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Formal modeling of multi-viewpoint ontology alignment by mappings composition

Manel KOLLI
Applied Mathematics Didactics Laboratory MAD,
Higher Normal School of Constantine,Algeria.
email: kollimanel@yahoo.fr

Abstract. We propose a formal approach based on Bigraphical Reactive Systems (BRS) to provide a formal modeling of multi-viewpoint ontology alignment by composition systems' structure using bigraphs their dynamic behaviors using bigraphical reaction rules. In the first phase of this approach, we address the modeling of the static structure the dynamic behavior of multi-viewpoint ontology alignment systems. We show how bigraphs enable the description of the different multi-view point ontology entities. Furthermore, we define a set of bigraphical reaction rules to model the dynamic nature of the alignment. We introduce composition strategies to describe multi-viewpoint ontology alignment systems' behaviors. Then, we present a case study on which we illustrate the application of our proposed approach. Finally, we combine the logical reflection of Maude language the hierarchical structure of the BRS to provide an executable formal model for multi-viewpoint ontology alignment by composition systems.

1 Introduction

During the last decades, several computing systems methods have been proposed to make the semantic interoperability a reality. The semantic web has

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led to the deployment of ontologies on the web connected through various mechanisms, in particular, ontology alignments [12]. Ontology alignment is one of the well-known emerging methods which aim to allow the joint use of several ontologies. The result of this task ensures facilitates the exchange, sharing, merging of data information between systems or communities in the Semantic Web. Generally, it's about constructing matches between elements described in different ontologies. In the literature, several ontology alignment methods have been proposed. They take advantage of the different aspects of ontologies they are interested in the alignment of ontologies described in different ontological languages. Therefore, the majority of alignment methods only detect relationships between classical ontologies that do not take into account the notion of multiple viewpoints. In this work, we are interested in the problem of developing ontologies in a heterogeneous organisation by taking into account different viewpoints, different terminologies of people, groups even diverse communities within this organisation. Such ontology, called a multi-viewpoint ontology, allows both heterogeneity consensus to coexist in a heterogeneous organisation. Unlike a classical ontology, a multi-viewpoint ontology confers on the same universe of discourse several different representations such that each relates to a particular viewpoint [7]. This need to take into account multi-point of view knowledge within the same ontology, essentially results from a multidisciplinary environment where several diverse groups of people coexist collaborate with each other. Each group has its own particular interests differently perceives the particular properties relationships of conceptual entities in the same knowledge universe to be represented. The MVp ontologies can be used to represent the exchanged data by different actors in a given domain. However, in a large organisation, different MVp ontologies can coexist. Partially, they can model the knowledge of the same domain used by several heterogeneous communities. Indeed, the interoperability between heterogeneous MVp ontologies is necessary in many applications. The heterogeneity comes from the fact that these ontologies are generally built collaboratively independently of each other. Thus, like classical ontologies, the MVp ontologies have no reason to have a common unique formalism or vocabulary, this makes it difficult to share, reuse exchange the knowledge represented by the different communities. This problem generates the need of an alignment of MVp ontologies for the purpose of merging, integrating, reusing them in other applications or for the more ambitious reason of having a global MVp ontology. In our context, an MVp ontology is composed of a set of viewpoints, global concepts, local concepts, roles, local roles set of bridge links. Therefore, these ontologies have a particular specificity that the alignment process must take into account. This particularity is the existence of bridge links, whose role is to represent the consensual links between local concepts from different viewpoints. They play a very crucial role in the construction of an MVp ontology. As a result, it is possible to exploit these different bridge links in an alignment process to identify new correspondences between multi-viewpoint ontologies. This identification can be done through the combination of the bridge links which are already existed can be realized by the composition operation of the alignments. According to [21], the alignment composition operation consists in deducing correspondences between two ontologies that are not yet aligned from a succession of alignments between these ontologies one or more intermediate ontologies.

One of the proposed solutions for specifying modelling these complex alignment systems is to use formal methods that offer unambiguous abstraction mechanisms, a rigour a precision in the specification of the structural behavioural aspects of these systems. In our work, we are interested in two formalisms for the modelling the realisation of multi-viewpoint ontology alignment systems. Namely: the bigraphic reactive systems the Maude formal language. The Bigraphic Reactive Systems (BRS) is a new formalism that is characterised by its graphical aspect its ability to represent both the locality the connectivity of ubiquitous distributed computing systems. Nevertheless, the tools developed around BRS are limited in terms of expressiveness performance. For this purpose, we also opted to use the language Maude language as the most suitable alternative. Maude is a functional language that enables realizable checkable specifications for a broad range of systems. The objective of this article is twofold. First, we clarify how we take on bigraphs to specify model both structural behavioral sides of multi-viewpoint ontology alignment by composition. Thus, an MVp ontology is treated as an ensemble of nodes links clustered in roots. multi-viewpoint ontology alignment by composition is established by different reaction rules. So, we can deduct that each MVp ontology component can have a specific semantic in the BRS formalism. Therefore, the designed bigraphs identify the graphical representation of a multi-viewpoint ontology alignment by composition, as well as its predicted mathematical patterns. Then, we demonstrate how we can use Maude language the hierarchical organization of the BRS to give an implementable model for multi-viewpoint ontology alignment system. The remainder of this article is organized as followings. The next section presents related work. Section 3 presents appropriate definitions for multi-viewpoint ontology its alignment. Section 4 provides a summary of BRS formalism gives a detailed presentation of the proposed approach to specify multi-viewpoint ontology alignment by composition. In Section 5, the proposed approach is demonstrated by a case study. In section 6, we encode the bigraphical specifications into Maude language. Finally, in section 7, we conclude with the future directions of work.

2 Related work

The ontology alignment has been investigated in different research works like [1], [2], [8], [12], [17], [19] , [16]. While, there are a few works concerning formal ontology alignment in the state of the art. Also, all these works are not able to handle the concept of multi-Viewpoints. For instance, Reference [20] presents Alin, an interactive ontology matching approach which uses expert feedback not only to approve or reject selected mappings, but also to dynamically improve the set of selected mappings. This supplementary exploit for expert answers tries increasing in the benefit brought by each expert answer. To achieve this goal, Alin relies on four mechanisms. The two first mechanisms were used to dynamically choose concept attribute mappings. The Two other mechanisms are established dynamically to choose relationship mappings to refuse inconsistent chosen mappings by anti-patterns. In the process of ontology alignment, the idea of mapping composition is significant has been perfectly considered in [11]. This paper provides a novel technique of the ontology alignment process. Here, the deduction of the relations between the entities is made by aggregating or composing the relations among their subsumers, which are previously deducted according to the semantic distance. The results were validated through the description logics (DLs) techniques. The author in [5] introduces new formal ontology Networks. These later are realized by a set of logic theories, called ontologies, linked by alignments. It demonstrates how belief revision operators, constrained by the structure of networks of ontologies, may be defined. Next, it establishes two revision operators as well as associated consequences two notions of consistency. The authors in [9], proposed an extended semantics to handle separately alignment interpretation of Network on various stage. Where, the focus was on formalisms which consist of specifying reasoning about aligned ontologies. According to [19], "The advantage of the extended semantics lies in the fact that each alignment expressed between a source target ontology is independently treated, as each one possesses its own distinct vocabulary semantics". In [18] authors introduced a novel solution, SubInterNM, focused on algebraic operations. These operations allow reducing the amount of comparisons necessary to match the networks following the System of systems, which are interconnected systems that bring value

