An Agent-Based Platform for Traffic Simulation

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Abstract Traffic is a phenomenon of high relevance for modern societies. Its study faces researchers with important challenges due to its complexity: it involves large numbers of heterogeneous vehicles, with drivers having different skills and attitudes, in a dynamic environment that is both artificial and natural, and subject to complex regulations. To address the study of traffic, researchers have made an intensive use of computer simulations over the last decades. Despite of these efforts, current simulations have still important limitations regarding the holistic study of traffic. They usually focus on some aspects of the phenomenon, disregarding the influence of others. Our work tries to address this problem with a platform for agent-based simulation of traffic. It allows the high-level specification of the environment, the vehicles and the drivers, and their interactions. Then, it adopts a model-driven development to implement these specifications in a given simulation platform. This approach provides flexibility to change the models of the simulation and adopt the target platform best-suited for the experiments at hand. The paper illustrates the approach with the first prototype implemented. The experiments carried out so far show the model is suitable to reproduce usual observations in Spanish traffic.

1 Introduction

Life in modern societies is highly mediated by traffic [12]. Its impact permeates a variety of aspects including, among others, economical factors, health issues, pollution, land loss, international relationships or leisure organization. In order to analyze this impact, researchers have developed a variety of approaches to understand the development of traffic phenomena and their mutual influences with the human and natural environment. The commonest approach is the study of data gathered from

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actual traffic settings (e.g. [7]). Models offer additional possibilities to test hypothesis about the principles governing traffic. They are usually classified [1] in analytical models (based on equations) and simulations (based on programming techniques). Analytical models have the advantage of being well-understood by experts and abstracting the key aspects of problems (e.g. [3]). However, simulation models are regarded as more flexible and scalable (e.g. [4]). In particular, they are well-suited to study non-linear phenomena. Nevertheless, the use of simulations faces two key problems: their bias towards certain aspects of traffic; and that social experts do not usually have the background to autonomously develop and understand them.

Simulations on traffic range from microscopic to macroscopic models [4]. The first ones deal with the individual components to study the resulting behaviour of the whole system. For instance, they model specific vehicles, drivers or pedestrians. The later abstract the individual components of the phenomena to study larger units, so they deal with whole traffic flows. The choice between these approaches largely depends on the specific aspects of the traffic to study, as it implies certain tradeoffs. The higher is the detail of the basic units of study, the little is their number. Thus, studies about large areas usually need to use units with simple behaviour, while studies focused on drivers or vehicles involve few units. These compromises bias the studies, since they disregard certain aspects of the traffic whose actual and mutual influence may be unknown. What is worse, there are not usually suitable mechanisms to change these tradeoffs for a simulation and analyse the validity of their results in different contexts. For instance, [11] is a microscopic simulation and only provides a high-level overview of its models. There are no indications about how it deals with non-key aspects in its study, making it difficult to reuse or validate other hypotheses.

The second limitation of simulation models is the difficulties that their development presents for social experts. While these experts are well-trained to develop analytical models, that is not usually the case for simulations. This makes necessary that social experts have the support of engineers to develop their simulations, which in turns open the possibility of misunderstandings and communication problems due to their different backgrounds [2].

Our work addresses these problems with an approach based on the specification of abstract models of the simulation and the automated generation of their code. It uses a platform for Agent-Based Modelling (ABM) [2] based on the INGENIAS methodology [14]. The approach addresses the previous problems as follows.

The INGENIAS language supports an integrated specification of both microscopic and macroscopic aspects through individual and societal abstractions respectively. The former level is related to drivers, vehicles and the environment, which are modelled with the abstractions of agent and environment application. The later level is modelled with groups and societies of the previous elements. Interactions among these abstractions provide explicit means to specify the mutual influences among the different primitives and levels appearing in models. In this way, the hypotheses of models and their bias can be specified as part of the simulation models.

The issue of generating the simulation from the models is addressed with Model Driven Development (MDD). MDD [9] promotes building systems through the gradual refinement of their models, migrating and modifying information from the abstract requirements to the final code. This refinement is partly supported with semi-automated transformations. INGENIAS adopts this kind of development.

The approach proposed in this paper has been tested with the development of a prototype whose results were compared with Spanish data on traffic [15]. The experiments show that the prototype effectively replicates real situations regarding average speed, successful manoeuvres and accidents.

