TACTICAL INFORMATION ABSTRACTION FRAMEWORK IN MARITIME COMMAND AND CONTROL

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1. SUMMARY

Various operational trends in naval warfare put the shipboard decision making process under pressure. As an example, there is a continuous advance in threat technology and an ongoing shift to crisis management scenario's in littoral waters. Data must be processed under time-critical conditions and, as a consequence, the risk of saturation in building a tactical picture increases.

In this complex context, the decision-makers need to gain a cognitive awareness of what is going on in their environment, by constructing a hierarchical situation model of this environment. This situation model consists of the basic elements present in the environment, relevant for understanding the situation. Furthermore, this situation model consists of combinations of interrelated elements, spatial and temporal structures, and abstractions expressing the situation at a functional and intentional level. Given our problem domain, maritime command and control, we will call this language according to which the situation model can be structured *Tactical Information Abstraction Framework* (TIAF).

The purpose of this paper is to derive and describe a maritime TIAF. This TIAF can be used as a language in which the result of data fusion can be expressed. If we are able to use a TIAF, according to which situation awareness can be structured, in the data fusion process, we can make a smooth match of this process with a situation awareness framework. Thus we will be able to integrate the human element into the design of a decision support system aiding the operators to achieve the appropriate situation awareness.

2. INTRODUCTION

At the heart of a shipboard combat system is a command and control system (CCS) by which the command team can plan, direct, control and monitor any operation for which it is responsible, to defend the ship and fulfil their mission. The increasing tempo and diversity of open-ocean and littoral scenarios, the technological advances in threat technology and the volume and imperfect nature of the data to be processed under time-critical conditions pose significant challenges for future shipboard CCS. Moreover, the ongoing shift to littoral warfare does also have a major impact on the maritime command and control process. In littoral areas, there generally is more commercial air traffic and more merchant shipping, potential threats can be multiple, with a high degree of uncertainty and only detectable at short ranges. As a consequence, due to saturation and high levels of uncertainty in the compilation of the tactical picture, the risks of taking wrong or inappropriate decisions increases.

This emphasises the need for warships to be fitted with an efficient combat system featuring a real-time, joint human-machine decision support system (DSS) integrated into the ship's CCS. This DSS consists in the combination of a multi-source data fusion (MSDF) capability, a situation and threat assessment (STA) capability, and a resource management (RM) capability (managing the ship's resources such weapons, sensors and communication means but also managing the ship's course and speed). These capabilities intimately match the four levels of the JDL (Joint Directors of Laboratories) data fusion model. One of the main roles of such a real-time DSS is to aid the operators to achieve the appropriate *situation awareness (SA)* state for their tactical decision-making activities, and to support the execution of the resulting actions.

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The Decision Support Technologies Section at the Defence Research Establishment Valcartier (DREV, Canada) and the Maritime Command and Control group of the Physics and Electronics Laboratory of the Netherlands Organization of Applied Scientific Research (TNO-FEL, The Netherlands) are conducting research and development (R&D) activities in the field of decision support for Maritime Command and Control at the shipboard level. Investigations have been undertaken to study the concepts and design of a real-time DSS for their respective frigate in order to improve its performance against current and future threats. The Information Processing department of the TNO Human Factors Research Institute (TNO-TM, The Netherlands) is conducting research in the field of human-machine interface design for operations rooms and command information centres based on the analysis and modelling of C2 tasks and functions.

In view of the overlapping interest in studying and comparing applicability and performance of advanced state-of-the-art of Maritime Command and Control concepts and techniques, the research establishments involved have decided to join their efforts in conducting research in the area of Maritime command and control. By joining their efforts, Canada and The Netherlands are mutually increasing their potential for exploring a wider range of design philosophies, as well as the opportunity to benefit from participants previous experiences and lessons learned.

This paper presents a brief overview of one of these collaborative efforts which is focused at deriving a *Tactical Information Abstraction Framework* (TIAF) taking into consideration situation awareness concepts. *Situation awareness* is essential for commanders and their staff to conduct decision-making activities. *Data Fusion* is seen as an essential process to enable operators to achieve situation awareness. This purpose of the Data Fusion process can be served if the derived TIAF can be used as a language to express the situation awareness. It must be noted that the term Data Fusion does not only include the fusion of sensor data but also fusions at higher levels of abstraction (information integration).

This paper is organised as follows. Section 3 provides background information on the command and control (C2) process and the role of a decision support system in this process. Data Fusion and the role of situation awareness in dynamic human decision-making are also presented in this section. Section 4 motivates the need for a Tactical Information Abstraction Framework and proposes and exemplifies one. In Section 5 some issues related to data fusion system design are highlighted. Section 6 provides conclusions and recommendations, and discusses future work.

3. BACKGROUND

3.1 Command and Control Process

Command and control (C2) is the process by which the command team can plan, direct, control and monitor any operation for which they are responsible. In a naval context, most tactical decisions taken within the ship's operations room are made through a number of perceptual, procedural and cognitive activities constituting the C2 process. The C2 process is a suite of periodic activities which mainly involves the perception of the domain (environment), an assessment of the tactical situation, decision making about a course of action and the implementation of the chosen plan

The C2 activities are performed by either humans, machines (i.e., hardware and software computer systems), or a combination of both. Characteristics of this suite of activities are described in [Chalmers, 1997] and were captured through the Boyd's Observe-Orient-Decide-Act (OODA) loop illustrated in Figure 1. Although this loop might give the impression that C2 processes are executed in a sequential way, in reality, the processes are concurrent and hierarchically structured.

