Shared Situation Awareness Architecture (S2A2) for Network Centric Disaster Management (NCDM)

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Abstract

Having shared situation awareness (SSA) in network centric disaster management (NCDM) lead to virtual collaboration, virtual organization and self-synchronization among people; therefore, having SSA reduces operation cost and risk and increases speed of responsibility and operation and total performance of decision-makers. In this paper, we present a new architecture to provide SSA for NCDM using multi-resolution level architecture. In this architecture decision-makers request the required SSA and the system provides the requested SSA for performing shared action plan. According to this architecture, knowledge organization, activity principles, theoretical approach for design, control and software engineering will be provided for shared situation awareness system. Finally, based on our proposed methodology, a technology for NCDM has been discussed.

Keywords: *Shared Situation awareness, Network centric disaster management, ELF model, Multi-resolution level representation, Data fusion.*

1. Introduction

Poor decision-makings lead to serious consequences in disaster and crisis management as network centric organization. Hence, Situation Awareness (SA) is very critical in these kinds of problems and having complete and accurate SA as the most critical basis of successful decision-makings is the main issue in dynamic and complex systems. Endsley defines the SA 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” [1].

SA is a form of knowledge obtained from current information related to the surrounding environment which an individual requires in order to achieve its goals. In other words, SA is the perception of the impact of information, actions and events on goals and objectives in the present time and future. The key factor in the process of decision making is based on correct SA. Therefore, in obtaining SA, mental models affect the process of achieving reality and SA helps mental models get closer to reality [1][2]. Organizations based on team cooperation, including NCDM are characterized by handling the dynamicity of environment changes using shared SA (SSA) for learning and adaptability to changes. In these organizations, the environment changes over time and also measured values are different; therefore, due to changing the user requirements in different conditions, different components should be added or removed without disturbing or stopping the system. Another feature of these systems is the mobility of their components. Thus each element of the system has different life time, communication bandwidth and power consumption. In network centric organizations, the bandwidth required for communication among entities is limited. On the other hand, because of dynamic environment, flood of data received from the other entities needs more bandwidth. Therefore, the components of the SA may not be provided in specific time. As a result, the absence of SA in the time required, the robustness and stability of such systems is being threatened [3].

In most network centric organizations like NCDM, SSA is a same view shared by different individuals toward a set of specific activities. In other words, individuals obtain SSA by observing a shared operation picture and their own mental processes [4]. Therefore, SSA consists of identical or similar views by members of the team toward a situation.

Providing SSA follows from several factors such as individual factors, team factors and environmental factors which have significant influence on SSA formation [5]. The main goal of this paper is offering a new architecture for achieving SSA for network centric disaster management (NCDM) to meet SSA for all team member that take part in disaster management operation.

According to Endsley's definition, perception, comprehension and projection as the main part of the SA, describe the mental attributes (Fig. 1) [1][4][6]. Therefore, SA has become as a mental phenomenon. Based on goals of the mission and the ability to understand the objectives, models are selected. Furthermore, mental model has a great impact in directing the attentions for perception from environment and providing comprehension and projection.

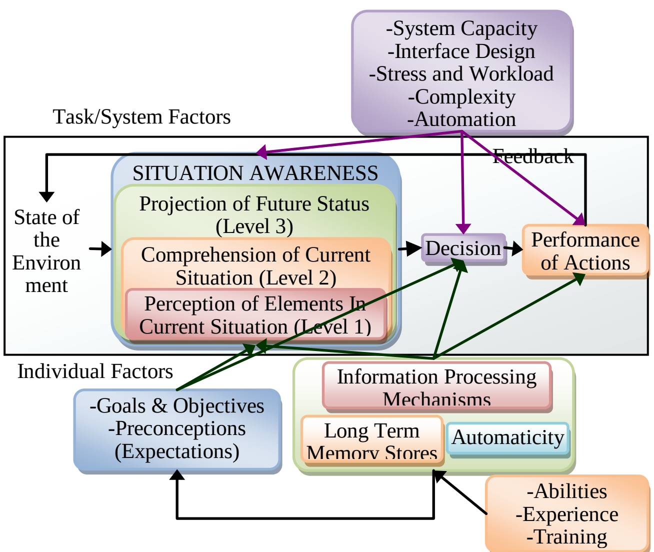

Fig. 1 Endsley's Situation Awareness Model [6]

The first level in achieving SA or perception is to perceive the status, attributes and dynamics of relevant elements or critical factors in environment. Comprehension of the situation is based on a synthesis of disjoint critical factors and understanding what those factors mean in relation to the operator's goals and comprehension of the significance of objects and events. The ability to project the near future actions of the entities in the environment forms the projection level of situation awareness that allows people to act in a timely and effective manner. Later, a fourth level which is called resolution was added to this model [6]. Resolution level provides awareness of the best path of following to achieve the desired outcome for the situation. Interacting among people in resolution level and achieving these kinds of outcomes, provides SSA.

