Application of the Semantics Enrichment Concept in the Information Fusion for Command Support

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ABSTRACT

In this paper we present the different notions surrounding the concept called semantics enrichment which may significantly contribute facilitating the fusion process. After having introduced the role of the semantics in any command aid support, we show how it is possible to increase the relevance of operational information from its semantics. We propose a way to enrich semantics, firstly by making symbolic fusion, secondly by determining compatibility relations between pre-defined domains of operational knowledge; for that purpose we rely upon the fuzzy logic elements. We finally present applications, in which, all notions referring to the semantics enrichment concept can be applied. A possible way of extending the semantics enrichment process is also presented.

Keywords: fusion, semantics, symbolic fusion, compatibility relations, knowledge representation, fuzzy logic.

RÉSUMÉ

Cet article concerne un nouveau concept, intitulé enrichissement de la sémantique, destiné à faciliter le processus de fusion d'information en s'intéressant essentiellement à un moyen d'améliorer la pertinence de la connaissance opérationnelle. On commence par rappeler ce que l'on entend par enrichissement sémantique et les notions qui lui sont sous-jacentes : espace et couches sémantiques. Il est proposé ensuite de réaliser l'enrichissement de la sémantique tout d'abord, par un processus de fusion symbolique puis par des relations de compatibilité basées sur la logique floue. L'intérêt du concept est illustré par plusieurs applications.

Mots clés : fusion, sémantique, fusion symbolique, relations de compatibilité, représentation de la connaissance, logique floue.

1. Introduction

The main objective of all aid command sytems, whatever may be the nature of their required techniques, is to support the decision–maker efficiently, viz to keep him well informed of the most current situation and to deliver the most relevant information at any moment. In other words, such a sytem cannot be considered efficient as long as it is not able to up to date the situation continuously in a proper way and to provide the aid command sytem with the most relevant knowledge at the right time. This knowledge relevance is largely dependant on an

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"intrisic quality" partly due to the fact that "imperfection dimensions" are brought along: uncertainty, imprecision, lack of plausibility, whenever it is captured in an external world. These imperfection dimensions must be taken into account as they direcly interfere with the quality of any command aid support. It is essential to have an idea of their importance and try to assess them, insofar as possible in a quantitative way, in order that we may master the relevance of the global information of any fusion process using it To be more complete one should notice that other attributes are intervening like : timely, deliverable in appropriate conditions, coherent (logical aspects) in conjunction with a given class, validity in pre-defined temporal intervals.

1.1. Motivations

In a fusion process we are obliged most of the time to combine informations or data, heterogeneous, deriving from different places, arriving at unexpected moments. So, the problem which has been just mentionned above, concerning the relevance, far from being minor, is liable to decrease drastically the information relevance of a fusion process issue, and that way, to contribute altering the worse the command aids. As one cannot do away with from these "side effects" one is better off researching a new way to limit their influence.

In this paper we are going to consider that, in a given context, all objects of knowledge have their own significance, in a certain maner, they have a proper semantics dimension**.** Then the idea which prevails here is to be only interested by the semantics dimension of the knowledge. If we combine the different semantics dimensions of a set of information, we are bound to reinforce the global semantics of this collection, and this way, we must obtain a useful relevance level at the end of the fusion process.

1.2. Concept of information enrichment

Let us imagine that we dispose of an ideal machine which enables us to make : either simple observations and detection : "gunshot at...", or to recognize and identify entities : "a tank company at...", even to recognize a system or to name an action : "they are running north...". These different facts or events, as soon as they are known, are not going to improve our knowledge about a situation in the same manner. In fact, these knowledge elements are not pertaining to the same informational complexity. The detection of simple facts is obviously less carrying information than identifying an entity or precising an element being a part of a system. This conducts us to make a distinction between different levels of knowledge semantics.

