Using View Types to Generate Explanations in Intelligent Tutoring Systems

Art Souther Liane Acker James Lester Bruce Porter
Department of Computer Sciences
University of Texas at Austin

ABSTRACT

Providing coherent explanations of domain knowledge is essential for a fully functioning Intelligent Tutoring System (ITS). Current ITSs that generate explanations directly from domain knowledge offer limited applicability because they place restrictions on the form and extent of the domain knowledge. Moreover, generating explanations in tutors that are designed to teach the breadth of foundational knowledge conveyed in most introductory college courses poses special problems. These problems arise because this knowledge is complex and contains multiple, highly-integrated viewpoints. To overcome these problems, we propose a method for selecting only the knowledge that is relevant for generating a coherent explanation from a desired viewpoint. This method uses domain-independent knowledge in the form of *view types* to select the appropriate knowledge.

INTRODUCTION

Providing coherent explanations of domain knowledge is essential for a fully functioning Intelligent Tutoring System (ITS). There are two ways to provide coherent explanations: presenting "canned text" and generating explanations directly from the domain knowledge. Generating explanations offers several advantages, including providing explanations for unanticipated questions, tailoring explanations for the current situation and student, and ensuring consistency between the explanations and the knowledge base when the knowledge base changes.

Current ITSs have a limited solution to explanation generation. Their success results from limitations on the form and extent of domain knowledge. These limitations include dedicating the ITS to a single task [Clancey 87, Hollan 84], representing the domain knowledge with a relatively small number of rules or axioms [White 87, vanLehn 80, Brown 82], covering only a small portion of a domain [Brown 73], and explicitly partitioning the knowledge base according to the tasks for which the knowledge will be used [Brown 82, White 87].

There is an important class of tutors, however, that requires a more comprehensive solution to generating explanations. The domain of these tutors is the foundational knowledge conveyed in introductory college courses. For most subjects, this knowledge broadly surveys the domain, contains multiple, highly-integrated viewpoints, and is not reducible to a small number of principles or axioms. Large-scale knowledge bases containing fundamental knowledge pose a serious problem for explanation generation: to answer a question, a generator must efficiently select only the knowledge it needs to present a relevant explanation.

To address this problem, we present a method for selecting information from a knowledge base to answer a question.[1] This method uses viewpoints, which specify the knowledge to be selected. For example, to answer the question, "What is a car?", the viewpoint of a "car as a manufactured artifact" contains different information than a "car as a vehicle for transportation."

The use of viewpoints in organizing knowledge for explanations has been proposed by other researchers [Swartout 83, McKeown 85, Suthers 88]. However, both Swartout and McKeown encode viewpoints explicitly into the representation of the domain knowledge. Viewpoints in Swartout's XPLAIN consist of annotations on elements of domain knowledge. The annotations indicate when a piece of knowledge should be included in an explanation. McKeown also explicitly represents each viewpoint. These viewpoints are represented as separate classification hierarchies, one for each task in the domain. Explicitly representing all possible coherent viewpoints in a large-scale knowledge base is an intractable problem. Our solution is to dynamically generate viewpoints through the use of a small number of *view types* and their associated strategies. Suthers [Suthers 88] has proposed a *View Retriever* which seems to operate like our view type strategies, although the preliminary nature of the work in both cases makes comparison difficult.

REPRESENTING FOUNDATIONAL KNOWLEDGE

To investigate the problem of generating explanations from foundational knowledge, we have constructed a knowledge base in the domain of botanical anatomy, physiology, and development. Although the knowledge base currently contains over 4,000 concepts, it is only a small portion of the information contained in an introductory botany course.

