International Technology Alliance
In Network & Information Sciences

Managing Intelligence Resources using Semantic Matchmaking and Argumentation

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(from Dec 1 2007: Cardiff University)

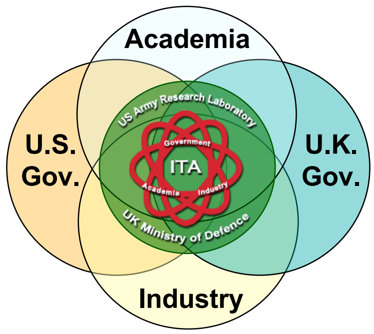
1

Outline

- Introduction to the ITA programme
  - especially Sensor Information Processing & Delivery (SIPD)
- Approaches from "agent technologies"
  - Ontologies & semantic matchmaking
  - Argumentation
- Links to other ITA (planned) work
- Acknowledgements

2

ITA: BACKGROUND & STRUCTURE



- Open collaborative research environment to support deep US/UK and public/private sector collaborations
- Initiated by the US Army Research Laboratory & UK Ministry of Defence
- Launched in May 2006, to run for a possible 10 years
- Aims to enhance flexible, distributed, and secure decision-making to improve networked coalition operations
- Consists of separate basic research and (national) technology transition contracts

3

ITA: 4 TECHNICAL AREAS

TA1: network theory

TA2: security across a system of systems

TA3: sensor information processing and delivery

TA4: distributed coalition planning and decision making

The work reported here is situated in TA3 but connects to TA4

4

ITA MEMBERSHIP

ITA Members	
US Partners	**UK Partners**
Industry: IBM Corporation (lead) BBNT Solutions The Boeing Company Honeywell Klein Associates Division, ARA	*Industry:* IBM United Kingdom (lead) Logica CMG Roke Manor Research SEA
Academic: Carnegie Mellon University City University of New York (HBCU) Columbia University Pennsylvania State University Rensselaer Polytechnic Institute University of California, Los Angeles University of Maryland University of Massachusetts	*Academic:* Cambridge University Cranfield University Imperial College Royal Holloway University of Aberdeen University of Southampton York University
Government: Army Research Laboratory (ARL)	*Government:* Ministry of Defence (MoD), Dstl

5

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

6

Motivation: The Problem

- Given
  - A mission with some information needs
  - Alternative means (assets) to collect information
- Goal is
  - To assess the fitness for purpose of alternative means to accomplish a mission: select best combination of sensors/platforms to accomplish mission

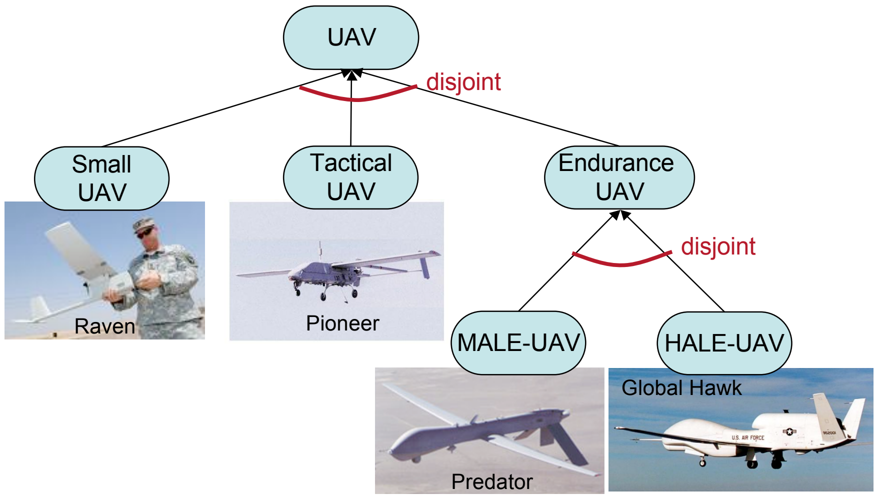
7

Approach: Semantic Reasoning

- Use **ontologies** to
  - Specify the ISR **requirements** of a mission
  - Specify the ISR **capabilities** provided by available assets
- Use **semantic reasoning**
  - to compare mission requirements and asset capabilities to assess the **fitness for purpose** of assets to mission
  - decide whether an asset (or group of assets) satisfies the sensing requirements of a mission, or to what degree (utility function)

