Active Knowledge Systems for the Pragmatic Web

Harry Delugach
Computer Science Department
University of Alabama in Huntsville
Huntsville, AL 35899 U.S.A.
delugach@cs.uah.edu

Abstract: As the limitations of the Semantic Web become apparent, the next step – creating the Pragmatic Web – requires active knowledge systems, that have the capability to support practical and complex human interaction and communication. A key ingredient in this effort is a system's ability to respond to events in the real world. The Pragmatic Web would therefore not be merely a knowledge interchange medium; it would actively support humans using that knowledge to accomplish tasks. The main goal of this paper is to show how an active knowledge system can support formal models of human pragmatic communication, combining earlier work on active knowledge systems, formal models of communication acts and formal models of organizational actors. We carry through an extended example illustrating some of these ideas.

1 Introduction

In the beginning, the Web was just text and files. The limitations of purely text- or file-based interactions on the Web are well known to anyone who has used a web search engine. In a sense, the words (text) are only the visible reflection of a wide range of cognitive and conceptual activities. The next challenge for the Web became: how do we figure out those cognitive and conceptual activities by examining the words? A number of approaches have been proposed, most of them relying on some previously constructed view of the world (an "ontology") on which some facts are based. Starting with the Cyc project in the 1980's [Cy96] and continuing through a number of other efforts (e.g., Guarino's [Gu95], KIF [GF92] and RDF [BG04]), these views of the world have formed the basis of efforts to codify and standardize ontologies.

For the most part, these efforts focus on first-order descriptions of properties and structure, from which we reason about the information stored on the Web. One could argue that the ability to reason (in any form) about information gives it the status of "knowledge". This aspect of the Web has been called the Semantic Web [BHL01].

First-order means that knowledge is encoded in the form of monotonic declarative statements about names and relations between them. Human activity, however, involves many non-monotonic aspects: learning, experimentation, scientific inquiry, negotiation, developing new norms, etc. One might argue that these are the most interesting activities among humans; in any case, they are among the most challenging to model and support with automated systems.

With the spreading of the Internet across the world, an enormous potential now exists for knowledge sharing and communication among people on an unprecedented scale. Millions of potential communities could be simultaneously supported by such a network. Unfortunately, the original intent of the Internet (resource sharing) and its sheer size still hamper the development of these communities. To realize their full potential, researchers have come to understand that augmenting human interaction through the network is the next step to achieve truly interactive and cooperative communities; we call this next step the Pragmatic Web [SMD06].

The main goal of this paper is to show how an active knowledge system can support formal models of human pragmatic communication, combining earlier work on active knowledge systems [De03], formal models of communication acts [HD03] [Ha06] and formal models of organizational actors [MJ01] [MD06]. With these kinds of models we have the opportunity to both analyze the communication itself and to simulate the communication with actual knowledge exchange. In the future, we believe an active knowledge system can anticipate some human needs and autonomously find knowledge that can be used in human communication.

The use of conceptual graphs [So92, So84] provides several advantages for modeling human collaborative activities. Its visual nature makes the models easier to grasp than traditional first-order logic. Its underlying formality allows us to model the activities so that we can detect possible sources of breakdowns and analyze new communication practices for their efficiency and completeness. Its ability to interface with the world outside the model allows a system to automatically gather additional information that may assist people in performing and improving their collaborative activities.

We should emphasize that while some parts of this system have been designed and some parts have been constructed, there is not yet a single coherent framework in which all these notions are realized. This is an area of ongoing research and development.

Section 2 of this paper sets the stage by describing some limitations of current modelling efforts focusing on the interpretations that must be established and communicated in order to maintain models in the Pragmatic Web. The goals and approach of active knowledge systems are also summarized briefly. Section 3 provides an extended example of some active knowledge systems features and suggests how they may support the goals and activities of the Pragmatic Web. Section 4 has some brief discussion and then Section 5 concludes the paper.

2 Modelling and Transformations

Much of modern electronic discourse is based on modelling – the formulation, representation and manipulation of symbolic models. This paper focuses on formal models – where the model's content can be automatically manipulated in some way and where its elements have well-defined relationships to each other so that we can reason about them. This section is meant to set the stage for the modelling approach in the rest of the paper.

