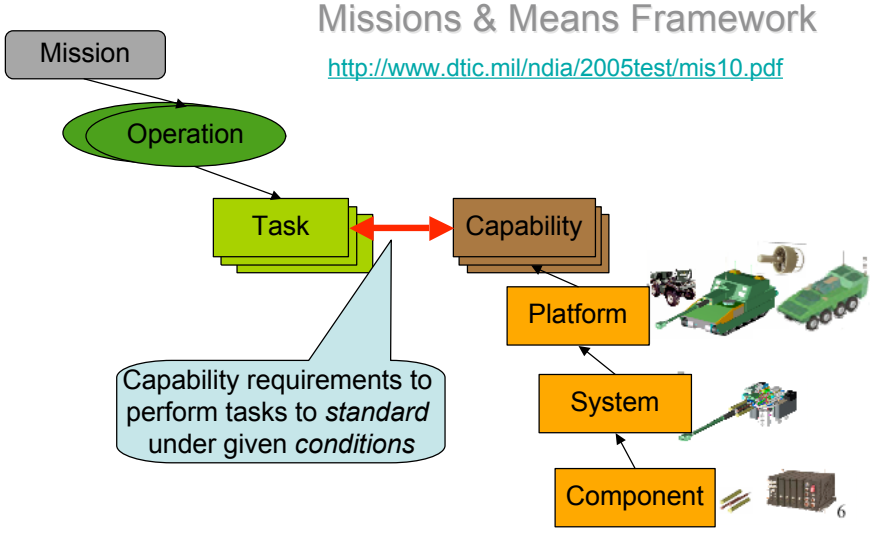
Mission-Sensor Matchmaking

Missions & Means Framework

http://www.dtic.mil/ndia/2005test/mis10.pdf



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Mission-Sensor Matchmaking II

- Entails assessing the **fitness for purpose** of sensors (and sources) to missions, which in turn boils down to assessing…
  - Fitness of sensors and sources to tasks
  - Fitness of platforms to tasks
  - Interaction between sensors/sources and platforms
- Approach: **semantic matchmaking**, using ontologies to specify and compare
  - ISR *requirements* of *missions* and *tasks*
  - ISR *capabilities* of *sensors*, *sources*, and *platforms*

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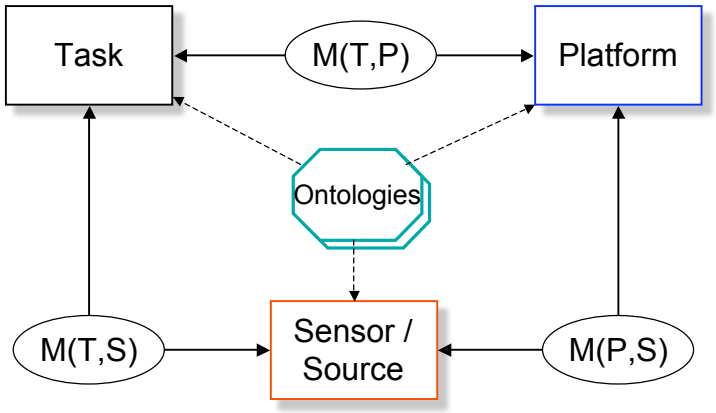
Mission-Sensor Matchmaking III



M(X,Y): matching relation between X and Y

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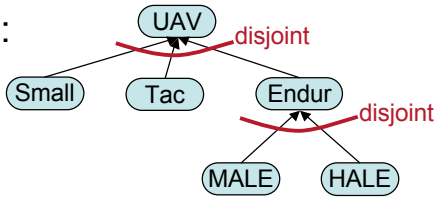
Motivating Example II

- Task T1 requires Persistent Surveillance
  - best served by an Endurance-UAV
- Three UAVs are available:
  - UAV1 is-a Tactical-UAV
  - UAV2 is-a MALE-UAV
  - UAV3 is-a HALE-UAV



- From only the concept definitions we know:
  - UAV1 is not an Endurance-UAV
  - UAV2 & UAV3 are kinds of Endurance-UAV
- So we can assign either UAV2 or UAV3

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Motivating Example III

- However, Task T1 is forecast to occur during bad weather
  - best served by a HALE-UAV (high altitude – can fly "above the weather")
- Preferred choice is now UAV3

- Notes:
  - We only state minimum explicit information about the UAVs (e.g. UAV1 is-a Tactical-UAV)
  - Everything else is inferred from the concept definitions (e.g. UAV1 is not a high altitude UAV)

