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Simulation Model of Carpooling with the Janus Multiagent Platform

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Abstract

Carpooling is an emerging alternative transportation mode that is eco-friendly and sustainable as it enables commuters to save time, travel resource, reduce emission and traffic congestion. The procedure of carpooling consists of a number of steps namely; (i) create a motive to carpool, (ii) communicate this motive with other agents, (iii) negotiate a plan with the interested agents, (iv) execute the agreed plans, and (v) provide a feedback to all concerned agents. The state-of-the-art research work on agent-based modeling is limited to a number of technical and empirical studies that are unable to handle the complex agent behavior in terms of coordination, communication and negotiations. In this paper, we present a conceptual design of an agent-based model (ABM) for the carpooling a that serves as a proof of concept. Our model for the carpooling application is a computational model that is used for simulating the interactions of autonomous agents and to analyze the effects of change in factors related to the infrastructure, behavior and cost. In our carpooling application, we use agent profiles and social networks to initiate our agent communication model and then employ a route matching algorithm, and a utility function to trigger the negotiation process between agents. We plan to, as a part of the future work, develop a prototype of our agent-based carpooling application based on the work presented in this paper. Furthermore, we also intend to carry out a validation study of our results with real data.

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1. Introduction

Nowadays, carpooling is emerging transportation mode that is eco-friendly and sustainable as it enables commuters not only saves the travel cost, such as fuel, toll and parking costs, of the carpooling participants but also reduces emissions and traffic congestions. Carpooling, known as ride-sharing, is the sharing of

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a car between people (agents) from a certain origin to a specific destination. Thus, in order to study the carpooling concept, we should take into account the interactions of two or more agents throughout the carpooling process. The procedure of carpooling consists of a number of steps namely (i) create a motive to carpool, (ii) communicate this motive with other agents, (iii) negotiate a plan with the interested agents, (iv) execute the agreed plans, and (v) provide a feedback to all concerned agents. Creating a motive means that a traveler (agent) may choose to carpool because of the availability of travel resources, time, monetary and route cost constraints.

Moreover, change in some socio-economic factors such as the increase in fuel price or establishment of a new traffic policy, may trigger the initiative to carpool. Once the decision has been made to carpool, the traveler (agent) will try to find one or more potential partners (agents). The carpool initiating agent will send a request to other interested agents in its vicinity. If one or more agents who receive this request are willing to carpool, then they begin the negotiation phase. In this phase, these agents will negotiate about sharing their travel resources and optimizing total costs and daily schedules. After reaching a compromise, these agents can carpool. Meanwhile, an agent can appraise its partners according to their degrees of faithfulness to the carpooling. We call this degree of faithfulness the agent reputation. This reputation factor can serve as a criterion for the selection of a potential partner for carpooling. An agent-based model (ABM) is a class of computational models for simulating the actions and interactions of autonomous agents with a view to assessing their effects on the systems as a whole [1]. ABM is now widely used for modeling increasingly complex systems [2]. Application of ABM is not only limited to the computer science domain. Currently, many research areas such as transportation behavior modeling, need to analyze and model the complex phenomenon of interactions between different entities. While traditional modeling tools cannot catch the complexity, ABM is able to do it through modeling the interaction of autonomous agents and deducing the rules for such a system. We, therefore, in this paper propose an agent-based interaction model for the carpooling application.

This paper briefly describes a conceptual design of the carpooling application, initially proposed by [3, 4] and using an agent-based model on the Janus platform. A simulation model needs to be created to support the individual behaviors of the participants. The contribution of this paper is the design and the implementation of an agent-based model upon the Janus multiagent platform. This platform permits to individuals to (i) select the best transport mode according to their characteristics; (ii) maintain a social network; (iii) negotiate for carpooling; (iv) carpool the driver and the passengers of a car.

In the rest of this paper, we present some related work on the carpooling concept and ABM in section 2. In section 3, we explain our ABM for the carpooling application with details about the activities and the roles of the agents, and of the environment. We discuss in section 4 several implementation notes. Section 5 is dedicated to our concluding thoughts and ideas for future work.

2. Background

Related research on the carpooling concept is largely separated into two parts: (i) a technical study, and (ii) an empirical study. The first one focuses on the development of carpooling support systems with techniques of travel route matching [5, 6]. In the second part, the overall trend of carpooling — or of interrelationship between willingness-to-carpool and the socio-economic attributes of the carpooling participants — is treated in general [7, 8]. The studies mentioned previously are limited and do not consider the potential agent (participants) interaction to perform carpooling.

