# Ontological Approach to the Representation of Military Knowledge

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## *ABSTRACT*

*The answers to commanders' priority intelligence requirements are typically based on a speedy, partial analysis of the information available. The research findings have made a significant progress in certain areas of data interpretation for* ***intelligence analyses*** *which are also referred to as* ***sensor fusion, data fusion and information fusion****. The accuracy and speed of the fusion can be significantly improved by utilizing the knowledge processed at the appropriate level.*

*In this document, the general problem of information provision for decision making is addressed. The most appropriate solution for implementation of a data fusion system, the-multi-agent architecture, is suggested. One multi-agent application related to a specific kind of knowledge, the social knowledge, is outlined, presenting some experience about usability of ontological approach to the representation of military knowledge.*


***Keywords:*** *data fusion, multi-agent architecture, social knowledge, ontology, background knowledge, pragmatic meaning of information*

## 1.0 INTRODUCTION

### 1.1 Command and Control Assessment Challenges

For the purposes of Code of Best Practice (COBP) [1], the term Command and Control (C2) is intended to be an umbrella term that encompasses the concepts, issues, organisations, activities, processes, and systems associated with the NATO definition of C2. Analyst will increasingly be called upon to provide insights into non traditional operations, Operations Other Than War (OOTW), and to work in a new conceptual dimension in order to examine the impact of new information-related capabilities coupled with new ways of organising and operating.

### 1.2 Principles

Three often cited principles of conventional warfare include the need for unity of command, the importance of hierarchical decision making, and the criticality of achieving surprise in operations. The COBP [1] has proposed alternative principles for OOTW. It cites the need for unity of purpose, consensus in decision making, and transparency of operations.

*Paper presented at the RTO IST Symposium on "Military Data and Information Fusion", held in Prague, Czech Republic, 20-22 October 2003, and published in RTO-MP-IST-040.*

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **00 MAR 2004** | **N/A** | **-** |

| 4. TITLE AND SUBTITLE | |
|---|---|
| **Ontological Approach to the Representation of Military Knowledge** | 5a. CONTRACT NUMBER |
| | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**Military Academy in Brno Command and Staff Faculty 612 00 Brno Kounicova 44 CZECH REPUBLIC** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S) |
| | 11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release, distribution unlimited**

13. SUPPLEMENTARY NOTES
**See also ADM001673, RTO-MP-IST-040, Military Data and Information Fusion (La fusion des informations et de données militaires)., The original document contains color images.**

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| **unclassified** | **unclassified** | **unclassified** | **UU** | **30** | |

## 1.3 Analysis

The analysis of C2 remains among the most challenging. In addition, the analyses of OOTW often require consideration of individual behaviour. This has led to the application of "softer" analytic approaches, e.g. extensive reliance of expert elicitations.

## 1.4 Decision Making Process

It is important to have a proper representation of the decision making process to represent information operation effects. Representation of the decision making process, however, remains difficult because of the difficulty in representing human performance, command styles and organisational relationships. As the first step, it seems suitable to address the general problem of information provision for decision making. The question is, what kind of information the observers should communicate to the decision makers? If we have an improvement in decision making through the provision of information, then we consider the information to be of *value*. Improvement of decision can be viewed in the following ways:

1) Improvement in the decision outcome, i.e. an alternative is selected resulting in a better outcome.
2) Improvement in the decision process. Here a decision is considered as improved, not (necessarily) because a new and better alternative is selected, but because the obtained information enables the selection procedure to become more logical, resulting either in a quicker selection or a selection with greater ease and confidence.
3) Through appropriate provisions of information: An improvement may result if decisions can be made delegable to other lower levels of decision makers.

## 1.5 Information

Thus, the information should be represented and handled as a commodity. Information should be considered as a resource that can be collected, processed, and disseminated. Information is rarely valuable in its original form. It usually has to be processed in some way. Typical processing requirements include filtering, correlation, aggregation, disaggregation, and *fusion of information*. These processes can be accomplished by either manual or automated means. The ability, or inability, to properly process information, and the time it takes, can have a direct impact on the combat operational outcome.

## 1.6 Data and Information Fusion Task

At the first level of information processing, we like to use data fusion methods for *object refinement*. In other words, based on the multi-sensor data, we have got our best estimate of the identity of the object or objects out there in the given distance.

Next, we are in need of estimating the position of the objects and constituting entities called *situations*.

