REPRESENTATION OF ANALOGIES FOUND IN HUMAN TUTORING SESSIONS

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Abstract

We describe the use of analogies in 75 one-on-one tutoring sessions with first-year medical students carried on by two professors of physiology at Rush Medical College. Analogies were not very frequent, but were extremely effective when they were used. We have analyzed the goals, the topics, and the discourse strategies for proposing analogies. We have also studied the ways that the tutors follow up on these analogies and clarify them when necessary, with the goal of implementing analogies in our intelligent tutoring system, CIRCSIM-Tutor. Our knowledge representation scheme is based on Gentner's theory and Forbus' MAC/FAC model, which allows for structural mappings between analogies.

Keywords
Knowledge Representation, Education, E-Learning, Analogy, ITS, Tutoring,

Introduction

It is apparent that analogies play a major role in learning [1]. New research in cognitive science, education, artificial intelligence, and psychology, makes it possible to contemplate using a computational model to generate analogies in an intelligent tutoring system, but as far as we know, no one has implemented analogies in natural language dialogues in electronic tutoring systems. We plan to use our analysis of human tutoring sessions to determine how tutors use analogies and then simulate their behavior in CIRCSIM-Tutor using a computational model of memory retrieval and analog mapping. We are using Gentner's [2] model and a knowledge representation scheme described by Forbus et al., [3], which is comprised of content vectors constructed from predicate calculus representations of each analogue of the possible analogies.

This paper analyzes the use of analogy in seventy-five one-on-one tutoring sessions carried out by two professors of physiology at Rush Medical College. We have performed extensive SGML markup of the analogies in these sessions and tried to classify them in terms of their goals and their topics, whether proposed by the student or the tutor.

CIRCSIM-Tutor

It is our goal to implement analogies in CIRCSIM-Tutor, an electronic tutoring system that uses discourse planning and natural language generation techniques to simulate human tutoring sessions [4]. The topic is the baroreceptor reflex, which controls blood pressure in the cardiovascular system. The tutor has proven to be effective based on pre- and post-tests that were administered to the students before and after a one-hour session with CIRCSIM-Tutor. Results of these clearly indicated that students performed significantly better on post-tests than pre-tests ($p<.001$). A survey to evaluate student attitudes towards the system was also administered with positive responses. Students indicated that the system helped them better understand the baroreceptor reflex and helped them learn to predict responses. The implementation of analogies in the tutor will increase understanding of the material and facilitate learning.

Analogies in Cognitive Science

Gentner [5, p.107] defines analogies as:

> partial similarities between different situations that support further inferences. Specifically, analogy is a kind of similarity in which the same system of relations holds across different objects. Analogies thus capture parallels across different situations.

She argues that analogies exist everywhere in education, in problem solving, in reasoning, and in persuasion. Studies have included:

- Analyzing the way humans store and retrieve items and analogies from memory [3, 6, 7, 8].
- Attempts to simulate the results of human studies in computational models [9, 3, 10].
- Analogy and problem solving/reasoning [10, 7].
- Analogies in education/medicine [1, 11].

In these studies, two viewpoints regarding the role analogies play in cognition have emerged. One view is the theory that analogy is "core to cognition," not just important to problem solving [6]. Hofstadter [6] states that all thoughts and all words are comprised of categories, which are analogies and that thinking is comprised of movements between analogies that are stored in memory.

He feels that people use analogies to decide which thoughts to think next. Forbus, Gentner, Markman, and Ferguson [12] state that "analogy just looks like high level perception." They give convincing arguments that analogy is distinguishable from other processes, and can be viewed as a "mapping between structured representations" [5, p. 108].

Although there is disagreement regarding the role analogy plays in cognition, there is agreement that analogy is extremely important and worthy of further study. There is agreement among many cognitive scientists that reasoning analogically can be broken down into the following steps [7]:

- Memory retrieval of possible analogs stored in long-term memory.
- Mapping one or more of these analogs to the target in a meaningful way.
- Inferring new knowledge from the mapping.
- Evaluating and altering this new knowledge as needed.
- Learning can result from adding the new knowledge to long-term memory.

