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# Ontological Analysis of the MibML Grammar using the Bunge-Wand-Weber Model

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## ABSTRACT

Proliferation of multiagent application in business domains prompts increasing studies in MIBIS (Multiagent-based Integrative Business Information Systems) development. Recently, MibML (Multiagent-based Integrative Business Modeling Language) has been proposed as a conceptual-modeling grammar for the MIBIS universe. In this paper, we investigate the MibML grammar from the perspective of the BWW (Bunge-Wand-Weber) ontology and equip the MibML constructs with unambiguous ontological semantics. This study facilitates the straightforward mapping from business domain knowledge into MibML modeling constructs.

## Keywords

Ontological analysis, the BWW model, multiagent systems, MIBIS, MibML, conceptual modeling, system analysis

## INTRODUCTION

Multiagent technology is being widely utilized for developing enterprise integration applications, such as in the areas of workflow, supply chain management, and enterprise resource planning. This phenomenon is partly driven by the fact that coordination is at the heart of both business integration applications and multiagent systems. While one of the fundamental requirements in business integration is that of coordination, multiagent systems are essentially coordination models and implement a number of coordination mechanisms. Such integrative application systems developed using multiagent technologies have been termed Multiagent-based Integrative Business Information System (MIBIS) applications and these constitute a special type of information systems and a bounded universe of discourse (Kishore et al., 2004). The MIBIS discourse universe requires a conceptual modeling grammar (Wand and Weber, 2002) to better understand the application domain and formally describe the pertinent aspects of the physical and social aspects of applications in this universe (Mylopoulos, 1992). Recently MibML (Multiagent-based Integrative Business Modeling Language) have been proposed as a conceptual modeling grammar for the MIBIS universe, based on earlier work in this direction (Zhang et al., 2001, 2004). MibML provides in first order predicate logic the basic constructs, definitions, relationships, and axioms that are necessary for modeling application systems in the MIBIS universe.

While the MibML grammar defines the foundation constructs and their relationships for MIBIS modeling, it lacks clear ontological semantics which help map domain knowledge into the MibML modeling constructs. This lack of ontological semantics may result in some degree of arbitrariness while modeling MIBIS applications, and may result in the mapping between domain knowledge and modeling constructs highly dependent upon the beliefs, knowledge, and prior experience of system analysts. This problem in MibML is similar to the lack of semantic clarity pertaining to the relationship construct in the ER modeling formalism, which has recently been addressed by Wand et al. (2000). We believe such difficulties are attributed to the lack of ontological clarity of MibML constructs.

