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Title: **Augmented Teams -- Assembling Smart Sensors, Intelligent Networks and Humans into Agile Task Groups.**

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Abstract
Safety and security environments are full of networked devices. Despite ample research on sensor networks and network technology, there is little practical comprehensive work on how to incorporate such technologies effectively into human-centered teams. This paper discusses the challenge of assembling networks of smart sensors, systems and humans into hybrid teams that are capable, effective and adaptive. We propose a functional model and illustrate how it can be used to create 'augmented teams'.

We use the Networked Adaptive Interactive Hybrid Systems (NAIHS) model as a blueprint. NAIHS is a JDL-based model, and describes a typical sensor-data driven networked system from a functional point of view. NAIHS considers both human actors and artificial entities to fulfill functional components, and sets the stage for inducing agility and adaptivity in hybrid systems. We focus on the interaction between human and artificial counterparts, with specific attention to task delegation, role adjustment and adaptive autonomy. We introduce design guidelines and interaction contracts to facilitate task- and teamwork between human and artificial actors in augmented teams.

We are currently experimenting with sensor-network supported teams to validate the concepts from a technical and operational point of view. This paper describes our approach and practical observations.

Augmented Teams – Assembling Smart Sensors, Intelligent Networks and Humans into Agile Task Groups.

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1. Introduction

Network-centric approaches are at the top of most defense and security research agendas. We are filling our working environments with networks of sensing and information devices, and we are just beginning to take advantage of the added capabilities they bring. Intelligent networks will especially impact fielded task groups and will change the way missions are performed. Intelligent networked systems will play an increasingly important role, and will be more comparable to active participants than supplemental technology. Intelligent networks will not only support observation and executive tasks, but will participate on higher cognitive level too.

In that sense, we are creating 'augmented teams' – teams of human and artificial actors that work together in a close and adaptive fashion, and that, by presence of the artificial actors are able to exceed the capabilities of the human actors alone. Such developments are especially relevant in the context of security and safety operations, where there is a constant demand for augmented sensing and acting capabilities. The insertion of intelligent networks into an organization significantly alters team dynamics and behaviour, and will require a new understanding of teamwork since it affects the way a team observes, communicates, collaborates and comes to decisions. Despite ample research on sensor networks, intelligent systems and network technology, there is little practical comprehensive work on how to integrate such networks into human-centered teams.

We are exploring design principles for such augmented, hybrid teams. We are especially interested in adaptive and agile capabilities of such organizations, because in those capabilities lies the added value of intelligent networks. By adding artificial distributing sensing and acting capabilities, we augment the observation capabilities of human teams. By using a comprehensive approach to organization design, that includes both human and artificial actors, we facilitate adaptive role and task allocation, and pave the way for more agility and robustness.

Currently, we are experimenting with augmented team concepts for emergency response teams. Recently, we haven started practical experiments with intelligent sensor networks in support of indoor safety crews. Despite obvious differences with fielded military teams and other operational task groups, we do believe that our observations carry over well. In this paper, we present some of our initial observations and conclusions.

2. Developing Augmented Teams

An 'augmented team' consists of a collective of sensors, actuators, information processing systems and humans that are interconnected though an intelligent network. An augmented team has adaptive capabilities with respect to organization structure, role and task allocation and information flow between elements. That implies that roles and tasks may be exchanged between team members without disrupting the integrity of the team and without needing a major redesign of the information flow through the system. It also means that the team can easily accommodate new elements (sensors, actuators, human actors), and that their added capabilities automatically become part of the feature set of the team.

The design of an augmented team differs from conventional team and system design. We need a design process that caters for the specifics of the human and artificial counterparts of the system, and uses an architecture that brings all actors together in a coherent form. We view an augmented team as a *cognitive system*, a system that is set in the real world, has perceptive and cognitive capabilities (self-reflection, reasoning, understanding, learning, decision making) and can respond to situations with reason and intention. In conventional automation processes, there is a clear divide between the human team and the technical system. Because of our adaptivity and agility requirements, we choose to remove this distinction. That means that the humans, networked devices and information systems that make up an augmented team should jointly cover all functions that are usually present in a cognitive system. This also means that we intentionally disregard the challenge of proper task division between human and artificial team members.

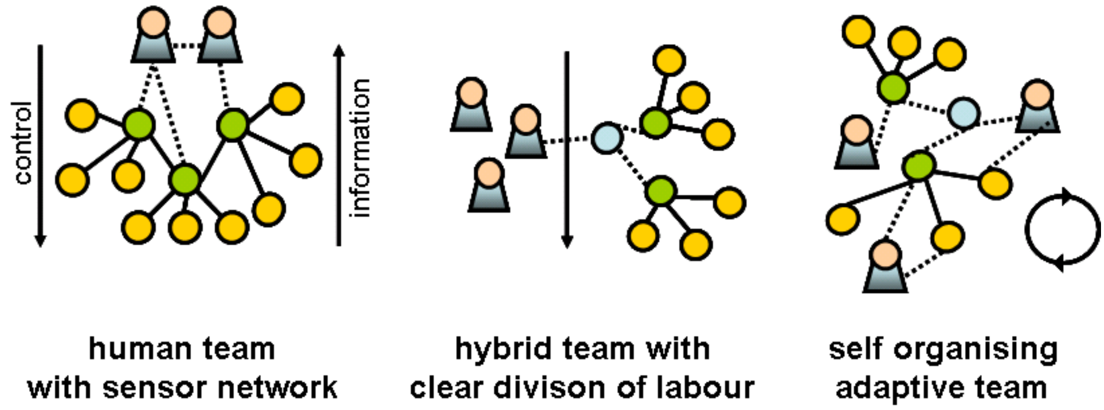

Figure 1: Types of 'augmented teams', with the left being the most conventional and the right being the most the most adaptive.

