Modelling Situation Awareness Information for Naval Decision Support Design

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SUMMARY

In nowadays complex and dynamic changing military environments supporting Situation Awareness (SA) of operators is a prerequisite for situation- and task-adequate decision making and action accomplishment. SA refers to information on three levels which represent relevant elements of the operator environment, element patterns describing complex mission situations, and projections of future states and dynamics of elements. A means for supporting SA of operators are adaptive knowledge-based user interfaces. For developing such interfaces information of the three different SA levels which operators need in performing their tasks have to be specified and modelled. One source from which that information can be acquired are scenarios which have to be developed in any case for system design as well as for operator training. For specifying relevant SA information a model of the problem domain has been developed which comprises the True World of scenarios, the Sensed World of detected tracks, and the Deduced World of concluded track information. To uniformly describe these different worlds an object oriented approach has been applied which is based on static and dynamic scenario and track objects which are specified mathematically. Attributes and operations of track objects constitute elements and patterns of relevant SA information to be identified. Additionally, the described mathematical model of track objects constitutes the basis for developing a software specification with the object-oriented Unified Modelling Language UML. Using a Navy Anti-Air Warfare scenario as an example the application of the developed modelling approach is demonstrated in detail.

1.0 INTRODUCTION

Recent technological developments of sensor and weapon systems as well as of all kinds of military command, control, communication, and information systems (C2/C3/C4I) have increased the amount and complexity of information at hand while the time available to process that information has dramatically decreased in present-day military operations. Additionally, in actual military operations, e.g., in Littoral Warfare, Crisis and Low Intensity Conflicts, or Missions other than War, operators who are responsible for planning and decision making are faced with natural dynamic situations. These situations can be characterised by extremely rapid changes in the tactical situation, highly insufficient, i.e., uncertain and/or incomplete information, and a large variety of potential situational hypotheses. Operators as decision makers undergo high mental stress due to the need to respond quickly and accurately, or face potentially fatal consequences. Human decision making in such situations is based on a large scale on situation awareness of operators which is defined as the state of operator knowledge about the external environment resulting from situation perception and situation assessment (Endsley, 2000).

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2.0 SITUATION AWARENESS AND ITS SUPPORT

Situation awareness (SA) is the constantly evolving degree of accuracy by which operator's perception and assessment of the external environment reflects reality. Therefore, SA is the prerequisite for situation- and task-adequate decision making and action accomplishment in complex dynamic situations (Fig. 1). As being the result of a reliable assessment of the situation in which, e.g., a ship operates, SA is vital for the successful completion of its mission. Therefore, intending to support military operators in decision making and action taking in any case and first of all SA has to be supported. According to Endsley, operator's SA is the perception of elements in his/her environment within a volume of time and space, the comprehension of their meaning, and the projection of their state in the near future. To specify required information Endsley (1995) distinguishes three levels of SA: 1.) Perception of the information elements in the environment, i.e., the states, attributes, and dynamics of relevant elements in the operator environment. 2.) Comprehension of the current situation by information processing based on a synthesis of disjoint level 1 elements by putting them together to perform patterns for getting a holistic picture of the environment and an assessment of the current state 3.) Projection of future states on the basis of actions of elements in the environment. This is achieved through knowledge of the states and dynamics of the elements and comprehension of the situation for both level 1 and level 2.

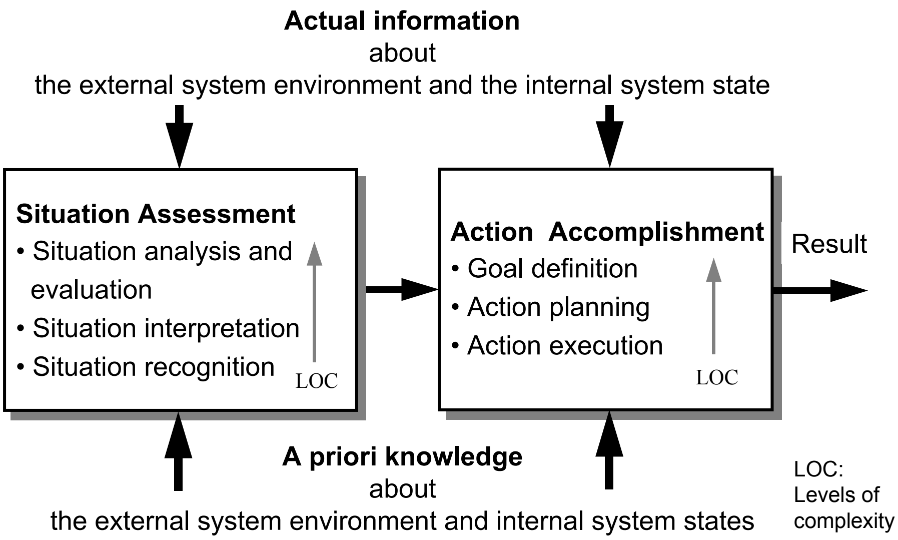

Figure 1: Structure of Human Problem Solving Activities.