The military community typically states that the dominant requirement to counter the threat and ensure the survivability of the ship is the ability to perform the C2 activities (i.e., the OODA loop) quicker and better than the adversary. Therefore, the speed of execution of the OODA loop and the degree of efficiency of its execution are the keys of success for shipboard tactical operations. Decision support systems can contribute significantly to the fast execution of this loop.

3.2 Decision Support System

The complexity of the shipboard environment in which operators conduct C2 activities emphasises the need for warships to be fitted with a real-time decision support system (DSS). The main role of this DSS is to aid the operators in achieving the appropriate situation awareness (perceptual and cognitive) in order to support them in their tactical decision making and action execution activities.

Operators need to be aided by a DSS that continuously fuses data from the ship's sensors and other sources (MSDF capability), helps the operators maintain a picture of the tactical situation (STA capability), and supports their response to actual or anticipated threats (RM capability). In addition, the representation of knowledge in a meaningful way to the decision-maker is under the responsibility of the DSS.

Figure 1 presents the mapping of the MSDF/STA/RM system onto the OODA loop. The data fusion process, described in the next section, is seen as an important element of a DSS to provide the appropriate situation awareness to operators in support of their C2 activities.

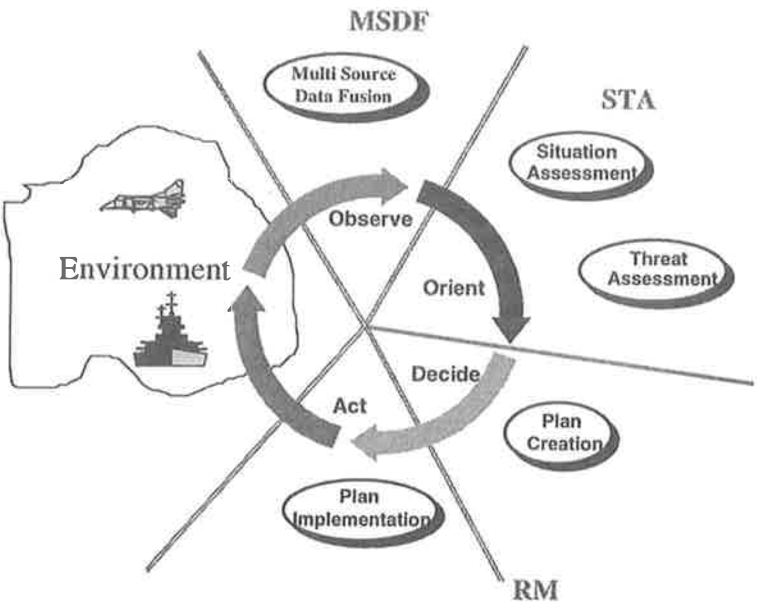

Figure 1: Mapping of the MSDF/STA/RM system onto the OODA loop.

Under time-critical conditions, automation is essential leaving the operator to a limited but essential role of go/no go decisions. In this context, DSS requires to be real-time efficient. When the tactical situation permits deliberation, tasks must be designed and developed to perform synergistically with the operator. This suggests that the design and development of a DSS to support the strengths and complement the weaknesses of operators by effective allocation of available resources to enable them to cope with the demands of the environment. For instance, taking advantage of the inductive intelligence of the human and deductive precision of the computer could lead to a joint human-machine system for the interpretation of complex tactical situation where the human is responsible to generate hypotheses and the machine responsible for the validation of these hypotheses against data.

Another general requirement for DSS is to support the human and to lighten his workload. This could be done through the automation of some simple deliberative tasks (i.e. commercial flight correlation) or by monitoring and aiding the combat operator during the execution of standard operational procedures in engagement situation. These enhancements have an impact on the interaction between the human-machine and modify the function allocation between them. For that reason, design and development of DSS requires taking into consideration the cognitive aspects of human information processing.

3.3 Data Fusion

According to the JDL model, DF is fundamentally a process designed to manage, organise, combine and interpret data and information obtained from a variety of sources, that may be required at any time by operators and commanders for decision making. It's an adaptive information process that continuously transforms the available data and information into richer information. Refined (and potentially optimal) kinematics and identity estimates of individual objects, and complete and timely assessments of current and potential future situations and threats (i.e., contextual reasoning) are achieved through continuous refinement of hypotheses or inferences about real-world events. The DF process is also characterised by the evaluation of the need for additional data and information sources, or the modification of the process itself, to achieve improved results.

Given these considerations, a complete DF system can typically be decomposed into five levels:

- Level 0 – Signal Data Refinement (source pre-processing);
- Level 1 – Object Refinement (Multi-Source Data Fusion (MSDF));
- Level 2 - Situation Assessment (SA);
- Level 3 - Threat Assessment (TA); and,
- Level 4 - Process Refinement through Resource Management (RM).

Each succeeding level of DF processing deals with a higher level of abstraction. Level 1 DF uses mostly numerical, statistical analysis methods, while levels 2, 3, and 4 of DF use mostly symbolic or Artificial Intelligence (AI) methods. Note that resource management in the context of level 4 fusion is mainly concerned with the refinement of the information gathering process (e.g., sensor management). However, the overall domain of resource management also encompasses the management of weapon systems and other resources (including the management of navigation and communication systems).

The JDL model provides a good description of the data fusion process. This process is an important element within the C2 cycle. One must also realise that the human plays an essential role in the C2 cycle. He is the one responsible for taking decisions. Because of the importance of humans, one needs a mechanism to reason about their role in the C2 cycle in order to facilitate the proper conceptualisation and design of DSS. Endsley [Endsley, 1995] showed that situation awareness is an essential precondition in this decision making process.