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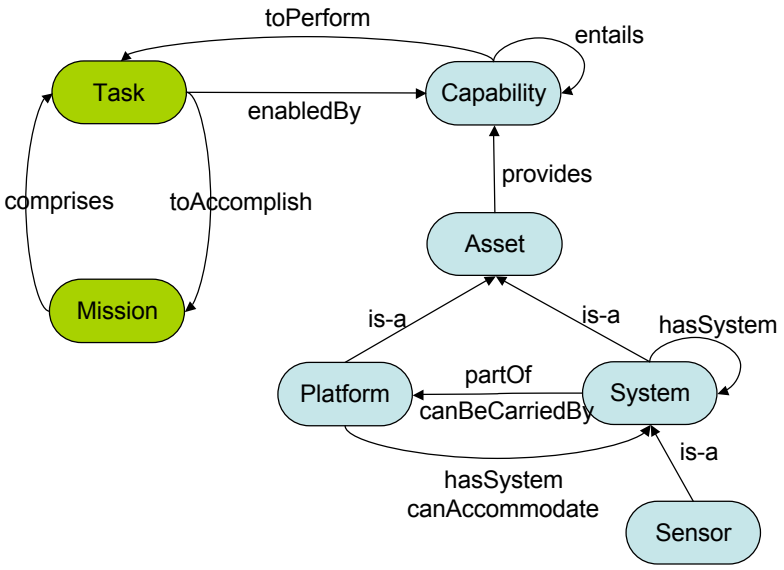
Mission & Sensor Ontologies: Overview



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"Ontological Lego"

- We adhere to the Semantic Web vision of multiple interlinking ontologies, including
  - Missions and tasks ontology (mostly based on MMF)
  - Sensors, sources, and platforms ontology
- Where possible we seek to incorporate elements of existing Web Ontology Language (OWL) ontologies including
  - OntoSensor www.ee.memphis.edu/cas/projects.htm
  - MMI platforms ontology marinemetadata.org/
  - CIMA instrument ontology www.instrumentmiddleware.org

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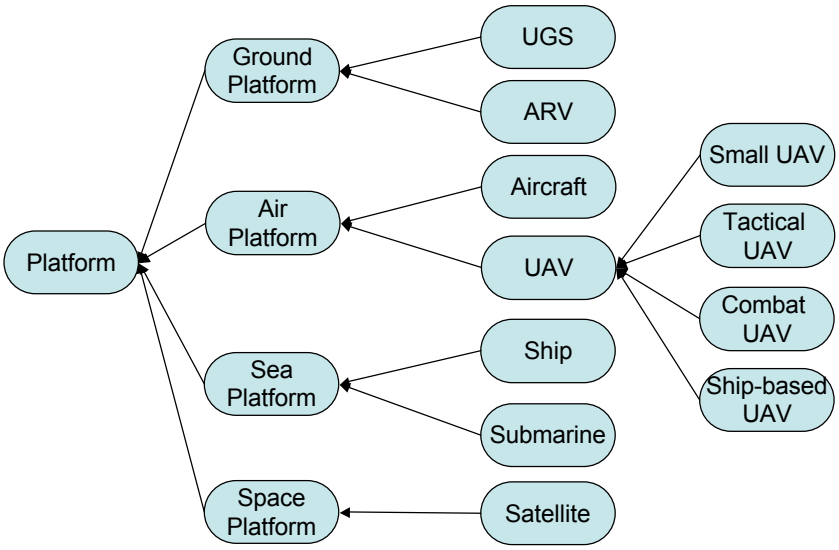
Concept Hierarchy: Platforms



Backed by MMI Platforms Ontology: http://www.ict.csiro.au/ssn06/Data/marine.pdf

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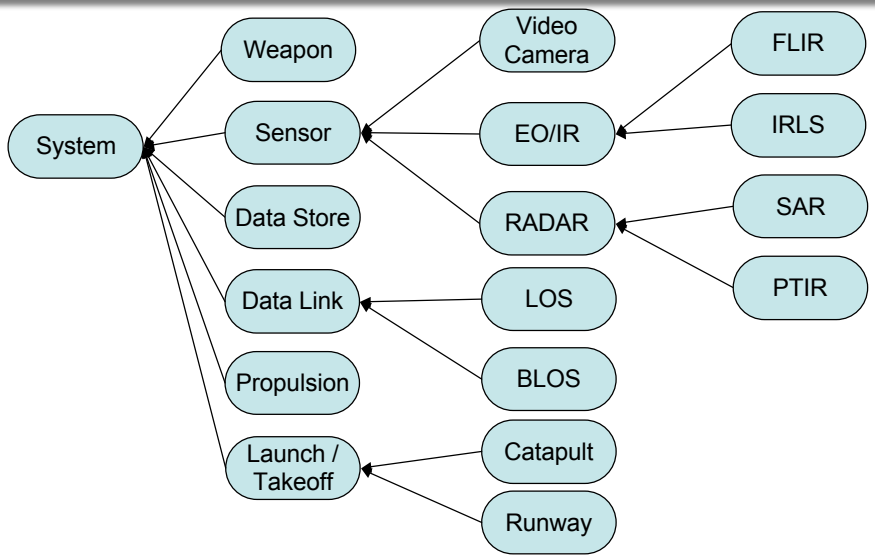
Concept Hierarchy: Systems



Sensor taxonomy partially covered by other ontologies, e.g. OntoSensor www.ee.memphis.edu/cas/publications/ica3194.pdf

