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BRS-based Model for the Specification of Multi-view Point Ontology

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***Abstract* – In this paper, we propose a new approach, based on bigraphic reactive systems (BRS), to provide a formal modelling of the architectural elements of a Multi-Viewpoints ontology (MVp ontology). We introduce a formal model in which the main elements of MVp ontology find their definition in terms of bigraphic concepts by preserving their semantics. Besides, we enrich the proposed model with reaction rules in order to handle the dynamic reactions of MVp ontology. In order to confirm the applicability of our approach, we have carried out a case study using the proposed model.**

***Keywords* – bigraphical reactive system, formal methods, ontology, viewpoint.**

I. Introduction

The semantic web infrastructure is based on the explicit conceptualization of a domain, shared by a community and represented in ontology of the concerned domain. Ontologies are a key requirement for many tasks concerning the Semantic Web notably in the information research and the integration of information systems [1]. Thus, the semantic web has led to the deployment of ontologies on the web connected through various mechanisms [2]. Ontologies become very popular, by occupying a prominent place in the field of knowledge engineering and they have proven their effectiveness in knowledge representation. In general, ontology contains a formalized vocabulary aggregating, for a given discipline, all the concepts, and their relations. The definitions associated with each concept come from a consensus between the various actors and future users of the ontology.

The ontologies are considered as the cornerstone of the Semantic Web for knowledge sharing, information extraction, information integration and many more [3].

The representation consists of abstracting an information-rich reality. This abstraction depends on the actor that performs it, their area of interest and prior knowledge. Thus, when several observers (actors) work on the same universe of knowledge, they observe different elements and relations. In complex and multi-disciplinary fields, often there are different ways of understanding the elements of knowledge, i.e. different points of view (or perceptions) according to which this knowledge can be represented. Thus, the same domain can have several alternative representations, where each of them is described according to a particular perception or point of view. Therefore, each viewpoint constitutes a discipline-specific way of representing, organising and using this knowledge.

In general, organisations live in a dynamic and heterogeneous environment. As a result, building and using ontologies within an organisation is not always an easy task. This is mainly due to the difficulty of finding consensual definitions of the concepts of a domain satisfying the definitions specific to each user, which reflect their point of view on the domain.

In this paper, we are interested in developing ontology in a heterogeneous organisation by taking into account different points of view and terminologies of the communities within this organisation. Such ontology, called a Multi-Viewpoints ontology, confers on the same universe of discourse several partial descriptions such that each one is relative to a point of view [4]. In addition, the various partial descriptions share at a global level consensual ontological elements and bridge links. These latter establish the communications between points of view and, thus, represent interdisciplinary collaboration.

The evolution of organisations over time causes changes in their MVp ontologies. In order to facilitate the exploitation of the different MVp ontologies, it is essential to provide a level of abstraction to the elements of these ontologies. This abstraction can be obtained by setting up a description model. Therefore, modelling is an imperative task in the design of an MVp ontology which requires the definition of a model to provide a high level description of abstraction of information. Thus, respecting a model is useful or even necessary.

In this context, many approaches have been proposed in the literature [5], [6] and [4]. These approaches are based on different models, namely, description logics, markup languages and conceptual graphs. However, the majority of these approaches focus their efforts on providing models to describe a specific context for a particular application or domain in a static way. They lack the necessary formalism for dynamic modelling. In addition, the heterogeneity of information from organisations requires the use of generic models to suite any type of information system.

Here, we are interested in bigraphic reactive systems (BRS) [7]–[9] which seem best suited to describe MVp ontologies that

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respond to the needs of organisations (mobility, distribution and dynamicity). BRS represent an arising formalism for modelling the temporal and spatial development of computation.

In fact, one of the main objectives of the theory of BRS is to integrate the important aspects into a single formalism. Moreover, BRS enriched with a set of reaction rules, are an excellent candidate to formalize fundamental architectural elements of the MVp ontology and their reconfiguration. Thus, BRS differ from traditional formalisms in their expressive power by offering designers a great flexibility to specify their own reaction rules. BRS are approved as a semantic framework for their graphical feature and rigorous foundation.

We aim, through this paper, to propose a formal model, based on BRS and their sorting logic, allowing modelling the architectural elements of MVp ontology. First, we present the principle modelling of the proposed model by introducing the different architectural elements constituting such ontology. Then, we propose a formal bigraph-based semantics which allows modelling independently each part of MVp ontology. In order to handle the dynamic reactions of multi-viewpoints ontology, we enrich the proposed bigraph-based model with reaction rules.

The remainder of this paper is organised as follows. In Section II we review the state of art on formal specification of MVp ontology. In Section III, we give an overview of bigraphical reactive systems and the model-checkerBigMC. Section VI details the various steps of the proposed approach to Model MVp ontology. Section V encodes the proposed BRS-based model of MVp ontology by integrating it in BigMC tool. Finally, Section IV concludes this paper and talks about further work.

II. Related Work

There have been multiple research studies in the literature using formal approaches to specify MVp ontology in semantic web. [10] and [11] present a multi-viewpoints ontology construction where concepts are associated with several formal definitions corresponding to the different viewpoints on the concepts in question. Concepts are organised in a hierarchy and their places depend on their definitions. Also, the proposed model allows for multiple representations of concepts and multiple hierarchies from different viewpoints. Instead of representing concepts in an ontology from multiple viewpoints by a multi viewpoint model of the ontology, the C-OWL formalism proposed in [5], [6] tries to contextualize ontologies in OWL to integrate the notion of viewpoint in the ontologies of the Semantic Web.

The paper [12] presents an application and extensions of semantic web principles and technologies for the construction of a portal dedicated to the management of knowledge in oncology. This work uses the C-OWL language [5], [6] in order to establish a multi-point of view representation of the knowledge contained in repositories (a kind of medical decision protocols) in the field of cancerology, where there are different points of view, different ways of considering the knowledge of the domain and different ways of using it.

In order to represent MVp ontologies and extend the expressive power of OWL, another MVP-OWL was created by Bach [13]. This language allows adding mechanisms to OWL to represent all the components of an MVp ontology in the Semantic Web framework.

In [4], the authors considered multi-viewpoints ontologies using the notions of a global and local concept, global and local role, individual, subsumption and bridge rules. They extended the description logic which was proposed as a knowledge representation language for the Semantic Web by the stamping mechanism. This logic was introduced in order to provide a language to support the MVp aspect in the representation of ontologies.

In regards to our chosen formalism here, Milner's bigraph has been already proven very efficient and useful in formalizing different systems along with other employments in different other domains [14], [15]. We notice that locality, connectivity and dynamicity are the main properties of MVp ontologies which makes BRS. Thus, compared to existing approaches of MVp ontology specification, our approach allows not only modelling structural aspects, but also describing different internal and external reconfigurations involved in the dynamic reactions of MVp ontologies.

III. Preliminaries

In this section, we first give a brief overview about the various aspects of bigraphical reactive systems and after we present the model-checkerBigMC.

A. Overview of Bigraphical Reactive Systems

The bigraph theory was initially introduced by Robin Milner [7] in order to provide an intuitive and fully graphical model capable of representing both the connectivity and the locality of entities. Thus, it corresponds perfectly to MVp ontology notions.

A bigraph combines two independent structures (the place and the link graphs). The place graph specifies the entities geographical distribution of the system. While the link graph captures interactions between these entities. Bigraphs are equipped by reaction rules defining their structural dynamics allowing one to specify how these bigraphs can be reconfigured [14]. Figure 1 illustrates the anatomy of a bigraph.