The designed architecture must overcome environment complexities. Therefore, the system has to be designed with more complexity than that of the environment. This article seeks to design processes presenting SA for individual team members and SSA for the whole team. Therefore, an architecture has been proposed for SSA using multi-resolutional levels and an intelligent systems model called Elementary Loop of Functioning (ELF) [7][8][9][10][11]. In this architecture, based on specific goals and objectives, decision makers achieve SA regarding their decisions and SSA regarding their team goal. In this architecture, based on desired operational process, a series of threshold values for each level based on existing algorithms must be specified by the designer.

The remainder of this paper is organized as follows: Section 2 describes multi-resolutional representation of intelligent systems. Section 3 proposes the SSA Architecture (S2A2) based on multi-resolutional representation. Section 4 introduces designing the CNDM. Finally, section 5 draws the conclusion.

2. Multi-resolutional Representation

In this section multi-resolutional computational theory is expressed. Any intelligent system consists of two parts: internal, or computational and external, or interfacing the reality of application. The internal part can be decomposed into four internal elements (subsystems) of intelligence: sensory processing (SP), world modeling (WM), behavior generation (BG), and value judgment (VJ). Inputs to and outputs from the internal part of intelligent systems are realized via sensors and actuators can be considered as external parts. In organizational or social systems, sensors and actuators can be individuals or groups of people.

According to intelligent architecture for SA system and multi-resolutional representation, the elementary loop of functioning (ELF) of an intelligent system can be defined at each level of the SA system and should be consistently closed in each communication link between the subsystems of ELF as described in [7][8][12]. In this architecture three main functions named grouping, focusing attention and combinational search are defined that provide different levels of resolution. Fig. 2 shows the ELF model.

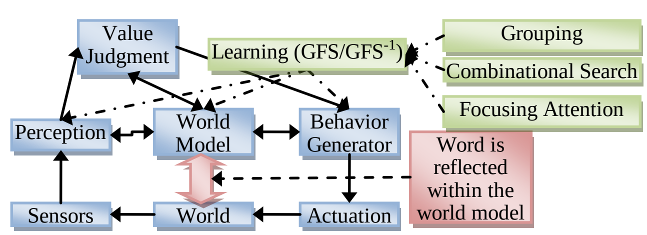

Fig. 2 Elementary Loop of Functioning (ELF) [3]

These computational loops from sensing to acting, from WM to SP, and from BG to WM to VJ and back again, are repeated many times within the internal part of the intelligent system at many different levels as the units of information in all of the subsystems are aggregated into entities, events, and situations, and goals are broken down into sub-goals and generate commands. Within each loop, WM maintains a knowledge database with a characteristic range and resolution. At each level, plans are made and updated with different planning horizons. At each level, short-term memory traces stored sensory experiences over different historical intervals. At each level, feedback control loops have a characteristic bandwidth and latency. Fig. 3 illustrates the relation between the processes of the ELF model [7]. As can be seen, these processes are consistent with presented models for data fusion and situation awareness.

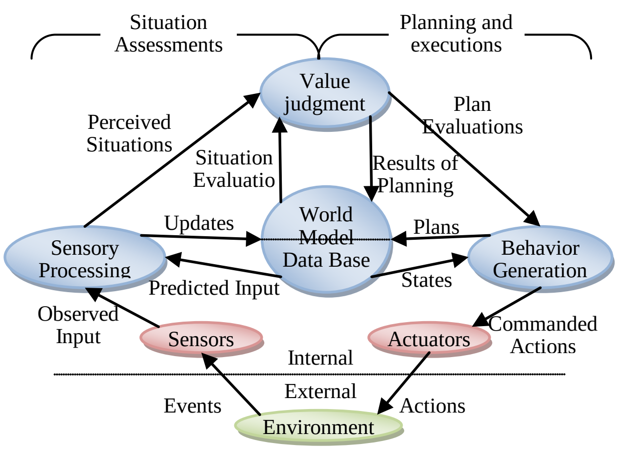

Fig. 3 Functional relationships between modules of ELF [7]

SP algorithms fuse input data from a wide variety of sensors over time and space and provide unified perception of the state of the world. The WM process provides best estimate of the state of the world and includes a database of knowledge about the world. Observed states of the world and the predicted results of hypothesized plans are evaluated by VJ process. This process provides the basis of decision making. And finally BG process provides behavior that selects goals and plans and executes tasks.