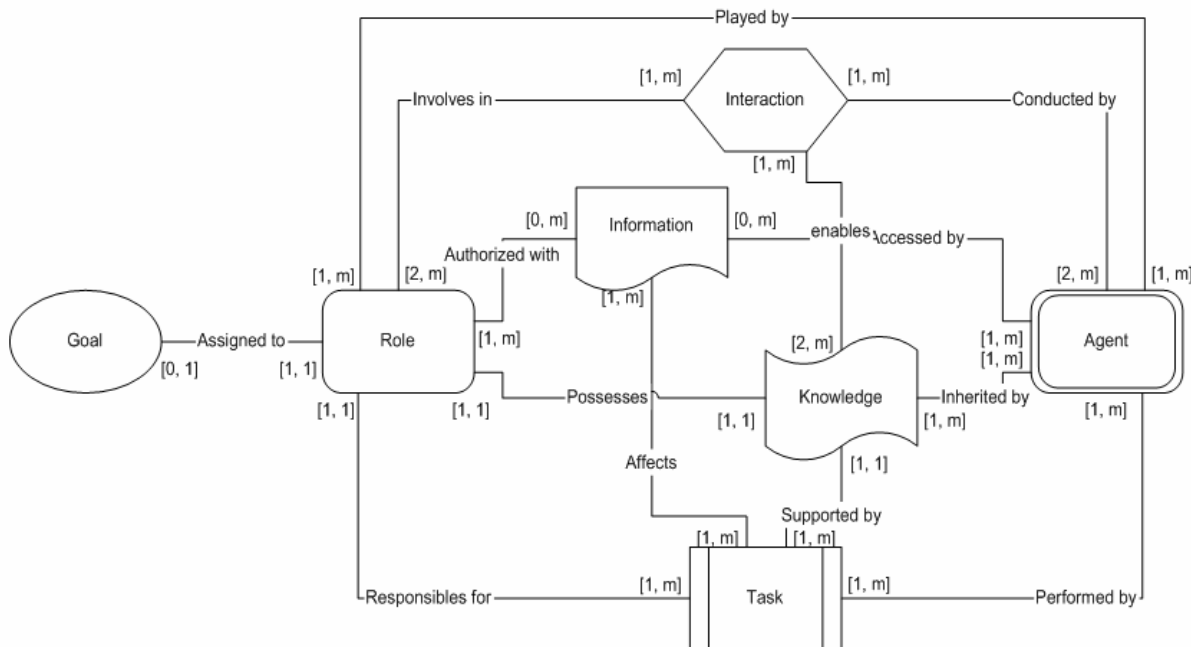
The goal of this paper is to amplify and clarify the semantics of MibML from an ontological perspective. In particular, we apply the upper-level ontology of the Bunge-Wand-Webber (BWW) model (Wand, 1996) to address the ontological expressiveness (Wand and Weber, 1993, Wand, 1996) of MibML. With clear ontological semantics assigned to the MibML constructs, it helps systems analysts not only capture MIBIS domain knowledge into a MibML model more easily but also in

a consistent manner. In addition, clear ontological semantics helps ensure that the mapping between the real world and their conceptual models suffer from minimum semantic gaps.

The paper is organized as follows. Section 2 gives an overview of the MibML grammar. Section 3 provides a brief recapitulation of the Bunge-Wand-Weber (BWW) model. Section 4 discusses the ontological approach of analyzing IS modeling grammars. Section 5 provides ontological analysis of MibML in the context of the BWW model. Section 6 proposes ontological semantics for MibML. And section 7 concludes the paper and discusses our future work.

**OVERVIEW OF MIBML**

MibML is a conceptual modeling grammar proposed recently especially for MIBIS modeling. It views a MIBIS as composed of interacting agents that coordinate to achieve business goals. The core MibML constructs are developed by examining and synthesizing key concepts in both IBIS and MAS literature. They are *agent*, *role*, *goal*, *task*, *interaction*, *information*, and *knowledge*. The meta-model of MibML is shown in Figure 1. Agents are problem-solving programs who play certain roles in the system. A role is a conceptual entity that defines duties and rights of agents. Goals describe the problem-solving functions of MIBIS required by users. The overall system goal is decomposed into a goal tree and leaf goals are assigned to agents as their responsibilities. Agents accomplish goals through performing tasks and interactions. A task is an activity performed solely by a single agent, whereas an interaction is an activity involving more than one agent. A task is able to be decomposed iteratively to form a task hierarchy along two dimensions – subparts and subtypes. An interaction is modeled as a coordinated sequence of speech acts. Information is data resources required for agents to perform tasks and interactions, which includes information entities and information flow. Information entities are static and stable stored data whereas information flow is dynamic and temporary data in transit. In addition, agents possess private knowledge. The knowledge is defined as justified true beliefs of the agent, in terms of factual (declarative) and task execution (procedural) knowledge. It includes facts, rules (used to deduct new facts), activity execution structure, and activity execution constraints.



**Figure 1: The MIBIS system-level meta-model**

**THE BWV MODEL**

The BWV model is an ontology of information systems proposed by Wand and Weber (1989, 1990, 1993) based on Bunge’s philosophical ontology (Bunge, 1974, 1979). In this section, we briefly explain the concepts of the BWV model that are used in this paper.