Once the situation has been determined, we want to know what the objects are doing, and we are trying to predict their future movement. We call this level of information processing *contextual understanding* and it also involves behavioural questions related to our goal of estimating human intents.

Thus, the objective of Data Fusion (DF) Task, and/or Information Fusion Task, is making decisions on the basis of distributed data sources accessible through a system (organisation). An objective of a DF System is to combine data from many different sources to make decisions.

According to the commonly accepted JDL[1] view [2], Data and/or Information Fusion is a multilevel process comprising several types of tasks:

[1] Joint Directors of Laboratory Data Fusion Model was formulated in 1992

- *Level 0 – Data Producing* – corresponds to the fusion of sensor signals to produce data specifying semantically understandable and interpretable attributes of objects.
- *Level 1 – Object Refinement.* This level is called *Data Fusion*, it aims at processing the above data to make decisions with regard to classes of the objects in question, i.e. the classes of the states of the objects.
- *Level 2 – Situations*. This level is normally called *Information Fusion* and its goal is to assess a *situation* constituted by the set of the above mentioned objects considered as a single whole called *a system* hereafter.
- *Level 3 – Contextual Understanding*. Information Fusion of this level corresponds to an *Impact Assessment*, which means, for example, adversary intent assessment produced on the basis of the situation development prediction.
- *Level 4 – The Feedback* – assumes calculation of a feedback, like planning resource usage, sensor management, etc.
- *Level 5 – Situation Management* – the upper level, involves human activity and situation management.

## 1.7 Communication

Any DF, or Information Fusion System, is inherently distributed. Information has a specific source, and that source is usually not the end user of the information. A requirement exists, therefore, to move information from one place to another in the operational environment. Communication systems of all forms exist to accomplish this movement.

The classical theory[2] differentiates three conceptual levels of communication:

1) *Syntactic level* which is concerned with the rules for building up sentences. At the syntactic level, we solve a technical problem: how accurately the symbols used in communications can be transmitted.
2) *Semantic level* which examines the meaning of signs in relation to the represented objects or actions. At the semantic level, we solve a representation problem: how intelligibly do the transmitted signs represent the intended message, and, how precisely the transmitted symbols convey the desired meaning.
3) *Pragmatic level* which features how the senders and receivers evaluate and understand the meaning including psychological impact, action consequences, etc. At the pragmatic level, we solve an efficiency problem: how efficiently the received message influences the behaviour of the receiver, or, more precisely, how effectively the received meaning affects the conduct in the desired way.

There is a close relation between these levels and the semiotic distinctions:

1) *Syntax* and the forms of language
2) *Semantics* and the meanings of language
3) *Pragmatics* and the use or function of the language

The first two levels of information processing, according to the JDL schema, produce estimates about the states of single (physical) objects. Estimates about more abstract entities called "situations", contextual understanding, feedback calculations, situation management and human intent estimating, are, in general,

[2] Shannon's Mathematical Theory of Communication and Warren Weaver's three levels of problems in communication (1949)

supposed to take knowledge from human experts as a line of reasoning that accurately reflects the way a military analyst would look at something.

Thus, according to the JDL schema, we are concerned:

1) with syntactic aspects of information at the Level 0
2) with syntactic and semantic aspects of information at the Level 1 and higher
3) with syntactic, semantic, and also pragmatic aspects of information at the Level 2 and higher

### 1.8 Pragmatic and Contextual Meaning of Information

The classical theory mentioned above is concerned with the syntactic level only, it is not at all concerned with the pragmatic aspects of information.

Attempts to raise the theory to the semantic level have been made by J. L. Austin in his work about *speech act theory*.[3] A need for the development of a pragmatic theory of information still exists.

## 2.0 MULTI-AGENT ARCHITECTURE OF DATA FUSION

For the design and implementation of a DF system, the most advantageous strategy is the strategy using a multi-level hierarchy of classifiers. The source based classifiers make decisions on the basis of data of particular sources followed by the meta-level decision making based on combining the source-level decisions. The advantages of such a scheme are

1) decrease of the data source information exchange
2) simplicity of data source classifier fusion even if they use data of different representation structure, certainty, accuracy, etc.
3) possibility to use mathematically sound mechanisms for combining decisions of multiple classifiers.

In some applications, this strategy is the only applicable one. For example, a group of applications in which the data are private and the data holders do not want to share the data, but agree to share decisions produced on the basis of such data sources.