The design process itself should be oblivious to the current state of technology, and start from a functional perspective. For the design of such a hybrid team, it is important to do away with the distinction between humans and their accompanying technology and take a holistic point of view from the first stages of design. It is easy to let the current state of technology (e.g. the suite of sensors available at design time) influence the outcome of the design process. For instance, the limitations of a certain camera might influence the image processing requirements, and might eventually lead to lessening the feature set of the system as a whole. This is unfortunate, because there might be other elements in the system that could compensate for the camera's limitations. A human actor could improve, for instance, the lighting conditions so that the camera can continue its monitoring task when conditions get too dark. We want the task allocation and problem solving challenges be the responsibility of the system itself as much as possible, not of the design process. This is an essential position in order to make a hybrid organization as versatile and agile as possible.

The figure above gives a general outline of the design process we are developing for augmented team design. Note that the actual role and task allocation comes into play after the structural model. Until then, there is no actual assignment of actors to tasks, apart from those that stem from requirements in the operational domain. For instance, it may be required that a certain job is in the hands of a human operator because of accountability requirements. Also note the feedback loops at the bottom. The feedback loops indicate that the available systems and actors may impose certain requirements on earlier phases. If the collection of available actors and systems are not in any way capable of fulfilling a certain function, then a change in functional structure may be necessary, or even a reassessment of the business model altogether.

There are three essential design challenges that we face: (a) the organization structure, (b) task allocation and (c) information flow.

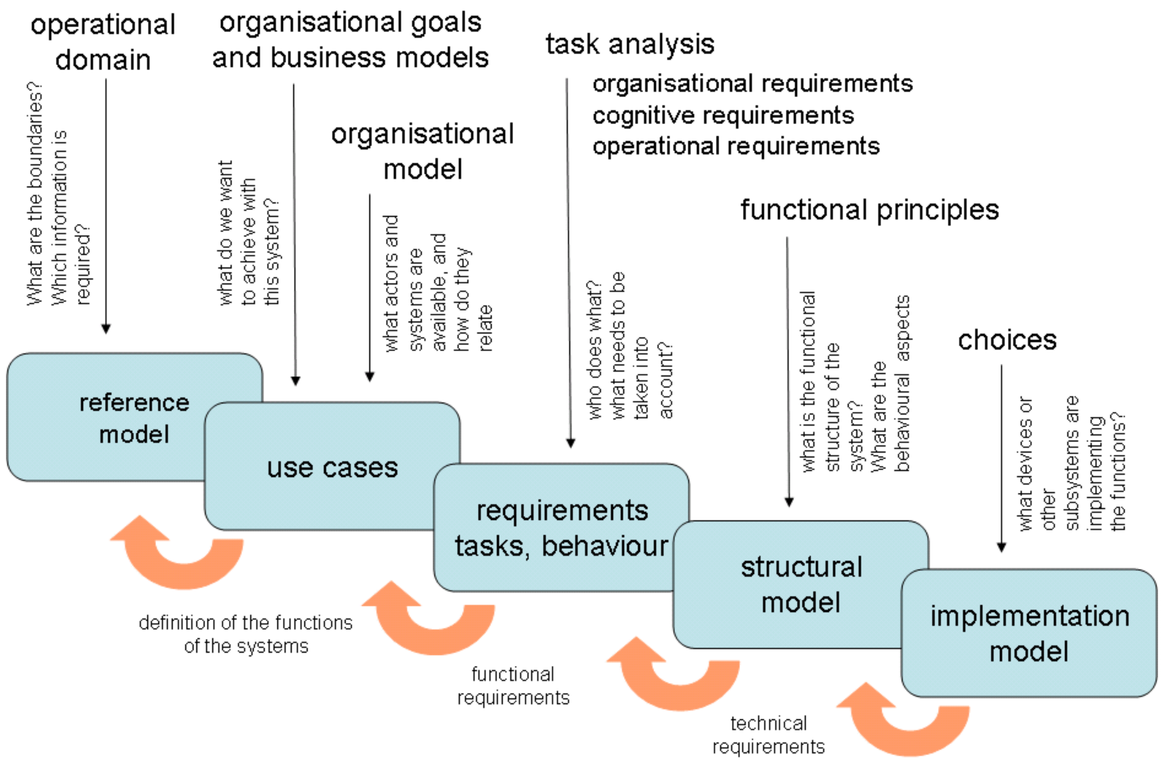

Figure 2: General outline of a design process for the development of augmented teams.

Organization structure
An augmented team is a networked collection of actors. That means that all participating systems, devices and humans must be connected to a network, either directly, or by means of an interface. This is essential because collaborations between team elements may change over time, and to make sure that the system remains coherent all elements must be reachable through the network. We also assume that all team elements can represent themselves, or if they are not able to, are represented by a proxy. Each member must be able to state their capabilities, interpret commands and communicate their status. We need these capabilities for

Task allocation
An augmented team contains humans and artificial systems. Every entity, human and artificial is able to deploy one or several tasks in an operation. As the team operates in a particular environment, tasks are being allocated to entities. Both humans and systems can take over tasks and roles from each other. Resources in a team are finite but for every assignment situation, context and time there is an optimal configuration of these resources. When entities within the team are capable of fulfilling multiple roles, the team can be configured real time. Each human and system is able to fulfill different roles. It is possible that some roles can only be done by humans or by systems. The roles which can be done by both form the basis for an adaptive capabilities.

