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An Activity-based Carpooling Microsimulation using Ontology

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Abstract

This study aims to show an ability of Ontology, which is a formal explicit description of concepts in a domain of interest, in an activity-based microsimulation. Thus, an agent-based carpooling application using ontology techniques is presented as a case study with a focus on three functions of the Ontology. First, Ontology facilitates integrating between heterogeneous databases by defining the relationship between their concepts. Second, Ontology verifies the compatibility and consistency between the different angles to combine varied models in a common structure by providing shared knowledge between different domains modelling with the definition of objects and concepts. Lastly, Ontology is useful for modelling agent communication by means of making explicit the parsed message between agents with the shared knowledge. This paper introduces related studies and basic knowledge about using methodologies, and supports an example of using Ontology in an agent-based carpooling simulation.

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1. Introduction

Since its emergence, the activity-based approach has been popular and widely applied for both research and the evaluation of traffic policy and infrastructure by forecasting changes in a traffic demand in reaction to introducing such a new traffic system. In comparison with a classic approach, the activity-based approach predicts a traffic demand by analyzing individual trip patterns derived from human behaviors, rather than aggregated trip patterns in a zone resulting from global factors, such as land use and population. In this sense, an activity-based microsimulation study has been often conducted by means of

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an agent-based model which is a new approach to modeling systems consisting of autonomous, interacting agents. The activity-based microsimulation using an agent-based model allows researchers to simulate not only each individual behavior of agents but also their interactions. Therefore, the agent-based model is useful to study intricate transportation phenomena arising from interaction between multiple agents.

Despite their usefulness in an activity-based approach, there also exist some difficulties in using the agent-based model. First, data handling is difficult in a simulation research because several types of data are generally required as input, and data pre-processing work is also involved in the process of the research. Second, researchers occasionally experience difficulties in building agents' behavioural rules due to the fact that the activity-based approach typically accounts for non-deterministic and strongly context-dependent human behaviours [16]. At last, agent interactions are difficult to be designed because knowledge from various domains tends to represent an ad-hoc manner according to a subjective point of view [3].

This study proposes Ontology as a solution to those difficulties in applying the agent-based model for the activity-based microsimulation research. This paper introduces related research, and briefly describes basic information about using methodologies in this study, and also provides a case study of using ontology techniques in an agent-based carpooling simulation in order to verify the capacity of Ontology in the activity-based microsimulation research. However, note that details of the carpooling application and a practical experiment using real data are not presented in this paper.

2. Related Research

This section introduces related studies that have been conducted using Ontology. In fact, there has been a lot of research using ontology techniques in various disciplines, but this paper only covers that in transportation. Most of transportation research on ontology application are associated with ITS (intelligent transportation system), but few ones apply an ontology for different topics with ITS, for example transportation data mining research and traffic demand forecasting model.

In detail, [9] tried to build an ontology-based spatial context model for a car park system in order to support information sharing between individual systems and higher-level information reasoning. [12] presented an integrated multi-agent system with an ontology application in a transport domain to provide convenient design and control methods. [17] designed an integrated traffic modeling with a simulation system using a domain *Ontology* model for improving extensibility and visualization of the system. [8] presents public transportation domain ontology to provide passengers with the base travel planning using Protégé software. Regarding data mining, [10] described a survey on standardization efforts for geographic information, GDF (geographic data files) standard and OTN (ontology for transportation systems) with a description of an OWL (web ontology language) -based ontology. [2] developed a prediction system for projecting potential hotspots of taxi requests to support taxi drivers with information about the demand distribution using an ontology and data mining skills. As for the last and most relevant research to this study, [1] presented an ontology for multi-modal transportation planning and scheduling by extending an existing scheduling ontology to define the representation framework and ontological basis for modeling and solution to the multi-modal transportation planning and scheduling. [5] proposed a decision support system generator for transportation demand forecasting, implemented by constraint logic programming (CLP).

To sum up, most of the related research in transportation account for how to deal with transportation information using Ontology with a focus on either information service or data analysis. On the other hand, few research efforts aim at studying transportation modeling for predicting demand using Ontology. However, they employed a classic traffic prediction model, which is normally called a four-step model, while this study makes us of the activity-based approach.

3. Basic Knowledge

3.1. Activity-based Approach

Since [13] studied the relationship between travel and activity. At first, the activity-based approach has been playing a major role as a new paradigm shifted from a classic approach in traffic demand forecasting model. The activity-based approach enables to do either a short- or long-term forecasting of traffic demand by analyzing the long-term or short-term effects on a travel behavior. Furthermore, one can simulate how to build individual activity-schedules based on personal constraints, such as time, space and budget, how to evolve the schedule according to his/her experience, and how to supplement the schedule by interpersonal interaction.

