Research of Situation Assessment oriented Hypothesis based Plan Recognition（SAOPR）

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Summary
New framework of situation assessment oriented plan recognition (SAOPR) based on the closed loop of "Cognition, Prediction, Validation" is proposed for the application of military situation assessment, and its implementing method has been researched too. In this paper firstly the workflow of the closed loop process is analyzed and the SAOPR framework is extracted. For to explain the describility and the calculability of the closed loop process, several concepts of situation elements are defined and the SAOPR architecture including the plan recognition algorithm is designed. Then the plan recognition knowledge model of SAOPR has been discussed. The designed model has a structure of knowledge hierarchy which consists of much kind of nodes as action, event, situation and purpose. Theoretical analysis and experimental results demonstrate that SAOPR could describe clearly the evolvement process of battlefield situation assessment, so it is expectable for SAOPR to play a useful role in situation assessment system.

Key words:
Plan recognition, Situation assessment, Knowledge model, Prediction

1. Introduction

Plan recognition (for short as PR) is a new research field of AI since 80's of last century. Its research object is to find the laws and methods of concluding an agent's purposes or intentions based agent's action sequence. As it emphasizes the process of analysis and extraction for the observed agent's actions and the current events, PR is fit for incremental uncertainty reasoning. Furthermore, Plan recognition is just coincident with Situation assessment which requires recognizing a hostile plan by observing and analyzing the dynamic actions of military units, so the view point has got much agreement that takes Situation assessment(for short as SA) as a practice process of PR.

PR has been applied widely in SA as there is much spontaneous comparability. Since the formalization system of PR was built by Kautz in 1968[1], many research works has been doing in PR's development and application. The familiar method is to design and construct a plan base above all, then use the strategy of search or match to recognize the target plans. The key point of this process is an idea of expectation template matching.

The priori model of some important factors of SA (As troop composing, troop assignation, event sequence and so on) is called template [2]. Methods based templates implement SA and TA by developing the kinds of transcendental templates which includes campaign byelaw, situation, event and decision supporting templates. In each time-step, the relations of agents and the types & sequences of the observed event in current battlefield are matched with expected templates from low-grade to high-grade and some hypotheses are formed. The most similar hypotheses would be selected as the most possible results for SA.

But in fact, it is the most effectual experimental verification method that continually comparing the predicting result based on hypotheses with current observation of the situation element's action. Some PR pursuers has proposed that the process of PR could be explained to two aspect as "wait" and "see" [3]: the first is to select reasonable plan hypotheses to explain agent's action, and then use the plan to predict the agent's next action. Usually there are many candidates could be selected, so it is required that using the observed agent's action to validate and modify the current hypotheses.

Hence there is a process of modifying plan in the course of "waiting" in conventional PR. In fact it is a closed loop of "Cognition, Prediction and Validation" With the reasoning mechanism of SAOPR, hypothesis formed at time t is made use to predict a situation element's action at time t+1, and the hypothesis could be modified and selected by comparing the predicting result with current observation of the situation element's action.

Conventional PR takes single agent as its research object, whereas SA takes multi-agents. Every SA system has a structure of knowledge hierarchy which consists of much kind of nodes as action, event, and situation. So it is necessary to research the contents and methods of information transferring in the closed loop of "Cognition, Prediction and Validation" and insure the validity and integrality of system cognition. Moreover, it is difficult to ensure the reliability of a PR's prediction on account of no

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possible to having the whole knowledge of the background. Therefore it is required to discuss and research situation assessment oriented hypothesis based plan recognition.

2. The process and the algorithm of SAOPR's PR

The decision information of SAOPR's PR comes from the time sequence action of armed entity in battlefields. An armed entity is an intelligent agent and a commander recognizes an agent's tactics only by observing the agent's actions due to hostile attitude between in opposing sides. This process is in accordance with PR. Meantime, war is a collective action and all two belligerent parties have many different entities in ordinary circumstances. Especially under the condition of the air-ground tactical cooperation, there are not only hostile entities in battlefields but also actions such as communication, cooperation and coordination among these hostile entities. For this reason, SA should not only be regard as a PR process, but also be a PR process of multi-agents.

