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In Network & Information Sciences

The Semantic Battlespace Infosphere: A Knowledge Infrastructure for Improved Coalition Inter-Operability

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Interoperability Challenges

- **Semantic Integration**
  - How can we enable the integration of heterogeneous information content in semantically-coherent ways?
- **Information Exchange**
  - How can we support meaning-preserving modes of information exchange across organizational and cultural boundaries?
- **Shared Understanding**
  - How can we promote a shared understanding of information content in a distributed and culturally heterogeneous coalition environment?
- **Information Exploitation**
  - How can we enable advanced modes of information exploitation that capitalize on the availability of advanced sensor systems and a global information space?
- **Communication & Collaboration**
  - How can we surmount barriers to communication and collaboration, especially in military coalition contexts?
  - How can we deal with a host of cultural and psycho-social issues that may undermine information sharing and mutual trust?
- **Information Representation**
  - How can we develop, use and exploit representational formalisms that serve as an effective vehicle for the communication and manipulation of information content?

– **To what extent is situation awareness important for coalition inter-operability?**

– **Does it merely reflect the outcome of information exchange, communication, collaboration, etc?**

– **How should situation awareness be characterized and analysed in coalition contexts?**

- **Varieties of TSA:**
  - Shared Situation Awareness
    - all team members have same awareness
  - Collective Situation Awareness
    - team members have distinct, but collective, awareness of situation
 - Emergent Situation Awareness
    - team members have limited (any?) individual awareness – awareness is 'ascribed' to team as system

Shared Situation Awareness

Collective Situation Awareness

Situation Picture

Emergent Situation Awareness

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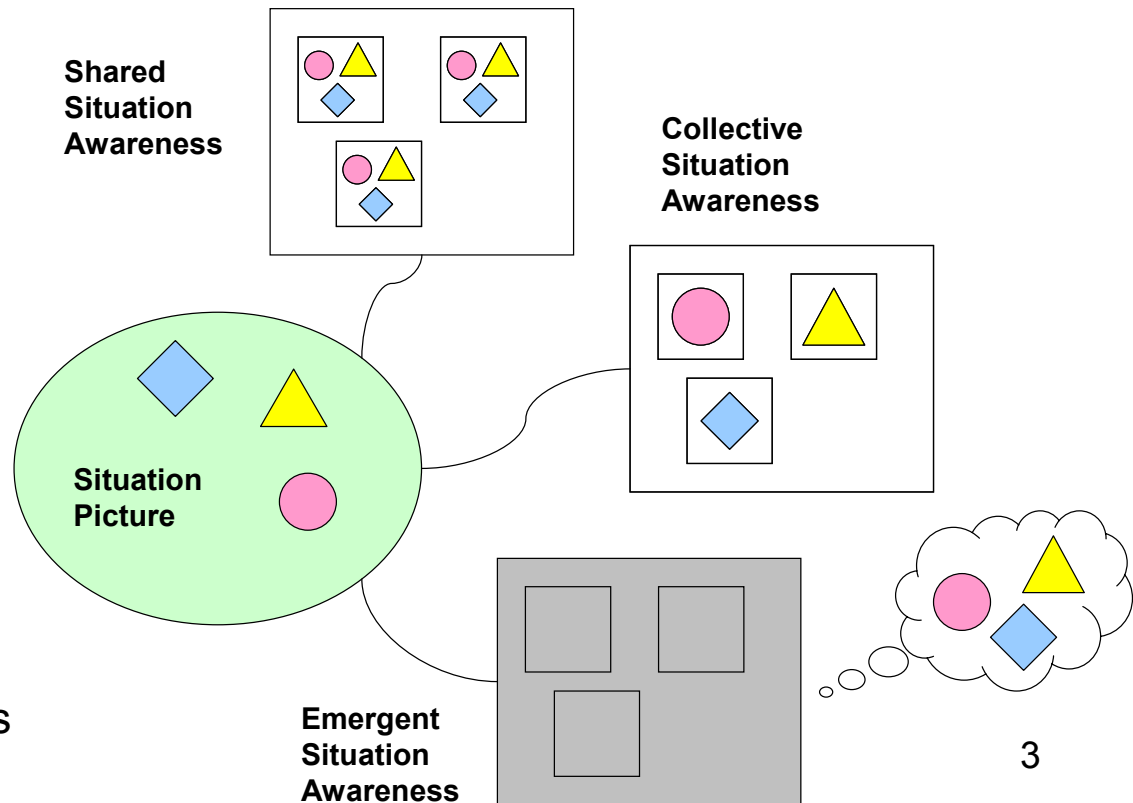
- **Developed as part of Semantic Web initiative**
- **Knowledge representation**
  - RDF/RDFS/OWL
  - semantic expressivity – derived from description logics
  - modelling axioms with accepted meaning permits inference, e.g. transitive closure of 'subClassOf' axiom
- **Query capabilities**
  - SPARQL/RDQL
  - query repositories at semantic level
  - exploit semantic infrastructure of domain
  - requires repositories to expose query interface