3.4 Situation Awareness

Endsley has derived a theoretical model of situation awareness (SA) based on its role in dynamic human decision making. Endsley defines situation awareness as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. Figure 2 depicts the three levels of situation awareness as identified by Endsley.

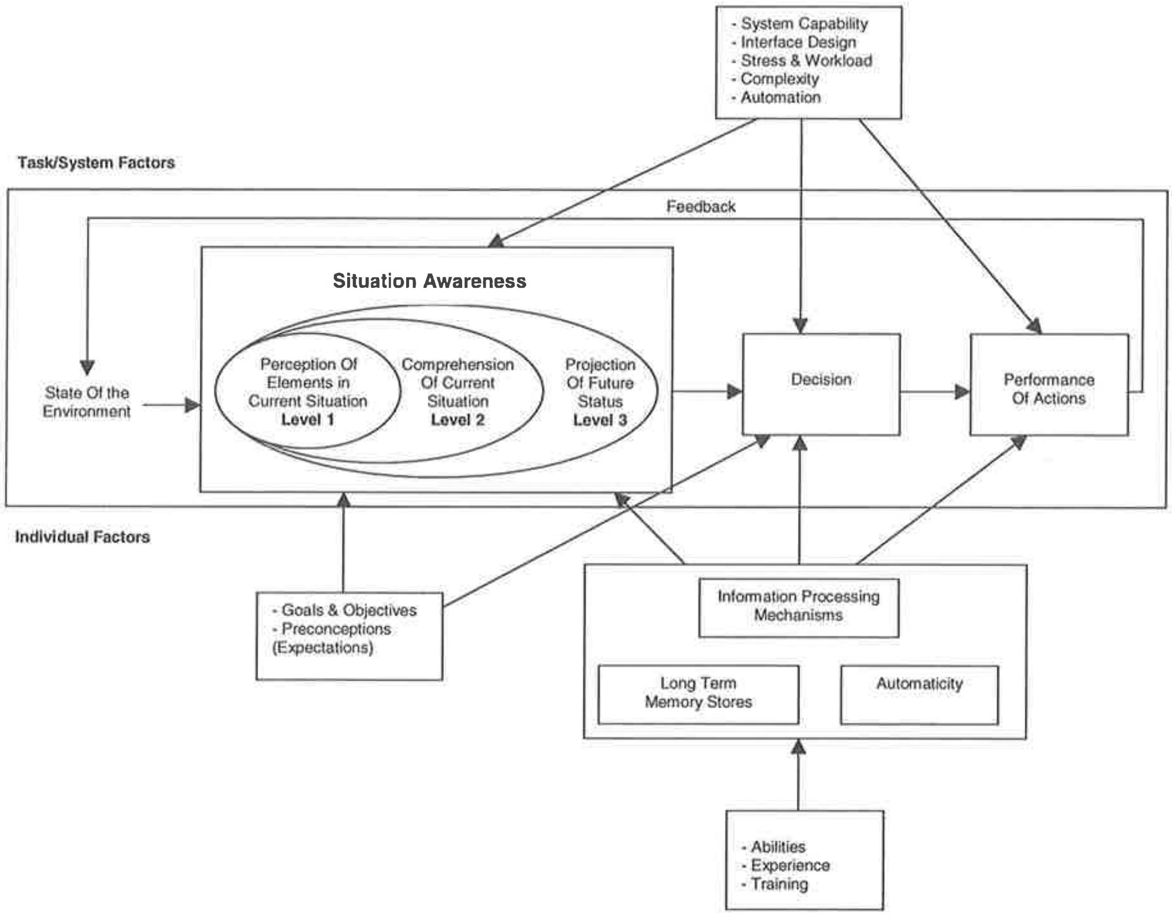

Figure 2: Situation Awareness model in dynamic decision making

SA can be interpreted as the operator's mental model of all pertinent aspects of the environment (process, state, and relationships). This mental model of the environment is also known in Rasmussen's work [Rasmussen, 1985, 1986 and 1996] as the *hierarchical knowledge representation* in decision-making. This paper focusses at the definition and application of this *hierarchical knowledge representation* in the context of naval C2.

Finally, bearing in mind the scope of this paper, one should note that SA could be achieved without the transformation and the fusion of data. For instance, training techniques typically enhance the operator's performance, resulting in a better SA. Similarly, advanced techniques in human computer interaction (HCI) allow a representation of the information in a meaningful way for the human.

4. Tactical Information Abstraction Framework

It has been shown earlier, by Endsley [Endsley, 1995] and Rasmussen [Rasmussen, 1985, 1986 and 1996] for example, but also [Carver, 1991], that human operators gain situation awareness of what is going on in the environment, by constructing a hierarchical situation model of this environment. In the description of the three awareness achievement steps, Endsley clearly presumes *patterns* and *higher level elements* to be present according to which the situation can be structured and expressed. This situation model consists of the basic elements present in the environment, relevant for understanding the situation. Furthermore, this situation model consists of combinations of interrelated elements, spatial and temporal structures, and abstractions expressing the situation at a functional and intentional level.

It would be beneficial if we are able to formalise the maritime situation model expressing the operator's situation awareness. The result of such a formalisation, a Tactical Information Abstraction Framework (TIAF), can be used in the development of decision support tools. Such support tools can optimally aid the human operator in gaining situation awareness, because the frameworks of both match. For the same reason, interactions between human operators and the decision support tools can be supported obviously, thus facilitating human-in-the-loop solutions.

