Towards Smart Intelligent Agents in the Command and Control Environment

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Abstract

Successful implementation of Software Agents (SA) depends on modeling the problem space and user needs and requirements. By partitioning large problem spaces into a smaller domain the modeling complexity is greatly reduced. This approach works well with SA since they are responsible for smaller problem domains. The complexity and efficiency of a system model depends on the number of SA employed, and the degree of interdependence between them. The larger the number of SA and the more interdependent they are, the higher the complexity and the lower the efficiency. A supervisory control mechanism must be implemented to insure the SA effectiveness when modeling large complex problem spaces. The Virtual Associative Network (VAN) [Yufik Y., U.S. Patent 5586219] is a good candidate for such supervisory mechanism. This paper offers a rationale for incorporating the VAN as a critical element in the Intelligent Agents (IA) architecture.

1.0 Introduction

The power of Intelligent Agents, or more appropriately Software Agents, applications is inherited in the individual agent entities [Dawidowicz E., 1999], but is amplified by their ability to solve problems in a distributive and collaborative fashion. However, the significance of SA in Command and Control (C2) applications is yet to be fully demonstrated. The cognitive aspect of an IA can be greatly improved by implementing techniques, which stress machine conceptualization [Sowa J, 1984], of the problem space and algorithms to allow the machine to solve problems based on very small sets of available data. The Finite Automata [Aleksander I., Hanna F.K., 1975] is a good abstract model for SA, however no significant success can be achieved without good modeling of the problem space and addressing the informational needs of the user.

The Problem Space of the Battlefield is very complex, subject to continuous changes, and presently cannot be well modeled due to associated combinatorial complexity. To be effective the IA suite has to quickly reorganize its computational assets to meet the dynamic changes of the environment as well as to deal with incomplete sets of information.

The VAN has an exceptional ability to quickly adapt to a dynamically changing problem space. This coupled with the ability to solve complex problems with a very small data set makes the VAN an attractive and plausible candidate for enhancing the "intelligence" of IA in individual and organizational architectures. The VAN is therefore a good model of a supervisory mechanism for a large SA population.

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2.0 Problem Space

Modeling the C2 problem space is complex and elusive. The multitude of variable elements and their relationships, which define the problem space, create a computational and combinatorial complexity. The constantly changing strategic, tactical, economical, political, and sociological conditions make the modeling conceptually elusive and computationally highly demanding.

The best way of solving a complex problem is to break it down into a number of smaller sub-problems. Apparently, this mechanism is employed in the human nervous system: due to memory partitioning into a large Long Term Memory (LTM) and a small Short Term Memory (STM), complex information processing tasks are broken down into a series of small subtasks solved in STM one-at-a-time. We can apply a similar method to a complex problem space, by partitioning it into smaller subspaces and concentrating on modeling smaller domains, with the additional advantage of having multiple dedicated agents operating simultaneously across the entire problem space. These smaller domains can be joined, by means of communication arcs, to form a more complex domain. The IA can be modeled on these smaller domains. As needed, the IA can be expanded to increase their capability to further fill the voids in the problem space (Figure 1).

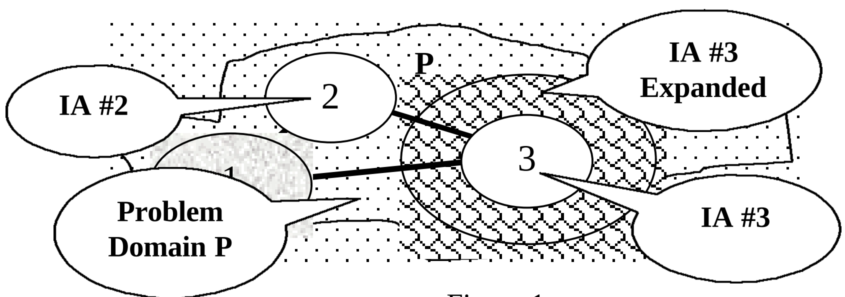

Figure 1
Modeling of complex problem domains

Let subsets A and B represent SA in problem space P

$A \subset P$ and $B \subset P$
$A=\{a_1, a_2, a_3, \ldots a_n\}$
$B=\{b_1, b_2, b_3, \ldots b_n\}$

The elements a, b represent the functional elements of subsets A and B respectively. The duplication of functionality as shown below is possible and particularly evident in agent-to-agent communications.