Work	Formalism	Dynamicity & evolution
[20]	No	No
[11]	Description Logics (DLs)	No
[5]	Collection of logic theories,	No
[9]	Distributed Description Logics (DDLs)	No
[18]	Algebraic operations	No
Our approach	BRS	Yes

Table 1: The comparison of ontology alignment work

to different domains. They implemented the subsumed internetwork matching, which reduces the amount of pairs in order to be assessed in the alignment. But, neither of these approaches provide a standard complete way for modeling specifying the feature of dynamicity of ontology networks. In this field, the developers mainly concentrate on the syntactic semantic aspect, which is the most commonly adopted solution for the formalization of networks of ontologies.

Table1 recapitulates this part by the comparison of the proposed approach with the previously presented works. This comparison was made according to a set of criteria such as: the used formalism or formal model the provided dynamicity evolution in the modeling approach. So, we can say that our approach is the first work which considers the dynamicity of alignment systems.

3 Multi-viewpoint ontology alignments by composition

A multi-viewpoint ontology is a multiple description of the same discourse context according to various viewpoints. Where, a viewpoint is a partial description of a discourse context within a particular perception. At a global level, the partial descriptions share ontological elements semantic links constituting a consensus between the different viewpoints. Such links, called bridge links, establish the communications between the viewpoints represent the interdisciplinary collaboration. Indeed, the bridge links are semantic links between local concepts; they define how a local concept in one viewpoint is related to another local concept in a different viewpoint, represent accessibility relationships be-

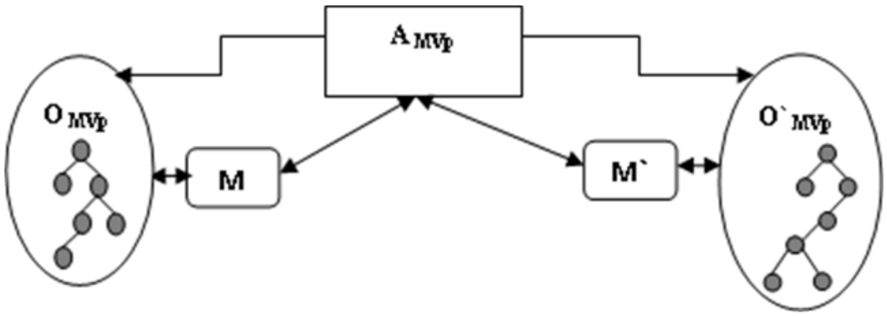

Figure 1: MVp Ontology alignment by composition

tween local concepts in two different viewpoints. These links are in the heart of the construction of an MVp ontology, as they allow the navigation between the different viewpoints. Given their importance, we consider to use them in a composition process to improve the set of identified correspondences. In our context, this operation takes as input the bridge links of two MVp ontologies, gives as output an alignment between these ontologies. Here, we base on MVp ontologies described in DLs, so our composition mechanism consists of using the properties of the relations involved in the different correspondences of the MVp ontologies those involved in the different bridge links. Formal definitions are given in what follows. The Definition 1 is according to [6].

Definition 1 *(MVp Ontology) An MVp ontology is defined as a four-tuple of the form OMVp = (CG, R, VP, M), where: CG is a set of global concepts, R is a set of roles, VP is a viewpoints set, M is a bridge links set. A viewpoint is given by a triple VP= (CG, CL, R), where: CL is a set of local concepts R is a set of roles. In what follows, we provide various essential definitions:*

- *Global concept represents a generic family of the real world. Each global concept can be expressed by different viewpoints.*
- *Local concept is expressed locally by a specific viewpoint.*
- *Role is a connection among two local concepts specified in two distinct viewpoints.*
- *Bridge links signify consensual relationships among two local concepts or roles specified in two varions viewpoints. Viewpoints are not totally disconnected. Bridges are semantic relationships which link local concepts under pairwise disjoint viewpoints to a local concept in another viewpoint.*

Definition 2 *(MVp Ontology alignment) Given two MVp ontologies OMVp O'MVp, the alignment of these two onttologies is defined as a 3-tuple:* $\mathsf{AMVp} = (\mathsf{OMVp}, \mathsf{O'MVp}, \Sigma\mathsf{M})$. *The product of* AMVp *is a set of concepts* $(\mathsf{C_i}, \mathsf{C_j})$ *related by a semantic relations Rel. So,* $\Sigma\mathsf{M}$ *is a set of mappings of concepts* $\mathsf{C_i}\ \mathsf{C_j}(\mathsf{M}(\mathsf{C_i}, \mathsf{C_j}) = \mathsf{Rel})$. *The semantic relation Rel is belonging to the set:* $\{\equiv, \subseteq, \supseteq, \perp\}$.

Where: the equivalence relation is represented by $\equiv$

This later is represented as the subsumption in both directions $\{\subseteq, \supseteq\}$ *. Finally, the relation of distinction is represented by* $\perp$.

Definition 3 *(MVp Ontology alignment by composition) The process of MVp Ontology alignment by composition consists of connecting the ontologies via their Bridge links (see Figure 1). Indeed, an MVp Ontology alignment by composition A MVp is defined as a semantic composition between the sets of Bridge links* $\mathsf{M_1}\ \mathsf{M_2}$ *of the ontologies* $\mathsf{OMVp_1}\ \mathsf{OMVp_2}$ *respectively. The composition operation is defined as a function associating to a pair* $(\mathsf{M_1}, \mathsf{M_2})$ *an alignment A MVp such as A* $\mathsf{MVp} = \mathsf{M_1} \circ \mathsf{M_2}$ *.*

The MVp Ontology alignment is directional because the correspondences start from the first to the second MVp ontology the composition operation is neither commutative nor associative, due to the fact that there are several viewpoints in each MVp ontology to be aligned. Therefore, it is necessary to define the composition operation suggest a rules set to achieve the MVp ontology alignment by composition.