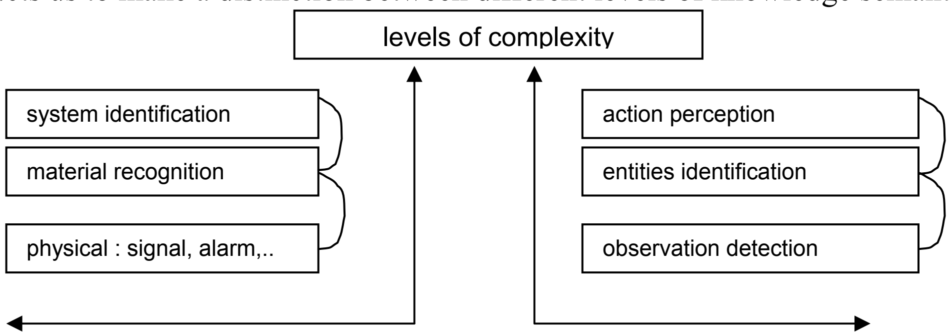

Fig. 1 semantics information complexity

1.3. Knowledge semantic dimension

Considering the above figure one observes that the knowledge, representing different objects which has been captured in the real world, are not relevant to the same complexity if we agree obviously to say that :

- the observation of an entity carries less significance than its recognition. In our mind recognition means the ability of designating an item relatively to a references list,
- the identification of an action, for instance : "the tanks are heading for north", has a larger significance than the simple recognition of an entity : " a tank has been spotted on the road",
- the observation of an action has a much weaker significance than the intention that one can infer from it : "the tanks are heading for north try to encircle us".

One must consider that the observed events, the represented objects of an universe of actions, do not all have the same level of complexity regarding semantics; in fact, they possess their own semantics. To underline this point of view, we introduce the notion of *semantics dimension* for characterising any object which must be captured in the external world when it is required by a command aid process. The semantics dimension is supposed differing largely from an object to an other.

1.4. Enrichment space

In an overview of semantics enrichment concept, we define a special space in which we try to position each object captured in the real world. We notice that they will not occupy neither the same level because they are not relevant of the same intricacy, nor the same place at a given level for the very reason they have not the same semantics dimension : at a complexity level they may carry more or less significance. Therefore, they are not going to have the same role in a fusion process according to their position in this space, entitled for the occasion : *enrichment semantics space.* In this space, we consider that is possible to enrich the semantics of different knowledge objects at a time into a vertical and an horizontal way.

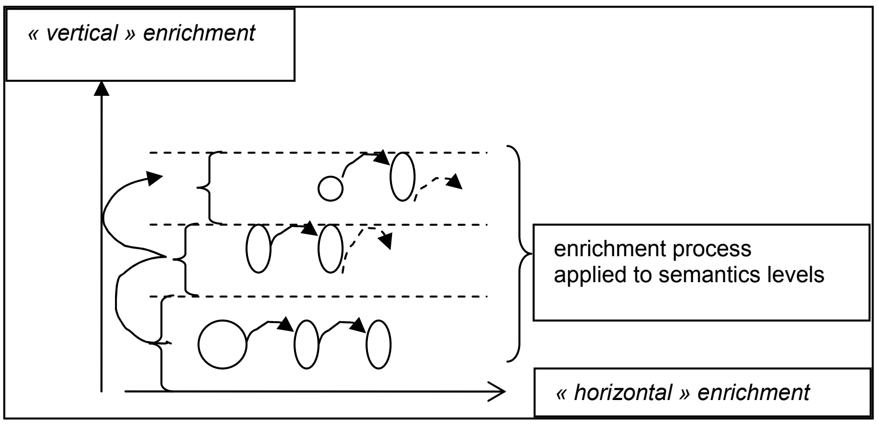

Fig. 2 semantics enrichment space

1.5. Semanics layer notion

The semantics enrichment in two dimensions above mentionned is made at the following conditions:

1. all objects pertaining to the the same semantics complexity can be "associated" in the same framework process in order they should improve the global semantics which can be obtained at this complexity level (horizontal enrichment),

2. the issue of a lower level can be used in an upper one (horizontal enrichment). The knowlege of the lower levels appear most of the time to be indispensable to the upper ones (vertical enrichment).