It is my claim in this paper that effective formal models will be both dynamic (i.e., always changing) and interactive (i.e., able to autonomously interact with their environment). This is especially important in human-centered systems, where participants come and go, where their shared needs and goals undergo negotiation and modification, and where workflow products evolve from milestone to milestone. Models for such activities therefore need to be supported by systems and communities that understand and accommodate these changes.

Though it is easy to say that knowledge systems must be *active*, it is much harder to achieve this in practice. In creating the Semantic Web, in fact, there have been many cases where the creation of a static ontology was fairly straightforward (at least by experts), yet maintaining it over time was problematic (even for those same experts).

Though we do not claim that all Pragmatic Web knowledge can be formally modelled, there remains a strong incentive for seeking formal models to represent as much of it as possible, especially considering the large amounts of knowledge to be made explicit.

Models and the modelling process are often misunderstood or misused. Over time, a domain's model tends to acquire a life of its own, as more users rely on the model to explain phenomena, organize their thoughts and solve problems. There is also a human tendency to confuse the model with the reality it is supposed to represent, so that our perception of that reality becomes biased to fit the model. Eventually people forget that there ever was a process that created the model. This paper advocates an awareness of what are appropriate roles for models. (As someone once said, "when the map and the territory disagree, trust the territory.")

This paper holds that the processes of creating a model, establishing its validity, and maintaining it over time are as important as the model's content. Models are created by people with particular socio-cultural norms and goals, who are creating a model for particular purposes. Within that purpose, it is possible for its users to develop well-defined rules that preserve and/or derive symbols and relations in the model. Outside of that purpose, though, the model may or may not still be useful (or even correct!)

This section explains a viewpoint on modelling and why it is important to understand where models come from and how they should be effectively used.

2.1 Pragmatic interpretation as a process

At its heart, a model is just symbols, created by people to stand for other things. They are intrinsically meaningless, yet we use them every day, attach meaning to them, and communicate with them quite naturally and effortlessly. We are successful because of our ability to interpret a model and understand what it is "about". How do we establish these interpretations?

There is a well-understood branch of philosophy known as *model theory*, where formal properties of models are expressed in terms of an *interpretation*, a way to describe what the model is "about". An interpretation is a mapping from elements of the model to individuals and relationships in what is called a "domain of discourse" (sometimes informally called the "real world"). In this paper, I use the phrase "pragmatic interpretation" less formally in order to establish a framework for describing why active modelling is so important.

In this paper, a pragmatic interpretation encompasses all of the semantic, social and cultural knowledge relevant to the use of the model. This includes (albeit informally) the same notion as the model-theoretic interpretation (in the sense of "representing" individuals and relationships), but goes beyond mere knowledge about the individuals alone.

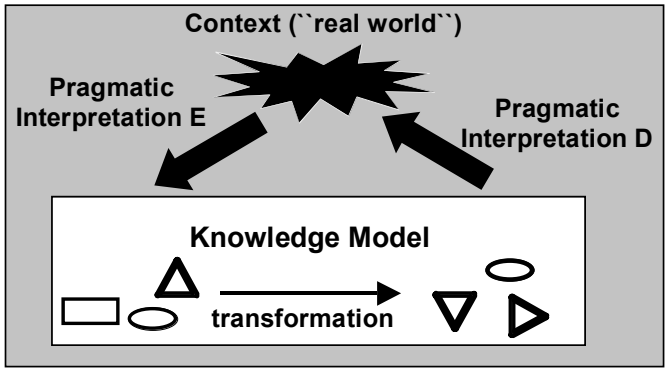

Figure 1: Pragmatic interpretations of a knowledge model.

Figure 1 shows the basic notion of the pragmatic interpretation. Its parts are explained in **Fehler! Verweisquelle konnte nicht gefunden werden.** below.