- **Reasoning & inference**
  - certain forms of inference supported by representation languages
 - rule languages – SWRL, RIF
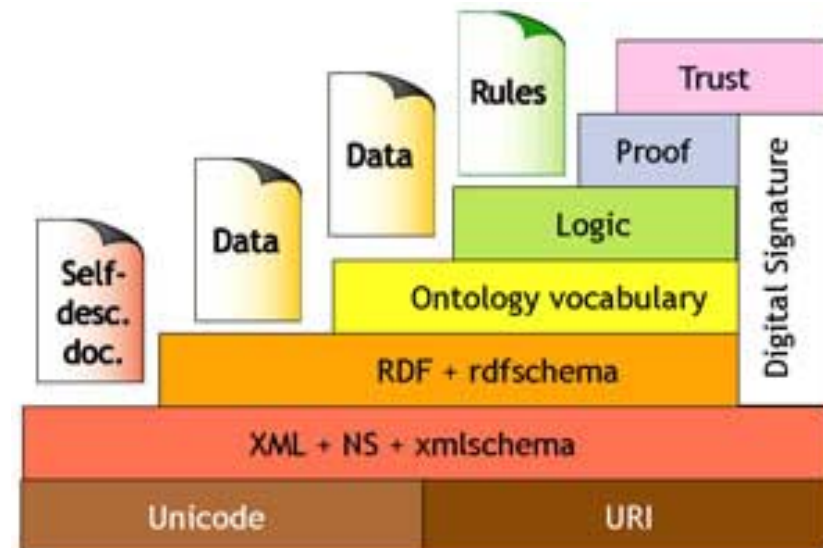
Semantic Battlespace Infosphere

- Semantically-enabled technological framework for improving information exploitation and operational effectiveness in wide variety of military contexts.
- Focus of a number of eDefence research projects:
  - MIMEX, ITA, SEMIOTIKS, AKTiveSA, OntoMediate
- Builds on notion of JBI
  - some similarities:
    - exploits information available in existing C2 systems, but it does not aim to replace them
    - support improved situation awareness based on its ability to integrate (fuse) information from different sources and to make inferences based on environmental data
  - key difference is extent to which semantic technologies, such as ontologies, underpin information representation and processing
- Claim is that coalition capabilities benefit from semantic technologies
 - sufficient, but also necessary?

- **How do semantic extensions to the JBI (and semantic technologies in general) contribute to improved capabilities?**
  - **Ontologies**
    - semantic vs. non-semantic approaches
    - ontologies provide semantic substrate for information integration and aggregation processes
    - provide explicit semantics which may be useful for information exchange between epistemically, culturally and organizationally heterogeneous communities
    - provide coalition-level common language or vocabulary for data elements
    - suited to distributed information environments
  - **Semantic Queries**
    - non-semantic approaches result in queries defined in terms of logical of structural organization of data, e.g. XQuery, SQL
    - heterogeneity of sources means that different queries must be written to match multiple schemas
    - semantic queries exploit conceptual knowledge that is independent of local schemas
    - good mechanism for expressing information requirements

