Towards Sensor *Knowledge* Processing & Delivery

"When sensors meet semantics"

Alun Preece

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

An old chestnut (for Christmas)

- Data
  - Uninterpreted symbols, numbers, strings, blobs, …
    - "red", 17
- Information
  - Contextualised data
    - "traffic light is red"
    - "Fred's age is 17"
- Knowledge
  - Actionable information
    - "if the traffic light is red then stop the car"
    - "if a person is 17 don't serve them alcohol in the UK"

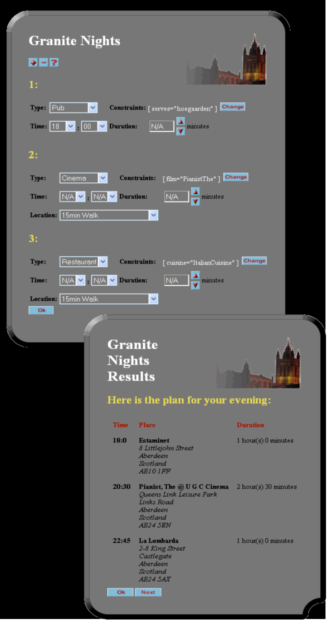
Knowledge in support of decision-making

- Eighties
  - Expert systems
    - Knowledge as rules (e.g. XCON)
    - “IF X THEN Y”
- Nineties
  - Recommender systems
    - Knowledge as links (e.g. Google)
    - “LIKE X? TRY Y!”
- Noughties
  - Semantic Web / Web 2.0
    - Knowledge as ontologies / tags
    - “THIS IS ABOUT X, WHICH IS A KIND OF Y”

Example: Granite Nights

agentcities

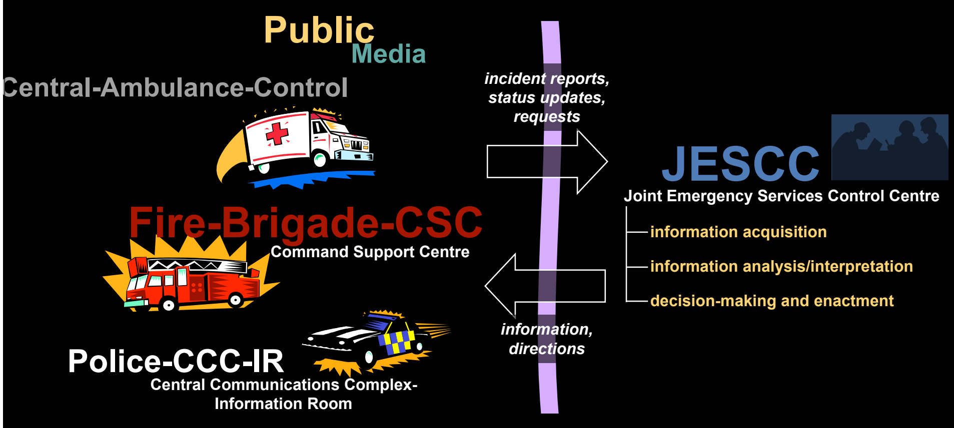
- Semantic Web (SW) service: helps a user to plan an evening out in Aberdeen
- Sources of information:
  - Restaurants (uses standard ontology)
  - Movies (uses standard ontology)
  - Pubs (uses a home-made ontology)
- Remembers and recalls user preferences
  - Semantic profiling
- Scheduler maps SW data to constraints and produces valid schedules



“Getting the right information to the right people at the right time”

- It’s a cliché, but the problem is still important
- We want to make decisions, and act, based on the best-available data/information/knowledge
  - … from our networks: inter-, ad hoc, social, …
  - … from our Webs: 1.0, 2.0, Semantic, …
  - … from “everyware” around us
- BUT: getting info is always easier than sifting by its “fitness for purpose”
- For the “best” available sources, demand may exceed supply
  - especially in the worst environments…

