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Perspectives: An Analysis of Multiple Viewpoints in Agent-Based Systems

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1 Introduction

This paper summarizes our ongoing effort to understand and characterize the uses of multiple perspectives in space science. We have attempted to bring together a variety of theories and research areas practiced by a variety of communities with apparently very limited cross-fertilization to date. For example, the combination of different levels of reasoning is widely recognized as being desirable in sensor data fusion applications (Hall & Llinas, 2001). However, we have not found a unifying account of the variety of possible approaches. In this effort, we try to perform such an accounting using the notion of *ontology*. Ontologies serve as a unifying device in a study of perspectives because they help to formalize the notion of an *interpretation*. There have been previous formalizations of the notions of observation and interpretation, such as Bennett *et al* (1989), but these have focused mostly on the quantitative treatment of uncertainty, rather than on the logical structure of an interpretation. Ontologies help in providing a logical treatment. By doing so, they provide a framework for integrating higher-level reasoning approaches.

2 A Model of Observation

At the most abstract level we can define an observer to be simply an entity that receives information. The nature of the information determines the type of observations being performed. Computationally, this notion of an observer can be modeled as an abstract entity containing a knowledge base (KB) and a port through which messages are received. Figure 1 illustrates the configuration.

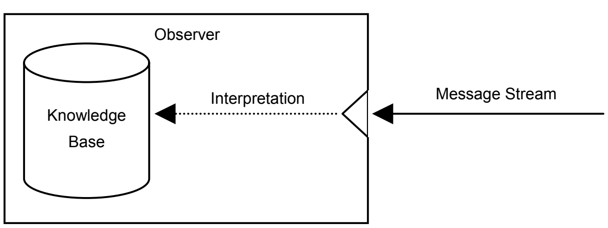

Figure 1. An abstract notion of observer can be formulated without any reference to the observed phenomena, since the observer knows the phenomena only through its observations and prior knowledge.

An observer interprets the messages it receives and updates its KB to accommodate the new information. In keeping with the abstract formulation of observer, we define *interpretation* to be this process of updating the KB in response to an observation.

We can make the notion of interpretation more precise by assuming that the KB comprises a set of knowledge *elements*. The nature of these elements depends on the knowledge representation, but they can usually be viewed as, or converted to, propositions, i.e., assertions. The product of the interpretation is a body of new knowledge consisting of one or more assertions. In the simplest case, the new elements are added to the KB. In more complex situations, portions of the KB may have to be retracted or modified in light of the newly acquired knowledge. This formulation is illustrated in Figure 2.

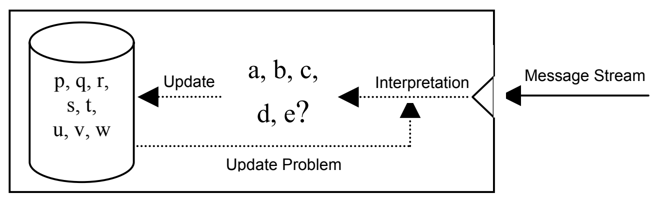

Figure 2. The product of interpretation is a set of knowledge elements, denoted in the figure by letters (a, b, c...). The new knowledge is then incorporated into the knowledge base. The prior contents of the KB, also denoted by letters (p, q, r...), may influence the interpretation by, for example, favoring an interpretation that is most consistent with what is currently believed.

3 Examples of Observation

3.1 Auditory Observation

Consider a person sitting in a room, listening to the faint sounds of piano music coming through one of the walls. The music, in this case, is the information being observed. The information can then be interpreted in a variety of ways: 1) Identification of the music – "that's Beethoven's Opus 110, second movement!" 2) An assessment of the musical performance – "the tempo is too slow!" 3) An assessment of the building's acoustics – "the walls are too thin!" 4) Hypotheses concerning the source of the music – "my neighbor is a pianist" or "my neighbor is an audio buff."

3.2 Remote Sensing

Consider a remote sensing device on an aircraft or spacecraft. The device measures electro-magnetic radiation in some spectral range. In this case, the information consists of the varying levels of radiation over time and over a spatial region. The information is encoded as a set of count rates or amplitudes correlated with a time interval, positioning information, and other contextual parameters. The information is used to determine a variety of properties of the body emitting the radiation. For example, it may (depending on the spectrum involved) be used to chart the topographic features of the body, to infer mineral abundances, or to identify and/or track particular objects.

3.3 Verbal Observation

Consider a political analyst trying to interpret events in a particular region of the world. He subscribes to several news services, which send him stories relevant to the interest areas he has selected. The stories arrive in the form of textual e-mail messages. In this case, the subjects of the stories—people, institutions, and events in the selected region—are the targets of observation. The stories are the analyst's sole source of information about the region; they are, therefore, the medium of his observations of these people, institutions, and events. The analyst's interpretation could range from the strictly factual, such as a map of the locations of key people over time, to the highly inferential, such as a model of a key person's intent or the prediction of an event.

4 Perspective Defined

4.1 Perspective as State

The abstract model described in Section 2 does not explicitly provide for observations occurring in time or space. It is easy to imagine a relative time parameter implicit in the notion of a message stream, since one message occurs after another in the stream. Where in space does this happen, however? In a remote sensing spacecraft scenario there are explicit spatial parameters; but in our textual observation example, does it make any sense to talk about perspective being determined by spatial parameters?

We can give meaning to the notion of spatial perspective in this example if we understand "space" in a more general way. The spatial relationship between the observer (the news story analyst) and the target of observation (the government referenced by the news) could be understood in an abstract sense—not in terms of spatial coordinates, but in terms of the countries to which they belong. The two countries do, of course, stand in an explicit spatial relationship, which are relevant to the new stories. For example, spatial proximity might indicate more vulnerability to attack. An analyst in a neighboring country might have a different perspective on the observations than an analyst in the USA.