- Collective Representations
    - does sufficient common ground exist in coalition contexts to ensure that a common languages would be accepted - do cultural differences militate against consensual representations?
- Socio-Technical Challenges
    - inter-personal relationships, socio-cultural and organizational factors seem to play a key role key to coalition interoperability – do semantic technologies really help here?
- Network Environment
    - ad hoc wireless mobile networks
    - volatility of query results
        - differential availability of nodes
        - confusing situation picture
        - intelligent caching? epistemic redundancy?
    - similar concerns with reasoning processes
    - information accessibility
        - information not always available
        - data charging approaches?
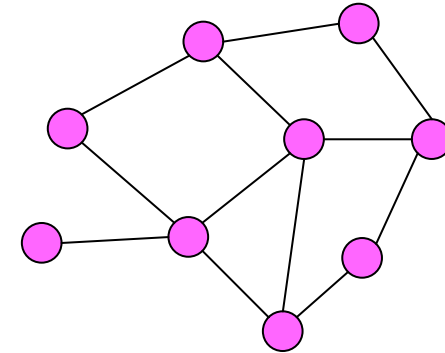
All nodes interconnected.
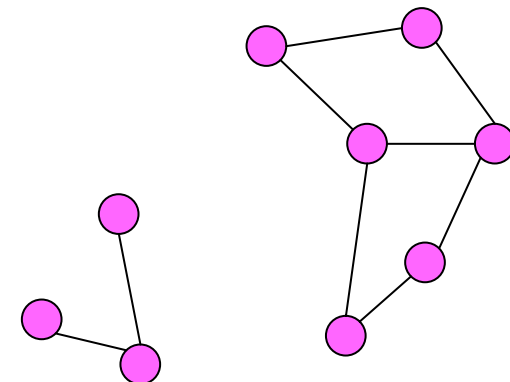
Physical displacement of mobile nodes leads to disruption in connectivity.

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SOME PROBLEMS (2)

- Semantic Technologies
  - reasoning processes must complete within operationally-useful timeframe
  - semantic expressivity is both a boon and a burden:

    "…the semantic expressivity of ontologies, at least OWL ontologies, supports a large number of rule firings following fact assertion. Semantic expressivity is a potential problem here because even a small change to the knowledge infrastructure (i.e. single fact assertion) can have semantically-significant implications, e.g. it may result in computation of the entire taxonomic hierarchy, and this results in extensive bouts of inference execution" – Smart et al, 1997

  - semantic queries may be difficult for users to design in terms of the underlying query language
- Knowledge Capture
  - knowledge acquisition bottleneck has not necessarily disappeared with advent of semantic technologies
- Semantic Integration
  - automated approaches to semantic information integration largely beyond current state-of-the-art
  - requirement for dynamic semantic integration
    - impossible to predict relevant information sources in light of rapidly changing operation commitments
    - information exchange with non-military agencies, e.g. NGOs is operational prerequisite
  - extant semantic integration solutions do not, in general, support information quality assessments

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Project 12:
Semantic Integration and Collaborative Planning

- **Task 1: Semantic Integration & Interoperability**
    - investigate techniques for semantically-mediated integration of information content
    - support coalition inter-operability

