Foundations of Case Based Reasoning and Applications to Hypertext

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Abstract

Case Based Reasoning (CBR) is a generalization of multiple learning techniques that uses remindings of similar situations in order to solve new problems. One of the key issues in CBR is the ability to identify these remindings through alternative indexes. Providing an adequate set of indexes provides a learner the random access required to support advanced knowledge acquisition in domains that are ill-structured. Combining CBR with hypertext can provide an environment that supports constructivism and the cognitive flexibility necessary for advanced learning. In this paper I provide a background of CBR, its foundations, and methodology. This is followed by a discussion of its applications in hypertext and how it can support the cognitive flexibility theory (Spiro R. J., 1992).

Introduction

Case Based Reasoning, (CBR), is a problem solving paradigm that utilizes the specific knowledge of previous experiences and concrete problems in order to solve new or similar situations (Aamodt, A., Plaza, E., 1994). It is a technique that supports incremental learning in that both our failures and our successes are cataloged for future use. As a cognitive model, CBR provides concrete knowledge, i.e. actual cases, versus abstract knowledge, i.e. rules. Experience is provided by means of a case library that has cause, effect, and lessons learned components. These cases have multiple indexes from which we may access this knowledge. Incorporating an appropriate set of indexes over these experiences provides the learner with alternative views into the same sets of cases. This technique provides support for learning in ill-structured domains, constructivism, and the cognitive flexibility required for advanced learning.

CBR in Context

Leake (1996) identifies two tenets of nature which underlie the CBR paradigm:

1. Similar problems have similar solutions.
2. The types of problems encountered by a learner tend to recur.

Thus, the primary source of knowledge is a set of cases in memory which can adapted to new situations. A learner builds upon knowledge of both success and failure. CBR explicitly integrates memory, learning, and reasoning (Kolodner, J.L. & Guzdial, M., 2000). This is motivated primarily from cognitive science and learning theory. As the knowledge base grows, the learner's intelligence grows as well. It is a natural evolution. In computer science this type learning is referred to as lazy learning because the learning is delayed until a new situation is encountered and solved (Mitchell, T. 1997).

Examples of CBR

Some examples of where CBR might be useful are illustrated in the following situations:

1. A teacher is trying to determine if she is breaking any copyright laws when she purchased a single copy of a workbook and wants to make copies of some of the pages for her students. She looks for similar situations and how they were approved or not approved by the authority at her school. Based upon these remindings she makes the decision not to copy the pages.
2. A speech pathologist is trying to evaluate a child's speech disorder that only occurs in high stress situations. He is reminded of several other children that had a similar disorder and reviews how they were treated and their success and failures. Based upon these remindings the speech pathologist recommends a treatment. The success and/or failure is recorded for future reference.

Types of CBR

CBR is, in essence, a paradigm covering a set of alternative methods that are based on accessing and using remindings. A reminding is nothing more than a past experience. This experience could be a previous conversation, cause-effect remembrance, or a situation in which the learner found herself before. These remindings are stored in a database of cases which can be accessed by the learner in order to solve a new or similar problem. The following is a list of the some of the primary types of CBR from (Aamodt, A., Plaza, E., 1994) including a brief discussion of each.

Exemplar-Based Reasoning

This category of CBR employs nothing more that classification of a new case based on how previous cases were classified. For example suppose a learner was trying to determine how to rate a movie G, PG, PG-13, or R. Using the case base the learner could look for similar movies with similar attributes and see how they were classified. Based upon how these were classified, the learner could then classify the new movie similarly. Because not all movies of the movies were perhaps classified, the same i.e. some may have been G and some PG, the learning could look at how the majority were classified and use that as it's classification scheme. The learner has the final say in the classification process and thus can override the solution. An alternative to this category is in instance-base learning which does not allow for the learner to override the solution.

Memory-based Reasoning

In memory-based reasoning decisions are based upon memories of specific events versus that of using relationships or rules built up from experience (Stanfill C. and Waltz D.L., 1988). For example, we remember a situation but we have no knowledge of how we got there or its relationship to anything else. An MBR system looks for those cases that match on indexes that are a close to the current situation as possible. The remindings are syntactic in nature versus the rich semantic nature of alternative CBR methods. Thus, computational processes that get the learner the most relevant cases based upon a matching of the index attributes are the ones employed in this method. Providing the cases in a relevance order allows the learner to explore the related cases to determine if they fit. How best to organize the memory separates this from other CBR methods.

Analogy-based Reasoning

Analogy-based Reasoning (ABR) is similar to CBR except that the learner solves the new situations with past experiences from a different domain. Transfer of knowledge is a major issue in the education of a learner. For example, we often use cross-domain analogies in education. In solving new computing applications we often look to biology and human cognition to help create the new solutions. Providing the learner with these cross-domain analogies is a quite complex task, but it offers a tremendous area of growth in the field.