### 2.1 Peculiarities of Data and Data Processing in DF Task

The first problem is the development of the shared thesaurus providing for *mono semantic understanding* of the terminology used in formal specification of domain entities. According to the modern understanding, it is necessary to use a meta-model of data and knowledge presented in terms of *ontology* and shared by all entities of the DF System. The structure of ontology used is depicted in Fig.1. It comprises the domain, problem ontology together with task ontology and also with the application ontology. The application ontology comprises two types of components of the DF system: a part of application ontology that is shared by all components of DF system and parts of the application ontology that are private for particular data source. It seems reasonable, at least in theory, to have a unified top-level ontology for large communities of users. Domain ontology and task ontology describe the vocabulary related to a generic domain and/or a generic task activity by specializing the terms introduced in the top-

[3] John Langshaw Austin's 1955 lectures were published posthumously under the title of *How to Do Things with Words* [7]. The basic idea is concerned with the provision of a measure of semantic information content of simple declarative sentences in a defined language system. Knowledge Communication Meta Language (KQML) was one of the earliest attempts to construct a communication language based on the speech act theory. The Agent Communication Language (ACL) represents a version of KQML which is more precisely defined. There is a standard version of ACL written in XML and sponsored by FIPA.

level ontology. Application ontology describes concepts depending both on a particular domain and task, which are often specializations of both the related ontologies.[4] These concepts often correspond to the roles played by domain entities while performing a certain activity.

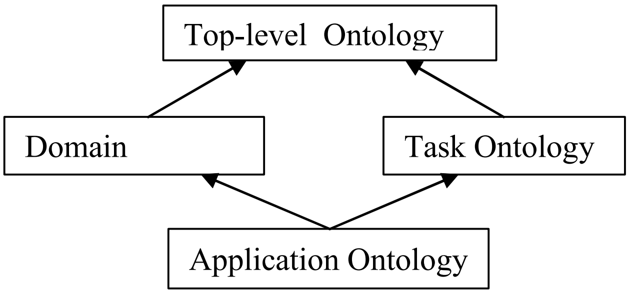


**Figure 1: The Structure of Ontology.**

The second problem corresponds to the *entity identification problem*. The data specifying an object may be represented in different data sources. This is why each local data source only partially specifies the above mentioned objects. Its complete specification is made up of data fragments distributed through the data sources. Therefore, to form a complete object specification, a mechanism to identify such fragments is needed. It should be noticed that some fragments of data associated with an object can be absent in a number of sources.

## 2.2 Combining Decisions of Multiple Classifiers

In the most DF tasks, decision is understood as classification of an entity (e.g. object, state of an object, situation), that is, assigning the entity a class label from a fixed set. Each local data source is associated with a single or several classifiers. Each of them produces classification of an entity using only local data or local data fragments and then transmits the classification produced to meta-level, where these classifications are combined by meta-level classifier(s) using an appropriate method.

## 2.3 Implementation of a DF System

To implement the above described conception, multi-agent architecture is the most appropriate solution for the desired DF system.

The developed architecture of DF software consists of two kinds of components:

1) the component responsible for the design of source based parts of the desired DF system
2) the component supporting iterative and interactive designs of the meta-level part of the desired DF system

Both of them present allocation of a particular task through agents. The source based component includes data source managing agent and local classification agents of a DF system. The meta-level component includes an agent-classifier of a meta-level which receives decisions from local source based agents of the DF system, and via the semantic processing of input messages produces a top-level decision. The selection

[4] It may be important to make clear the difference between an ontology and a knowledge base. Ontology is a particular knowledge base, describing facts assumed to be always true by a community of users. Within a generic knowledge base, we can therefore distinguish two components: the ontology, containing state-independent information, and the core knowledge base, containing state-dependent information.

of scenario depends on the input and inner state of the agent. In turn, inner agent's state depends on the prehistory of the agent's operations. This prehistory is reflected in the state of agent's knowledge base.

Design and implementation issues of such a DF system are proposed in [3].[5]

## 3.0 SOCIAL KNOWLEDGE IN MULTI-AGENT SYSTEM

Any DF system deals with distributed data sources and executes distributed or decentralized data processing. Decision about decisions from local sources is produced by meta-level agent. The base-level and the meta-level agents interact during solving a DF task. Both the idea of advancing decision to reasoning and the usability of the multi-agent system for Information Fusion seem suitable.