Example: emergency response



Thanks to Steven Potter, University of Edinburgh

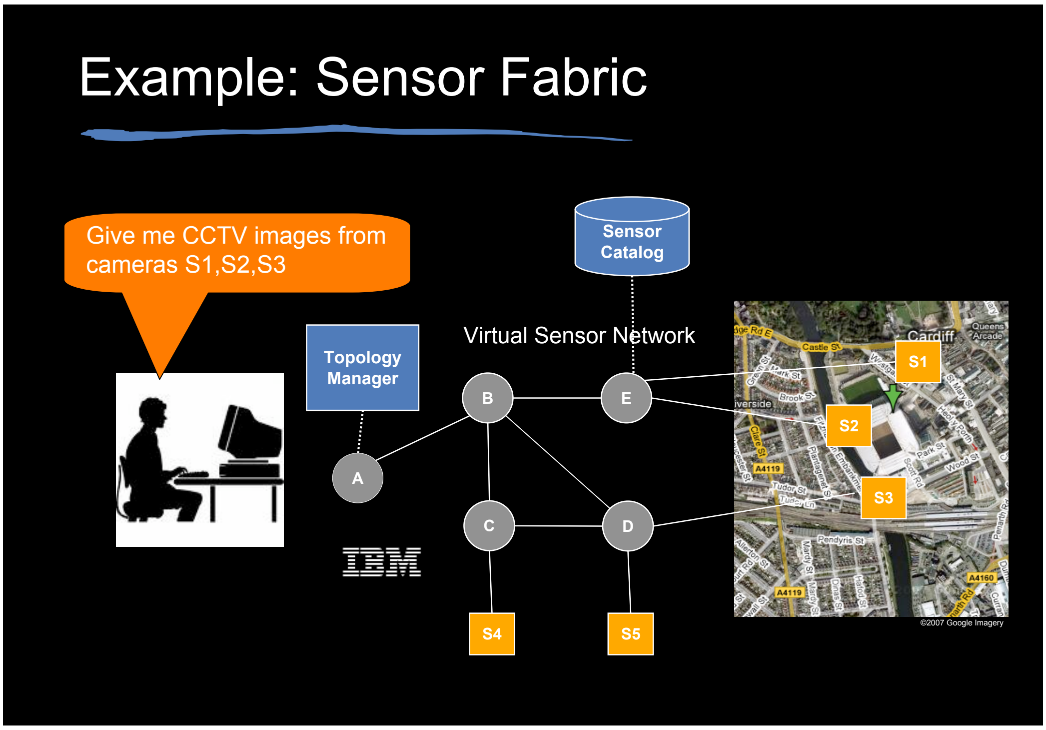
http://www.leslp.gov.uk

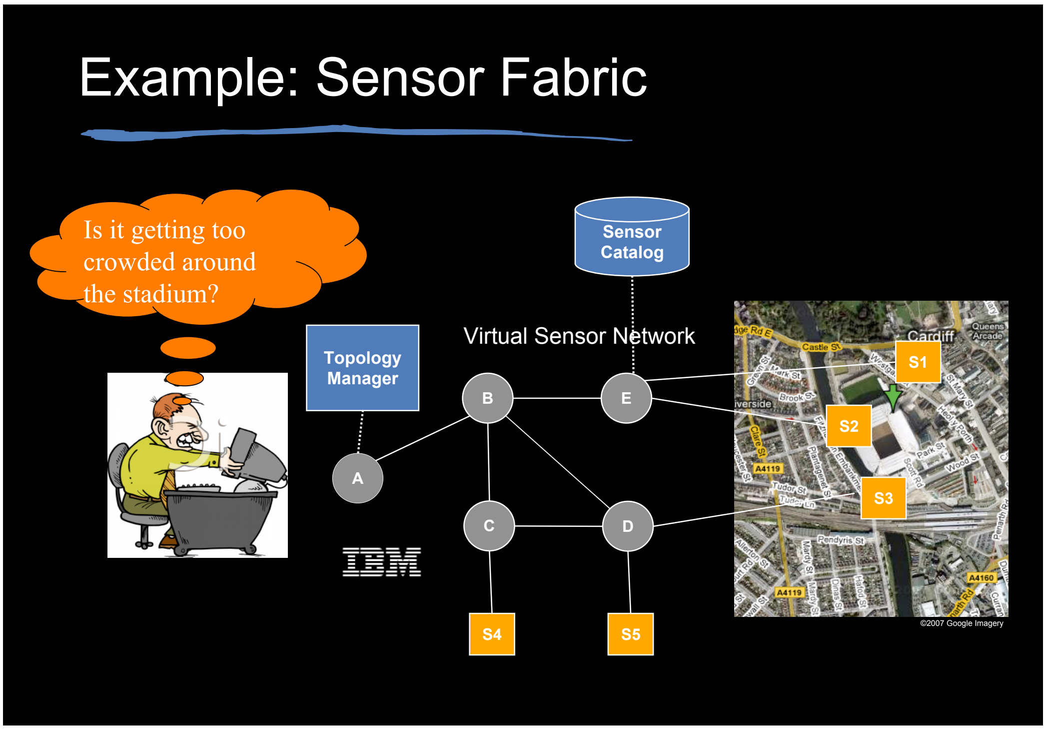
The network as decision-support system

- Imagine we could "ask the network"
  - submit a query
  - pose a hypothesis for it to confirm or refute
  - try out some "what ifs" on it
- And have "the network" do its best to satisfy the needs of all its users

Narrowing down the problem

- Looking at sensor networks from a "knowledge management" perspective
- Challenges in *Sensor Information Processing & Delivery* (SIPD):
  - finding sources of data
  - configuring fusion pipelines (data => info)
  - managing topologies for delivery
  - tasking & controlling …
- But this doesn't take a task-oriented view: the network best-serving the *needs* of users
  - providing "actionable info" - knowledge

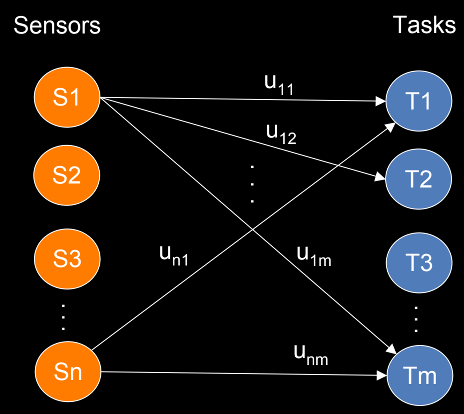

Example: Sensor Fabric
Give me CCTV images from cameras S1,S2,S3
Sensor Catalog
Topology Manager
Virtual Sensor Network
A
B
C
D
E
IBM
S1
S2
S3
S4
S5
Cardiff
©2007 Google Imagery


Example: Sensor Fabric
Is it getting too crowded around the stadium?
Sensor Catalog
Topology Manager
Virtual Sensor Network
A
B
C
D
E
IBM
S1
S2
S3
S4
S5
Cardiff
©2007 Google Imagery

A simpler subproblem

- Given
  - a number of information-providing *assets* (sensors & sensor platforms)
  - a number of *tasks* competing for the same assets
- Goal is
  - to allocate assets to tasks in a way that maximizes global utility

Sensor-task matching



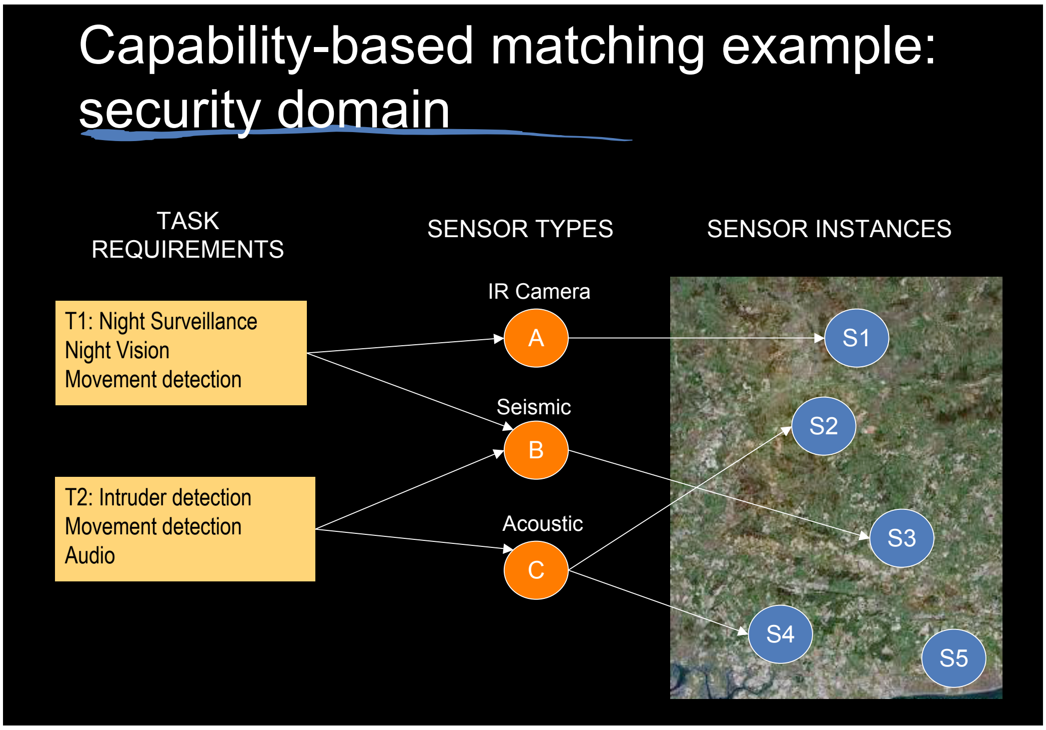
- How to obtain the utility of sensors to tasks (u_{ij})?
- How to deal with different types of sensors?
- How to represent different task requirements?