Information Flow
With smart sensors and actuators and network technologies, the performance of teams can be enhanced. Robust indoor and outdoor communication means, and localization and sensory equipment, situational awareness can be shared in real time. The sharing of relevant information about the environment and team activity, makes it possible to share and distribute processes among team members. This approach opens the door for a new ways of working, but will also require new approaches to information system design. Building an effective flow of information becomes a challenge that can no longer be solved in advance. The information flow will need to be created during operation.

For systems with a fixed deployment of roles problems arise when the environment or changes. These systems might have problems to adapt to changing circumstances. In many cases it is hard to predict every possible situation that can arise as engineer when designing a system. Therefore, any flexibility in role deployment will be more than welcome. This creates the possibility to adapt the deployment of roles within the system and enhance the adaptivity of the system as a whole to the changing circumstances.

Adaptivity requires that roles and tasks can be done by both humans and artificial components. Also an adaptive system allows switching between roles by either human or machine actors. This could be done before an operation, in this case a team is composed before an operation. In this composition tasks are identified necessary to perform the operation. Task of the humans and artificial components are identified. In the composition of the team a match is made between the operational tasks and the availability of tasks of the components of the team. If a component is assigned to a set of tasks an role is identified. This task composition can also be done during the operation and even real-time. The faster this building process iterates the more adaptive the system will be.

Functional relationships in an augmented team arise when a system is taken in to operation. Every element deploys one or several roles and as the system operates in a particular environment, tasks are being allocated by task allocation. A new organization structure is necessary for task allocation and the flexibility of every element. But the role changing approach for teams also brings other advantages. For example robustness when an entity falls out and cannot fulfill a critical team functionality any more, the role can be 'given' to another capable (maybe less capable but still capable) entity.

There are three major features to our augmented team concept: (a) the use of a networked cognitive system model to define a functional model, (b) the use of interaction contracts to organize team structures and behaviour and (c) a collection of guidelines to facilitate the design process. We will discuss these three features in the upcoming chapters.

Experiments with augmented teams
For the development of our augmented team concept, we are experimenting with smart sensor networks and adaptive teaming in an indoor security and safety fieldlab. The fieldlab is set in an actual office environment and covers an entire floor. The corridors of the fieldlab have been fitted with a number of intelligent networked cameras for autonomous observation, and a network of smart radio beacons and tags for tracking and tracing purposes. In addition, there are various information processing systems for situation awareness and forecasting. The fieldlab also includes wireless communication devices and a central command room with information display facilities. The human actors communicate through analog radios, but receive digital information on wireless PDA's. All these elements are networked through wired and wireless network facilities and connected in a service-oriented framework.

The current set of experiments uses an intruder detection and apprehension scenario. The intention is that the smart cameras detect and continue to monitor the intruder, while alerting the safety team. The safety team, initially consisting of a coordinator and two mobile explorers, need to figure out the position of the intruder and capture him by inclusion.

The purpose of this fieldlab is two-fold. We are investigating the potential of smart sensor networks for situated teams, and we are experimenting with agile and adaptive coordination strategies in small teams. Usually, emergency response teams are guided by strict regulations and instructions. This means that tasks and team structure are largely prearranged, and that there is little room for adaptive behavior. Strict agreements on team structure and behavior hamper the ability to respond efficiently to unforeseen events, but are necessary to ensure competent performance in normal circumstances. On the other hand, unforeseen events may call for a departure of the original plan, i.e. agile coordination. Achieving agile capabilities with an augmented, hybrid system, is a challenge, because not only the human side of the team needs to be adapted to a new situation, but also the synthetic part of the team. For instance, when the human coordinator decides to transfer his coordinator role to another team member, the flow of information will need to be adjusted as well, so that the new coordinator receives all relevant information and control options.

3. A networked cognitive system model for augmented teams

An augmented team is in essence a mixture between an information fusion system and decision making and action system. Information fusion processes will play an important part in an augmented team because of the presence of sensing devices. Information fusion builds up towards situation awareness, which is a requirement for effective decision making and response. We need a functional model for our augmented team that caters for both information fusion processes and decision making processes.

There are many architecture models for scalable and modular information fusion and decision making systems, especially in NEC defense communities. For our purposes, we use the Networked Adaptive Interactive Hybrid Systems (NAIHS) model (Kester, 2006) as a foundation. NAIHS builds upon the well-known Joint Directors of Laboratories (JDL) data fusion model (Steinberg, 1999), and adds distributed and cognitive architecture elements. NAIHS provides a layered set of functional categories that form a blueprint for networked cognitive systems.

NAIHS is a functional architecture model. NAIHS decomposes systems into smaller Functional Components (FC's). A Functional Component is an essential function that needs to be realized by an element of the system. For instance, 'Object Recognition' might be a FC, and it could be realized by a subsystem capable of image processing. FC's may be fulfilled by either artificial systems or human actors, by a complex system or a network of simpler components. The NAIHS model does not prescribe what type of actors should take responsibility for a certain function, as long as performance criteria associated with each FC are met during execution. This also means that an element of the system could be responsible for fulfilling multiple FC's, or that a multiple elements jointly achieve a single FC.

