# A Semantically-Rich, Graphical Environment for Collaborative Ontology Development in Agentcities

Luigi Ceccaroni
Fujitsu Laboratories of America
595 Lawrence Expressway
Sunnyvale, CA 94085, USA
+1 408 530 4563
luigi.ceccaroni@fla.fujitsu.com

Elisa Kendall
Sandpiper Software, Inc.
16400 Lark Avenue, Suite 210
Los Gatos, CA 95032, USA
+1 408 402 0727
ekendall@sandsoft.com

## ABSTRACT
This paper presents current research on a semantically-rich, graphical representation of ontologies in the framework of collaborative construction for the Agentcities initiative. The application domain is an open, dynamic test-bed for agent deployment, and the ontologies are encoded in DAML+OIL and explicitly designed to be shared by several agent-based services within this environment. A new tool, called Visual Ontology Modeler, is presented, which meets most of the requirements for collaborative ontology development and management in large-scale efforts, such as Agentcities. The requirements that the Visual Ontology Modeler meets are: an easy to use, easy to understand, graphical representation; configuration management capabilities, including integration with version control; integrated consistency and completeness checking; automated export of DAML+OIL code. However, there are other requirements that are not yet met and form part of current investigation and future work, such as: a real-time, multi-user development environment; the ability to view, analyze, compare and compose multiple models at a time; automated import of DAML+OIL, OWL, RDFS and possibly other traditional ontology languages such as KIF and conceptual graphs.

## General Terms
Design, Experimentation, Languages.

## Keywords
Ontologies, Agentcities, DAML+OIL, Web Ontology Language (OWL), Unified Modeling Language (UML).

## 1. INTRODUCTION
In this paper we present an overview of tools for ontology management and, in particular, we describe a new tool for semantically-rich, graphical representation of ontologies. One of the aims of this tool's development is to meet the requirements for collaborative ontology development and management in large-scale agent systems, such as Agentcities. This tool is an extension to Rational Rose and enables the construction of ontologies through user-friendly wizards, automatically creating the required logical model and related diagrams.

*Ontologies* provide: (1) a shared and common understanding of a domain that can be communicated among agents and application systems; (2) an explicit conceptualization that describes the semantics of a particular resource; (3) a basis for Web Services markup, facilitating their composition and mapping [7][21][24]. Ontologies are critical to current research and emerging commercial applications relevant to the Semantic Web [1]. They allow software agents to communicate with one another in meaningful ways [1], attracting attention not only from academic disciplines such as computer science, information science and artificial intelligence, but also from industries as diverse as the communications and high technology, financial services, medical informatics, education, and environmental sectors [10]. Currently, one of the key issues in ontology research is mapping and merging, but existing problems in creation, maintenance and sharing are far from being solved. For a comprehensive review of the ontology field, refer to Deliverable 1.1.1 of the OntoWeb project[1].

The European Commission funded *Agentcities*.RTD[2] project is part of a worldwide initiative [25] intended to realize and advance the potential of agent-based applications by constructing an open, distributed network of platforms hosting diverse agents and services. The ultimate aim of Agentcities[3] is to enable the dynamic, intelligent and autonomous composition of Web services to achieve user and business goals. The Agentcities.RTD project includes 14 partners from academia and industry. Each partner has deployed an agent platform, and agents and services hosted on that platform. Communication among these services has part of its semantic grounding in a series of utility ontologies [4] that model common, general concepts, and in several domain ontologies, such as: accommodation, geographic information, rating, restaurant, shows, transport and weather.

- In Agentcities.RTD, *DAML+OIL* [11][12][17] was selected as the preferred ontology modeling language, while FIPA-SL[4] was chosen as the content language.

[1] See [http://ontoweb.aifb.uni-karlsruhe.de/About/Deliverables/Deliverable111.pdf].

[2] See [http://www.agentcities.org/EURTD/].

[3] See [http://www.agentcities.org/].

[4] See [http://www.fipa.org/specs/fipa00008/].