Place graph consists of a forest of trees, called roots, identifying the part of a bigraph that can be hosted; it can contain a set of nodes. A node represents a physical or logical component of system represented as ovals, circles, triangles and other graphic shapes. The nodes can be nested or located at the intersection of one or more nodes. All the nodes in a bigraph have an identifier (type), called control and designated by a letter (e.g., A, B, etc.). The set of controls of a bigraph is called the signature of the bigraph. Each node can have zero or more ports to represent the possible connections. A port, specific to a node, is a connection point with the other bigraph entities. The ports are depicted by bullets. The edges are used to connect two or more ports. The dotted rectangles indicate regions (sometimes called roots), their role is to describe the parts of the system that are not necessarily adjacent. The squares in grey

represent sites; they are abstract parts of the model. The regions and sites are indexed by natural numbers (starting from 0) left to right. Nodes, sites, and regions are called the places of a bigraph. In addition to hyper-arcs, a bigraph can have other types of communication links which are Inner/Outer names. In our example (see Fig. 1), y_0 and y_1 are inner names, while x represents outer name. They express (potential) links to other bigraphs, representing of external environments. The possibilities of a bigraph to interact with the external environment are saved in its interface. For example, we write G: $<1,\{x\}>\rightarrow<2,\{y_0, y_1\}>$to indicate that the bigraph G has one site, two regions and two outer name sets $\{y_0, y_1\}$ and one inner name $\{x\}$.

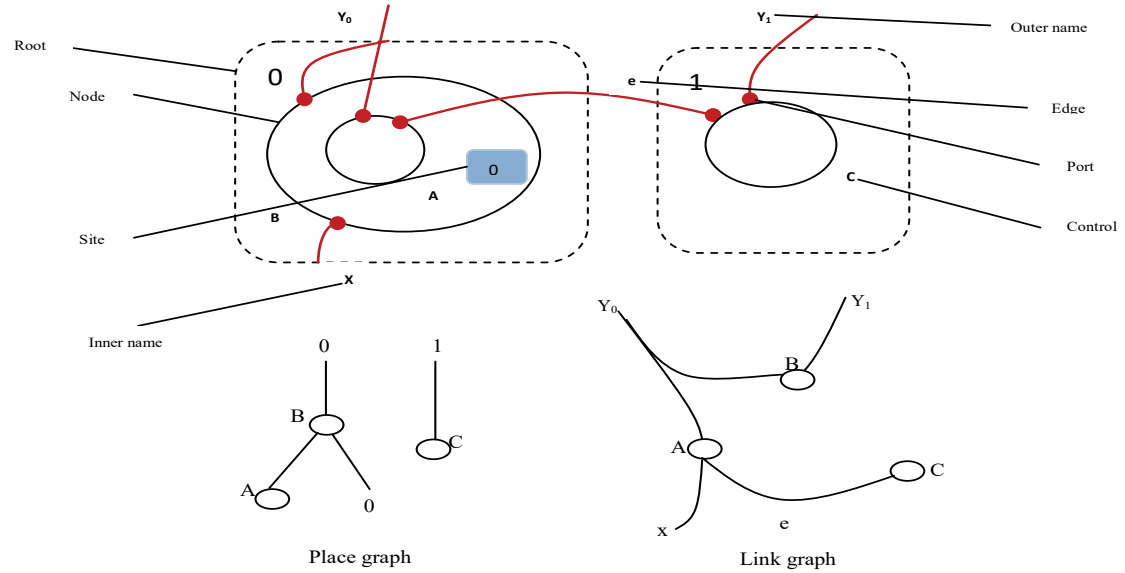


Fig. 1. Anatomy of a bigraph.

In addition to their rich and intuitive graphic form, a language of algebraic terms is defined to express the bigraphs. We recapitulate the basic operations of the term language in Table I.

The BRSs are also equipped with dynamic semantics that define how the bigraphs can reconfigure their places and their links. These reconfigurations are defined in terms of reaction rules. A reaction rule: R → R` has a pair of bigraph <redex, reactum>. The redex is a pre-condition for the reaction. This reaction represents a pattern to be changed. The reactum represents the post-condition which specifies the pattern after the change effected by the reaction. There are two types of reconfigurations: (a) Reconfiguration on the places by adding, deleting or moving of a node; (b) Reconfiguration on the links by the creation or the destruction of a link between two nodes or between a node and an inner / outer name.

TABLE I

TERMS FOR BIGRAPHS

Algebraic form	Interpretation
U ° V	Composition of nodes
U | V	Merge product (Juxtaposition of nodes)
U ‖ V	Parallel product (Juxtaposition of roots)
U. V	Nesting. *U* contains *V*
U ⊗ V	Tensor product
d_i	Numbered site
id_i	Identity (elementary bigraph)

B. BigMC: Bigraphical Model Checker

BigMC [16] is a model-checker designed to operate on bigraphs. The principle of this tool is to define a bigraphic model by using its own grammar as well as a series of reaction rules associated with this model. The full BigMC grammar terms are given in Table II.

TABLE II

THE BIG MC GRAMMAR TERMS

Terms for bigraphs
$M ::= E; M \mid E$
$E ::= \%passive\ k : arity$
$E ::= \%active\ k : arity$
$E ::= \%rule\ n\ T \rightarrow T$
$E ::= \%property\ n\ P$
$E ::= T \rightarrow T \mid T$
$T ::= K.T \mid T \mid T \mid T \parallel T \mid \$n \mid K \mid nil$
$K ::= k[names] \mid k$
$names ::= n, names \mid n$
$n ::= [a-zA-Z][a-zA-Z0-9]* \mid -$
$P ::= matches(T) \mid terminal() \mid !\ P$

A BigMC model (nominated by M) can be composed using other models and/or expressions (nominated by E). An expression E can be a control (k), a node declaration, a reaction rule, a term (T), or a property (P). A control k must be defined by the declaration of the % active or % passive signature

defining the arity (number of ports) of the control as well as whether it is active or passive. A term T can represent a single node, site, region or a combination of all these elements. Terms of the form $T \rightarrow T$ are considered reaction rules. A property P represents a state definition to be checked with BigMC tool. We will use this grammar to specify our Multi-Viewpoints ontology model.

IV. BRS-based Model for the Multi-View Point Ontology Specification

In this section, we present a formal model based on BRS and their logic of sorting which consist of modelling the architectural aspects of MVp ontology as well as their evolutionary reconfiguration. First, we introduce the different architectural elements constituting this ontology. Then, we present a formal semantics based on BRS to represent them formally.

A. Multi-Viewpoints Ontology (MVp Ontology)

A Multi-Viewpoints ontology is a multiple description of the same discourse context according to various viewpoints. A viewpoint is a partial description of a discourse context within a particular perception. At a global level, the partial descriptions share ontological elements and semantic links constituting a consensus between the different viewpoints. These links establish the communications between the points of view and represent the interdisciplinary collaboration.

In this case, the modelling of MVp ontology consists of identifying the set of viewpoints, the global and the local concepts, as well as the roles, and the bridge links in order to represent the relations between concepts from the same or the different viewpoints of a context (see Fig. 2).

According to [4], an MVp ontology is defined as a four-tuple of the form O = (C_G, R, VP, M), where C_G is a set of global concepts, R is a set of roles, PV is a set of viewpoints, and M a set of bridge links.

A viewpoint is defined by a triple VP= (C_G, C_L, R), where C_L a set of local concepts and Ra set of roles. In the following, we give some fundamental definitions:

- Global concept models a generic family of the real world and groups a set of individuals. Each global concept can be described according to different viewpoints.
- Local concept is a concept that is seen and described locally according to a particular viewpoint.
- Role is a relationship between two local concepts defined in two different perspectives.
- Bridge links represent consensual relationships between two local concepts or two local roles represented in two different viewpoints. Viewpoints are not totally disconnected. Bridges are semantic relationships which link local concepts under pairwise disjoint viewpoints to a local concept in yet another viewpoint. Two types of bridges are possible: unidirectional and bi-directional. Bi-directional bridges represent set equality (≡) and set exclusion (⊥) relations; while unidirectional ones represent set inclusion relation (⊇, ⊆).