Context ("real world")	The semantic, social and cultural context for which the model is intended to be useful. This may appear to mean the entire universe, but that is never the case (unless someone intends to talk about literally everything).
Pragmatic Interpretation E (encode)	This simple "arrow" has wrapped into it the entire process of formulating knowledge model elements and mapping them to the real world, including deciding the purpose of the model. The context includes a wide range of social and cultural knowledge, including goals and intentions.
Knowledge Model	Any representation of the context that is deemed useful. This could be as simple as a text document or as complicated as a formal model.
Transformations	Model elements (see Knowledge Model) can be transformed into other model elements. This paper assumes that these transformations are to be done automatically, but that is not really required by the framework. Manual transformations may be adequate for some small models.
Pragmatic Interpretation D (decode)	This represents the process of decoding knowledge model element into human understandable things. Of course, it is strongly tied to the encoding process.

Table 2: Elements of figure 1

From Figure 1, it should be clear that there are multiple interpretations possible for any given knowledge model. If two or more participants assume different purposes for the model, then they will almost certainly obtain conflicting or at least unusable results. For effective communication, they must agree on some ontology as prescribed in the Semantic Web, but as pointed out in [SMD06], this ontology must be domain-specific, as well as culture-specific. It is up to an active knowledge system to provide such an ontology, or at the very least, greatly assist human participants in forming a custom or special-purpose ontology for their problem domain. See section 3 for details.

2.2 Active Knowledge Systems

The concept of an active knowledge system has been introduced elsewhere [De03]. Here we summarize its features in order to motivate the discussion of its features to support the Pragmatic Web. With active knowledge systems, we are interested in solving real-world problems using knowledge-based systems. The following are some of its goals:

- To build large-scale and robust models
- To move beyond declarative knowledge
- To model procedures and activities
- To model community goals and norms
- To remain firmly rooted in formal theory and representation
- A sound and complete system with respect to some part of the real-world

An effective knowledge system is therefore one that does at least the following things.

- Addresses needs that can be articulated in the real world
- Produces results that are meaningful and useful to people in the real world in addressing their needs
- Can be easily (re-)configured to provide meaningful and useful results in various domains
- Incorporates and accommodate new information
- Can reason about processes and activities as well as their steps and goals
- Can recognize nonsense
- Explains how it operates, including where its knowledge comes from, and how it reached its conclusions
- Is scalable to human-sized problems

The next section illustrates some (but not all) of these features, using conceptual graphs [12, 13] as a representation of an active knowledge system.

3 Features to support the Pragmatic Web

The major thrust of active knowledge systems is to develop formal systems that go beyond first-order logic, in particular their monotonicity – that is, the characteristic that premises and conclusions are unchanging over time. One of the most interesting aspects of human activity is that our world is constantly changing – sometimes changed by us, sometimes changed by external circumstances to which we must adapt. Though some knowledge can be effectively regarded as unchanging and permanent, we cannot complete the knowledge environment without accommodating change. In short, a knowledge base is not a photograph but a movie.

Another goal of using active knowledge systems is to establish the socio-cultural context of the participants in an activity. This involves a system becoming "aware" of each person's environment – their physical location, their occupation, their level of expertise in the activity, their accepted norms and of course their goals in pursuing the activity. Since these may change from activity to activity, the active knowledge system must be equipped to handle these changes also.

This section forms the heart of the paper, where we show some examples of how active knowledge systems can support human collaborative activities. As a sample activity, we will consider the simple scenario of a student working on a research paper for a professor's class. In order to motivate the use of the Pragmatic Web for this activity, we will assume the student and professor are widely dispersed on the globe, so that face-to-face or other real-time communication is inconvenient. (While admittedly a somewhat contrived example, it embodies enough pragmatic aspects for our purposes.)

We further assume that each participant is supported by a knowledge assistant that maintains a conceptual graph representation of their current context, goals, mental state, etc. These graphs are exchangeable with other participants' assistants in order to communicate and collaborate. Such a system has not yet been built; however, there are several current efforts to support such environments [Ka06] [KB06] [BP06].

An additional aspect of what can be formally modeled is the semantics of communication acts, e.g., the theories of Searle [Se79] and Habermas [Ha87] [Mc78]. This work has been pioneered by Harper [HD03] [Ha06] for the basic "inform" performatives. Using these formal models of communication, various additional performatives will be modeled, and thereby formally assist the active knowledge system in supporting the semantics of negotiation and argumentation.