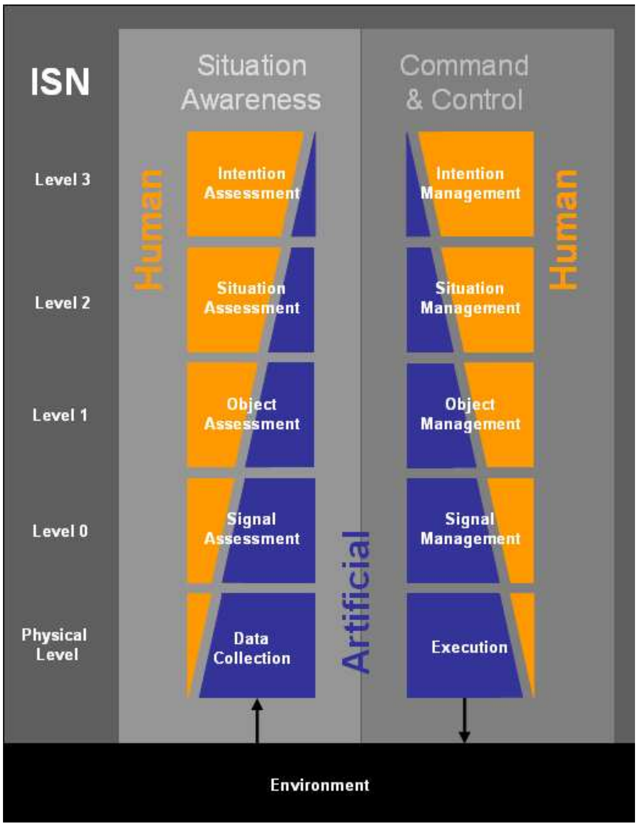

Figure 3: The Networked Adaptive Interactive Hybrid Systems Architecture Model.

NAIHS employs three principles to further structure the FC's: (1) the level of information abstraction, (2) the timescale of desired effects and (3) the physical structure of the system in its environment.

Level of information abstraction

The NAIHS model uses two dimensions to define the level of abstraction of functional components. Firstly, it distinguishes between situation awareness components and 'command and control' components. The left column contains functional components that deal with information fusion and generation of situation awareness, whereas the right column holds components that are directed at decision making and action planning and execution.

NAIHS uses also uses the four levels of information abstraction of the JDL model. Components on level 0 are mainly concerned with basic signal assessment and management processes, such as signal processing, feature extraction, and data processing. At level 1, the object assessment and management level, functions obtain a notion of objects from level 0 data. Functional components at level 2 explore the relationships between the objects of level 1 to come to a degree of situation awareness. At level 3, components estimate the impact of the situation for the given objectives and decide on action.

Together, these dimensions give us eight basic categories of functional components. Jointly, these categories are reminiscent of many decision making processes, such as the well-known OODA (Observe, Orient, Decide and Act) loop (Boyd, 1987).

Timescale of desired effects

Another dimension along which FC's can be categorized is the timescale of their effects. Some processes need to be performed within a limited time span, e.g. raising an alarm or image processing. Other processes may take more time, such as strategic planning. It is important to characterize FC's by their timescale, because the success of course of action depends on correct timing of contributing elements.

Physical structure

The third dimension is the physical structure of the elements that make up the system, i.e. whether an element is artificial or human, and what its specific traits are. The type of embodiment of elements has a distinct impact on information flow and action capabilities. In the above figure, orange and blue areas represent the suitability of human and artificial actors for tasks in the various levels of abstractions. In general one could claim that humans are more proficient in higher level, knowledge-based tasks than artificial systems, while artificial systems are more adept at lower level, calculative tasks. This is mainly because higher level tasks require more context and worldly knowledge than lower-level tasks, and it is still a challenge to properly represent human knowledge and reasoning capabilities in machines. This has been the usual perspective since the early days of AI (see for example Fitts' list (1951), and it is still largely true. However, artificial systems are becoming more proficient in human-level reasoning, and can certainly play an important role in achieving higher-level tasks. Conversely, humans cannot compete with the data-processing capabilities of machines, but they can take on lower-level tasks notwithstanding speed consequences. We will not discuss the suitability of human and artificial actors for specific types of tasks in this paper. We will talk about some related issues in the chapter on design guidelines.

NAIHS uses these dimensions as elemental steering guides for the assembly of effective chains of tasks in a networked system. For further details, see (Kester, 2006).

NAIHS for augmented teams design

The functional decomposition of NAIHS is very useful for our augmented team design purposes. The dimensions in which NAIHS decomposes a system actually identifies the roles of the system structured with the NAIHS model. Decomposing an augmented team identifies the different tasks and the availability of the functional components to fulfill these different tasks. Roles are created from structured collections of tasks.