Such considerations, however, involve more than just spatial relationships. At the very least, they include considerations of higher-level concepts that are derived only in part from explicitly spatial properties. They may also include considerations about the countries' relationships that have little to do with geography.

For this reason, we generalize the notion of time and space attributes to a more abstract notion of *state*. In our model of observation, the following formulation holds: *The perspective of an observer consists, in part, of its own* state *and the target's* state.

Since we do not have an explicit representation of the target, we must look to the observer's knowledge base for this information. Thus, an observer's perspective is partially determined by any state information, available in its knowledge base, describing either the observer or the target at the time the observation occurs. (Interestingly, the notion of time remains explicit, even in this generalization.)

4.2 Perspective as Data Types

The *medium* of an observation is another component of the observer's perspective. Auditory, electro-magnetic, and textual information represent three distinct media in our examples. More specific media in the remote sensing example correspond to frequency bands such as infrared, X-ray, gamma ray, etc. Different instruments will be capable of observing different frequency bands, and these may be construed as differences in the instruments' perspectives.

Our model of observation provides no notion of frequency band, nor does it explicitly identify any modalities such as audio, electro-magnetic, or textual signals. However, the notion of *message* suggests the presence of data types. We can construe the modalities of our running examples as different data types in the incoming message stream of the respective observers.

The perspective of the observer is not just a function of the data types of the incoming messages, but also of the data types of the interpretations. For example, spectral data may be interpreted to infer the chemical composition of the observed body's surface. They may also be used to map physical geographic properties such as altitude, smoothness, etc. These complementary uses of the same data may be considered two different perspectives.

Similarly, in the example auditory observation, the listener may infer different types of knowledge, which may be considered different perspectives taken towards the same observations. These include: 1) Properties of the music being played; 2) Properties of the neighbor from whose apartment the music is coming; 3) Properties of the building in which they live.

We can therefore expand the notion of perspective to include not only the data types of the incoming messages, but also the types of knowledge inferred through interpretation. This leads to the following formulation: *The perspective of an observer consists, in part, of the types of information in both the* domain *and the* range *of the interpretation function.*

4.3 Perspective as Interpretation Function

There is still another aspect of an observer's perspective, which is most apparent in the way the term is applied to human behavior. We often say that a person might draw different conclusions about a situation by taking a different perspective. At the level of data types, this amounts to drawing conclusions in different ontological categories: for example, conclusions about one's neighbor *vs.* conclusions about one's building. But there is more to perspective than this difference in categories. It is also a matter of drawing different, perhaps contradictory, conclusions within the same ontological category.

For example, from the presence of music coming through the wall of our apartment during the small hours of the morning, we might infer that our neighbor is inconsiderate. A different perspective, however, might suggest that our neighbor is overly optimistic about the sound-proofing of the walls, or that he feels compelled to practice the night before a big audition, or that he is hard of hearing and has turned up the volume on his stereo set without realizing how loud it is. Such reassessments are often referred to as "gaining a perspective on a problem." We may use similar colloquial expressions, such as "look at the situation a little bit differently," "take a step back and gain a broader view," or "look at it from the other person's perspective."

All of these cases involve taking the same incoming information—the message stream—and interpreting it according to a different algorithm. The different algorithm frequently involves combining the incoming information with different choices of previously acquired knowledge. It may involve identifying different questions, the answers to which might provide different interpretations of the data. For example, in the auditory scenario, instead of jumping to a conclusion about the neighbor's personality, we might ask: "What could conceivably be motivating him to play the piano at this hour?"

The posing of such questions, and more generally the choice of supplementary knowledge in light of which the current observations should be interpreted, is closely related to the topic of abductive reasoning, i.e., the search for explanations. We can formulate the following principle: *The perspective of an observer consists, in part, of the* choice of knowledge *brought to bear during the interpretation process—more generally, by the rules or algorithms governing the interpretation process.*

5 Application

Our model appears rather informal, but it can be given computational semantics using an object-oriented formalism. We are particularly interested in using the model to systematize the resolution of conflicting observations. One source of conflict is *noise*, which we construe to be any unsolicited information. Noise may be either *background* or *exceptional*. In remote sensing applications, the *calibration* process identifies the overall level of background noise and adjusts the signal processing to reflect this fact. An analogous process can be identified in other forms of observations. In our news story scenario, for example, the analyst might recognize certain speech acts as a constant of social discourse in the country being observed. She might therefore consider them insignificant and filter them out of the analysis. Conflicts stemming from exceptional noise are closely related to state-based conflicts of perspective. In such cases, the conflict may be resolved by including parametric state information in the interpretation functions.

If both calibration and parametric state information fail to resolve the conflict, then two possibilities remain. One or both interpretations may be defeasible (tentative). If not, then the conflict must be due to a difference in semantics in the respective target ontologies—in particular, the overloading of a term to mean different things. Frequently this occurs because a term is used by one ontology in a more specialized way than in another ontology. The conflict can then be resolved by "sliding" up or down the specialization hierarchy to obtain equivalent ontology categories.

We see this process at work in the interpretation of data from NASA lunar missions. Information from gamma ray and near-infrared instruments pertaining to iron abundances on the moon seemed to be conflicting, until it was realized that one of the instruments really provided information about only a particular class of iron compounds (Clark & McFadden, 2000). Thus, the conflict was resolved by reinterpreting an assumed ontological category as a more specialized category.

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