A multi-agent system (MAS) usually consists of a set of autonomous units capable of:

1) independent operations aimed at meeting their *local goals*
2) cooperative actions contributing jointly to the *global goal* shared across the community.

The agents' abilities to communicate, mutually coordinate their actions, cooperate and share the global goals determine the level of their integration oriented behaviour. These abilities depend mainly on the extent and quality of knowledge available to the agents. Knowledge, a true piece of evidence in which the agent believes, can either

1) guide the agent's autonomous local decision making processes, aimed e.g. at providing an expertise or search in the agent's database; this is what we call agent's problem solving knowledge, or
2) express the other agents' behavioural patterns, their capabilities, working loads, experience, commitments, knowledge describing conversations or negotiation scenarios, which we will refer to later as *social knowledge*.

Let us outline one application related to this specific kind of knowledge.

### 3.1 CPlanT Multi-Agent System

This part will describe the CPlanT multi-agent system that has been implemented for planning the OOTW coalition.[6] [4] The further specified principles and ideas have been tested and implemented on humanitarian relief (HR) operations which are a subset of the OOTW types of operations. A hypothetical humanitarian scenario has been designed and implemented for this purpose.[7]

Unlike in classical war operations, where the technology of control is strictly hierarchical, OOTW are very likely to be based on the cooperation of a number of different, vaguely organized groups of people, such as non-governmental organizations (NGOs) providing humanitarian aid, but also of army troops and official governmental initiatives.

Unlike hierarchical approach, collaborative approach to the operation planning allows greater deal of flexibility and dynamics in grouping optimal parties playing active roles in the operation. The main reason

5 This research was supported by grant of AFRL/IF-European Office of Aerospace Research and Development (Project 1993P)

6 This project was supported by AFOSR/European Office of Aerospace Research and Development under contract number F61775-00-WE043.

7 The scenario has been encoded in the XML files and the computational model of the scenario has been implemented in Allegro Common Lisp. While the inter-agent communication is FIPA compliant, each agent in CPlanT is a stand-alone application, and the agents communicate via TCP/IP connection.

why we can hardly plan operations involving different NGOs by a central authority results from their reluctance to provide information about their intentions, goals and resources. Actual information may become unavailable also due to unreliable communication channels. It may happen that a collaborative entity gets cut off the communication links for a certain period of time and the rest of the community still wishes to be able to form/execute plans relying upon the missing player. For this reason, each participating entity should be able to maintain approximate model of the collaborating members of the coalition.

For the above described OOTW, *the multi-agent community* denotes the whole collection of participating agents. A *coalition* is a set of agents who agreed to fulfil a single, well specified goal. An agent may participate in multiple coalitions. A process of *coalition planning* will be understood as an agent's reasoning about possible candidate for membership in the planned coalition. *Coalition formation* is the process of reaching an agreement among candidates for membership in a planed coalition. Unlike in classical coalition formation problems, the quality of coalition in OOTW is not given only by the function of different utilities, such as a task completion time or the number of collaborating agents, but also by the amount of private information that the agents had to reveal.

There are three levels of agent's knowledge representation suggested:

1) *Public Knowledge* is shared within the entire multi-agent community. This class of knowledge is freely accessible within a community. As public knowledge we understand agents name, type of the organization the agent represents, general objective of the agent's activity, country where the agent is registered, agent's human-human contact (fax number).
2) *Alliance Accessible Knowledge* is shared within a specific alliance. We do not assume the knowledge to be shared within the overlapping alliances. Members of an alliance will primarily share information about free availability of their resources and respective positions. This resource oriented type of knowledge may be further distinguished as material resources, human resources and transport resources.
3) *Private Knowledge* is owned and administered by the agent himself. The agent, provided he finds it useful, may communicate some pieces of the private information upon a request. As an instance of private knowledge we can consider mainly specific status of the resources the agent administers, future plans and allocations of resources, his past performance, agent's collaboration preferences and restrictions, and agent's planning and scheduling algorithms.

## 3.2 Acquaintance Model

Models containing social knowledge are usually called *acquaintance models*. An acquaintance model is a knowledge based model of agent's mutual awareness that summarizes the agent's knowledge about his collaborators and about suitable communication and negotiation scenarios. An acquaintance model is meant to maintain permanent, semi-permanent and non-permanent information about other agent's services, knowledge, statuses, about potential negotiation scenarios, delegation principles etc. It is required that the acquaintance model will also contain certain knowledge about its own knowledge, status and intended activities which is usually referred to as agent's self-knowledge. The corresponding part of this knowledge can be accessible to the collaborating agents and they maintain it in an identical form.

