The Use of Multiple Knowledge Types in an Intelligent Tutoring System

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CIRCSIM-Tutor v. 3 is a natural-language based intelligent tutoring system (ITS) whose domain is cardiovascular physiology. Since the problems which CIRCSIM-Tutor teaches involve causal reasoning, it is not sufficient to tutor the student on a list of 'facts' or 'topics.' Instead, we must ensure that the tutor's utterances lead students through the reasoning we want them to learn. We present several examples showing that the knowledge base must include such *domain-dependent pedagogical knowledge*, as the knowledge required cannot be derived from domain axioms.

The following reasoning shows the derivation of the value of a variable using a rule from the domain knowledge base and a set of propositions representing a problem the student is working on. In this example, TPR (total peripheral resistance) is the name of a variable whose value the student is required to determine. 'Neural' and 'primary' are possible attributes of variables. 'DR' refers to the direct response stage of the physiological process being discussed.

1. TPR is neural.
2. TPR isn't primary.
3. Current stage is DR.
4. If V is neural and not primary, then V doesn't change in DR. *(domain axiom)*
5. Therefore TPR doesn't change.

This logic is sufficient for the mechanized tutor to 'know' the answer. But it is not sufficient to determine the form or content of a dialogue with a student.

To start with, this reasoning does not tell us how much of the content to say. For example, human tutors often give the student a hint by choosing only one fact to express:

T: But TPR is neural.

Second, once the content is chosen, the rule used to solve the problem is not necessarily the formulation the tutor wishes to give the student. For example, item 4 of the syllogism above could be expressed as follows:

T: Neural variables don't change in DR, unless they're primary.

But our expert tutors never use this formulation when the topic is a neural variable. What they actually say is:

T: Neural variables don't change in DR.

The latter is the fundamental idea which the tutors want the student to remember. The information about primary variables is secondary.

Furthermore, we must decide which logic to teach. Consider the process of using qualitative causal reasoning to determine the value of a variable from the values of previously determined variables. The mechanized tutor requires reasoning such as the following:

1. HR and SV are the determinants of CO.
2. HR increases.
3. SV does not have a value yet.
4. If V has two determinants and one of them has a value and the other one does not, then the value of V is determined by the one which has a value. *(domain axiom)*
5. Therefore CO increases.

Human beings, by contrast, can look at a diagram and follow the arrows without using an algorithm explicit enough for a computer. What human tutors actually say, either when working the problem or when teaching the solution to a student, is:

T: HR increases, so CO increases.

People typically simply ignore variables which do not have values yet. Thus the human tutor's utterance matches the student's implicit thought process, although the latter is not precise enough to encode in software.

Finally, once the content of the tutor's tutorial plan has been determined, there are multiple ways to interact with the student to teach it. Options might include generating a paragraph-style explanation for the student or engaging the student in a dialogue. For example, the hint above could be expressed in dialogue form as follows:

T: What controls TPR?
S: TPR is neural.
T: Well, then, how can you say that it increases?

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