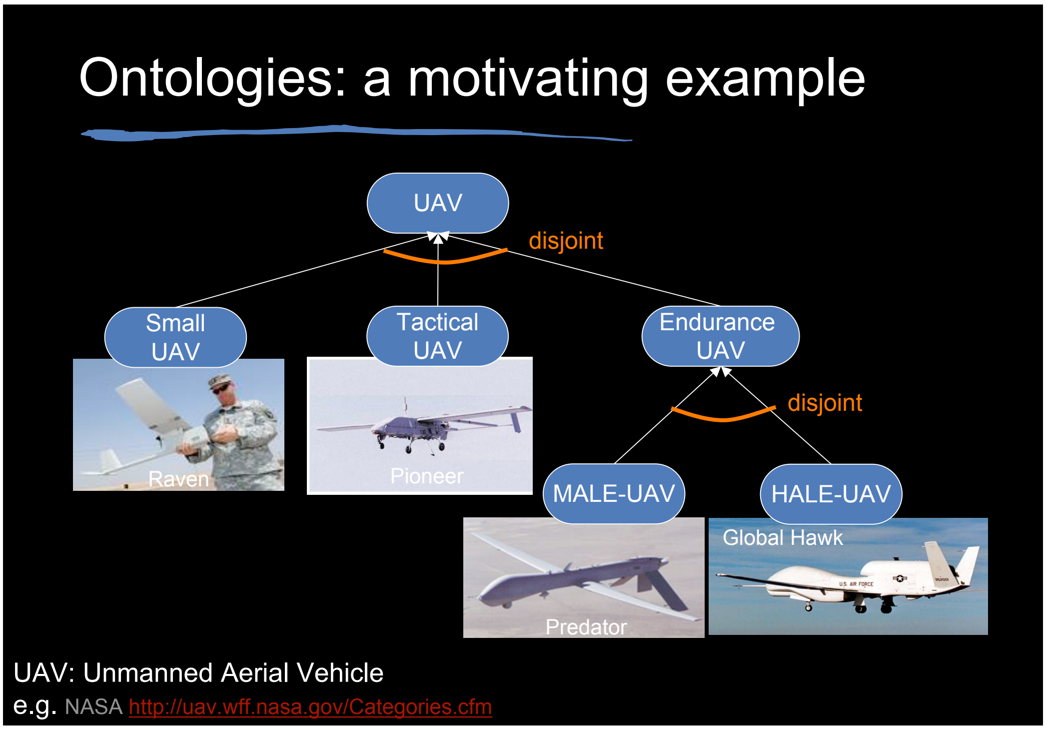
Refocusing the subproblem

- Given
  - a task with specific information requirements
  - alternative means (assets) to provide information
- Goal is
  - to assess the "fitness for purpose" of alternative means to accomplish a task
  - … qualitatively & quantitatively

Ontology-based approach

- Use ontologies to
  - specify the information requirements of a task
  - specify the capabilities provided by different asset types
- Use semantic reasoning
  - to compare task requirements and asset capabilities
  - decide whether requirements are satisfied (fully or partially)


Capability-based matching example: security domain
TASK REQUIREMENTS
SENSOR TYPES
SENSOR INSTANCES
T1: Night Surveillance
Night Vision
Movement detection
T2: Intruder detection
Movement detection
Audio
IR Camera
A
Seismic
B
Acoustic
C
S1
S2
S3
S4
S5