Some conceptions about situation element in battlefields have been given in literatures [4~6] based on various viewpoint. In this paper, these conceptions are proposed for the background of air fighting as follow.

Definition 1: Entity

An entity could be represented by triple $<t, Id, Attribute>$. Here Id is identification of the entity and Id is the only one of its kind. *Attribute* is an entity's attribute set. Attribute= $\{a_i \mid i=1, 2,...,n\}$. For example, an entity's attribute set could include an entity's name, type, attack ability, action and others. An entity' attributes set varieties with its type. If an entity is a fighter plane, its action attribute could be flatly flying, turning, diving and rolling etc. . . .

Definition 2: Situation

Here the situation is a dynamic conception which is defined as the sum total of all factors about the two belligerent parties and operational environment at one moment. Let the hostile entities set be *E1*, our entities set be *E2*, the third party be *E3*, the current operational environment (includes weather, geographic conditions and so on) is expressed with *CE*, then the battlefield situation at the movement could be represented by quintuple $<t,E1,E2,E3,CE>$.

Definition 3: Purpose.

Purpose is described as a kind of battlefield situation that the hostile entities set *E1* attempts to reach in an operational time section $[t_1, t_2]$. Let the situation set as S, then Purpose$\in S$.

It could be seen from definition 3 that purpose is a kind of special situation, and all actions of the hostile entities set E1 is in the service of coming true the purpose.

Definition 4: Plan.

Plan is a specially appointed tactics action sequence $\{a_1,a_2,\ldots a_i,\ldots a_n\}$ of the hostile entities set *E1* to convert an original situation into a purpose $Intend \in S$ in an operational time section $[t_1, t_2]$. Here any action a_i of *E1* does not stand for an entity's action but stands for a collective action. That is above mentioned SA is a PR process of multi-agents. In a multi-agents system every agent accomplishes its mission by coordination with one another; this kind of behavior is called as tactics coordination.

Tactics action could be responded by triple $a_i = \{E, M, P\}$. Here E= $\{e_i\}$ stands for the composition of tactics entities, P= $\{p_j\}$ stands for the composition of tactics behavior, M= $\{\{ e_i , p_j \}\}$stands for tactics plan which is described as the basic action sequences of every entity.

Definition 5: Situation event.

Situation event means the various battlefield events that could influence the current situation, includes tactics, armed forces, environment and so on. In our system, it is discussed only the relevant events in connection with variation of hostile tactics and armed forces. For example, an event is "hostile executes a_i in time section $[t_1, t_2]$".

Based on it, the PR process of SA could be abstracted as follow (Fig.1).

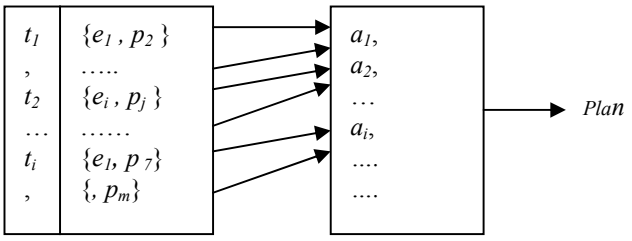

Fig.1 The PR process of SA

Fig.2 is the fundamental structure of SAOPR. SAOPR is made up of three parts as situation extraction, situation analysis and situation prediction. Two –stage mechanism of predicting feedback is built in situation prediction: the first is entity –stage prediction and feedback, the second is event-stage prediction and feedback. On the one hand the event-stage prediction results is regard as one important input data for generating prediction of entities' action sequence, on the other hand, some special events independent of previous entities (for example, new hostile object appearing and so on) would be directly feedback to event input end of situation analysis and be dealt with after comparing with situation

extraction.