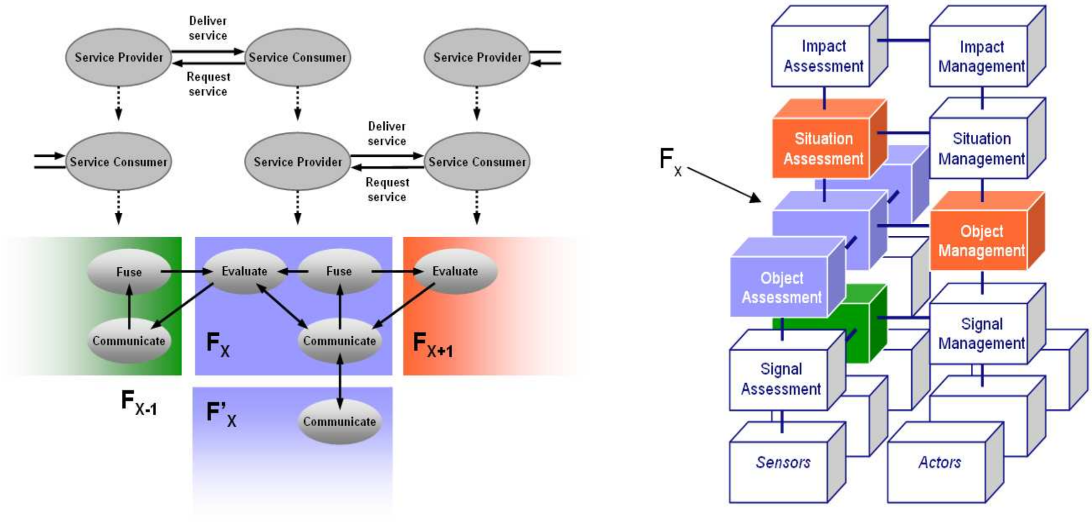

Figure 4: NAIHS Mapping Functional Components onto Interactions

The layout of the NAIHS model facilitates the process of task allocation. By using its decomposition approach, it becomes clear which functional components are able to communicate with each other. For example, the JDL level of a component indicates if communication is possible. Two different JDL levels, for example level 0 and 3 indicate a difficult communication. If the different between the levels is less, there is a better chance of communication between the functional components.

4. Organizing Team Structures and Interaction

The functional model gave us a transparent way to describe the various functions of an augmented team, and how they interrelate. Functional components will be fulfilled by system entities, and through interaction they achieve the team objectives. But how do we organize the teamwork, and describe the various interactions between elements? The dynamic nature of an augmented team makes it unpractical and undesirable to arrange all possible task allocations and interactions in advance. This means that we need a flexible way to describe the tasks of each element, and the relationship it has with other elements. Such descriptions should effectively describe what kind of behaviour one can expect from an element, and can subsequently be used to arrange effective collaborations between elements.

Element interaction in networked augmented teams is comparable with interactions in multi-agent systems. We use a specification framework from the agent research community to represent the organization of an augmented team and the interactions between elements. OperA (Dignum, 2004) offers a comprehensive methodology and specification language to represent structure dynamic cooperation of artificial agents. OperA uses three models to represent multi-agent systems: the organizational, social and interaction model.

The Organizational Model represents organizational goals and requirements. It describes roles, generic interaction structures, performance criteria, norms, ontologies and other aspects of an organization that define the boundaries of operation. These are all aspects that can determined without any knowledge about the actual elements that will make up the organization, but provide essential rules along which elements must behave.

The Social Model represents the agreements that individual elements enter when they become part of the organization. Simply put, when an element takes on a certain role in the organization, it signs 'job contract' that specifies what that role involves. This 'social contract' includes descriptions of the tasks associated with that role, the timing constraints, obligations and permissions and so forth. It also specifies the structural relation with other roles, and the associated hierarchy and line of command.

The Interaction Model represents dynamic agreements on interaction between the elements themselves. Elements negotiate interaction commitments with each other for each task that requires their interaction. They enter such a negotiation process to find an interaction scheme that best fits both elements and satisfies their needs. The result of this negotiation is an 'interaction contract' that specifies the exact format and frequency of interaction. It can also include agreements on how to solve conflict and other process agreements.

OperA uses a formal description language to represent the contracts, so that the organization can be validated through logical verification methods. Logical verification of the models can reveal unsatisfied objectives or contracts that are not fulfilled. This is, of course, an interesting feature for distributed systems for with respect to task planning and system performance assessment.

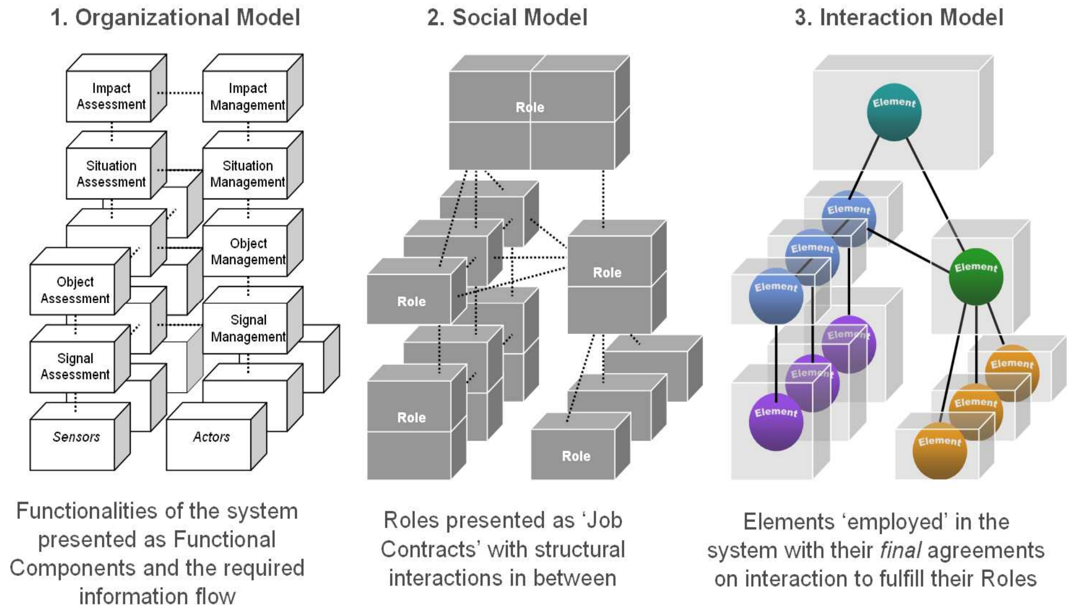

Figure 5: Using OperA to implement the organizational structure of a NAIHS functional model

The OperA methodology fits very well with the functional approach of the NAIHS model. They actually complement each other, and thus make a suitable basis for augmented teams. NAIHS gives us a clear functional structure for cognitive, networked systems, and OperA gives us the tools to realize and manage its organizational structure. Figure 5 shows how this works out. A role in the OperA organizational model is quite similar to a Functional Component (FC) in NAIHS. The Organizational Model becomes a network of FC's, structured following the NAIHS decomposition dimensions. In the social model, elements agree to roles, and work out interaction agreements among themselves. Elements will most likely take on the roles that are similar in nature with respect to required knowledge, timing constraints or level of abstraction. In this way, the role assignment among elements will lead to a natural distribution of tasks, based on capabilities and availabilities.