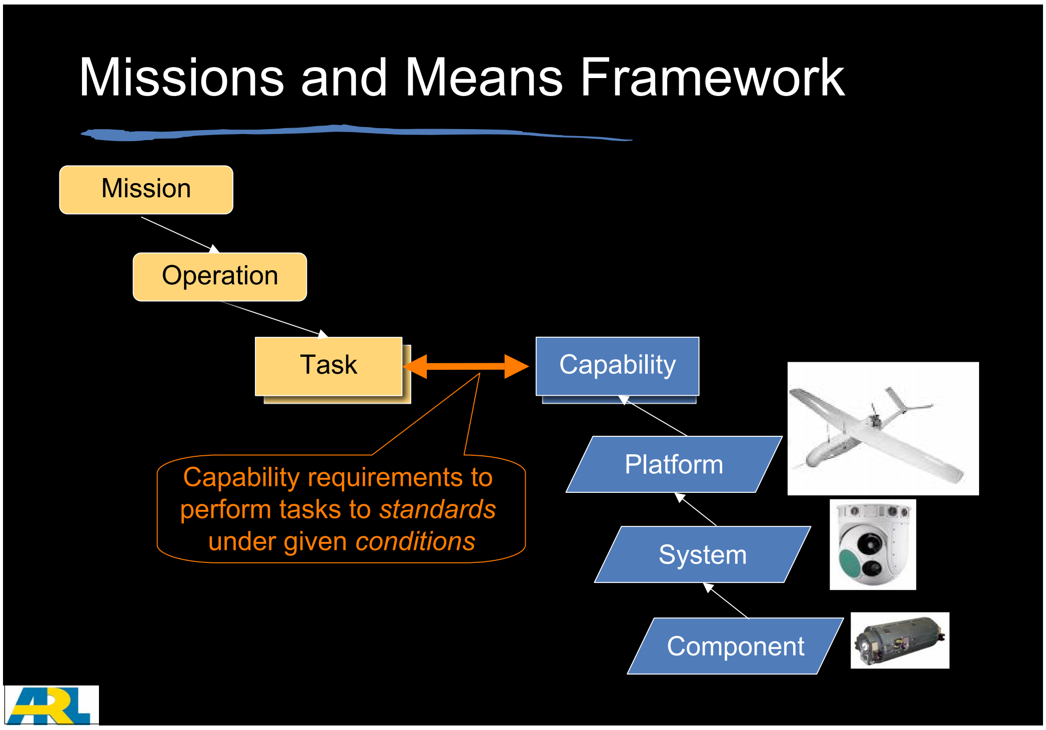

Ontologies: a motivating example
UAV
disjoint
Small UAV
Tactical UAV
Endurance UAV
Raven
Pioneer
disjoint
MALE-UAV
HALE-UAV
Global Hawk
Predator
UAV: Unmanned Aerial Vehicle
e.g. NASA http://uav.wff.nasa.gov/Categories.cfm

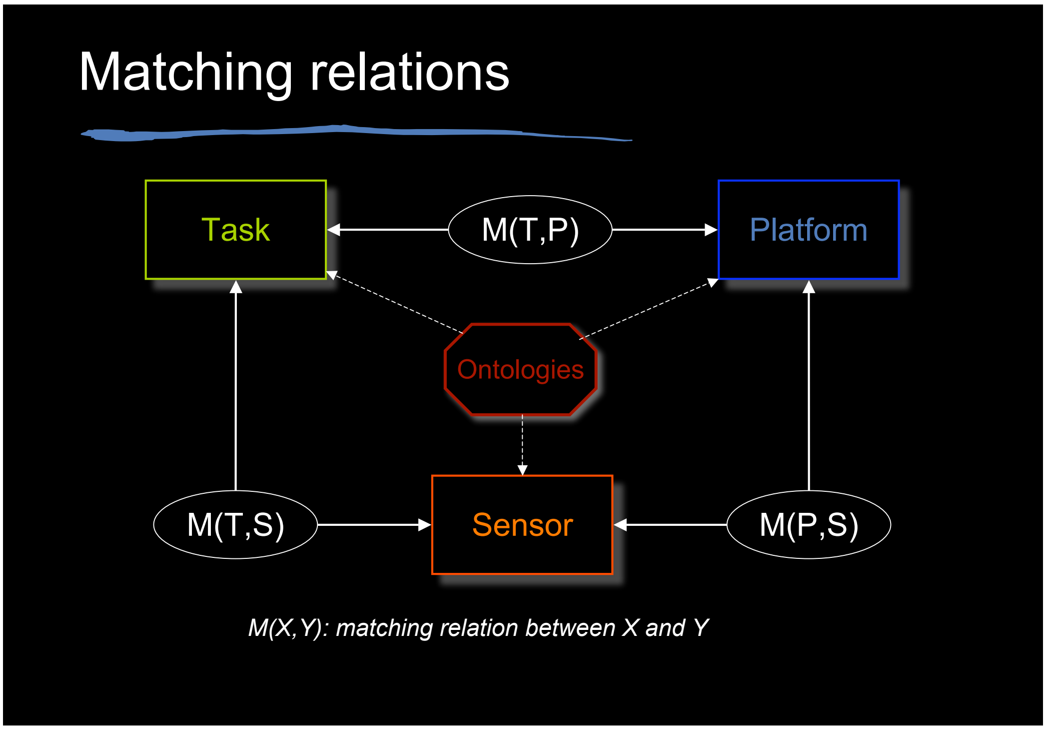
Ontologies: a motivating example

- Given a task that requires Wide Area Surveillance
  - This capability is provided by Endurance-UAV
- Three UAVs are available:
  - Pioneer is-a Tactical-UAV
  - Predator is-a MALE-UAV
  - Global Hawk is-a HALE-UAV
- From only the concept definitions we know:
  - Pioneer is not an Endurance-UAV
  - Predator & Global Hawk are types of Endurance-UAV
- So we can use either Predator or Global Hawk

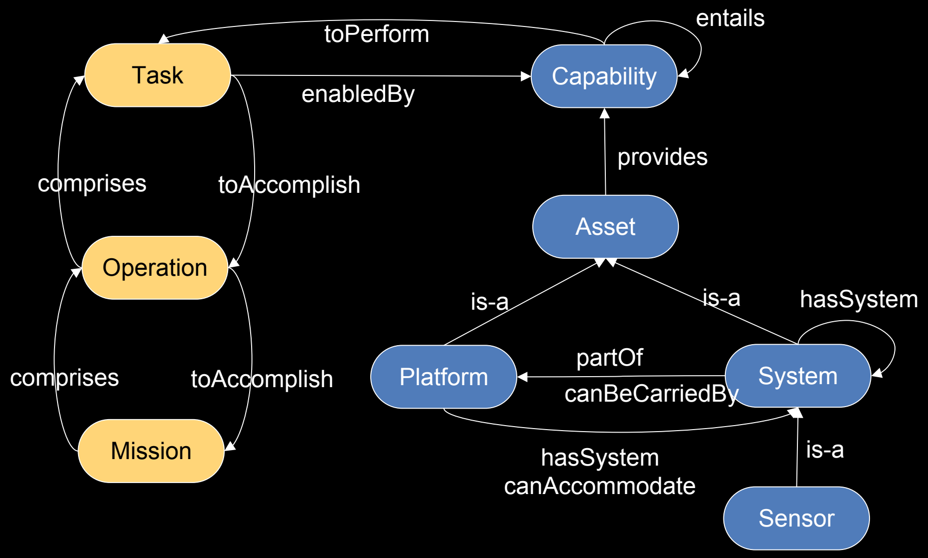
Ontologies: a motivating example

- Suppose there is bad weather, an additional capability is to be able to fly "above the weather"
  - Capability provided by HALE-UAV (high altitude)
- Preferred choice is now Global Hawk
- Note that:
  - We only state minimum explicit information about the UAVs (e.g. Pioneer is-a Tactical-UAV)
  - Everything else is inferred from the concept definitions (e.g. Pioneer is <u>not</u> a high altitude UAV)