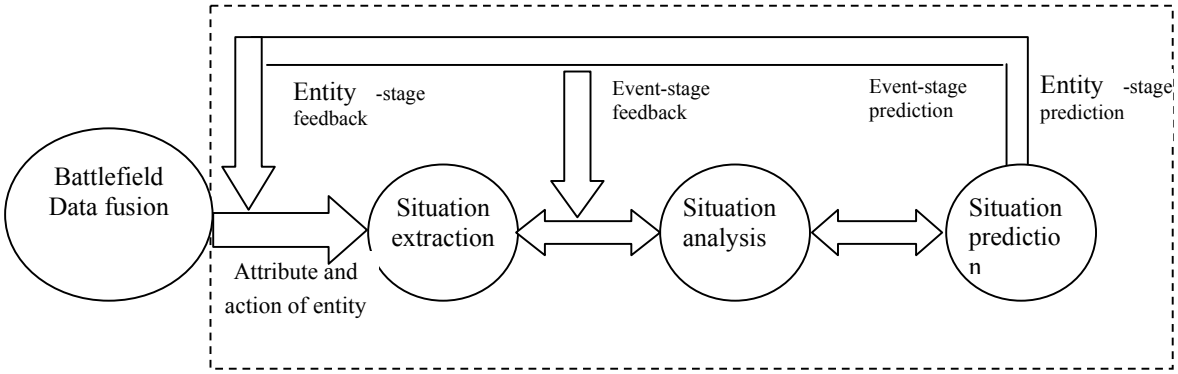

Fig.2 The fundamental structure of SAOPR

Let the set of current battlefield entity be E, the result of observation at time t is $O(E,t)$. The event hypothesis set of SAOPR at the last moment is P. Based on above definitions the PR process of SAOPR could be divided into 7 steps as follow.

Algorithm 1 （The process of SAOPR's PR）

Step1: SAOPR obtains the observation of the current entity E' actions $O(E, t)$;

Step2: Map the observation $O(E,t)$ to a sequence element a_i and judge whether there is contradiction between a_i and ω or not. If it is incompatible, put new hypothesis of event to the candidate set P;

Step3: Adjust the element confidence of candidate event set P;

Step4: Reason from bottom up to update the confidence of all the middle nodes;

Step5: Select each hypothesis in order and reason from the top down to predict the expected time sequence events , put them to set P;

Step6: Predict all the action of entity E according to each of event hypothesis.

Step7: Assign value of the prediction result to set ω, go Step1.

3. Knowledge model of SAOPR's PR and its implement

In preceding part of the text we have defined some conceptions about entity, situation, purpose and plan for a SA system of air fighting. As a practice system for PR applying to SA, a knowledge model is required to build inside SAOPR. Here some new conceptions concerned are defined based on the previous definition in foregoing paragraphs.

Definition 6: Basic action of entity (agent).

Basic action of an entity e_i is represented by $\{e_i, p_j\}$, which reflects the status of entity e_i includes the feature of entity's action and attitude at one moment.

Therefore event could be regarded as a set of an agent's action sequence in its being observed time section. An event could be a group of action of multi-agents as well as an agent's independent action. Here the relation of event and action is a correspondence of Kqutz's decomposition. Let us suppose the event "the foe plane is coming near our position" could be decomposed into three actions: (1) "the foe plane is not enough 80 Km distant from our position"; (2) "the foe plane is not enough 50 Km distant from our position"; (3) "the foe plane is not enough 30 Km distant from our position".

$$\forall xlay\ \_\ aboard\ (x) \supset \text{int}\ erval\ \_\ 80\ (f_1(x)) \wedge \text{int}\ erval\ \_\ 50\ (f_2(x))\ \text{int}\ erval\ \_\ 30\ (f_3(x))$$

$$\text{and}\ lay\_aboard = true$$

$$iff\quad \text{int}\, erval\_80 = true, \text{int}\, erval\_50 = true,$$

$$nterval\_30 = true$$

Meantime there is a link of 1: N between in the action sequence and event relates. That is to say an event could be achieved by multifarious action sequences, or multifarious action sequences may be extracted the same event. In the case the action sequence and specifically event form a relation of extraction called by Kqutz. If the event "the foe plane is coming near object O" could be realized by two action sequences: (1) "The foe plane arrives to position 11, the foe plane the foe plane arrives to position 13"; (2) "The foe plane arrives to position 22, the foe plane arrives to position 22, the foe plane arrives to position 23"; The former is air route 1, the latter is air route 2. So the relation of the example could be described as flow according to Kqutz:

$$\forall xlay\ \_\ abord\ (x) \supset lane\ \_1(x) \wedge lane\ \_2(x)$$

$$and \quad lay\_abord = true$$

$$iff \quad (lane\_1 = true \quad and \quad lane\_2 = false)$$

$$or \quad (lane\_2 = true \quad lane\_1 = false)$$

The relation of extraction implies a prerequisite that all hypotheses are mutual exclusion. That is to say if an event is the mirror of extraction from various action sequences, these action sequences must be different from each other.