One considers that the different treatments participating in the process of decision-making do not all proceed to the same complexity. It is advisable thus to try to identify and to isolate the different levels of complexity of decisional process of command to get the most of the multi-level approach in which each level is responsible for symbolic treatments pertaining to a degree of semantics data complexity which it can be accepted and processed. By the way, this approach presents the good advantage to be open, which enables to add a level as required by a new encountered complexity. Each level, termed a *semantics layer* in this paper, becomes the functional entity in a fusion treatment, and for doing the job must own all the symbolic operators which are necessary to treatments which devolve upon them.

2. Semantic enrichment by symbolic fusion

2.1. Principles of semantics enrichment

Let a couple (a,b), and,

$\exists\, \alpha_1 \mid (\alpha_1 > a) \wedge (\alpha_1 > b)$,

$\exists\, \beta_1 \mid (\beta_1 < a) \wedge (\beta_1 < b)$,

α_1 and β_1 constitue two bounds for (a,b) which intuitively carries more significance than a, b taken separately, otherwise it will not be possible to bound them. In continuing the process with an other element c we obtain :

$\exists\, \alpha_2 \mid (\alpha_2 > c) \wedge (\alpha_2 > \alpha_1)$,

$\exists\, \beta_2 \mid (\beta_2 < c) \wedge (\beta_2 < \beta_1)$,

If we are up to proceed on this way we are, in our view, we are going to increase the semantics level of a, b , c by a kind of propagation.

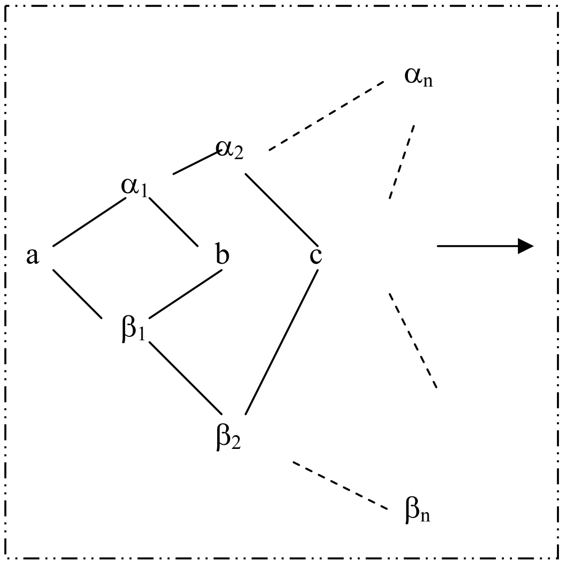

Fig. 3 symbolic fusion principles

The above figure shows that a and b may be bounded by two subsets of bounds surrounding the two elements : a, b.

U (upper bounds) :: $\{\alpha_1, \alpha_2, ..., \alpha_n\}$,

L (lower bounds) :: $\{\beta_2, \beta_2, ..., \beta_2\}$.

From an semantics enrichment point of view we have to consider that the upper bounds are not playing the same role by comparison of the couple (a, b). For instance, if we wish to match the two companies a and b in a fusion process we have to construe that they are encompassed in the same level to which they are subordinated, viz the regiment. In a symbolic fusion view the upper levels : α_2 :: brigade, α_n :: army are strictly without any interest. In addition, α_2 :: brigade, α_n :: army have not the same semantics dimension to α_1 :: regiment. That means that nodes a and b of the graph (cf figure 3) must belong to a closest common node : node α_1. For the couple (a, b), the node α_1 is in fact the smallest bound among the greatest bounds of the set U. We can of course proceed in the same mind by using the inferior bounds of the set L.

An element u of a set U is the *least upper bound* (denoted l.u.b) often called *supremum*, if :

1. it is an upper bound in U; that is $\forall\ x \in U\ u \geq x$,
2. it is the smallest of all other upper bounds in U, that is $u \leq v$, $\forall v \in$ {upper bounds in U}.

An element l of a set L is the *greatest lower bound* (denoted g.l.b) often called *infimum*, if :

3. it is an lower bound in L; that is $\forall\ x \in L\ \exists\ x \geq l$,
4. it is the greatest of all other lower bounds in U, that is,

$\forall\ m \in$ {lower bounds in U} $\exists .l \mid m \leq l$.