Missions and Means Framework
Mission
Operation
Task
Capability
Capability requirements to perform tasks to *standards* under given *conditions*
Platform
System
Component


Matching relations
Task
M(T,P)
Platform
Ontologies
M(T,S)
Sensor
M(P,S)
M(X,Y): matching relation between X and Y

MMF ontology: main concepts



"Ontological Lego"

- We adhere to the Semantic Web vision of multiple interlinking ontologies, including
  - Missions and tasks ontology (mostly based on MMF)
  - Sensors 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

Platforms & systems

- Platform
  - AerialPlatform
    - Aircarft
    - UAV
      - EnduranceUAV
        - HALE
        - MALE
      - LethalUAV
      - Shipboard
      - SmallUAV
        - MicroUA
        - MiniUA
      - TUAV
      - UCAV
      - UnmannedAirship
        - Aerostat
        - Blimp
  - GroundPlatform
  - SeaPlatform
  - UnderwaterPlatform

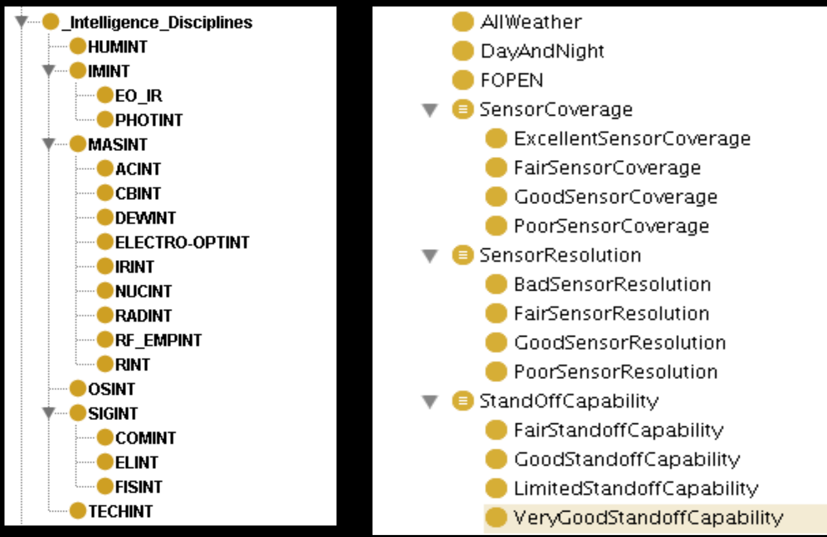
- System
  - Communication
  - DataLink
  - ElectronicWarfare
  - Guidance
  - Landing-Recovery
  - PowerPlant
  - Sensor
    - Acoustic
    - Chem-Bio
    - IntegratedSystem
    - IonisingRadiation
    - LDR
    - MetalDetector
    - Optical
      - EO
      - IR
      - TV
    - Radar
    - SIGINTSystem
    - Thermal
  - Sustentation
  - Takeoff-Launch

Platform capabilities

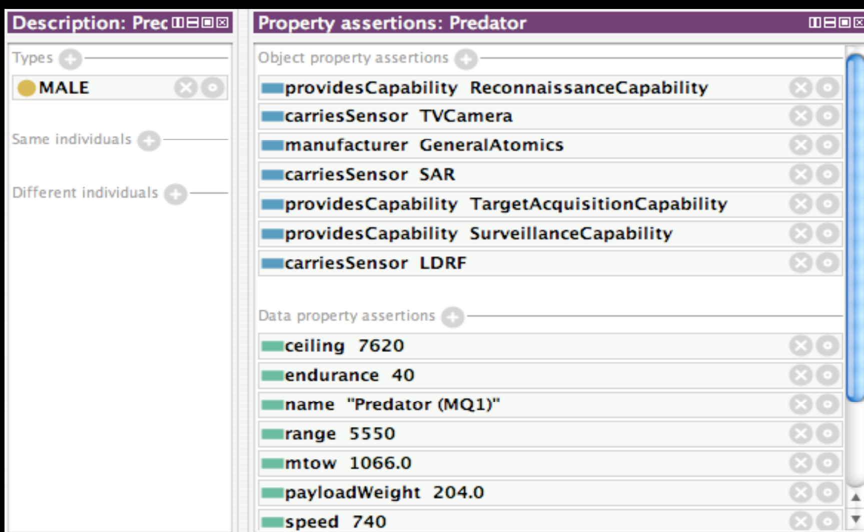
- _Reconnaissance_Surveillance_Target_Aquisiti
  - ArtilleryAdjustment
  - DamageAssessment
  - Reconnaissance
    - AreaReconnaissance
    - ArmedReconnaissance
    - ByFireReconnaissance
    - DayAndNightReconnaissance
    - ElectronicReconnaissance
    - MaritimeReconnaissance
    - MediumRangeReconnaissance
    - NightReconnaissance
    - RouteReconnaissance
    - SiteReconnaissance
    - TacticalReconnaissance

- Surveillance
  - AirSurveillance
  - BattlefieldSurveillance
  - BorderSurveillance
  - CoastalSurveillance
  - ConstantSurveillance
  - MaritimeSurveillance
  - MissileWarningAndSpaceSurveillance
  - TacticalSurveillance
  - WideAreaSurveillance
- TargetAcquisition
  - TargetClassification
  - TargetDetection
  - TargetIdentification
  - TargetLocation
  - TargetTracking