The "backbone" of the knowledge base is a hierarchy of related botanical objects and processes. The relations support the inheritance of facts from general concepts to specific concepts. Each concept is represented by a *node*, and relations between concepts are represented by *arcs*. Figure 1 depicts the current state of the knowledge base with respect to chloroplast photosynthesis. Representing this process requires multiple viewpoints, such as "photosynthesis viewed as photochemical energy transduction" and "photosynthesis viewed as a producer of chemical bond energy." Although the representation is complex, it represents only a small part of the scientific knowledge about chloroplast photosynthesis.

Explanations are subgraphs of the knowledge base which is represented as a semantic network. Although a very large number of subgraphs of the botany knowledge base are possible, most subgraphs correspond to incoherent explanations. Therefore, some means must be provided to limit the nodes and arcs included when explanations are generated.

---

[1] Once selected, this knowledge constitutes a core from which an ITS's natural language generator may fashion an explanation. However, natural language generation is outside the scope of our current project.

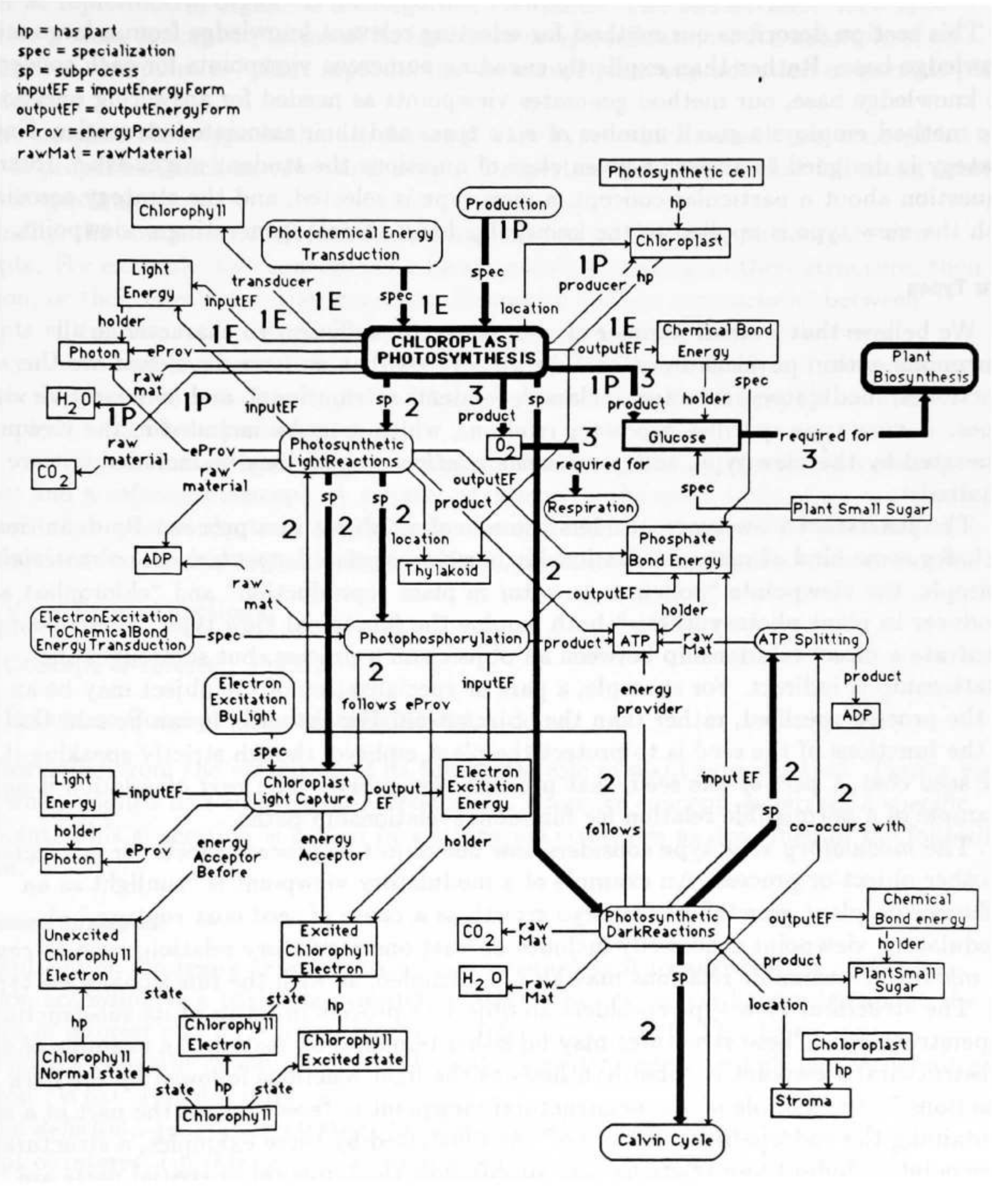

Figure 1: Chloroplast Photosynthesis

SELECTING KNOWLEDGE FOR EXPLANATION GENERATION

This section describes our method for selecting relevant knowledge from a large-scale knowledge base. Rather than explicitly encoding numerous viewpoints for each concept in the knowledge base, our method generates viewpoints as needed for answering questions. The method employs a small number of *view types* and their associated strategies. Each strategy is designed to answer a given class of questions the student might ask.[2] To answer a question about a particular concept, a view type is selected, and the strategy associated with the view type is applied to the knowledge base, thereby generating a viewpoint.

View Types

We believe that a small number of view types are sufficient to characterize all viewpoints within physical domains. The view types that we have developed are the functional, modulatory, structural, class-dependent, attributional, and comparative view types. A view type specifies *necessary relations*, which must be included in the viewpoints generated by the view type, and *permissible relations*, which may be included but are not required.