A specific methodology for organization and administration of agent's mutual awareness is known as the *tri-base acquaintance model (3bA)*. The most important virtue of the 3bA is the absence of a central element. If an agent in the community dies or gets overloaded, the system is expected to reorganize itself in order to solve its tasks anyway.

### 3.3 Knowledge Structures of the Acquaintance Model

Within the tri-base model, each agent maintains three knowledge bases where all the relevant information about the rest of the community is stored.

1) *Co-operator Base (CB)* maintains permanent information of co-operating agents, i.e. their addresses, communication languages, their predefined responsibility. This type of knowledge is expected to be changed rather rarely.

2) *Task Base (TB)* stores in its *Problem Section (PRS)* general problem solving knowledge – information about possible decompositions of the tasks to be solved by the agent, and in its *Plan Section (PLS*) the agent maintains the actual and most up-to-date plans on how to carry out those tasks.

3) *State Base (SB)* has two parts, the *Agent Section (AS)* and the *Task Section (TS).*

The agent *A* stores in his AS all relevant information characterizing the present state of the relevant part of the system, e.g. the current load of cooperating agents. This part of the state base is updated frequently and informs the agent who is busy, who is available for collaboration and makes the agent possible to evaluate what conditions hold at present. A sophisticated agent can include here very complex knowledge including knowledge about himself.

A slightly redefined tri-base model has been designed for planning peacekeeping operations. The co-operator base, as the community belief-base, stores public information about all the community members. The task base keeps possible coalition with respect to a particular task. The state-base has been split into two bases: social-belief base, where non-permanent information about the alliance members is stored, and the self-belief base, where the alliance accessible information of the agent himself is stored and offered to the other alliance members. All three types of knowledge – private knowledge, alliance accessible knowledge and public knowledge may be stored in a single knowledge structure.

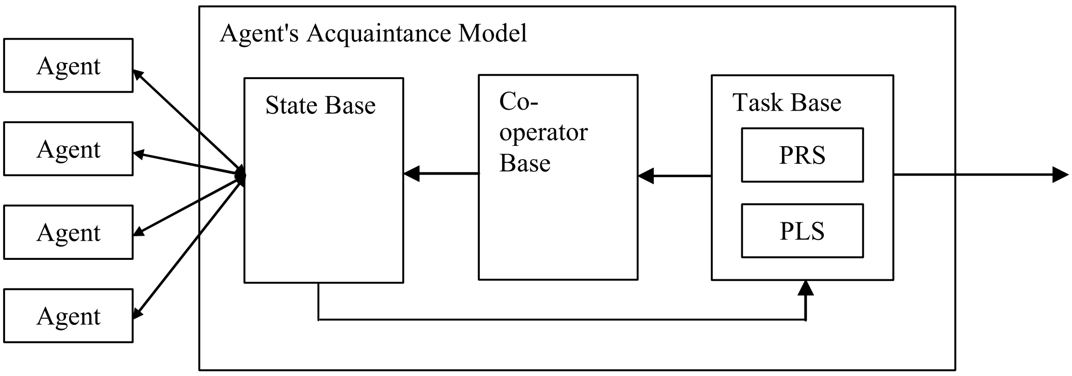


**Figure 2: Tri-Base Acquaintance Model.**

### 3.4 Generation of Plans

Suppose that the agent *A* is in charge of a task *T*. The agent can either

1) use an existing plan stored in the plan section PLS of his task base, or

2) generate a new plan using his own knowledge and inference mechanisms.

In the latter case the agent *A* takes problem knowledge found in the problem section PRS of his task base. There can exist several rules in PRS the conditions of which are met. A good choice has to be supported by appropriate techniques of conflict resolution. The plan with the highest *trust* is viewed as the actual plan. Whenever the contents of the agent section of the state base gets updated, the *trust* is to be recomputed and each of the rules is to be re-evaluated. This kind of activity makes the plan the most up-to-date.

## 3.5 Knowledge Improvement

Besides knowledge maintenance, which keeps the knowledge in the state base up-to-date, the 3bA concept allows knowledge to be improved as well. There are two ways how to implement permanent knowledge improvement:

### 3.5.1 Object Level Knowledge Improvement

Object level knowledge improvement is based on agent's ability and responsibility to optimise, reorganize, deduce new pieces of knowledge and improve the knowledge stored. Object level knowledge improvement is primarily implemented by machine learning techniques that allow the agent mainly to find specific patterns of inter-agent communication, produce generalization, etc. Alternatively, the agent may be equipped with meta-reasoning (reasoning about other agents) capabilities and with explicit knowledge how the pieces of state base knowledge may be put together and new knowledge formed.