4.1 Tactical Information according to STANAG 4420

In Appendix 1 of Annex A of STANAG 4420 [MAS, 1995] a Tactical Information Hierarchy is described. The purpose of the Tactical Information Hierarchy is to define the full range of tactical information required by the operational user at the command level. In this Tactical Information Hierarchy items are shown in a tree-like manner. This tree-structure represents several types of information and interrelationships. The tree represents objects[1] as well as attributes[2] of objects. For example: a *Track* is an object and *Kinematics* and *ID* are attributes of the track. Besides, several types of interrelationships are described in the tree:

- the relationships between an object and its attributes (Track and Kinematics for example)
- generalisation/specialisation relationships (for example: Track - (Track Description -) Surface Track - Combatant - Line)

In Figure 3 a part of the Tactical Information Hierarchy is depicted.

[1] In [Rumbaugh, 1991] an *object* is defined as a concept, abstraction, or thing with crisp boundaries and meaning for the problem at hand. All objects have *identity* and are distinguishable. An object class describes a group of objects with similar properties, common behaviour, common relationships to other objects, and common semantics.

[2] According to [Rumbaugh, 1991] an attribute is a data value held by the objects in a class. Each attribute has a value for each object instance. An attribute should be a pure data value, not an object. Unlike objects, pure data values do not have identity.

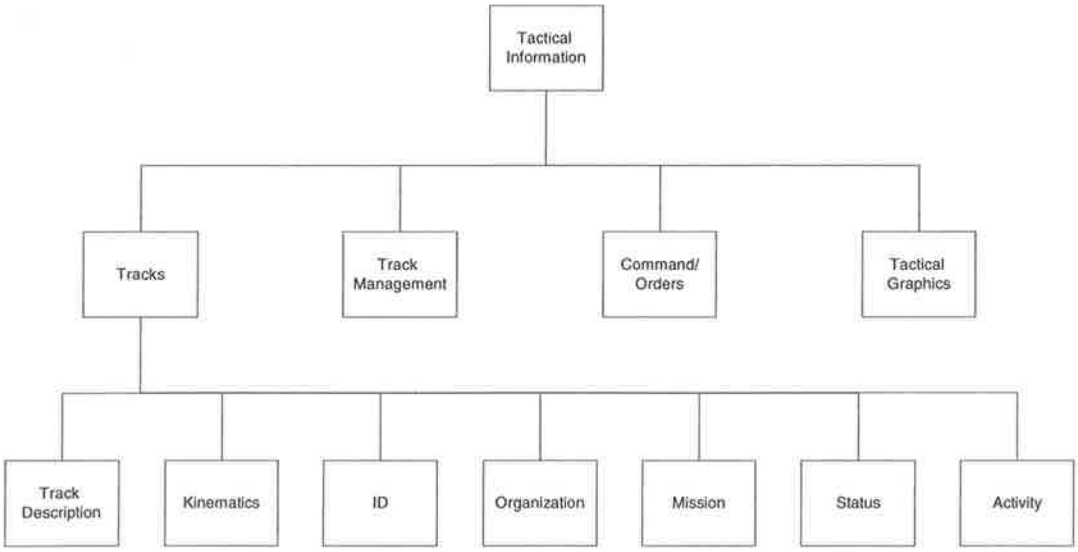

Figure 3: Part of the Tactical Information Hierarchy specified in STANAG 4420

The subtree of *Tracks* specifies all information about the entities in the environment.

- The *Track Description* subtree is a specialisation tree of Target types. The top-level specialisations are: Surface Track, Subsurface Track, Air Track, Land Track, Space Track, Special Point (such as Reference Point, Sonar Dip Position, Weapon Impact Point, etc.), Bearing (EM Intercept, Acoustic Intercept or Electro-Optical Intercept) and Own Track.
- The *Kinematics* subtree specifies all kinematic information considered relevant: Position (including History Points), Speed, Direction, Time and Rate (Rate of Turn and Rate of Climb).
- The *ID* subtree specifies the standard identity classes a target can be assigned to.
- The *Organisation* subtree specifies information about the organisation of Targets: Nationality, Alliance and Military Group (Task Force, Task Group, Task Unit and/or Convoy).
- The *Mission* node specifies the task or the mission of a Target or a group of Targets respectively (e.g. Reconnaissance, Escort, AAW, etc.)
- The *Status* subtree specifies various attributes regarding the status and the characteristics of a Target: Information regarding the Engagement of a Target, Availability of consumables, System readiness, Capability information and Strength.
- The *Activity* node specifies the type of activities that can be associated with mission and behavioural data based on kinematics.

4.2 What is missing?

What we like to express in our Situation Model is perfectly described in the purpose statement of the Tactical Information Hierarchy: *the full range of tactical information required by the operational user at the command level.* Given the characteristics of the derived Maritime C2 abstraction framework the following information is lacking:

- Some higher level abstractions (behavioural patterns at several levels)
- Rich representation of history (only history points)
- Explicit representation of interrelationships (Whole/part relationships are not shown in the tree. An example would be the relationship between a Military Group and its composing entities)
- Explicit representation of uncertainty (several types including uncertainty in detection, localisation, recognition and identification)
- Representations of capability information and intentions.

4.3 Rasmussen's abstraction hierarchy

Rasmussen et al. proposed a knowledge abstraction hierarchy with five levels ([Rasmussen, 1985], [Rasmussen, 1986], [Rasmussen, 1994]). This abstraction hierarchy was primarily meant to represent knowledge about a system for system management and diagnosis purposes (see Table 1)[3]. In [Rasmussen, 1986] he stresses that the description of a system can be varied in at least two ways. It can be varied independently along the abstract-concrete dimension, representing means-end relationships, and the dimension representing whole-parts relationships. Changes along the two dimensions are very often made simultaneously, but can in fact be done separately.

