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A Case-Based Approach to Creative Design

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1 Productivity Measures

Refereed papers submitted but not yet published: 5

Refereed papers published: 6

Unrefereed reports and articles: 2

Books or parts thereof submitted but not yet published: 1

Books or parts thereof published: 1

Patents filed but not yet granted: 0

Patents granted: 0

Invited presentations: 8

Contributed presentations: 4

Honors received: 4

> Kolodner has been appointed steering committee chair for the Cognitive Science Conference to be held in Atlanta, GA in August 1994. She has also been acting as EduTech Institute interim director and has been selected to be a member of the steering committee for the proposed Engineering Research Center.
>
> Goel has been appointed a Vice-Chair of the third International AI in Design Conference to be held in Zurich, Switzerland in August 1994.

Prizes or awards received (Nobel, Japan, Turing, etc.): 0

Promotions obtained: 0

Graduate students supported $\geq$ 25% of full time: 3

Post-docs supported $\geq$ 25% of full time: 1

Minorities supported: 3

2 Detailed Summary of Technical Progress

We are studying and modeling creative design processes. Our goals are two-fold. One is to make intelligent, computer-based design assistants more creative (e.g., able to suggest unusual but useful solutions and to bring up important issues that might not have been considered otherwise). The other is to build computational models that help us understand human creativity. This will have implications for design education and suggest ways of enhancing the creativity of human designers.

2.1 Exploratory Study

To gain insights into the knowledge and reasoning involved in creative design, we performed an exploratory study of student mechanical engineers engaged in a seven-week undergraduate design project. In this study, we observed a great deal of the design process, including informal team meetings (e.g., while choosing materials at a store) as well as "official" meetings. This has given us insights into the processes underlying many creative design activities, particularly the following. How designers generate multiple alternative views of a problem through situation assessment and reformulation. How problem constraints, evaluation criteria, and preferences gradually emerge or become refined as ideas are proposed and critiqued. How designers serendipitously recognize solutions to pending problems, often seeing new functions and purposes for common design pieces in the process.

2.2 Results of Study

Our study has found that creativity is not a process that gets turned on and off but arises out of a confluence of processes (such as problem elaboration and understanding, remembering, adaptation, evaluation and refinement of proposed solutions), each of which we all do everyday, and each of which interacts with the other processes in complex ways. Much of what we talk about as creativity arises from interesting strategic control of these processes and their integration. Thus, under our view, one doesn't talk about a creative person or even a creative product, but rather a creative *process*. Those of us with more interesting strategic control of our reasoning processes, including the ability to make connections between things, tend to reason in ways that produce more interesting results. (Our analysis of our observations is summarized in [Kolodner 1993a] and [Kolodner 1993b].)

Our model of the creative design process is shown in Figure ??. Creative designers often start with an incomplete, contradictory, and underconstrained description of what needs to be designed and transform it into something with more detail, more concrete specifications, and more clearly defined and consistent constraints. At the same time. creative designers generate several design alternatives, elaborating and adapting them, and often corporating pieces of one into another.

It is the evaluation of these alternatives that is the core driving force behind these processes. The designer continually updates the design specification as well as a pool of design ideas under consideration. Each alternative generated is evaluated to identify its advantages and disadvantages and to check that it satisfies the constraints in the current design specification. A key part of evaluation is "trying out" the alternative (e.g., through experimentation or mental simulation). This generates a more detailed description of the alternative, including the consequences of its operation and how environmental factors affect it.

Evaluation raises questions of legality or desirableness of features of a design alternative and it detects contradictions and ambiguities in the specification. The resolution of these questions, contradictions, and ambiguities serves to refine, augment, and reformulate the design specification. On the generative side, the critique generated during evaluation provides the basis for comparison of alternatives, often suggesting interesting adaptations or ways of merging them.

The three processes interact opportunistically. The generative phase, guided by critiques from the evaluation phase, watches for opportunities to merge or adapt design ideas to create new alternatives. The design specification is incrementally updated as ideas are tested and flaws or desirable features become apparent.

The continual elaboration and reformulation of the problem (i.e., the design specification) derives abstract connections between the current problem and similar problems in other domains, facilitating cross-contextual transfer of design ideas. Continual redescription of what the solution (i.e., the evolving design) looks like primes the designer to serendipitously recognize the solution if the designer comes across it. In other words, redescription creates a "lens" with which to assess new situations, enabling the designer to overcome functional fixation and see alternative functions and uses for common design pieces [Wills and Kolodner 1994b].