Definition 4 *(The composition of multi-viewpoint) The Semantic Web domain is based on the description logics for the MVp ontology creation. This implies that the concepts are structured by the subsumption relation the bridge links, which permits the inference of semantic relations between the concepts in a simple straight manner. The operation which allows this inference is called composition. The application of this composition is presented in Table 2.*

The proof of these results was done by the interpretation notion of DLs in [10].

C₂ R C₃ \ C₁ R C₂	≡	⊆	⊥
⊨	≡	⊆	⊥
⊆ (⊇)	⊆ (⊇)	⊆ (⊇)	⊥
⊥	⊥	undecidable	undecidable

Table 2: Composition of the semantic relations

4 A BRS model for multi-viewpoint ontology alignment by composition

4.1 Bigraphical reactive systems overview

Bigraphical Reactive Systems (BRS) is a formalism designed to model the temporal spatial evolution of computing. The bigraph theory was recently introduced by Robin Milner, co-workers [13], [14] , [15] to provide an intuitive graphical model for representing the locality connectivity of systems. Therefore, it strongly appropriates with MVp ontology alignment concepts. A reactive bigraph system consists of a set of bigraphs representing the state of the system a set of reaction rules describing its evolution. The theory of bigraphs has two main objectives: (1) to be able to integrate in the same formalism the important aspects of the systems; (2) to provide a unification of existing theories by developing a general theory, which contains the different calculations for concurrency mobility.

Bigraph anatomy graphic form Let us consider the following example, depicted in Figure 2. In the graphical form of bigraphs, the entities components (real or virtual) of a system are expressed as nodes represented as ovals, circles, triangles other graphical shapes. The spatial location of nodes is described in terms of arbitrary nestings between different nodes in a given system. All nodes in a bigraph have an identifier (type), called a control designated by letters (e.g. A; B; etc.). The interactions between different nodes are represented by links, for example, the hyper-arc in Figure 2 connecting node A node C. Each

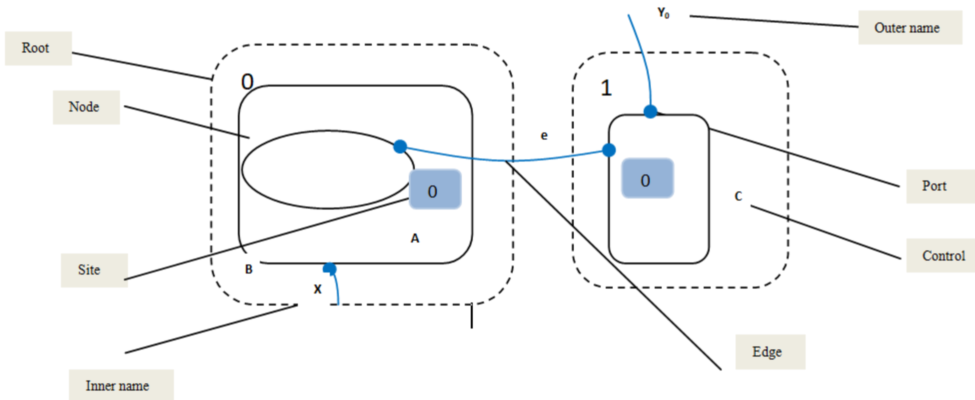

Figure 2: Bigraph example

node can have zero, one or more ports, represented by round points to express possible connections. Ports are represented by bullets. In the example, connections are depicted as links, by curvy lines, which may connect ports names (x z). These links, also called hyperedges, indicate the bigraph's connectivity (e.g., they can be considered as links to other bigraphs). We note that nodes which have the same control also have the same number of ports. The dotted rectangles indicate regions (also, called roots), their role is to describe parts of the system that are not necessarily adjacent. The blue squares represent sites that are abstract parts of the model. The regions sites are indexed by natural numbers from left to right (starting from 0). The nodes, sites regions are called the places of a bigraph. In addition to hyper-arcs, a bigraph can have other types of communication links which are internal external names. In our example (see Figure 2), y is an external name, while x represents an internal name. They express (potential) links to other bigraphs, representing external environments. Besides to their simple generous graphical form, an algebraic term language was provided to represent BRS. Indeed, the bigraphs can be constructed using elementary bigraphs with the help of algebraic operations. For instance, merge product designates the adjacency of bigraphs A B which are located in a one region (noted by $\mathsf{A} \mid \mathsf{B}$) .

Nesting operation (noted by $\mathsf{A}.\mathsf{B}$) allows placing bigraph B inside A parallel product term can be involved to create bigraphs by adjacencing their roots integrating their joint names (noted by $\mathsf{A} \parallel \mathsf{B}$).

For additional information concerning algebraic operations of bigraphs, the lector is invited to consult [15].

Sorting mechanism The sorting discipline for bigraphs was proposed in [15]. This discipline classifies controls links in diverse sorts. The sorting discipline is defined as $\Sigma = \{\Theta, k, \Phi\}$, where Θ is a non-empty sort set, k is a signature, Φ is a rule set. A rule is a property set that a bigraph must to gratify.

Dynamical aspects: To finalize the description of a dynamic system by specifying its dynamic behavior, the corresponding bigraphs are provided with a set of bigracal reaction rules. This mixture generates the BRS. Formally, a reaction rule takes the form: $R \longrightarrow R'$ where the redex R defines the conditions that must be met, the reactum R' depicts the result of this rule.

4.2 Modeling multi-viewpoint ontology alignment structures

An MVp ontology is represented as a node set corresponding to the viewpoints as well as the concepts (global local) which can be determined by the context. Also, the viewpoint is represented by a set the nodes corresponding to the different internal concepts (global local). An MVp ontology alignment by composition system is interpreted by a bigraph OM_A including all MVp ontology elements. The bigraph OM is made of set of regions marked 0, 1, ... N that depict the viewpoints of a context. Where, each viewpoint is modeled separately by a distinct bigraph. Where, the hierarchical aspect in an MVp ontology is supported by the concept of node nesting. The interactions between the different entities of an MVp ontology are defined by hyper arcs (roles bridge links). The configuration of the Bigraph OM is obtained by the tensor product of viewpoints bigraphs. The bigraph OM_A is generated by the parallel product of MVp ontology bigraphs. The introduced sorting logic gives mapping rules formulates all constraints formation rules, that OM_A satisfies in order to guarantee appropriate exact encoding of MVp ontology alignment semantics into BRS concepts. In what follows, formal definitions are given.