Rasmussen argues that such an abstraction hierarchy applies to so-called *causal systems* i.e. systems of which the response to an external influence is predicted bottom-up from causal laws. Furthermore he argues that a similar abstraction hierarchy applies to so called *intentional systems*, i.e. systems controlled in their response to external influence within their range of capability by their "intention" to act derived from the individual values structure and internal goals.

In summary the human's model of the world is a hierarchical representation; it enables recognition of objects an scenes at the level of physical appearance; it makes it possible to identify objects by their functional values rather than their appearance; and patterns of purposive behaviour can be activated by high-level intentions. [Rasmussen, 1986, page 93] A description of a system at a certain level of abstraction ('what') describes the 'why' of a lower level and the 'how' of a higher level. This holds for each level of abstraction.

4.4 Derivation of a Maritime C2 analogy

Starting from the ideas of Rasmussen, we can try to derive a maritime C2 analogy of the Abstraction Hierarchy.

4.4.1 Physical Form Level

If we look at our domain, maritime command and control, the basic element constituting our 'system' is an object in the environment (air target, surface target or subsurface target) regardless of its allegiance (friendly, neutral or hostile).

A target can be described using several kinds of attributes. In [Bossé, 1997] two main attribute types are distinguished: Positional attributes, representing the dynamic parameter describing the position and the movement of an object, and Identity attributes, i.e. declarations, propositions or statements that contribute to establish the identify of an object.

If we look at the way Rasmussen describes the Physical Form Level only a subset of these attributes is of relevance at this level. The system is described statically in terms of objects and their positions. So, only the Identity attributes and the current position of the targets is of relevance.

4.4.2 Physical Function Level

The Physical Function Level is oriented toward the functioning of physical components constituting our system, i.e. the functioning of the objects identified at the Physical Form Level. In our Maritime C2 analogy, the system is described in terms of dynamic behaviour of objects. At this level kinematic as well as non-kinematic behaviour of targets is relevant. Kinematic behaviour of targets can be expressed in terms of course, speed but also the fact that a target is manoeuvring. Examples non-kinematic behaviour are launching of weapons, use of (active) sensors and communication.

4.4.3 Generalised Function Level

The Generalised Function Level is the first level where the tie to the physical implementation (objects as well as processes) is cut. In our Maritime C2 analogy, the system is described in terms of *tasks* that must be performed, irrespective of the unit or the units performing it. Examples of such tasks are Conduct Search, Conduct Surveillance and Hunt and Destroy Submarines. Of course one platform may be better equipped to conduct a specific task than another platform, but essentially these tasks can be regarded irrespective of the tasked unit. As an example, a surveillance task can be assigned to a frigate as well as to a Military Patrol Aircraft (MPA).

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[3] In various sources, Rasmussen uses dissimilar terms for the Abstraction Levels. In this paper we will use the terms as shown in Table 1.

Table 1: System abstraction levels (after [Rasmussen, 1985] and [Rasmussen, 1994]).

Abstraction Level	*Properties represented*	*Characterisation*	*Example in the System Description domain*
Physical Form	Properties necessary and sufficient for classification, identification and recognition of particular material objects and their configuration; for navigation in the system.	At this level the system is represented in terms of the physical appearance and configuration of the system and its parts. The purpose of the system will control the representation to a certain extent.	Physical appearance and anatomy, material & form, locations, etc.
Physical Function	Properties necessary and sufficient for control of physical work activities and use of equipment: To adjust operation to match specifications or limits; to predict response to control actions; to maintain and repair equipment.	This level represents the physical processes of the system and/or its parts.	Electrical, mechanical, chemical processes of components and equipment
Generalised Function	Properties necessary and sufficient to identify the 'functions' which are to be co-ordinated irrespective of their underlying physical processes.	Descriptions at this level deal with functional relationships that are widely found independent of material manifestations. Generalised functions are structured according to available models of functional relationships.	"Standard" functions & processes, control loops, heat-transfer, etc.
Abstract Function	Properties necessary and sufficient to establish priorities according to the intention behind design and operation: Topology of flow and accumulation of mass, energy, information, people, monetary value.	At this level, the overall function of a system can be represented by a generalised causal network, e.g., in terms of information, energy, or mass flow structures reflecting the intended operational state.	Causal structure, mass, energy & information flow topology, etc.
Functional Purpose	Properties necessary and sufficient to establish relations between the performance of the system and the reasons for its design, that is, the purposes and constraints of its coupling to the environment.	At the highest level of abstraction, the purpose or intended functional effect of a system is described.	Production flow models, control system objectives, etc.

4.4.4 Abstract Function Level

The Abstract Function Level represents the concepts that are necessary for setting priorities and allocating resources to the various general functions and activities at the level below ([Rasmussen, 1994]). In other words at the Abstract Function Level the generalised functions identified at the Generalised Function Level are regarded in interrelation with each other. The overall functioning of the system, determined by the co-functioning of all the elements of the system, is regarded.

In our Maritime C2 analogy, the system is described in terms of a network of co-operating tasks. Generally, a number of tasks, each with a specific goal, together serve a higher level goal or mission. While the Generalised Function Level describes the system in term of individual tasks carried out, this level interrelates these tasks and focuses on the contribution, the added value of the tasks to the full system.

As an example, consider a hostile frigate equipped with surface-to-surface missiles and a hostile fighter. The fighter is tasked to search and acquire our platform. The hostile frigate has an Anti Surface Warfare (ASuW) task. Both tasks are interrelated. The results of the search and acquisition task can or even will be used in the ASuW task to be able to target the missiles.