The *functional* view type considers the role of an object in a process. By definition, it includes some kind of *actor in* relationship, such as *producer, agent*, and *raw material.* For example, the viewpoints "pollen as an actor in plant reproduction" and "chloroplast as the producer in plant photosynthesis" both employ the functional view type. These examples illustrate a direct relationship between an object and a process, but sometimes the relationship is indirect. For example, a part or specialization of the object may be an actor in the process specified, rather than the object itself. For instance, it can be said that one of the functions of the seed is to protect the plant embryo, though strictly speaking it is the seed coat, a *part of* the seed, that protects the embryo. The *part of* relation is an example of a permissible relation for functional relationship paths.

The *modulatory* view type considers how one object or process affects (or is affected by) another object or process. An example of a modulatory viewpoint is "sunlight as an influence on plant growth" or "embryo growth as a cause of seed coat rupture." A modulatory viewpoint necessarily includes at least one regulatory relation, such as *causes* or *inhibits.* Permissible relations may also be included, as with the functional view type.

The *structural* view type considers an object or process in terms of its substructures or superstructures. These structures may be either temporal or spatial. An example of a substructural viewpoint is "photosynthesis as the light reactions followed by the dark reactions." An example of a superstructural viewpoint is "seed coat as the part of a seed containing the endosperm and embryo." As illustrated by these examples, a structural viewpoint includes those relations that specify how the temporal or spatial parts are interconnected.

The *class-dependent* view type considers a concept in terms of how it fits into a class hierarchy. There are two subtypes: categorical view type and enumerative view type. The *categorical* view type considers a concept in terms of the properties and relations it inherits

---

[2] These question types are described in [Porter 89].

from one of its generalizations or from a concept of which it is an instance. For example, "flower as reproductive organ" is a categorical viewpoint. The *enumerative* view type considers a class concept in terms of its instances or specializations. An example of an enumerative viewpoint is "plant reproduction as sexual plant reproduction or asexual plant reproduction."

The simplest view type is the *attributional* view type, which considers a concept in terms of properties, such as *color* and *weight.* Properties have values that fall along some range or spectrum.