NB By the way a partially ordered set in which two elements have a i.u.b and a g.l.b constitutes here an useful structure : a lattice, for the symbolic fusion process.

The problem of symbolic fusion for any couple of elements resides in the adequate way of managing either their I.u.b (infimum) or their g.l.b (supremum) from different couples of knowledge objects. In the case where a = b, that is to say that α cannot be greater than (a, b) and β not lower than (a, b) means that a knowledge canot be eriched by itself.

2.2. Semantics enrichment application

One no longer looks to apply correlation techniques (or techniques of aggregation), but rather, to understand how a knowledge by being applied to a situation brings about a new situation, in this sense, that the knowledge which one possesses is improved. The notion of symbolic fusion calls forward two remarks:

it must be conceived in an application (cf. Barès), that is to say :

(knowledge(s)) applied to the situation |—> improved (enriched)situation,

that is different from aggregated fusion, which is more apparented to a tool since :

{data, info} aggregated to {data, info} |—> new situation.

The finality of a symbolic fusion is that, in the midst of permanent knowledge relative to a situation, to enrich it of such a sort that its level of pertinence can be increased. This idea of enrichment of knowledge constitutes also one of the original concepts of the project of decision-making MATIS1 for modeling this knowledge, while the symbolic treatments which operate on it are conceived to intrinsically increase the information content of a situation and not to elaborate a quantification under form of criteria, which take account of the intensity of this increase (as in the case of numeric criteria of a similarity oscillating in an interval [-a, +a]).

If one considers at present the following points:

an OB (Order of Battle) can be represented by a branching β

the perceptual system of a command system can only capture the fragmentary elements of this OB for two reasons :

1) the OB is never completely revealed in its totality in a theater,

2) sensors sytems have their field of perception forcibly limited for technological reasons and also for reasons of the conditions of observation (not only meteorological ones).

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[1] **Modèlisation Aide à la décision par Traitement de l'Information Symbolique decision-making project lead by ex DRET (Direction de la Recherche, Etudes et Technologie) – Délégation Générale de L'Armement – French MoD**

One is thus brought to define (cf Chaudron) the collection of all connected parts of an OB, which one will note A (β), in which β is the branching.

- (A ,⊂) is an ordered collection, A is stable by intersection, unstable by addition except in the specific case where A is a chain,
- what will be committed in the theatre will correspond to a certain sub-collection A'(β) such that A'(β) ⊂ A (β).

In the observation space of a perceptual system will only be re-found the fragments of OB noted : O(**β**), for reasons mentioned before, in remarking that:

O(**β**) ⊆ ***P*** (**β**). (***P :*** power set***)*** since a succession of observations is going to concern itself very certainly with the non-connected elements of the OB. From these different points, it is possible to specify the vision which one has at present of the symbolic fusion applied to the situation

{elements ∈ situ1} ⊂ ***A*** (**β**), ⊂ {elements ∈ observation space} ⊂ ***P*** (**β**).

A' (**β**) O (**β**),

if an element a ∈ ***A'*** (**β**) and an element p∈ O (**β**),

then there is a possible symbolic fusion :

fusion(a,p) ⇒ a' , with a' ∈ ***A*** (**β**).

It is advisable then to be able to have available a relation (cf L Chaudron), allowing construction and comparison of 4 elements : the couple a, p, then the maximal elements to induct and the minimal element.

One must in fact be able to say if a' is a maximal element or a minimal element in connection with a and p, in order to determine if there has been an improvement or not.

3. Enrichment with compatibility relations

We convene to say that it exists a compatibilty relation between two, or more, domains of knowledge, if it is possible either to establish or to handle relations between them, these relations having a semantics dimension in a certain context. At that point, we are going to examine how we may improve, from an initial domain, the general cognizance knowledge resulting of the combination of the diffent domains.