8

Motivating Example



NASA http://uav.wff.nasa.gov/Categories.cfm
Defense Update: http://www.defense-update.com/features/du-2-05/feature-uav.htm

9

Motivating Example II

- Given a mission that requires Wide Area Surveillance
  - Capability provided by any 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 types of Endurance-UAV
- So we can assign either UAV2 or UAV3

10

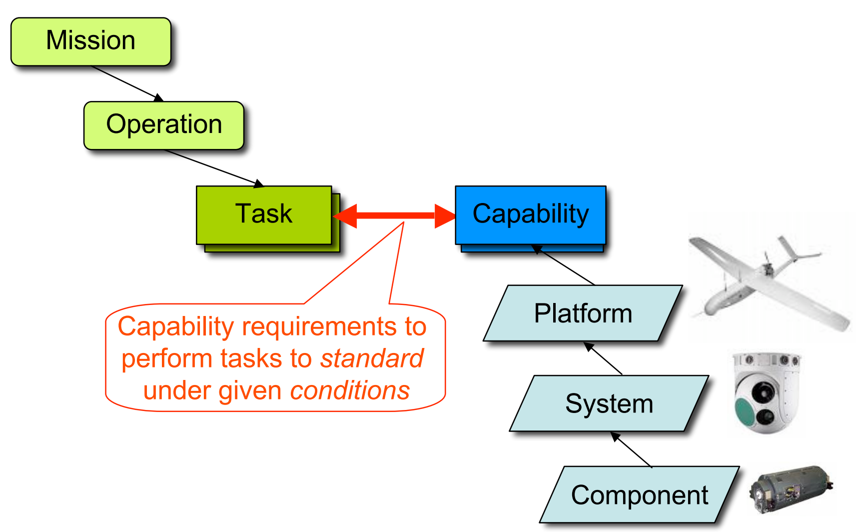
Motivating Example III

- Suppose there is bad weather, additional capability is to be able to fly “above the weather”
  - Capability provided by HALE-UAV (high altitude)
- 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 <u>not</u> a high altitude UAV)

11

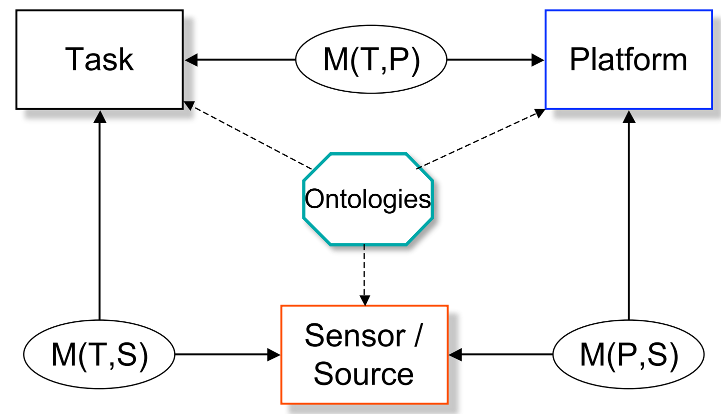
Missions and Means Framework



J. H. Sheehan, P. H. Deitz, B. E. Bray, B. A. Harris, and A. B. H. Wong, The Military Missions and Means Framework, *IITSEC 2003*