4.4.5 Functional Purpose Level

The highest level of functional abstraction represents the system's functional meaning. What is the purpose of the existence and the dynamic behaviour of all the objects constituting the system. In our Maritime C2 analogy, the system is described in terms of missions or better[4]: intents. In our system their will generally be a number of (often conflicting) intents.

As an example consider a task force with the mission to protect a High Value Unit (HVU). Three different tasks can be distinguished to fulfil this mission: Conduct Reactive AAW, Conduct Reactive ASuW and Conduct Reactive ASW. Each of these tasks serve a common goal, namely protection of the HVU.

4.5 Example

In this section we will illustrate the derived abstraction hierarchy by means of a simple scenario. The scenario is derived from a scenario described in [Miles, 1988] and is depicted in Figure 4.

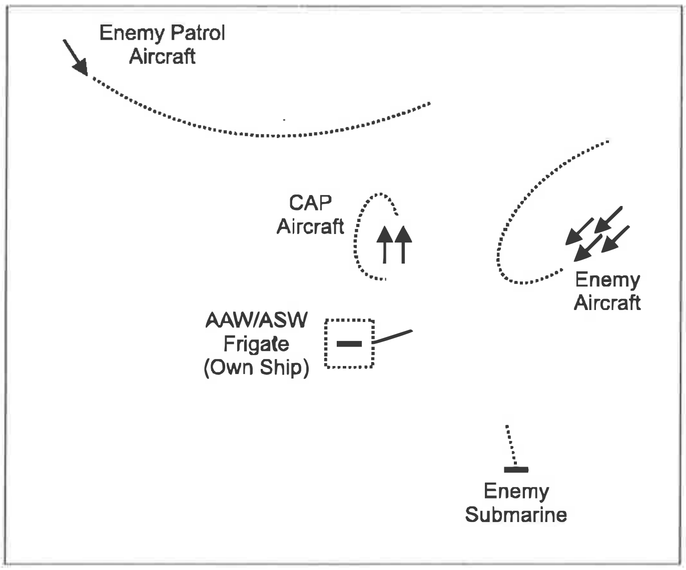

Figure 4: Simple scenario

Our own ship is a frigate with an Anti Air Warfare (AAW) and an Anti Submarine Warfare (ASW) task. We have a Combat Air Patrol (CAP) at our disposal consisting of two fighter aircraft. An enemy Military Patrol

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[4] The term *mission* in a Maritime C2 context often denotes more than just *purpose* or *objective*. Mostly, it includes a description of *how* an objective can be achieved (an operation) as well. See for example [Delmee, 1998]

Aircraft (MPA) enters the picture from north-west. Its purpose is to locate our ships and guide other units to attack. One possibility for attack is an enemy submarine in the south-east sector. Another element for attack is a group of strike aircraft which fly in from the east to launch missiles at our ship.

In Figure 5 the situation awareness during the scenario aboard our own frigate is depicted. Two distinct time steps are represented, separated by a vertical dashed line. The five abstraction levels are separated by the horizontal lines. Observations are greyed and can typically be found at the two lowest abstraction levels. Derived hypotheses are placed at the abstraction level where they belong.

At the first time step our radar system detects our own CAP. This detection corresponds with its planned position. Our ESM-equipment detects an emission in north-west direction. This emission can be recognised as an enemy patrol aircraft. There are no sonar contacts. Finally, there is an intelligence report, reporting an enemy aircraft of a specific type in eastern direction, heading west. These observations and reports belong to the first two levels of abstraction. Some observations, such as radar detections for example, indicate presence and/or position of an object in our environment. Other observations, such as the fact that the enemy aircraft is heading west, indicate dynamic behaviour of an object. Yet other observations, such as ESM-detections, indicate both. ESM-detections reveal the presence of an object, they may also provide evidence for the type and the activity of the object.

If we combine the observations done in the first time-step, propositions belonging to higher abstraction levels can be derived. As an example, the fact that we have a recognised ESM-contact in north-west direction while it is not possible to correlate radar contacts with this contact, gives evidence to the proposition that the enemy MPA is beyond the radar range. An MPA can typically be used to shadow our ship. The ESM indicates this activity. This shadowing or search task is a proposition at the Generalised Function level. This search activity is not a goal in itself. A search activity typically provides input to other units (Abstract Function level). If the search-proposition is combined with the reported enemy aircraft, a Functional Purpose proposition of an air raid from the east can be derived.

At the second time step new observations are done. Like we did in the first step, higher level propositions can be derived from these observations as well. Eventually, we arrive at two Functional Purpose propositions, representing an air attack and a submarine attack.