- **Task 2: Plan Representation within the Collaborative Planning Model**
    - investigate representational issues associated with the understanding, communication and enactment of coalition plans
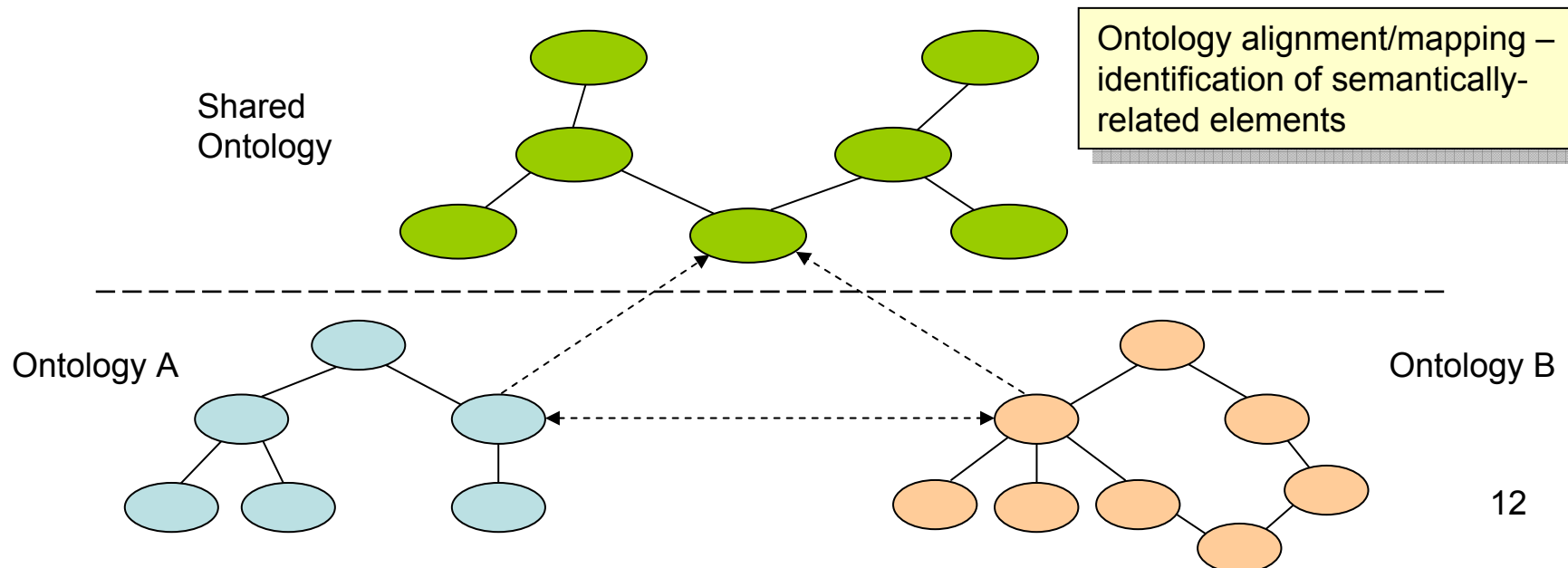   - support collaborative planning and plan execution

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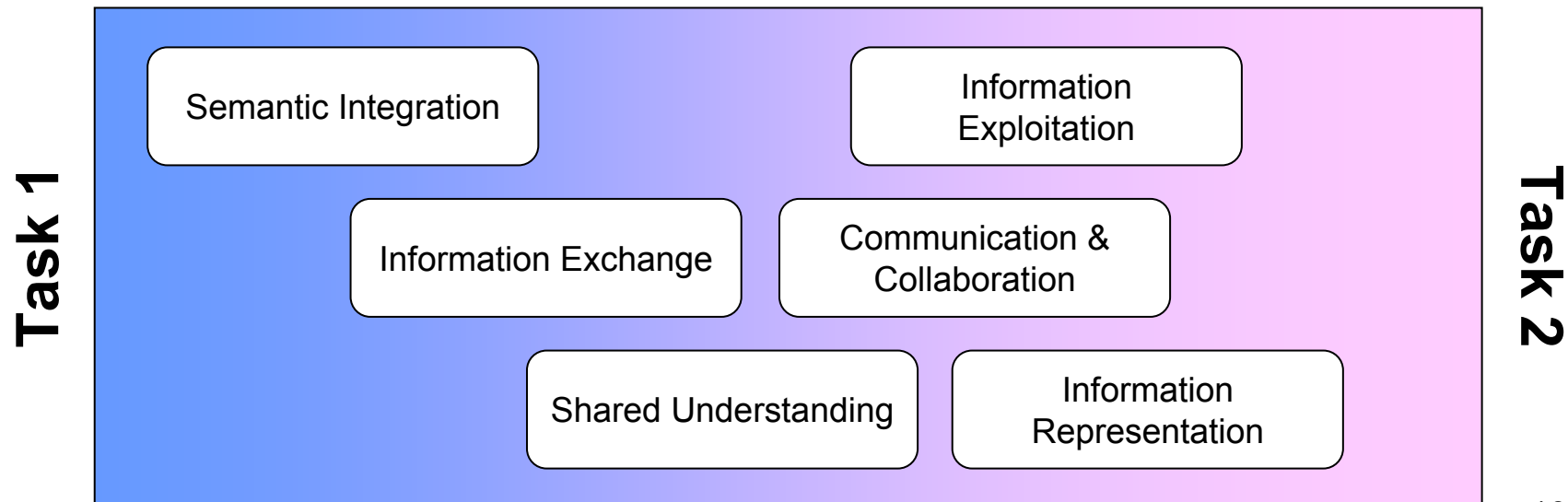
- **semantic integration & inter-operability**
  - improved modes of inter-agent information exchange & communication
  - semantically-sensible transformations of information/data content between the elements of a coalition formation
  - inter-operation between legacy military systems and application
  - exploitation of semantically heterogeneous information sources
  - federated access to a variety of military and non-military information repositories