12

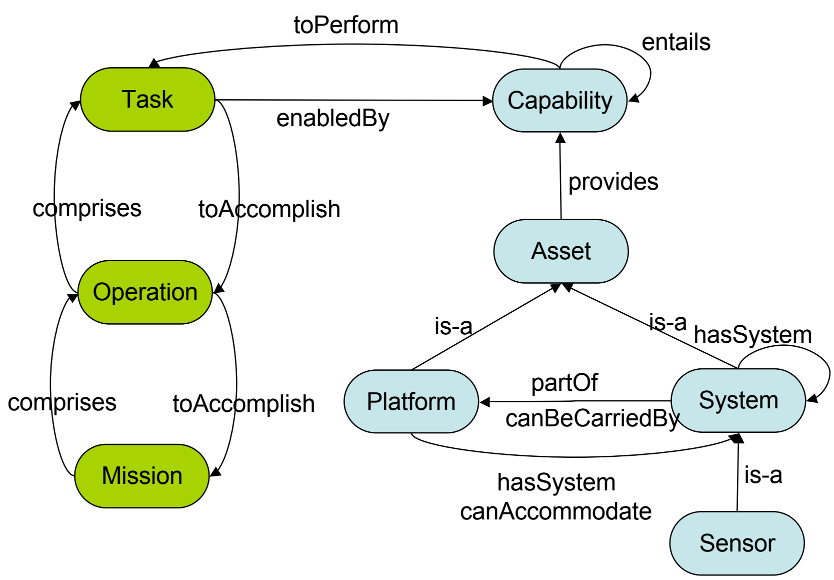
Matchmaking Architecture



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

13

Ontologies: Main Concepts



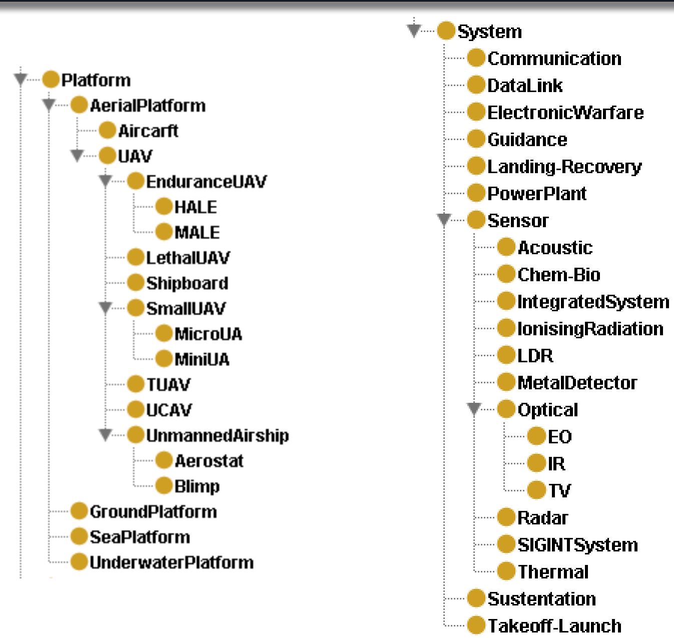
14

"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

15

Platforms and Systems



16

Platform Capabilities

- _Reconnaissance_Surveillance_Target_Aquisition
  - 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

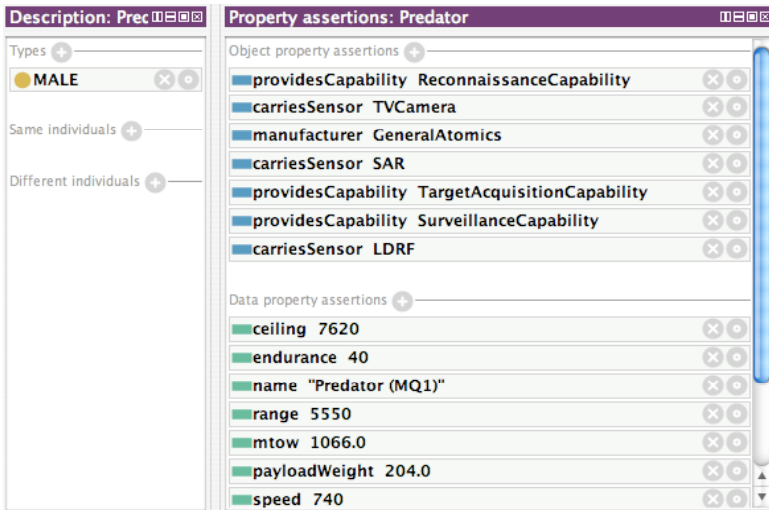
17

Sensor Capabilities

- _Intelligence_Disciplines
  - HUMINT
  - IMINT
    - EO_IR
    - PHOTINT
  - MASINT
    - ACINT
    - CBINT
    - DEWINT
    - ELECTRO-OPTINT
    - IRINT
    - NUCINT
    - RADINT
    - RF_EMPINT
    - RINT
  - OSINT
  - SIGINT
    - COMINT
    - ELINT
    - FISINT
  - TECHINT