Definition 5 *(viewpoint bigraph). The bigraph of a pointview* $View_i$ *is formally given by:* $View_i = (V_i, E_i, ctrl_i, OP_i, OL_i) : I \longrightarrow K$

- V_i *is a finite set of nodes representing the different local global concepts of the* $View_i$.
- E_i *is a finite set of roles (internal hyper-arcs).*
- $Ctrl_i : V_i \longrightarrow K$ *is a transformation function which associates with each node* $v_i \in V_i$ *a control* $k \in K_i$ *indicating the number of ports. The signature K is a finite set of controls associated with the elements of ontologies.*

- $OP_i = (V_i, ctr_i, prnt_i) : m_0 \longrightarrow n_0$ *is the place graph associated with Viewid.* m_0 n_0 *are the number of sites regions.* $Prnt_i : m_0 \biguplus V_i \longrightarrow V_i \biguplus n_0$ *is a parent map that associates each entity with its hierarchical parent (e.g. the parent of a Man node is a human node).*

- $OL_i = (V_i, E_i, ctrl_i, link_i) : X_0 \longrightarrow Y_0$ *is the link graph of* $View_i$*, where* $link_i$ *:* $X_0 \biguplus P_0 \longrightarrow E_i \biguplus Y_0$ *is a transformation function that specifies the interactions of each entity of the ontology.* X_0*,* Y_0 P_0 *are respectively, the inner names, the outer names, the port set of* $View_i$.

- $I_0 = (m_0, X_0)$ $J_0 = (n_0, Y_0)$ *are respectively, the inner outer interfaces of the bigraph* $View_i$.

Definition 6 *(Multi-viewpoint ontology bigraph). A bigraph* OM *modeling a multi-viewpoints ontology of a context id is formally given by:*
$OM \equiv View_1 \bigotimes View_2 \bigotimes \ldots \bigotimes View_n$
Where: $OM = (V, E, ctrl, OP, OL) : I \longrightarrow J$

- $V = V_1 \biguplus V_2 \biguplus \ldots \biguplus V_n$ *is a finite set of nodes (local concepts, global concepts views) in a context i which given by the union of the set of* V_i *nodes of all views.*

- $E = E_1 \biguplus E_2 \biguplus \ldots . \biguplus E_n \biguplus$ *M is a finite set of hyper-arcs representing in a context id which given by the union of the set of hyperarcs* E_i *the set of the bridge links M.*

- $K = K_1 \biguplus K_2 \biguplus \ldots \biguplus K_n$ *is an extended signature, defined by a set of controls where,* $Ctrl : V \longrightarrow K$ *is a new transformation which associates with each node* $vi \in V_i$ *a control* $k \in K_i$ *indicating the number of its fixed ports.*

- $OP = OP_1 \bigotimes OP_2 \bigotimes \ldots \bigotimes OP_n : m \longrightarrow n$ *is the places graph associated with* OM *given by the tensor product of the graphs of places* $OP_1 : m_1 \longrightarrow n_1, OP_2 : m_2 \longrightarrow n_2$ *, ...* $OP_n : m_n \longrightarrow n_n$ *, where its parent map is:* $prnt = prnt_1 \biguplus prnt_2 \biguplus \ldots \biguplus prnt_n$

- $OL = OL_1 \bigotimes OL_2 \bigotimes \ldots \bigotimes OL_n$ *: is the links graph of* OM *given by the tensor product of the links graphs* $OL_1 : X_1 \longrightarrow Y_1, OL_2 : X_2 \longrightarrow Y_2, \ldots, OL_n : X_n \longrightarrow Y_n$. *Where,*

  $OL \equiv (V, E, ctrl_1 \biguplus ctrl_2 \biguplus \ldots \biguplus ctrl_n, link_1 \biguplus link_2 \biguplus \ldots \biguplus link_n)$

- *I J are respectively, the inner outer interfaces of the bigraph* OM.

Definition 7 *(Multi-viewpoint ontology alignment bigraph) The bigraph* OM_A *is formally given by:* $OM_A \equiv OM \parallel OM`$ *Where:*

$$OM_A = (VOM_A, EOM_A, ctrlOM_A, OMAP, OMAL) : IOM_A \longrightarrow JOM_A$$

- $VOM_A = VOM \biguplus VOM`$ *is a finite set of nodes representing the different entities of ontologies* $OM$ $OM`$ *which given by the union of nodes sets* VOM $VOM`$.
- $EOM_A = EOM \biguplus EOM`$ *is a finite set of hyper-arcs representing the different connections that can link entities together which given by the union of hyper-arcs sets* $EOM$ $EOM`$.
- $K = KOM \biguplus KOM`$ *is an extended signature, defined by a set of controls. Where,* $ctrlOM_A : VOM_A \longrightarrow K$ *a control map that assigns each node* $v_i \in VOM_A$ *with a control* $k \in KOM_A$.
- $OMAP = OPOM \parallel OPOM` : m \longrightarrow n$ *is the places graph associated with* $OM_A$ *given by the parallel product of the graphs of places* $OPOM$ $OPOM`$. *Where its parent map is:* $prnt = prntOM \biguplus prntOM`$.
- $OMAL = OLOM \parallel OLOM`$ *: is the links graph associated with* $OM_A$ *given by the parallel product of the graphs of links* $OLOM : X_O \longrightarrow Y_O$ $OLOM` : X`_O \longrightarrow Y`_O$. *Where,*

  $OL \equiv (V, E, ctrlOM \biguplus ctrlOM`, linkOM \biguplus linkOM`)$*:*

  $(XOM \biguplus XOM`) \longrightarrow (YOM \biguplus YOM`)$
- IOM_A JOM_A *are respectively, the inner outer interfaces of the bigraph* OM_A.

Definition 8 *(Multi-viewpoint ontology alignment discipline of sorting). The sorting discipline associated with the* OM_A *bigraph modeling a multi-viewpoint ontology alignment is defined by the triplet* $\Sigma OM_A = \{\Theta OM_A, k, \Phi\ OM_A\}$.

Where ΘOM_A *represents a non-empty set of sorts of* OM_A, KOM_A *is a* ΣOM_A*-typed signature which associates a sort with each control of* OM_A, ΦOM_A *is a non-empty set of training rules imposing construction restrictions for* OM_A.

Table 3 grants for each ontology concept, mapping rules for BRS equivalence. This consists of the control associated to the entity, its arity (number of ports) (e.g. view has at least 1 port), its associated sort its graphic notation (e.g. a local concept instance is represented by a circle). Sorts are involed to

Description	Control	Arity	Sorts	Graphical notation	Bigraph
Entity					
Global concept	GC	N	g	Rectangle	OMA, OM and View
Local concept	LC	N	l	Circle	OMA, OM and View
View	$View_i$	≥1	V	Rectangle	OMA and OM
MVp ontology	OM	≥1	O	Rectangle	OMA

Table 3: Controls sorts of the bigraph $\mathsf{OM_A}$

	Rule Descriptions
Φ_0	All children of a 0-region and 1-region have a sort x ∈ { g, l, v, O }
Φ_1	All children of a 0-node have a sort x ∈ { g, l, O}
Φ_2	All nodes of sort l are atomic
Φ_3	In a v-node, at least one port is linked to other child v-node of the same bigraph
Φ_4	In a g-node, one or more ports can be linked to other child g-nodes of the others v-nodes
Φ_5	In a l-node, one or more ports can be linked to other child l-nodes or g-nodes of the same bigraph
Φ_6	In a O-node, at least one port is linked to other child O-node of the same bigraph

Table 4: Training rules PhiOM for the bigraph OM

differentiate node types for structural goals constraints while controls identify states parameters that a node can have.

