A Foundation for Strange Agent Negotiation

John Avery, John Yearwood

School of Information Technology and Mathematical Sciences, University of Ballarat, Australia
9952596@students.ballarat.edu.au
j.yearwood@ballarat.edu.au

Abstract

We define a strange agent as an agent with an ontology that is unknown, and possibly dissimilar, to another agent's. Proposed here are the foundations for a protocol, which will enable strange agents to, via a process of negotiation, discover something of each other's ontology's and represent these ontologies within their own. The purpose of this discovery being to enable the agents to decide if they may be of use to each other, and in the case where they can, enabling the agents to make use of each other.

Introduction

The vast array of existing agents with widely differing specialties, and very little interoperability, provides the impetus for strange agent negotiation. According to Bailin and Truszkowski (2001a):

> Ontology negotiation is becoming increasingly recognized as a crucial element of scalable agent technology. This is because agents by their very nature are supposed to operate with a fair amount of autonomy and independence from their end user. Part of this independence is the ability to enlist the help of other agents for help in performing a task.

Lister and Sterling (2001) site ontological differences as a fundamental obstacle to the development of informational agents and argue for systems that are tolerant of heterogeneity. They also discuss their system, the Automatic Reconciliation of XML Structures (AreXS) system that uses values of instances of attributes, as well as attribute names, to reconcile differences in XML structures encoding the same concepts.

Weinsten and Bimingham (1998) note that semantic interoperability requires some form of translation between terms. Truszkowski and Bailin (2001b, 2001c) propose a model of negotiation to implement this translation. The essence of their work is in the stage of negotiation they call the dialogue to deepen mutual understandings, where agents exchange and clarify descriptions of various parts of their ontologies. Using this model of ontology negotiation as a starting point, we explain a detailed theoretical model for implementing this dialogue to deepen mutual understandings. Much like Cybenko and Jiang's (1999) services matching, our work focuses on discovering what we call, functional ontology, that is the parts of an agent's ontology that relates to what the agent can do (actions), but not how the agent does them. Although in some instances this functional ontology may not account for much of the agent's ontology in terms of proportion, it is certainly an important part of the ontology as it describes what the agent is capable of doing.

An action model

In order to formally negotiate actions in a useful way we must have some kind of model to represent possible actions, an important part of this model is the definition of the input and output data of the action . Figure 1 describes

Action				The action.
	Label+			The name given to the action by the agent.
	Input*			Input if any to the action.
		Label+		Label given to the input data type.
		Measure		The way the data is measured.
			Type	The type of data (integer, string, real number, etc).
			Scale	The scale in which the data is measured.
			Label*	The label given to the scale in which the data is measured.
	Output*			Output if any of the action.
		Label+		Label given to the output data type.
		Measure		The way the data is measured.
			Type	The type of data (integer, string, real number, etc).
			Scale	The scale in which the data is measured.
			Label*	The label given to the scale in which the data is measured.

Figure 1 - Our action model.   grey - Indicates abstract/conceptual class.

our action model. Note that our action model is an abstract representation of actions and the concepts of the model may be represented in many ways in an actual agent's ontology.

Within the context of our action model, the functional ontology negotiation process is a process of negotiation in which strange agents discover each other's possible actions by discovering mutually understood parts of an action and by reconciling differences in parts of the action which are not mutually understood.

Reconciliation

For mutual understanding to be reached understanding must be shared at each level of the action tree hierarchy. Although the reconciliation of data and actions cannot be completely delineated, as understanding the data may facilitate understanding the action and vice-versa, we have found the distinction between actions and their data a useful subdivision to make when discussing the various means of reconciling them.

For agents to attempt to understand each other's ontology, there must be some common conceptual ground to work from, it is from this springboard that our ontology negotiation begins. Our negotiation process begins after the stage that Truszkowski and Bailin [4] name guess, confirm and clarify, in which the agent has determined the strange agents basic job description via a simple dialogue and now desires to learn more about it. Figure 2 shows a simple guess, confirm, and clarify dialogue.

Agent	What do you do?
StrangeAgent	I am the University of Ballarat credit transfer agent.
Agent	OK… So you can tell me if I am eligible for credit in computing units offered by the University of Ballarat.
StrangeAgent	Yes… I can find correlations between units at the Univeristy of Ballarat, and other universities.
Agent	OK

Figure 2 – A simple guess, confirm, and clarify example.