### 3.5.2 Meta-Level Knowledge Improvement

Meta-level knowledge improvement is not carried out directly by the agent owning the knowledge. Improvement and knowledge revision is provided by an independent meta-agent, who observes activities of the community, collects relevant pieces of information and tries to draw certain assumptions about the individual agent's behaviour. Meta-agent can meta-reason and learn how to enhance the community efficiency and he is able to provide advice to the agents.

In the next part it will be explained how the concept of meta-reasoning can contribute to improvement of the 3bA knowledge.

## 3.6 Meta-Reasoning and Reflectivity in Multi-Agent System

Let us consider a computational system capable of certain class of decision making, for example, language translation. The system will carry out computation in order to perform behaviour that will meet its designed objective. Such a computation is regarded as primary reasoning (object level reasoning). If we require this computational system to be reflective, it needs to be able to reason about itself.

A reflective system consists of

1) object component (object agent)
2) reflective component (meta-agent(s))

Reflective reasoning allows the system

1) to analyse and learn from its past course of decision making (*learning*)
2) to detect inconsistence in manipulated knowledge (*reality check*)
3) to suggest efficiency improvements in the respective problem solving (*adaptation*).

A reflective multi-agent system should contain either a single meta-agent, or a collection of meta-agents who are capable of reasoning about other agents who carry out the primary decision making:

1) about their knowledge
2) about their reasoning process.

The meta-agents individually or collectively constitute a *reflective component* of the multi-agent system. The multi-agent system performs reflective reasoning, reasoning about itself, by *meta-reasoning* carried out by meta-agents. Meta-reasoning in a 3bA model can be considered as a form of *social reasoning*.

If we understand meta-reasoning as to be reasoning about reasoning, meta-reasoning is not only useful for implementation of reflection. The idea of meta-reasoning extends the concept of the 3bA model twofold:

1) Assumed Belief. An agent can update a record in his state base not only by being told. Due to the content of his state base, the agent can reason about other agents to analyse their behaviour and to predict future course of actions. This capability will upgrade agent's social intelligence.
2) Patterns of Community Interactions. Sometimes it is impossible to detect interesting patterns of community interactions from the single agent's point of view. This is true mainly due to the fact that the agents have usually their organizational roles and cannot monitor or even understand the whole of the community.

## 4.0 ONTOLOGICAL APPROACH TO KNOWLEDGE REPRESENTATION

As a basis for cooperation, the capability of cooperative agents' actions assumes the communication across the multi-agent community. The communication among different agents is therefore an important aspect of multi-agent systems.

Agents do not have a direct access to each other but they can request services by sending messages. For the agents, the act of communication denotes the activity of sending some information from a sender to a set of (intended) receivers. An advantage of this approach is that one can get loosely coupled open systems that only use message passing as a vehicle for collaboration. The use of ontologies in message exchange communication gives meaning to the contents of messages sent between the agents.

### 4.1 Message Content Ontology

*Message Content Ontology* is a technology to support inter-agent communication by providing a definition of the world on which an agent can ground his beliefs and actions, as well as by providing terms that can be used in communication. Thus, a message content ontology helps agents to describe facts, beliefs, hypotheses and predications about a domain.

### 4.2 Agent Communication

The most appropriate model of agent communication seems to be the abstract communication model of FIPA[8] derived from the speech act theory. In this model, communication occurs through the exchange of asynchronous messages corresponding to communicative acts. The Agent Communication Language (ACL) defines format of these messages. Within a message, elements in the world are defined in a domain ontology. A content language expression is used to represent the content of the message. Finally, a speech act as the agent's intention to describe or alter the world is wrapped around.

[8] FIPA, The Foundation of Intelligent Physical Agents, is a non-profit organisation aimed at producing standards for the interoperation of heterogeneous software agents.