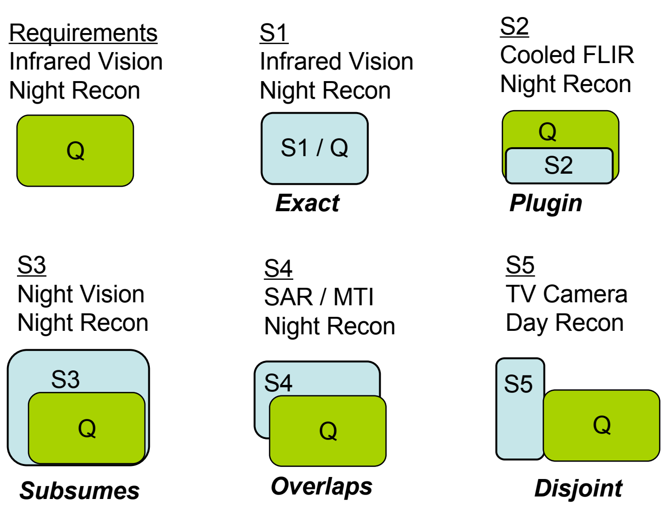
18

Platform Example

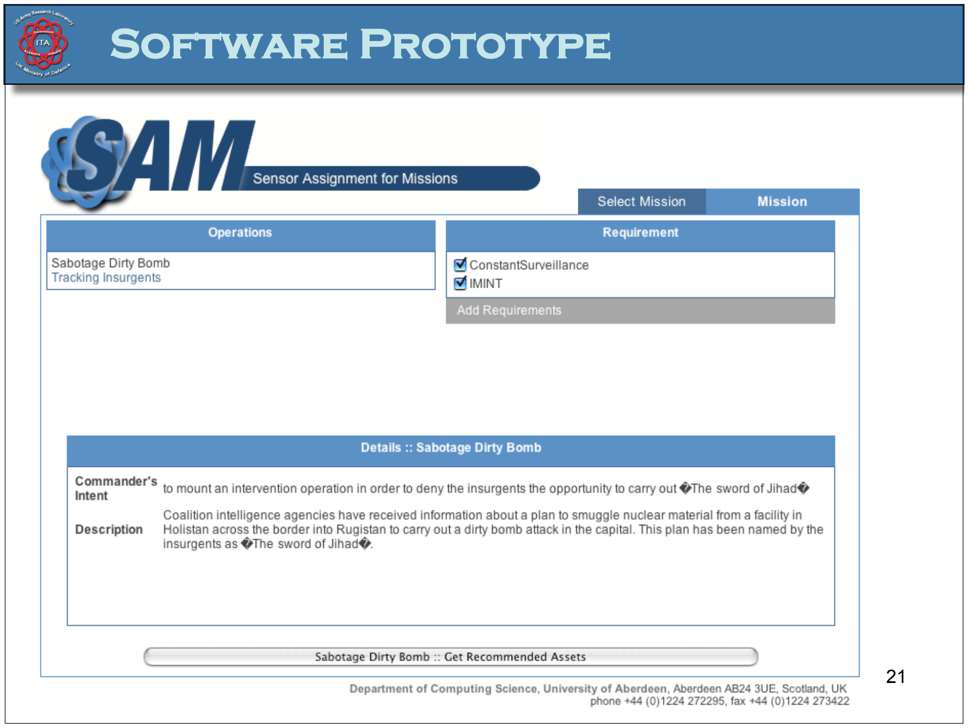


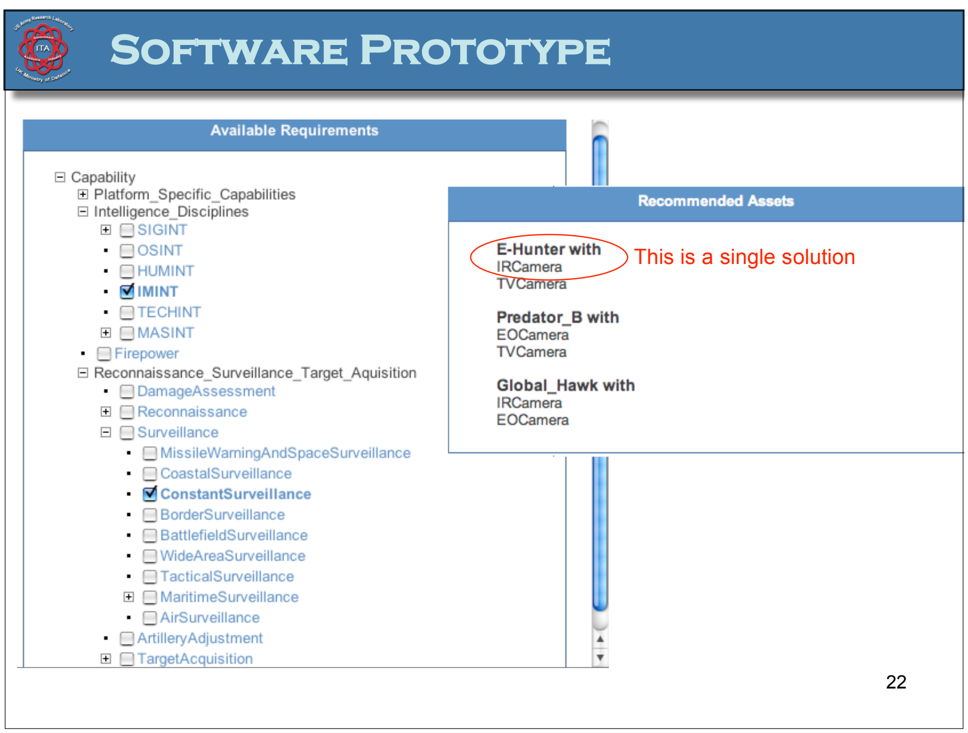
19

Matching Relationships



20


SOFTWARE PROTOTYPE
SAM
Sensor Assignment for Missions
Select Mission
Mission
Operations
Sabotage Dirty Bomb
Tracking Insurgents
Requirement
ConstantSurveillance
IMINT
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
21


SOFTWARE PROTOTYPE
Available Requirements
Capability
Platform_Specific_Capabilities
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
ArtilleryAdjustment
TargetAcquisition
Recommended Assets
E-Hunter with
IRCamera
TVCamera
This is a single solution
Predator_B with
EOCamera
TVCamera
Global_Hawk with
IRCamera
EOCamera
22

Conclusions

- Formal ontologies enable solutions that are logically "sound"
- Complex problem, rich modelling languages seem appropriate
- Semantic matchmaking is a feasible and interesting approach

Future Work: Recommended Assets

- From qualitative to quantitative assessment (utility values)
  - Based on the proportion of requirements satisfied and the semantic distance (fitness)
  - Based on quantitative mission demands (distance to target, area to cover, QoI…)
- Multiple asset configurations (packages)
- From asset classes to instances:
  - Readiness/Availability status
  - Operational status (distance, battery, etc…)

Roles for Argumentation

- Why argue?
  - To obtain resources where there is contention
  - To deliberate with possibly conflicting evidence
- Argumentation offers a “natural” approach for
  - Dialogue-driven deliberation
  - Accrual of evidence
  - Transparent/auditable decision-making
  - Including consideration of cost/utility

Evidence & Sensors

- Evidence is gathered via sensors
  - Abstractly, anything that can determine the state of (part of) the environment
- Some sensors may be more accurate than others
- Sensors may not perform their services for free

- The logic of our framework is built on Subjective Logic
  - which, in turn, is based on Dempster-Schafer theory
- We may assign an *opinion* to predicates representing portions of the environment

  < belief, disbelief, uncertainty >

Jøsang, A.: A logic for uncertain probabilities. *Int. Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* **9** (2001) 279–311

Subjective logic operators

Conjunction:

$$b_{x\wedge y} = b_x b_y$$
$$d_{x\wedge y} = d_x + d_y - d_x d_y$$
$$u_{x\wedge y} = b_x u_y + u_x b_y + u_x u_y$$