Table 4 shows the formation rules $\Phi i, i \in [0 \dots 6]$ *which provide construction constraints over the BRS specification. Formation rules present structural constraints over the BRS model. The rules* $\Phi 0 - \Phi 2$ *define the constraints on the hierarchical nesting of the different entities while the rules* $\Phi 3 - \Phi 6$ *define the restrictions on their links. For example, the rule* $\Phi 0$ *states that the principal region denoted 0 which represents a multi-viewpoint ontology, can only have children of nodes of sort g, l, v, O. Finally, the rule* $\Phi 3$ *requires that all viewpoints must be related to at least one another multi-viewpoint ontology.*

4.3 Modeling composition behaviors with BRS

In addition to their ability to model the infrastructure of the MVp ontology alignment by composition system, BRS allow the formal specification of this system state evolution thanks to their reaction rules. In this Section, our main contribution is to propose a set of parametric reaction rules that model the behavior of the MVp ontology alignment.

Here, the defined reaction rules describe the different mechanisms applied to the proposed system, in order to manage its alignment. It is about modeling

Reaction rule	Algebraic form
Generate new equivalence link	$R_1 \stackrel{def}{=} c.OM_i \mid c`.OM_j \rightarrow c_{\equiv}.OM_i \mid c`_{\equiv}.OM_j$
Generate new subsumption link	$R_2 \stackrel{def}{=} c.OM_i \mid c`.OM_j \rightarrow c_{\sqsubseteq}.OM_i \mid c`_{\sqsubseteq}.OM_j$
Generate new disjunction link	$R_3 \stackrel{def}{=} c.OM_i \mid c`.OM_j \rightarrow c_{\perp}.OM_i \mid c`_{\perp}.OM_j$
Update bridge link	$R_4 \stackrel{def}{=} c_R.OM \mid c_R`.OM_i \rightarrow c_{R`}.OM \mid c`_{R`}.OM_j$

Table 5: Reaction rules modeling alignment by composition actions in MVp ontology bigraph

the actions related to the creation of new mappings through the composition between the bridge links already existing in the system. Table 5 gives the defined reaction rules Ri expressing a set of possible actions that can be applied over an alignment system. These rules take the form Ri = R →R‘, where i is the index of the rule, R is the redex part of the reaction R‘ is its reactum part. A reaction is applied by replacing the redex bigraph (left-hand side) with the reactum bigraph (right-hand side of the reaction). As both redex reactum bigraphs respect the formation rules. Concretely, the specified rules describe the different actions related to the generation of new mappings (R1 - R3) at the MVp ontology level. Composition strategies:

In this section, we explain how we can use the reaction rules previously defined to formalize the overall behavior of an alignment system in terms of composition strategies. Indeed, the presented reaction rules can be used to simulate different evolution strategies of MVp ontology alignment by composition systems. Each strategy consists of a sequence of applications of reaction rules. This leads to restricting the application of rules via conditions, so that a reaction rule is only applied when desired (i.e. when the conditions for triggering that action are satisfied). Here, we introduce reactive composition strategies of the form: IF (s) then (s).

In the context of bigraphic semantics, a condition takes the form ($OM_A \models \Phi i$). This condition is satisfied iff ∃ a bigraph OM_A‘ ($OM_A \Phi i$), encoding the predicate Φi, which occurs in the context of OM_A. A predicate Φi, often expressed in first-order logic, is used to define a state of the MVp ontology alignment systems OM_A Φi defines a bigraphic model encoding this state. So, a strategy that reacts to a condition ($OM_A \models \Phi i$) is expressed as: START; IF $OM_A \models \Phi i$ THEN Ri. The actions Ri are modeled as bigraphical reaction rules.

Level	Condition
MVp ontology alignement system	Existance of equivalence bridge link between two concepts C_i and C_j of two MVp ontology OM and OM\` $\varphi 1 \stackrel{def}{=} \exists C_i \in OM$ and $\exists C_j \in OM`$ $link_{OMA}(C_i, C_j) = \equiv$
	Existance of equivalence bridge link between two concepts C_i and C_k of a same MVp ontology OM $\varphi 2 \stackrel{def}{=} \exists C_i$ and $\exists C_k \in OM`$ $link_{OMA}(C_i, C_k) = \equiv$
	Existance of disjction bridge link between two concepts C_i and C_j of two MVp ontology OM and OM\` $\varphi 3 \stackrel{def}{=} \exists C_i \in OM$ and $\exists C_j \in OM`$ $link_{OMA}(C_i, C_j) = \perp$
	Existance of bridge link between two concepts C_i and C_k of a same MVp ontology OMA $\varphi 4 \stackrel{def}{=} \exists C_i$ and $\exists C_k \in OMA$ $link_{OMA}(C_i, C_k) = \perp$
	Existance of subsumption bridge link between two concepts C_i and C_j of two MVp ontology OMA and OMA\` $\varphi 5 \stackrel{def}{=} \exists C_i \in OMA$ and $\exists C_j \in OMA`$ $link_{OMA}(C_i, C_j) = \subseteq (\supseteq)$
	Existance of subsumption bridge link between two concepts C_i and C_k of a same MVp ontology OMA $\varphi 6 \stackrel{def}{=} \exists C_i$ and $\exists C_k \in OMA$ $link_{OMA}(C_i, C_k) = \subseteq (\supseteq)$

Table 6: Definitions of conditions

Level	Conditions	Action
MVp ontology alignement system	$\varphi 1$ and $\varphi 2$	R1
	$\varphi 3$ and $\varphi 4$	R2
	$\varphi 5$ and $\varphi 6$	R3
	$\varphi 1$ and $\varphi 4$	R2
	$\varphi 1$ and $\varphi 6$	R3
	$\varphi 3$ and $\varphi 4$	R2
	$\varphi 5$ and $\varphi 4$	R3

Table 7: Composition strategies

These strategies consist of creating new mappings which used to ensure correspondences between the different concepts of the different MVp ontologies. This involves authorizing the addition of new mapping links by applying the associated reaction rules according to the composition table cited in Definition 8. These strategies can be applied at the level of the MVp ontology alignment system as following:

It reacts to conditions: "if there exists an equivalence bridge link among concepts C_i of MVp ontology OM C_j of MVp ontology OM'", "if there exists one more equivalence bridge link among concepts C_j C_k of the same MVp ontology (OM')", respectively expressed through the predicates $\Phi 1$ $\Phi 2$. The verification of existence consists of checking if there exists a node node1, which belongs to the node set VOM_1 of OM_1 another node node2, belonging to the node set VOM_2 of OM_2, whose control is $linkOM_A(node_1, node_2)$ is equivalence. The definitions of all possible conditions are introduced in Table 6. If the predicates $\Phi 1$ $\Phi 2$ are satisfied, the rule R1 is applied to generate a novel mapping link. In the same way, the reaction rules R3 R2 are applied, according to table 7.