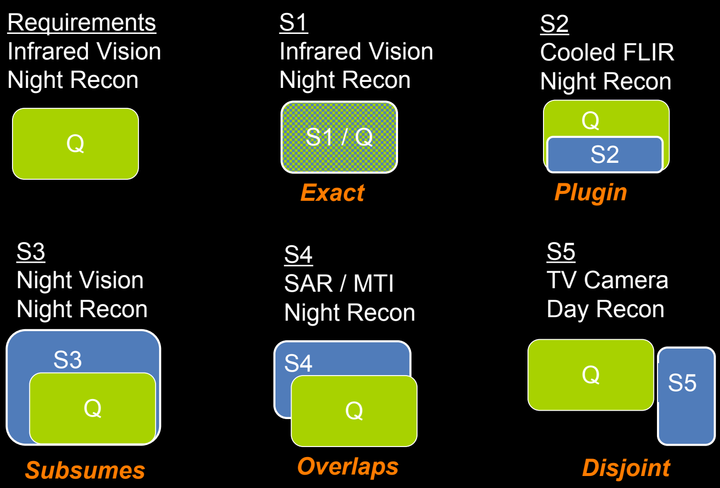
Sensor capabilities



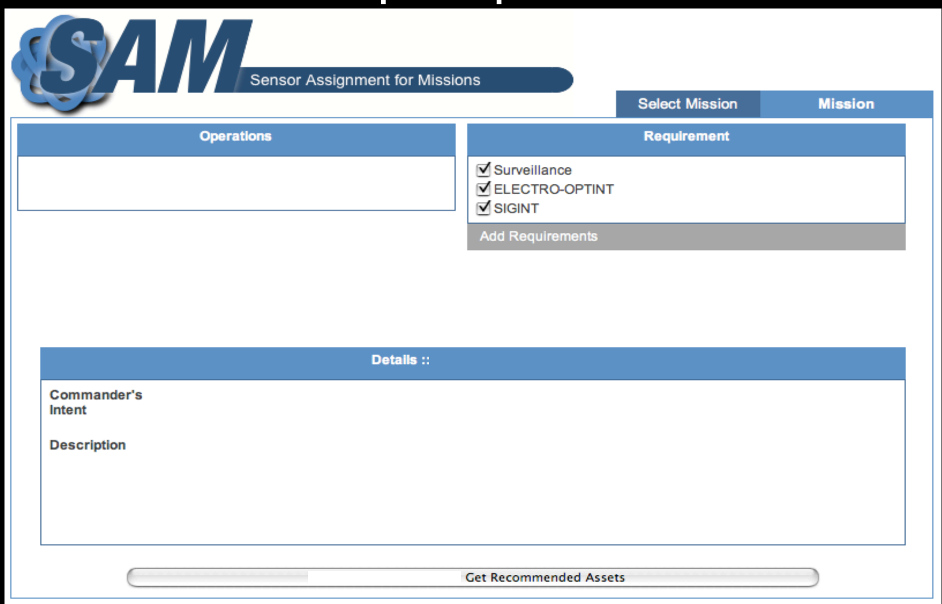
Platform specification example

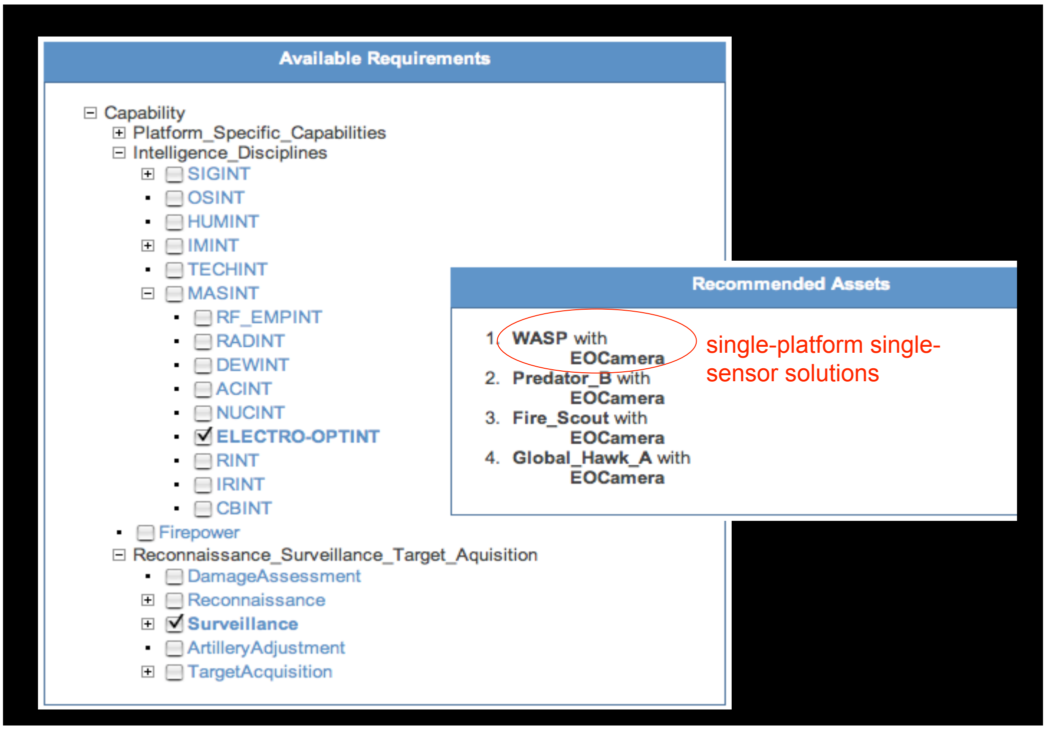


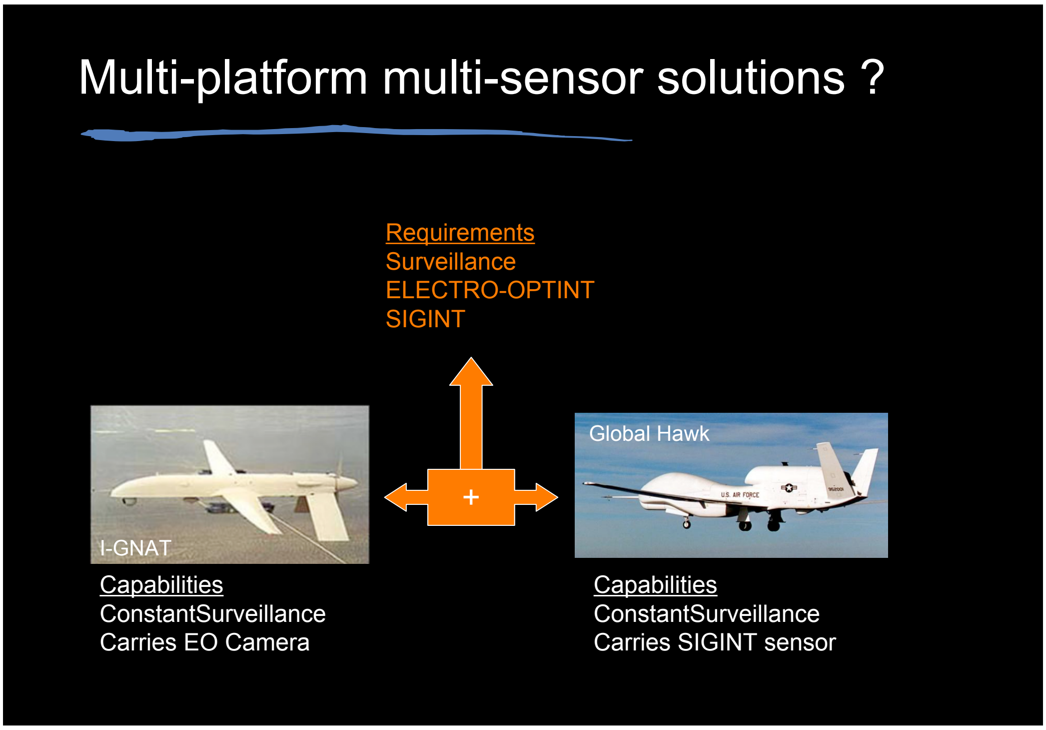
Semantic matching relations

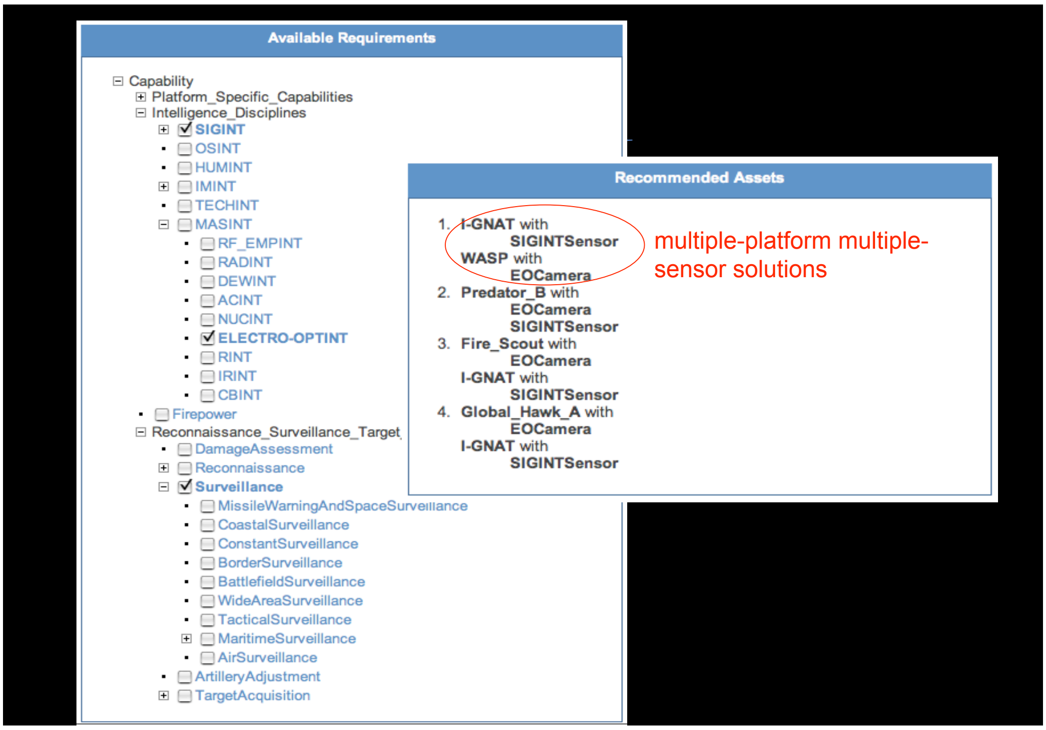


Proof-of-concept implementation

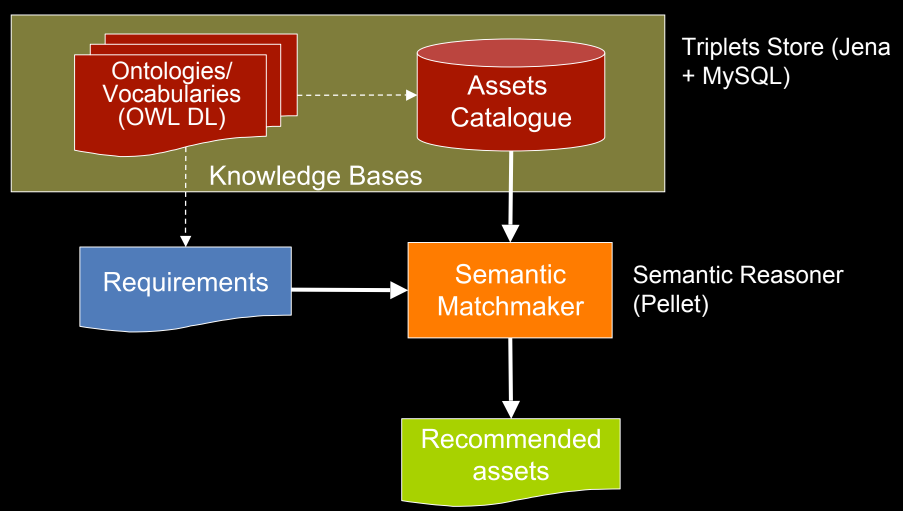



Available Requirements
Capability
Platform_Specific_Capabilities
Intelligence_Disciplines
SIGINT
OSINT
HUMINT
IMINT
TECHINT
MASINT
RF_EMPINT
RADINT
DEWINT
ACINT
NUCINT
ELECTRO-OPTINT
RINT
IRINT
CBINT
Firepower
Reconnaissance_Surveillance_Target_Aquisition
DamageAssessment
Reconnaissance
Surveillance
ArtilleryAdjustment
TargetAcquisition
Recommended Assets
1. WASP with EOCamera
2. Predator_B with EOCamera
3. Fire_Scout with EOCamera
4. Global_Hawk_A with EOCamera
single-platform single-sensor solutions