Case-based Reasoning

Although this term is often confused with the actual paradigm, it does have a specific meaning as well. CBR distinguishes itself in that it employs more than an index structure to the case base. The cases are more complex and are supported by background knowledge. In a computer implementation this background knowledge could be a set of if-then rules or decision trees. Additionally, not all cases in the case base are complete but may be sub-cases that can be rolled together to solve the problem. In (Mitchell, T. 1997) several generic properties are listed that distinguish case-based reasoning from exemplar-based reasoning. Summarized, CBR is an instance-based method in which the cases may be rich relational descriptions, the retrieval and recombination process relies on both the case base and general knowledge, and there tends to be a tight coupling between the retrieval, the reasoning from the general knowledge, and the problem solving.

The Learning Cycle and its Implementation

The learning cycle in CBR can be generalized to have the following four steps (Aamodt, A., Plaza, E., 1994).

- Retrieve the most similar case or cases
- Reuse the information and knowledge in that case to solve the problem
- Revise the proposed solution
- Retain the parts of the experience likely to be useful for future problem solving

Although Aamodt and Plaza are speaking in computational terms, this process is very analogous to a human's cognitive process for problem solving. Remindings are retrieved to solve new problems. These remindings could cross domains and could be used in an analogy process. These retrieved experiences are then reused to solve the new problem. It may include a revision to an existing case or a combination of solutions from more than one case. The solution is then tested by the learner and some level of success or failure is recorded. Based upon this feedback, the case and it's solution are tagged appropriately for further reference. This process is additionally supported by the learner's general knowledge of the problem domain.

Computer implementation of the CBR cycle requires that a knowledge acquisition and engineering process take place first. This includes defining the cases electronically and providing the proper index and search capability. It often requires that experts be interviewed and their solutions to problems be recorded. Additionally, background knowledge is implemented in some fashion such as if-then rules, decision trees, or any number of mechanisms. An interface is developed that allows a learner to query the case base and retrieve cases that are similar to the one that needs to be solved. If similar cases are not found, then others may be generated that are either derived or are a combination of more than one case. This intelligent system may need to access the knowledge base to assist in the derivation. The learner has the option to create whole new cases if necessary. Finally, the computer implementation must provide the mechanism to remember the new situation and how it was eventually solve. This may include both success and failure information.

Applications to Cognitive Flexibility Theory

Spiro, et al., (1992) describe a constructivist theory of learning, Cognitive Flexibility Theory, which suggests that advanced learning in ill-structured domains must be supported through alternative cases and paths through a set of knowledge content. They suggest that the complexity of these types of domains cannot simply be learned in a single pass. Instead, the learning environment must be flexible with the ability to present the same knowledge of items in a variety of different ways. Their argument entails the notion that simply providing a set of situations and their solutions in order to illustrate a concept is not sufficient to provide support for advanced learning. Instead, the learner must have the ability to construct solutions to new situations from the knowledge content. This ability to adapt and form new content and knowledge can be implemented using theory-based hypertext systems which incorporate this flexibility. One of the theory-based alternatives is a hypertext system with a built-in case-based reasoner.

Cognitive Flexibility Theory (CFT) is actually a theory of case-base learning. As such, a case-based learning environment should incorporate features that support the five principles of a CFT as identified by (Spiro and Jacobson, 1995). These include:

- Use Multiple Conceptual Representations of Knowledge
- Link and Tailor Abstract Concepts to Different Case Examples
- Introduce Domain Complexity Early

- Stress Interrelated and Web-Like Nature of Knowledge
- Encourage Knowledge Assembly

By the very nature of a system built around case-based reasoning, these principles are upheld. For example, use of analogies to identify similar cases is an example of using multiple conceptual representations of knowledge. An alternative to this might be to use alternate points of view (i.e. student, instructor, or administrator) as indexes into a case-base. Again this supports the multiple conceptual representation of knowledge. CBR systems provide real-life case examples with their causes and their solutions as opposed to abstract concepts. This technique supports the second principle of linking and tailoring abstract concepts to different case examples. CBR systems provide cases that entail relationships that are not learned in isolation, but rather packaged together. This feature supports the third principle that domain complexity should be introduced early. With multiple indexes into its case-base, a CBR system provides for a web-like nature of knowledge and stresses interrelationships between the cases which support the fourth principle. Finally, a CBR system, by providing multiple alternative cases, supports the fifth principle of encouraging knowledge assembly.