3. Shared Situation Awareness Architecture (S2A2) Based on Multi-resolutional Representation

Most processes related to SA are mental; therefore the architecture based on abstraction level of human mental processes is required. Four levels of abstraction in human fusion or mental process is suggested[13]: a sensory motor calculation of the difference, a categorical calculus of objects and relations, a modal calculation that combines concepts into deductive, inductive and abductive propositions that are falsifiable and finally an ecological calculus of interacting systems. Comparing these four levels with Ensley's model of situation awareness, we can map them into perception, comprehension, projection and resolution levels in Endsly's model respectively.

In our previous work[3], based on cognitive theories using multi-resolutional levels, the architectural reference model for intelligent systems named Elementary Loop of Functioning (ELF) [7] and inspiring data fusion and SA models, A new architecture named S2A2 was introduced that provides SSA for team members in network centric operation. The major difference of our architecture with others is its emphasis on cognition. Another innovation of S2A2 is dynamic planning for providing SA and SSA based on intents of decision-makers fed into the system in an online manner.

For each element of multi-resolutional representation, some threshold values, constraints and user preferences must be determined that are given from higher level or user. Using multi-resolutional representation and threshold values related to the desired goal in each level, we can prove the S2A2.

Fig. 4 illustrates S2A2 based on multi-resolutional representation. Decision maker in resolution level requests the needed information based on desired goal from the system. This information includes SA, ability or intention that is achieved by the system. Value judgment process performs process refinement and dynamic planning. In this architecture each decision maker shares the obtained SA with others and finally SSA for all individuals is provided.

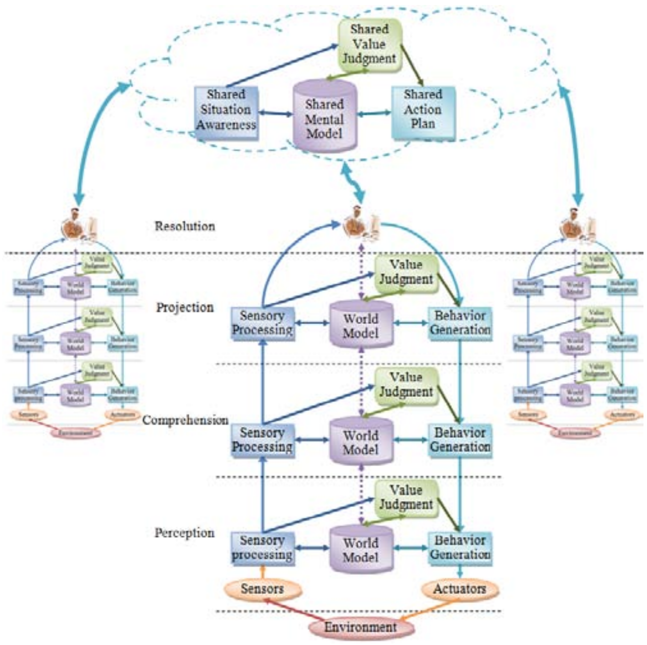

Fig. 4 S2A2 based on multi-resolutional levels

The first three levels named Perception, Comprehension and Projection in each SA system provide required SA for decision-maker and in the Resolution level SSA achieves through sharing the obtained SAs from SA systems. The BG and the VJ processes in each level provide dynamic planning and the SP process in each level integrates required information obtained from environment. WM process in each level stores defined concepts based on operational process goal and obtained SAs and plans. Reference [3] contains more details on SA system processes.

Considering fig. 4, in the Resolution level, based on operational process and planning for shared action plans, required SAA for team members and SA for each decision-maker are instantiated. Decision-makers in the Resolution level give required information for SA obtained from the SSA process to the BG process in the Projection level of their SA system. Each SA system gathers required SA through processes in each level of Projection, Comprehension and Perception level and finally provides required information for the decision-maker. Afterwards, each decision-maker in the Resolution level shares the obtained SA with others based on main goal of the network centric organization; as a result, SSA obtains for all team members.

Shared VJ in the Resolution level evaluates cognitive thresholds as necessary condition for coherency in the network centric organization's operational processes. Cognitive thresholds emanate from the culture of the organization [14][15] and obtain from Goal Directed Task Analysis (GDTA) [1]. In proposed architecture, based on some requirements for necessary conditions such as organizational culture, individuals' capability and tools, training methods, leadership and doctrine, as threshold values for coherency of the SSA formation must be defined before and throughout the mission.