5 Case study

We introduce in this section a simplified application case of an MVp ontology alignment by composition system. In the beginning, we apply the proposed approach to realize this application case. After, we identify the related Maude descriptions of the resulted BRS models, as presented in section 6, to carry out them by the Maude program. We considered two MVp ontologies: OM_1 OM_2 describing the staff domain. The first MPV ontology is composed of two viewpoints: personnel affairs civil status while the second MVP ontology is composed of the two viewpoints: family membership nationality (see Figure3 Figure 4).

The parallel product of the graphs OM_1 OM_2 generates a new bigraph: $OM_A \equiv OM_1 \parallel OM_2$. OM_A models a composite ontology for alignment (see Figure 6) by :

- $VOM_A = \{Familymembership, Nationality, Personnelaffairs, \ldots\}$ (set of internal nodes).
- $EOM_A = \{sexe, is, has, \equiv, \supseteq, \perp\}$
- $CtrlOM_A = \{human : 3, man : 1, boy : 1, father : 1, person : 3, woman : 1 \ldots\}$ indicates the number of fixed ports for each node.

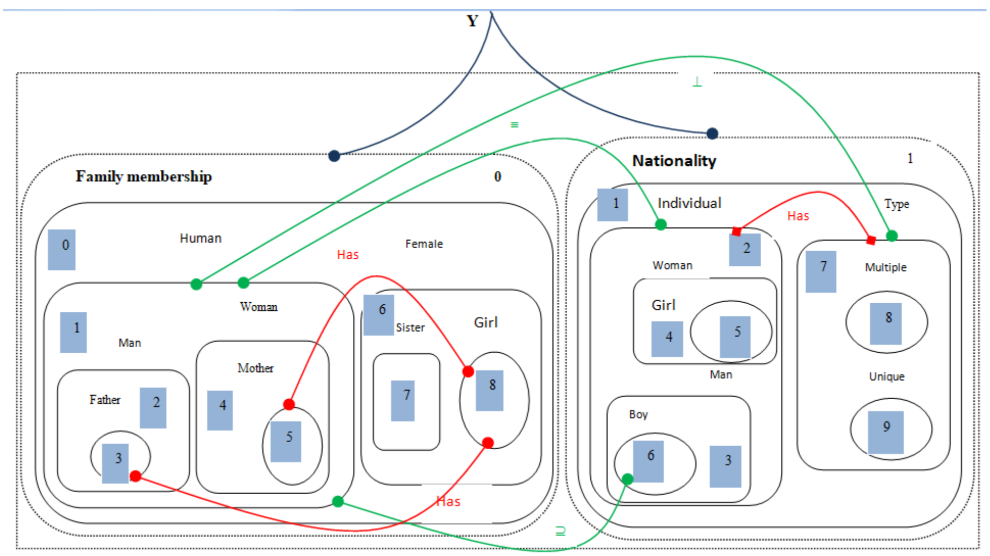

Figure 3: Example of a multi-viewpoint ontology bigraph OM_1.

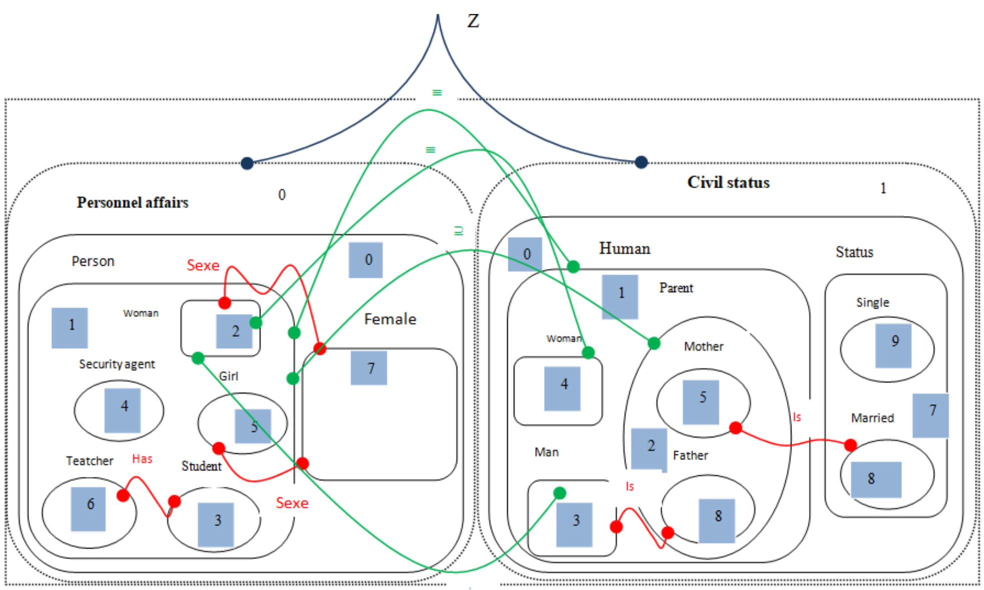

Figure 4: Example of a multi-viewpoint ontology bigraph OM_2.

y/Family membership (human (man(father. d_1) | d_2) | d_3) | (woman(mother. d_5) … | d_0|| | y/ Nationality (individual (man (boy. d_6) | d_3) | d_1| woman ...) |d_0 || z/ Personal affairs (person (woman . d_2) ... | d_1 |d_0 || z/ Civil status (human (parent (mother . d_5) | d_2) | d_1 ...) | d_0 → y/Family membership (human (man(father. d_1) | d_2 | d_3 | (woman(mother. d_5) … | d_0|| | y/ Nationality ($individual_{\equiv}$ (man (boy. d_6) | d_3) | d_1| woman ...) |d_0 || z/ Personal affairs ($person_{\equiv}$ (woman . d_2) ... | d_1 |d_0 || z/ Civil status (human (parent (mother . d_5) | d_2) | d_1 ...) | d_0

Figure 5: The rule R1 application

- $Prnt = \{human : man, man : boy, man : father, person : man, person : boy, person : woman \ldots\}$ indicates the hierarchical parent of each internal node.