The coupling of NAIHS and OperA gives us a sound basis for the design and management of augmented teams. NIAHS provides a suitable functional model that fits well with information fusion and decision making processes, and that is open to situation specific features. OperA provides representations and techniques to structure the organization process.

Element Interaction and interaction contracts
In an augmented team, the information flow must 'bring' the right (relevant) information to the right functional component. The functional and organizational model suggests that the information flow emerges from role adoptions at the social level and interaction agreements on the interaction level. Elements need to ensure that they receive the proper information from other elements in the right form, and at the right time, and if necessary trigger changes

at the social or organizational level to fulfill their information needs. Whether elements are satisfied in their needs depends heavily on the interaction agreements they have agreed to.

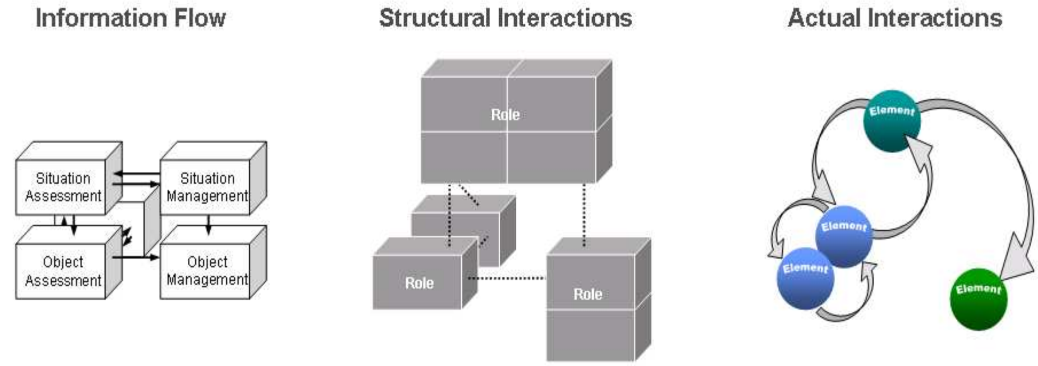

Figure 6: The basic flow of information results from the relationship between functional components in the organizational model. After role allocation, the structural interactions between roles become evident. From here on, the elements work out the actual interactions through negotiation processes.

There are different types of interaction between elements. For example, elements can interact in a hierarchical manner, act cooperatively or engage in an advisory interaction. Which interaction type is optimal depends largely on the situation and state of organization. For example, Under severe time pressure there is usually little time for extensive collaborative problem solving, so hierarchical interactions will be more suitable. To make it easier to describe elements interactions, we use work from Parasuraman (2000) on levels of automation. He proposed ten levels that describe the degree of autonomy a system has with respect to a human operator. We use his levels to facilitate the construction of social and interaction contracts between elements, as to make it easier to define the responsibilities of entities. The table below list ten levels of Parasuraman, adapted to the relationship between a Functional Components A (FC_A) and a functional component B (FC_B). The Levels ranges from total autonomy of FC_B to total autonomy of FC_A:

Type	Level of Automation	Description
No Interaction	10	FC_A decides everything and acts autonomously, ignoring FC_B,
Informative	9	FC_A informs FC_B only if FC_A decides to
Informative	8	FC_A informs FC_B only if asked
Informative	7	FC_A executes autonomously, then necessarily informs FC_B
Collaborative	6	FC_A allows FC_B restricted time to veto before autonomous execution
Collaborative	5	FC_A executes it's own suggestion if FC_B approves
Collaborative	4	FC_A suggests one alternative
Collaborative	3	FC_A narrows the selection down to a few
Collaborative	2	FC_A offers a complete set of decision / action alternatives
No Interaction	1	FC_A offers no assistance: FC_B must take all decisions and actions

We can group the ten level into three types of element interaction (a) No interaction, (b) Informative, and (c) Collaborative. On levels 1 and 10 there is no interaction. The elements do not influence each other, and act autonomously. In the informative levels, there is a varying degree of information sharing, but no option to exert direct influence by the receiving element. In the collaborative levels, the interaction range from an advisory role of A (level 2) to a executive role with a limited option for B to intervene (level 6). The collaborative levels could also be regarded as service-oriented interactions, where A offers a service in response to a request by B.

When an element accepts a 'job contract' for a specific role in a system, it either implicit or explicitly accepts responsibility for a given set of tasks. A task always has two parts: an action part and associated communication responsibilities. The responsibilities for a set of tasks are formalized in this job contract, which describes which action should be taken and how to communicate with whom. We can use the above categorizations to have the communication responsibilities adapt rapidly to changing circumstances without needing to renegotiate the action part of the social contract. For instance, under time pressure, an element could choose to shift its autonomy level from collaborative to informative when his peer element fails to respond quickly enough. Elements could allow such autonomy shift in their interaction contracts, and greatly accelerate interaction agreements.

Levels of adaptivity

Humans are skilled at adapting to changing circumstances. Technical systems are usually unable to swiftly change their behaviour. One of the key aspects of our augmented team concept is an inherent capability for adaptive structure and behavior. This means that the team must be able to change its formation and course of action in response to certain circumstances in a short period of time. The three OperA models give us an interesting option to describe such adaptive behaviors in three levels of adaptivity.

