A situational awareness approach to intelligent vehicle agents*

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1 Introduction

Developments in the field of autonomous vehicles are already visible on the roads of the world and likely to increase in both quantity and importance with time. Having been demonstrated operating individually – such as Google's [13] and more recently Nissan's [7] – as well as collectively in convoys [3], the question is raised: how can groups of intelligent vehicles act together in order to achieve (i) their own goals, (ii) those of the larger collective, and (iii) those of society as a whole?

We start from the assumption that some communication between vehicles is a necessity (and an inevitability) to facilitate coordination, an assumption supported by a recent announcement from the US National Highway Traffic Safety Administration (NHTSA) [14] that Vehicle to Vehicle (V2V) communication devices may become mandatory in a year. With such technology set to enable V2V communication, there follows the consideration of *how much* information needs to be exchanged in order to manage cooperation and coordination between vehicles. We consider this issue in the context of Endsley's [6] Situational Awareness work, that is, "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". This provides a framework in which to consider knowledge exchange between system components, that is, 'low level' perception data (e.g. a vehicle's x,y position) though to 'high level' projection considerations (e.g. given speed and orientation, there will be a collision with that detected vehicle).

Given such an environment, it becomes possible to explore what levels of data (quantitative, qualitative) and communication (high frequency, low frequency) are effective in resolving complex scenarios between vehicles. We can also take account of social conventions (e.g. in a given context, what does a flash of headlights indicate) as well as regulation (e.g. at red traffic lights with an emergency vehicle approaching, what action to select).

To investigate these questions, we have built a distributed framework, connecting intelligent agents (Jason [4]), a rich simulation environment (SUMO [9]), data analysis tools, plus system and domain specific visualization tools, that allows components to publish and subscribe to information as required. Through the selection of appropriately abstract message types, components are able to process and react to information regardless of whether the data originates from the real world, or a simulation. SUMO is used to provide a realistic traffic and vehicle simulation component, with an intelligent agent layer controlling representation of autonomous vehicles, in order to explore what such interactions between 'vehicles of the future' and 'vehicles of the past' may look like. This is coupled with an institutional framework [5], capable of issuing obligations to these vehicles in an attempt to maximise the broader collective needs and resolve complex social situations. Finally, the simulation is based as far as possible on real world information, using Open Source Map (OSM) data to build 3D models and SUMO maps, combined with realistic traffic flows. For this aspect, data was used from the UK Highways Agency Traffic Flow Database System (TRADS [1]), where vehicle trips for a section of the M25 motorway over a 15 minute period have been extracted, and are used to build flows in SUMO.

Contributions from this work can be considered in terms of infrastructure development, in that a number of widely used mature applications have been combined via the simulation framework to facilitate experimentation. Building on the initial success of Jason agents controlling SUMO vehicles, this work goes on to highlight the role that institution norms can have in the future of autonomous vehicles. In summary, the contributions of this work are: (i) extending the scope of vehicle control to incorporate the use of intelligent agents (ii) integrating open map data to allow geographically situated simulations and visualizations (iii) utilizing real-world vehicle data to reproduce actual initial conditions, and (iv) capturing conventions and regulations in institutional models to provide guidance to vehicle agents.

*In keeping with the nature of this submission as an abstract, we focus on the main elements of the contribution of our work and defer discussion of detailed mechanisms, related work and future work to a full version of the paper.