To establish SA, information about the environmental situation from own sensors or other sources of significant data and conditions must be gathered and processed. This information concerns the external system environment as well as the internal operational state(s) of own combat (sub)system(s) involved. But not only actual situation information is necessary for accomplishing the process to reach SA. For Level 2 and Level 3 of SA which contain assessment steps pre-existing relevant "a priori" information is necessary to relate actual information elements to already known situational information and patterns. The following considerations will be focussed especially on a priori information about the external system environment. SA occurs as a consequence of integrating a priori information together with actual information by cognitive processing skills that include attention allocation, perception, data extraction, comprehension, and projection (Salas et al., 1995). In order to provide a reliable information basis for carrying out missions it will be necessary to assess and reassess the situation on a continuous basis. Therefore, to not only establish but also to maintain SA the continuous extraction of information about a dynamic system and/or environment, the integration of this information with previously acquired knowledge to form a coherent mental picture, and the use of that picture in directing further perception of, anticipation of, and attention to future events is necessary (Wickens, 1996).

Operator support by intelligent and adaptive knowledge-based user interfaces is considered to be a viable approach to overcome some of those difficulties decision makers are faced with when having to cope with complex command and control systems in novel military situations. It may currently not be possible to design a system which can cope with all conceivable events in highly ambiguous situations, e.g., with those found in present-day military operations. But it is already possible to develop systems that complements human's abilities in perceiving and assessing such situations as well as appropriately responding in unknown situations. Such intelligent user interfaces consist of a knowledge-based assistance system and an interactive graphical or multimedia user interface (Fig. 2). They can support military decision makers in performing information gathering, information processing, and information entering in all phases of a command and control (C2) cycle, i.e., in situation perception (observe), situation assessment (orient), decision making (decide), and action taking (act) (Dept. of the Navy, 1995). The basic idea of these concepts is that an overall automation must not be the objective of system development. The human operator should be involved in the decision making process as far as his abilities and his performance are sufficient for goal achievement. An aid is provided only to exploit human abilities (e.g. in detecting and evaluating complex patterns or reacting on unforeseen events) and to overcome human deficiencies (e.g. when doing mathematical calculations), i.e., to complement individual human performances.

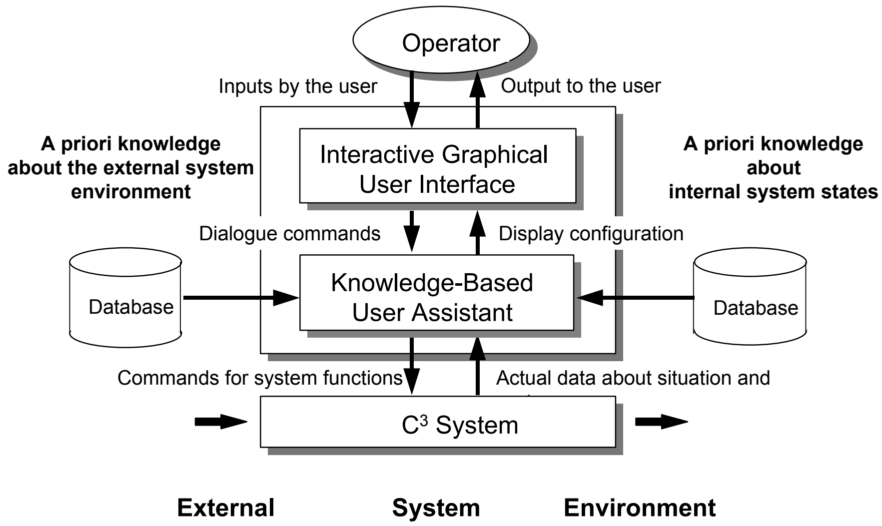

Figure 2: Concept of a Knowledge-Based User Interface.

For the design of effective human-machine interfaces which support human operators in military operations required SA information has to be determined, specified, and implemented. One source from which especially information about the external system environment can be acquired are scenarios which have to be developed for designing systems as well as for training military operators. In a recent study (Distelmaier et al., 2000) this acquisition process has been accomplished on the basis of an Anti-Air Warfare scenario developed for training Navy operators in identifying air targets in a surveillance mission.

The scenario includes ownship with different safety and engagement zones, an airway, a transition corridor, a land area with coastal line, neutral and friendly air targets with normal behaviour, and suspect air targets with dubious behaviour. The scenario describes graphically not only a snapshot of a dynamic situation but rather a combination of different static scenes of a dynamically evolving situation with air tracks to be identified. It includes the following situations:

1. An approach of two air targets with suspicious behaviour.
2. An approach of two friendly air targets which identify themselves by executing a predefined flight pattern.

3. An approach of a friendly air target in a transition corridor.
4. Neutral air targets flying in an airway.
5. An approach of a suspicious air target from inside the airway with a final harassment manoeuvre.

3.0 MODEL OF THE PROBLEM DOMAIN

To acquire the information necessary for getting SA a model of the scenario problem domain has been developed. The model comprises three worlds (Fig. 3) which represent three different views: 1.) The True World stands for the real mission environment of ownship respectively for the developed scenario which is a model of that environment. 2.) The Sensed World describes the information sphere of track objects acquired to a large extent by ownship sensors. 3.) The Deduced World represents the sphere of deduced information concluded from the Sensed World and corresponding inference processes. To uniformly describe these different views an object oriented approach is applied. This approach also supports an object oriented problem analysis and facilitates the implementation with modern object-oriented programming languages when later developing a decision support system. To accomplish this approach static and dynamic objects are identified as relevant model elements. These objects can be specified by means of attributes which describe characteristics and states of an object and by operations which characterise its behaviour (Rumbaugh et al., 1991).