- $IOM_A = (34, \phi)$ is the internal interface of the bigraph OM_A. m = 34 represents the number of regions. Where 2 regions containing nodes that can be hosted, $X = phi$ represents the set of internal names.

- $JOM_A = (4, \{y, z\})$ is the external interface of the bigraph OM_A. Where n = 4 Y represents the number of sites the set of external names, respectively.

- Finally, the places graph $OMAP : 34 \longrightarrow 4$ is the result of the parallel product of the graphs of places OMP_1 OMP_2, the links graph $OMAL$ $\{\} \longrightarrow \{y, z\}$ is the result of the parallel product of the graphs of links OML_1 OML_2.

In the ontology OM_A , the bridge links among the concepts: person, human individual are as follows: (human ≡ individual) which means that the condition: $OM_A \models \Phi 1$ is satisfied ($human \equiv person$) which means that the condition: $OM_A \models \Phi 2$ is satisfied. According to the table 7, we can deduct the bridge link: ($person \equiv individual$). After applying R1, this link is easily added to the bigraph OM_A as shown in Figure 5. In the same way, we apply the other possible rules. Figure 6 shows the result of applying the composition strategies.

In the next section, we show how we apply the Maude program to implement simulate our models. Furthermore, we demonstrate how Maude's mecanism can be used to attain the composition process at the MVp ontology alignment system level.

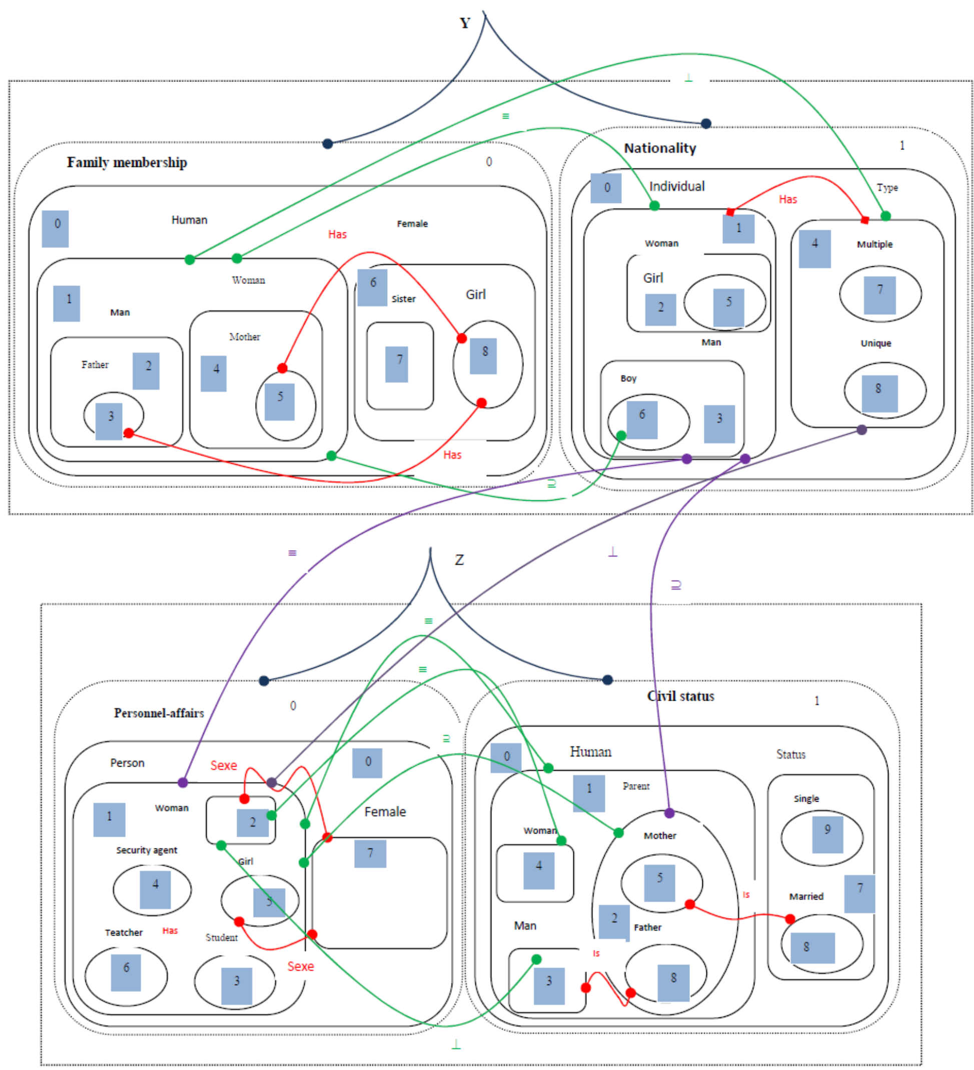

Figure 6: The result of applying the composition strategies on the bigraph OM_A

<table>
<tr><th>MVp ontology alignment by composition based model</th><th>Maude language</th></tr>
<tr><td colspan="2">Syntax</td></tr>
<tr><td>Multi-viewpoint ontology alignment bigraph</td><td>Sort bigraph
op -|- ||-|- MVp-ontology1 site MVp-ontology2 → Bigraph</td></tr>
<tr><td>MVp-ontology roots</td><td>Sorts MVp-ontology Viewpoint Concept
Subsort global-concept < Concept
Subsort local-concept < Concept
Op MVp-ontology -, (-|-) Nat Viewpoint Viewpoint → MVp-ontology [ctor]
Op Family-membership [-] Link → Viewpoint [ctor]
Op Personnel-affairs [-] Link → Viewpoint [ctor]
Op Human [-, -, -] Link Link Link → global-concept [ctor]
Op Father [-] Link → local-concept [ctor]
........................</td></tr>
<tr><td>Types of links</td><td>Sort Link
Subsorts Inner Outer Role < Link
Subsorts equivalent subsume disjoint < Inner
Subsorts sexe is has < Role

Op Y - : Nat → Outer [ctor]</td></tr>
<tr><td>Concepts relationship predicates</td><td>Op Isequivalent (-, -): Concept Concept → Bool
Op Issubsume (-, -): Concept Concept → Bool
Op Isdisjoint (-, -): Concept Concept → Bool</td></tr>
<tr><td>Site</td><td>Sort Site
Op $- : Nat → Site [ctor]</td></tr>
<tr><td colspan="2">Dynamic</td></tr>
<tr><td>Reaction rules</td><td>Conditional rewrite rules of the form:
Crl [rewrite rule name] : bigraph ⇒ bigraph` if conditions</td></tr>
</table>

Table 8: Mapping MVp-ontology BRS-based model to Maude.