Negation:

$$b_{\neg x} = d_x$$
$$d_{\neg x} = b_x$$
$$u_{\neg x} = u_x$$

27

Subjective logic operators: discounting

Discounting:

$$b^{\alpha\beta_x} = b^{\alpha}_{\beta} b^{\beta}_{x}$$
$$d^{\alpha\beta_x} = b^{\alpha}_{\beta} d^{\beta}_{x}$$
$$u^{\alpha\beta_x} = d^{\alpha}_{\beta} + u^{\alpha}_{\beta} + b^{\alpha}_{\beta} u^{\beta}_{x}$$

$$\omega^{AB}_{x} = \omega^{A}_{B} \otimes \omega^{B}_{x}$$

Model of “hearsay”: the opinion agent α holds about x when β holds an opinion about x, and α holds an opinion about β

28

Subjective Logic Operators: Consensus

- Consensus:

$$b_x^{\alpha,\beta} = (b_x^\alpha u_x^\beta + b_x^\beta u_x^\alpha)/\kappa$$
$$d_x^{\alpha,\beta} = (d_x^\alpha u_x^\beta + d_x^\beta u_x^\alpha)/\kappa$$
$$u_x^{\alpha,\beta} = u_x^\alpha u_x^\beta/\kappa$$

Where $\kappa = u_x^\alpha + u_x^\beta - u_x^\alpha u_x^\beta$ such that $\kappa \neq 0$ and $a_x^{\alpha,\beta} = (a_x^\alpha + a_x^\beta)/2$ if $u_x^\alpha = u_x^\beta = 1$

$$\omega_x^{A,B} = \omega_x^A \oplus \omega_x^B$$

The opinion an imaginary agent would hold about x if it had to assign equal weight to the opinions of agents α and β about x

29

Arguments & Argument Schemes

- An argument is an instantiated argument scheme [Walton 1996] linking facts to other facts
- Argument schemes are common, stereotypical patterns of reasoning
- A simple argument scheme (Modus Ponens) could be represented as follows:

$$(ModusPonens, \{holds(A), implies(A,B)\}, \{holds(B))\}, F, true)$$

Here, F is:

$$\omega(holds(B)) = \begin{cases} \langle 0,0,1\rangle & b(holds(A)) < 0.5 \text{ or } \\ & b(implies(A,B)) < 0.5 \\ \omega(holds(A)) & b(holds(A) < b(implies(A,B)) \\ \omega(implies(A,B) & \text{otherwise} \end{cases}$$

30

Dialogue & Accrual of arguments

- Agents take turns to make utterances by
  - advancing a connected set of arguments
  - probing a number of sensors (at some cost)
- At each step in the dialogue, an opinion is calculated for every fact
- We associate a cost to probing actions, and a utility gain to the showing that certain facts hold in the world
  - An agent selects the utterance that maximises their utility (one step lookahead)
- The dialogue ends when both agents say nothing during their turn
- Note: simple cases of accrual of arguments can be handled by the consensus operator
  - As long as we avoid double-counting evidence
  - Algorithm appears in Oren et al, *AIJ*, 2007

31

Example Scenario I

- A commander, fronted by an agent α, has a mission *m* to accomplish
- To successfully execute *m*, α requires the use of a sensor package that can be deployed on either
  - Predator UAV (preferred by α)
  - Sentry UGV
- Another agent β is also present - could be another commander, a member of a coalition, etc
- Both agents share some knowledge; both also have private beliefs
- Some sensors have already been deployed in the field; the agents have access to these and other sources of information such as GIS systems

32

Example Scenario II

Available argument schemes:

Name	Premises	Conclusions
$ModPon$	$A, B, implies(A, B, C)$	C
$HumInt$	$atLocation(E, L), claims(E, A), inArea(A, L)$	A
$MisAss$	$capable(T, R), available(R), hasTask(M, T)$	$assigned(M, R)$
M_1	$higherPriority(M, N), uses(N, R)$	$reassignReq(N, M, R)$
M_2	$reassignReq(N, M, R), reassign(M, R)$	$assigned(M, R)$
D_1	$ugv(U), taskLocated(T, L), hasRoad(L)$	$capable(U)$
D_2	$ugv(U), taskLocated(T, L), mud(L)$	$capable(U)$
D_3	$ugv(U), taskLocated(T, L), mud(L), hasRoad(L)$	$capable(U)$