Definition 7: Transition situation.

Transition situation is an expected situation achieved through a series of events under an original situation.

(1)An event node is confirmed by a certain action sequence;

(2) An entity's transition situation is confirmed by adding certain original situation to a series of events within a time section;

(3) Transition situation at different levels is confirmed by the transition situation at its inferior levels and the set of events which cause situation transiting;

(4) Stage plan at different levels is confirmed by the stage plan at its inferior levels and the set of events which cause situation transiting.

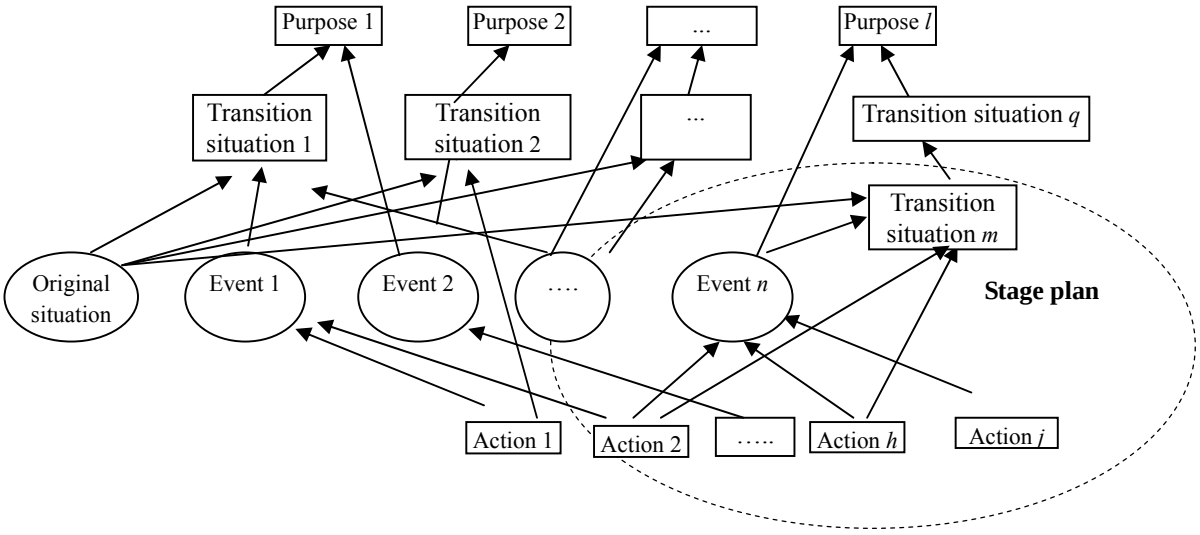

Fig. 3 The structure of knowledge hierarchy inside SAOPR

Definition 8: Stage plan.

A stage plan is the required certain event sequence from a transition situation to another one. By extracting the event sequence, stage plan reveals the tactics behavior of multi-agents.

Therefore a plan is a sequence of many stage plans for agent realizes its purpose from an original situation, and a plan may be extracted to a set of transition situations in proper order.

Obviously the "event" inside SAOPR is well-matched with the lower level event of Kqutz's model, whereas the "stage plan" and "plan" inside SAOPR mostly appropriate to the "event" of Kqutz's model. In the paper these terms are so defined as to comply with the common law in the field of SA.

A multi-level node model is built in SAOPR and the operating rule among various nodes is specified. It is the basic principle of node correlation in SAOPR too.

The structure of knowledge hierarchy inside SAOPR is shown as Fig.3. The idea comes from Kqutz's model but SAOPR devotes much attention to background of multi-agents cooperation, whereas Kqutz's model takes event seriously. Mostly PR systems don't lay so much stress on influence of environment. In SAOPR system it is should be determined by current battlefield situation that what the transition situation is no matter in any step of PR.