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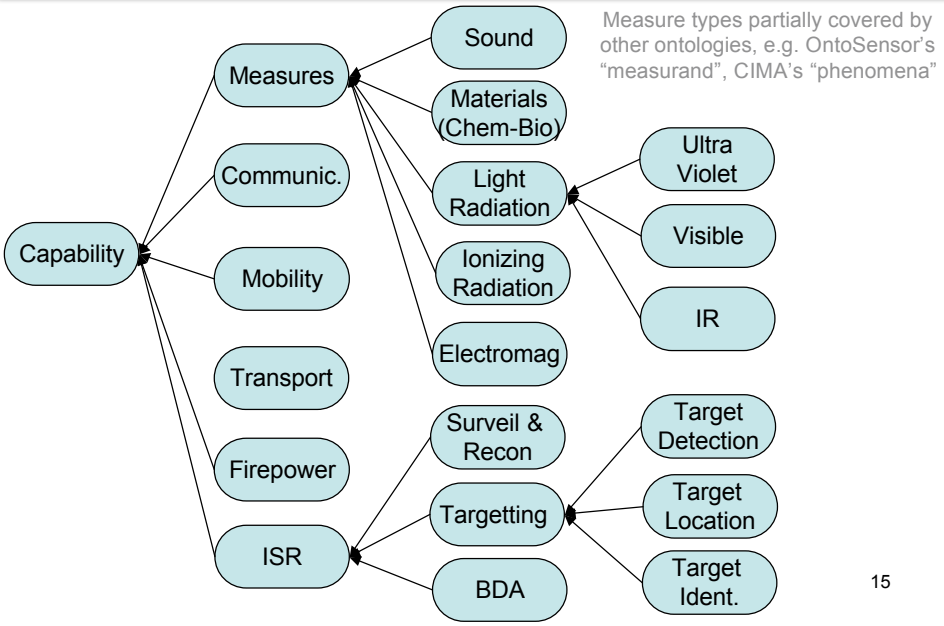
Concept Hierarchy: Capabilities



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Domain Modelling Issues

- Alternative classifications, multiple dimensions, usually mixed
  - e.g. platforms classified by size, purpose, performance (altitude/range), mix
- Fuzzy Concepts
  - LADAR (Laser Radar): Radar or Optical Sensor?
- Different levels of abstraction and composite vs primitive concepts (specially capabilities)
  - Reconnaissance: Mobility + Sensing
  - Armed Reconnaissance: Reconnaissance + Firepower

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Solution Sketches I

- Multi-dimensional and compositional approach ("Logic Lego") to specify concepts
  - Predator B is…
    - An Aircraft: is-a Platform & has Realm Atmosphere
    - An UnmannedVehicle: is-a Platform & has Quality Without-crew-mobility
    - A UAV: is-a Aircraft & is-a UnmannedVehicle
    - Combat UAV: is-a Aircraft & is-a Unmanned Vehicle & has Capability Firepower
    - A MediumAltitudeLongEndurance (MALE) UAV: is-a UAV & has Quality Endurance & has Quality MediumAltitude
- Well-suited to the Description Logic (DL) sublanguage of OWL www.w3.org/TR/owl-guide

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Solution Sketches II

- Use **multiple dimensions** to capture the capability specifications of sensors/platforms/missions
  - For platforms
    - Mobility
      - Realm
      - Performance (range, endurance/dwell time, altitude, speed, etc...)
    - Application type (Surveillance, Reconnaissance, TA, BDA…)
    - Firepower
    - Launch/Recovery System
    - Communications
    - Vulnerability/Survivavility
    - Availability
  - For Sensors
    - Phenomena Detected (type and spectrum)
    - Performance (Quality of data, accuracy, etc)
    - Weather/Terrain/Contamination influence
    - Vulnerability
    - Availability

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Solution Sketches III

- For missions (intelligence requirements)
  - Target characteristics
  - Range to the target
  - Timeliness
  - Battlespace factors
    - Threat
    - Terrain
    - Contamination
    - Weather

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Existing ISR Thesaurii

- Reconnaissance
  - amphibious reconnaissance
  - area reconnaissance
  - armed reconnaissance
  - armed surface reconnaissance
  - bridge reconnaissance
  - counterreconnaissance
  - electronic reconnaissance
  - hydrographic reconnaissance
  - infrared reconnaissance
  - intelligence, surveillance and reconnaissance
  - NBC reconnaissance
  - night reconnaissance
  - poststrike reconnaissance
  - prestrike reconnaissance
  - reconnaissance by fire
  - reconnaissance in force
  - route reconnaissance
  - site reconnaissance
  - special reconnaissance
  - strategic reconnaissance
  - weather reconnaissance
- Surveillance
  - Air surveillance
  - Battlefield surveillance
  - Coastal surveillance
  - Constant surveillance
  - Countersurveillance
  - Electronic surveillance
  - Long range surveillance
  - Maritime surveillance
  - Missile warning and space surveillance
  - Ocean surveillance