The elementary construct in the BWV model is a *thing*. A thing is a real-world phenomenon on the instance level. Things can associate to form a *composite thing*. The world is made of things that possess *properties*. Properties can be *intrinsic* or *mutual* to several things. An *intrinsic property* is possessed by the thing itself (e.g., color, height). A *mutual property* is jointly possessed by two or more things (e.g., being married). Properties cannot be observed directly by human; therefore, *attributes* are used as representation of properties to things. A *functional schema* is a set of attributes which are chosen to represent only the properties of interest to the observer for a certain purpose. The *state* of a thing comprises the values of the attributes in the functional schema at a given point of time.

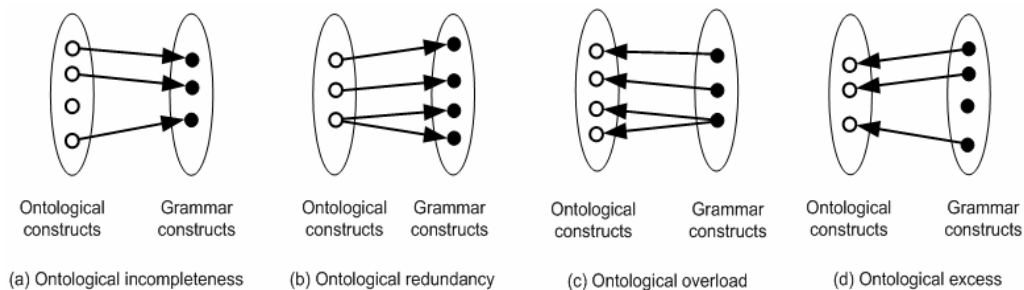
Things change. Changes to things are manifested as changes of properties, and therefore changes are modeled as changes of state. The behavior of a thing is its state evolution in time. A state transition is termed *events*. A change generated by the actions of another thing is termed an *external event*. A change due to a transformation inside the thing is termed an *internal event*. A state from which such a transition exists is called an *unstable state*. A state from which no internal transition exists is termed a *stable state*. A thing can change its state from a stable state only due to an external event. A thing *acts on* another thing if and only if the first thing affects the states that the second thing would traverse. Two things interact if one of them acts on the other. An interaction is a *binding mutual property*. A set of interacting things form a *system*.

**ONTOLOGICAL APPROACH FOR IS GRAMMARS ANALYSIS**

Ontological analysis of IS conceptual modeling grammar follows the notion of ontological expressiveness (Wand and Weber, 1993, Wand, 1996). Ontological expressiveness is based upon the view that an information system is a representation of the perceived real-world system. Therefore, a good modeling grammar must manifest the meaning of the real-world to be represented. Because ontology is traditionally studied as philosophical theory concerning the basic traits of the world (Bunge, 1974), a conceptual modeling grammar can be evaluated via matching between modeling constructs and ontological constructs. In this way, semantics of modeling grammar can be clarified and amplified.

Ontological expressiveness includes two types of mappings: a *representation mapping* from real-world concepts to the modeling constructs, and an *interpretation mapping* from a ‘script’ in the grammar, into ontological concepts (Wand and Weber, 1993). From these two mappings, four ontological deficiencies may be found in the grammar:

- *Ontological incompleteness* or *construct deficit* occurs when ontological constructs do not have equivalent constructs in the conceptual modeling grammar (Figure 2(a)).
- *Construct redundancy* is where several constructs from the conceptual-modeling grammar map onto a single ontological construct (Figure 2 (b)).
- *Construct overload* is where several ontological constructs are mapped onto a single construct in the grammar (Figure 2 (c)).
- *Construct excess* is where a grammatical construct might not map to any ontological construct (Figure 2 (d)).