The next step is for Agent to ask for a description of the action that they are interested in. This corresponds to a request for the labels of the action and it's data (i.e. it's input and output). On receiving the labels of the action from StrangeAgent, Agent attempts to represent this action in it's ontology and responds to StrangeAgent with a reformulation of the labels of this action. StrangeAgent, who generally should have a greater understanding of this action than Agent, then either confirms or clarify's Agents description of this action. Clarification of the action label takes the form of a new description of the action, clarification of data labels is discussed in the next section.

This process of continuous reformulations continues until the action is understood, one or both of the agents decide that the action can never be understood by Agent, or Agent determines that the action will not be useful to it. Once the action's label, and the data types have been understood by Agent, Agent can represent the action within it's own ontology. If Agent wishes to know other actions a new action negotiation can begin.

When attempting to come to mutual understanding about data types, the first step is the reformulation process similar to that used in action label reconciliation. When the agents believe a mutual understanding of the data label has been reached StrangeAgent can communicate the data type to Agent. Agent can then test it's understanding of the data label. The method of testing depends on the data type. String data can be tested by an exchange of possible instances. For example two agents hoping to exchange information about universities might have the dialogue shown in Figure 2.

StrangeAgent	The input data is labeled course and contains strings.
Agent	OK… So course contains information such as "Bachelor of Computer Science" and "Bachelor of Information Technology"?
StrangeAgent	No… Course contains such information as "Introduction to Operating Systems" and "C Programming".
Agent	OK… It also contains information such as "Systems Programming" and "Software Engineering"?
StrangeAgent	Yes.
Agent	OK.

Figure 3 – Reconciling string data types.

StrangeAgent informs Agent that the input data is labeled "course", Agent has it's own data type labeled course, therefore believing understanding to be reached Agent tests this understanding by giving some example instances. StrangeAgent however does not recognise these instances as belonging to course, so provides some instances that do belong to course. These instances cause Agent to come to a different understanding about course (maybe Agent calls these pieces of information units, or subjects), and attempt to verify this new understanding. StrangeAgent then confirms Agent's new understanding.

If the data type is numeric (real, integer, etc) then before testing the concept the agents first use the reformulation process to come to a mutual understanding about the scale of the data. If this understanding is reached Agent can test it's understanding by providing a standard measure, for example an agent attempting to understand a strange agents concept of temperature may provide the value for the boiling point or freezing point of water. The strange agent may then involve the agent in counter reconciliation for the

meaning of the standard; values can then be compared and verified. Figure 3 shows a possible negotiation testing a numerical data type hypothesis.

Agent	What is the data scale?
StrangeAgent	The data scale is degrees celsius.
Agent	OK… So the boiling point of water is 100?
StrangeAgent	By boiling point of water do you mean the temperature at which water turns from liquid to gas.
Agent	Yes.
StrangeAgent	Then yes, in this scale the boiling point of water is 100.
Agent	OK.

Figure 4 – Testing a numerical hypothesis.

If no understanding about the scale can be reached, the agents can attempt to come to a mutual understanding of the scale by comparing standards or other mutually understood concepts and searching for relations between the known scales of the data label (which has already been reconciled) and the unknown scale. For example agents could reconcile the notions of degrees Celsius and degrees Fahrenheit by comparing two standards (boiling and freezing points of water for example) and making the assumption that the relation was linear. This hypothesis could be tested by the comparison of other standards (such as standard lab conditions or the current temperature).

Negotiation Protocol

A negotiation protocol is a set of rules that govern a negotiation. The negotiation protocol consists of the permissible players, the possible states of the negotiation, and the valid acts of players in particular states. The permissible players in our negotiation are any two agents implementing the protocol. The negotiation consists of eight possible negotiation states whose purpose and relationships are shown in Figure 5 and 6.
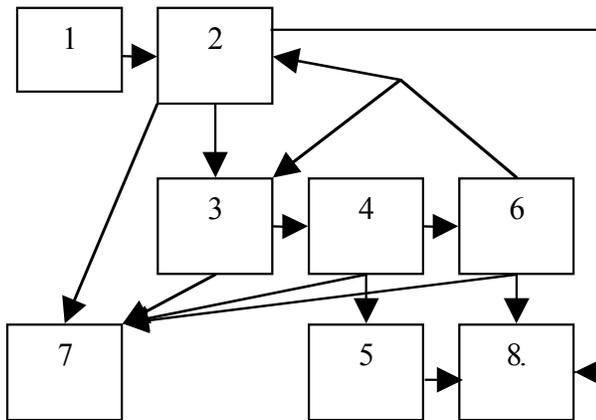

Figure 5 – Relationships between negotiation states.