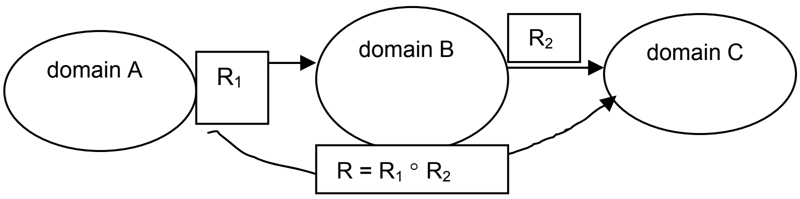

Fig. 4 compatibility relations

For instance, if R1 represents a compatibility between :

domain A : {observations} and domain B : {postures},

R_2 representing a compatibility between :

B and domain C :{actions}, therefore, in using relations combination, it must be possible to infer an possible action from an initial observation :

$o(\text{observation}) \in A\ ,\ R_2(R_1(o)) \Rightarrow a(\text{action}) \in C.$

The elements of a knowledge attached to precedent domains A, B, C are generally accessible (or known) in an approximative way, this motivates that we define them helping a fuzzy measure, ie : a possibility measure. For that reason, we need rely upon three fuzzy logic notions like possibility measure, cartesian product fuzzy relation

3.1. Possibility measure

Given a universal set R, a possibility measure is defined as a mapping Π :

$\Pi : \boldsymbol{P}(R) \rightarrow [0, 1]$ (***P** : power set),*

with $\Pi(\varnothing) = 0$ et $\Pi(R) = 1$,

$\forall E_i \in P(E_i) \rightarrow \Pi(\cup_{i=1,\ldots,n} E_i) = \text{Sup}_{i=1,\ldots,n}\, \Pi(E_i)$

The possibility Π is a fuzzy measure, vérification of the 3 axioms :

1. *limits* : $\Pi(0) = 0, \Pi(R) = 1$,
2. *monotony :* $\forall A, B \in \boldsymbol{P}(R) \mid B \supseteq A \Rightarrow \Pi(B) \geq \Pi(A)$,
3. *continuity :* $A_1 \subseteq A_2 \ldots A_{n-1} \subseteq A_n$, $\lim \Pi(A_n) = \Pi \lim (A_n)$ *$n \rightarrow$ infinity.*

3.2. Fuzzy cartesian product in the enrichment process

The fuzzy cartesian product (CP) represents the adequate instrument when it is necessary to make a decision, express a preference, from a context characterized by fuzzy classes. Given two fuzzy sub sets $A \subset U$, $B \subset U$; their cartesian product will be denoted by : CP :: A x B . CP is a fuzzy set known by its membership function denoted :

$$\boldsymbol{\mu_{AxB}(x, y) :: \text{Min}[\mu_A(x), \mu_B(y)].}$$

Table 1 cartesian product application

CP	A : location choice	M : dwelling choice	μ_{AxB} : : Min [$\mu_A(x)$, $\mu_B(x)$]
location x type(dwelling)	M/0.3	P/0.8	0.3 / (P, M)
		V/0.6	0.3 / (V, M)
		C/0.4	0.3 / (C, M)
	A/0.7	P/0.8	O.7 / (P, A)
		V/0.6	0.6 / (V, A)
		B/0.4	0.4 / (C,A)

As it is shown on above mentionned example, it is already possible to conduct an enrichment by using the CP, after constructing the tree decision, we obtain the final choice ie : an knowledge enrichment from the initial classes.

Table 2 : cartesian product use

	P	V	C
A	0.7	0.6	0.4
M	0.3	0.3	0.3

In generalising a CP to several fuzzy classes it becomes very easy to augment on the semantics enrichment in this process.

3.3. Fuzzy relation use in the enrichment process

This corresponds to a formal extension of the classical relation. Let U : universal set, two fuzzy sub sets $A \subset U$, $B \subset U$, a fuzzy relation R_f defined in conjunction with a CP : $R_f \subseteq A \times B$ represents a fuzzy subset whose the membership function is :

μ_{Rf} (different from the CP membership function μ_{AxB}): $\boldsymbol{\mu_{Rf} : A \times B \rightarrow [0, 1]}$.