It is well known that human instructors use analogies to explain new concepts to students [1, 10, 7]. Goldblum [1] explains that humans learn more quickly when they can make connections, or analogies, between current knowledge and new knowledge. "Understanding one thing in terms of another is fundamental to the learning process," she says (p. 64-65). She advises instructors to use analogy to anchor new material to whatever relevant knowledge the student already possesses.

A well-known problem with analogies in education is that misunderstandings can occur. Feltovich et al. [13] studied misconceptions in cardiovascular physiology and argued that inappropriate analogies were at the root of many of them. Holyoak and Thagard [10] have devised a theory to utilize analogies while avoiding the problem of misconceptions, called the multiconstraint theory. It is based on three constraints that are needed to support an analogy: similarity, structure, and purpose. For example, it often helps medical students to compare the heart with a balloon (as we show in examples below), so it is understandable that they would also compare a failing heart to a sagging balloon. However, in this case, the analogy fails—the tension in the heart does not decrease, but increases as it fails, as opposed to a balloon that becomes stretched out.

We have been surveying computational models of analogy with the goal of finding one to use when simulating human tutoring in the CIRCSIM-Tutor System [4]. These models mainly focus on modeling the first two steps described above. The first step, memory retrieval based on similarity, has been modeled in two ways. One approach is to use case-based reasoning. Here the memory model is organized into cases or scenarios that can be retrieved when a similar case appears [8, 14, 15, 16, 17, 18, 19]. The other approach behaves more like a conventional document retrieval system; it is less accurate and may retrieve many irrelevant items along with the relevant ones. In the second step the information retrieved is mapped onto the target. Here again, there are two approaches: projection first, where inferences are made before the mappings, and alignment first, where structure mapping is performed first and then predictions are made. We have decided to use MAC/FAC, which uses an alignment-first mapping called Structure-Mapping Engine (SME) [5, 20, 21].

MAC/FAC

MAC/FAC (Many Are Called/Few Are Chosen) is based on Gentner's [2] theory called structure-mapping, where current knowledge is stored in memory and used to make inferences about new situations by mapping, or "aligning," relationships—not attributes—that exist in a "base" representation to relationships that exist in a "target" representation. The theory employs two main features regarding the rules used to make the mappings: (1) the rules must not depend on the content of the knowledge or domains, but only on the "syntactic properties of the knowledge representation" and (2) analogies are separate from "literal similarity, application of abstractions, and other kinds of comparisons" [2, p. 155].

The focus of the theory lies in the structured representation of the mapping from a base representation that is stored in memory to a target representation that one wants to make an analogy with. In MAC/FAC [3], content vectors are constructed for each entry in memory and the target from their predicate calculus representations. Each vector is comprised of a pairing of the functors that appear in the description and the number of times that functor occurs. The functors form a set of all "relations, connectives, object attributes, functions, etc.," [3, p. 162] that appear in all the predicate calculus descriptions for items in memory.

In MAC/FAC [3] the goals are to model:

- The fact that relationships are more important to humans than object attributes when comparing items in memory to the target.
- When recalling things from memory, superficial similarities between objects are more important to people than analogical similarities.
- Although more superficial retrievals are observed, people sometimes retrieve the more relevant analogical (structural) comparisons.

The first part of the two-stage process, the MAC stage, is designed to be "cheap and inefficient." Working memory, comprised of content vectors, is scanned in a parallel fashion, seeking vectors that are similar to the target's vectors, and utilizes the predicate calculus to compute the dot products between content vectors for the base and the target. Numerous items are retrieved, but the output will consist only of the best one, and ones within 10% of the best, to be used for the input of stage two. Stage two is the FAC stage. It utilizes a structure-mapping engine (SME) that takes its input from MAC. It does the structure-mapping described in Gentner [2] between the target and the base and selects the best mapping and all those within 10% of it.