3.1 The True World

Descriptive elements of the True World which is defined by the used scenario are static and dynamic scenario objects. Static scenario objects possess only one state and no operation. Examples of such objects which constitute the static mission environment of the scenario are, for instance, airways, transition corridors, and coastal lines. Dynamic scenario objects correspond to active air, surface, and land targets of the scenario. They are specified by changing attribute values, that means, changing object states caused by object operations.

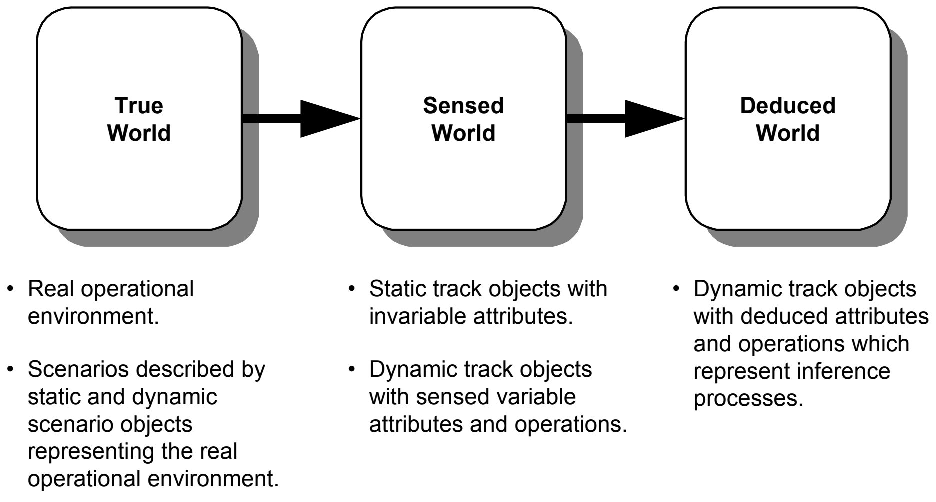

Figure 3: Model of the Three Worlds.

To describe scenario objects mathematically formalisms of the general system theory (e.g., Klir, 1969) have been applied. Generally, the analysis starts with determining the set SO of all scenario objects so_i :

$$SO = \{ so_i : i \in I_{SO} \} . \quad (1)$$

An scenario object so_i can be described by the set so_i_OP of its operations $so_i\_op_k$, the set so_i_ATT of its attributes $so_i\_att_k$, the value set $so_i\_ATV_k$ of all values $so_i\_att_k(t)$ of an attribute $so_i\_att_k$, with the time set T, the set of the positive real numbers R+, and $t \in T \subset R+ \cup \{ 0 \}$, and the set so_i_S of object states $so_i\_s_k$:

$$so_i\_OP = \{ so_i\_op_k : k \in I_{soi\_OP} \} ,$$

$$so_i\_ATT = \{ so_i\_att_k : k \in I_{soi\_ATT} \} ,$$

$$so_i\_ATV_k = \{ so_i\_att_k(t) : t \in T \} , \quad (2)$$

$$so_i\_S = \{ so_i\_s_k = (so_i\_att_m(t), so_i\_att_{m+1}(t), so_i\_att_{m+2}(t), \dots) : k \in I_{soi\_S} \wedge so_i\_att_m(t) \in so_i\_ATV_m \wedge so_i\_att_{m+1}(t) \in so_i\_ATV_{m+1} \wedge so_i\_att_{m+2}(t) \in so_i\_ATV_{m+2} \wedge \dots \} ,$$

$$so_i\_S \subset so_i\_ATV_m \times so_i\_ATV_{m+1} \times so_i\_ATV_{m+2} \times \dots .$$

As an example, the airway identified in the mentioned Navy scenario is considered. It represents a static scenario object so_1 which is characterised by its attributes $so_1\_att_k$ and their related values $so_1\_att_k(t)$. Because o_1 represents a static scenario object there exists no operation and all related attribute values are constant:

$$so_1\_object\_identifier(t) = \text{airway number} ,$$

$$so_1\_reference\_point(t) = (posX(t): a\ [^o], posY(t): b\ [^o], posZ(t): c\ [ft]) ,$$

$$so_1\_width(t) = d\ [nm] ,$$

$$so_1\_length(t) = e\ [nm] ,$$

$$so_1\_height(t) = f\ [ft] , \quad (3)$$

$$so_1\_direction(t) = g\ [^o] ,$$

$$so_1\_region(t) = function(so_1\_reference\_point(t), so_1\_width(t), so_1\_length(t), so_1\_height(t), so_1\_direction(t)) ,$$

$$so_1\_speed(t) = h\ [kn] ,$$

$$so_1\_flight\_level(t) = (i, j)\ [ft] .$$

As another example of the scenario an aircraft inside the airway is considered. It appears to be a dynamic scenario object so_4 which can be specified by attributes, their values, and operations. Some attribute values $so_4\_att_k(t)$ and operations $so_4\_op_k$ are:

$$so_4\_aircraft\_identifier(t) = \text{registration number} ,$$

$$so_4\_position(t) = (posX(t): x\ [^o], posY(t): y\ [^o], posZ(t) : z\ [ft]) ,$$

$$so_4\_altitude(t) = so_4\_posZ(t) = z\ [ft] ,$$

$$so_4\_altitude\_change(t) = 0\ [ft/min] ,$$

$$so_4\_course(t) = g\ [^o] , \quad (4)$$

$$so_4\_course\_change(t) = 0\ [^o/sec] ,$$

$$so_4\_speed(t) = h\ [kn] ,$$

$$so_4\_speed\_change(t) = 0\ [kn/min] ,$$

$$so_4\_IFF\_signal(t) = \text{Mode 3} ,$$

$$so_4\_emitter(t) = \text{Radar R3} ,$$

so_4_role(t) = commercial_airliner ,

so_4_activity(t) = fly_in_accordance_with_airway ,

so_4_identity(t) = neutral .

so_4_op_1 = IF creation event THEN create object ,

so_4_op_2 = IF extinction event THEN delete object ,

so_4_op_3 = IF state change event THEN change state ELSE retain state .

The dynamic scenario object o_4 may be in the actual state so_4_s_1 = flying_inside_the_airway which is defined by the above attributes. As soon as there occurs an event, for instance, if the value so_4_course_change(t) > x [^{o}/sec] indicates a course change then the activity takes the value so_4_att_2(t) = fly_not_in_accordance_with_airway. The state remains the same.

The dynamic processes of a scenario with all state changes of scenario objects can be simulated and in this way be accessible to an analysis. One possible simulation tool is, e.g., the Commercial-Off-The-Shelf (COTS) product STAGE (Scenario Toolkit And Generation Environment). STAGE is a real-time, reconfigurable, extendible simulation framework for military applications. It is a complete toolkit not only for tactical simulation but also for research and development, man-in-the-loop simulation, and mission planning and rehearsal (Virtual Prototypes, 2002).

3.2 The Sensed World

The second part of the model constitutes the Sensed World (Fig. 3) which describes the information sphere of track objects acquired to a large extent by ownship sensors. Corresponding to scenario objects of the True World there are again static and dynamic track objects in the Sensed World with the same meaning as the scenario objects. Static track objects in the Sensed World correspond for the most part to static scenario objects and, therefore, are known in advance either from the scenario or other geographical data sources like nautical charts. Examples of such static track objects which posses only one state and no operation are again airways, transition corridors, and coastal lines constituting the static mission environment. But there may be certain static track objects which ship sensors may detect, e.g., the wreck of a recently sunk ship which may be detected by the ship sonar but not being registered yet in the corresponding nautical chart. All static objects are stored onboard ownship, for instance, in the central data store of the ship which may contain also a geographical database with nautical chart information. Dynamic track objects correspond again to dynamic scenario objects. They represent active air, surface, and land tracks detected by ownship sensors and stored with attributes and operations in the central data store. That means, that dynamic scenario objects of the True World are transformed into track objects of the Sensed World by considering ship sensor characteristics. Attributes and their values are updated if sensors provide new data. As attributes of dynamic track objects depend on the available sensors on board, only that information can be sensed for which sensors are available. For instance, if there is a 3D-radar available then the altitude of an air track can be determined as track attribute. If the ship has only a 2D-radar then the altitude cannot be assessed. But there are also track attributes which can be determined from sensed attributes by calculation, e.g., the vertical speed of an air track from the change of its altitude. These attributes are also considered as sensed attributes. With dynamic track objects operations specify processes like creating, updating, and deleting those objects in the data store of the ship.

With TO as the set of all track objects to_i again such an object can be described formally by a set to_i _OP of its operations to_i_op_k, a set to_i _ATT of its attributes to_i_att_k, a value set to_i_ATV_k of all values to_i_att_k(t) of attribute to_i_att_k, with the time set T, the set of positive real numbers R+, and $t \in T \subset R+ \cup \{ 0 \}$, a set to_i_ATV of all value sets to_i_ATV_k, and a set to_i_S of all states to_i_s_k of object to_i:

$TO = \{ to_i : i \in I_{TO} \}$,

$$
\begin{aligned}
&to_i\_OP = \{ to_i\_op_k. : k \in I_{toi\_OP} \} , \\
&to_i\_ATT = \{ to_i\_att_k : k \in I_{toi\_ATT} \} , \\
&to_i\_ATV_k = \{ to_i\_att_k(t) : t \in T \} , \qquad (5) \\
&to_i\_ATV = \{ to_i\_ATV_k : k \in I_{toi\_ATT} \} , \\
&to_i\_S \subset to_i\_ATV_k \times to_i\_ATV_{k+1} \times to_i\_ATV_{k+2} \times .... , \\
&to_i\_S = \{ to_i\_s_m = (to_i\_att_k(t), to_i\_att_{k+1}(t), to_i\_att_{k+2}(t), ...) : m \in I_{toi\_S} \wedge to_i\_att_k(t) \in \\
&\qquad to_i\_ATV_k \wedge to_i\_att_{k+1}(t) \in to_i\_ATV_{k+1} \wedge to_i\_att_{k+2}(t) \in to_i\_ATV_{k+2} \wedge ... \} .
\end{aligned}
$$