CALL Thesaurus
http://call.army.mil/thesaurus.asp

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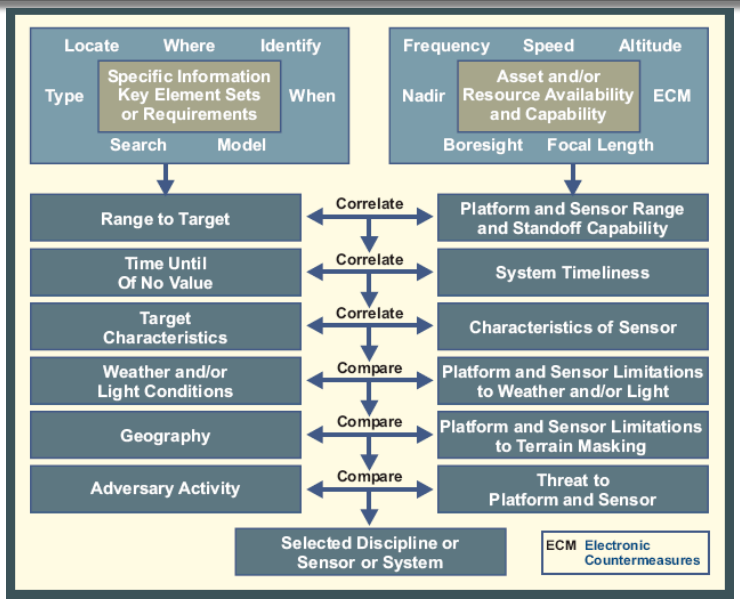
Matching Sensors to Missions is a Multidimensional Problem



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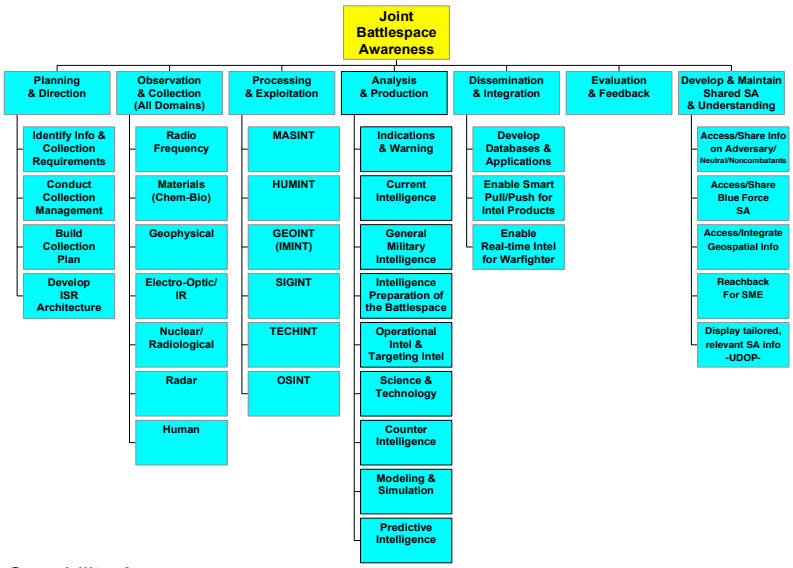
JP 2-01 http://www.dtic.mil/doctrine/jel/new_pubs/jp2_01print.pdf

ISR Capability Map



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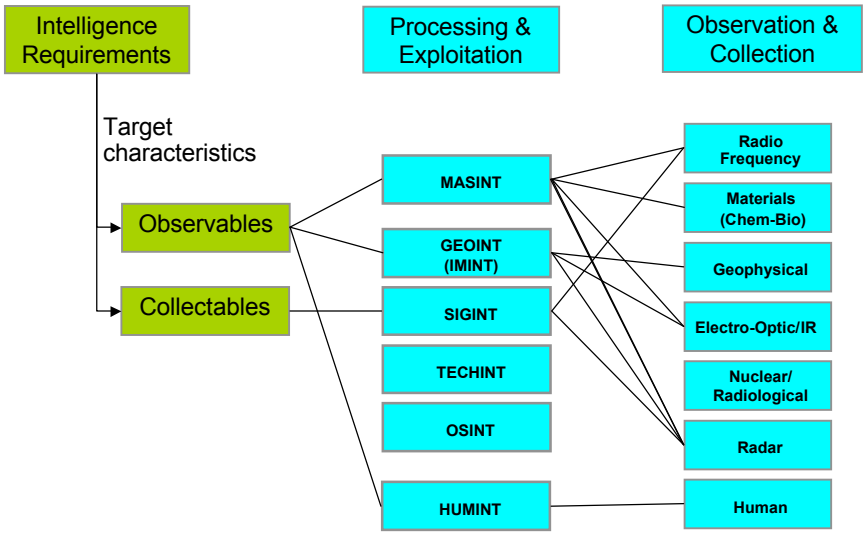
Joint Capability Areas:
www.jiamdsummit.org/readAheads/Family/Joint%20Capability%20Areas%20Lexicon%2024%20Aug%2006.pdf

"Missions & Means" Revisited



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Web Services Perspective: SWE

- The Open GeoSpatial Consortium's Sensor Web Enablement WG are defining a suite of standards for "sensor web" services
  http://www.opengeospatial.org/projects/groups/sensorweb
- Includes SensorML (Sensor Model Language):
  - "Standard models and XML Schema for describing sensors systems and processes; provides information needed for discovery of sensors, location of sensor observations, processing of low-level sensor observations, and listing of taskable properties"