Example : A : : {1/a ; 0.2/,b ; 0.3/c } and B : : {0.1/α; 0.2/β; 1/γ},

A x B : : $\{0.1/(a,\alpha) \cup 0.2/(a,\beta) \cup 1/(a,\gamma) \cup 0.1/(b,\alpha) \cup 0.2/(b,\beta) \cup 0.2/(b,\gamma) \cup 0.1/(c,\alpha) \cup 0.2/(c,\beta) \cup 0.3/(c,\gamma)\}$.

We define the fuzzy relation :

$R_f \subset A \times B$: : $\{0.1/(a,\alpha) \cup 0.2/(a,\beta) \cup 0.1/(b, \alpha) \cup 0.1/(c,\alpha) \cup 0.2/(c,\beta) \cup 0.3/(c,\gamma)\}$

R_f may be either diagrammed or represented with a matrix.

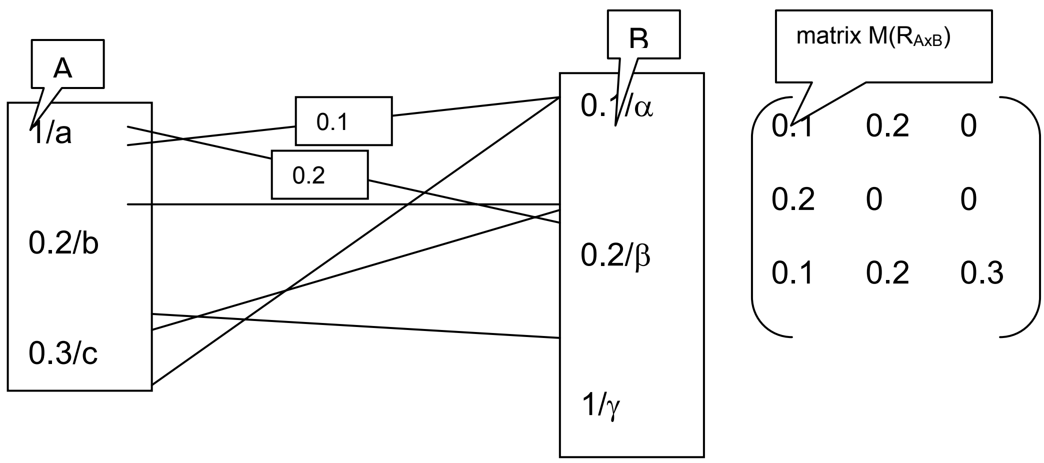

Fig. 5 fuzzy relation representations

If several domains are in relationship and their elements are only assessed through a possibility measure because of their vageness, it becomes interesting to seek composing the relations existing between domains. If we should suppose that a context exists which is characterized as follows :

- observations about the ennemy's postures are possible but they are imprécise and not certain,
- friend experts are able to establish more or less possible compatible relations between a ennemy's postures and their possible corresponding actions.

In that case, the appliance of the semantics enrichment is about to consist to determine what kind of possible actions may be infered from observed postures. The three domains : A :: {observations},B :: {postures}, C :: {actions} are fuzzy sets, linked by compatible relations, in fact fuzzy sets. To infer a possible action from an element belonging to A it is necessary to use a composition of fuzzy relations.

Let , A :: {1/a ; 0.2/,b ; 0.3/c }; B :: {0.1/α; 0.2/β; 1/γ};C :: {0.6/Δ; 0.5/Φ ; 0.1/Ω},

the CP, B x C :: {0.1/(α,Δ) ; 0.1/(α,Φ) ; 0.1/(α, Ω) ; 0.2/(β,Δ) ; 0.2/(β,Φ) ; 0.1/(β, Ω); 0.6/(γ, Δ) ; 0.5/(γ, Φ) ; 0.1/(γ, Ω)}, $R_f \subset$ B x C = {0.1/(α,Δ) ; 0.1/(α, Ω);0.1/(β, Ω);0.5/(γ, Φ) }

