Cooperative Agent Framework

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***Abstract*— The basic purpose of this study was to investigate and provide a methodology for communication scenarios and decision-making procedures within a unified, distributed, multi-agent framework that would allow different problem domains. To handle the reuse of the agent framework, there must be an agreement on what constitutes the properties of an agent which is basically undetermined in the AI community.**

A relational distributed actor/agent solution was utilized for the correspondence of knowledge and interaction that occurred between the participants of a multi–agent environment. Relational methods are versatile. They provide means for knowledge acquisition, representation as well as the flexible substratum for developing platforms for relational computations. Therefore the collaboration/communication necessary for interaction between the participating agents within the environment is based on fuzzy relational B–Products and relational BK Capability Criterion of Generalized Morphisms and matrix manipulations. The BK–Products are used to compare and analyze the fuzzy relational structures used to represent new interpretations of the original data within the agent's knowledge domain.

I. Introduction

The notion of an agent and agency play an important role in artificial and computational intelligence, as well as in the design of intelligent distributed computing systems. Due to the rapid development of global distributed networks (such as Internet) and multimedia systems, the agent technology has developed very rapidly and in a very ad hoc way. Currently there exist large numbers of practical applications that use computational agents with diverse and often incompatible competencies.

To handle the reuse of the agent framework, there must be an agreement on what constitutes the properties of an agent. A desirable agent must have the following properties: autonomy, reactive, pro-active, socialability, knowledge, intentions, and obligations. These properties are the necessary properties to allow the agents to perform their respective duties, but general enough to allow reuse.

The versatility of the relational approach provides mechanisms for communication and decision-making procedures within a unified, distributed, flexible multi-agent framework. Relational structures are used to support a distributed agent solution for the correspondence of knowledge and interaction that occurs between the participants of a multiagent environment. The Bandler and Kohout (BK) relational products and their relational compatibility criterion theorems define these relations which are used to communicate and interact among participants within the system. Specifically the concept of Generalized Homomorphism defines the partial correspondence mappings between collaborating participants. The concept of partiality as well as the impreciseness of real world problems and environment s lends itself directly to representations in fuzzy and generalized homomorphisms.

II. Relational Approach

Systemic models are often used to capture the relevant knowledge concerning the entities of the world we live in. Relations can be used to represent knowledge and evaluate the interdependencies of various entities we analyze and study. Relational methods, both crisp and fuzzy, are helpful in discovering meaningful structural relationships that exist between entities. Relational computations can be useful in providing ways for sharing information. As well as distributing inference tasks that involve two or more participating agents. In cooperating systems, there may exist conflicts and indeterminacies but also considerable benefits may be brought out by cooperation. When agents cooperate (i) the sources of knowledge of these agents may be only *partially* compatible, (ii) there exist a possibility of *disagreements*, and (iii) knowledge can be shared and may lead to enriched co-operative situations because each agent may have a different competence if there is at least partial compatibility.

Relational representation of knowledge makes it possible to perform necessary computations and decision making in a uniform relational manner, by the use of special relational compositions of triangle and square products. The products were first introduced by Bandler and Kohout in 1977 [3], and are referred to as BK-products. BK-relational products can be used to compare relational structures. Relations so constructed might exhibit some important relational properties that reveal important characteristics and inter-relationships of the source of information from which they were generated. Hence, methods for detecting various relational properties of given relations are important. Fuzzy Relational within Generalized Homomorphics constructs allow for exploring the partial compatibility, by providing the means for identifying partial complementary expertise and competencies of participating agents. Our work demonstrates these capabilities.

III. The Role of Generalized Morphisms

A. Knowledge Sharing

For example, a participating agent may be able to perform certain different portions of a task that other agents cannot perform. This agent can, however, do it only if it receives from other agents some information relevant to this particular task.