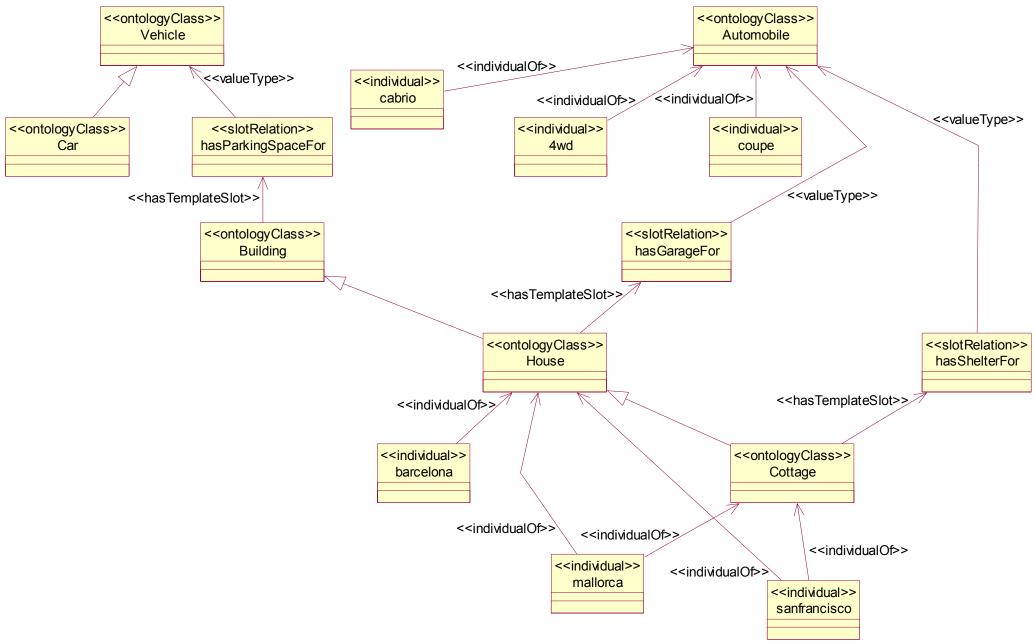


**Figure 1. Graphical representation of an ontology with the Visual Ontology Modeler.**

Although DAML+OIL (and, more recently, the Web Ontology Language, or OWL [5][18]) is the primary knowledge representation language used for current research on the Semantic Web, there are drawbacks in using it, including [4]:

- The language is still immature and unstable with respect to the representation of Web services.
- The tools available in early 2002 for ontology editing were limited and they do not yet support all features of the language (see section 2).
- Little work has been done with respect to methodology and best practices in using DAML+OIL to construct *reusable* ontologies, including issues such as scalability and component-based construction. Currently, reusing a DAML+OIL ontology is more difficult than creating a new one. One system attempts to use (or *reuse*) another system's ontology only if it needs to communicate with that system. In multi-agent environments such as those under development for Agentcities, shared ontologies are essential to communications, mandating the development and deployment of reusable ontologies.

## 2. ONTOLOGY REQUIREMENTS AND TOOLS

Several publicly available ontology editors were investigated initially for use in Agentcities.RTD, but none directly supported the DAML+OIL language or provided a logically consistent, graphical notation for representation of the ontologies. These editors, including *OilEd* [2], Protégé-2000 [9][15], Ontolingua [6], Chimaera [16][19][20], WebODE[5], and KAON[6], were developed primarily by the artificial intelligence research community. Unfortunately, most are not well known outside that arena and their use requires significant understanding of knowledge representation languages and methodologies. Because these tools have not had the benefit of commercial investment, they are not integrated with software engineering or configuration management tools, and are only supported as funding permits; none scale to the degree required for the construction of large-scale bioinformatics or other equally complex ontologies. This limits their utility for projects such as Agentcities, which is a multi-year program involving a number of distributed teams of research scientists.

By mid-2002, further review of commercially available tools uncovered several new options for ontology development and maintenance. Indeed, as the commercial world increasingly becomes aware of the importance of knowledge representation and agent-based technologies, new tools are emerging in the marketplace. In a couple of cases, commercial methodologies for object-oriented analysis, design, and implementation such as the Object Management Group's Unified Modeling Language (UML) [3][23] have been applied or extended to support ontology development [14]. UML is an industry standard supported by a large, corporate user community. Most UML development tools are multi-user and many are integrated with commercial-quality configuration management capabilities. In addition to the UML-based approach, other emerging ontology development environments have

[5] See [http://delicias.dia.fi.upm.es/webODE/].

[6] See [http://kaon.semanticweb.org/].

extended tools such as Microsoft's Visio; several are completely new.