3.2. Agent-based Model

As further increasing a complexity in our societies, the agent-based model has been received a more attention with an ability of simulating non-deterministic agent behavior resulted by learning and adaptation, and also the emergence of agent interactions having a heterogeneous feature. Developing the agent-based model typically follows three steps [11]: i) identifying agents, ii) specifying their behaviors, iii) representing agent interactions. In the first step, one starts to identify the agent types (or classes) according to their attributes. Then, agent behaviors are specified using a behavioral theory or modeling that defines how an agent act or re-act. BDI (belief-desire-intent) is one of the most popular behavioral modeling frameworks [15]. Once the agent behaviors are specified, agent interactions are designed. Therefore, when developing the agent-based model, input data for identifying agents, a behavioral theory or model and agent interaction method are really important and carefully considered in the research.

3.3. Ontology

The definition of ontology, which is the most cited, is the definition of [6]; "Ontology is a specification of a conceptualization. According to [7], Ontology categorizes knowledge in a specific domain. Although in information science Ontology used for understanding entities of specific world, the purpose of Ontology is to categorize concepts regarding specific domains as well as restrictions and axioms of those. In this study, ontology restricts it as Ontology in information science.

The *Ontology* consists of four components; classes, attributes instances and relations. First, classes describe things (objects) in the domain. Attributes and instances indicate properties of classes and instances and basic objects, respectively. Relations present ways how to connect to one another. To design an *Ontology*, "*Development 101*" [14] is applied as a methodology, which is rather explicit and appropriated for an agent-based model like the carpooling case in this study.

When developing Ontology, the following steps give a helpful guideline. First of all, one needs to consider a scope and domain based on a goal, type and user before developing Ontology. Once determining the scope and domain, existing ontologies need to be checked in a domain of interest, in particular when the system will interact with others. Next, making a list of keywords of interest is useful to make statements about and to account for. The following two steps are the most important ones in the ontology-design process; one is to define the class hierarchy, and the other is to define properties of classes. After that, one has to describe the internal structure of the class defined in the previous step by defining their properties. The last step is to generate individual instances of classes in the hierarchy by selecting a class, creating an instance and filling in the value of the instance.

4. Agent-based Carpooling Simulation

In this section, we are going to supply an agent-based carpooling simulation as a case study to account for the capability of the *Ontology* in an activity-based microsimulation. Therefore, this section explains input data and the carpooling simulation framework, and the *Ontology* design process.

4.1. Input Data and Framework

As input, individual activity-travel schedules in Flanders in Belgium are applied for the agent-based carpooling simulation. The schedule data are generated by FEATHERS, which is a traffic demand forecasting modeling framework developed by IMOB (transportation research institute) in Belgium. The data structure is made up of both activity and travel information about when, how and what people do, as well as general information about socio-economic features. Moreover, network and location information are used as environment data in the study.

The agent-based carpooling simulation framework consists of several modules. In detail, the whole procedure in the simulation framework is as follows:

1) run FEATHERS using population and environment data to generate schedule data;
2) generate *AgentProfile* using population data (and also *feedback* and *SocNet* (social network data) after the first iteration);
3) build *SocNet* with *PFS* (profile similarity) using *AgentProfile* and *PTS* (path similarity) using schedule data;
4) run agent-based model to simulate how agents negotiate with others and execute carpool;
5) update schedule based on the result of negotiation, using *ReScheduler*, and *AgentProfile* (and also *SocNet*) according to feedback resulted from the simulation;
6) and repeat from 4) to 5) until terminated.

4.2. Ontology development process

This section presents the process of an ontology design for the agent-based carpooling simulation through three steps of agent-based model development as introduced above: i) build agents, ii) design behavioral rule, and iii) determine agent interactions, with some examples.

In the agent building step, we identify agent types (or classes) based on agent attributes relative to the carpooling simulation. As mentioned in the previous section, before building ontology we have to do few things; first determining the domain and scope of the ontology and then checking existing ontologies and considering reusing it. In this study, carpooling is the contextual domain for the carpooling simulation, and Flanders in Belgium and a 24-hour period[†] is considered as the spatial domain and temporal domain, respectively. Then, we decided not to reuse existing ontology because indeed there are no existing carpooling ontologies customized to the study area, but we consider the extendibility of this carpooling ontology to integrate with an agent-based carpooling application and other projects that we are currently working on.

Next, we make a list of carpooling terminologies, and then defined the classes and their hierarchy. We only choose relatively general terminologies because of a limited space. As can be seen in table 1, the terminologies are divided into three parts; resource, negotiation and feedback.