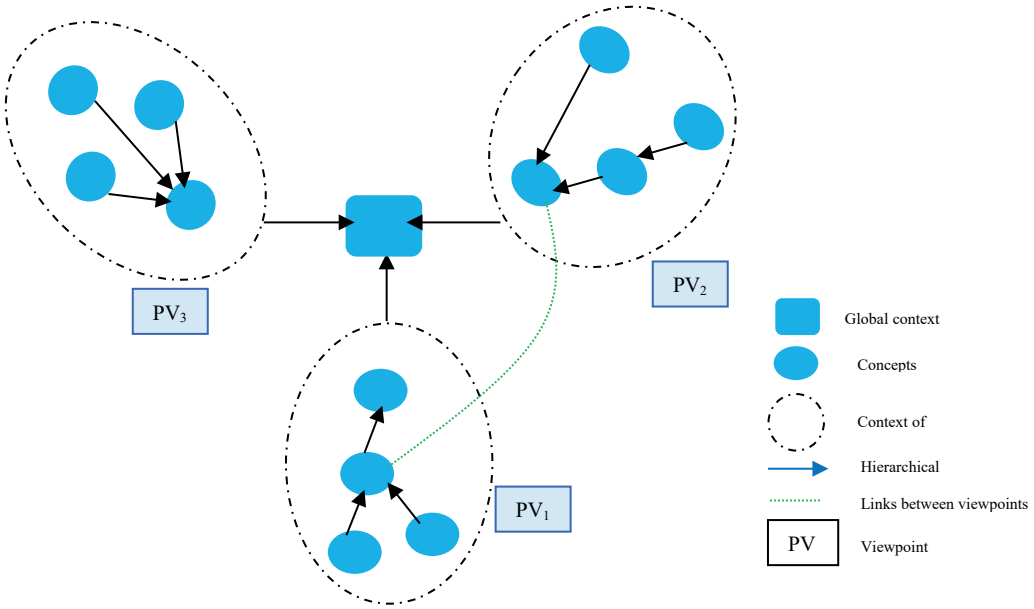


Fig. 2. Multi-viewpoint model.

B. Modelling a Multi-Viewpoints Ontology

Modelling is a fundamental step in the design of MVp ontology. It consists of defining a structurally abstract and semantically rich model that consist of representing the concepts of an MVp ontology, the relations among these concepts and their constraints.

In this context, we propose a formal model based on bigraphic reactive systems, known as BigMVO (*Bigraphical Multi-Viewpoints Ontology*), in which the main elements of an MVp ontology find their definition in terms of bigraphic concepts by preserving their semantics. For this purpose, correspondences between the concepts of MVp ontologies and

those of BRS are established. The following description summarises these correspondences:

- The *viewpoint* is represented by a bigraph where the nodes correspond to the different internal concepts (global and local).
- The *MVp ontology* is modelled by a bigraph containing nodes corresponding to the points of view as well as the concepts (global and local), which can be determined by the context.
- Each entity of an MVp ontology is modelled by a node and associated with a control to represent its identity.
- 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 and bridge links).
- The change in an MVp ontology is modelled as a result of applying a new category of reaction rules that support internal and external reconfiguration of an MVp ontology.

Table III presents the correspondences between the elements of an MVp ontology and those of the BRS.

TABLE III
BIGRAPHIC SEMANTICS OF ELEMENTS OF A MULTI-VIEWPOINTS ONTOLOGY

Element	Bigraphic semantics
Structure	
View point	Bigraph : $View_{id}= (V_{id}, E_{id}, ctrl_{id}, O^P, O^L) : I \rightarrow K$
Ontology multi view points	Bigraph: OM : I→ J $\stackrel{def}{=}$ $View_{id1} \otimes View_{id2} \otimes \dots \otimes View_{idn}$
Entity	Node: $v_i \in V$ / $V= V_{id1} \uplus V_{id2} \uplus \dots \uplus V_{idn}$
Identity	Control: $k \in K$ / $K = K_{id1} \uplus K_{id2} \uplus \dots \uplus K_{idn}$
Interaction	Hyperarc: $e_I \in E$ / $E = E_{id1} \uplus E_{id2} \uplus \dots \uplus E_{idn} \uplus M$
Behavior (applications)	
Internal reconfiguration	Reaction rule: $R_I = (R_{id} : z \rightarrow J, R`_{id} : z` \rightarrow J, \eta)$
External reconfiguration	Reaction rule: $R_E = (R_{id} : m \rightarrow k, R`_{id}: m` \rightarrow k, \eta)$
Composite reconfiguration	Reaction rule: $\mathscr{R} = (R : m \rightarrow J, R`: m` \rightarrow J, \eta)$

Structurally, BigMVO offers a clear separation between the different points of view of a context, where each point of view is modelled separately by a separate bigraph. The tensor product of these bigraphs is also a bigraph that models the general structure of MVp ontology. In addition, the dynamic change of these viewpoints is supported by reaction rules allowing the modelling of the internal and external reconfigurations of an MVp ontology. Here, we give the necessary formal definitions to understand this manuscript, as well as some illustrative examples.

Structural Aspect of Multi-Viewpoints Ontology

In this section, the structural definition of BRS is enriched to represent the structure of MVp ontology, where the viewpoints of any context are modelled using distinct bigraphs. $View_{id}$: I → K is the bigraph which models a viewpoint id. The tensor product of the graphs $View_{id1}$, $View_{id2}$, …, $View_{idn}$ generates a new bigraph OM: I → J which models the MVp ontology. Finally, the elements of the viewpoints and the elements of the multi-viewpoints ontology are respectively called internal and external.

Structure of a viewpoint: As we have already mentioned, a viewpoint is a partial description of a context of discourse within a particular perception. Thus, a viewpoint is defined by a set of local and global concepts and roles. From a bigraphic point of view, each concept is modelled by an internal node and the interactions between them (i.e., roles) are modelled by internal hyper arcs.

Definition 1 (viewpoint bigraph). The bigraph of a pointview $View_{id}$ is formally given by:

$View_{id} = (V_{id}, E_{id}, ctrl_{id}, O^P_{id}, O^L_{id}): I \rightarrow K$

- $V_{id}$is a finite set of nodes representing the different local and global concepts of the $View_i$**.**
- E_{id} is a finite set of roles (internal hyper-arcs).
- $Ctrl_{id}$: $V_{id} \rightarrow K$ is a transformation function which associates with each node $v_i \in V_{id}$a control $k \in K_{id}$ indicating the number of ports. The signature K is a finite set of controls associated with the elements of ontologies.
- $O^P_{id} = (V_{id}, ctrl_{id}, prnt_{id})$: $m_O \rightarrow n_O$is the place graph associated with $View_{id}$. $m_O$and n_O are the number of sites and regions. $Prnt_{id}$: $m_O \uplus V_{id} \rightarrow V_{id} \uplus n_O$ is a parent map that associates each entity with its hierarchical parent (e.g., the parent of a Man node is a human node).
- $O^L_{id} = (V_{id,} E_{id}, ctrl_{id}, link_{id})$: $X_O \rightarrow Y_O$is the link graph of $View_{id}$, where $link_O$: $X_O \uplus P_O \rightarrow E_{id} \uplus Y_O$ is a transformation function that specifies the interactions of each entity of the ontology. X_O, Y_O and P_O are, respectively, the inner names, the outer names, and the port set of $View_{id}$.
- $I_O=<m_O, X_O>$and $J_O=<n_O, Y_O>$are, respectively, the inner and outer interfaces of the bigraph$View_{id}$.

Example (Bigraph$View_{id}$)**.** Let $View_{Production}$ (Fig. 3) and $View_{Sale}$ (Fig. 4) be two bigraphs modelling the production and sale viewpoints of an automotive service, respectively. The bigraph $View_{Production}$ is given by: $<9,\{\}> \rightarrow <1,\{y\}>$ such as:

- V = {Production, automotive, driver, coarse, expensive, inexpensive, noble material, passenger, user} represents the set of internal nodes.
- E = {drive, take}.
- Ctrl = {Production: 1, automotive: 2, driver: 1, coarse: 0, expensive: 0, Inexpensive: 0, noble material: 0, passenger: 1, user: 0} indicates the number of fixed ports for each node. For example, the Production node has only one fixed port.
- *Prnt*= {Production: automotive, production: user, automotive: expensive, automotive: Inexpensive, … } indicates the hierarchical parent of each internal node. For example, Production is the hierarchical parent of automotive.
- $I = <9, \emptyset>$ is the internal interface of the bigraph $View_{Production}$. $k = 9$ represents the number of regions where one region containing nodes that can be hosted, and $Z = \emptyset$ represents the set of internal names.

