Rethinking the NAIHS Model for NEC

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ABSTRACT

Advances in network technologies enable distributed systems, operating in complex environments to co-ordinate their activities over larger areas within shorter time intervals.

Recently a model for such systems called the NAIHS model has been proposed, where NAIHS stands for Networked Adaptive Interactive Hybrid (human and artificial) System. The NAIHS model identifies information, temporal and physical abstractions to structure the system functions that act as agents.

In this paper we investigate how this model relates to other models that try to structure such systems like the JDL model that focuses on sensor fusion, the model of Endsley on human situation awareness, the approach of Rasmussen that focuses on (physical) structure and the approach of Brooks that advocates a temporal hierarchy of sensor-actuator layers.

We then investigate the applicability of this NAIHS model for NEC.

In the domain of NEC a number of maturity levels have been identified. Particularly at the higher maturity levels, next to the humans, the artificial part of the system will also behave in a more intelligent manner.

From this perspective it seems natural to model the future NEC systems as a (complex adaptive) multi (human and artificial) agent system where the agents have the intention to cooperate as good as possible while they adapt themselves to a dynamic environment.

The applicability of the NAIHS model to NEC is first considered from a functional perspective, i.e. how do the functional components identified in the NAIHS model relate to the NEC domain. Then we consider, for the higher NEC maturity levels, the interaction mechanisms between the agents.

1 INTRODUCTION

Since the introduction of the NAIHS model [1], this model is considered for applications in the domain of NEC. These activities have lead to further understanding and improvement. In this paper we investigate in more detail how this model relates to other models and recent developments therein. In chapter 2 the high level model is discussed. In chapters 3 different decomposition principles are proposed. In chapter 4 the applicability of the NAIHS model to NEC is considered and chapter 5 concludes this paper.

2 HIGH LEVEL MODEL

The NAIHS under consideration is a system of networked entities or components that strive to co-operate to cause an effect in the outside world according to a certain system goal. The first distinction is therefore between system and outside world. As the expression ‘hybrid’ already suggests, one would be tempted to decompose the system in a human and machine. Although different in nature, both can perform similar tasks like, sense the outside world, recognise, act on the outside world and reason how to reach certain goals. Therefore, the approach taken here is to focus on modelling the system according to specific functional components, irrespective of whether they are performed by a human or machine.

In figure 1 a schematic picture is given for such a system. One can characterise the system as a distributed set of hybrid functional components (or hybrid mind) that interacts with collectors (sensors, observers or other information sources), effectors (actuators or actors) and a (distributed) service that takes care of communication between the distributed functional components.

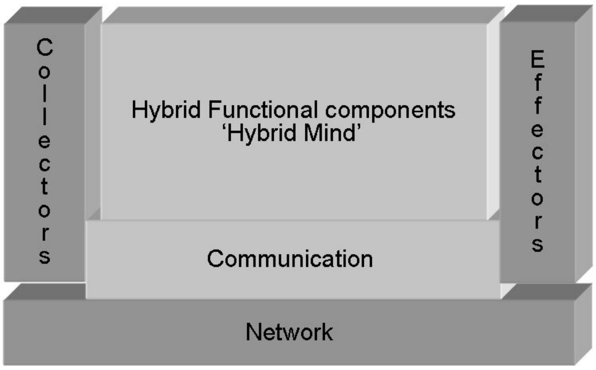

Figure 1 : High level System Model

A common approach is to decompose the system in the chain from collectors to effectors. In this 'dimension' a well established model is in use, the Observe Orient Decide Act (OODA) cycle [2]. According to the OODA cycle, functional components can be identified that are engaged in creating situation awareness and components that are engaged in deciding which effects to generate. This view is depicted in figure 2.

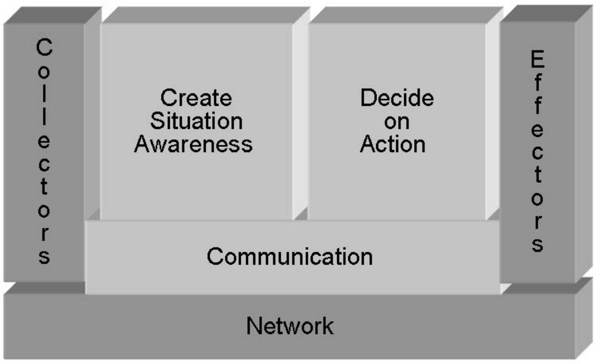

Figure 2 : Separation of the hybrid mind in creating situation awareness and decision making

The goal of such a system is to grasp that part of the situation, defined as the system in its environment, based on which the most effective actions can be taken.