$A \cap B = \Delta$
Where $\Delta=\varnothing \Leftrightarrow A \cap B=\{a \mid a \in A \text{ and } a \notin B\}$
And $\Delta \neq \varnothing \Leftrightarrow A \cap B=\{a \mid a \in A \text{ and } a \in B\}$

For the strategy of problem partitioning (as in Figure 1) to work efficiently, problem sub-domains (sub-problems) must be made maximally independent from each other. In this way, computational load experienced by each agent is determined by the information processing needs of its own domain, and is minimally influenced by the activity of the other agents. However, as the conditions in the entire problem space change, the boundaries of the sub-domains must be redrawn. The key function of the VAN-based supervisory system is to monitor conditions in the problem space, to adjust the sub-domains, and to re-assign the agents accordingly.

3.0 Virtual Associative Networks

An optimization governing process must be employed to provide a rapid information delivery to the user. The information provided by the SA must be pertinent to the current situation and the need for information must be anticipated by the system. The large number of SA, associated with a comprehensive modeling of a complex problem space, creates a combinatorial problem while the computational limitations of machines require the assistance of an optimization process.

The current implementations of IA are cognitive model-driven approaches to problem solving which lack the flexibility of generalization and learning dexterity. The generalization ability can greatly reduce the uncertainty of the solution, require less data, and facilitate collaboration between agents. The advantage of VAN, over conventional model-driven techniques, was shown [Yufik, Y. et al 1998, p 179]. The power derived from collaborative and distributed IA architecture can be further improved by incorporating a VAN driven agent architecture. The formulation of VAN is relatively simple, however a rigorous modeling is required.

Let elements $\mathbf{a}_1, \mathbf{a}_2,..\mathbf{a}_i$, have associations $\mathbf{W}$ throughout the problem space and constitute nodes of a topological network which spans the problem domain. The clustering of elements or packet formation is achieved when the total strength of internal association $\Sigma \mathbf{W}_{int}$ is larger then the sum of the external ones $\Sigma \mathbf{W}_{ext}$. (Figure 2)

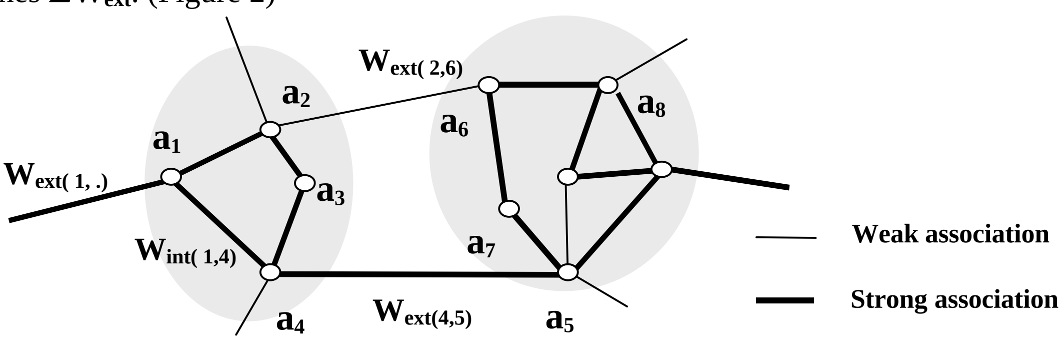

Figure 2. The formation of packets in VAN.

$\Sigma \mathbf{W}_{int} > \Sigma \mathbf{W}_{ext}$ formation of packets
$\Sigma \mathbf{W}_{int} < \Sigma \mathbf{W}_{ext}$ destruction of packets

The elements form packets as the associations between them increase, and the packets are dissolved when the associations between their elements decrease. The associations can be viewed as forces that are instrumental in forming and dissolving packets. In the model, the strength of associations is dependent on the environmental variables.
The initially formed VAN packets form nodes of a network of higher level. The upper level of the network forms a map of the lower one. This phenomenon demonstrates VAN's scalability property.

4.0 Conclusion

Given that we can model complex problem poses an important question - namely, how quickly can the machine give us the correct answer? When we break down a complex problem space in tiny domains, with some interrelationship between these domains, a network is formed. The total number of iterations to examine every association grows rapidly with the number of network nodes, as demonstrated in the equation below:

$$\mathbf{N = n\,(n-1)/2}$$

Where **N** is the number of associations and **n** is the number of nodes.

After training, the VAN reduces the combinatorial complexity and is more efficient than traditional heuristic approaches modeled to work in complex problem spaces. The VAN scale up in a natural way where conventional algebraically based techniques cannot [Yufik, Y. and Malhotra, 1998]

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