No.	State	Description
1	Start	The Guess, Confirm and Clarify stage has been completed and the agents are ready to begin an action negotiation.
2	Reconciling Action Label	The agents begin negotiating about a specific action.
3	Reconciling Data Label	The agents attempt to reconcile the data types of the action
4	Reconciling Data Scale Label	The agents attempt to reconcile the scale of the data.
5	Testing Data Reconciliation	The agents believe data has been reconciled and test this understanding.
6	Reconciling Data Scale	The data scale is unknown to agent so an attempt to determine the scale is made.
7	Action could not be Reconciled	At least one part of the action could not be reconciled.
8	Action and Data Labels Reconciled.	The action and its data has been reconciled.

Figure 6 – The negotiation states.

Within each of these states there are valid actions, Figures 8-14 list and describe the various negotiation acts possible from each state of the negotiation. To demonstrate the protocol the example from figure 3 is presented and formatted according to the negotiation acts in figure 7.

```
Strange Agent-InformDataLabel("course")
            InformDataType("string")
Agent -     IndicateUnderstandingOfDataLabel("course")
            ProvideExampleOfData("Bachelor of Computer
            Science", "Bachelor of Information Technology")
Strange Agent-ProvideAlternativeExamplesOfData("Introduction to
            Operating System","C Programming")
Agent -     IndicateUnderstandingOfDataLabel("course")
            ProvideExampleOfData("Systems Programming",
            "Software Engineering")
Strange Agent-   AffirmExamplesOfData()
```

Figure 7 – Negotiation from figure 3 presented in negotiation acts.

Action	Initiated by	Description
Negotiate Action(action)	Agent	Agent wishes to begin reconciliation of action.
InformAction Label(label)	Strange Agent	Strange agent informs agent of action label.
InformData Label(lLabel)	Strange Agent	Strange agent informs agent of data label.

Figure 8 – Valid actions possible from the S*tart* state.

Action	Initiated by	Description
Indicate UnderstandingOfActionLabel (label)	Agent	Agent believes they understand action label.
Reformulate ActionLabel(re-formulation)	Agent	Agent reformulates action label and informs strange agent.
Affirm Reformulation OfActionLabel ()	Strange Agent	Strange agent affirms that agent's reformulation was accurate.
Correct Reformulation OfActionLabel (correction)	Strange Agent	Strange agent provides an alternate label for the action as agent's reformulation was inaccurate.
SuspendActionLabel Reconciliation (data label)	Agent or Strange Agent	Agent or strange agent suspends the action negotiation so that a data label can be reconciled before proceeding.
QuitAction LabelReconciliation(label)	Agent or Strange Agent	Agent or strange agent decides that action cannot be reconciled.

Figure 9 - Valid actions possible from the *Reconciling Action Label* state.

Action	Initiated by	Description
AssertStandard(standard)	Agent or Strange Agent	Either agent asserts a standard to be used for reconciling data scale.
Reformulate Standard (re-formulation)	Agent or Strange Agent	Receiving agent reformulates standard.
Affirm Reformulation OfStandard()	Agent or Strange Agent	Reformulation is affirmed.
Correct Reformulation OfStandard (correction)	Agent or Strange Agent	Reformulation was inaccurate and a corrected reformulation is provided.
ProvideValue ForStandard (value)	Agent or Strange Agent	A value is provided for an agreed upon standard.
QuitDataScale Reconciliation (label)	Agent StrangeAgent	Agent or strange agent decides that data scale label cannot be reconciled.

Figure 10 - Valid actions possible from *Reconciling Data Scale* state.

Action	Initiated by	Description
InformDataType(type)	Strange Agent	Strange agent informs agent of the data's type.
Indicate UnderstandingOfDataLabel (label)	Agent	Agent believes they understand data label.
Reformulate DataLabel(re-formulation)	Agent	Agent reformulates data label and informs strange agent.
AffirmReformulationOfDataLabel()	Strange Agent	Strange agent affirms that agent's reformulation was accurate.
Correct Reformulation OfDataLabel (correction)	Strange Agent	Strange agent provides an alternate label for the data as agent's reformulation was incorrect.
Provide ExamplesOfData (examples)	Agent	Agent believes they understand data label and presents some example data.
Affirm ExamplesOfData()	Strange Agent	Strange agent affirms that agents examples of data were appropriate.
Provide Alternative ExamplesOfData (examples)	Strange Agent	Strange agent provides alternative examples to those provided by agent.
QuitDataLabel Reconciliation (label)	Agent or Strange Agent	Agent or strange agent decides that data label cannot be reconciled.

Figure 11 - Valid actions possible from the *Reconciling Data Label* state.