2.3 Case-Based Computational Model

These processes rely heavily on previous design experiences and knowledge of designed artifacts. An expert designer knows of many design experiences, accumulated from personally designing artifacts, being given case studies of designs in school, and observing artifacts designed by others. Through our observations and analyses we have found that reminding of these experiences is crucial to generating design alternatives, reformulating and elaborating the problem specification or proposed solutions, predicting the outcome of making certain design decisions, enabling visualization and simulation of proposed designs, and communicating abstract ideas in concrete terms.

The experiences that are most valuable are often highly contextualized pieces of knowledge about these artifacts, such as how a device behaves in some context of use, circumstances in which it can fail, and knowledge about situations that might come up not only in use, but in all phases of its life cycle. Given the nature of these experiences, we are using case-based representations and reasoning techniques [Kolodner 1993bk] to model the creative processes we have identified.

A particularly significant role that design cases play is in addressing the problem of *focus*: How does the designer know which details to pay attention to? Which aspects of an old design can suggest problem reformulations or can fill in missing details of the specification? During problem reformulation, which constraints should be relaxed or strengthened? Which evaluative questions and criteria should be raised to critique the proposed design options?

Design cases help address these issues by providing information about the consequences of past situations and what details were important in previous designs. Intentionally interpreting the current situation in terms of past experiences and reinterpreting previous solutions in the current context help to reveal and make explicit underlying assumptions. This can often lead to a useful problem reformulation or relaxation of constraints. (Details of how cases help address focus-related issues can be found in [Kolodner 1993b].)

We are also exploring the important role design experiences play in the theory development and conceptual change that occur in evolving a design specification [Griffith, et al. 1994]. In our study, the student designers came to a better understanding of what the constraints of the problem were by performing many experiments with proposed design pieces and by recalling experiences they had had with devices for solving similar problems. These led to theories to account for the outcome of the experiments and previous designs. Sometimes an experiment or recalled case did not fit within an existing theory; explaining this anomalous data resulted in a conceptual change which led to a new way of viewing the problem to be solved. In general, theory development helps to refine vague, abstract problem constraints making them more concrete and operationalized.

Conceptual change involves a fundamental change in the underlying knowledge representations in terms of which the reasoner thinks about the domain. It involves the construction of new concepts and theories, and the modification and extrapolation of existing concepts and theories in novel situations [Ram 1993a]. We are studying conceptual change not only in the context of specification evolution, but also in the context of story comprehension [Moorman 1994]. Consider, for example, reading a science fiction story, in which one must learn enough about an unusual world to accept it as the background for the story, and then must understand the story itself. In general, all types of reading – indeed, all types of comprehension – require us to learn about and modify our conceptions and beliefs to some extent. We have found that many of the same creative processes are involved in understanding unusual and novel situations as are involved in solving problems and designing in these situations.

Research in case-based reasoning (CBR) has provided extensive knowledge of how to reuse solutions to old problems in new situations, how to build and search case libraries (for exploration of design alternatives), and how to merge and adapt cases. It has developed powerful techniques for partial matching and the formation of analogical maps between seemingly disparate situations [Kolodner 1993bk] – exactly the kinds of phenomena that are central to creativity.

In applying case-based representations and reasoning techniques to modeling creative design, we are finding ways of improving existing case-based reasoning systems. Many existing CBR systems are not living up to their potential. They tend to adapt and reuse old solutions in routine ways, producing robust but uninspired results. They do not attempt to extend their exploration by deriving constraints and preferences that improve or go beyond those stated in the original problem.

We have found that case-based reasoning systems can be improved by focusing more research attention on the kinds of situation assessment, evaluation, and assimilation processes that facilitate the exploration of ideas and the elaboration and redefinition of problems that are crucial to creative design. Also, to facilitate the kinds of opportunism inherent in creative reasoning, we are developing a CBR system that does not have a rigid control structure, allowing more flexible interleaving and communication among processes. We are concentrating on identifying and capturing explicit strategic control mechanisms that guide a creative designer in deciding what to do next. [Wills and Kolodner 1994a] describes the types of creative behavior we believe case-based design systems should have and shows how the standard case-based reasoning framework can be extended to achieve these desired behaviors. It describes an architecture we are developing to experiment with these ideas.