3 PRINCIPLES OF ABSTRACTION

An important problem that has to be addressed now is what principles should be used to further decompose 'create situation awareness' and 'decide on action' into more specific functional components. Three principles can be distinguished: Information abstraction hierarchy, physical structure of the situation and time scale at which decisions have to be made. In the next paragraphs these principles are discussed.

3.1 Information abstraction Hierarchy

The most well known model that uses a decomposition based on an information abstraction hierarchy is the JDL model [3], depicted in figure 3.

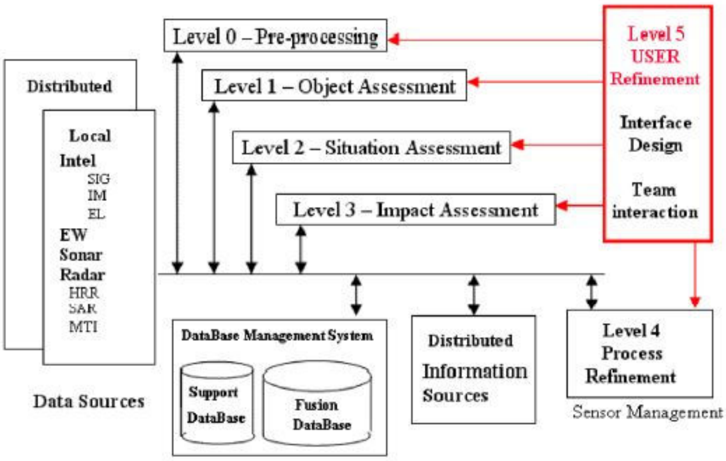

Figure 3: JDL model

We can match this model easily with the high level model of figure 2 for the part of situation awareness.

The JDL model distinguishes four levels of information abstraction:

Level 0: Estimation of States of Sub-Object Entities (e.g. signals, features)

Level 1: Estimation of States of Discrete Physical Objects (e.g. vehicles, buildings)

Level 2: Estimation of Relationships Among Entities (e.g. aggregates, cueing, intent, acting on)

Level 3: Estimation of Impacts (e.g. consequences of threat activities on one's own assets and goals)

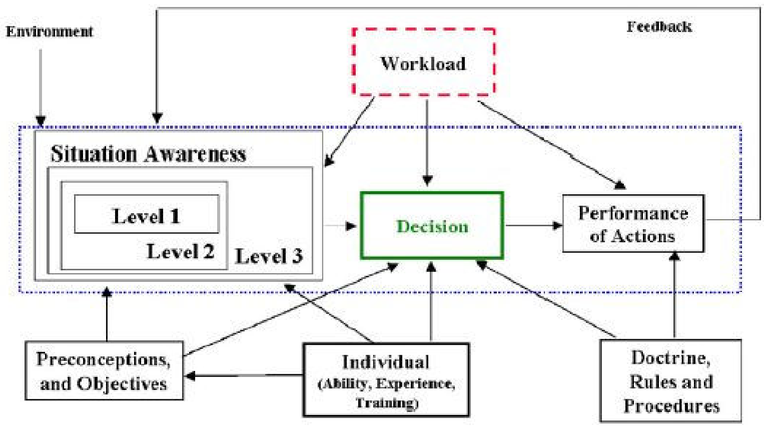

Figure 4: Endsley's situation awareness model

A model very similar to that but more from the human perspective is the model of Endsley [4] depicted in figure 4. While the JDL model is confined to creating situation awareness the model of Endsley includes decision making and performing actions.

Inspired by these models is the decomposition that was adopted for the NAIHS model is:

1: Signal (Pre)-Processing – generating the feature space from the collector raw data

2: Filtering in Feature Space – selecting phenomena from the feature space likely to originate from objects (detection)

3: Filtering in Time – associating detected phenomena in time and estimate state, tracking

4: Recognition – classification and identification

5: Situation Assessment – Relationships among entities, similar to level 2 of the JDL model.

6; Relevance Assessment – threat evaluation, risk assessment, similar to level 3 of the JDL model.

7: Action Assessment – decide on what actions to take

8: Execution – execute the actions

In figure 4 the interacting functional components are shown.