Hence, in such a situation, participation of several agents is essential for performing the task of concern. To deal with such problems, not only the low level hardware/software interaction has to be dealt with, but also the more abstract conceptual and semantic questions have to be formulated and resolved. Any abstraction to be useful in building intelligent agent systems for real-life applications, must (i) capture how the co-operating agents communicate and exchange information in order to co-operate in solving joint tasks; (ii) address the defects of this communication; and (iii) formulate the minimal conditions for successful communication and cooperation.

B. Semiotics of Communication

Requirement (3) necessarily implies that it must be possible to find at least partial compatibility and *mutual translatability* between the messages and knowledge structures of co-operating agents. This can be formulated as follows.

Definition (Minimal Conditions for Effective Communication:)

Given two communicating participants, $P1$ and $P2$ using languages $L1$ and $L2$ respectively, the

shared parts, say $L1s$ and $L2s$ have to satisfy the following conditions [1]:

1. a partial correspondence νs between the shared parts of the languages;

2. a partial correspondence between the syntactic structures of $L1s$ and $L2s$;

3. at least partial semantic agreement between the ways participants interpret the meaning of communicated sentences.

These three requirements determine the minimal conditions that a conversation of two

actors must satisfy.

C. Sharing and Comparison of Knowledge Structures

It is well established that comparison of structures is done through mappings that define isomorphisms and homomorphisms. However, because of partiality and possible ambiguity of correspondences, the usual formal treatment of the mutual correspondences between the notions used by two distinct agents cannot be done using conventinal homomorphisms and isomorphisms. This becames clearly the case for generalized morphisms that are more suited to this problem. We shall demonstrate this in the example that follows. The example will clearly show the computational importance of the BK-products.

Collaboration/communication between agents, based on relational BKProducts, relational BK Capability Criterion of Generalized Morphisms and matrix manipulations, provides new interpretations of the original data within the actor's knowledge domain.

IV. Pilot Model

For the purpose of this study we explore a base application that would demonstrate the use of two knowledge structures that comply with the minimal conditions stated above. The environment should accept and recognize fuzzy structures providing individual and collaborative decision-making, where applicable. The agents are bounded and inter-related by generalized homomorphic structures and then manipulated and evaluated using relational BKProducts and relational BK Capability Criterion. Once this base application was implemented and evaluated, we then wanted to see if the system would lend itself to another application. One of the problems of agency is that each problem domain usually demands systems uniquely designed for its knowledge structures and problem set. Given that the knowledge structures adhere to the stated minimal conditions our approach should allow interactive collaboration with more domain flexibility.

V. Base Application

The two separate diagnostic approaches, CMIT and WTE, are represented by the two participating agents. These agents are semiautonomous abstractions that embody two different fuzzy knowledge sources as well as distinct languages of communication. The collaboration between these agents provides a higher level of diagnosis than would be possible for each actor independently. The system has the following required capabilities:

1. Provides a distributive multiagent application that supports two distinct knowledge sources that can be used in collaboration to make a medical diagnosis.

2. Have the capability to carry out a collaborative diagnosis when an actor does not have the knowledge to make the diagnosis independently.

3. Provide a relational approach to implement the intelligence of the agents.

4. Provide translations or communication between agents via relational generalized morphisms.

5. Relationally determine which agent is most competent to provide the medical diagnosis, independently or collaboratively.

A. Semiotic Descriptors

The two participating agents, A and B respectively, are defined via two binary relations R and S. The semiotic descriptions of the two agents are described as follows:

Agent A: $\boldsymbol{R \in \beta(C \to D)}$***:*** $\boldsymbol{C \subseteq SYM}$***,*** $\boldsymbol{D \subseteq DIS}$***,*** *where R is a relational representation of CMIT,*

Agent B: $\boldsymbol{S \in \beta(W \to E)}$***:*** $\boldsymbol{W \subseteq SYM}$***,*** $\boldsymbol{E \subseteq DIS}$***,*** *where S is the relational representation of WTE.*

The knowledge domain was from the area of Internal Medicine, the Endocrine body system. Both diagnostic approaches were tested on the same body system, however they used different diagnostic approaches. There are translator relations through generalized homomorphic mappings that relationally controlled the communication and interaction between the participating agents. The definition and formulas used to create these relational translators are given below.