The tools reviewed include: Sandpiper Software's Visual Ontology Modeler (VOM) [13], Unicorn Software's Unicorn Coherence IDE[7], GRCI/AT&T Solutions' DUET UML visualization and authoring environment for DAML[8], Ontoprise's OntoEdit ontology editor[9], SemTalk's Visio-based ontology editor[10] and OntologyWorks's Integrated Ontology Development Environment[11]. Of these, few are capable of accommodating two basic needs of the Agentcities community:

- Support for ontology development using DAML+OIL or OWL.
- Support for collaborative ontology development and maintenance.

In other words, a number of *requirements* need to be met in order to support Agentcities and other large-scale, collaborative ontology development efforts (see also [4]):

1. an easy to use, easy to communicate graphical representation;
2. a multi-user development environment;
3. configuration management capabilities, including integration with version control;
4. the ability to view, analyze, compare and compose multiple models at a time;
5. integrated consistency and completeness checking;
6. automated import/export of DAML+OIL, OWL, RDFS and possibly other traditional ontology languages such as KIF [8] and conceptual graphs.

There is no tool which meets all of these requirements, but there are tools meeting some of them, especially the first three ones (refer to Deliverable 1.3.1 of the OntoWeb project[12] for a comprehensive survey of a large number of tools).

## 2.1 Problems in ontology management

Partners of the Agentcities project have identified important difficulties in collaboratively creating ontologies and making subsequent modifications, due to a lack of adequate tools. As a temporary solution, they exchanged the DAML+OIL code and a corresponding graphical representation created with either Visio, PowerPoint or Rational Rose. But there was no automatic, logical relation between the two, and the modification and maintenance of such ontologies often led to confusion and inaccuracy.

In May 2002, some of the Agentcities.RTD partners (represented by one of the authors) migrated from a Visio- or PowerPoint-based ontology development tool, with manual or *OilEd*-based creation of the appropriate DAML+OIL code, to VOM, a UML-based development environment supporting automated generation of DAML+OIL. Due to its novelty, VOM is not included in any reference survey, but our comparison, based on previously stated requirements, showed that it performs better than the other tools taken into consideration. Here we briefly introduce this new tool, while in the next section we will justify our choice, detailing VOM's performance with respect to stated requirements.

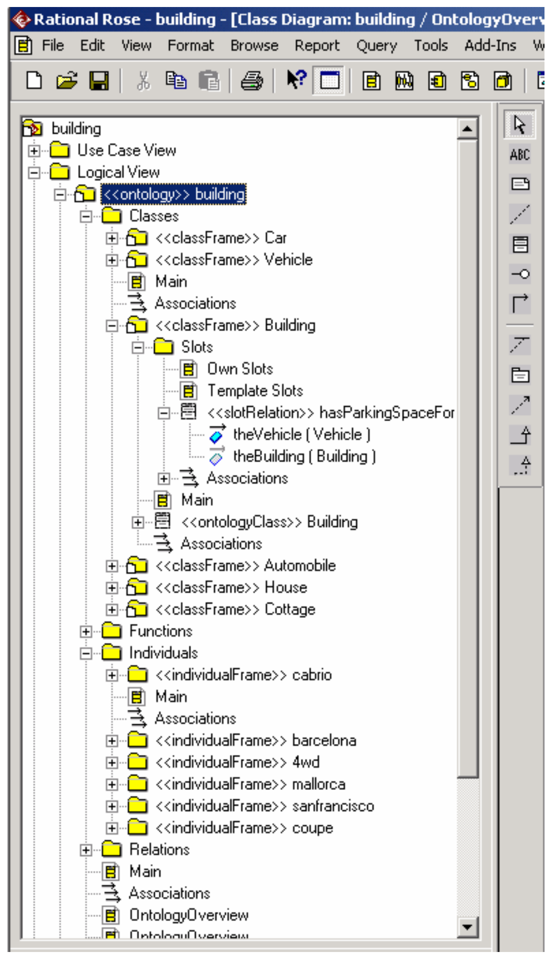

**Figure 2: Logical representation of the ontology.**

VOM is an extension to Rational Rose [22] (which is used extensively by businesses), and enables the construction of ontologies through user-friendly wizards, automatically creating the required UML model elements and related diagrams. VOM enables graphical model development in a standards-based notation, can be integrated with Rational ClearCase[13] or other configuration management tools, and provides automated export of most required constructs for Agentcities' DAML+OIL ontologies (e.g., *disjointWith*, *complementOf*, *sameClassAs*).

[7] See [http://www.unicorn.com/].

[8] See [http://grcinet.grci.com/maria/www/CodipSite/Tools/Tools.html].