With these parts of the communication process modeled formally, we can begin to describe an example negotiation between the student and the professor. This scenario is summarized in Table 1. The rest of this section expands the actions and illustrates how the active knowledge system supports the scenario's pragmatic aspects.

Student Action	**Professor Action**
	Request paper from the student
Proposes a short paper with 3 sections	
	Tells student that the paper needs 4 sections, 10 pages is minimum

Table 1: Student-professor scenario.

While it is our intention to model each step in the scenario using conceptual graphs, space does not permit all of them to be shown in this paper. The reader should consider the graphs shown as illustrations of the representation and the reasoning and activities which accompany it.

The initial situation is represented in conceptual graphs as in Figure 2. The student has a goal; namely, a report that has three parts; the professor believes a report has four. The graph represents the knowledge that the student believes a report has three parts: an introduction section, a body section and a conclusion section. The report has some unspecified length. The student also believes that he/she has a seat in the course that the professor is teaching. (This is also part of the professor's belief but is omitted for brevity.) The professor believes that a report has four parts: sections for introduction, background, discussion and conclusion. Note that the student does not have direct access to what the professor believes.

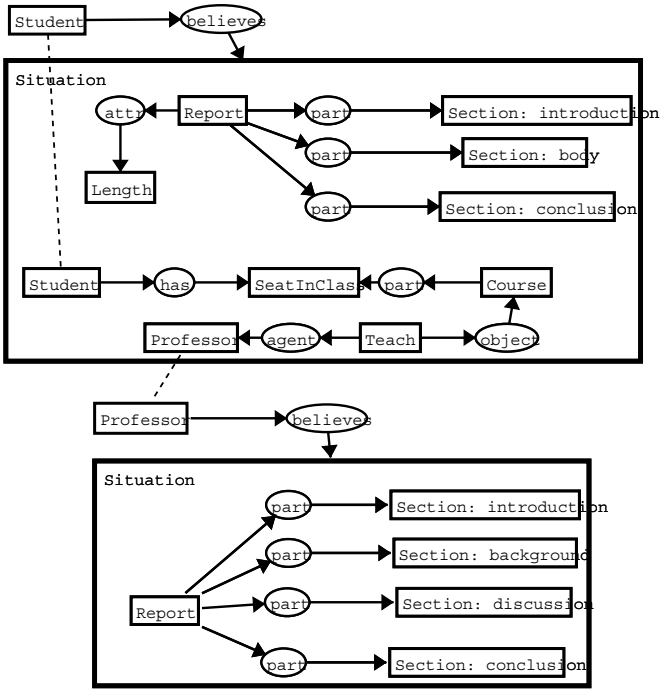

Figure 2. Student and professor's initial beliefs for the scenario.

In a conceptual graph, rectangles represent *concepts*, while ovals represent *relations* between them. The *arrows* simply represent the directional sense of each relation – i.e., relations are not symmetrical – they do not denote any flow or sequence. The dashed lines represent *identity* – in Figure 2 both **Student** concepts represent the single student of the scenario, etc. The larger boxes labeled **Situation** are composite concepts called *contexts*. The allow assertions about groups of concepts and relations.
The graphs in this paper illustrate some of the main strengths of conceptual graphs for the purposes of formal modeling, reasoning and simulation:

- Graphs are easy to understand, and therefore easier to validate with respect to the correctness of the models
- Contexts and possible worlds are represented formally
- Messages and interactions with the world outside the model are represented formally; this is illustrated by *CG-actors* in the later graphs.

The first part of the scenario involves the professor requesting a paper from the student, as shown in Figure 3. This action would be supported by a formal model of the "request" action, as suggested by extensions to the work of Harper [Ha06]. The diamond-shaped node in the graph represents a CG-actor (not to be confused with an organizational actor). It denotes a function that can operate on the graph and interact with the outside world. In this case, it represents the sending of a message to the student, which is modeled outside Figure 3. With CG-actors, the arrows' direction does in fact convey a flow – denoting the inputs (and outputs where present) for the CG-actor.