33

Example Scenario III

- α's goals:
  $assigned(mission(m), uav(predator)), assigned(mission(m), ugv(sentry))$
  the former has higher priority (obtain the UAV)
- Both agents are aware of the facts:
  $hasTask(mission(m), task(t))$ $higherPriority(mission(m), mission(n))$
  $capable(t, uav(predator))$ $implies(recentRain(l), sand(l), mud(l))$
  $ugv(sentry)$ $taskLocated(t, l)$
  $atLocation(h, l)$
- α begins with the utterance:
  $((MisAss, \{hasTask(mission(m), task(t)), capable(t, uav(predator)), available(uav(predator))\}, \{assigned(mission(m), uav(predator))\}), \{available(uav(predator))\})$
  i.e. it attempts to check that the UAV is available, and assign it (if possible). Assume that the probe succeeds

34

Example Scenario IV

- β responds with its own probe as it believes the UAV is not available:
  - The opinion returned is <0.1,0.9,0>
  - α's initial argument is defeated
- α now argues to use the UGV as it believes there are roads at the location:

$$(\{(D_1, \{hasRoad(l), taskLocated(t,l), ugv(sentry)\}, \{capable(t, ugv(sentry)\}), (MisAss, \{hasTask(mission(m), task(t)), capable(t, ugv(sentry)), available(ugv(sentry))\}, \{assigned(mission(m), ugv(sentry))\})\}, \{available(ugv(sentry)), hasRoad(l)\})$$

- However, β argues there is mud at the location:

$$((\{ModPon, \{recentRain(l), sand(l), implies(recentRain(l), sand(l), mud(l))\}, \{mud(l)\}), (D_3, \{ugv(sentry), taskLocated(t,l), mud(l), hasRoad(l)\}, \{capable(t, ugv(sentry))\}), \{recentRain(l), sand(l)\})$$

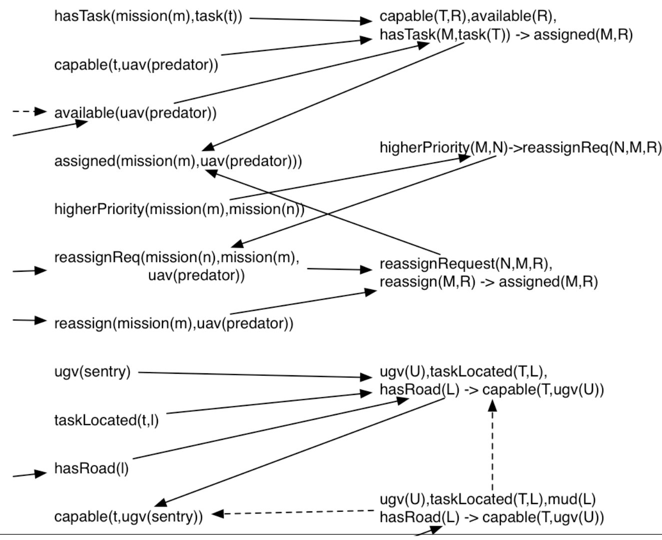
Example Scenario V

- α has two remaining options:
  - Probe HUMINT to check the existence of mud (costly), or
  - Argue mission *m* is more important than the one the UAV is assigned to (cheaper, so yields higher utility)
- α opts to use argument schemes M_1 and M_2 to get the UAV reassigned
- β has no further response; nor does α
- At this point α has "won" iff the opinion on $assigned(mission(m), uav(predator))$ exceeds the threshold for admissible conclusions

36

Example Scenario VI

Part of the resulting argument graph:



37

Conclusion & Future Work

- Cautious optimism for roles of semantic matchmaking and argumentation based on positive feedback from UK MoD and US DoD
- Need to evaluate roles for agent technologies assisting human teams through experimentation
- Links to other work in ITA
  - Role of ontologies in articulating mismatches within coalitions (informational, operational, cultural…)
  - Capturing theoretical limits of network technologies in Sensor Ontology
  - Use of agent mediation to apply security policies
  - … and many more!

38

Thanks to...

- Aberdonians:
  - Mario Gomez & Nir Oren (ITA postdocs)
  - Tim Norman (Aberdeen ITA co-PI)
  - Everyone else in the Aberdeen ITA Team
- ITA collaborators
  - especially Tom La Porta (PSU), Gavin Pearson & Stuart Colley (Dstl), Tien Pham & colleagues (ARL)
- Matthias for inviting me back to CIA :)
- You for listening and for any questions!