Most transportation-related applications of ABM are related to vehicle routing, pedestrian-flow simulation or demand modeling efforts [9]. Among these applications two of the more widely known are TRANSIMS and MATSIM ABM simulation platforms. TRANSIMS, developed by Los Alamos Lab, is designed to supply transportation planners with more delicate information about traffic impacts, energy consumption, land-use planning and emergency evacuation [10]. MATSIM is also a large-scale agent-based simulator similar to TRANSIMS, but it is different using XML and quickly run simulation, due to a simplified traffic simulator [11]. Those applications only consider the whole effect of each agent's action in a system and cannot handle a detailed agent-to-agent or agent-to-environment coordination, communication and negotiation.

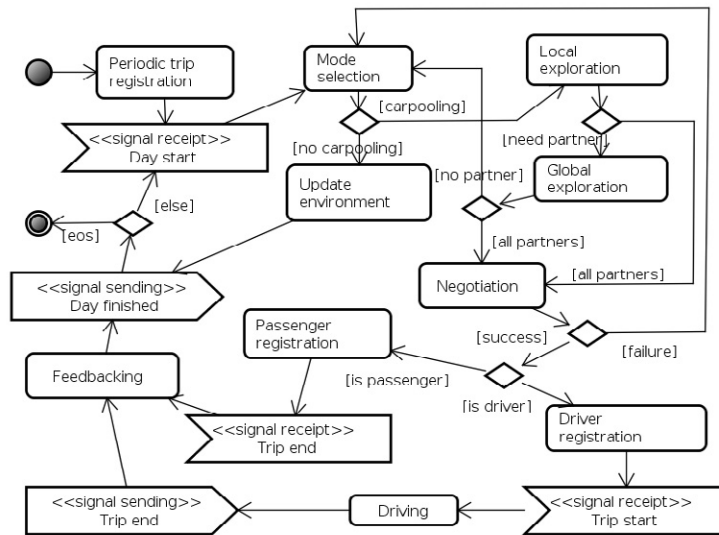


Figure 1. Diagram of the activities of a carpooling agent

According to James Odell [12], “the environment provides the conditions under which an entity (agent or object) exists.” The author distinguishes between the *physical environment* and the *communication environment*. The physical environment provides the laws, rules, constraints and policies that govern and support the physical existence of agents and entities. The communication environment provides (i) the principles and processes that govern and support exchanges of ideas, knowledge and information, and (ii) the functions and structures that are commonly deployed to exchange communication, such as roles, groups and interactions protocols between roles and groups. James Odell [12] defines an agent’s social environment as “a communication environment in which the agents interact in a coordinated manner.” This approach is shared by Ferber *et al.* [13], Cossentino *et al.* [14], and Galland *et al.* [15] who proposed to integrate the environment with organizational models. The Janus platform [16, 17] provides an efficient implementation of agent-based and organizational concepts based on the Capacity-Role-Interaction-Organization metamodel [14]. In the rest of this paper, the graphical notation is inspired from [14].

3. Carpooling Model

An agent is defined as someone who lives in our study area and executes his or her own daily schedule in order to satisfy his or her needs. A schedule is a combination of a number of trips associated with a number of activities. There are two categories of agents. An agent could either belong to one or both categories. The first category is a member of household such as the husband, the wife, the parents or the children. The second one is a member of the society such as a friend, a colleague, a neighbor, an employee (or an employer) or a student. In our model, we consider the socio-economic attributes, including age, gender, income, education, relationship (within a family), job, vehicle and driving license ownership, as a set of input data. These schedules and attributes are supplied by FEATHERS [18], an activity-based traffic demand model, which is developed by the IMOB Institute. The environment is established as the spatio-temporal aggregate where an agent lives and executes its own daily schedule.

Agents follow a number of steps, including (i) goal setting, (ii) scheduling based on a given resource and environment, and (iii) execution of their schedule. Figure 3 describes the activities of an agent during the simulation. The following sections detail the global behavior of the agent and its activities.

The behavior of each agent is described by an activity diagram illustrated by Figure 3. First people post information about each trip they periodically plan to execute in the “Periodic trip registration:” those

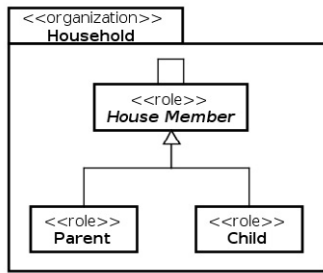


Figure 2. Household

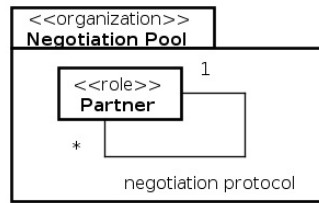


Figure 3. Negotiation Pool

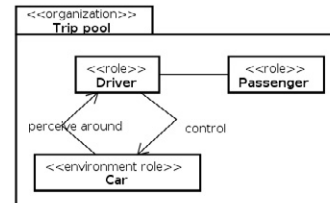


Figure 4. Trip Pool

data consist of source and destination locations, earliest and latest departure and arrival times, the maximal detour distance that is acceptable and the availability of a car (possibility to drive). Note a particular driver license owner can be unavailable for driving on a specific day of the week because the family car on that day is in use by her/his partner. Each day, a person has the following activities:

1. “Mode selection:” the agent is selecting its preferred transport mode. Here, the FEATHERS data are used to determine the mode choice stochastically. If the agent decides to carpool, he goes in step 2, otherwise he runs its activity in step 6.
2. “Matching” is applied in both *local* and *global* exploration phases. In both cases, matching precedes the negotiation phase where final decisions to carpool are taken. A person looks for other individuals to cooperate while executing its periodic trip (*periodicTripEx*): this is called *exploration*. *Local* exploration within the private social network (*PrivNet*) is applied before the *global* exploration. *PrivNet* is represented by an organization (Figure 2) in which each agent is playing a role, and has relationship with the other members of the organization. If *carpool candidates* can be found within an agent’s *PrivNet*, they will be contacted first (as preferred candidates). *Global* exploration is applied only in a second stage when no suitable *pool* was found in *PrivNet*. In the *Global* exploration phase, the *matcher* provides advice about which *pools* an individual should negotiate with. This corresponds to the use of an online service by to explore the set of formerly unknown carpooling candidates. Two people may carpool together if there $CP = \{L, SR, I, R\}$ are matching. Location (*L*) is matching the start location of the agents. Spatial Relevance (*SR*) is the match between the paths from the origin to the destination of all interacting agents. Interests (*I*) and Requirements (*R*) are matching the interests and the requirements of each agent in their profiles, respectively.
3. “Negotiation” is the process during which the members of a *pool* are negotiating the details of their *periodicTripExs* (time window, who is the driver and the passengers...) If the negotiation fails, the agent goes back to the step 1; otherwise to the step 4. The negotiation is based on a specific protocol. According to our organizational approach, an agent, who is negotiating, is a member of the same organization “Negotiation Pool” (Figure 3). The negotiation protocol is described as a sequence of messages exchanged by the different participants, as illustrated by Figure 5. This negotiation protocol is relaunched with different proposed time windows until all the participants were found.
4. “Driving” activity corresponds to the execution of the trip. The driver controls its car (with the car-pooled passengers inside) on the roads. The road network is represented by a graph built from geographic data. The Janus platform provides an environment model able to support the displacements of the cars on the roads [15]. Figure 4 presents the organization that is supporting the trip simulation. All the agents in a trip pool must play a role in an instance of this organization. The behavior of the Driver role is composed of two layers: (i) the path planning on the roads; and (ii) the path following and collision avoidance. The path planning is dynamic: the driver adapts its path according to its perceptions from the environment jams, roadworks...) with a variant of the D* algorithm [19]. The

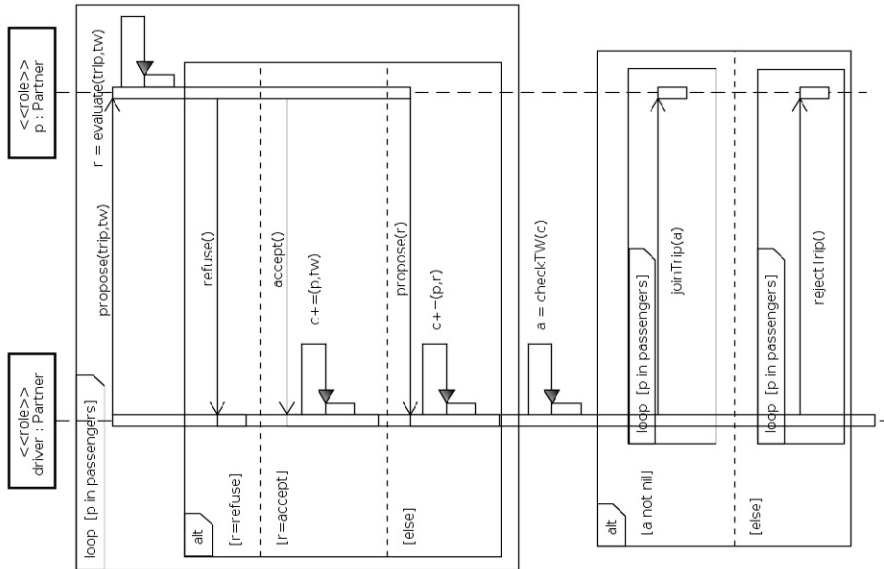


Figure 5. Sequence Diagram of the Negotiation Protocol

D* algorithm has two advantages: it enables path recomputation during the simulation according to a new state of the environment; and it is suitable for a partial knowledge of the environment's state. After the driving agent has updated its path, he follows it, and he avoids collisions with the other cars around. A standard Intelligent Driver Model is used to adapt the velocity of the car according to the ahead vehicles and to the road signs: the traffic lights and stop signs are assimilated to immobile vehicles until the driver decided to pass through. The other road signs are used to update the variables of the driving model (cruise velocity...). After the *pool*'s vehicle has reached its goal, all the agents of the *pool* execute the activity at step 5.