As an example of a static track object the above mentioned airway which represents in the True World the static scenario object so_1 is considered. In the Sensed World it constitutes the static track object to_1 with the same attributes and values as so_1 specified in equation (3). As example of a dynamic track object the above mentioned aircraft is regarded. In the True World this aircraft has been represented by the dynamic scenario object so_4. If this object is in the ownship sensor range it will be detected and a dynamic track object, e.g., to_7 will be created in the ship's central data store which represents the Sensed World. Object attributes and values depend on the sensor observation time. It is assumed that attributes like altitude, speed, and course and their alteration can be determined. Assuming sufficient observation time for reaching a stable state values $to_7\_att_k(t)$ of some sensed attributes $to_7\_att_k$ and operations $to_7\_op_k$ are listed below:

$$
\begin{aligned}
&to_7\_track\_identifier(t) = \text{track number} , \\
&to_7\_position = (posX(t): x\ [^o] , posY(t): y\ [^o] , posZ(t): z\ [ft]) , \\
&to_7\_altitude(t) = to_7\_posZ(t) \approx z\ [ft] , \\
&to_7\_altitude\_change(t) \approx 0\ [ft/min] , \\
&to_7\_course(t) \approx g\ [^o] , \qquad (6) \\
&to_7\_course\_change(t) \approx 0\ [^o/sec] , \\
&to_7\_speed(t) \approx h\ [kn] , \\
&to_7\_speed\_change(t) \approx 0\ [kn/min] , \\
&to_7\_IFF\_signal(t) = \text{Mode 3} , \\
&to_7\_emitter(t) = \text{Radar R3} ,
\end{aligned}
$$

$$
\begin{aligned}
&to_7\_op_1 = \text{IF detection event THEN create object} , \\
&to_7\_op_2 = \text{IF update event THEN update sensed attributes} , \\
&to_7\_op_3 = \text{IF extinction event THEN delete object} .
\end{aligned}
$$

3.3 The Deduced World

The Deduced World is the third part of the developed model (Fig. 3). It is represented by the deduced attributes of dynamic track objects, their values, and by the inference processes necessary for deducing those attributes. Taking again as an example the dynamic track object to_7 specified above the following additional deduced attributes $to_7\_d\text{-}att_k$ and operations $to_7\_d\text{-}op_k$ of the object to_7 arise in the Deduced World:

to_7_d-distance_between_objects, to_7_d-formation,

to_7_d-activity, to_7_d-activity sequence,

to_7_d-role, to_7_d-application, (7)

to_7_d-category, to_7_d-type,

to_7_d-class, to_7_d-option,

to_7_d-identity, to_7_d-threat.

to_7_d-op_4 = IF update event THEN update deduced attributes

Generally, with equations (5) for a deduced attribute to_i_d-att_m of track object to_i, its values to_i_d-$att_m(t)$ and the object operation to_i_d-op_k which specifies the update and inference process of these attribute it counts:

$$to_i\_d\text{-}att_m \in to_i\_ATT ,$$

$$to_i\_d\text{-}att_m(t) \in to_i\_d\text{-}ATV_m \in to_i\_ATV , \quad (8)$$

$$to_i\_d\text{-}op_k \in to_i\_OP .$$

A deduced attribute of a dynamic track object can be derived from sensed and other already deduced attributes of the same object. Additionally, different attributes of other static and dynamic track objects may be involved in the inference process as well. For modelling that interference process mathematical relations are applied. To deduce an attribute to_i_d-att_m of a dynamic track object to_i and its value set to_i_d-ATV_m those other value sets to_i_ATV_n and to_i_d-ATV_n of to_i which contribute to the inference process have to be selected. For describing this selection a set to_i_ATVsel which contains all contributing value sets to_i_ATV_n and to_i_d-ATV_n will be defined. Besides to_i there may be other track objects to_p, to_q, ... with their attribute value sets to_p_ATV, to_q_ATV ... contributing as well for deducing the attribute to_i_d-att_m. The contributing value sets of those objects can be again specified by means of selected value sets to_p_ATVsel, to_q_ATVsel .... Then, to describe the inference process in detail an inference relation to_i_ir_k is defined. With to_i_IR as the set of all to_i_ir_k it follows:

$$to_i\_ATVsel = \{ to_i\_ATV_n , to_i\_d\text{-}ATV_{n+k} : to_i\_ATV_n, to_i\_d\text{-}ATV_{n+k} \in to_i\_ATV \wedge to_i\_ATV_n \text{ and } to_i\_d\text{-}att_{n+k} \text{ are relevant to deduce } to_i\_d\text{-}att_m \} ,$$

$$to_p\_ATVsel = \{ to_p\_ATV_u , to_p\_d\text{-}ATV_{u+k} : to_p\_ATV_u, to_p\_d\text{-}ATV_{u+k} \in to_p\_ATV \wedge to_p\_ATV_u \text{ and } to_p\_d\text{-}att_{u+k} \text{ are relevant to deduce } to_i\_d\text{-}att_m \} ,$$