Finally, the *comparative* view type uses a subordinate view type to compare two concepts. For example, two concepts can be compared according to their structure, their function, or their effects on other concepts. Examples include comparisons between concepts within the same category, as in "the similarities and differences between photosynthesis and chemosynthesis as energy transduction processes," and comparisons of the functional role of two objects, as in "the differences between 'chlorophyll a' and 'chlorophyll b' in photosynthesis."

A view type is instantiated to create a particular viewpoint by specifying a concept of interest and a reference concept. A *concept of interest* is the main topic of an explanation. A *reference concept* is the term to which the concept of interest should be related and is only required for the functional, categorical, and modulatory view types.[3] For example,

- View Type: Functional
- Concept of Interest: Pollen
- Reference Concept: Plant Reproduction

specifies pollen from the viewpoint of its functional role in plant reproduction. Thus a view type, when applied to a concept of interest and a reference concept, generates a specific viewpoint. This generation is guided by explanation strategies as described in the following section.[4]

Explanation Strategies

Explanation strategies select domain knowledge relevant to answering a particular question according to a particular viewpoint. Each strategy selects knowledge about the concept of interest and its relationship to the reference concept. This knowledge constitutes a coherent explanation. To illustrate these strategies we will use the definition question "What is photosynthesis?"

The *definition-generation* strategy for the categorical view type explains how the concept of interest (in this case, Photosynthesis) is a specialization of the reference concept. For the categorical view type, the reference concept can be any generalization of the concept of interest. Two possible choices for reference concept in this case are the knowledge base nodes Production and Photochemical Energy Transduction.

---

[3] The choice of reference concept depends on the dialogue history, the student's current understanding of the domain, and explanation heuristics.

[4] A more thorough discussion of the explanation strategies for each of the view types is found in [Porter 89].

A system using this strategy first collects all relations and properties that the concept of interest inherits from the reference concept. The relations inherited to Photosynthesis from Production are *producer*, *products*, and *raw materials* (see Figure 1, paths marked **1P**). Thus, the resulting definition contains the information that "Photosynthesis is a kind of production that has a chloroplast as the producer, water and carbon dioxide as the raw materials, and oxygen and glucose as the products." If Photochemical Energy Transduction is chosen as the reference concept instead of Production, the result contains the information "Photosynthesis is a kind of photochemical energy transduction that has chlorophyll as the transducer, a photon as the energy provider, light energy as the input energy form, and chemical bond energy as the output energy form" (Figure 1, paths marked **1E**).

The definition-generation strategy for the structural view type explains the substructural or superstructural relationships for an event or object. A substructural definition reports the values on all substructure arcs (*parts* or *stages* for objects, *subevents* for events). This definition also includes relations that describe the interconnection of parts or the ordering of subevents or stages. For example, a substructural definition of photosynthesis contains the information "Photosynthesis is an event consisting of two subevents: the light reactions followed by the dark reactions. The light reactions consist of chloroplast light capture followed by photophosphorylation. The dark reactions consist of the Calvin cycle and ATP splitting which occur simultaneously" (Figure 1, paths labeled **2**). A superstructural definition is constructed in an analogous manner and contains information about how the object or event is a component of an encompassing object or event.

The definition-generation strategy for the modulatory view type explains how the concept of interest explains how the concept of interest modulates the reference concept, or vice versa. This strategy requires a search for a path from the concept of interest to the reference concept consisting only of modulatory and permissible relations. This limitation on the kinds of arcs that may be traversed constrains search more effectively than general spreading activation. For example, suppose the chosen reference concept is Plant Biosynthesis. The search begins at Photosynthesis, but because no modulatory relations emanate from the concept Photosynthesis, a permissible relation must be chosen. One of the permissible relations is *products*, with values Oxygen and Glucose. Oxygen has a modulatory relation (*required for*) to Respiration, and Glucose has the same relation to Plant Biosynthesis (See Figure 1, paths labeled **3**). The search terminates because Plant Biosynthesis is the reference concept, and the resulting explanation contains the information "Photosynthesis has product glucose, which is required for plant biosynthesis."