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SensorML & Semantics

- SensorML is not intended to capture the semantics of sensor capabilities
  - XML is syntax
- However, capability elements have **definition** attributes, which allow them to refer to well-defined terms
- In principle, these could link to capabilities we define (i.e. our OWL concept definitions)

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SensorML Capabilities Example

```
<sml:capabilities>
  <swe:DataRecord>
    <swe:field name="Depth Capability"
        xlink:role="urn:x-ogc:def:property:operationalLimit">
      <swe:Quantity
        definition="urn:x-ogc:def:classifier:SBE:depthCapability" >
       <swe:uom code="m"/>
       <swe:value>7000</swe:value>
   </swe:Quantity>
    </swe:field>
    ...
    <swe:field name="Battery Current"
        xlink:role="urn:x-ogc:def:property:powerSupply">
      <swe:Quantity
        definition="urn:x-ogc:def:phenomenon:SBE:batteryCurrent">
      <swe:uom code="A.h"/>
      <swe:value>7.2</swe:value>
    </swe:Quantity>
    </swe:field>
  </swe:DataRecord>
</sml:capabilities>
```

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OntoSensor: A Semantic Web Approach

- Work in progress at Department of Electrical and Computer Engineering, University of Memphis
  - "A prototype sensor knowledge repository compatible with evolving Semantic Web infrastructure. OntoSensor includes definitions of concepts and properties adopted (in part) from SensorML, extensions to IEEE SUMO and references to ISO 19115"
- Plus points:
  - It's an OWL ontology, so we can extend it
  - It's a compositional approach
  - Sensors have capabilities, defined as "supported applications"…

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OntoSensor Example

```
<FLIR rdf:ID="FLIR_001">
  <hasCapabilities>
    <SensorCapabilities rdf:ID="FLIR_001_capabilities">
      <supportedApplication rdf:resource="#Fineresolutionimagery"/>
      <supportedApplication rdf:resource="#Daynightoperation"/>
      <supportedApplication rdf:resource="#Covert"/>
      ...
    </SensorCapabilities>
  </hasCapabilities>
</FLIR>
```

- This is an instance of a Forward Looking Infrared (FLIR) sensor
- In the current version of OntoSensor, there appears to be no defined typology of applications
- Moreover, with this approach capabilities and sensors are tightly coupled

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Grid Perspective: CIMA

- Common Instrument Middleware Architecture (CIMA) ontology provides an extensible and standardized vocabulary for describing hardware resources (sensors) linked to a network
  - "aimed at "Grid enabling" instruments as real-time data sources to improve accessibility of instruments and to facilitate their integration into the Grid"
- NSF-funded work at Indiana University
- Ontology includes classes that describe **physical phenomena** that can be detected by instrument components
- Phenomena are defined in a concept hierarchy, allowing reasoning

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Recap

- Key features of our approach
  - Takes a "missions & means" perspective
  - Multidimensional descriptions of mission requirements & sensor/source/platform capabilities
  - Open, extensible
- Where have we got to?
  - Framework (see TRs on ITACS)
  - Initial versions of core ontologies
  - Lots of "model fragments" backed by open source literature
  - A demo…