Analysis of Analogies

We analyzed the use of analogies in 75 hour-long tutoring sessions with first year medical students carried out at Rush Medical College by two professors of physiology, Joel Michael and Allen Rovick. The topic was the baroreceptor reflex, which controls blood pressure in the cardiovascular system. The human sessions were marked up, by hand, using an annotation language based on SGML and described in [22]. Complete transcripts of the sessions are available by request. The sessions were conducted Face-To-Face and Keyboard-To-Keyboard (using the software called CDS, or Computer Dialogue System, which forces each person—student and tutor—to take turns typing [23]. Following is a discussion of five examples of the use of analogies found in the sessions. In these examples, the initial F or K indicates whether the session is Face-To-Face or Keyboard-To-Keyboard. The session number is next. The other two numbers indicate the turn and the sentence within the turn. For the examples shown, we decided not to correct the spelling and grammar errors in the original data, created as both tutor and student typed as fast as possible, in order to preserve its authenticity.

Example 1. An example of analogical use to explain new material appears in Face-To-Face session number one (F1). In this session, the student (st) makes an analogy by comparing the heart to a sink. This analogy does not meet Holyoak and Thagard's [10] structure constraint—the sink is not distensible and the heart is. The tutor (tu) advises the student to pick a more suitable analogy.

F1-st-62-1: If I make an analogy of you try to fill a sink with water and you...
F1-tu-63-1: Try to fill a balloon with water, since that's what we're dealing with, a distensible object.
F1-st-64-1: OK.

The session continues with the tutor guiding the student to making the appropriate, or analogical, structure-mapping—process as described in Holyoak and Thagard [10] and Gentner [2]—between the balloon and the heart:

Structure for the balloon
- fill a balloon with water
- it will distend
- the pressure in the balloon increases as it distends

Structure for the heart
- fill the right atrium
- the right atrium will distend
- pressure will increase as it distends

Making a one-to-one mapping between the relationships present in the two scenarios provided the student with a familiar situation to connect new knowledge to old, thereby increasing understanding of the new knowledge [1, 10, 2, 5].

Example 2. We see the tutor correcting a misconception in Face-To-Face session #7.

F7-tu-267-1: Well, let's give it another thought, OK?
F7-tu-267-2: We can look at that central blood chamber that means the big veins and the atria together as though they were an elastic chamber.
F7-tu-267-3: Is that not correct?
F7-st-268-1: Yeah, and the heart is the pump.
F7-tu-269-1: Well, let's stick to this elastic chamber and look at it first more or less in isolation.
F7-tu-269-2: If you have an elastic chamber what are the things that determine the pressure inside that chamber.
F7-st-270-1: Size.
F7-st-270-2: No.
F7-st-270-3: I mean if you..
F7-st-270-4: I mean...
F7-st-270-5: Area is one but I gather for the heart..
F7-tu-271-1: Area of what?
F7-st-272-1: Area that..
F7-st-272-2: I mean if you want to know what the pressure is of a gas or well liquids aren't that...
F7-st-272-3: We're not talking about gas, we're talking about liquids.
F7-st-272-4: And liquids are not affected by size because you can't compress the molecules that much.
F7-tu-273-1: Oh, you mean the volume occupied by the liquid, expansion and condensation of the liquid.
F7-tu-273-2: No.
F7-tu-273-3: That's not an issue.
F7-st-274-1: No, because we're talking about liquids and liquids aren't affected.
F7-st-274-2: Like with gas, besides the container matters a lot....
F7-tu-275-1: Let's throw away this atria central venous system and take instead something inanimate elastic stretcher, say like a balloon.
F7-tu-275-2: Right?
F7-tu-275-3: What determines what the pressure is inside the balloon?

The tutor presents the analogy of the atria as an elastic chamber, but the student fails to make the "connection" between existing knowledge and the new knowledge. The tutor, searching for existing knowledge that the student can use to make the appropriate "connections," switches to another analogy and instructs the student to compare the atria to a balloon. The student is able to make the correct mapping between the balloon and the atria and, as a result, understands the new material.