- $J = < 1, Y>$ is the external interface of the bigraph $View_{Production}$ where $n = 1$ and $Y = \{y\}$ represent the number of sites and the set of external names, respectively.
- Place graphs: $O^{P}{}_{Production}$ and $O^{P}{}_{Sale}$ and link graphs $O^{L}{}_{Production}$ and $O^{L}{}_{Sale}$ are given in Figs.5 and 6, respectively.

Structure of multi-viewpoints ontology: As we have mentioned before, an MVp ontology is a multiple description of the same discourse context according to different viewpoints. Thus, its structure is defined by a set of global and local concepts, a set of roles, a set of viewpoints and a set of bridge links.

Definition 2 (Multi-viewpoints ontology bigraph). A bigraph OM modelling a multi-viewpoints ontology of a context id is formally given by:

$OM \stackrel{def}{=} View_{id1} \otimes View_{id2} \otimes \ldots \otimes View_{idn}$,

where: $OM = (V, E, ctrl, O^{P}, O^{L}): I \rightarrow J$.

- $V = V_{id1} \uplus V_{id2} \uplus \ldots \uplus V_{idn}$ i s a finite set of nodes (local concepts, global concepts and views) in a context id which is given by the union of the set of V_{id} nodes of all views.
- $E = E_{id1} \uplus E_{id2} \uplus \ldots \uplus E_{idn} \uplus M$ is a finite set of hyper-arcs representing in a context id which is given by the union of the set of hyperarcs E_{id} and the set of the bridge links M.

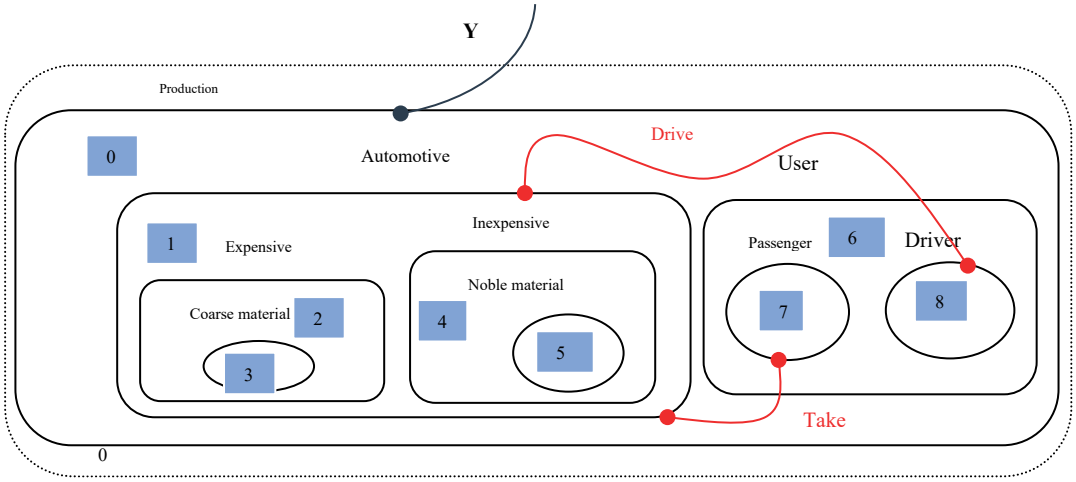


Fig. 3. Production viewpoint modelling.

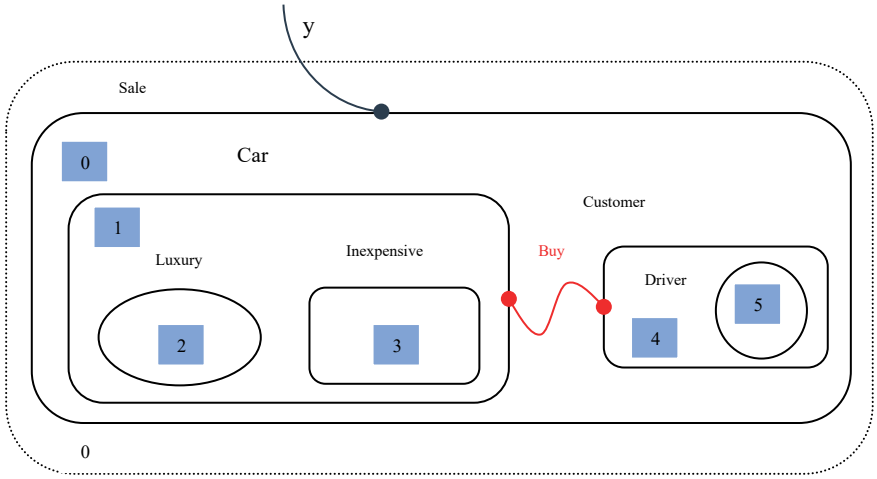


Fig. 4. Sale viewpoint modelling.

- $K = K_{id1} \uplus K_{id2} \uplus \ldots \uplus K_{idn}$is an extended signature, defined by a set of controls, where Ctrl: $V \rightarrow K$ is a new transformation, which associates with each node $v_i \in V_{id}$a control $k \in K_{id}$ indicating the number of its fixed ports.
- $O^{P} = O^{P}{}_{id1} \otimes O^{P}{}_{id2} \otimes \ldots \otimes O^{P}{}_{idn}$: $m \rightarrow n$is the place graph associated with OM given by the tensor product of the graphs of places $O^{P}{}_{id1}$: $m_1 \rightarrow n_1$, $O^{P}{}_{id2}$: $m_2 \rightarrow n_2$, … and $O^{P}{}_{idn}$: $m_n \rightarrow n_n$,where its parent map is: $prnt = prnt_{id1} \uplus prnt_{id2} \uplus \ldots \uplus prnt_{idn}$
- $O^{L} = O^{L}{}_{id1} \otimes O^{L}{}_{id2} \otimes \ldots \otimes O^{L}{}_{idn}$:is the links graph of OM given by the tensor product of the links graphs $O^{L}{}_{id1}$: $X_1 \rightarrow Y_1$, $O^{L}{}_{id1}$: $X_2 \rightarrow Y_2$, …, $O^{L}{}_{idn}$: $X_n \rightarrow Y_n$. Where, $O^{L} \stackrel{def}{=} (V, E, ctrl_{id1} \uplus ctrl_{id2} \uplus \ldots \uplus ctrl_{idn}, link_{id1} \uplus link_{id2} \uplus \ldots \uplus link_{idn}) : (X_1 \uplus X_2 \uplus \ldots \uplus X_n) \rightarrow (Y_1 \uplus Y_2 \uplus \ldots \uplus Y_n)$
- $I = <m, X>$and $J = <n, Y>$are, respectively, the inner and outer interfaces of the bigraph OM, where m is the number of sites, X is the set of internal names, n is the number of regions, and Y is the set of external names.

In order to give a precise and rigorous semantics, we associate to the bigraph OM a discipline of sorting $\sum_{OM}$. The introduced logic of sorting defines mapping rules and expresses all constraints and formation rules that OM satisfies to ensure proper and precise encoding of MVp ontology semantics into BRS concepts. The formal definition of the discipline of sorting is as follows.

Definition 3 (Discipline of sorting). The sorting discipline associated with the OM bigraph modelling a multi-viewpoints ontology is defined by the triplet $\sum_{OM} = \{\Theta_{OM}, K_{OM}, \Phi_{OM}\}$, where Θ_{OM} represents a non-empty set of sorts of OM, K_{OM} is a $\sum_{OM}$-typed signature which associates a sort with each control of OM, and Φ_{OM} is a non-empty set of training rules imposing construction restrictions for OM.