$$to_q\_ATVsel = \{ to_q\_ATV_v , to_q\_d\text{-}ATV_{v+k} : to_q\_ATV_v, to_q\_d\text{-}ATV_{v+k} \in to_q\_ATV \wedge to_q\_ATV_v \text{ and } to_q\_d\text{-}att_{v+k} \text{ are relevant to deduce } to_i\_d\text{-}att_m \} ,$$

$$to_i\_ATVsel \subset to_i\_ATV , to_p\_ATVsel \subset to_p\_ATV , to_q\_ATVsel \subset to_q\_ATV ,$$

$$to_i\_ir_k \subset to_i\_d\text{-}ATV_m \text{ x X } to_i\_ATVsel \text{ x X } to_p\_ATVsel \text{ x X } to_q\_ATVsel \text{ x } ...., \quad (9)$$

$$to_i\_IR = \{ to_i\_ir_k : k \in I_{toi\_IR} \} ,$$

$$IR = \{ to_i\_IR : i \in I_{TO} \} .$$

The set to_i_IR containing all relations of a dynamic track object to_i specifies the total inference process of that object. This process is part of the object operation to_i_d-op_4 = “IF update event THEN update deduced attributes” and will be activated if an update event occurs. Moreover, the total Deduced World is represented by the set of all relations IR which comprises total inference processes of all considered dynamic track objects. This inference process represents especially the a priori knowledge needed by human operators when performing their operational tasks.

As an example, again the dynamic track object to_7 representing an aircraft is selected. To specify the inference process for deducing the attribute to_7_d-activity the value set to_7_d-ACTIVITY is interrelated with value sets of relevant sensed attributes to_7_(POSX, POSY, POSZ), to_7_ALITUDE, to_7_COURSE, and to_7_SPEED of object to_7 (see Eq. 6). (In the preceding and in the following all value sets of an attribute are named with capital letters.) Additionally, value sets of the static track object to_1 representing an airway have to be considered in this inference process. Airway attribute value sets are to_1_REGION, to_1_DIRECTION, to_1_SPEED, and to_1_FLIGHT_LEVEL (see Eq. 3). If the process is specified with equations (9) then the inference relation o_7_ir$_1$ results as follows:

$$to_7\_ATVsel = \{ to_7\_(POSX, POSY, POSZ), to_7\_ALTITUDE, to_7\_COURSE, to_7\_SPEED \} ,$$

$$to_1\_ATVsel = \{ to_1\_REGION, to_1\_DIRECTION, to_1\_SPEED, to_1\_FLIGHT\_LEVEL \} , \quad (10)$$

$$to_7\_ir_1 \subset to_7\_d\text{-}ACTIVITY \text{ x X } to_7\_ATVsel \text{ x X } to_1\_ATVsel .$$

For representing graphically this inference process interaction matrices introduced by Sage (1991) can be applied. Figure 4 shows the example described with equations (10). In the upper part of the picture the static track object to_1 with its attribute value sets is displayed. The lower part shows attribute value sets of the dynamic track object of interest to_7. The arrows indicate the direction of the inference process.

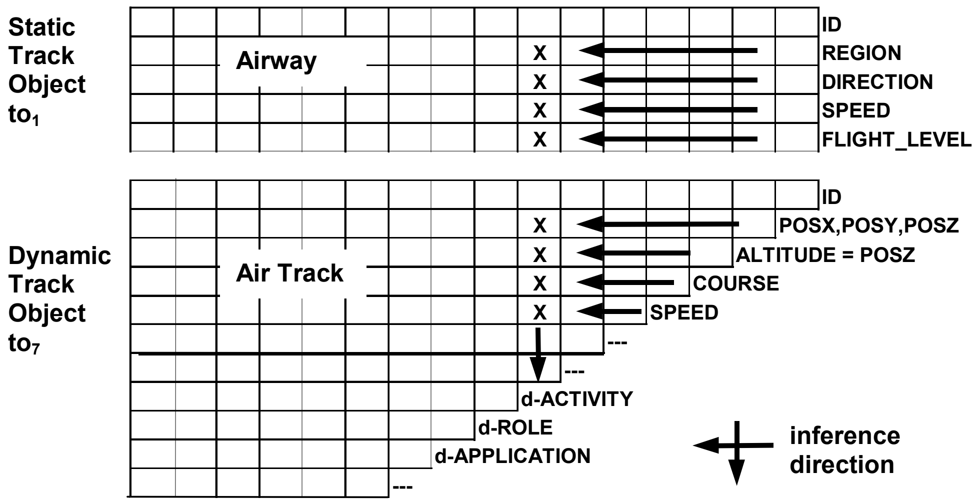

Figure 4: Example of the Inference Process for the Deduced Attribute to_7_d-activity.

For describing the inference process in detail a table form can be used. As an example, in Table 1 some components of the relation to_7_ir$_1$ which specifies the attribute values for deducing the attribute to_7_d-activity with reference to the airway are listed. Each row of the table specifies a single component of that relation whereby attribute values of the airway are taken from equation (3). Of course there are still other values to_7_d-activity(t) of that attribute which arise by referencing the dynamic track object to_7 to other objects. For instance, by additionally referencing to_7 to ownship the resulting value set is to_7_d-ACTIVITY = { fly in accordance with airway, fly not in accordance with airway, pass ownship, fly ownship inbound manoeuvre, leave ownship }.