A CBR Hypertext Example without an Automated Reasoner

An interesting example of how a hypertext environment can be implemented as a case-base reasoning system without an automated reasoner is clearly illustrated by the hyper-book Engines for Educations (Schank R. and Cleary C., 1995). The hyper-book describes a learning theory that suggests learners build knowledge through reasoning on what they remember or their past experiences. What makes this hyper-book unique is the ability to crisscross the material through multiple paths which is a requirement of the cognitive flexibility theory. By providing alternate indexes into the same body of material, Schank and Cleary have cleverly incorporated the techniques described in (Spiro, et. al., 1992). Additionally, examples (or cases) have been provided as a support mechanism throughout the text. They are provided as remindings for the learner to use in their construction of new knowledge. This has all been accomplished with no automated reasoner which makes it all the more intriguing.

A CBR Hypermedia Example with an Automated Reasoner

Creanimate is a case based teaching system that uses hypermedia and an automated reasoner to teach children about biology (Edelson, D., 1998). It was designed to help elementary school-aged children learn about how animals adapt with particular emphasis on physical features and how the physical features enable them to survive. The case-based reasoning system asks the students questions about creating new animals based upon the remindings. These remindings might suggest why some animals have wings and how it helps them adapt and survive in their environment. It is left up to the learner to create a new animal with the appropriate features that will allow them to survive. The learner can crisscross through the case-base creating new animals and learn biology in the process. Although this is not an implementation in hypertext, it provides us with an alternative that illustrates how a case-based reasoning system can help students learn.

A Proposed CBR Hypertext Example with an Automated Reasoner

Assessment Rubrics are used to measure outcomes of student performance in relationship to goals and objectives of a particular unit or course. Typically these rubrics can be broken down and indexed by a skill, dimension of the skill, a ranking of the skill, and a related textual description of the rank. Below is an example:

	UNSATISFACTORY	**BASIC**	**PROFICIENT**
Writing			
Responsive To Article	Presents a response to the ideas presented in the article that is surface and/or lacks in-depth engagement of the ideas presented. Weak presentation of the relationship between the ideas presented in the article and an education related issue.	Presents a logical response to the ideas presented in the article, and an exploration of the impact of these ideas on an education related issue that is fairly well supported.	Presents an insightful, logical, and compelling response to the ideas presented in the article and a well-supported exploration of the impact of these ideas on an education related issue.

In this example there is one skill listed, *Writing*, with one dimension called *Responsive to Article*. It has three rankings including unsatisfactory, basic, and proficient. The relationship between the ranks, skills, and dimensions are described in the text. These are referred to as benchmarks.

Assessment of students and the use of the assessment knowledge are very complex and are ill-structured. To get an idea of this, just ask a couple of different people in education about their thoughts on it, and you will get many different answers. Thus, the building of a rubric and its use for assessment is a great opportunity for us to use a case-based reasoning system to support this process.

To get an idea of how we might implement such a system and conform to the CFT principles set forth by Spiro and Jacobson (1995) we need to consider the indexing mechanisms, accessing strategies, alternative points of view, and the crisscrossing mechanisms for this application. Much of that work has yet to be done, but here might be some alternatives. For the indexing mechanism it is probably appropriate to provide at a minimum indexes on the skill, dimension, rank, and benchmark. Additionally since rubrics are tied to units or courses, these might be indexes as well. Sample queries into the case-base could provide lists such as give me a list of the rubrics that test writing skills and are math based. Additionally alternate points of view could be implemented to support the student, teacher, and the administrator. A student might have a different view point of assessment of writing in math versus that of a teacher. Thus the system should provide for that. Accessing and implementation will be through a hyperlinked document with an underlying relational database. Finally, A CBR system should be able to adapt and incorporate new knowledge. Thus, as new rubrics are generated, the system will need to allow for the storage and retrieval of the new knowledge. It is my intent to implement this application in the near future (note: CBRubric is currently in prototype form).

Concluding Remarks

CBR is a principle of constructivism that can be used to support advanced learning in an ill-structured domain. It provides an environment that allows for the crisscrossing of the knowledge content, and it underlies the cognitive flexibility theory. As such, hypertext learning environments can be established that incorporate CBR in a variety of ways. Examples can be provided in an automated way through an advanced search, reuse, and revise mechanism, or they can be provided with clever hypertext indexing schemes. As Kolodner & Guzdial (2000) point out CBR can:

- suggest resources - i.e. through well indexed case libraries and lessons learned
- suggest activities - i.e. through the writing of new cases
- suggest ways of moving forward - i.e. managing the classroom to move forward through sharing
- suggest ways of creating useful case libraries - i.e. seed the library and let it grow

There are many opportunities for us to use CBR in a hypertext environment. In this paper I have presented yet another alternative, the rubric example. Perhaps this discussion has prompted you to think of some as well.

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