**Figure 2: Ontological deficiencies of a conceptual model grammar**

Ontological analysis has been used to evaluate the notations and their semantics of various conceptual modeling grammars. Milton et al (2002, 2003/4) propose a framework based on Chisholm's ontology to evaluate and compare various data modeling languages including Entity-Relationship (ER) Model, Functional Data Model, Semantic Data Model, NIAM, and OMT's Object Model., Wand et al (2000) apply the BWW ontology in analyzing ER modeling constructs. Their analysis not only provides precise definitions of conceptual modeling constructs, but also derives rules for the use of relationships in ER conceptual modeling. Weber and Zhang (1996) examine and indicate the ontological deficiencies of Nijssen Information Analysis Method (NIAM) using the BWW ontology. Green and Rosemann (2000) use the BWW ontology to analyze the five views – process, data, function, organization and output – provided in the Architecture of Integrated Information Systems (ARIS). Their analysis indicates potential problems in representing all required business rules, specifying the scope and boundaries of the system, and employing a “top-down” approach to analysis and design. In addition, the BWW ontology is also applied to examining Data Flow Diagrams (Wand and Weber, 1989), Object-Oriented Modeling (Parsons and Wand, 1997, Takagaki and Wand, 1991, Evermann and Wand, 2001), and reference models in information systems development (Fettke and Loos, 2003).

Similarly, the semantics of MibML can be amplified and clarified by assessing its ontological expressiveness. As depicted in Figure 3, a MIBIS system can be regarded as a model of the real-world integrative business system. Accordingly, the MibML grammar should include necessary grammatical constructs to represent the ontological constructs that are used to describe the integrative business systems in the real-world domain. In this paper, we seek to identify principles that will ensure that ontological deficiencies are avoided in the grammar. This not only reduces semantic ambiguity of MibML, it also helps amplify the semantics of the MibML grammar.

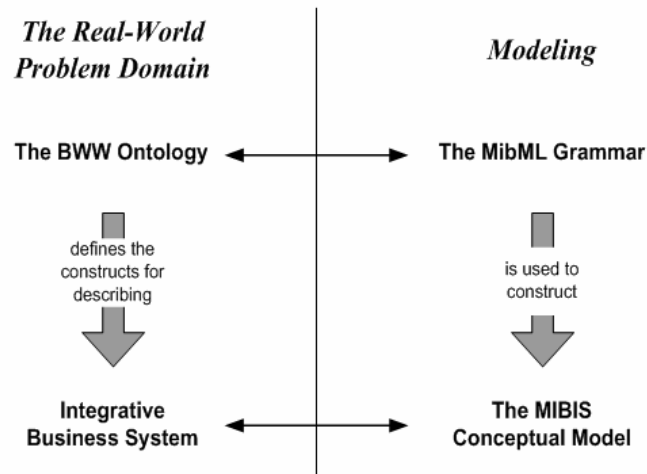


Figure 3: The relationship between the MIBIS modeling and the real-world problem domain.

## ONTOLOGICAL ANALYSIS OF MIBML

In this section, we interpret the MibML grammar in the context of the BWW model.

### Agent

A MibML agent is a problem-solving entity in MIBIS. It is a surrogate of a human actor in the real business organization. The primary focus of MIBIS conceptual modeling is to identify the relevant agents and their coordination mechanisms. Agents with closely working relationship can form an agent cluster, which coincides with its related work system in the business organization. An agent cluster may further include sub-level agent clusters, and a MIBIS system may be composed of several agent clusters. In this light, a MibML agent represents a BWW thing within the scope of the application. Correspondingly, both an agent cluster and a MIBIS system represent a BWW composite thing. From the system perspective, they represent a BWW-subsystem and a BWW-system respectively as well.

An external entity is an entity existing in the environment of the MIBIS system but communicating with the system to require or provide services. External entities are not the focus of MIBIS modeling, but they help specify the scope and the necessary functions of the desired MIBIS application. Because they are entities outside the system, external entities represent BWW things outside the scope of the MIBIS application.

## Role

The MibML role construct adopts the role concept in the real business organizations, in which a role is defined as a collection of rights and duties. Human actors who assume a role obtains the rights and responsibilities defined by the role. Similarly, a MibML role works as a template for the work agents will perform and goals they will achieve in certain circumstances. From the ontological perspective, a role defines common properties of a set of agents. Therefore, a MibML role represents a BWW class of things within the scope of the application. Correspondingly, the definition of a MibML role maps to a BWW functional schema. A role defines the attributes of agents. The values of attributes of an agent at a certain time point become a state of the agent.