For designing a decision support system the described mathematical model of track objects constitutes the basis for developing a software specification with the object-oriented Unified Modelling Language UML (Booch et al., 1999). This specification may comprise different types of diagrams like class diagrams, state diagrams, sequence diagrams, etc. As an example, figure 5 shows upper levels of a class diagram of the modelled track objects containing the class Track Objects with its subclasses Static Track Objects, Dynamic Track Objects, and Inference Processes. In this diagram inference processes are dealt with as separate association class which is used usually to specify complex association between other classes. Each subclass can be further decomposed into more elementary classes with smaller dimensions, for instance, the class Dynamic Track Objects into classes like Air, Surface, and Subsurface, and Land

Tracks. Nowadays, the development of an UML specification will be supported by modelling tools like TOGETHER (TogetherSoft Corp., 2002) which simplifies and integrates the analysis, design, implementation, deployment, and debugging of complex software applications.

Table 1: Example Components of the Relation to_7_ir_1 (Eq. 10)

to_7_ activity(t)	**to_7_ (posX(t), posY(t), posZ(t))**	**to_7_ altitude(t)**	**to_7_ course(t)**	**to_7_ speed(t)**	**to_1_ region(t)**	**to_1_ direction(t)**	**to_1_ speed(t)**	**to_1_ flight_ level(t)**
fly in accordance with airway	inside to_1_ region(t)	≈ to_1_flight_ level(t)	≈ to_1_ direction(t)	≈ to_1_ speed(t)	see Eq. 3	g [°]	h [kn]	(i, j) [ft]t
fly not in accordance with airway	inside to_1_ region(t)	≠ to_1_flight_ level(t)	≈ to_1_ direction(t)	≈ to_1_ speed(t)	see Eq. 3	g [°]	h [kn]	(i, j) [ft]
fly not in accordance with airway	inside to_1_ region(t)	≈ to_1_flight_ level(t)	≠ to_1_ direction(t)	≈ to_1_ speed(t)	see Eq. 3	g [°]	h [kn]	(i, j) [ft]
fly not in accordance with airway	inside to_1_ region(t)	≈ to_1_flight_ level(t)	≈ to_1_ direction(t)	≠ to_1_ speed(t)	see Eq. 3	g [°]	h [kn]	(i, j) [ft]
fly not in accordance with airway	inside to_1_ region(t)	...	...	...	...	...	...	...

4.0 RELATIONSHIPS BETWEEN THREE WORLDS AND INFORMATION LEVELS OF SA

To establish relationships between the three worlds and the information levels of SA described in the beginning the specified objects and their attributes are analysed in detail. Because an operator in the combat information centre of a warship does not have a direct contact to the mission environment outside the ship it becomes obviously that there does not exist any direct relationship between the True World and the different SA level information. The True World represents either the real mission environment of a ship or a scenario as a model of this environment. An operator, for instance, in the ownship combat direction centre does not have any direct access to this world but there is only an indirect interaction between both via sensors and communication facilities on board the ship. Nevertheless, identified static scenario objects, like air routes, transition corridors, and coastal lines, as well as dynamic scenario objects, like air and surface targets, constitute the starting point of the analysis because from them objects and their attributes of the Sensed World can be derived.

The Sensed World represent the basis for identifying elements of the SA level 1 which refers to the perception of information elements in the environment of an operator. This environment is represented by characteristics of track objects, i.e., their attributes, states, and behaviour. Therefore, relevant SA information are attributes of static track objects which, as described in detail above, correspond to attributes of static scenario objects of the True World. This information represents a priori knowledge stored on board, for instance, in a geographical data base. Other information of SA level 1 are attributes of dynamic track objects which can be identified by considering available sensors and communication facilities on board the ship and present dynamic scenario objects of the True World. Such track attributes are, e.g., position, course, and speed. This SA information is stored as dynamic track objects with their attributes, e.g., in the central data store of the ship and displayed in any form on consoles of the combat information centre.

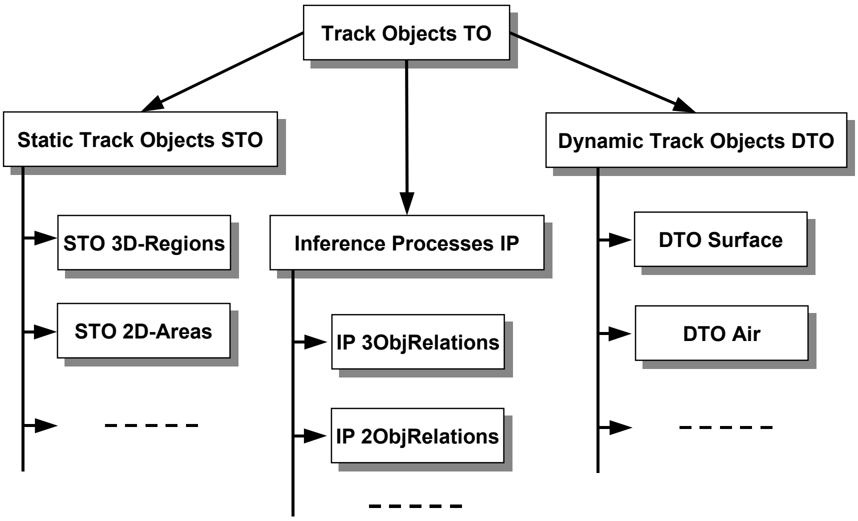

Figure 5: UML Class Diagram for Upper Levels of Track Object Classes.