Level	Changes	Description	Impact
1	Real-time adjustments in the Interaction Model	Elements change their interaction agreements to adapt to a certain situation. Example: Two elements decide to use a different form of communication in response to new circumstances.	Low
2	Real-time adjustments in the Social Model.	A role is transferred from one element to another element that is better qualified. This will most likely cause changes in the Interaction Model too because of the different features of the new element. Example: the 'coordinator' role is transferred from the actor in the control room to an actor in the field, because he is in a better position to coordinate other actors.	Medium
3	Real-time adjustments in the Organizational Model	At this level, the organization is redesigned in some degree. This might involve added or deleting roles, changing objectives or behavior rules. Changes on this level might necessitate changes in the Social and Interaction Model too. Example: Because several elements have stopped working, the objectives can no longer be reached. In response, new objectives are set with the remaining set of elements.	Severe

Managing contracts and adaptivity

Social and interaction contracts are normally not present in an explicit form in organizations. Human teamwork is bound by common agreements that are usually informal in nature. In an augmented team however, we cannot depend on informal understandings, since artificial entities need to comprehend agreements in order to participate. The presence of artificial team members in augmented team makes it necessary to make every collaborative agreement explicit and accessible. This also includes agreements between humans. If human actors reach an interaction agreement, their interaction contract must be available in the organization so it can be administered and monitored by other elements. This means that either the actors themselves need to produce the contract, or that another element needs to capture the details of the contract and make it available.

We believe that it is wise to define a contract manager role. This functional component is responsible for maintaining an overview of all elements and their contracts. Upon entering an augmented team, an element needs to accept the interactions contracts that are associated with the roles it will fulfill. The contract manager manages this process and keeps an administration of all contracts. Because of its administrative role, the contract manager is also in position to identify which element fulfils which functionality, and can signal mismatches and impossibilities in task allocation.

5. Design Issues and Guidelines

In the previous sections, we introduced a number of concepts design of augmented teams. We introduced a functional model (NAIHS), introduced a methodology that we can use to manage organizational structure and behaviour (OperA) and gave some insights on how to attain adaptive capabilities. The dynamic deployment of roles among human and artificial entities is an interesting proposition, but there are many issues that need to be addressed. Some result from the obvious differences between human and artificial entities, others result from adaptive behaviour itself. In this section, we list some design issues and guidelines that follow from our approach and that we observed in practice.

1. Define who is responsible for roles and task allocation
Role and task allocation could be a joint responsibility of all entities or the responsibility of an allocation manager, or both. This is an important matter, because it directly sets the stage for the chain of command. One could also imagine a hybrid approach in which a central commander is responsible for allocating strategic planning and decision making tasks, and where lower-level tasks are allocated through self-organizing methods.

2. Set boundaries for dynamic allocation
Not all tasks may be suitable for allocation to artificial entities. Especially tasks with a high-risk profile, or those that require a large amount of context awareness might not be executed by artificial elements. In addition, accountability might play a role here. It is important to define upper and lower bounds of automation, i.e. which tasks may and may not be allocated to artificial entities? During the design phase, it should become clear which tasks, or roles for that matter, are open for dynamic allocation, and which should be pre-allocated.

3. Ensure observability of attributes and responsibilities
Attributes and responsibilities of elements, both artificial and human, should be clear and observable. This is an essential condition to enable dynamic role deployment. In a regular organization or system, it is clear from the start who or which system is responsible for which task. In a dynamic setting, assignments of elements change, and there is a distinct danger of loss of organization awareness, i.e. keeping an accurate overview of who is part of the organization and their responsibilities. Organization awareness is essential for proper coordination. Therefore, we advocate the use of explicit social contracts to represent responsibilities and capabilities, and the creation of an administrative role to keep an overview of all elements and their contracts in an organization.

4. Select a type of adaptivity
There are many forms of adaptivity. For instance, we discussed three different levels of adaptivity in an earlier section of this paper. There are many more forms of dynamic behaviour, and it is important to define the desired type of adaptivity, so that the design process can accommodate it. An important decision that needs to be made in the design phase is whether to use prearranged behavioral patterns for adaptive behaviour, or to have adaptivity emerge from an internal collaborative process. In other words, do the elements need to reorganize themselves, or do they just switch over to another 'mode'? The former is perhaps the most interesting and effective approach, while the latter is far more easier to design.

5. Issues caused by multi-level or multi-role allocation of an element
It is possible for elements to take on multiple roles or tasks with different characteristics, such as a different level of abstraction or a different timescale. For each role change, it needs to be checked whether an element is not faced with roles that are too divergent, and will cause performance issues. For instance, a complex information analysis task might not fare well with an immediate apprehension task that would send the actor into the field. There need to be criteria available to assess the combination of multiple roles.

6. Prevent communication and interaction issues after role change
All kinds of communication issues may occur when heterogeneous groups of entities collaborate. These problems are commonly known as interoperability problems. The question

is whether the elements can understand each other and make themselves clear. Before two elements can collaborate, there must be an agreement on how to communicate, and through which means. If the elements communicate at different levels, they will most likely fail to reach an agreement. As a rule of thumb, we suggest that elements should only communicate with others elements on the same JDL level (see the NAIHS model). An element that functions on level 3 (e.g. a human actor) will most likely not be able to converse with elements on level 1 (e.g. a radar), due to a different level of abstraction.

7. Prevent loss of situation and system awareness among human actors
In an augmented team, artificial elements will play a far more active role than usual. That means that typical human teamwork tasks, such as maintaining a common understanding of the situation or keeping each other alert, will change. There is a risk that, because of artificial elements taking over many tasks, that human actors lose oversight and become detached form the actual situation, i.e. 'out of the loop'. To prevent this from happening, we need to make sure that the internal processes and criteria are observable, and that human actors remain engaged in the processes.