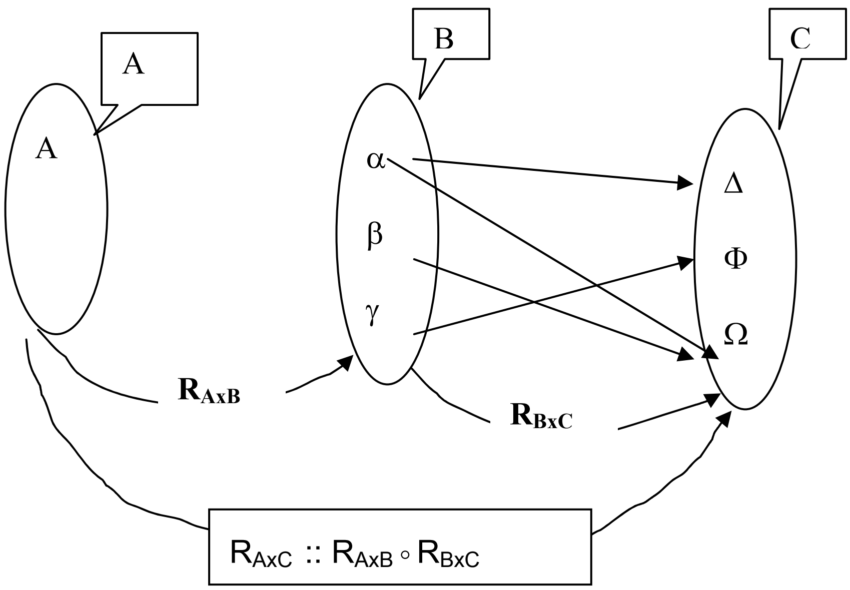

Fig. 6 application of the relations composition

R_{AxC} results of the composition of the two relations $R_{AxB} \circ R_{BxC}$ represents a fuzzy relation of which the membership function is defined by :

$$\mu_{R A \times C}(x,z) :: \mathrm{Max}_{y \in B} [\mathrm{Min} [\mu_{R A \times B}(x,y), \mu_{R B \times C}(y,z)]].$$

As the relation composition may be usefully represented by matrices we obtain from the above example.

$$M(R_{AxB}) \times M(R_{BxC}) = \begin{array}{c} \\ \alpha \\ \beta \\ \gamma \end{array} \begin{array}{c} \begin{array}{ccc} \Delta & \Phi & \Omega \end{array} \\ \begin{pmatrix} 0.1 & 0.2 & 0 \\ 0.2 & 0 & 0 \\ 0.1 & 0.2 & 0.3 \end{pmatrix} \end{array}$$

3.4. Extension of the semantics enrichment

If we should now infer what kind of effects are linked to the actions previously deduced from the initial observations, we must extend the fuzzy cartesian product :

A :: {observations} x B :: {postures} x C :: {actions} x D :: {effects}.

Therefore we must determine fuzzy relations corresponding to the different compatibility matching between A, B, C, D which can possibly established. Afterwards the enrichment process is obtained by a matrices multiplication :

1. $[M(R_{AxC})] = [M(R_{AxB})] \times [M(R_{BxC})]$
2. $[M(R_{CxD})] = [M(R_{AxC})] \times [M(R_{CxD})]$

3.5. Conclusion

In a fusion process we are often facing a situation in which, we try to predict an evolution from elements of which values have been beforehand fixed. Referring to the above exampleand and in considering :

- an observation of a known posture : $(b = b_0) \in B$,
- the cartesian product : C x D,

is it possible to predict what can be the possible actions $c_i \in C$ (possibilities distribution), later on di $\in$ D by pursuing the process ? This supposes the use of more elaborate notions of fuzzy logic such as conjunct possibilities distribution and the ability to achieve a projection of a distribution of possibilities (dop). The domains C, D may be identified by their distribution of possibilities, respectively : dop B, dop C and dop R_{BxC}, so we can apply:

$$\text{dop } C(c) :: \text{projection } [\text{dop } R_{BxC}\ (b)]$$

All notions which have been mentionned in the above paragraphs like : semantic space and layers as well compatibility relations have been applied in a research project : MATIS.

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