Proceedings of the FAABS Conference, Greenbelt, MD, October 28-30, 2002.

# Applications Panel: Agents Applied to Autonomous Vehicles

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In order to make an unmanned vehicle drive truly autonomously, many different software components are needed. Each of these components is tasked with providing a particular function that is necessary to accomplish the ultimate goal of autonomous driving. Typical functions include perception, sensory processing, world modeling, planning, route following, behavior generation and value judgment. Each component can be seen as an individual agent, and the entire system can be viewed as an agent architecture. The agent architecture that is the focus of this paper is the RCS Control System (RCS) [1] developed in the Intelligent Systems Division at the National Institute of Standards and Technology (NIST).

As with many agent architectures, one of the major challenges is how to completely and accurately exchange pertinent information among different agents. Although each agent has a specific set of actions to perform, all of the agents are jointly working towards a common goals, namely, autonomous driving. As such, one agent often relies on information that may reside in other agents. Some types of information that one agent may need from another agent are:

| **Requesting Agent** | **Receiving Agent** | **Information Type** |
|---|---|---|
| World Modeling | Perception | What are the objects that reside in the environment? |
| World Modeling | Sensory Processing | What are the pertinent characteristics of objects in the environment? |
| Planning | World Modeling | What can be inferred about the motion of objects in the environment (e.g., the goal of the object)? |
| Planning | Behavior Generation | How can the overall goal of the vehicle be decomposed into actionable items? |
| Planning | Value Judgment | Did the planner identify all possible plans to accomplish the stated goal? |
| Planning | Value Judgment | Did the chosen plan truly accomplish the stated goal? |

One approach to ensuring complete and unambiguous communication among different agents is to develop a formal ontology of the concepts that need to be exchanged in

the realm of autonomous driving.[1] An ontology is different from other types of interchange specification in that it focuses exclusively on the semantics or the meaning of the concepts instead of placing the focus on the syntax that is used to represent the concepts. Efforts have already begun at NIST in developing such an ontology, with initial emphasis focusing on formally encoding the "rules of the road" based upon the Driver Education Task Analysis: Instructional Objectives document [3] developed by the Human Resources Research Organization for the Department of Transportation.

The ontology is represented in the Knowledge Interchange Format (KIF) [4]. An example of a KIF axiom is included below.

*If the force on the car prior to an occurrence of the accelerate activity is ?acc, then the force on the car after the occurrence is increased by the amount ?increment.*

```
(forall (?car ?acc ?occ ?increment)
        (=>     (and    (occurrence_of ?occ (accelerate ?car ?increment))
                        (prior (force ?car ?acc) ?occ))
                (holds (force ?car (+ ?acc ?increment)) ?occ)))
```

Even with the ontology developed, there are still numerous challenges that need to be addressed, including:

- How important is reusability, and how do we decide which parts of the ontology should be reused in other applications and which parts are situation specific?
- Are ontologies and agents useful in representing low-level data, such as the pixel-level data that is the output of perception systems? If ontologies are useful at this level, how do you represent this type of data?
- What language should be used to communicate between agents? Although the data may be represented in ontologies, there still need to be a communication/query language to pass the data between agents.
- What other types of information should be unambiguously defined in the ontology besides driving activities and the "rules of the road"?

## References


1. Albus, J., "4-D/RCS: A Reference Model Architecture for Demo III," NISTIR 5994, Gaithersburg, MD, March 1997.
2. Gage, Douglas, Information Processing Technology Office - Mobile Autonomous Mobile Software http://www.darpa.mil/ipto/research/mars/. Last Viewed May 30, 2002.
3. McKnight, A.J. and A.G. Hundt. 1971. *Driver Education Task Analysis: Instructional Objectives*. Human Resources Research Organization.
4. Genesereth M., Fikes R. 1992. Knowledge Interchange Format. Stanford Logic Report Logic-92-1, Stanford Univ. http://logic.stanford.edu/kif/kif.html.


[1] This work is being performed under the auspices of the DARPA-funded MARS project. [2]