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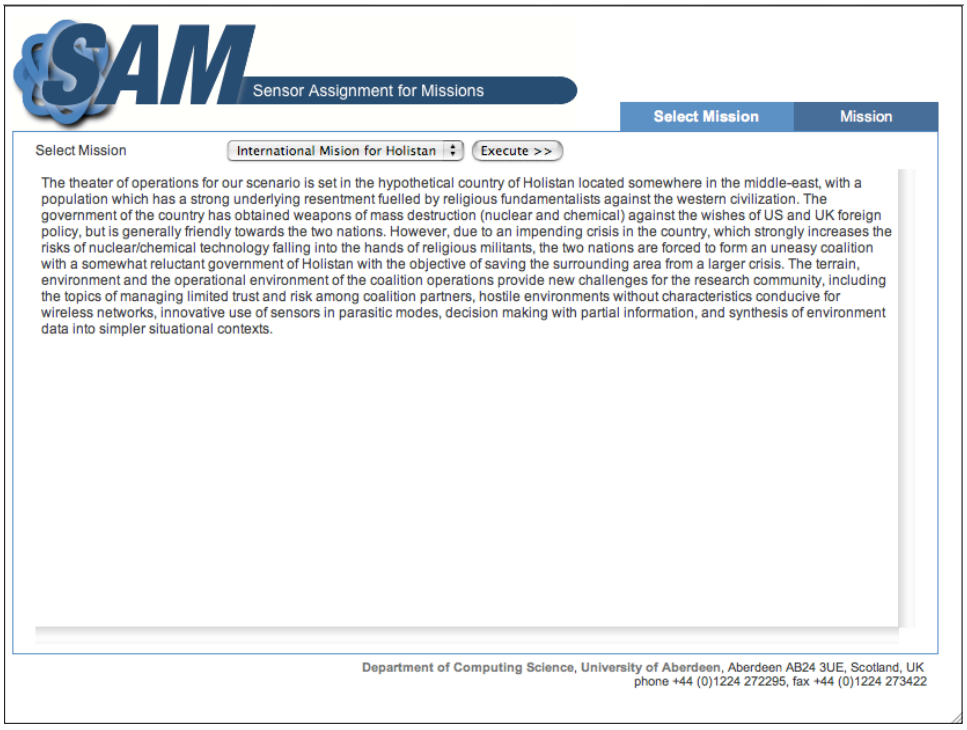
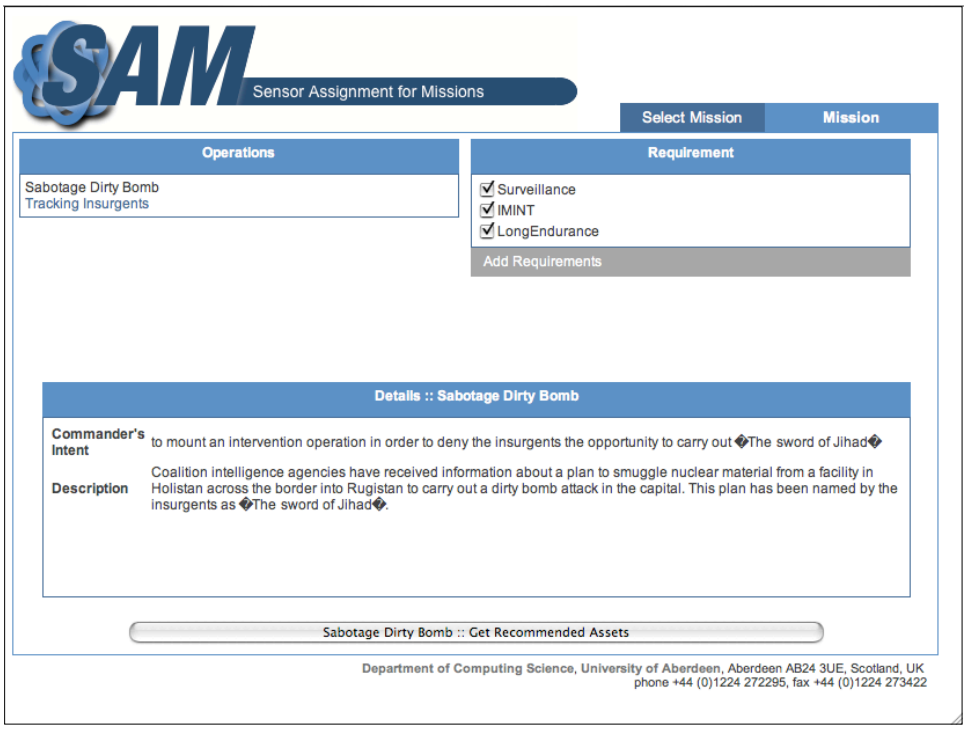
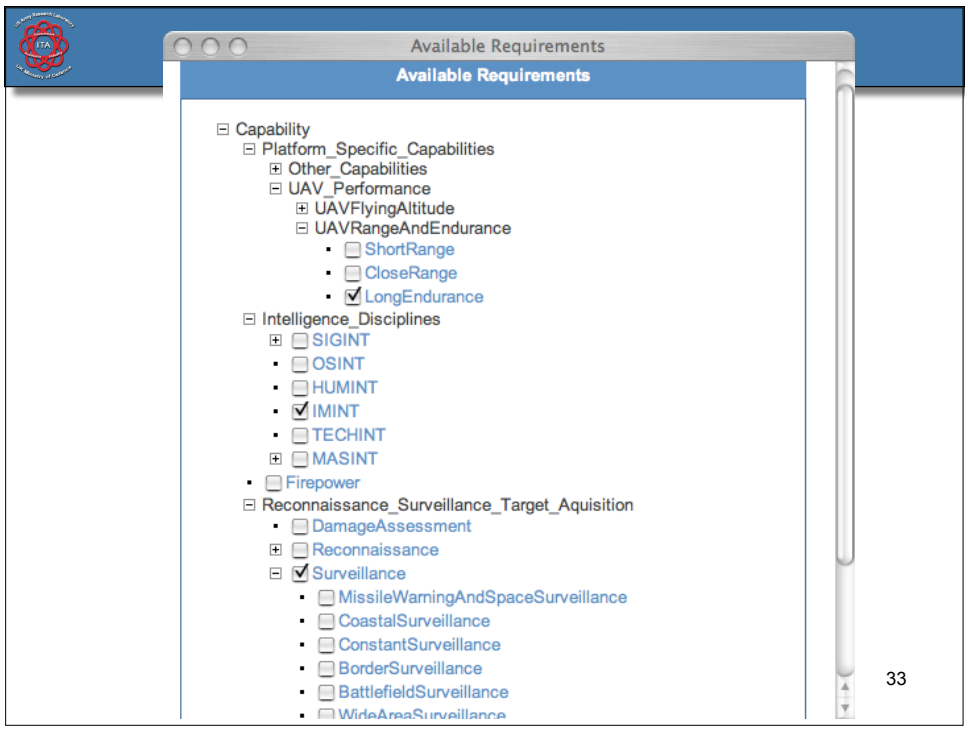