Definition: Generalized Morphisms[1]: *Let F, R, G, S be heterogenous relations between the sets A, B, C, D, such that* $F \in R(A \to C)$, $R \in R(A \to B)$, $G \in R(B \to D)$, $S \in R(C \to D)$.

1) *The conditions that(for all $a \in A$, $b \in B$, $c \in C$, $d \in D$) (aF c & aRb & bGd) $\rightarrow$ cSd) will be expressed in any of the following ways (i) FRG:S is forward compatible, (ii)F,G respect R, S forwards, (iii) R, S absorb F, G forwards and (iv) F, G are generalized homomorphisms from R to S .*
2) *The conditions that (for all $a \in A$, $b \in B$, $c \in C$, d $\in D$) (aFc & cSd & bGd) $\rightarrow$ aRb will be expressed in any of the following ways: (i) FRG:S is backward compatible, (ii) F, G respect R,S backwards, (iii) R,S absorb F,G backwards, and (vi) F,G are generalized proteromorphisms from R to S.*

Theorem Compatibility Theorem [1]

1) *FRG :S are forward compatible* $\Leftrightarrow F^{T} \circ R \circ G \sqsubseteq S \Leftrightarrow R \sqsubseteq F \triangleleft S \triangleright G^{T}$
2) *FRG: S are backward compatible* $F \circ S \circ G^{T} \sqsubseteq R \Leftrightarrow S \sqsubseteq F^{T} \triangleleft R \triangleright G$,
3) *FRG:S are bothways compatible if they are both forward and backward* compatible .

F and G , relational translators, are only partially compatible. Therefore the above defined compatibility criteria is used to determine the agent most competent to perform the requested diagnosis. When tested the resulting diagnosis, determined from systems provided by the clinician, accuracy depended upon the accuracy of the symptoms and decided threshold of the alpha cut.

VI. Test Application

The knowledge used for the test application is based on the Cardiovascular body system, utilizing data provided by Professor John Anderson, Kings College, University of London, UK. Each agent has different well-structure fuzzy knowledge of signs and symptoms that correlate to specific syndromes within the Cardiovascular body system. These agents are also semiautonomous that relationally embody two different knowledge sources as well as distinct languages of communication.

A. Semiotic Descriptors

The two participating agents, A and B respectively, are defined via two binary relations R and S. The semiotic descriptions of the two agents are described as follows:

Agent A:R $\in \beta(M_1 \rightarrow G_1)$:

$M_1 \subseteq SYM, G_1 \subseteq SYND$ *, where R is a relational representation of* G_1,

Syndromes - Sample from Relational Representations

Agent 1: m14 = { G6} m23 = {G5, G11, G12}
m25 = {G5, G6, G8, G10, G11
m29 = { G5}
m31 = {G8, G12}
m34 = {G10}
m36 = {G6, G1}
m39 = {G6,G7, G11}
m40 = { G5, G7, G11, G12}
m44 = { G5, G6, G7}
m63 = {G6, G8, G11, G12}
m125 = { G6, G7, G8, G11, G12} .

Agent B: $S \in \beta(M_2 \rightarrow G_2)$: $M_2 \subseteq SYM$,
$G_2 \subseteq SYND$*, where S is the relational representation of* G_2*Syndromes.*

Sample from Relational Representation

Agent 2: *m8 = {G1}*
m13 = {G8}
m14 = {G6, G9}
m20 = {G2, G8}
m22 = {G2, G5, G6}
m23 = {G2, G5, G11, G12}
m25 = {G2, G5, G6, G11, G12}
m27 = {G2}
m28 = {G2, G5, G6, G11}
m29 = {G2}
m31 = {G8, G9, G12}
m34 = {G10}
m36 = {G6, G10}
m37 = {G10}
m58 = {G9}
m63 = {G5, G8, G9, G11, G12}