8. Counter complacency and skill degredation
If automation is highly reliable, people tend to trust the system quickly. This over-trust is more prevalent if the operator is also engaged in other tasks. This may lead to dangerous situations in case of failure. Similarly, if the operator does actively exercise necessary skills, they will decay over time. In case of automation failure, the operator will not be able to step in. For instance, if the system does all the low level information fusing on raw data, operators might not understand what is happening because they are not actively-engaged. If for some reason a human operator needs to take over some of the more low-level roles, then out of the loop unfamiliarity might occur (Wickens, 2000). There are two way to prevent this unfamiliarity as much as possible, (a) deliberately have human actors engage in low-level tasks to preserver skill and vigilance, and (b) regularly inform human actors about the various activities within the organization. Both stimulate the human actors to resist complacency and gain an actual understanding about the information flow within the organization.

9. Prevent unnecessary increase of mental workload
Well-designed technical systems can reduce the mental workload of human operators but 'clumsy' automation may increase the mental workload unnecessarily (Woods, 1997). In our augmented team concept, the feeling of 'clumsy' automation could follow from a bad allocation process. It will probably not be possible to prevent allocation problems altogether. There, as a alternative solution, we suggest that human actors always have an option to give feedback about their interaction peers. If a human actor is not satisfied with the way an element behaves after a role change, he should be able to provide feedback and trigger a change process to fix the interaction.

10. Gradually build up user acceptance
The behaviour of an augmented team is quite a departure from ordinary use of technology. We are working towards a setup in which role and task allocations are mutable, and in which the artificial part of the system may play a distinct pro-active role. If the starting point is an existing organization, then extra care needs to be taken to let the human actors get used to the new way of working. Without proper user acceptance, user will mistrust the system and have less job satisfaction.

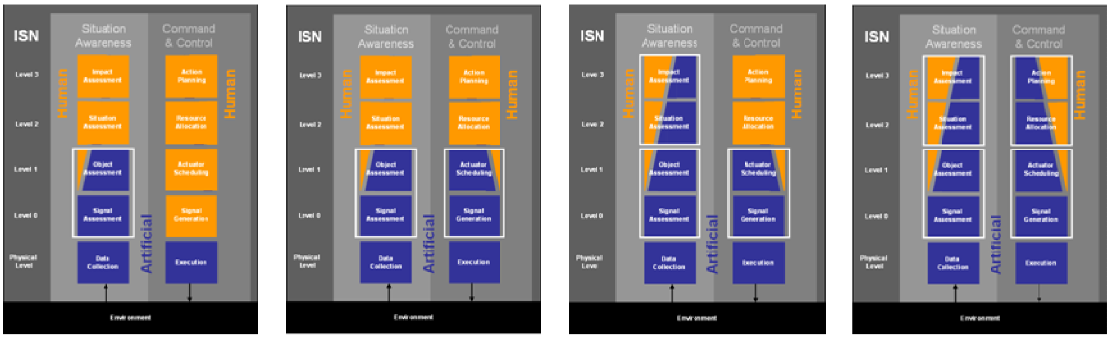

Figure 7: A staged implementation strategy. In each stage, the degree of involvement of artificial elements increases. The above example shows a trajectory from Observe to Act to Orient to Decide.

User accepted can be increased by using a staged implementation of automation. In a staged approach the involvement of artificial elements is increased with each stage. This approach will let the user understand the capabilities of the system in phases, and will reduce the risk of mistrust or complacency.

6. Conclusions

This paper discussed the challenge of turning networks of sensors, computers, agents and humans into hybrid teams that are capable, effective and adaptive. We propose a functional model and illustrate how such a model can be put into practice and augment the capabilities of the human organization. We specifically focus on the interaction between the human and artificial parts of the system, with specific attention to task delegation and role adjustment.

We use the Networked Adaptive Interactive Hybrid Systems (NAIHS) model as a blueprint for our hybrid organizations. The NAIHS model considers both man and machine to fulfill functional components of the system and distinguishes three principles to decompose a system into roles: information abstraction, the timescale of desired effects and the physical structure of the system in its environment. To explicate the interactions between these roles, we make use of OperA, an organization modeling framework from multi-agent systems research. These models make it possible to express various aspects of a multi-agent organization, and as a result, help to organize a collection of autonomous agents into a coherent system. The Organizational Model determines which roles are present in the organization. The Social Model links actors to roles, and the Interaction Model describes the practical collaborative aspects between actors during task execution. Despite of the obvious differences between human and artificial actors, we find that these models also form an interesting basis to build hybrid organizations from.

Every entity, human and artificial fulfils one or several roles in a system. As the system operates in a particular environment, tasks are being allocated to entities. However, systems with a fixed deployment of roles might have problems to adapt to changing circumstances. Usually it is hard to foresee every possible state of the environment when designing a system. This creates an inherent need to make augmented teams adaptable. The team should be able to change the deployment of roles when circumstances change. This does not only include the role transfer from a human actor to the networked system, but also vice versa. In this paper we describe guidelines to implement adaptivity in augmented teams by introducing interaction contracts. Interaction contracts establish the ground rules for actors regarding the role they deploy in a given situation. The use of interaction contracts facilitate the interaction and role transfer between actors, and gives a practical solution to articulate teamwork requirements in augmented teams. We believe that these interaction contracts are essential to fulfill basic cognitive engineering needs such as mutual observability, directability and resilience.

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