SAM
Sensor Assignment for Missions
Select Mission
Mission
Select Mission
International Mision for Holistan
Execute >>
The theater of operations for our scenario is set in the hypothetical country of Holistan located somewhere in the middle-east, with a population which has a strong underlying resentment fuelled by religious fundamentalists against the western civilization. The government of the country has obtained weapons of mass destruction (nuclear and chemical) against the wishes of US and UK foreign policy, but is generally friendly towards the two nations. However, due to an impending crisis in the country, which strongly increases the risks of nuclear/chemical technology falling into the hands of religious militants, the two nations are forced to form an uneasy coalition with a somewhat reluctant government of Holistan with the objective of saving the surrounding area from a larger crisis. The terrain, environment and the operational environment of the coalition operations provide new challenges for the research community, including the topics of managing limited trust and risk among coalition partners, hostile environments without characteristics conducive for wireless networks, innovative use of sensors in parasitic modes, decision making with partial information, and synthesis of environment data into simpler situational contexts.
Department of Computing Science, University of Aberdeen, Aberdeen AB24 3UE, Scotland, UK
phone +44 (0)1224 272295, fax +44 (0)1224 273422


SAM
Sensor Assignment for Missions
Select Mission
Mission
Operations
Sabotage Dirty Bomb
Tracking Insurgents
Requirement
Surveillance
IMINT
LongEndurance
Add Requirements
Details :: Sabotage Dirty Bomb
Commander's Intent
to mount an intervention operation in order to deny the insurgents the opportunity to carry out The sword of Jihad
Description
Coalition intelligence agencies have received information about a plan to smuggle nuclear material from a facility in Holistan across the border into Rugistan to carry out a dirty bomb attack in the capital. This plan has been named by the insurgents as The sword of Jihad.
Sabotage Dirty Bomb :: Get Recommended Assets
Department of Computing Science, University of Aberdeen, Aberdeen AB24 3UE, Scotland, UK
phone +44 (0)1224 272295, fax +44 (0)1224 273422


Available Requirements
Available Requirements
Capability
Platform_Specific_Capabilities
Other_Capabilities
UAV_Performance
UAVFlyingAltitude
UAVRangeAndEndurance
ShortRange
CloseRange
LongEndurance
Intelligence_Disciplines
SIGINT
OSINT
HUMINT
IMINT
TECHINT
MASINT
Firepower
Reconnaissance_Surveillance_Target_Aquisition
DamageAssessment
Reconnaissance
Surveillance
MissileWarningAndSpaceSurveillance
CoastalSurveillance
ConstantSurveillance
BorderSurveillance
BattlefieldSurveillance

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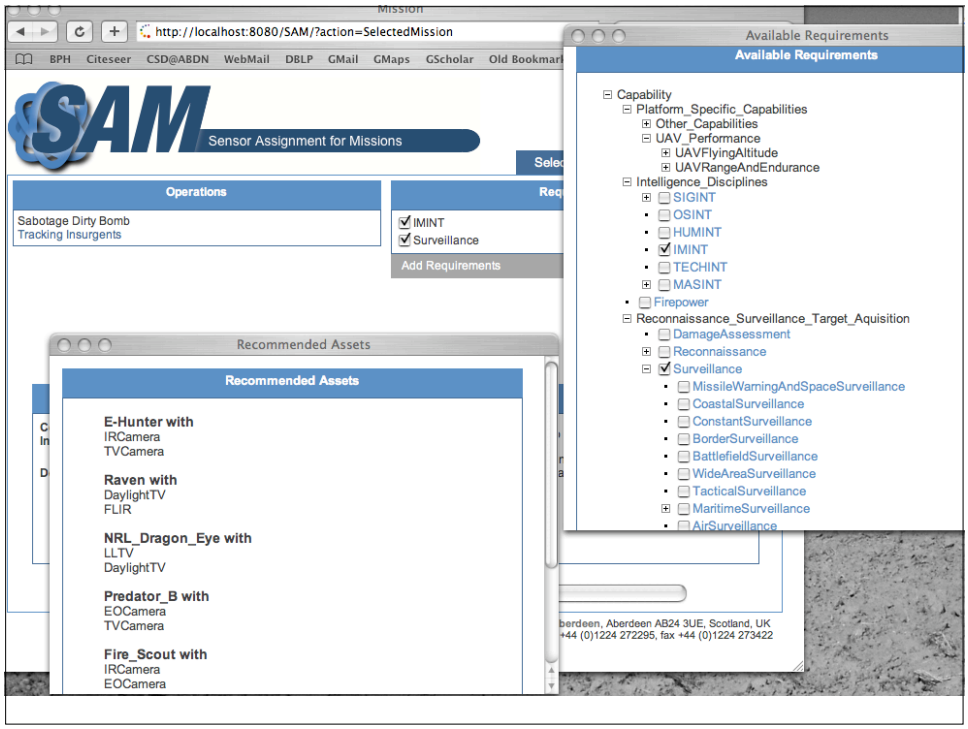
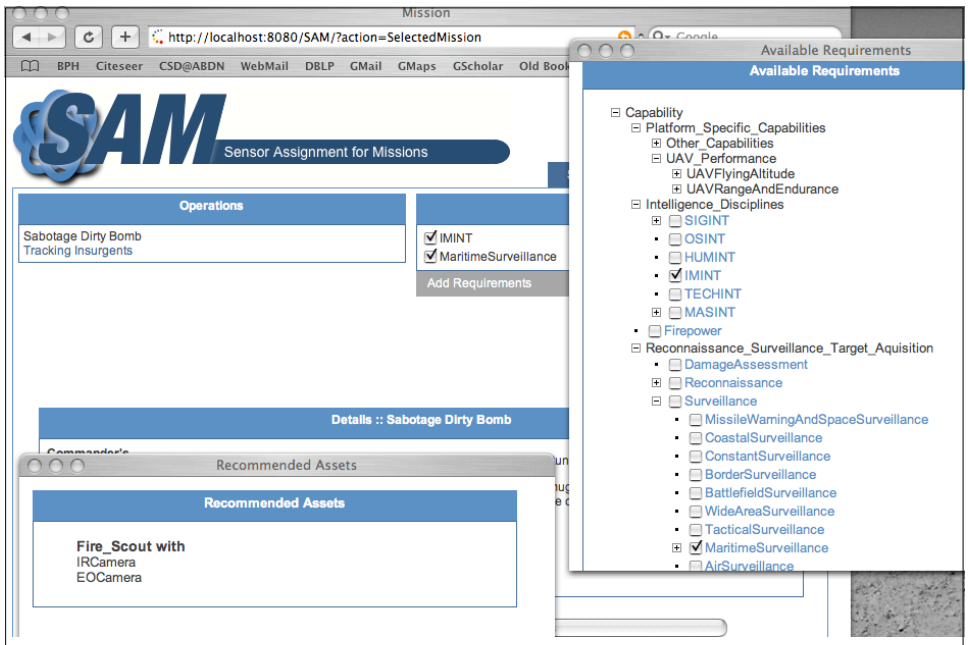