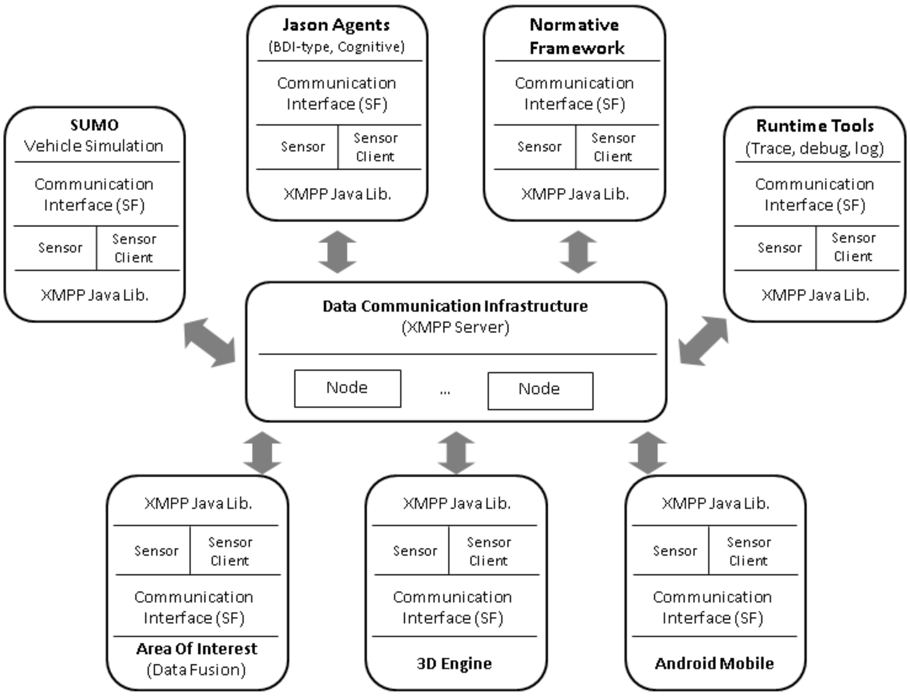

Figure 1: Illustration of available BSF system components

2 Simulation Framework

One of the central objectives of our work is to use so-called 'intelligent agents' in the context of large-scale agent-based simulation. Such agents have been perceived as mismatched with ABM because of the clearly higher computational requirements. Our aim here is to use a few such agents situated in an environment populated by many more conventional agents, in order to develop and evaluate behaviours that can operate effectively in typical scenarios. Consequently, we are using data obtained from the UK Highways Agency to construct such typical scenarios by generating SUMO vehicle populations that reflect real-world data collected from the M25 (a motorway that goes around London UK).

These informal requirements have lead to the creation of a distributed environment called the 'Bath Sensor Framework' (BSF) [10], whose primary features are (i) a bus-like communications system based on the eXtended Messaging and Presence Protocol (XMPP) [17], and (ii) a publish/subscribe interface that can be implemented for a variety of programming languages (we currently use Java, C# and Python). Similar XMPP-based approaches have been demonstrated in other distributed applications [15, 16]. A notable additional aspect of our framework, is the adoption of two de-facto standard messaging formats: Resource Description Framework (RDF), allowing the association of semantics with messages by reference to common ontologies and JSON, allowing the low-overhead communication of structured data. Simulation components interact via publish-subscribe, where each component provides a 'Sensor' (output) and 'Sensor Client' (input), that connect to topic nodes in an XMPP server.

A sketch of the framework appears in Figure 1 populated with some of the components making up a typical instantiation of the framework as used for the work reported here:

- The SUMO interface is based on the traci4j library, allowing commands to be sent to SUMO (based on received input via BSF subscriptions) and information extracted from SUMO and published out to the BSF. This component also controls the update rate of SUMO, allowing the processing and creation of BSF messages between each simulation step.
- The Jason component provides an **intelligent agent** capability, and in the case of vehicle scenarios allows Jason agents to request the creation of a SUMO vehicle, which they then control. A similar approach has been employed to the control of non-player-characters in Second Life [11]
- The **normative framework** component introduces the element of institutions [5] into the simulation, allowing obligations to be issued to simulation participants (e.g. for a vehicle to slow down, or move out of the way), following the principles set out in [2] and developed for Jason in [12].
- The **Area of Interest** (AOI) component acts as a data fusion module relative to individual vehicles for a given 'interest volume'. This is based on the assumption that the agents controlling a vehicle have a greater interest in certain events and states near to their current location, and reduces the noise from being informed

about the entire simulation state. This reports information such as upcoming traffic light states given the vehicle's current route, vehicles in the same lane which may become collision hazards, and so on.