Example 3. Examples of a tutor prompting the student to make an analogy appear in many Keyboard-To-Keyboard sessions. This example is in Keyboard-To-Keyboard session #1.

K1-st-29-1: During the DR period it would remain unchanged.
K1-tu-30-1: Correct.
K1-tu-30-2: What other variables are neurally controlled?
K1-st-31-1: CC, HR
K1-tu-32-1: Again correct.

After discussing how a neurally controlled variable (TPR) behaves in the DR period, the tutor requests that the student come up with another neurally controlled variable. He then invites the student to infer from the analogy that the other variable will behave the same manner during this time period.

Example 4. Keyboard-To-Keyboard session #5 provides an example of a situation where the tutor prompts the student to make an analogy, but the student does not make the connection. As a result, the tutor finally tells the student the analogy that he is seeking.

K5-tu-31-1: No, it is under neural (sympathetic) control.
K5-tu-31-2: We are now discussing what happens in the DR period, before any neural (reflex) effects.
K5-tu-31-3: Sowhat will happ en to CC in this period?
K5-st-32-1: Cc 0.
K5-tu-33-1: Correct.
K5-tu-33-2: While we're on the subject, what other Variable is underneural contro l and how will it be affected in the DR?
K5-st-34-1: SV 0.
K5-st-34-2: It will not be affected in the DR.
K5-tu-35-1: Not true.
K5-tu-35-2: SV is only partially under neural control via CC, one of its importan t determinants.
K5-tu-35-3: We'll come back to this in a moment.
K5-tu-35-4: What othervariable is under neural control?
K5-tu-39-3: LIKE CC!.
K5-st-40-1: TPR 0.
K5-st-40-2: Sorry.
K5-tu-41-1: Yes.
K5-tu-41-2: Excused.

First, the student correctly predicts how CC, a neurally controlled variable, will react during this period. The tutor then prompts the student to make an analogy to other neurally controlled variables, because they react the same way. The tutor wants the student to recall what the other neurally controlled variables are and predict their behaviors. After several prompts, the tutor gives up and tells the student that he wants the student to infer that the other neurally controlled variables will behave like CC.

Example 5. In Keyboard-To-Keyboard session #64, the student initiates an analogy of the "heart like a traffic cop." The tutor seizes the opportunity to connect the new material to something that the student already understands and can relate to, but modifies the analogy to better suit the new knowledge. He instructs the student to think of a "traffic jam." Again, we see evidence of the process discussed in Goldblum [1], Holyoak and Thagard [10], and Gentner [2, 5].

K64-st-54-1: Would it be a reasonable analogy to look at the heart like a traffic cop?
K64-st-54-2: If it slows down the rate of blood flow (lets fewer cars through) then there will be a backup behind it (a backflow of blood prior to the heart, and therefore an increase in CVP) and fewer cars coming through (less blood coming out of the heart and therefore a decrease in MAP)
K64-tu-55-1: The analogy is OK.
K64-tu-55-2: But just as a traffic jam does not occur because cars back up, the increase in CVP caused by a fall in CO is not the result of blood BACKING UP.
K64-tu-55-3: Everything soes in one direction.
K64-st-56-1: well, slowing down would be a better way to put it then
K64-tu-57-1: Yes.
K64-tu-57-2: A traffic jam caused by everybody piling into the same area at once.

Results

Tables 1, 2, and 3 summarize the analogies that we found in human tutoring sessions described here. Out of the fifty analogies proposed by the tutors, nine were apparently intended only to enhance the student's understanding of the material discussed and not to lead to further development. Correct inferences had been made by the students and the analogies were used to reinforce the material learned. The remaining forty-one were intended to tutor the student on the material by making a correct structural mapping between the analogs and lead the student to correct their earlier predictions. In thirty-seven of those cases, an inference was requested by the tutor. These requests were met by seventeen successful attempts without the need for repair of the analogy. Fifteen cases resulted in correct inferences by the students after repairs to the analogy were made by the tutor. In only five out of the forty-one cases did the tutor abandon the analogy in favor of another teaching plan.