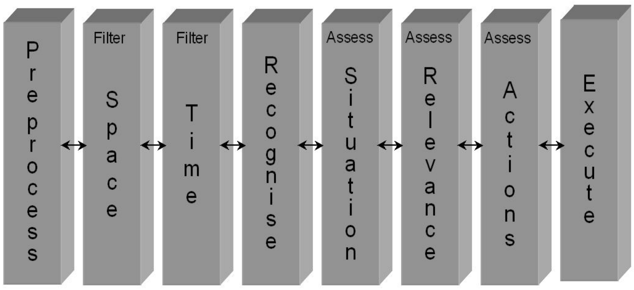

Figure 5 : Functional components of the process cycle and their interactions

As mentioned before, each component may be artificial, human or hybrid.

While the OODA loop and the high level model of figure 2 suggest a balance between creating situation awareness and decision making the models in this chapter focus on creating situation awareness.

3.2 Decomposition based on Physical Structure

A second principle on which decomposition can be based is physical structure. This is the primary principle the Rasmussen adopted in his abstraction hierarchy [5]. The application he had in mind was the control of power plants. In systems considered here the physical structure is due to the network of platforms and the various collectors and effectors. An example of such a decomposition is depicted in figure 6 where the abbreviations correspond to the components in figure 5. The view of the NAIHS model is here that the two principles of abstraction are in most cases related in the sense that the higher the information abstraction level usually there is less of a necessity to distribute the processes. This also shown in the 2D structure of figure 6. However, their may be exceptions and in the design phase there must be possibilities to accommodate this.

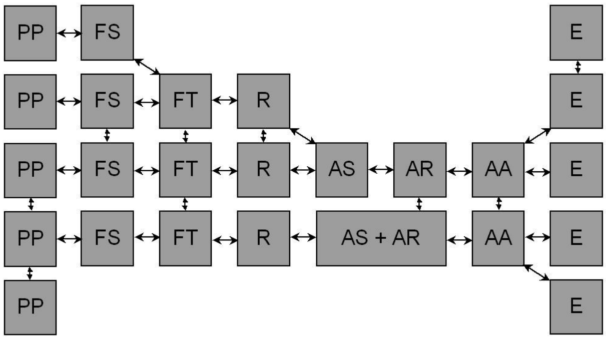

Figure 6 : Interacting functional components in the networked system of dissimilar collectors and effectors.

3.3 Hierarchies in Temporal Abstractions

The effects the system would like to generate in the situation (system and environment) can widely vary in time. A decomposition of the process cycle in this dimension has been adopted in various application domains. In the military field a strategic, operational and tactical level is in use. For (business) planning the same levels in use, however, contrary to the military case the operational level acts on a shorter time scale than the tactical level.

In the AI domain Brooks [6], who discards the decomposition of the process cycle, proposes a hierarchical composition of process cycles based on reaction or cycle time.

The need for decomposition into temporal abstractions is also acknowledged in the case of decision making processes in complex situations [7].

Another reason for taking reaction time as a basis is that is can be directly related to the network properties; e.g. it is clearly impossible to co-ordinate behaviour if the required cycle time is less than the network latency.

The time scale can be much larger, e.g. in the case of business planning or much shorter, e.g. in the case of robotic motion control. A suitable decomposition therefore depends on the application.

3.4 Integrating Abstractions

Most models use only one type of abstraction, there are some that distinguish these different principles but integrate them in one abstraction hierarchy [8,9]. Although it is a tempting thought to do so the NAIHS model considers the three principles on which decomposition can be based independent and results therefore in a three dimensional decomposition of the 'hybrid mind'. The reason for this is that it is well imaginable that information processing at a high information abstraction level is very fast and relevant for short term decision making or that information processing from one sensor at one platform needs to be decomposed in many components at the higher information levels. In the NAIHS model we want to keep the freedom of choosing the decomposition depending on the particular application.

4 DISTRIBUTED BEHAVIOUR

Now that we have analysed the functional decomposition strategies the question remains how to organise the distributed behaviour of the functional components in such a way that the interaction and or dependency between these functional components is minimal while at the same time they operate in a most effective way. In the NATO NEC roadmap four levels of maturity are characterised (figure 7): Deconflict, Coordinate, Integrate and Coherent