[9] See [http://www.ontoprise.de/com/index.htm].

[10] See [http://www.semtalk.com/].

[11] See [http://www.ontologyworks.com/].

[12] See [http://ontoweb.aifb.uni-karlsruhe.de/About/Deliverables/D13_v1-0.zip].

[13] See [http://www.rational.com/products/clearcase].

With VOM, substantial productivity gains can be achieved in terms of:

- development time;
- consistency and correctness of the DAML+OIL code exported;
- ease in maintenance when substantial changes to the ontologies are introduced.

Drawbacks include the need to learn a new and possibly unfamiliar user interface and notation, immature implementation, and the inability to import existing DAML+OIL ontologies.

## 3. A COLLABORATIVE DEVELOPMENT ENVIRONMENT AND APPROACH FOR ONTOLOGIES

Collaborative construction and reuse of ontologies is important for Agentcities due to requirements for inter-systems communication. The bulk of the initial development was carried out through a combination of face-to-face meetings and remote communication [4]. As a consequence of this phase of the development, it became clear that sharing a consistent, visual representation of the ontologies among team members would be optimal. DAML+OIL code can be difficult to read, particularly if team members have not agreed on development methodologies and code layout. Not only is a formal, graphical representation easier to read, it provides a much more consistent vehicle for conveying ontological concepts and for sharing them with other domain experts, not versed in the DAML+OIL language. Automated code generation would ensure consistency and correctness in the DAML+OIL encoding, and result in substantial time-savings, particularly in the maintenance phase of the program.

We believe that VOM meets most of the requirements identified to date, and will meet all of them in the next several months. Using VOM, we implemented several existing Agentcities' utility-ontologies, without modification, to evaluate its capabilities as well as the DAML+OIL code produced. As a result, and for the reasons given with the example discussed below, we have elected to use it for the creation of all new ontologies as well as for maintenance of the existing ones. In Figure 1, the graphical representation of an ontology is given in UML notation. A similar graphical view is achievable with a number of basic UML modeling tools. Figure 2 provides a logical view of the same ontology. While a number of ontology development tools can model the logical or hierarchical view of an ontology, few have implemented the underlying semantics to produce both logical and graphical perspectives. In Figure 3, an excerpt of the DAML+OIL code automatically generated by VOM is shown. None of the other tools reviewed are capable of generating the code associated with both representations of an ontology. Additionally, with VOM, using Rose's Web Publisher feature, it is possible to automatically publish an HTML (fully browseable) version of these representations to the Web for review by all distributed team members not using Rational Rose (see Figure 4).

This simple example demonstrates the level of improvement provided by VOM over other tools for collaborative construction of ontologies. We think tools that meet the set of requirements outlined above will be increasingly important for agent-system engineers who need tight collaboration for interacting-services development and are members of distributed teams or constructing multiple, interrelated ontologies for agent use.

```
<?xml version="1.0" encoding="UTF-8" ?>
<!-- Generated by the Medius Visual Ontology Modeler
V0.18 -->
<rdf:RDF
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:daml="http://www.daml.org/2001/03/daml+oil#"
  xmlns:xsd="http://www.w3.org/2000/10/XMLSchema#"
  xmlns="http://sf.us.agentcities.net/ontologies/building.daml"
>
<daml:Ontology rdf:about="building">
  <daml:versionInfo>$ID: building.daml, v 1.0 of
11-01-2002$</daml:versionInfo>
</daml:Ontology>

<daml:Class rdf:ID="Car">
  <rdfs:label>Car</rdfs:label>
  <rdfs:subClassOf rdf:resource="#Vehicle"/>
</daml:Class>

<daml:ObjectProperty rdf:ID="hasParkingSpaceFor">
  <rdfs:label>hasParkingSpaceFor</rdfs:label>
  <rdfs:domain rdf:resource="#Building"/>
  <rdfs:range rdf:resource="#Vehicle"/>
</daml:ObjectProperty>
...
```

**Figure 3: DAML+OIL code of the ontology.**

## 4. FUTURE WORK

Sandpiper's Visual Ontology Modeler is currently in beta test with Agentcities partners and other government and commercial organizations. The company plans to incorporate a number of features in the VOM over the course of the next 12 months, including import of DAML+OIL, OWL and RDFS ontologies, and a more complete management of versioning and maintenance. Sandpiper currently provides a library of base ontologies with the tool, as a starting point for ontology development, and it is working with beta users to identify high priority library ontologies for inclusion, such as ontologies that define concepts specified by ISO metadata standards.