Eight cases of students proposing analogies were observed (Table 2). All eight resulted in correct mapping of the analogs with seven resulting in correct inferences made by the students. Although there were few student initiated analogies, all were very successful. Students are already aware of their own "existing knowledge" and are able to draw inferences based on mappings between what they already know and new material. These observations are in synchrony with Goldblum's [1] theory that all new knowledge must be connected to existing knowledge in order to be learned. These students sought to tie new material to what was already familiar to them.

Table 1: Observed Analogies Proposed by Tutors

Type	number of sessions
enhancement	9
no inference requested	
successful mapping	4
failed mapping	0
inference requested	
successful inference	17
failed inference	5
success after repair	15
failure after repair	0
Total	50

The wealth of bases for possible analogies can be seen in Table 3. The analogy that was most often proposed by the tutors was another neural variable—twenty-two times (once this analogy was proposed by a student). In five of these cases, the tutors eventually gave up on the analogy and utilized a different approach to the material, but the other seventeen were ultimately successful. There was one successful mapping without an attempt at an inference, twelve successful mappings with correct inferences, and four successful mappings with correct inferences after repairs. Other successful mappings occurred in a wide variety of bases such as the heart as a balloon or pump, Ohm's law, airplane wings, bootstraps, a dimmer switch, traffic jams, and a black box. These bases were not used as often, but made for extremely productive and interesting structural mappings resulting in correct inferences.

Table 2: Observed Analogies Proposed by Students

Type	number of sessions
no inference made	
successful mapping	1
failed mapping	0
inference made	
successful inference	7
failed inference	0
Total	8

In the tutoring sessions that we have studied, we observe expert tutors taking steps to avoid misconceptions, as recommended by Holyoak and Thagard [10]. They suggest that tutors:

- Make certain that students understand the system mapping.
- Use a variety of analogies.
- Inform students when an analogy is relevant and when it is not—point out the differences, as well as the similarities, between the known knowledge (bases) and the target.
- Correct misconceptions when they occur.

Table 3: Analogy Bases for Tutor Analogies

Base	Number of Session
another neural variable	23
balloon	5
reflex	2
Ohm's Law	2
traffic jam	2
bootstraps	1
brake & accelerator	1
dimmer switch	1
black box	1
pump	1
airplane wing	1
other	10

Conclusion

We have seen that analogies are relatively infrequent; on the average they occur less than once a session. But when human tutors use them, they are overwhelmingly effective. In these sessions, the expert tutors carry out repair and structure-mapping to make sure that the student understands the implications and makes correct inferences. They often take steps to be certain that their analogies do not lead to misconceptions, by explaining the range of application.

In the future, we hope to implement analogies in our intelligent tutoring system, CIRCSIM-Tutor [4], using the schemas observed in human tutors as our guide. The analogies found in the human tutoring sessions conducted by experts Michael and Rovick regarding the baroreceptor reflex will be further analyzed for structure-mapping [10, 2] and coding for memory retrieval [3]. The experts will be consulted regarding the construction of new analogies relevant to the material taking into account Thagard's [11] standard, schema, serendipity, and generation models of analog transfer used in medicine in an effort to avoid the superficial analogies mentioned by Holyoak and Thagard [10].

Computational issues that need to be addressed are (1) when to provide an analogy and (2) how to interpret student responses and correct misunderstandings. We hope to implement many of the schemas that we see human tutors using to support analogies. These steps are also recommended by Goldblum [1] and Hollywood & Thagard [10]: connecting new material to knowledge that the student already possesses and can relate it to, using a variety of analogies, informing students about the scope of relevance of the analogies proposed, correcting misunderstandings, and refining analogies to fit the material better.

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