Although MibML roles represent a type of BWW classes, there are differences between MibML roles and BWW classes. In MibML, roles precede agents in the sense that roles define agents and agents are instantiations of roles. In the BWW model, however, things precede classes because classes exist only as abstractions of things. As a consequence, the definition of roles imposes additional common attributes such as ID and description to make the roles easier to maintain and implement. However, these additional attributes do not represent properties of the BWW things.

## Goal

MibML goals are used to capture user requirements of the MIBIS application. A goal specifies the services the desired MIBIS application should provide. In MIBIS system development, an overall goal is first identified, and then it is decomposed iteratively into a goal tree. The leaf goals of the tree are then assigned to agents for accomplishment. Therefore, a leaf goal represents a kind of intrinsic property of an agent. Although the goal tree describes the composition relationships between different levels of goals, there is no counter part of the goal tree in the BWW model. In fact, the goal tree is a system-oriented concept which is included in MibML for the purpose of helping system developers specify user requirements and identify necessary agents more easily. Each MibML goal is associated with a goal status which indicates whether the goal is accomplished or not. Likewise, goal status is also an imposed attribute which does not represent any property of agent. It is included in MibML to ease the program development later on.

## Task

A task is an activity performed by an agent in order to achieve its goal. It represents an internal transformation of an agent in the context of the BWW model. A MibML task schema includes input, output, and method. An input is information or knowledge required for an agent to execute the task. An output is information or knowledge generated by the task. A method is a script describing how the task should be executed. Inputs, outputs and methods determine the pre-conditions, post-conditions, and procedures of a task. Therefore, they all represent BWW transformation laws<sup>1+</sup>.

A MibML task can be decomposed along the dimensions of subpart and subtype. A subpart of a task  $t$  is a component task of  $t$ , which reflects the composition relationship between tasks. A subtype of a task  $s$  is a specialization of the task  $s$ . From the ontological perspective, task decomposition is a type of constraints on task execution. For example, if task  $a_1$ ,  $a_2$ , and  $a_3$  are subparts of task  $a$ , then execution of task  $a$  requires task  $a_1$ ,  $a_2$ , and  $a_3$  all are executed. In this light, both the task subpart and the task subtype relationship represent BWW transformation laws.

A MibML task is triggered by an event. MibML differentiates external event, temporal event, and state event. An external event is generated by an action of external entities or other agents. A temporal event is generated by the passage of time. A state event is an event that occurs inside the agent and changes its state. The mapping between the MibML event and BWW constructs are straightforward. A MibML event corresponds to a BWW event. Both the external event and the temporal event in MibML represent the BWW external event. The MibML state event represents the BWW internal event.

## Interaction

An interaction is an activity occurring between two agents in order to coordinate goal dependencies, task dependencies, or resource dependencies. It is modeled as a coordinated sequence of speech acts. A speech act is an action performed by an agent that may affect another agent's future course of action. Therefore, a speech act represents a BWW event which is able to change a binding mutual property of an agent. Correspondingly, an interaction represents a group of coupled BWW events. In MibML, a message is sent to another agent with each speech act. Such message represents the BWW binding mutual property that is changed when an interaction takes place.

## Information

Information is data resources required for accomplishment of goals. It includes information entities and information flow. Information entities refer to static and stable stored data that are part of data stores. These data represent internal business objects (e.g., PRODUCT), external entities (e.g., CUSTOMER) and other materialized views of data. The schema of information entities includes the structure of tables, the relationships, entity integrity constraints, referential integrity constraints, cardinality constraints, etc. Information entities may be implemented using relational databases and the schema corresponds to items typically stored in database repositories. In this light, information entity is a complex construct which does not have explicit counterpart in the BWW model. Information entities can represent BWW things, properties and state laws.

Information flows are dynamic and temporary data that is in transit. They are data moving between external entities and agents, between information entities and agents, or between two agents. Information flows are different from information entities in their time orientation. Information flows are temporary and cease to exist once they are acted upon by an agent or stored in a data store or provided to an entity external to the MIBIS system. In this light, information flows represent binding mutual properties of BWW things.