5. "Feedbacks" are computed at the end of the day according to the activities of the day, and given to the carpoolers. This activity is the last of the day for a carpooling agent.
6. "Environment Updating" is the optional activity that permits to a non-carpooling agent to register its mobility behavior in the environment in order to influence the driving simulation of the carpooler agents. Individual vehicles may be generated in the microscopic simulation model used in step 4. This activity is the last of the day for a non-carpooling agent.

If an individual joins a *pool*, (s)he is added to the *PrivNet* for all other participants in the *pool* (if still required) so that if i_0 and i_1 cooperate in a *pool*, (i_0, i_1) and (i_1, i_0) belong to each others private networks. Because links never are removed from the *PrivNet*, if i_0 and i_1 ever carpooled, $(i_1) \in PrivNet(i_0, 1) \wedge (i_0) \in PrivNet(i_1, 1)$. Candidates register, join and leave *pools* at random moments in time. As a consequence the main data structures dynamically change due to events external to the matching process.

4. Implementation Discussion

Figure 6 gives the average computational times for the simulation of one day (10 hours) on an Intel Core i7 CPU 960 at 3.20GHz, four cores, with Windows Seven (64 bits). The bench is done on a population of 10,000 entities, where approximately 20% are carpooling. The average number of people per pool is of 3 with standard deviation of 1. Because the Janus environment model is based on the Influence-Reaction model, which permits to handle and solve the conflicts among simultaneous actions, the scheduling of the

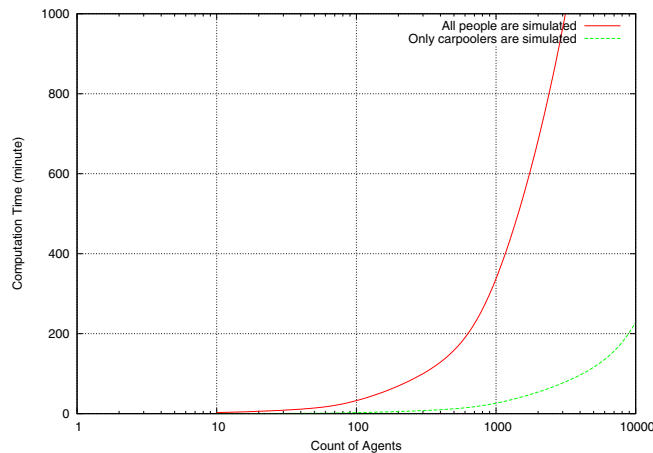


Figure 6. Average Computation Time for a Day

agents is a standard loop (each loop represents two seconds of the day). This approach does not cause a causality problem among the agent actions during the simulation. For the first curve, the people who do not want to carpool are also simulated during the trip execution. For the second curve, only the carpoolers are simulated.

Our simulator may be improved on several points: (i) the quality of the simulation's results; and (ii) the global performance of the simulator. The algorithms deployed in our model are the simplest ones. For example, we may replace the current negotiation protocol by a more complex one in which a complete and sophisticated negotiation between the partners may occur. The global exploration is skipped in this study. The microscopic simulation of the vehicles may be replaced by a mesoscopic or macroscopic simulation model to improve the performances of this module. In the case of a microscopic simulation, the agent scheduler used on the Janus platform may be replaced by an asynchronous scheduler (based on operating-system threads). This solution enables to run groups of agents in parallel in place of the current sequential approach. The current implementation is a proof-of-concept. All the algorithms must be tuned and redesigned to improve their performances.

Despite their drawbacks, our model and its implementation reproduces the behavior of a population in a carpooling problem. The microscopic simulation permits to reproduce the trip execution with high level of details (traffic jams...)

5. Conclusion

In comparison to the state-of-the-art research work, the work/study presented in this paper has a number of advantages. Some of these advantages include (i) the ability to analyze various effects of agent interaction with a detailed view on both communication and negotiation aspects, (ii) the ability to simulate learning, adaptation and feature reproduction of agents through modeling their interactions. Our simulation model on the Janus platform provides a solution to a complex simulation but needs a lot of computing resources (*e.g.* processing time, memory, and data storage) because of the high number of agents to simulate, and the big data processing for each agent. The simulation model proposed in the paper has a few drawbacks: (i) detailed and accurate input data requirement, including agent's socio-economic attributes, network information and so on, and (ii) the model must be used in a real-size problem with millions of individuals for checking the scalability of the simulation model.

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