- A **3D engine** component is used to provide a human observer with a variety of views to the simulation. As this subscribes to multiple feeds, it is able to display: (i) basic spatial information (e.g. a 3D view of the SUMO simulation, traffic light states) (ii) vehicle state information (e.g. lights, smoke if crashed), (iii) augmented with other system component information (e.g. calculated collision volumes, Jason agent belief state data), as well as system information (e.g. messages per second graph). The visualizer has proved an essential tool in debugging, as the task of understanding unintended behaviours with a distributed intelligent system can be very challenging otherwise.
- Finally, there are some **runtime tools**, one of which is the RDF Monitor suite that provides analysis tools for the messages being exchanged over the BSF. This covers measures from lower level performance metrics (e.g. message delivery time, volume) to higher level simulation specific metrics (SUMO fuel consumption, mean speed). There is also a database logger and replayer tool, allowing simulations to be recorded, analysed via SparQL queries, and replayed or stepped through as required.

All simulation components are built around the Open Source Map (OSM) data format. This has been imported into SUMO, and a corresponding 3D model built using the osm2world tool [8]. Some modification to osm2world were necessary to ensure accurate correlation between the 3D model and SUMO vehicle positions, but the two now match closely. Therefore, all tools, models, data, and code can be provided open source to the community and are available for download (`http://code.google.com/p/bsf/`).

3 Experimental Scenarios

We have built two scenarios, using the platforms and tools described above, through which we can explore the 'comprehension' and 'projection' elements of situational awareness. The institutional framework plays an essential role in each of these because it provides a form of behavioural specification of what a vehicle agent *ought* to do in a given situation. Thus, rather than loading each agent with every conceivable behaviour for every conceivable situation, it is instead able to acquire that behaviour via an instance of an institution that is created when a situation arises, while still retaining the autonomy to decide whether to follow the direction given by the institution. In this way, it becomes possible to encode different regulations and different conventions, delivering them through (multiple) institutional models, enabling both experimentation with regulations and with their combinations[1] as well as re-use.

3.1 Scenario 1: Motorway change lane request

In this scenario, we are interested in examining the benefit institutions can have in resolving inter-vehicle requests. In the UK there are a variety of visual and audible cues used to transmit some intention or request to another vehicle. These can range from clear legal obligations (e.g. blue flashing lights of emergency vehicles create an obligation to allow that vehicle past) to the more ambiguous (e.g. a flash of headlights can indicate some hazard, or a desire to overtake). Given the improved capacity to communicate via V2V technology, this "headlight flash" request is explored in conjunction with an institution, allowing one vehicle to inform the institution of its desire to overtake, and for the institution to resolve this (by issuing an obligation to the other vehicle to change lanes).

In Figure 2 the context for the M25 scenario can be seen, with the background flow of vehicles and the Jason agents' calculated collision volume visible. Through the use of detectors placed along the vehicle route, a number of measurements can be extracted from the SUMO simulation and reported via the BSF. These metrics are then displayed in realtime via the RDF monitor tool, which can also created graphs and CSV exports of the data. In Figure 3, initial analysis has been performed of one of these detectors, attempting to identify where sudden braking of the faster vehicle having to slow down to prevent a collision has impacted the overall vehicle community, by reducing their speed. Work on this scenario has only recently begun, although it can be seen in Figure 3 that at approximately 90 seconds the scenario with no institution does suffer from a slower speed. Improvements are planned to the simulation configuration in order to remove the likelihood of this being due to random vehicle behaviour (for example, lane changes occurring at different times in different simulation runs).

Future work based on the M25 context is planned which will investigate Variable Speed Limit (VSL) scenarios, with variations of no VSL, using existing VSL practise, and using institution based VSL.

[1] Conflict between regulations is inevitable and while there are mechanisms to resolve these (not discussed here), in the first instance, the decision about which regulation to follow can be left to the vehicle agent.