- **plan representation**
  - improve coalition planning capabilities
  - improve the understanding, communication and acceptance of plans
  - facilitate inter-agent communication of coalition plans within hybrid (human/agent) teams
  - improve trustworthiness of plan solutions by enhancing plan relevance and credibility
  - enhance opportunities for automated plan evaluation/execution
  - improve information aggregation for goal-relevant information processing during the development or execution of coalition plans
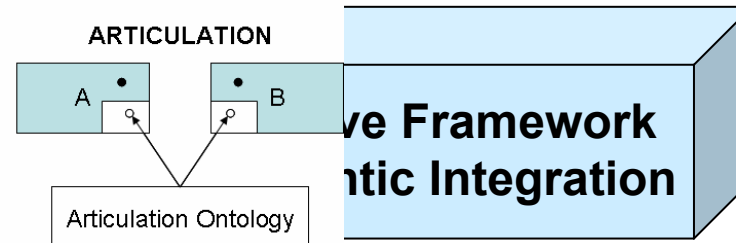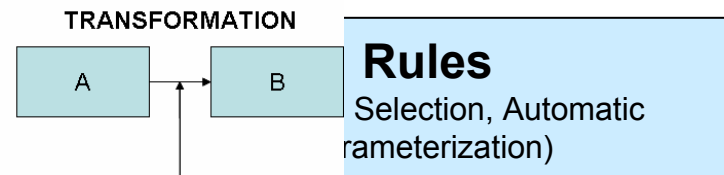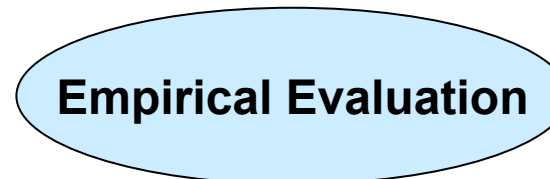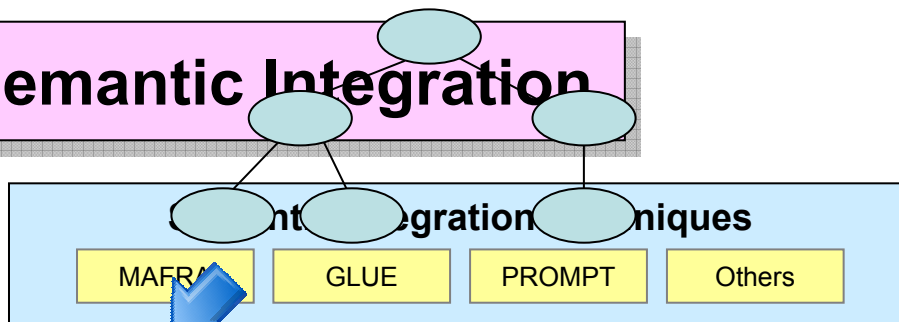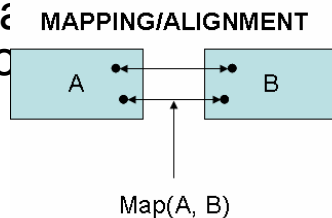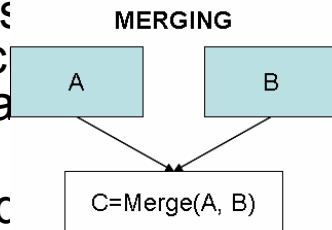
The Semantics of Semantic Integration

- generate a test suite of semantically similar ontologies (used for empirical evaluation)
- develop a representational framework to support the interpretation, evaluation and execution of semantic integration solutions

- evaluate approaches to representing uncertainty, e.g. fuzzy logic, probabilistic extensions to OWL
- extend the representation framework to include support for certainty, trust, provenance, explanations, justifications, etc.