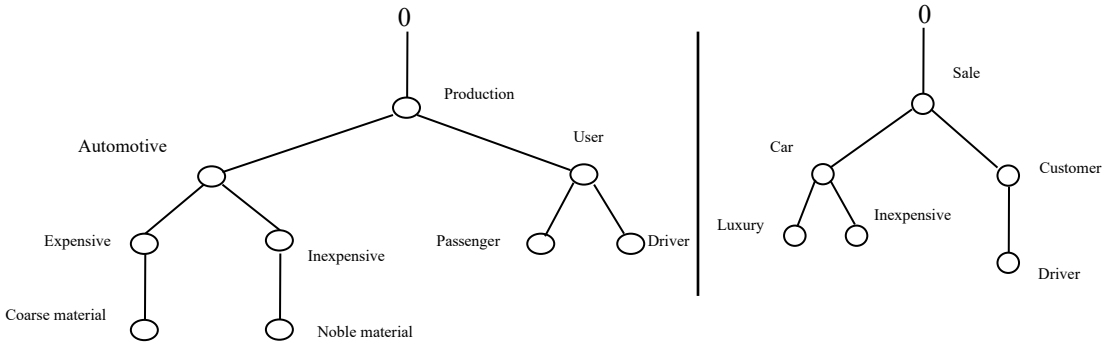


Fig. 5. Place graph of $View_{Production}$ and $View_{Sale}$ bigraphs.

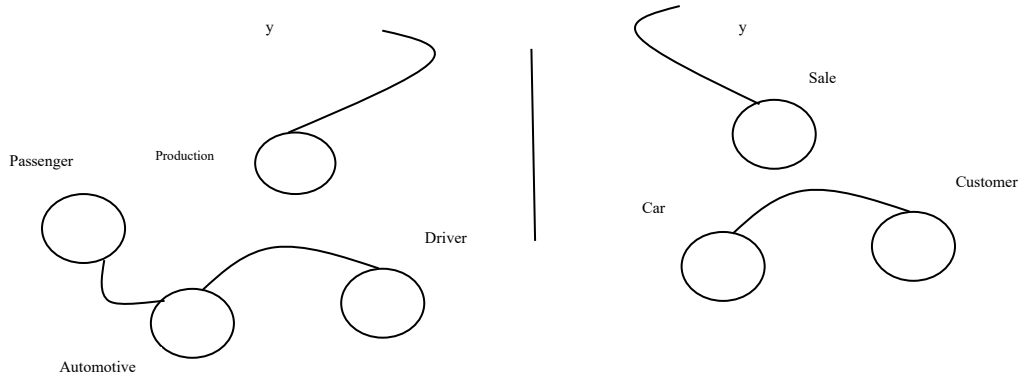


Fig. 6. Links graph of bigraphs $View_{Production}$ and $View_{Sale}$.

The different used sorts are associated with the controls describing the different nodes that make up the system. The nodes of the same sort can have different signatures to indicate their state or role. Also, the signature associated with each control defines a number of ports (e.g., view has at least 1 port) and a given graphic notation (e.g., a local concept instance is represented by a circle). The used sorts and controls to formally represent the different elements of the OM bigraph are shown in Table IV.

TABLE IV
CONTROLS AND SORTS OF THE BIGRAPH OM

Description	Control	Arity	Sort	Graphical notation	Bigraph
Entity					
Global concept	GC	N	g	Rectangle	OM and View
Local concept	LC	N	l	Circle	OM and View
View	$View_i$	≥1	V	Rectangle	OM

The construction rules Φ_{OM} take the form Φ_i, $i \in [0...5]$. They make it possible to impose structural constraints in order to guarantee correct models authorized by the bigraph OM (see Table V).

In particular, the rules Φ_0–Φ_2 define the constraints on the hierarchical nesting of the different entities, while the rules Φ_3–Φ_5 define the restrictions on their links.

TABLE V
TRAINING RULES Φ_{OM} FOR THE BIGRAPH OM

	Rule Descriptions
Φ_0	All children of a 0-region and 1-region have a sort x ∈{g, l, v}
Φ_1	All children of a 0-node have a sort x ∈{g, l}
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

For example, the rule Φ_0 states that the principal region denoted 0 which represents a multi-viewpoints ontology, can only have children of nodes of sort {g, l, v}. Finally, rule Φ_3 requires that all viewpoints must be related to at least one another view point ontology.

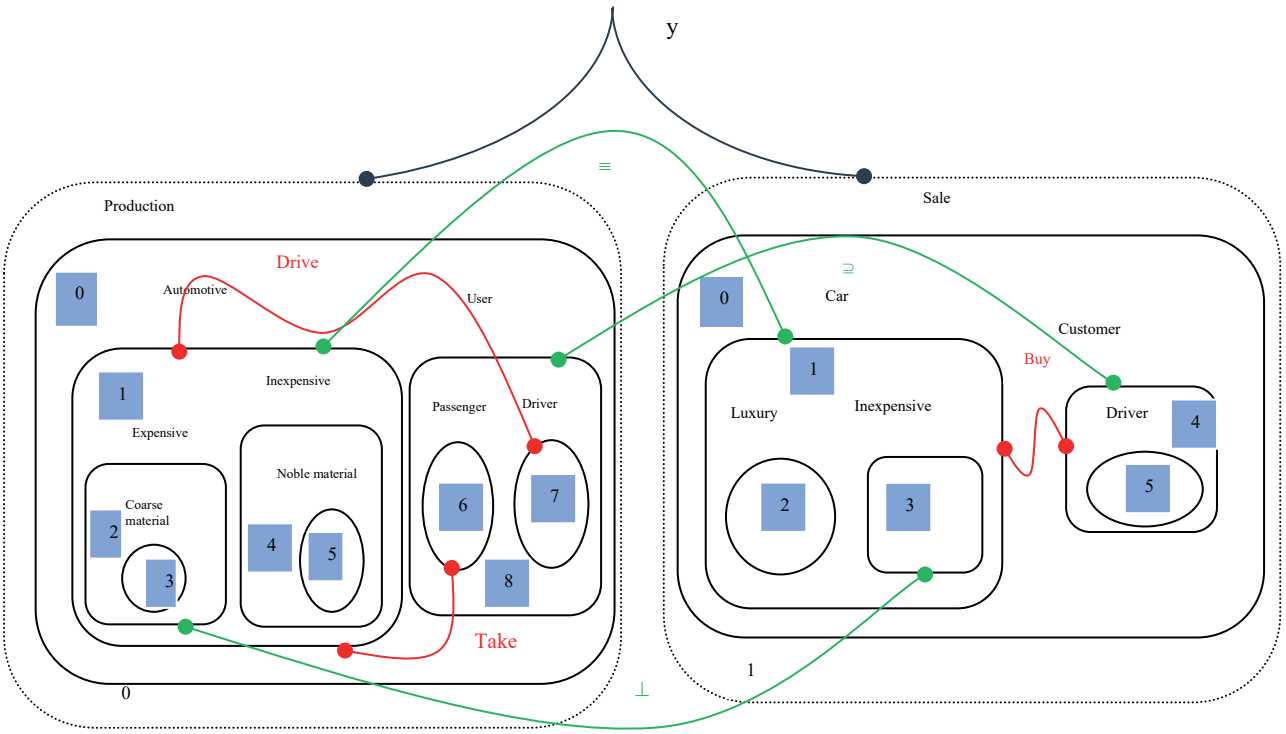


Fig. 7. Example of a multi-viewpoints ontology bigraph OM.

Example (Bigraph OM). Let $View_{Production}$ and $View_{Sale}$ be two bigraphs modelling, respectively, the production and sale viewpoints of an automotive service. The tensor product of the graphs $View_{Production}$ and $View_{Sale}$ generates a new bigraph: $OM \stackrel{def}{\equiv} View_{Production} \otimes View_{Sale}$ (Fig. 7). OM models a multi-viewpoints ontology of automotive services given by :<15,{}>→<2,{y}>.

- V = {production, sale, automotive, driver, coarse, expensive, Inexpensive, noble material, passenger, user, Car, Customer, Luxury, Inexpensive, Driver } represents the set of internal nodes.
- E = {drive, take, buy, ≡, ⊥, ⊇}, (the bridge links are indicated in green colour in Fig. 6).
- Ctrl = {production: 1, automotive: 3, coarse: 0, expensive: 1, Inexpensive: 0, noble material: 0, passenger: 1, user: 1 …….} indicates the number of fixed ports for each node.
- Prnt= {production: automotive, sale: user, automotive: expensive, automotive: Inexpensive, … } indicates the hierarchical parent of each internal node.
- I = < 15, ∅> is the internal interface of the bigraph OM. m = 15 represents the number of regions where 15 regions containing nodes that can be hosted, and X = ∅ represents the set of internal names.
- J = < 2, Y> is the external interface of the bigraph OM where n = 2 and Y = {y} represent the number of sites and the set of external names, respectively. Here, the external names of the two viewpoints are merged.
- Finally, the place graph O^P (Fig. 8) is the result of the tensor product of the graphs of places $O^P{}_{Production}$ and $O^P{}_{Sale}$, and the link graph O^L (Fig. 9) is the result of the tensor product of the graphs of links $O^L{}_{Production}$ and $O^L{}_{Sale}$.