The rest of the paper discusses with more details the aspects considered in this introduction. Section 2 provides a brief introduction to the INGENIAS methodology, including its modelling language and development process. Section 3 discusses the development of a simulation following the proposed approach. It discusses the aspects of traffic considered and how the platform treats them. This simulation has been used to carry out the experiments reported in Sect. 4. Section 5 compares the presented work with related research on traffic. Finally, Sect. 6 presents some conclusions and discussion on future work.

2 INGENIAS

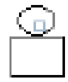
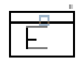
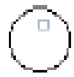
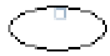
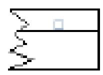
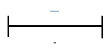
INGENIAS [14] is an agent-oriented software development methodology. It includes a modelling language, a development process, and support tools.

The INGENIAS language is built around the concept of agent as an intentional and social entity. *Agents* pursue *goals* that they are able to achieve through the execution of their own *tasks* or asking other agents for services. The fact that agents interact to make up complex services provide the social dimension of systems. This dimension is represented through *groups* and *societies*. The language also considers non-intentional abstractions represented as *environment applications*. These essentially trigger events and provide methods to act over the environment. Table 1 summarizes these and related concepts. The table does not include the relationships allowed among concepts. The relationships used in this paper have self-explanatory names, though they are further described when introduced. Consider for instance the relationship ”WFResponsible” from an agent to a task. The first two letters indicate the main type of diagram where the type of relationship appears. In this example, ”WF” stands for ”WorkFlow” diagram. The rest of the name gives the meaning of the relationship. In this case, ”Responsible” states that the agent is in charge of the execution of the task.

The INGENIAS Development Kit (IDK) is a tool for the graphical specification of models compliant with the INGENIAS language and the execution of transformations implemented as modules. These transformations allow the generation of simulation code from models using templates, i.e. text files annotated with tags.

The rest of the paper focuses on the use of the INGENIAS modelling language to define the models of traffic simulations in our approach. The development of the actual code has been considered in previous works of our group [10].

Table 1 Main concepts of the INGENIAS modelling language used in the case study.

Concept	Meaning	Icon
Agent	An active element with explicit goals that is able to initiate some actions involving other elements of the simulation.	
Environment application	An element of the environment. Agents can act on the environment using its actions and perceive information through its events.	
Goal	An objective of a role/agent. Roles/agents try to satisfy their goals executing tasks. A goal is achieved or fails if some elements (i.e. frame facts and events) are present or absent in the agent groups or the environment.	
Task	A capability of a role/agent. To execute a task, certain elements (i.e. frame facts and events) must be available. The execution produces/consumes some elements as result.	
Frame Fact	An element produced by a task, and therefore by the roles/agents.	
Event	An element produced by an environment application.	
Mental state	Part of the internal state of a role/agent. It groups goals, frame facts and events, and specify conditions on them.	

3 System models

As stated in the introduction, traffic is a complex phenomenon where multiple aspects interact. Drivers govern vehicles through roads and streets with signals, following the norms of their traffic regulations. In this process, they interact with other drivers and vehicles, but also with pedestrians. The environment is not only restricted to the human one, as factors such as weather or animals also affect traffic. In order to illustrate the use of INGENIAS as a platform to develop simulations, this paper considers a system focused on the drivers' attitude to driving. It follows works as [13], where drivers are classified according to their proneness to carry out aggressive manoeuvres, and [6], where they have an impatience level that rises when traffic is not fluid, leading them to drive riskier. The other aspects affecting the traffic, such as vehicles and environment, are also considered but in a simpler way.

The current simulation regards drivers as the only type of intentional element. They are modelled as the agent *driver* shown in Fig. 1. Agents are characterized pursuing certain goals. In this case, there is only one high level goal, i.e. *arrived early to destination*. Agents have capabilities, i.e. *tasks*, that are potentially able to satisfy those goals (discussed later in this section). The agent triggers tasks depending on the available information, e.g. if the goal has been fulfilled or if the tasks can be executed. This information includes knowledge about the agent itself (e.g. beliefs, plans or capabilities), its environment, and its past history. The *driver's mental state* accounts this information. Essentially, it indicates the path the driver wants to follow and other parameters about the current driving, such as *number of attempts* or *current direction*.