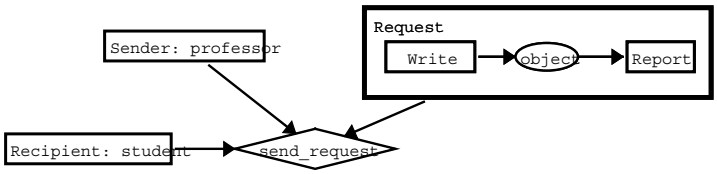

Figure 3. Professor requests the writing of a report.

Note that the model in Figure 3 does not just indicate that a message will be sent; the active knowledge system itself can simulate the sending of the message. Furthermore, we can assume that this request is made in the context of a traditional professor-student relationship to which certain norms of behavior apply. Another strength of conceptual graphs for pragmatic modeling is their ability to model these norms, as in [MD06], which both the student and professor (presumably) share. The graph in Figure 4 shows an example of these norms. The graph says that there is a professor teaching a class in which a student has a seat. If the professor requests a report of the student, then that student is required to initiate the writing of the report. This is in accordance with established norms between student and professor.

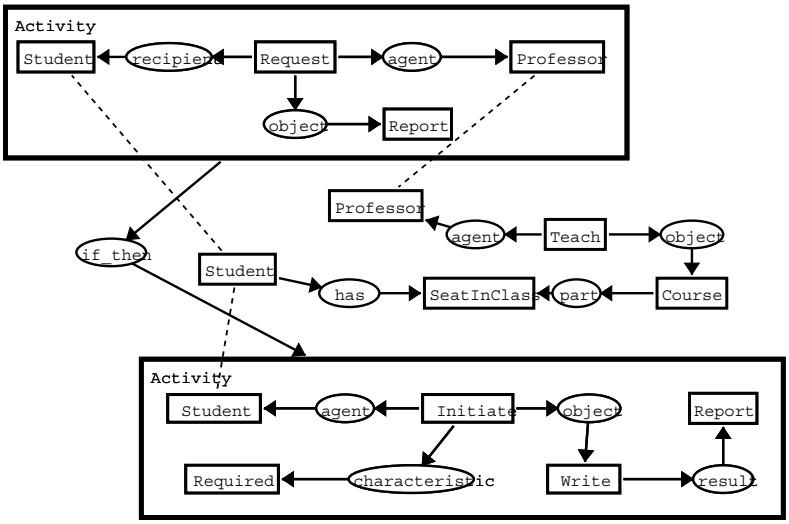

Figure 4. Professor-student norms with respect to a request to write a paper.

Based on these norms, when the student receives the request, the student incorporates a new activity; namely, initiating the writing of the report. The student's belief has an uninstantiated **Length** attribute in his belief about the report. Here is where the active knowledge system can augment human knowledge. Concepts in a graph can be linked to CG-actors that are capable of accessing a network and gathering information to either instantiate parts of a graph or insert new graphs (effectively representing new knowledge). The graph in Figure 5 shows a **survey** CG-actor that has surveyed a set of 3-section papers on the Web and determined the median length to be 8 pages. (The entire graph in Figure 5 is part of the student beliefs; the enclosing context as in Figure 2 is omitted for brevity.) As a result, the student now believes that the paper should be 8 pages long.

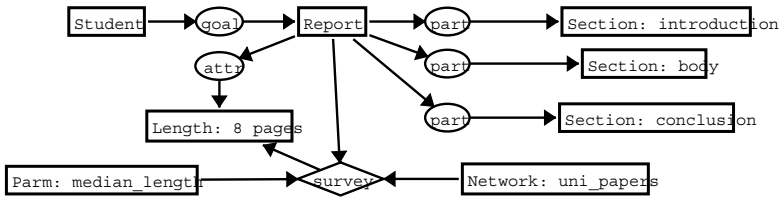

Figure 5. Result of CG-actor **survey** instantiated into student graph.

The student then informs the professor that he has the goal of a report in three sections, with a length of 8 pages. This communication is shown in Figure 6. Note that the justification (i.e., the survey) is not explicitly conveyed to the professor; however, there is nothing that would prevent it being sent along with the student's intention. We are still exploring techniques to determine when to include the justification for a decision or situation.