(See the example given [9])

In order to preserve agent autonomy as much as possible, the FIPA communication model is based only on the speech act as the communication idea. For the agents to be able to reason about the effects of their communications, ACL messages could be inserted into proper Agent Interaction Protocol (AIP) which describes communication patterns as allowed sequences between agents and the constraints on the content of those messages.[10] [5]

### 4.3 Background Knowledge as Context

This type of knowledge has been called *real world knowledge*. What is usually meant is the knowledge the conversation participants might deduce that the others had before, or independently of, a particular conversation, by *virtue of a membership in a community*. Each community implies certain types of knowledge which might be shared with other members and which the listener must deduce in the course of the interaction.

(See an example given [11])

### 4.4 Ontology as Background Knowledge

Ontology might be built which could quickly reveal the extent to which a human readers make inferences to gain an understanding of a message context. Those inferences are often based on background knowledge. Various forms of knowledge representation have been proposed to model this background information.

Implementation of the background knowledge as ontology in appropriate knowledge structure should significantly decrease the traffic across the agent community.

[9] The ACL message shows an example in which agent Peter informs agent John that today it is raining. Domain ontology is 'Weather-ontology', language is English, content language expression is 'today it is raining', and speech act is 'INFORM':

<fipa-message act="INFORM">
<agent-identifier>
<sender>
<.name id=Peter@host1:8888/JADE/>
</sender>
<receiver>
<.name id=John@host1:8888/JADE/>
</receiver>
</agent-identifier>
<content>today it is raining</content>
<language>English</language>
<ontology>Weather-ontology</ontology>
<.conversation-id>Peter-John253781</conversation-id>
</fipa-message>

[10] CPlanT multi agent system for planning humanitarian relief operations uses classical negotiation algorithms such as Contract Net Protocol (CNP)

[11] The following example demonstrates how the cultural knowledge is the basis for the inference:

*A*: Come over next week for lunch.
*B*: It is Ramadan.
If *A* and *B* are Muslims then *A* will probably infer that *B*'s reply means *No*

## CONCLUSIONS

In this document, the general problem of information provision for decision making process is dealt with, focusing on the typical processing requirements including fusion of information. Since any data or fusion information system deals with distributed data sources, the multi-agent paradigm was mentioned as a challenging framework for solving very complex tasks in a distributed way. The CPlanT multi-agent system was outlined as being intended for the OOTW coalition with collaborative approach to operation planning.

In virtue of the fact that the quality of coordination, cooperation and functional integration in multi-agent systems depends strongly upon the knowledge explored, a specific part of knowledge called *social knowledge* was described, as well as the models containing this kind of knowledge, acquaintance models, enabling to perform 'reasoning about reasoning' that allows agent to analyse behaviour and to predict future course of actions as a form of social reasoning.

Because the capability of cooperative agents' actions assumes the communication across the multi-agent community, the message content ontology was mentioned as a technology supporting inter-agent communication, as well as the background knowledge the implementation of which as ontology structure allows message context understanding.

It may be important to suggest that ontologies traditionally reside within the field of knowledge organization. The *sharing of ontologies* between diverse communities allows them to compare their own information structures with other communities that share a common terminology and semantics. *Information Flow* provides a foundation for the sharing of ontologies in a distributed setting. For more detailed discussion, see [6].

Successful and effective communication is heavily reliant on the capability of agents to communicate not only data and information, but knowledge as well, and calls for information sharing on all levels – syntactic, semantic and pragmatic. The pragmatic aspect of communication among agents focuses on two basic spheres:

1) the knowledge which agent to address, and how to locate that agent in question
2) the knowledge how to initiate and maintain the communication.

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Research &Technology Organisation Symposium on Military Data and Information Fusion

Prague, Czech Republic, 20 – 22 October 2003

# Ontological Approach to the Representation of Military Knowledge

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# C2 Assessment Challenges

- insights into non traditional operations
- consensus in decision making
- application of "softer" analytic approaches
- information operation effects

# Decision Making Process

- information provision for decision making
- improvement of the decision:
  - in the decision outcome
  - in the decision process
  - through appropriate provision of information

# Data and Information Fusion Task

- multilevel process comprising:
  - Level 0 – Data Producing
  - Level 1 – Object Refinement
  - Level 2 – Situations
  - Level 3 – Contextual Understanding
  - Level 4 – Feedback
  - Level 5 – Situation Management

# Communication

- three conceptual levels of communication:
  - syntactic level - a technical problem
  - semantic level - a representation problem
  - pragmatic level - an efficiency problem

# Design of a DF system

- strategy using a multi-level hierarchy of classifiers:
  - source based classifiers
  - meta-level decision making