In MibML, an agent needs to have privileges in order to access information. These privileges are constraints on agents to determine their ways to manipulate information. Therefore, agent privileges represent BWW transformation laws.

## Knowledge

Knowledge is a MibML construct that describes an agent's beliefs on its environment and constraints that govern the agent's behaviors. It includes facts, deduction rules, activity execution structure, and activity execution constraints. Facts are descriptive knowledge that an agent keeps about other agents and about the environment it resides in. Deduction rules are used by agents to form new facts from existing facts. The activity execution structure determines the order of performing tasks inside an agent. The activity execution constrain is used to coordinate activities between agents. It defines the necessary events to trigger the tasks. Therefore, knowledge represents a complex property of agents. Fact, as a component of the knowledge construct, represents an intrinsic property. Deduction rules, activity execution structure, and activity execution constraint are constraints on agent tasks and interactions, and thus, represent transformation laws in the context of the BWW model.

In summary, we present mapping between the BWW model and the MibML constructs in Table 1.

The BWW Construct	MibML Representation
Thing	Agent, External entity, Information entity
Composite thing	Agent cluster, MIBIS system
Property	Leaf goal, Fact, Information flow, Message,
Complex property	Knowledge
Intrinsic property	Leaf goal, Fact
Mutual property	Information flow, Message, information entity
Class	Role, Information entity type
Functional schema	Definitions of role, definitions of information entity type
State	No explicit MibML representation. Represented by the values of goal, knowledge, message, information flow, task input, and task output at some point in time.
State law	Not represented for agents
Event	Event, Speech act
Event space	Not represented
Lawful event space	Not represented
External event	External event, Temporal event
Internal event	State event
Transformation	Task
Transformation law	Deduction rule, Execution structure, Execution constraint, Task method, Task input, Task output, agent privilege
Act on another thing / coupling	Interaction
System	MIBIS system
System composition	A MIBIS system is composed of agent clusters and agents. An agent cluster is further composed of sub-level agent clusters and agents.
System environment	A set of external entities.
System structure	Represented by roles and interactions among roles
Subsystem	Agent cluster

**Table 1: Mapping between the BWW- and the MibML- constructs**

**PROPOSED ONTOLOGICAL SEMANTICS OF MIBML**

The primary focus of the BWW model is things. MibML includes three constructs – agent, external entities, and information entities - to represent the things in the MIBIS universe. While agent and external entity have unambiguous ontological semantics, the semantics of information entity is not clear. On the one hand, information entity suffers construct overload. It represents not only BWW things, but also mutual properties and state laws of things. On the other hand, as a representation of BWW things, information entity has construct redundancy with external entities. Construct overload and construct redundancy of information entity may result in confusion of developers whether a business domain phenomenon should be modeled as an external entity, as an information entity, or as a property. Furthermore, same business domain phenomenon to be modeled under different constructs may cause model consistency problem. Therefore, we want to confine the semantics of information entity and make the following proposal.

*Proposal 1.* Information entities are only used to represent passive business objects (e.g., product, account, etc) that are within the scope of the MIBIS application and are used by agents to support their activities.