4. Illustration of knowledge model

An illustration of PR knowledge model for SA based on SAOPR is shown as Fig.4. In the example, S_1 stands for original situation; S_7 (I_1) ,S_8 (I_2) and S_9 (I_3) are three target situations (hostile purposes). Here there are some transition situation $(S_2, S_3, S_4, S_5, S_6)$, and they could be transformed each other. For example, there are many plans

to get to a attack purpose S_9 (I_3) : (1) $S_1 \rightarrow S_3 \rightarrow S_5 \rightarrow S_9$; (2) $S_1 \rightarrow S_3 \rightarrow S_4 \rightarrow S_5 \rightarrow S_9$; (3) $S_1 \rightarrow S_2 \rightarrow S_6 \rightarrow S_4 \rightarrow S_5 \rightarrow S_9$; (4) By other plans.

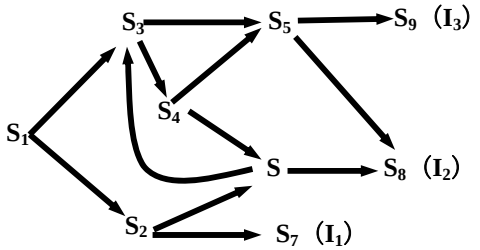

Fig.4 Illustration of PR knowledge model for SA based on SAOPR

The above plan map is not only alterable but also in characteristic of time inhomogeneity due to the limitation of battlefield. For example, when such a stage plan as $S_1 \rightarrow S_3$ is done, S_3 accessed for the first time (for short as S_{3a}) has two kinds of possibility to respectively transform S_5 and S_4. but according to the plan as $S_1 \rightarrow S_3 \rightarrow S_4 \rightarrow S_6 \rightarrow S_3$, the node S_3 accessed for the second time (for short as S_{3b}) only could be transformed into to S_5 and the plan $S_3 \rightarrow S_4 \rightarrow S_5$ is impossible to be done. Because the limitation of S_{3a} is not as same as S_{3b} after the plan $S_1 \rightarrow S_3 \rightarrow S_4 \rightarrow S_6 \rightarrow S_3$ has been done. In fact a PR model for battlefield SA has the features as follow.

(1) Under the condition of the same original situation, the different target situation may be reached to if different sequence of evidence (action, event) has been observed;

(2) Under the condition of the same original situation, the same target situation may be reached to although different sequence of evidence has been observed;

(3) Under the condition of the same original situation but different limitation of time inhomogeneity, the different target situation may be reached to although same sequence is to be done;

Therefore the transform of situation is irreversible. For this reason the time limitation is regarded as a precondition for status differentiation. The loop is eliminated after we discriminate the S_3 as S_{3a} and S_{3b}, and the updated knowledge model of PR is shown as Fig.5.

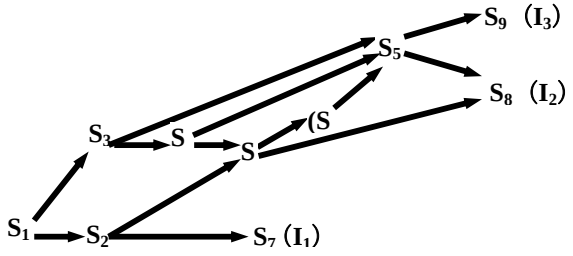

Fig.5 The updated knowledge model of PR

5. Conclusion

(1) It should be a comprehensive and nature methods for SAOPR based on the closed loop of "Cognition, Prediction, Validation" to describe the process of battlefield situation assessment, and the closed loop process is typical of describibility and the calculability.

(2) SAOPR has a structure of knowledge hierarchy which consists of much kind of nodes as action, event, situation and purpose. Every node could be subdivided into different hierarchy sub-nodes, and lower nodes usually provide evidence supports for upper nodes.

(3)Theoretical analysis and experimental results demonstrate that SAOPR could describe clearly the evolvement process of battlefield situation assessment, so it is expectable for SAOPR to play a useful role in situation assessment system.

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