Table 1. Classes and properties in the carpooling domain

[†] This is because using schedule data represents travels and activities in a 24-hour period and also this study only consider daily carpooling events (i.e. commuting), not non-daily one (i.e. hitch-hiking)

High class	Middle class	Low class	Property
Resource	Participant	Driver	Driver license (yes, no)
		Passenger	
		Profile	Age (integer) Gender (male, female), Income category (euro) Job (type)
	Vehicle	Private mode	Automobile, Van, Rent car
		Public mode	Bus, Taxi
		Vacancy	Number of seats (integer)
	Location	Origin, Destination	Zone ID
	Time	Departure, Arrival Waiting time	(hour: minute)
Negotiation	Cost	Fuel price, Tolls Parking fee	Price (euro)
	Time	(same as resource)	(hour: minute)
	Location	(same as resource)	Name (text), Zone ID (text)
	Capacity	(same vehicle)	Number of seats (integer)
	Preference	Profile	Smoking, Music, Food and drink
Feedback	Reputation	Loyalty, Safety Punctuality	(Good, Normal, Bad)

In addition, it also presents a hierarchical structure that each part has several terminologies in the two lower levels and also some terminologies are duplicative in different categories. This is because the terminologies have a relationship with others (i.e. inheritance), that is, a taxonomical hierarchy in the domain. In general it is important to recognize recurring patterns during the knowledge elicitation phase.

Once the classes and the hierarchy are built, then the properties of each class are defined to describe the internal structure of the classes. In general, there are three types of properties; categorical and continuous and nominal class. In fig 1, an ontological diagram in UML is represented for the carpooling simulation model, which is composed of three (high-level) classes; resource, negotiation and feedback. As can be seen, time and location (middle-level) classes are linked to both resource and negotiation class. The participant as a subclass of the resource class indicates agent in the agent-based model.

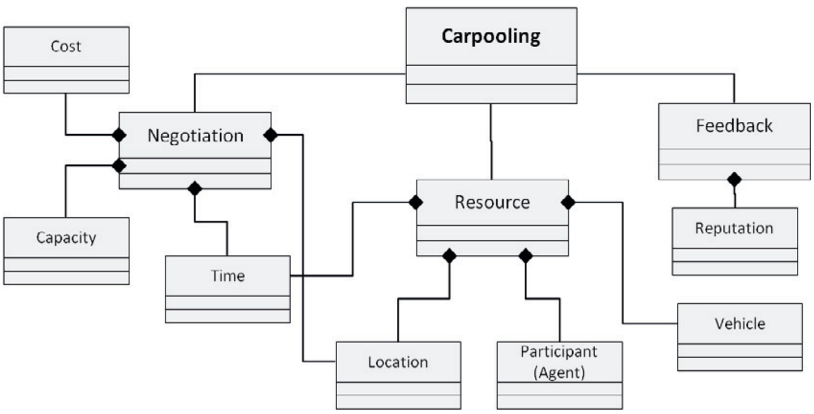

Fig. 1. A simple UML ontology of the carpooling model

The last step for building the carpooling ontology is to create individual instances of classes in the hierarchy. As mentioned above, creating an individual instance of a class has to be followed by three steps; selecting a class, creating instance of the given classes and then filling in the properties.

In the next step, agent behaviors are designed using a behavioral modeling that captures structural and behavioral concepts, using ADL (architecture description languages) ontology based on BDI (belief-desire-intention), which is one of the most popular behavioral modeling frameworks [15]. The conceptualization of the internal model proposed by [4] is applied for designing agent behaviors. Fig 2 illustrates the concept of ADL Ontology required to model agent behavior. In the carpooling model, the agent behavior is depicted by participating to *negotiation.* Negotiation is produced by *travel* that changes *beliefs* and *goal* based on domain *knowledge*; and triggers *carpool* if negotiation is successful. *Carpool* executes serial travels by the agents who try to reach a goal.