To deal with the dynamic reaction of multi-viewpoints ontology at runtime, we enrich the proposed bigraph-based model with reaction rules. Hence, a set of reaction rules defining MVp ontology configurations and their evolution at runtime is specified.

Reactive Aspect of Multi-Viewpoints Ontology

The dynamic reaction of a multi-viewpoints ontology is the result of a transition from one discourse context to another, triggered by an event that affects the state of the ontology. Formally, a context transition has the form R: OM → OM` and defined by a reaction rule given by R where OM models the current state of MVp ontology and OM` models the next state of the ontology in a new context. R is the so-called composite reaction rule representing a sequence of reaction rules that occur in each part of the MVp ontology to make it proceed from one state to another.

Internal Reconfiguration: Internal reaction rules are rules applied to the viewpoint bigraph in order to define the internal dynamic reaction of a multi-viewpoints ontology.

Definition 4 (Internal reaction rule). An internal reaction rule is given by:

$R_I = (R_{id} : z \rightarrow J, R`_{id} : z` \rightarrow J, \eta)$,

where $R_{id} : z \rightarrow J$ is a bigraph called redex (the pattern to change) in a viewpoint id, $R`_{id} : z` \rightarrow J$, η is also a bigraph called reactum (the new pattern) from the same viewpoint id and the instantiation $\eta : z` \rightarrow z$ is a correspondence function between z` and z.

Example. Let R_I be an internal reaction rule such as:

$$R_I = (R: 6 \rightarrow <1,\{y\}>, R`: 5 \rightarrow <1,\{y\}>, 5 \rightarrow 6).$$

The application of R_I to the bigraph of $View_{Sale}$(Fig. 10) has the effect of deleting the internal node driver, which expresses the deletion of the element modelled by this node as well as all of its connections. The algebraic expression corresponding to the internal reaction rule R_I is as follows:

y/Sale.(d_0 ׀ car. (d_1 ׀luxury. d_2 ׀ inexpensive. d_3) ׀ (customer. (d_4 ׀driver. D_5))→y/ Sale.(d_0 ׀ car. (d_1 ׀luxury. d_2 ׀ inexpensive. d_3) ׀ (customer.d_4).

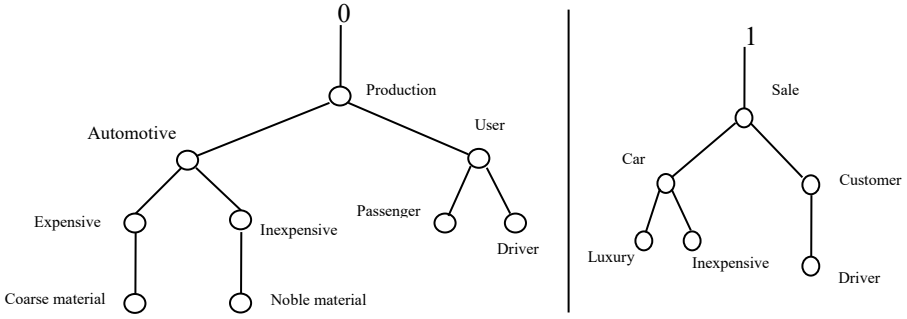


Fig. 8. Place graph of OMbigraph.

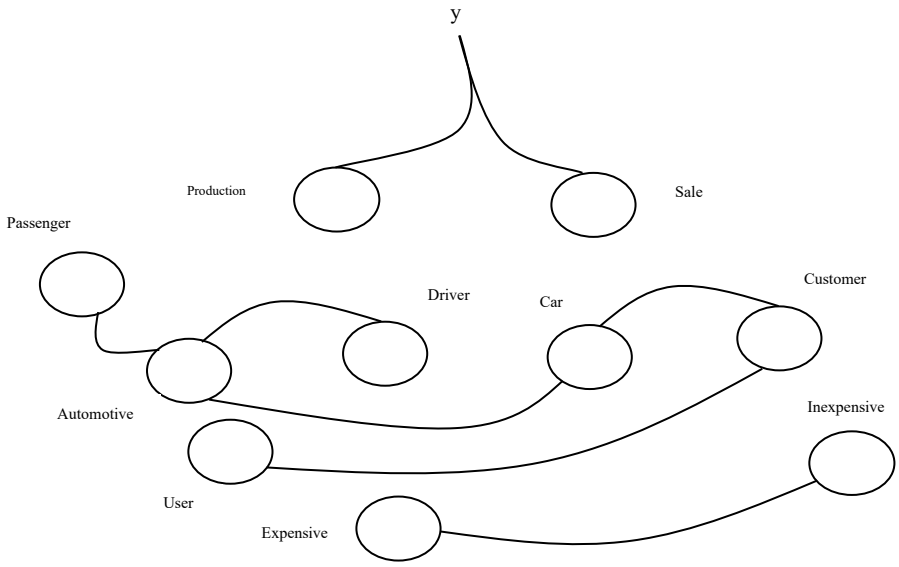


Fig. 9. Links graph of OM bigraph.

External reconfiguration: The external reaction rules are applied to the bigraph OM to define the dynamic reaction between the different viewpoints of MVp ontology.

Definition 5 (External reaction rule). An external reaction rule is given by:

$$R_E = (R_{id} : m \rightarrow k, R`_{id`}: m` \rightarrow k, \eta),$$

where $R_{id} : m \rightarrow k$ is a bigraph called redex for a viewpoint id, $R`_{id`}: m` \rightarrow k$, η is also a bigraph called reactum for a viewpoint id` and the instantiation $\eta : m` \rightarrow m$ is a correspondence function between *m*` and *m*.

Example. Let R_E be an external reaction rule applied such as:

$$R_E = (R : 14 \rightarrow <2,\{y\}>, R` : 14 \rightarrow <2,\{y\}>, 14 \rightarrow 14).$$

The application of the rule R_E to the bigraph OM (Fig. 11) allows for the migration of the node customer from the $view_{sale}$ to the $View_{production}$, which involves moving the element modelled by this node to the node user. The algebraic expression corresponding to the external reaction rule R_E is as follows:

y/Sale. (d_0 ׀ car. (d_1 ׀luxury. d_2 ׀inexpensive. d_3) ׀ (customer. d_4)) ‖ y/production. (d_0 ׀ automotive. (d_1 ׀ expensive. (d_2 ׀coare. d_3)) ׀ (inexpensive. (d_4 ׀ noble. d_5)) ׀ user. (d_6 ׀ passerger.d_7 ׀ driver. D_8)) →y/ Sale.(d_0 ׀ car. (d_1 ׀luxury. d_2 ׀ inexpensive. d_3) // y/production.(d_0 ׀ (automotive. (d_1 ׀ expensive.(d_2 ׀coare. d_3)) ׀(inexpensive. (d_4 ׀ noble. d_5)) ׀ user. (d_6 ׀ passerger.d_7 ׀ customer. (D_8 ׀ driver. d_9))

Composite Reconfiguration: A composite reaction rule is the result of applying a finite sequence of internal and external reaction rules to the bigraphOM. In other words, it represents the different changes of a multi-viewpoints ontology.

Definition 6 (Composite reaction rule). A composite reaction rule is a triplet of the form:

$$\mathscr{R} = (R : m \rightarrow J, R`: m` \rightarrow J, \eta),$$

where R: $m \rightarrow J$ is a redex bigraph of an MVp ontology, R`: $m` \rightarrow J$, η is a reactum bigraph of the same MVp ontology and the instantiation η: $m` \rightarrow m$.