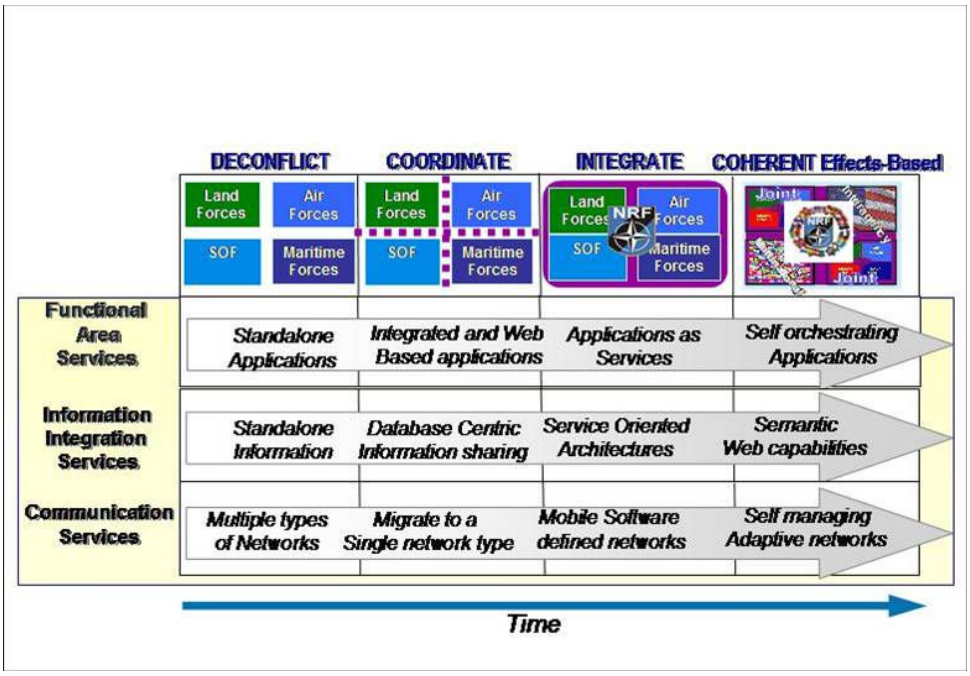

Figure 7 : NATO NEC maturity roadmap

The three levels identified in the figure correspond well with the three levels identified in the high level model depicted by figure 2. For the higher maturity levels the functional components need to act as services on a service oriented architecture platform and as self organising/orchestrating applications with semantic capabilities.

Besides this for the interaction between the networked components the issue of interoperability is considered. A common model for interoperability is the LISI model [10] that distinguishes five interoperability levels:

- Level 0: no interaction or unintelligible data/information
- Level 1: unstructured representation of data/information
- Level 2: a common representation of data/information (syntactic level)
- Level 3: a common understanding (also referred to as context or *a priori* knowledge) of the data/information (semantic level)
- Level 4: common methods, procedures, algorithms to use or process the data/information (behavioural level)

The highest level of interoperability offers the best perspectives for coherent behaviour.

In the NAIHS model [1] a detailed example is described how in a service oriented approach and with interoperability 4 adaptivity to changing needs in information can be accommodated in a distributed setting.

Given the description of the components and the nature of their interactions at the higher maturity levels of NEC it is tempting to consider the components as hybrid agents. The behaviour of the agent is determined by its place in the three dimensional hierarchy structure of the 'hybrid mind' analogous to the idea of the society of mind [11]. For these agents the NAIHS model distinguishes five different interactions; with agents higher in the information hierarchy, with agents lower in the information hierarchy, with agents similar in functionality/behaviour, with agents higher in temporal hierarchy and with agents lower in the temporal hierarchy. The behaviour of the agent can therefore be influenced by these interactions.

Although the terminology relates better to embodied agents this corresponds remarkably well with five types of autonomy identified by Carabelea [12], i.e.:

- U-autonomy (user-autonomy); the user is in our case the agent higher in the information hierarchy or in terminology of the service oriented architecture; the consumer.
- I-autonomy (social-autonomy); this is clearly related to the interactions between agents with similar functionality.
- O-autonomy (norm-autonomy); interaction with the agent higher in temporal hierarchy. This agent may provide directives on behaviour from the higher abstraction level.
- E-autonomy (environmental autonomy); the behaviour of the agent depends on the input from the components lower in the information or temporal hierarchy.
- A-autonomy (self-autonomy); innate/pre-defined or learned behaviour.

The adaptability of the system to changing goals and environment is therefore directly related to the capability of the agents to successfully adapt their behaviour and learn new behaviour.

An additional advantage of a system configured in such a way is that, as long as the components are not unique, it is robust to malfunctioning of single components. In this case the systems performance may degrade but the system does not break down.

5 CONCLUSIONS

In this paper we have compared the principles of decomposition used for the NAIHS model with that used by other models. It can be concluded that three types of abstractions can be distinguished in different models. There maybe a correlation between the three abstractions but for optimal designing freedom, the can be considered independently in the NAIHS model.

Since the NAIHS model considers the components to act as services to maximise the effect and as agents with a certain level of autonomy that can be controlled in a well defined way the model is suitable for designing systems at the higher maturity levels of NEC.

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