http://localhost:8080/SAM/?action=SelectedMission
SAM
Sensor Assignment for Missions
Operations
Sabotage Dirty Bomb
Tracking Insurgents
IMINT
Surveillance
Add Requirements
Recommended Assets
Recommended Assets
E-Hunter with
IRCamera
TVCamera
Raven with
DaylightTV
FLIR
NRL_Dragon_Eye with
LLTV
DaylightTV
Predator_B with
EOCamera
TVCamera
Fire_Scout with
IRCamera
EOCamera
Available Requirements
Available Requirements
Capability
Platform_Specific_Capabilities
Other_Capabilities
UAV_Performance
UAVFlyingAltitude
UAVRangeAndEndurance
Intelligence_Disciplines
SIGINT
OSINT
HUMINT
IMINT
TECHINT
MASINT
Firepower
Reconnaissance_Surveillance_Target_Aquisition
DamageAssessment
Reconnaissance
Surveillance
MissileWarningAndSpaceSurveillance
CoastalSurveillance
ConstantSurveillance
BorderSurveillance
BattlefieldSurveillance
WideAreaSurveillance
TacticalSurveillance
MaritimeSurveillance
AirSurveillance



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Next?

- Plan is to focus on UAV assignment
  - lots of available OS material
  - right size for a proof-of-concept
- Create initial set of ontologies and use off-the-shelf reasoners
  - Classification/subsumption (“is-a” / “is-not-a”)
  - Rules (“if…then…”)
  - Constraints (“for all…”)

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LINKING SENSORS AND MISSIONS

- MASINT: Scientific and technical intelligence information obtained by quantitative and qualitative analysis of data derived from specific technical sensors for the purpose of identifying any distinctive features associated with the source, emitter, or sender and to facilitate subsequent identification and/or measurement of the same.
  - Acoustic (ACINT)
  - Electro Optical (ELECTRO-OPTINT)
    - Laser (LASINT)
    - Spectroscopic
  - Infrared (IRINT)
  - Materials
    - Chemical and Biological (CBINT)
  - Nuclear (NUCINT)
  - Radar (RADINT)
  - Radio Frequency/Electromagnetic pulse (RF/EMPINT)
  - Unintentional Radiation (RINT)
  - Directed Energy Weapons (DEWINT)

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LINKING SENSORS AND MISSIONS

- IMINT: Intelligence derived from the exploitation of collection by visual photography, infrared sensors, lasers, electro-optics, and radar sensors such as synthetic aperture radar wherein images of objects are reproduced optically or electronically on film, electronic display devices, or other media.
  - Photographic
  - Electro-Optical
  - Infrared
  - Radar
- SIGINT: A category of intelligence comprising either individually or in combination all communications intelligence, electronics intelligence, and foreign instrumentation signals intelligence, however transmitted.
  - Electronic (ELINT)
  - Communications (COMINT)
  - Foreign Instrumentation Signals (FISINT): telemetry, beaconry, electronic interrogators, tracking/fusing/arming command systems, video links

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