6 Executing MVp ontology alignment by composition model

BRS represents an ideal formalism for specifying the structural behavioral issues of MVp ontology alignment. However, existing tools based on this formalism are restricted fixed to some application fields. Here, we have chosen the Maude program [3] for realizing the BRS-based MVp ontology alignment model. The selection of the Maude program is justified by its capacity to specify at a high formal level.

In this section, we explain how to interpret our models to Maude codifications. So, two fundamental modules are given: the Syntax Dynamic modules. Table 8 summarizes the mapping rules among BRS concepts Maude language.

```
Vars d0 d1 d2 d3 d4 d5 s0 s1 : Nat.

rl [ Add-Equivalence-Link]:

… Nationality (individual[Equivalent, Has] d0. (man .d3  … | $s1) Personal-
affairs | person[Equivalent, subsume]d0 . (woman . d2) … | $s0) ||…   => … ||
Nationality (individual[Equivalent, Has, Equivalent] d0. (man .d3  …  | $s1)
Personal-affairs | person [Equivalent, subsume, Equivalent] d0 . (woman .
d2) … | $s0) ||…
If (Isequivalent (human, individual) and Isequivalent (human, person)
```

Figure 7: Generating new equivalence link rewrite rule.

Encoding MVp ontology alignment compositions: For the Syntax module, the sorts g, l, v o (global concept, local concept, viewpoint MVp ontlogy) are generated depending to their related Maude constructors (ctor). We design the sorts like: global-concept, local-concept, view MVp ontology we propose sort Link Site for identifying the different links sites of an MVp ontology alignment system. Finally, a sub-sort relationship is established between some mentioned sorts. The main operator of this part is: (op− | − ‖ − |- MVp ontology1 site MVp ontology2 → Bigraph). It consists of declaring of the static composition of an MVp ontology alignment bigraphical model, that is established by two diverse roots performing the MVp ontology1 the MVp ontology2 of an alignment process. The term of juxtaposition (‖) is used to split MVp ontology1 the MVp ontology2.

Encoding Alignment Predicates: the syntax part identify a predicate set that reflects a relation among two concepts. For example, Isequivalent() means that "the concepts are equivalents". Issubsume()means that "there exists a subsumption relation among concepts". Finally, Isdisjoint () is a predicate that stands for "the concepts are disjoints".

Encoding Alignment Strategies: The dynamic part implements the alignment strategy in the form of conditional rewrite rules. Figure 7 illustrates an example of rule; that is in charge of generating the new bridge link: (person $\equiv$ individual).

6.1 Evaluation

In the following sections, we achieve a sequence of experiments to evaluate our approach on different aligned ontologies of different domains (including smart homes, education, healthcare) with different ontology sizes (number of concepts rules). These experiments are conducted on the precision, recall, F-

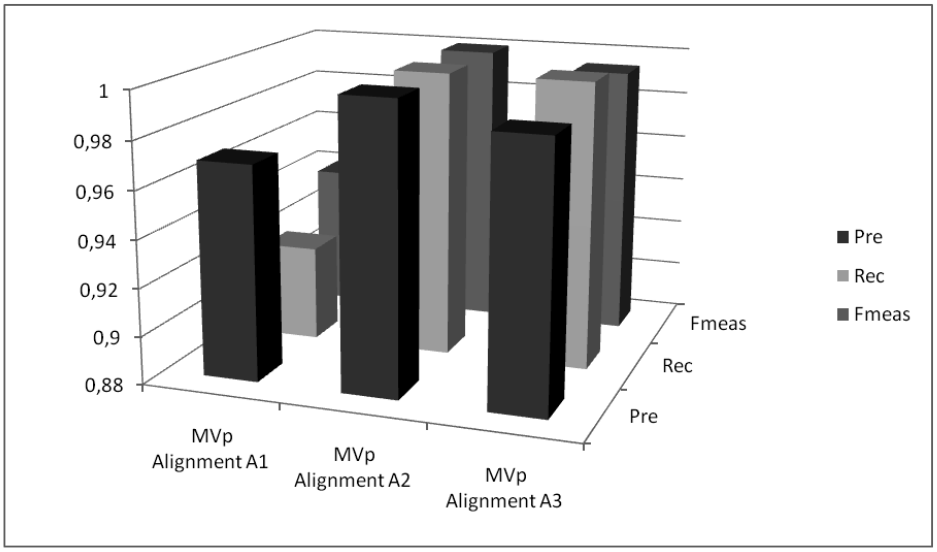

Figure 8: Figure 8. MVp ontology alignment results comparison

measure suggested by [4] as follows: Given a reference alignment $R - AMVp$, the precision Pre, the recall Rec $F - measure$ $Fmeas$ of an MVp Ontology alignment $A - MVp$ is considered such that:

$Pre(A - MVp, RA - MVp) =| RA - MVp \cap A - MVp \mid /A - MVp$

$Rec(A - MVp, RA - MVp) =| RA - MVp \cap A - MVp \mid /RA - MVp$

F-measure merges precision recall such that: $Fmeas(A-MVp, RA-MVp) = [2*Pre(A-MVp, RA-MVp)*Rec(A-MVp, RA-MVp)]/[Pre(A-MVp, RA-MVp) + Rec(A - MVp, RA - MVp)]$

The alignments generated by the proposed approach, are assimilated to the reference alignment (realized manually by experts in domains). Indeed, the values of the alignment quality measures (precision, recall F-measure) are calculated.

The results are provided in Figure 8. It can be seen that the results of the alignments generated by the experts the proposed approach are very similar. So in general, we can say that our approach proves good performance.

7 Conclusion

For the Semantic Web, ontology-based semantic interoperability is considered as a major defy. Ontology alignment is a key process that plays a significant role in improving this interoperability resolve ontological heterogeneity issue. The main goal of this work is to deal with this problem by adopting the BRS as formalism to Specify MVp ontology alignment system. Especially, we have proposed a novel approach, relied on BRS with their sorting controlling function. Concerning the static structural side, we have established the definitions of all MVp ontology alignment entities such as viewpoints, concepts roles. As for the behavioral side, is established by a generic reaction rule set that depicts the alignment system in terms of composition strategies. After, we have explained how to merge Maude program BRS to carry out the MVp ontology alignment. Finally, the possibility of realizing the proposed approach is proven by a case study. As far as we know, this is the first paper to deal with the MVp ontology alignment using BRS. As part of the forthcoming works, our goal is to more elaborating expanding our bigraphical model of multi-viewpoint ontology alignment by composition systems, in order to handle all kinds of alignment.

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