The driver's attitude to traffic is characterized with two elements. First, there is an inheritance hierarchy of drivers with three subtypes: *aggressive*, *normal* and *moderate*. These subtypes add new parameters to the driver's mental state. For instance, they establish the minimum distance with another car to try to overtake it or if it stops when the traffic lights are yellow. Besides this, the driving conditions can be very different and this affects the drivers' behaviour. For instance, drivers stuck in a traffic jam tend to dismiss some traffic regulations to run away from it. These changes are measured through the *anxiety level* in the mental state, which is at the moment a parameter in the initial driver's configuration. Future releases will include a dynamic calculation of this level depending on the actual average speed compared with the legal limit, the number of aborted manoeuvres, and the travel priority.

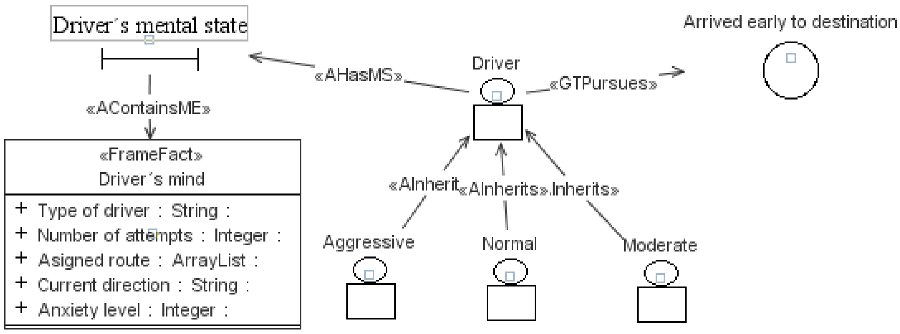


Fig. 1 Basic structure of drivers.

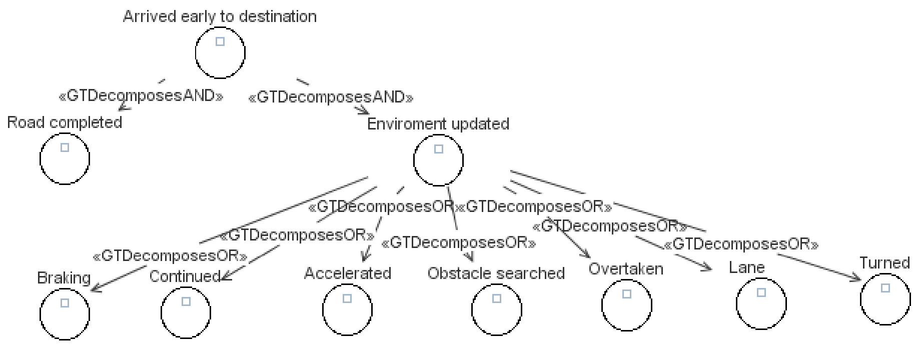


Fig. 2 Partial view of the first levels of the hierarchy of goals for drivers.

The path that characterizes the route of the agent allows it to make different decisions. It can choose alternative roads and manoeuvres as long as it goes through all the stops. Fig. 2 shows the first two levels of the goal decomposition for the driver. The lower level includes some of the potential manoeuvres to choose, as *accelerated*, *obstacle searched*, *overtaken*, or *lane changed*. These are high-level objectives, further decomposed in lower level goals such as *examined left lane*, *determined neighbour vehicle speed*, or *hit the accelerator*. These goal decompositions can indicate both alternative ways to achieve a goal or sub-goals.

The actual agent's choices on goals depend on the traffic, its vehicle, its type of driver, and its level of anxiety. At the lowest level in the decomposition hierarchy, goals are linked to tasks. The execution of these tasks requires certain information (i.e. INGENIAS *events* and *frame facts*) and is able to provide evidence on the fulfilment or failure to achieve the goal as new information. Thus, the actuation of the agent includes the traditional cycle: perceive the environment, update information, evaluate the applicability of the different alternatives, choose the best suited for the current situation, and apply the choice.