Shared Ontology

Ontology alignment/mapping – identification of semantically-related elements

Ontology A

Ontology B

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A Framework for Adaptive Semantic Integration

- empirical evaluate extant semantic integration techniques using a controlled testing and evaluation framework

- develop an integrative, knowledge-driven framework for the adaptive selection and automatic parameterization of semantic integration techniques

- understand how to combine multiple semantic similarity metrics to improve the accuracy (and efficiency) of semantic solutions

- investigate the tradeoff semantic expressivity representational power semantic integration

Semantic Integration Techniques

| MAFRA | GLUE | PROMPT | Others |

Empirical Evaluation

Rules
(Selection, Automatic Parameterization)

MERGING

| A | B |

C=Merge(A, B)

TRANSFORMATION

| A | B |

T:B=T(A)

MAPPING/ALIGNMENT

| A | B |

Map(A, B)

ARTICULATION

| A | B |

Articulation Ontology

Adaptive Framework Semantic Integration

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Strategies for Enhanced Semantic Integration

- investigate strategies for improving the current state-of-the-art with respect to automated modes of semantic integration
- evaluate novel approaches to semantic integration
  - recursive neural networks
  - structural heuristic methods
- evaluate the importance of upper or mid-level ontologies for semantic integration in coalition contexts
  - provide best-practice ontology development recommendations to facilitate future coalition inter-operability and information integration
  - develop and test the use of an 'upper' ontology for coalition operations

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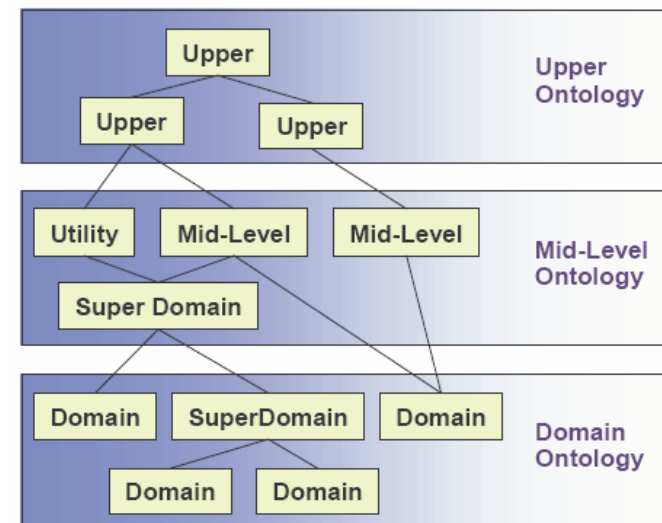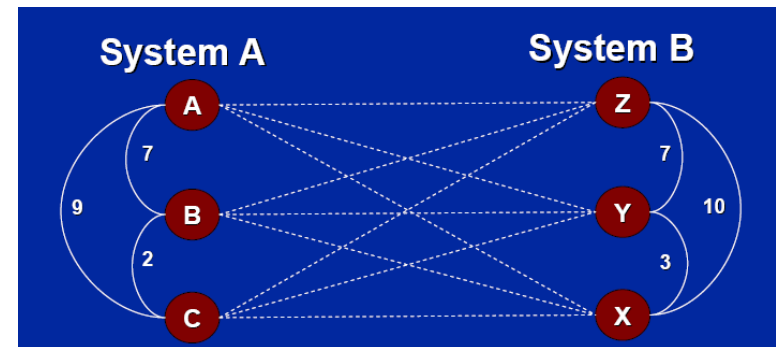
CONCLUSION

- The notion of the SBI provides a vision of how semantic technologies may be used to improve information exploitation and operational effectiveness in coalition military contexts.

- Semantic technologies may assist with some aspects of coalition inter-operability, but significant challenges remain, e.g.
  - knowledge capture
  - the idiosyncrasies of the military network environment
  - semantic technologies themselves

- Some of these challenges are being explored in a number of ongoing research projects.

- Semantic integration emerges as a critical problem-opportunity area for SBI-related research – this will be the focus of our work within the ITA initiative.