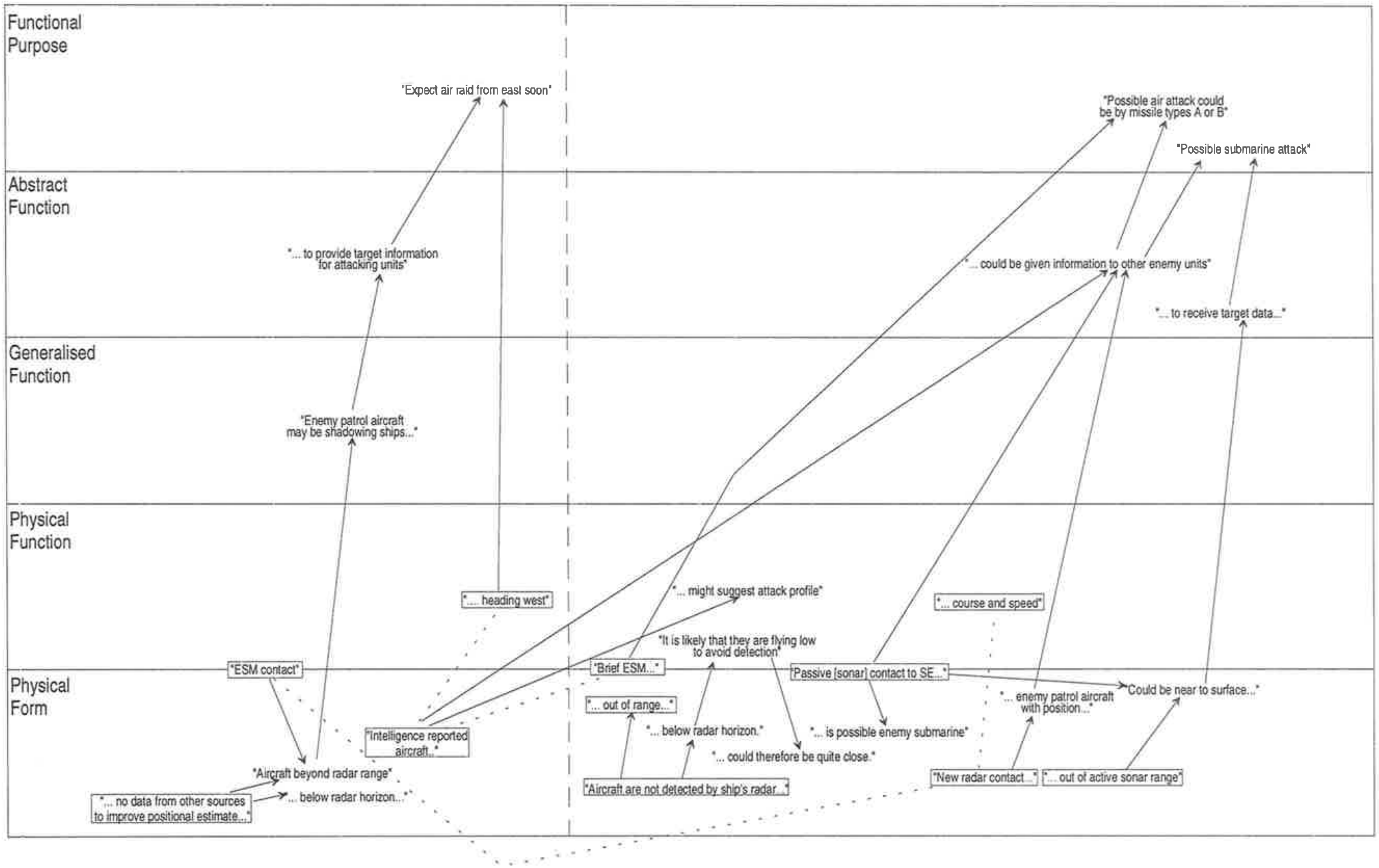

Figure 5: Example of application of abstraction levels. The boxes represent observations, the dotted lines represent correlation of observations and the drawn arrows represent reasoning steps. Reasoning as well as time proceeds from left to right.

4.6 Résumé

In Table 2 the derived Maritime C2 analogy is summarised and exemplified with references to the example scenario given in the previous section.

Table 2: Maritime C2 analogy derived from Rasmussen's Abstraction Hierarchy

Abstraction level	*Maritime C2 analogy*	*Typical aspects*	*Example*
Physical Form	Target	Observable attributes (RCS, IR-image, visual image, ...)	MPA
Physical Function	Dynamic Behaviour	Kinematics, course, speed, manoeuvring Yes/No, EM-emission, ...	Flying in NW direction, ESM-emission
Generalised Function	Behavioural Patterns, Tasks	Searching, Acquiring, Attacking, ...	Searching
Abstract Function[5]	Functional co-operation	Functional co-operation of units; roles of units in a functional group	Enabling a frigate to engage us
Functional Purpose	Mission	Intent	Submarine attack

The real-life objects in the environment of our own ship can be represented by object propositions at five levels of abstraction. The propositional or hypothetical nature of these objects can be found at several places in the example described in Section 4.5. Gaining, increasing and maintaining situation awareness essentially boils down to reasoning among those propositions. Furthermore, at each level of abstraction whole-part relations can be found. At the physical form level whole-part relations represent aggregations of units, such as formations and dispositions. At the Generalised Function level, for example, functionally interrelated tasks can be aggregated. The functional interrelations themselves belong to the Abstract Function level.

5. Data Fusion System design issues

What is the benefit of structuring the propositions representing our awareness of the situation like we proposed in the previous sections? In present systems, construction of a picture of the environment is only supported at the lowest abstraction levels. The Recognised Maritime Picture represents individual targets, their types, their identity, their positions and their kinematics. Of course, for self-defence purposes this is very important information. The information we represented at the higher levels of abstraction is very important if we look at longer term planning and decision-making activities. Current systems have very poor means to derive or even represent this type of information. Decision-makers, needing awareness of the situation at these higher levels of abstraction can hardly receive support from present systems in gaining this awareness.

A first step towards development of support in this process of gaining awareness is identification and formalisation of the propositions constituting the description of the situation at the higher abstraction level. We feel that it is possible to use the TIAF in the process of gaining situation awareness by regarding this process as a number of co-operating Data Fusion Agents (Figure 6) interconnected by a network, which is structured similar to the structure of the TIAF derived in the previous section. For a detailed foundation see [Paradis, 1998b].