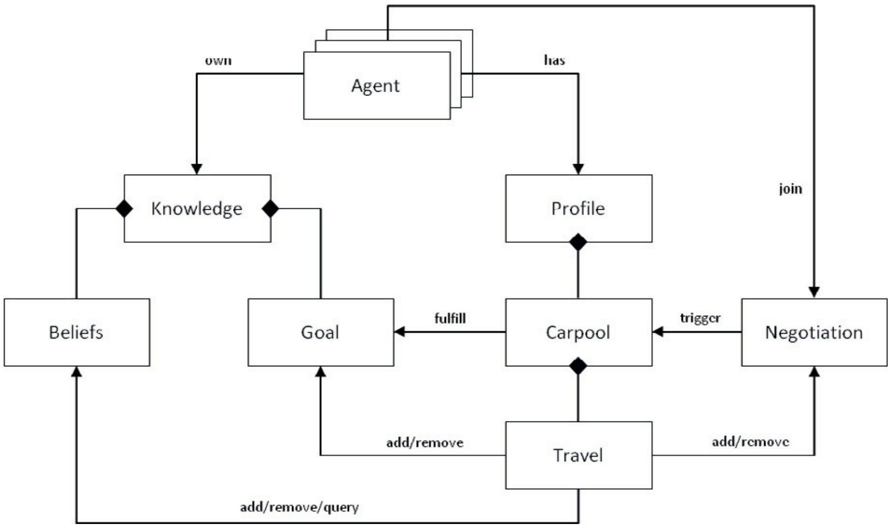

Fig. 2. Concept of agent behavior using ADL ontology

Once the agent behaviors are specified, agent interactions are designed. Fig 3 shows the comparison between a normal agent communication using ACL (agent communication language) (left hand) and an ontology-based communication using ontology (right hand). The difference between those communication tools is dependent on a way of how to deal with unambiguous message either between heterogeneous agents or in a different context. While in the normal agent communication such vague message is disposed, it is clarified on a further conceptual level by Ontology in the ontology-based communication. Therefore, a simulation research using Ontology enables to simulate relatively complicated interaction between heterogeneous agents or under various contexts.

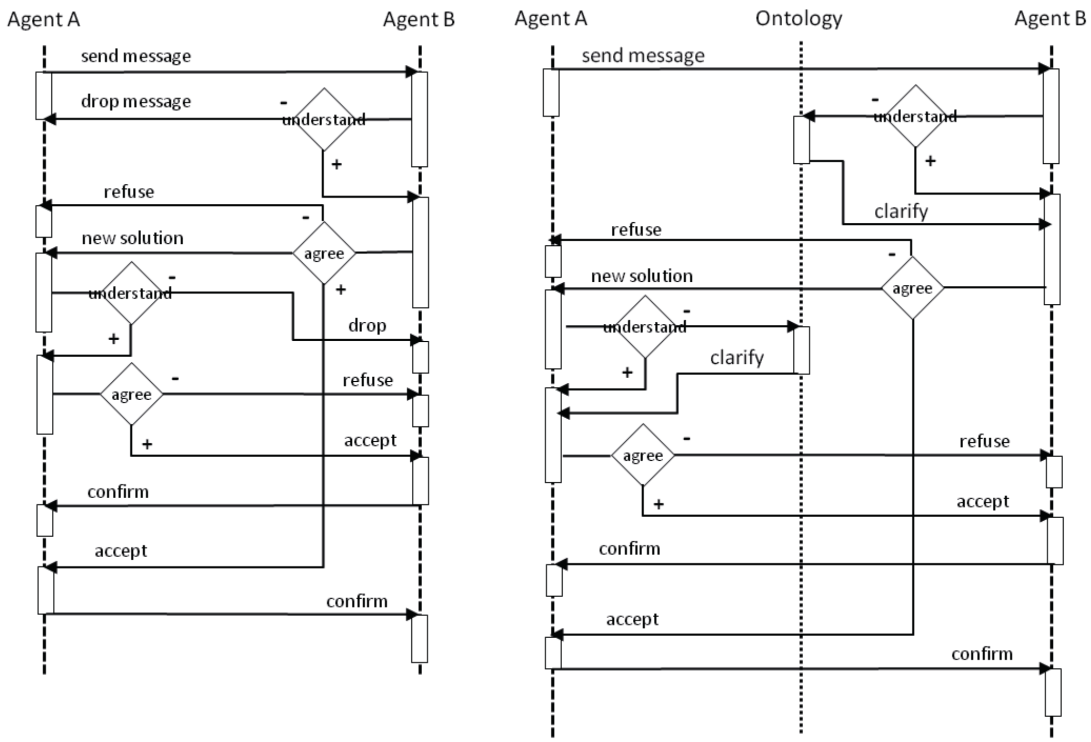

Fig. 3. Agent communication method: normal agent communication using ACL (left) and ontology-based communication using Ontology (right)

5. Conclusion

This study shows the advantage of using Ontology in an activity-based microsimulation by providing a carpooling case. While no explicit evidence is presented in this paper, at least we can recognize Ontology is a useful and appropriate method for the activity-based microsimulation research. However, only conceptual design and framework are suggested, and this study is on a clearly preliminary step, so that there are a lot of challenges and future work in the *Ontology* research. As a future study, we are going to apply an *ontology* technique for the agent-based carpooling application by integrating with the agent-based model framework and also making shared knowledge based on the conceptual definition and the structural relationship between agents of interest.

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