Action	Initiated by	Description
Finish Negotiation()	Agent	Agent has finished negotiating with strange agent.
Negotiate Action(action)	Agent	Agent wishes to begin reconciliation of another action.

Figure 12 – Valid actions possible from the *Action and Data Labels Reconciled*, and the *Action Could Not Be Reconciled* states.

Action	Initiated by	Description
RequestValue ForStandard (standard)	Agent	Agent asks strange agent to provide value for the given standard.
Reformulate Standard(re-fomulation)	Strange Agent	Strange agent reformulates the standard and informs agent.
Affirm Reformulation OfStandard()	Agent	Agent affirms that strange agent's reformulation was accurate.
Correct Reformulation OfStandard (correction)	Agent	Agent provides an alternate (correct) description for the standard.
ProvideValue ForStandard (value)	Strange Agent	Strange agent provides a value for the mutually understood standard.
AffirmValue ForStandard()	Agent	Agent agrees with strange agents value for standard.
RefuteValue ForStandard()	Agent	Agent disagrees with strange agents value for standard.
QuitTesting DataReconcili ation(label)	Agent or Strange Agent	Agent or strange agent decides that data cannot be reconciled.

Figure 13 - Valid actions possible from *Testing Data Reconciliation* state.

Action	Initiated by	Description
Indicate Understanding OfDataScale Label(label)	Agent	Agent believes they understand data scale label.
Reformulate DataScale Label(re-formulation)	Agent	Agent reformulates data scale label and informs strange agent.
Affirm Reformulation OfDataScale Label()	Strange Agent	Strange agent affirms that agent's reformulation was accurate.
Correct Reformulation OfDataScale Label (correction)	Strange Agent	Strange agent provides an alternate label for the data scale as agent's reformulation was incorrect.
QuitDataScale Label Reconciliation (label)	Agent or Strange Agent	Agent or strange agent decides that data scale label cannot be reconciled.

Figure 14 - Valid actions possible from the *Reconciling Data Scale Label* state.

Implementation and Facilitation

This protocol relies heavily on the ability of the implementing agents to be able to reformulate the concepts represented within their ontology into a new description of that concept. This reformulation requires agents to have a rich knowledge of their domain and the domain's language. There will also need to be some base concepts that are mutually understood from which other concepts can be derived. We contend that this is not a limitation of the protocol but a limitation inherent in the process of strange agent negotiation. Unless agents have very similar understandings of the area of negotiation, they will require this rich knowledge of their domain and their domains language in order to arrive at a common understanding.

However, it is not necessary (although it may be beneficial) that *both* agents have such rich knowledge. If one agent has knowledge rich enough to understand the other agent's descriptions, and to reformulate their own descriptions into the language of the *simpler* agent, then the more complex agent can effectively teach the simple agent about the domain by sharing with it its own reformulations of the domain concepts.

Extending this idea we contend that a special class of agents, that we call facilitating agents, could make the process of implementing the protocol on existing agents much simpler. This class of agent has a rich knowledge of language and they aim to build information about a particular domain and it's language. They do this via ontology negotiation with a wide range of agents within the domain. These agents can then act as central enquiry points, and serve as a proxy between agents whose own negotiation capabilities are insignificant. Facilitating agents have ramifications not only in the stage of negotiation outlined in this paper but in earlier stages of negotiation and in the location of appropriate agents to begin negotiations with.

By using facilitating agents an existing agent can be modified to implement a *lightweight* version of the protocol which implements only those actions and states (those that present data, and those that indicate understanding or lack of understanding) that are required when one party is unable to reformulate concepts. The protocol can thus be added as a communication protocol with no necessary modifications to agent reasoning (and therefore can be easily added to agents with relatively simple reasoning capabilities, or even reactive agents). Obviously such a lightweight implementation sacrifices much of the power provided by the strange agent negotiation protocol, but it also significantly broadens the potential scope of the protocol.

Future Research

Future work will concentrate on three areas:

> The design, justification and testing of a method for measuring the amount of shared understanding reached by agents in ontology negotiation.
>
> Further implementation, refinement and testing of agents, both normal and facilitating, that implement this protocol.
>
> The design, justification and testing of standard frameworks for the addition of this protocol to an existing agent, and for the creation of an agent implementing this protocol.

Conclusion

The foundation we present will enable strange agents implementing our protocol to engage in functional ontology negotiation, and through this negotiation discover the ontology of each other's actions, enabling them to make use of these actions. Imperative to this process is the abstraction provided by our action model and the aspects of the protocol that use this model to facilitate the reconciliation of concepts at least partially understood by both agents, but internally represented in different ways.

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