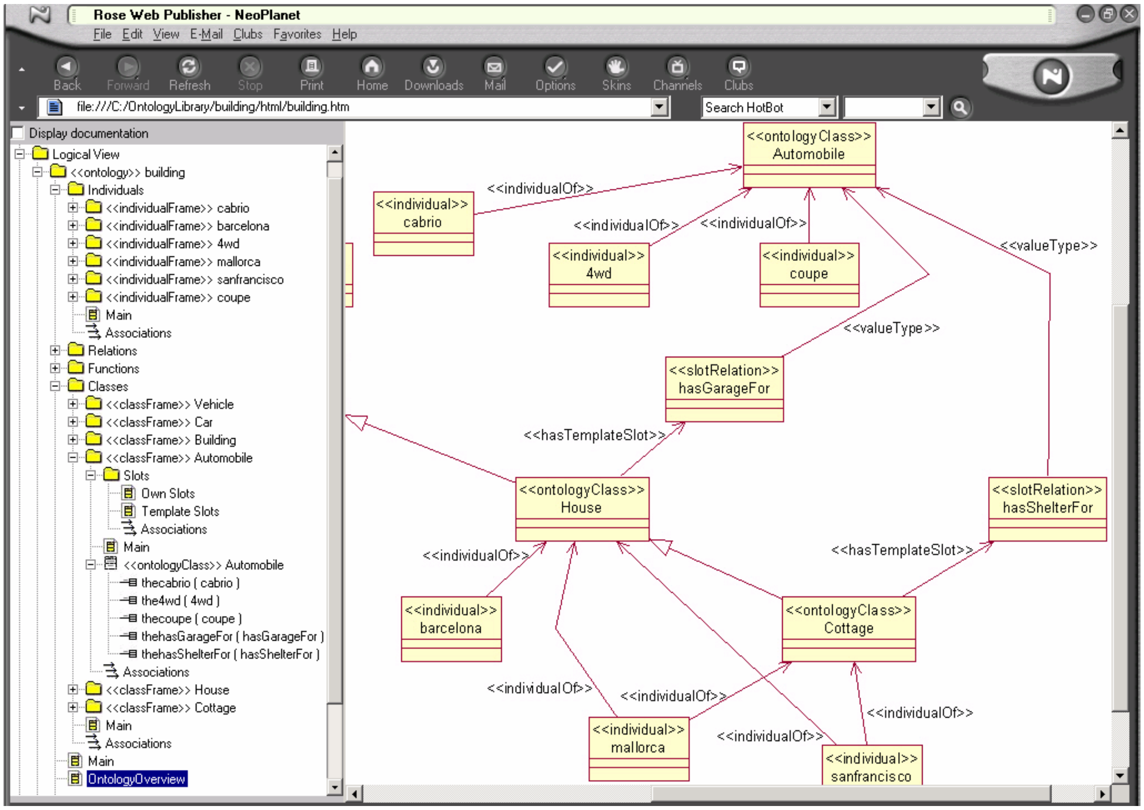


**Figure 4: HTML version of the ontology.**

Together, we plan to update the current set of Agentcities' utility ontologies to ground them in the standards-based libraries in work or in the IEEE-sponsored initiative for standardizing an Upper Ontology[14]. We also plan to collaborate with Agentcities' Ontology Server developers on the integration and deployment of these and other ontologies developed with VOM. Most importantly, we are planning to refine and document key elements of the collaborative ontology-development methodology work we have carried out as a part of this effort.

## 5. CONCLUSIONS

In this paper we presented a novel tool for semantically-grounded, graphical representation of ontologies. We described a tool, Sandpiper Software's Visual Ontology Modeler (VOM), able to generate, for an ontology: a logical view of all its elements, the corresponding UML-based graphical representation, its DAML+OIL code and an HTML version that can be published and browsed over the Web. VOM meets most of the necessities for collaborative ontology development and management in large-scale efforts, such as Agentcities. In particular, the requirements that VOM meets are: an easy to use, easy to communicate graphical representation; configuration management capabilities, including integration with version control; integrated consistency and completeness checking; automated export of DAML+OIL code. We think this tool can dramatically improve collaborative ontology development and maintenance in the framework of multi-agent system development, as in the case of the Agentcities initiative.

[14] See [http://suo.ieee.org/].

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