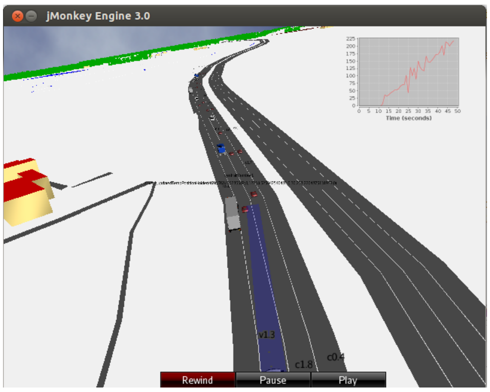

Figure 2: M25 Motorway scenario

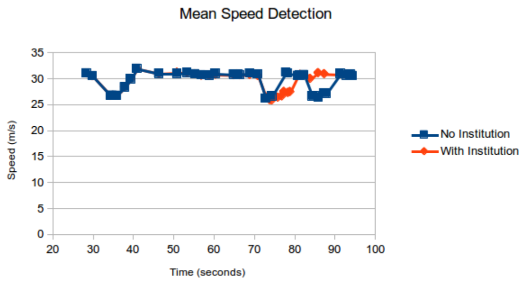

Figure 3: Impact on vehicle speeds

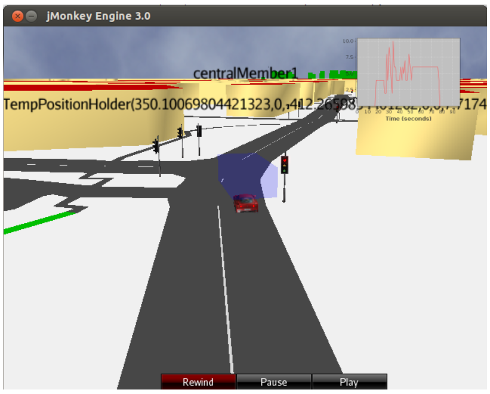

Figure 4: Vehicles waiting at traffic lights

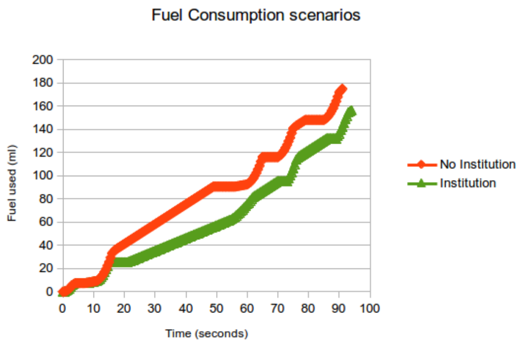

Figure 5: Impact on fuel consumption

3.2 Scenario 2: City traffic lights

In this scenario, the capability of reasoning about future states is explored, combining the Situational Awareness concept of 'projection' with the Area Of Interest component. A city context is used, based on Bath in the UK, which generates more complex routes as well as interactions with traffic lights. It is the effect of such traffic lights interactions which is explored in the current scenario, investigating the role institutions could play in managing vehicles speed in order to coordinate with traffic light states.

In Figure 5 the results of two experimental runs are shown, with the first showing the effect of the institution being disabled. In this case, the vehicle progresses along its route, until it is held up by a red light at a junction. This results in fuel expense while sat idling, and also in fuel required to accelerate from stationary after the light changes to green. In contrast, in the second experiment, the institution is informed about the upcoming light along this vehicles route, and issues an obligation for the vehicle to slow down. By doing so, the vehicle arrives at the light when it is green, and the graph show this results in a fuel saving. The expectation is that there would be an increase in journey time, but in fact the vehicle only loses three seconds which can be traded off against the saved fuel. In Figure 4 the 3D component is shown in use with the traffic light scenario. Here the vehicle can be seen held at the red traffic light, and the impact in terms of fuel consumption is shown in Figure 5.

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