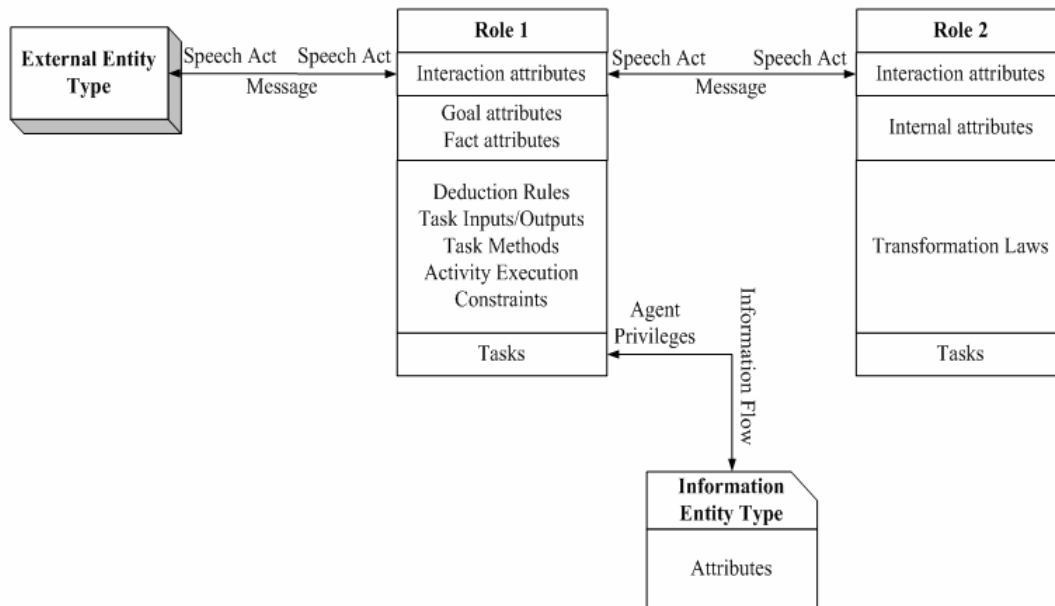
The existence of information flow between two agents indicates that there are interactions between them. Therefore, there is overlap between information flow and interaction message. In addition, the constructs of interaction speech act and external event have similar overlap. In order to avoid construct redundancy, we make the following proposals.

*Proposal 2.* Information flows represent data exchanges between agents and information entities, whereas interaction messages are data exchanges between agents.

*Proposal 3.* A speech act is an event that triggers an interaction, whereas an external event is an event that triggers a task.

In MibML, internal tasks of agents are managed by activity execution structure and tasks between agents are coordinated by activity execution constraints through external events. In BWW, all internal transformations are triggered by events. Therefore, there is no need to differentiate between activity execution structure and activity execution constraints as long as each task is associated with a triggering event.

*Proposal 4.* A task is triggered by an event. The activity execution structure associates tasks to state events, whereas the activity execution constraints associate tasks to external events and temporal events.



**Figure 4: Ontological semantics of MibML**



Figure 4 presents a model to describe our proposed semantics for MibML constructs. Agents, represented as role schema in the figure, is defined in four parts in the MIBIS concept model: interaction attributes, internal attributes, transformation laws, and tasks. Interaction attributes are used to model interactions between two agents or between agents and external entities. The values of interaction attributes of an agent are able to be modified by another agent through speech act and message, and such modification results in the state change of the first agent. Such state change of the agent may be ignored, trigger a response, or trigger a task. Internal attributes include goal attributes and fact attributes. The value of internal attributes can only be changed by tasks. For example, tasks may generate new facts. Tasks may need information for execution and it is represented as information flow between tasks and information entities. Each information flow is associated with an agent privileges to determine how the task can manipulate data. Execution of tasks is constrained by transformation laws. For example, a task must be trigger by an event defined in activity execution constraints and it must have necessary information inputs.

### CONCLUSIONS AND FUTURE WORK

MibML is a conceptual-modeling grammar for multiagent-based integrative business information systems. The goal of this paper is to amplify and clarify ontological semantics of the MibML constructs through ontological analysis. In this paper, we have carefully examined the MibML constructs and discussed their ontological semantics in the context of the Bunge-Wand-Webber ontology. While most MibML constructs have clear ontological semantics, our analysis does indicate existence of some construct redundancies in the MibML grammar. In order to overcome such redundancies, we have also made several proposals to clarify ontological semantics of the MibML constructs.

While we feel this first ontological analysis of MibML is encouraging, we recognize that this is an initial effort. Our future works include: 1) to provide formal definitions of ontological semantics of the MibML constructs; 2) to identify MibML modeling rules from the ontological perspective; 3) to provide a step-by-step guideline for MIBIS conceptual modeling (e.g. how to identify the scope of the model, how to identify relevant MIBIS entities, etc); and 4) to develop a CASE tool to enforce the MibML model consistency based on ontological rules.

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