The perception and actuation over the environment is characterized in INGENIAS with environment applications (see Sect. 2). The current environment includes the *vehicle* and the *road system*. As stated in the introduction to this section, the current model adopts a minimal representation of the environment as it is focused on the drivers' attitudes. Anyway, some basic information must be considered to perform the simulation. The *vehicle* includes information about its *maximum speed* and *maximum acceleration*, and methods such as *accelerate*, *turn* or *try exit*. The *road system* includes, among others, methods to *get type of road*, *get speed limit*, *identify traffic signal*, or *interpret traffic lights*. There are currently three types of roads, i.e. *city*, *highway* and *secondary road*. They differ in their speed limits, the appearance of certain traffic signals and their lanes. The methods of these environment applications are linked with the pertaining tasks of the driver.

4 Experiments

The abstract models from Sect. 3 have been implemented in a prototype following the INGENIAS development process [14]. This process implies the development of templates for the target platform and running the IDK module that instantiates them with information from the models. As the prototype has been written in plain Java, i.e. it does not use any simulation platform, most of translations are straightforward. In those cases where neither models nor templates provide enough information to generate code, the INGENIAS language offers the possibility of attaching code snippets to components in models. For instance, the actual representation of the environment and the graphical interface of the simulation are not included in the diagrams. They are implemented as external classes and the snippets indicate how to instantiate them and invoke their methods from those in models. Note that at the moment, the models do not include certain parameters that limit the behaviour of drivers, in particular the distance to which they perceive events (e.g. other vehicles or traffic signals), and vehicles (e.g. their size or the speed of their turn to change the lane). They are currently included in the templates for code generation but some of them will be promoted to models in next versions of the simulation.

The prototype has been used to perform several experiments. These run in a machine with an Intel Core Duo processor at 2.53 GHz and 4 GB of RAM, and using Java SE 6. These experiments were customized in several parameters:

- *Type of road*. Including city, highway and secondary road. City scenarios have traffic signals, but highways and roads do not. Highways have several lanes for each direction and roads only one. All of them have junctions and different speed limits according to Spanish regulations [15].
- *Anxiety level*. Includes three levels for high, medium and low anxiety. The driver's average speed regarding the norms is affected by this level.
- *Traffic volume*. Considering a high or low density of vehicles. High density corresponds to 30$\pm$3 drivers for each lane, and low density to 8$\pm$3 drivers.
- *Predominant type of driver*. All the experiments include drivers of all the types, i.e. aggressive, normal and moderate. The type affects the percentage of times drivers respect traffic signals and lights and speed limits. The driver distribution can be balanced or biased towards a given type. Biased distributions include at least 40% of drivers of a given type and less percentage of each of the other types.
- *Types of vehicles*. The simulation includes slow and fast vehicles, with maximum speeds of 150 and 220 kilometres per hour respectively. Their distribution can be balanced or biased. Anyway, experiments distributed each type in a balanced way among the different types of drivers and anxiety levels.

In order to compare the results from the experiments with data from real traffic, two metrics were considered: the number of observed takeovers and of conflicting situations. A takeover happens when two vehicles in the same lane exchange their positions. A conflicting situation appears when a driver aborts a manoeuvre to avoid a collision or there is a collision. The data about real traffic were taken from the Spanish government [15]. Table 2 summarizes the comparison for some experimental settings, indicating whether they reproduce the actual traffic or not. This comparison is qualitative: it regards whether metric figures rise or drop when changing some parameter as it happens in real traffic. Experiments were repeated an average of 20 times for each configuration, with random variations about time of entrance of vehicles in the simulation (within the first 20% of simulation time) and number of drivers (traffic volume $\pm$3). Results about variations in traffic volume and type of vehicles are omitted, as all of them reproduced the results expected from real traffic.

The summarized results deserve some remarks. The results in some experiments for secondary roads differ from what was expected. For instance, aggressive drivers with medium and high anxiety levels produce less conflicting situations than expected. The explanation after analysing the results of the simulation was the following. In the case of medium anxiety, drivers resolutely perform takeovers and they do not take highly absurd risks, so there is little chance for accidents. In the case of high anxiety, most of drivers run at the speed limit, or even slightly over, so there is little

Table 2 Experimental results of the simulation. Fidelity to results in real traffic.

Predominant drivers	Predominant anxiety level	Type of road		
		City	Secondary	Highway
Aggressive	Low	Yes	Yes	Yes
	Medium	Yes	No	Yes
	High	Yes	No	Yes
Normal	Low	Yes	Yes	Yes
	Medium	Yes	Yes	Yes
	High	Yes	No	Yes
Moderate	Low	Yes	Yes	Yes
	Medium	Yes	Yes	Yes
	High	Yes	No	Yes

chance for takeovers or any other manoeuvre. This last case shows the relevance of taking into account the possibility of drivers making mistakes in their tasks. For instance, the current simulation does not consider the possibility that the driver loses the control of the vehicle because of a too high speed or adverse weather conditions.