The Deduced World contains the same dynamic track objects as the Sensed World but with additionally deduced attributes. These additional attributes constitute information of SA level 2 which are necessary for operator's comprehension of the current situation. By information processing based on a synthesis of disjoint SA level 1 elements the operator puts these elements together to perform patterns for getting a holistic picture of the environment and an assessment of the current state. As an example, again the dynamic track object to_7 which represents an aircraft can be considered. Deduced attributes of this object belonging to SA level 2 information are, e.g., to_7_d-activity, to_7_d-type, and to_7_d-identity.

But in addition, the Deduced World contains also attributes which reflect information of SA level 3. This information represents projections of future states of a dynamic track object on the basis of its actual actions and possible actions in future. This is achieved through knowledge of object states and behaviour and comprehension of the situation for both level 1 and level 2 information. As an example of such a deduced attribute belonging to SA level 3, e.g., the attribute to_7_d-option of the air track to_7 is considered. In contrary to the deduced attribute to_7_d-activity which describes the actual observable behaviour of the air track the attribute to_7_d-option portrays the predictable possible object behaviour in the near future (with a maximal prediction time of about five minutes ahead). Both attributes posses the same value sets (see Table 2). Another deduced attribute which belongs to the SA level 3 is the attribute to_7_d-threat with a value set to_7_d-THREAT. This attribute describes possible future threats which depend on the actual activity of the air track and its possible future options. The inference process of this attribute can be specified with the relation $to_7\_ir_2$ as follows:

$$to_7\text{\_d-THREAT} = \{ \text{ no threat, looming threat, acute threat, critical threat } \} ,$$

$$to_7\text{\_ATVsel} = \{ to_7\text{\_d-ACTIVITY}, o_7\text{\_d-OPTION} \} , \qquad (11)$$

$$to_7\_ir_2 \subset to_7\text{\_d-THREAT x } to_7\text{\_d-ACTIVITY x } o_1\text{\_d-OPTION} .$$

Some components of this relation are specified in table 2. The first column of the table does not belong to the relation $to_7\_ir_2$ but contains advancing points in time to demonstrate a possible dynamic progress of the situation in time. For each point in time different components of the relation exist indicating that each activity has more than one possible option in future. E.g., if the air track does not fly in accordance with the airway then possible options, i.e., future activities, are to leave ownship, to pass ownship outside its closest point of approach (CPA), or to fly an ownship inbound manoeuvre, i.e., approaching inside ownship CPA. The related threat values depending on the combination of activity and option values at each time (see Table 2) are expressed on a ordinal scale.

Table 2: Example Components of the Relation $to_7\_ir_2$ (Eq. 11)

time(t)	to_7_d-threat(t)	to_7_d-activity(t)	to_7_d-option(t)
t_m	no threat	fly in accordance with airway	fly in accordance with airway
	no threat	fly in accordance with airway	fly not in accordance with airway
t_{m+1}	no threat	fly not in accordance with airway	leave ownship
	looming threat	fly not in accordance with airway	pass ownship
	looming threat	fly not in accordance with airway	fly ownship inbound manoeuvre
t_{m+2}	acute threat	fly ownship inbound manoeuvre	reconnoitre ownship
	acute threat	fly ownship inbound manoeuvre	harass ownship
	acute threat	fly ownship inbound manoeuvre	release weapon
t_{m+3}	critical threat	release weapon	attack ownship

5.0 CONCLUSION

In nowadays complex and dynamic changing military environments supporting Situation Awareness (SA) of operators is a prerequisite for situation and tasks adequate decision making and action accomplishment. A means for supporting SA of operators are adaptive knowledge-based user interfaces. For developing such interfaces information of Endsley's three different SA levels which operators need in performing their tasks have to be specified and modelled. One source from which that information can be acquired are scenarios which have to be developed in any case for system design as well as for operator training. For identifying relevant SA information of operators a model of the scenario problem domain has been developed which comprises the True World, the Sensed World, and the Deduced World. To uniformly describe these different worlds an object-oriented approach has been applied which is based on static and dynamic scenario and track objects which are specified mathematically. Attributes and operations of track objects constitute elements and patterns of relevant SA information to be identified. Main object characteristics are attributes and operations. Interrelating this characteristics with information of different SA levels the relevant SA information needed by operators can be identified and modelled exhaustively and clearly. Additionally, the described mathematical model of track objects constitutes the basis for developing a software specification with the object-oriented Unified Modelling Language UML. Therefore, the described modelling approach supports an object oriented problem analysis and facilitates the implementation with modern object-oriented programming languages when later developing a decision support system. The application of the approach and its advantageous structure have been demonstrated in detail using as an example a Navy Anti-Air Warfare scenario developed for training Navy operators in identifying air targets in a surveillance mission.

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