This knowledge domain is from the area of Cardiac Medicine, the Cardiovascular body system. Both domains are defined on the same body system, however they contain different competencies. Agents possibly have incomplete, imperfect knowledge. They also have some common syndromes, but not all. Syndromes also have overlapping symptoms. The relations linking the signs and symptoms of the syndrome agents are computed by Generalized Homomorphic formulas defined above. These relational translators internally determine competency of and select the best path of computation. The results is a refinement of which syndromes within the Cardiovascular body system the patient's signs and symptoms best belong, which can in itself provide medical insight or used to determine actual diseases.

B. Example: Sample Product Relations

These are the relational translators based upon the Sample Representations defined above.

Product $F = R \triangleleft (G \triangleleft S^{-1})$
(Forward Compatible)
$m_1 14$ = { $m_2 14$, $m_2 22$,$m_2 25$, $m_2 28$, $m_2 36$}
$m_1 23$ = {$m_2 23$,$m_2 25$, $m_2 63$}
$m_1 29$ = { $m_2 22$, $m_2 23$, $m_2 25$}
$m_1 31$ = {$m_2 31$, $m_2 63$}
$m_1 34$ = {$m_2 34$, $m_2 36$, $m_2 37$}
$m_1 36$ = {$m_2 36$}
$m_1 40$ = { $m_2 23$}
Product $G = R^{t} \triangleleft (F \triangleleft S)$
(Forward Compatible)
$G_1 5$ ={$G_2 5$}
$G_1 6$ ={$G_2 6$}
$G_1 8$ ={$G_2 3$, $G_2 8$, $G_2 9$, $G_2 12$}
$G_1 10$ ={$G_2 10$} $G_1 11$ ={$G_2 5$,$G_2 11$, $G_2 12$}
$G_1 12$ ={$G_2 12$}

VII. Evaluation

Example 1: *Clinician has input the following Symptom to Agent B: Crepitations* $_{m14}$
After determining the aftersets: Agent B can produce the following Syndromes {*G4, G6, G9*}*;*
Symptom Crepitations$_{m14}$*is a direct translation to Agent A (see Product F above infer* F^T*).*
Agent A can produce the following Syndromes {*G6*}*;*

Depending on the desired results the Clinician may only want Syndrome G6 which is determined by Product G (infer G^t*), or they might want to select more symptoms and observe all three syndromes and determine overlapping diseases.*

Example 2: *Clinician has input the following Symptom to Agent A: Blood Pressure High*$_{m34}$

After determining the aftesets:

Agent A can uniquely identify Syndromes {*G10*}.

Example 3: *Clinician has input the following Symptom to Agent A: Dydpnoeas* $_{m23}$

After determining the aftersets:

Agent A can produce the following Syndromes {*G5, G11, G12*}*;*

Symptom Crepitations$_{m23}$*is a direct translation to Agent B (see Product F).*

After determining the Aftersets:

Agent B can produce the following Syndromes {*G7,G3, G5, G7, G11, G12*}*;*

(Using Product G^t*) produces Syndromes :*

{ *G5, G6, G8, G11, G12)*

Depending on the desired results the Clinician can only want Syndrome {*G5, G6, G8, G11, G12*} *which is determined Product G (infer* G^t*), or they might want to select more symptoms and*

observe all possible syndromes and determine overlapping diseases.

The main advantage of relational approaches is that they are inherently parallel. Particularly important zare architectures for knowledge-based systems that can w ork with partial or imprecise information. Expressed by interval fuzzy logics. Fuzzy relational methods are significant in discovering meaningful structural relationships implicit the scientific and medical data. The use of relations not only provides for quantitative numerical evaluations, but they also support semiotic and semantic notations which promotes general frameworks to be used with various problem domains that have different interpretations semantically. Depending upon the desired refinement, various boundary intervals can be set to extract higher degrees of solution competence.

VIII. References

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