CONCLUSION

Generating explanations using a large-scale knowledge base creates a serious problem: selecting relevant and coherent information. Past research on this problem has employed viewpoints to constrain knowledge selection. These viewpoints have been encoded by hand in a domain-dependent manner. However, a large-scale knowledge base, such as the one we have constructed in the domain of botany, requires a very large number of viewpoints. Our method for solving these problems uses view types, which can be used to generate viewpoints.

For each of our six view types, we have developed explanation generation strategies for two different classes of questions: definition requests and comparison questions. Each strategy locates the knowledge required to generate an explanation according to a particular view type. The strategies, either singly or in combination, were sufficient to generate each of 50 definitions selected from a botany textbook.

We are applying our research to the ITS task of presenting domain knowledge to students in a mixed-initiative environment. A question answerer, in conjunction with a pedagogical planner, will use the view types to answer students' questions and to provide instruction in the domain. By accessing a student model and a dialogue history, the system will be able to generate context-specific presentations.

ACKNOWLEDGEMENTS

We appreciate the work of Ken Murray, Karen Pittman, and Tom Jones on the Botany Knowledge Base Project. We are grateful to Ken Murray for helpful comments on previous drafts of this paper.

Support for this research was provided by the Army Research Office under grant ARO-DAAG29-84-K-0060, the National Science Foundation under grant IRI-8620052, and donations from Apple, Texas Instruments, and the Cray Foundation.

REFERENCES

[Brown 82] Brown, J.; Burton, R.; and de Kleer, J. (1982) Pedagogical, natural language, and knowledge engineering techniques in SOPHIE I, II, and III. In Sleeman, D.; and Brown, J. (Eds.) *Intelligent Tutoring Systems.* Academic Press, London.

[Brown 73] Brown, J.; Burton, R.; and Zdybel, F. (1973) A model-driven question-answering system for mixed-initiative computer-assisted instruction. *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 3, 248-257.

[Clancey 87] Clancey, W. (1987) *Knowledge-Based Tutoring: The GUIDON Program.* Cambridge, MA.: MIT Press.

[Hollan 84] Hollan, J.; Hutchins, E.; and Weitzman, L. (1984) STEAMER: An interactive inspectable simulation-based training system. *AI Magazine*, vol. 5, no. 2, 15-27.

[McKeown 85] McKeown, K. (1985). Tailoring Explanations for the User. *Columbia University Technical Report CUCS-172-85.*

[Porter 88] Porter, B.; Lester, J.; Murray, K.; Pittman, K.; Souther, A.; Acker, L.; and Jones, T. (1988) AI Research in the Context of a Multifunctional Knowledge Base Project. *AI Laboratory Technical Report AI88-88.* University of Texas at Austin.

[Porter 89] Porter, B.; Acker, L.; Lester, J.; and Souther, A. (1989) Generating explanations in an intelligent tutor designed to teach fundamental knowledge. *Second Intelligent Tutoring Systems Research Forum.* San Antonio.

[Suthers 88] Suthers, D. (1988). Providing multiple views of reasoning for explanation. *International Conference on Intelligent Tutoring Systems.* Montreal, Canada.

[Swartout 83] Swartout, W. (1983). XPLAIN: A system for creating and explaining expert consulting programs. *Artificial Intelligence*, vol. 21, 285-325.

[vanLehn 80] vanLehn, K.; and Brown, J. (1980) Planning nets: A representation for formalizing analogies and semantic models of procedural skills. In Snow, R.; Frederico, P.; and Montague, W. (Eds.) *Aptitude, Learning, and Instruction: Cognitive Process Analyses.* Hillsdale, NJ: Lawrence Erlbaum Associates.

[White 87] White, B.; and Frederiksen, J. (1987) Qualitative models and intelligent learning environments. In Lawler, R.; and Yazdani, M. (Eds.), *AI and Education.* New York: Ablex Publishing Co.