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[5] The transition from the level of generalised function to that of abstract function is probably most evident when considering information-processing systems. Here, a set of coding conventions relates the actual functioning of the system at the physical and generalised levels to the abstract function in terms of information processes. The abstract function represents the semantic content of the physical signals and, hence, the overall organising principle. ([Rasmussen, 1986])

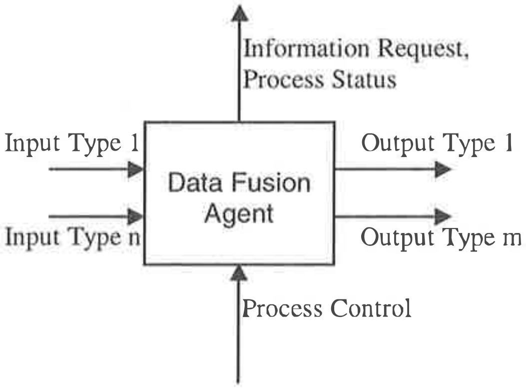

Figure 6: Generic Interfaces of a Data Fusion Agent

A model of the data fusion process structured according to the given description, is depicted in Figure 7. The data fusion agents are interconnected according to a TIAF. The agents are controlled by a process refinement process, based upon explicit requests for information and the process status of the data fusion agents.

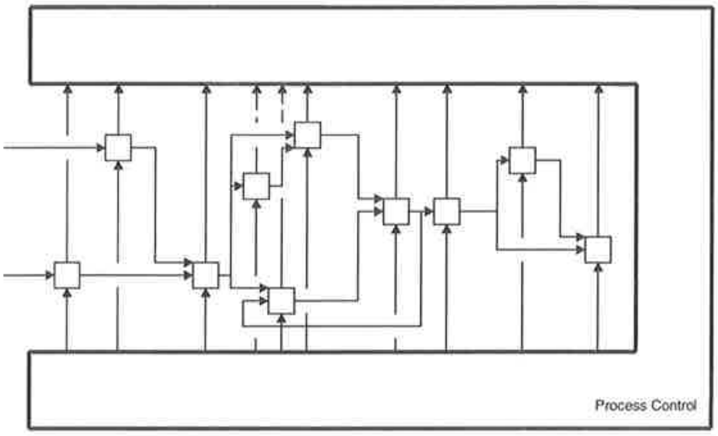

Figure 7: Co-operating Data Fusion Agents

Figure 7 doesn't depict any realistic data fusion system. It attempts to visualise the concept of co-operating data fusion agents. Most often, outputs from lower level data fusion agents flows provide input for higher level data fusion agents. In level 1 an example is depicted of an agent, using higher level information to enhance the result of level 1 processing. In [Paradis, 1998a] this concept has been illustrated in detail.

In a Data Fusion model as depicted in Figure 7 the role of a human operator can be modelled as a number of Data Fusion Agents. Feasibility of automation of the Data Fusion process is beyond the scope of this paper. Apart from *feasibility* of automation however, it is debatable whether or not far-reaching automation of the Data Fusion process is *desirable*. Recall that the Data Fusion process can be seen as a process of gaining situation awareness. It may be better to primarily *support* the human in the process of gaining situation awareness rather than *automating* it. The primary goal is to provide the human with a better understanding of what is going on, in order to enable him to do a better assessment and decision-making job. If the system does the process of constructing a model of the situation, leaving the actual assessment of the situation to a human being, there is a serious risk that the human being will get his wires crossed sooner or later because he cannot keep step with the reasoning process of the system. See also [Lipshitz, 1997].

If it is possible to represent a maritime data fusion process as described above a blackboard architecture will be a promising architecture for such a data fusion system. See for example [Paradis, 1998b] and [Corkill, 1991]. In de DRESUN testbed [Carver, 1991] a blackboard has been successfully applied.

6. Summary, conclusions and suggestions for further work

The Tactical Information Abstraction Framework (TIAF) described in this paper, can be used to structure the process of gaining situation awareness but also to structure the assessment process. Assessment functionality can be identified at each level (the physical target level up to the intent level). Threat assessment presently focuses primarily on the target level. The Threat assessment process can be improved by explicitly considering higher abstraction levels as well. Probably, we can even take this a step further. Resource Management can be seen as a multi-level activity as well. It may be possible to extend the levels distinguished in this paper to Resource Management.

A data fusion system can be designed by combining the ideas of this paper with the ideas of [Paradis, 1998a] and [Paradis, 1998b]. In [Paradis, 1998b] the notion of data fusion agent is introduced. These data fusion agents can be interrelated conform the TIAF described in this paper.

If you use the abstraction framework for representation of the objects in the environment, more abstract objects can be derived from less abstract ones. More abstract information, on the other hand, can be used to refine less abstract objects (see [Paradis, 1998a]). If you combine these derivation and refinement activities carelessly, then there is a data looping risk, i.e. a risk that a proposition indirectly serves as evidence for itself ([Bossé, 1997]).

We referred to a Standardization Agreement on Display Symbology and Colours for NATO Maritime Units [MAS, 1995]. We found that the Tactical Information Hierarchy in this STANAG was inadequate for our purpose. This Tactical Information Hierarchy however, formed the basis for a display symbology described in the STANAG. In this paper we proposed a structure for the information required by an operator to gain insight in what is going on in the environment. To enable this operator to interact with a computer system supporting him in this process, it may be necessary to adapt or extend the symbology specified in [MAS, 1995].

The promises of applying the TIAF as proposed in this paper must be verified. For this verification, scenario's must be developed as well as Measures of Performance and Measures of Effectiveness. Furthermore, the knowledge necessary for derivation of higher level abstractions from lower level ones must be acquired and structured in a maintainable and accessible way.

7. References

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