5 Related Work

Traffic simulation can be classified regarding the level of detail of their basic simulation units. Going from those considering the units with the higher levels of detail to those with more abstract units, there are nanoscopic, microscopic, mesoscopic or hybrid, and macroscopic simulations [4]. This discussion follows this classification.

Nanoscopic simulations account for the individual parts of vehicles, drivers and other components in the environment. For instance, they can consider vehicles composed by motor, tyres, doors, navigation systems... Examples of these works are [5], which analyses the impact of adaptive cruise control in journey time and speed, and [8], which uses fuzzy techniques to control vehicles. This kind of information does not appear in our case study, but it can be integrated considering vehicles and drivers as societies of agents. Their components would be modelled as additional agents or environment applications that interact to offer the complete behaviour.

Microscopic simulations for traffic consider as their main analysis units drivers or vehicles in roads. An example of them is the already cited [11]. The levels of detail of these works can be very different, from simple follow or automata cell models, to complex ones including path awareness, decisions about routes, or dynamic models of vehicles. The main drawback of these works is that they commonly present their models discussing their parts (e.g. vehicles and drivers) but not their actual links, which makes difficult understanding their mutual influences and embedded hypotheses. For instance, it is not enough providing models for drivers and environments without specifying how the driver perceives that environment.

Macroscopic simulations consider flows of traffic instead of individual elements. They use measures such as density, space-mean-speed and flow rate. They benefit from the simplification of individual simulation units to describe larger areas and groups of elements. However, they lack of capability to model complex roadway geometries, vehicles features or driver behaviours, make them less used today. Our approach could consider some of the features of macroscopic simulations through the aggregation primitives of its modelling language. For instance, the previous measures could be assigned to groups of agents and processed with common group tasks.

Finally, mesoscopic models are hybrid, with micro and macroscopic features. They try to achieve tradeoffs between modelling with detail some aspects of the traffic and providing enough information for the rest of aspects with more abstract concepts. For instance, [4] studies the traffic in Stockholm, Sweden, at several levels: vehicles in specific roads and streets, and sectors at a higher level, trying to cover the whole city. Our approach, with individual and social abstraction also pursues covering different levels of the simulation allowing the proper granularity for each part of the analysis.

6 Conclusions

This paper has presented an approach to build mesoscopic simulations based on ABM. It adopts an existing agent-oriented methodology, INGENIAS, as the basis that provides a modelling language and development process for its simulations.

The adopted modelling language offers primitives for both individual concepts and social aggregations. This facilitates considering the individual units participating in the traffic as well as groups with a common behaviour. Regarding the individual units, the use of agents offers conceptual tools for a modelling based on goals and complex decision making. This provides an intuitive representation of the influence of driver's attitudes in their observed behaviour. The language also includes primitives to represent interactions between these units. Although these have not been used in the case study, they will allow an explicit representation of the information exchange between the participants in the simulation. This will relieve the environment (i.e. roads) from being also the communication device between the units in the simulation, a common representation that is not however close to reality.

The MDD process adopted facilitates reusing the abstract models in different target implementations. It makes use of generic code templates, that a tool automatically instantiates with information from models to generate code. This approach makes explicit a large part of the decisions made when implementing the models.

This work still has several open issues that must be addressed to provide complete traffic simulations. First, it must make explicit in the models all the information relevant for a given problem. Currently, part of this information is stored in the templates. While it can be expected experts in traffic being able to model with an agent-oriented language, it is far more difficult that they manipulate template or code depending on the target platform. Second, richer representations of the environment are required. In particular, the driver's models of vehicles and roads are necessary to model certain pre-emptive behaviours of drivers, and weather conditions are a well-known factor influencing traffic. These features are suitable for approaches based on fuzzy techniques. Third, the use of simulations to study actual road systems requires integration with geographical simulation systems. This is an aspect already addressed in the literature and some available systems. Finally, the limited complexity of the experiments allows us running them on a single machine. However, literature shows that when complexity rises, distribution of the simulation is a must. This issue is being studied considering available distributed platforms.

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