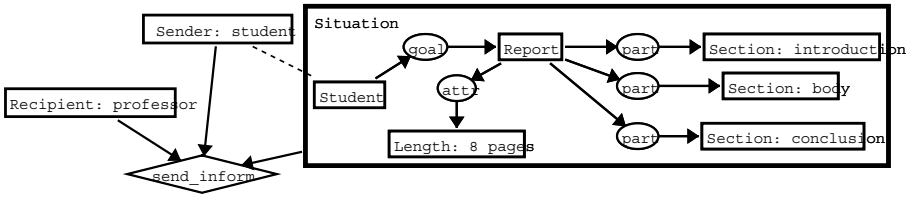

Figure 6. Student informs professor of intentions.

The reasoning system is able to compare the intent of the student with the belief of the professor. This comparison is based on well-understood semantics of conceptual graphs, and can be done automatically. As can be seen comparing Figure 2 with Figure 6, there is a conflict between the 3-section report proposed by the student and the 4-section report assumed by the professor. There is also an attribute **Length** (8 pages) in Figure 6 that does not appear at all in the professor's belief (though this is not necessarily a conflict). Both of these occurrences need to be handled by the active knowledge system.

The first conflict (i.e., the number of sections) is easily handled by having the professor send a revised request to the student that is more specific; i.e., gives the actual sections that the professor intended to be included. We do not show that revised request here, but the reader can construct it using Figure 2 and Figure 3.

The second "conflict" of the **Length** attribute would be more interesting to handle. An active knowledge system would look for the professor's sources of the length of a paper. We are still exploring the triggering mechanisms for this, but a reasonable source would be the professor's syllabus: the system would examine the syllabus, determine that papers have a specified length of, say, 10 pages, and would return that value as part of the specification of the paper.

The extended example in this section illustrated several different aspects of knowledge modeling for the Pragmatic Web and showed how an active knowledge systems, in addition to already-accepted features of conceptual graphs, can support human interaction and communication. This support can also be used to analyze and simulate the communication in order to better understand it.

4 Discussion

A strength of this approach (not illustrated here) is the use of norms in communication to validate acts themselves. For example, when the professor requests a paper of the student, the norms specify that the student is required to initiate the writing of the report. If the student did not do so, then an active assistant could detect that and note a breakdown in the communication.

A weakness of the chosen example is that there is usually a clear line of authority from a professor to a student. While there is some negotiation and collaboration involved, in this example the professor has shown little regard for compromise! This makes the example easier to present of course, since we do not have to account for a "meeting of the minds" in choosing a course of action.

Another weakness of the example is that each step in the scenario required only one response. For example, at the end in our conflict resolution, we could have combined the acquired length attribute with the paper's 4-section outline and sent a single message with the complete specification. Whether this is done in one message or two is an important issue to explored further.

As stated previously, while some parts of the approach have been realized, the parts have not yet been integrated into a practical system. Some of the reasons are that each part requires its own development and validation, and as these often rely on human involvement, progress is often slow. (It is interesting to speculate how the process of developing and validating active knowledge systems would be improved by using active knowledge systems themselves!)

Some parts of this approach have been validated in small experiments and projects. The modeling of process steps has been used in an actual aerospace development environment [MD06]. Conceptual graphs models have been used to compare various agent communication languages with respect to their grounding in speech act theory [Ha06].

5 Conclusion

Though clearly a work-in-progress, this approach has the potential to greatly enhance the effectiveness of human interaction over a network. Furthermore, it is likely to facilitate the study of organizational behavior in general, that that it can be analyzed and made more effective and efficient.

This paper argues that active knowledge systems can be an effective approach to supporting the Pragmatic Web. We would say that such systems complement, rather than replace current approaches. We have said little about what pragmatic content needs to be included in such systems; other researchers are also focused on those issues. Our systems can't be built without a clear understanding of the pragmatic knowledge necessary to solve these kinds of problems. Active knowledge systems merely provide a framework within which these other ideas can be incorporated into practical systems.

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