4. Designing the NCDM

To show different aspects in our architecture, the NCDM is presented. The main goal of NCDM is gathering the information and rescue teams' capabilities, the impact of the crisis, selecting and fusing related information about the crisis, resource allocation, and performance evaluation of teams and planning the mission. In the disaster management headquarter, base on existing crisis and the GDTA, one or more roles are assigned to one or more Generic Management Entity (GME) for obtaining specified goal or sub-goals and cognitive thresholds are also defined. In fact, each GME selects one or some operational zones based on its role. Then GME manages its members with related capabilities as Local Management Entity (LME) to act in the zone or receive regional data. The GMEs can get access to different sensors and information resources to get crisis situation. Using a secure communication network, all GMEs and LMEs can communicate with crisis management headquarter and others and can share the provided information. Fig. 5 shows general schema of NCDM for crisis management.

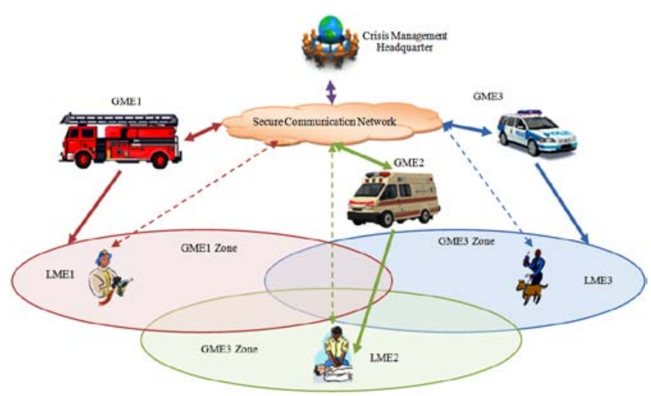

Fig. 5 General Schema of NCDM

Based on our proposed architecture, first, disaster management headquarter determines roles and cognitive thresholds for each GME based on the specified goal. Assigned members in each GME cooperate with themselves for obtaining the best shared action plan based on required shared mental model (SMM) that is achieved from SSA. The LMEs also have capabilities to play role to perform desired action based on issued commands. An SSA System is embedded to each GME which provides SSA and SAs related to the specified operational zone.

To explain details of the NCDM, an example of a disaster management scenario is presented. In this scenario based on TDGA and a natural disaster such as earthquake, tasks and operational zones are assigned. Each GME based on its roles and goals in defined operational zone decides to act. The assigned members in GMEs and LMEs have to get the SMM to plan the best shared action. Hence, required SSA based on specified goals has to determine in the SMM actor. The assigned SSA along with specific threshold feed to the SSA System. The SSA System provides information such as possibility of surviving citizens by LMEs.

In our architectural, required information that each GME has to receive from the environment determines based on required SSA that is assigned by members in GMEs as system operator. GME operators obtain required SSA to reach SMM by instantiating obtained thresholds from cognitive thresholds and also required SSA (e.g. which team in which zone could rescue?).

The SSA system provides required information plan of each GME independently based on the required SSA. Information plan includes determining citizens who are waiting to rescue, capabilities of teams, probability of surviving which are performed in the synthesis phase. If the information plan could satisfy the required thresholds based on GME capabilities, it will send to the Projection level of SSA system to generate the situational plan. When situational plan is obtained, the Comprehension level generates situational indexes. Situational indexes in this system are people who are waiting for help, rescue teams and survived citizens, events related to the situation and relations between citizens and rescue teams in specific time and place. Therefore, information resources have to provide for identifying situational indexes. By determining required information resources of each situational index in the Perception level, GME receives related environmental data.

By receiving the environmental data, agents of the Perception level provide the state vectors of environmental data include information of citizens, place of rescue teams and other environmental data and send them to the Comprehension level. Agents of the Comprehension level transform the state vectors and relation between them into specific semantic format and form the situation vector based on generated situational indexes. In The Projection level, related agents based on provided situational vectors, estimate set of possible actions based on current situations and provide new situations. In other words, probability of surviving of each citizen by rescue team is checked. By providing SA in each GME, all GMEs share provided SAs with each other, assigned members in GME can obtain SMM by received data and send required commands to LMEs and finally, perform the best action.

5. Conclusions

In this paper, Inspired from the multi-resolutional representing of the intelligent system's model named ELF in addition to existing data fusion and SA models, an architecture for designing and developing the network centric disaster management (NCDM) based on SSA architecture named S2A2 is proposed. The major difference of our architecture with others is its emphasis on cognition. Another innovation of S2A2 is dynamic planning for providing SA and SSA based on intents of decision-makers fed into the system in an online manner. Finally, a practical example, the technology is used for developing NCDM for crisis management.

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