Example. Figure 12 shows the result of applying the internal reaction rule R_I (Fig. 10) and the external rule R_E (Fig. 11).

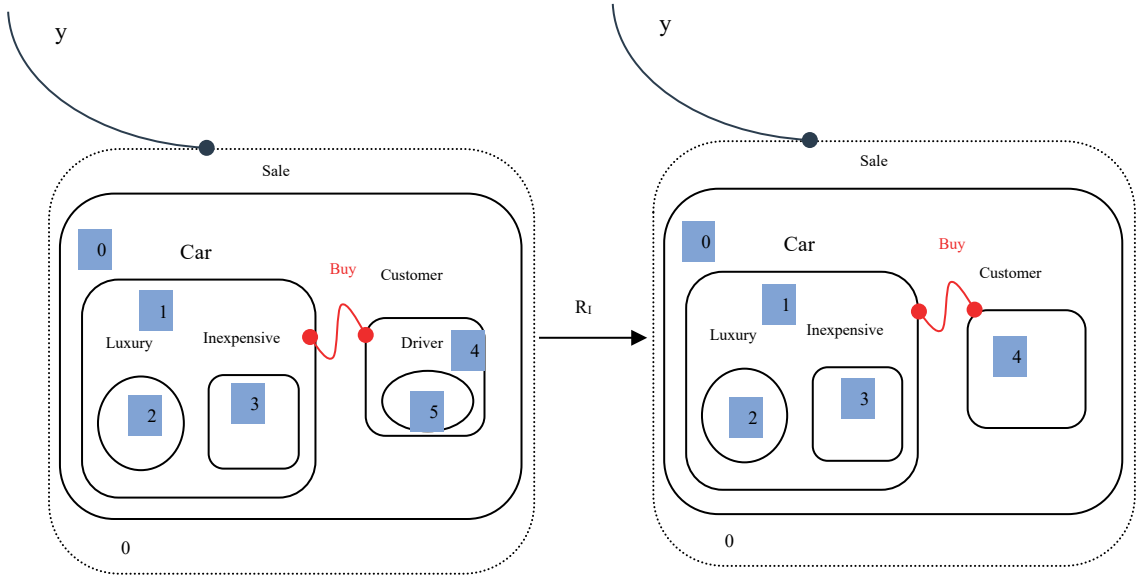


Fig. 10. Modelling of an internal reaction rule.

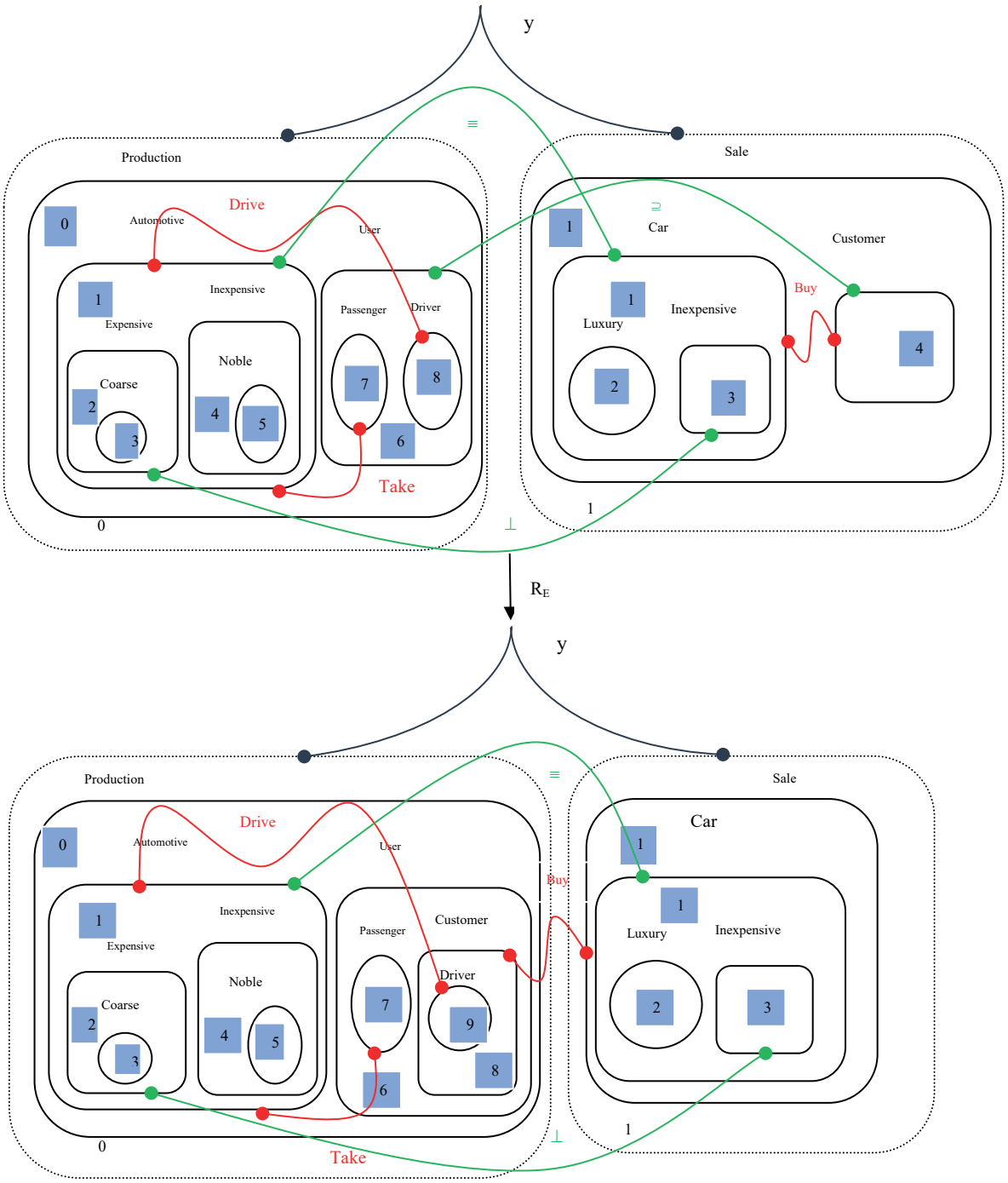


Fig. 11. Modelling of an external reaction rule.