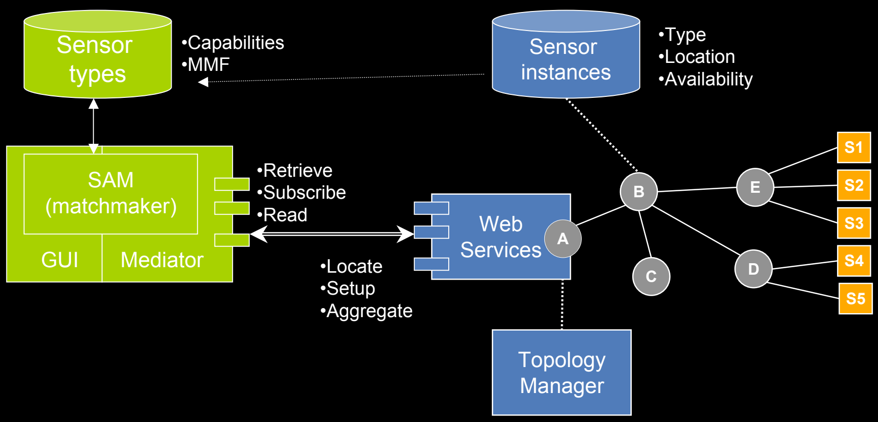

Multi-platform multi-sensor solutions ?
Requirements
Surveillance
ELECTRO-OPTINT
SIGINT
+
I-GNAT
Capabilities
ConstantSurveillance
Carries EO Camera
Global Hawk
Capabilities
ConstantSurveillance
Carries SIGINT sensor

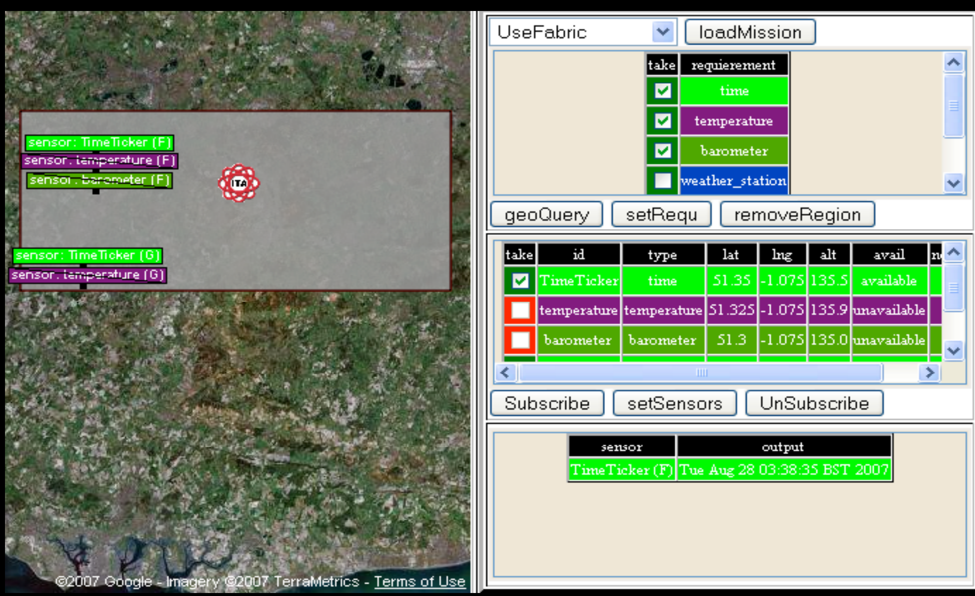


SAM architecture



Integrated architecture: SAM + Sensor Fabric





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"

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)

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>
```

Ongoing & future work

- Validate by working more closely with domain experts
- Explore human-in-the-loop vs agent-in-the-loop variants
- Factor Quality-of-Information models into fitness assessment
- Address the scalability issue
  - DL reasoning is worst-case exponential

Human-in-the-loop strategies

- Justify recommendations: why some solution is preferable?
- If there is no feasible solution, why?
- Suggest constraints that can be removed/weakened to open up possible recommendations…
- To what extent can SAM operate in automatic agent-in-the-loop mode?

Imagery QoI example: Civil NIIRS

(Extract from visible National Imagery Interpretability Rating Scale)

- Rating Level 4
  - Identify farm buildings as barns, silos, or residences.
  - Detect basketball court, tennis court, volleyball court in urban areas.
  - Detect jeep trails through grassland.
  - …
- Rating Level 5
  - Identify Christmas tree plantations.
  - Identify tents (larger than two person) at established recreational camping areas.
  - Detect large animals (e.g., elephants, rhinoceros, giraffes) in grasslands.
  - …

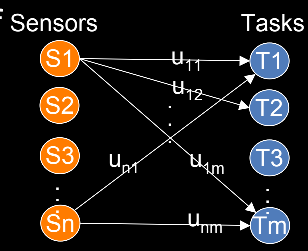
Matching degrees

Performance

- The DL-based reasoning is worst-case exponential, but is expected to be OK for 100s of sensor types
- (The Pellet reasoner also works fine to assign 100s of sensor instances)
- BUT this approach won't scale to 1000s or 10000s of instances
- Open question: can we adopt a hybrid approach?

Hybrid approach to assignment

- There exist many formulations of the sensor-task assignment problem
  - that are NP-hard
  - that achieve results within “reasonable” reach of the optimal (e.g. 7%)



- Can we do better using a “best of both worlds” approach?
  - use the reasoner to cut down the search space by eliminating “unfit” types
  - use the allocation algorithms to assign instances (where are assignments are “semantically sound”

Collaboration / credits

- Aberdeen
  - (esp Mario Gomez, Geeth de Mel, Wamberto Vasconcelos, Diego Pizzocaro, Konrad Borowiecki)
- Edinburgh
  - Emergency response (Steve Potter, Austin Tate)
- Dstl Malvern
  - Task requirements (Stuart Colley, Gavin Pearson)
- IBM UK
  - Integration with Sensor Fabric (Christopher Gibson)
- CUNY/Penn State University
  - Reasoning & allocation algorithms (Matt Johnson, Hosam Rawihy, Amotz Bar Noy, Tom La Porta)

Thanks for coming!

Any questions?