# Data Processing in a DF Task

- mono semantic understanding
  - application ontology
  - domain ontology
  - task ontology
  - top-level ontology
- entity identification problem

# Multi-Agent Architecture of DF

- source based component
  - data source managing agent
  - local classification agents
- meta-level component
  - meta-level classification agent

# CPlanT Multi-Agent System

- for the OOTW coalition planning
- based on the cooperation of members
- collaborative approach to the operation planning
- multi-agent community:
  - whole collection of participating agents

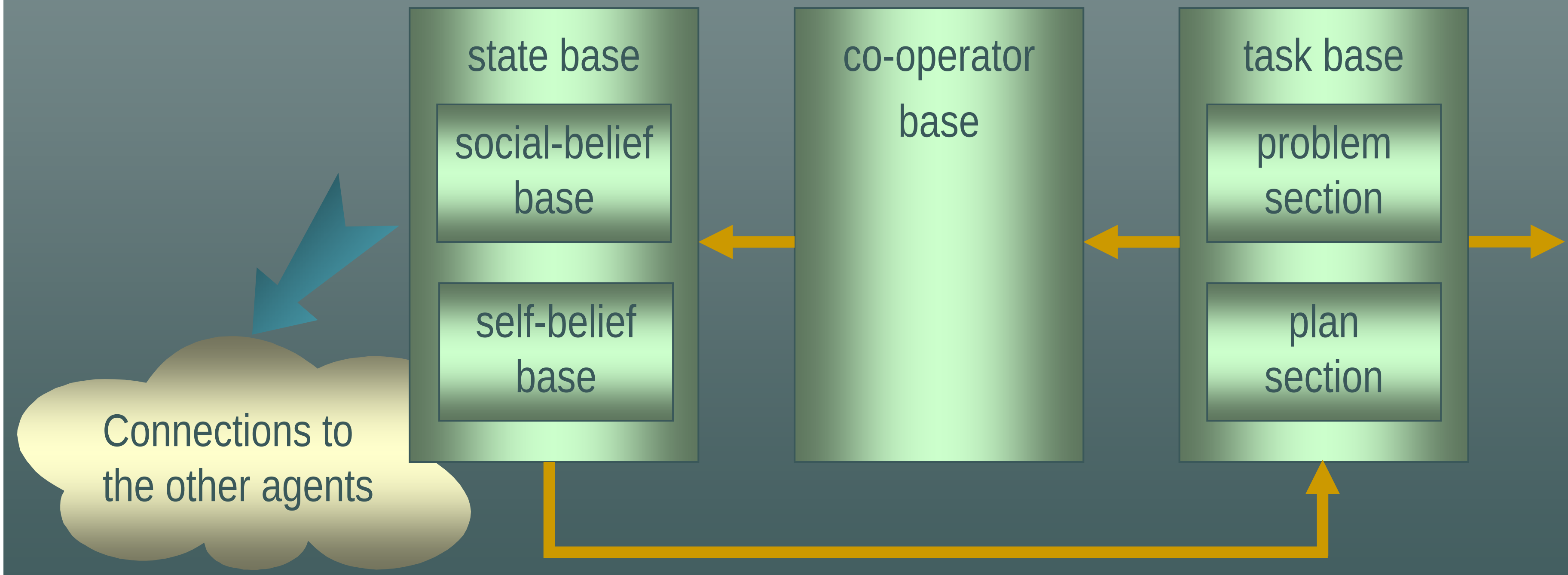
# Types of Knowledge

- meeting goal aspect:
  - problem solving knowledge
  - social knowledge
- providing information aspect:
  - public knowledge
  - alliance accessible knowledge
  - private knowledge

# Tri-Base Acquaintance Model

- knowledge structures:
  - co-operator base
  - task base
    - problem section
    - plan section
  - state base
    - agent section
    - task section

# Tri-Base Acquaintance Model(2)



# Tri-Base Knowledge Maintenance

- generation of plans
- knowledge improvement
  - object level
  - meta-level
- meta-reasoning and reflectivity
  - assumed belief
  - patterns of community interactions

# Knowledge Representation

- ontological approach:
  - message content ontology
    - to support inter-agent communication by providing terms
  - background knowledge ontology
    - message context understanding

# Conclusions

- multi-agent architecture
  - framework for solving very complex tasks in a distributed way
- social knowledge
  - for the quality of coordination, cooperation and functional integration
- ontologies within the knowledge organisation
  - the pragmatic aspect of communication

# End of presentation