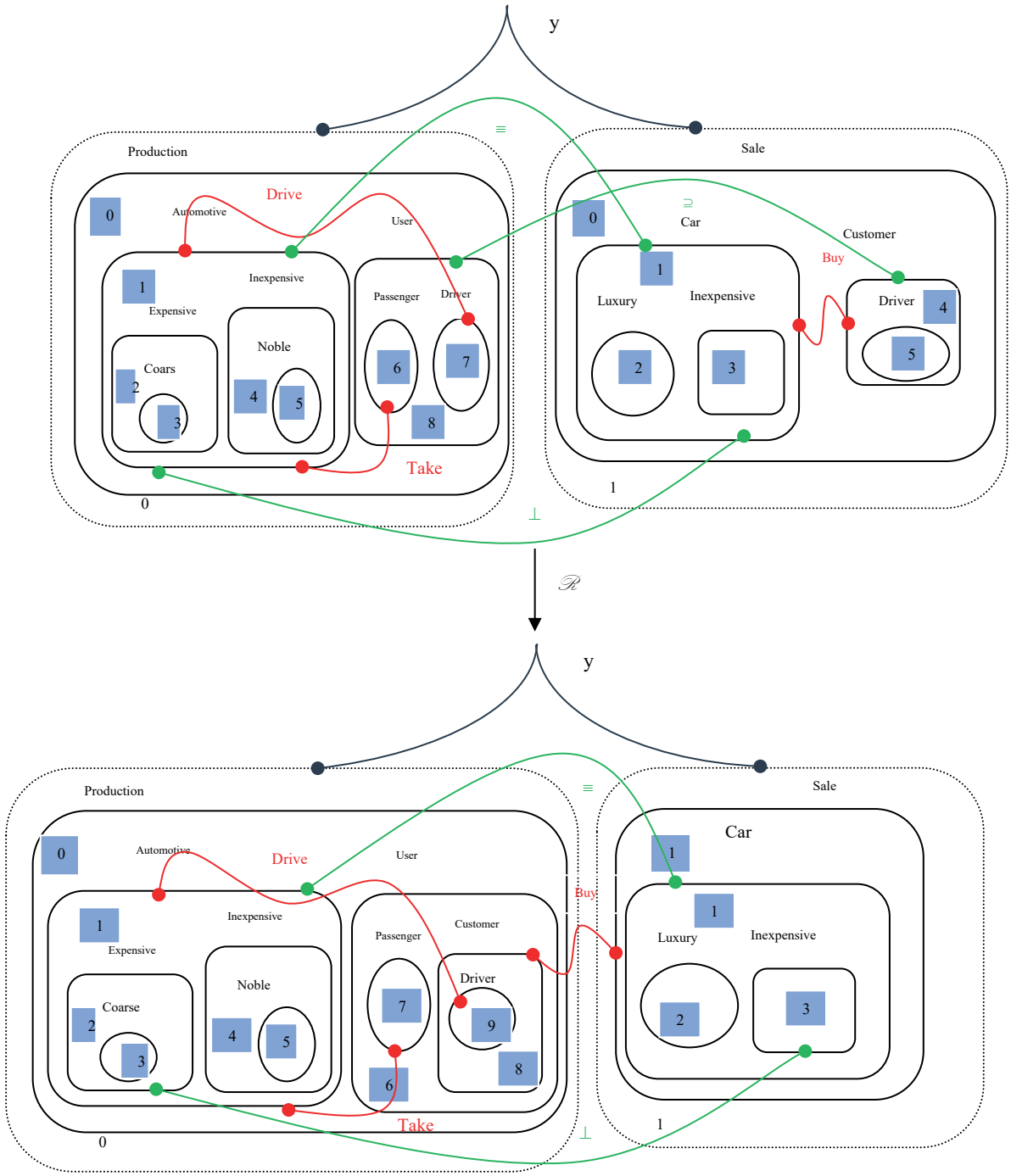


Fig. 12. Modelling of a composite reaction rule.

V. Executing BigMVO Model

In purpose of caring out the Multi-Viewpoints ontology, we apply the same BRS-based model of Multi-Viewpoints ontology by integrating it in BigMC tool. Hence, two essential modules are defined, giving a clear distinction between structural and behavioural aspects of our bigraphical models of Multi-Viewpoints ontology: the BigMVO_SYNTAX and BigMVO_DYNAMIC modules.

First, using a set of declarations we reflect the structural aspects of our bigraphical model by defining its signatures and semantics within the functional module BigMVO _SYNTAX (see Fig. 13).

Finally, we note that our proposed Bigraph-based approach is generic enough and may be easily extended to model other contexts and other behavioural aspects of Multi-Viewpoints ontology. Furthermore, the conceived bigraphs do not specify just the graphical representation, but also the intended mathematical models.

Results and Discussion

This section evaluated our proposed model. In order to assess the performance and efficiency of our current model, we

applied it in several domains, including staff, personnel affairs and civil status domains. Then, the specification of the MVp ontologies of these domains was manually generated by experts in these domains.

```
# BigMVO_SYNTAX
# Nodes production viewpoints
# Global concepts
% active Production : 2;
% active Automotive : 2;
% active User : 2;
% active Expensive : 2;
% active Inexpensive : 2;
# Local concepts
% active Passenger : 2;
% active Noble-material : 2;
# Hyperarcs
% name Drive;
% name Take;
# External names
% name y;
# Nodes sale viewpoints
# Global concepts
% active Car : 2;
% active Customer : 2;
% active Inexpensive : 2;
# Local concepts
% active Luxury : 2;
% active Driver : 2;
# Hyperarcs
% name Buy;
# External names
% name y;
# Multi-viewpoints ontology of an automotive services model
Sale [y]. (car [buy, equivalent]. (luxury  | inexpensive[different]) | (customer [buy,
subsume])) | $1  | production[y]. (automotive [drive]. (expensive[Different].
(coarse))  |  (inexpensive. (noble))  | user. (passenger[take]  |  driver [drive]))
```

Fig. 13. Appling bigraphical model in BigMVO.

We deal with the behavioural aspects of our bigraphical model, by defining the module BigMVO_DYNAMIC. This module contains a set of rule declarations corresponding to BRS reaction rules. Figure 14 depicts the internal and external reaction rules of our example that are applied respectively to removing the internal node driver and to migrating the node customer from the sale view to the production view. The principle of these rules has been explained previously in Subsection VI.B.

```
# BigMVO_DYNAMIC
# Internal reaction rule: deleting the internal node driver
Sale [y]. (car [buy]. (luxury  | inexpensive) | (customer[buy]. driver))→ Sale [y]. (car [buy]. (luxury  |
inexpensive) | (customer[buy]))

# External reaction rule: migration of the node customer from the sale view to the production view
Sale [y]. (car [buy, Equivalent]. (luxury  | inexpensive[different]) | (customer[buy, subsume])) | $1  |
production[y]. (automotive [drive]. (expensive[different]. (coarse))  |  (inexpensive. ( noble))  | user.
(passenger[take]  |  driver [drive])) → Sale [y]. (car [buy, Equivalent]. (luxury  | inexpensive[different])) |
$1  | production[y]. (automotive [drive]. (expensive[different]. ( coarse))  |  (inexpensive. (noble))  | user.
(passenger[take]  | (customer[buy, subsume].( driver [drive])))
```

Fig. 14. The reaction rule application.

We compared the results of our model with the experts' results, calculating the error rate in order to evaluate our results. The error rate is the number of erroneous specifications (compared to the experts' results) divided by the total number of specifications. We recapitulate our results in Table VI. It can be observed that the average error rates are very low. Consequently, we conclude that we have achieved good results with our model.

As shown in Table VI, the error rate of BigMVO increases with the number of global and local concepts to be specified. It increases from 0 % to 0.7 %. This increase is very small and acceptable. Table VI clearly shows the efficiency of the model BigMVO.

In this paper, we have demonstrated the theory, use and exploitation of the BRS for MVp ontology specification. Theoretical improvement is focused on the integration of BRS and BigMC tool.

Our approach and analysis were presented to demonstrate the effectiveness of the proposed BigMVO model with results explained and justified for MVp ontology specification. In order to give explanation for our research contributions and validity of our model, we clarify as follows.

- MVp ontology formalization: Section VI provides six formal definitions to the MVp ontology specification in semantic web.
- Section VI demonstrates the full use case for the proposed MVp ontology specification model. We have taken two viewpoints: the production and sale viewpoints of an automotive service.

- Automatic reactions of MVp ontology: for each kind of reactions of MVp ontology; Subsection VI.B gives a solution to automatically handle ontology changes.
- The demonstrated employment can be useful in different fields, while it can be used for all MVp ontologies formalized with BRS.

TABLE VI
EXPERIMENTAL RESULTS

Domain	Ontology size (Number of global and local concepts)	Role number	Viewpoints number	The error rate for the specification of global concepts	The error rate for the specification of local concepts
Staff	45	15	2	0 %	0 %
Personnel affairs	58	37	4	0 %	0.02 %
Civil status	390	52	5	0.3 %	0.7 %

VI. CONCLUSION

In this paper, we have presented a formal modelling approach for the specification of MVp ontology based on bigraphical reactive systems. First, we adopted BRS as a semantic framework to model the structural and reactive aspects of MVp ontology. The structure is defined by a bigraph OM represented by a region, and each structural entity of the component is represented by a node except the viewpoint structural entity, which is itself represented by a bigraph $View_{id}$. Thus, each viewpoint is modelled by a distinct bigraph, and its composition yields a new bigraph describing the whole structure of the MVp ontology. Besides, the dynamic reaction of MVp ontology has been characterised by bigraphical reaction rules with respect to both internal and external ontology changes. Then, we applied the case study using the BigMC model and effectively proven the applicability of our approach. Furthermore, the proposed formalization approach is general enough; it remains valid for any Multi-Viewpoints ontology architecture examples.

As future work, we intend to refine and enrich our proposed model BigMVO in order to address all possible configurations (internal or external) of MVp ontology.

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