2.4 Integrated Case-Based and Model-Based Computational Models

We are also studying integrated computational models that combine the use of design cases with the use of functional models for analyzing and modeling design processes. The functional models may be design-specific or design-independent. Design-specific models specify how the structure of a given designed artifact results in the achievement of its functions (e.g., how the functions of the components in an electrical circuit get composed into the functions of the circuit as a whole), while design-independent models represent how a causal process results in a specific behavior (e.g., how the process of heat flow results in a change in temperature). In our earlier work we showed that functional models can provide answers to several issues in case-based design, e.g., they provide a vocabulary for indexing designs cases in memory (model-based indexing), an array of repair plans for adapting a past case to meet new design specifications (model-based adaptation), and a method for evaluating a candidate design (model-based evaluation).

In our current work we are building on this theme to model the processes of creative design. A key characteristic of creative design is the discovery of new design constraints in the process of evaluating a candidate design. The discovered constraints lead to a reformulation of the design problem because they introduce new design variables into the design problem space. Prabhakar and Goel [1992] have shown how design-specific and design-independent functional models together enable the evaluation of a candidate design, the discovery of new design constraints, the reformulation of the design problem, and the incorporation of the modified constraints into the process of case-based design generation.

Another key characteristic of creative design is the use of innovative strategies for adapting a past design to meet the specifications of a new problem. Cross-domain analogical transfer of knowledge is an example of an innovative adaptation strategy. Bhatta and Goel [1993a, 1993b] have shown how design-specific and design-independent models together enable analogical transfer of design knowledge from one engineering domain (e.g., electrical circuits) to another (e.g., heat exchangers). They describe how design-specific functional models enable the learning of design-independent physical processes (e.g., the process of heat flow) and engineering mechanisms (e.g., the cascading mechanism) from specific design experiences in one domain, and how these abstract processes and mechanisms can be used for solving design problems in a different domain.

3 Publications, Presentations and Reports

This section lists the products of our research. We would like to highlight the following.

- Kolodner's book *Case-Based Reasoning* was published in November, 1993.
- Kolodner has given several invited talks at workshops and universities in the U.S., Germany, Holland, and Belgium, including a keynote address at the European Workshop on Case-Based Reasoning, and a distinguished lecture at Trinity College.
- Kolodner has also been acting as interim director of the EduTech Institute, which supports design education-related research and innovation at Georgia Tech. EduTech provides both financial support (from the Woodruff Foundation) and technical expertise, particularly in the cognition of design, education, and learning.
- Kolodner and Wills' paper "Case-Based Creative Design," which was presented at the AAAI-93 Spring Symposium on AI and Creativity, appeared as an invited reprint in the Autumn 1993 edition of *AISB Quarterly*. This special edition contains a selection of papers that provide an overview of the field and that give an indication of future directions.
- Georgia Tech has been selected to host the Sixteenth Annual Conference of the Cognitive Science Society in August, 1994. Kurt Eiselt and Ashwin Ram are conference chairs. Janet Kolodner has been appointed steering committee chair.
- Since summer 1993, several students and faculty members in AI, psychology, and philosophy of science have been meeting weekly to discuss creativity. This allows us to identify interesting new research issues and directions (e.g., in mental imagery and visualization), exchange information about our research, explore possibilities for collaboration, and discuss related research. Two tangible products of our regular discussions so far have been the reviews of Boden's book *The Creative Mind* which we prepared for the journals *Behavioral and Brain Sciences* and *Artificial Intelligence*.

Invited Talks

Kolodner, J.L. A Case-Based Approach to Creativity in Problem Solving, Distinguished Lecture at Trinity College, Hartford, Connecticut, April 1993.

> **Abstract:** In case-based reasoning, new problems are solved by remembering (retrieving) previous problem situations similar to a new one and adapting retrieved solutions to fit the new problem. Case-based reasoning is useful for design tasks, planning, diagnosis problems, and common-sense problem solving. It is an inference method people use quite often in their day-to-day reasoning for both expert and common-sense tasks, and it provides an alternate way of building expert systems.
> If we take case-based reasoning seriously as a cognitive model of the problem solving people do, then we can use it to begin to explain creative problem solving. A case-based approach to creative problem solving starts with case-based processes at its core and asks how those processes need to be augmented and/or extended and/or redefined so that they can also be used to explain creative thought.

An informal analysis of several instances of creative problem solving has shown us that a major activity creative problem solvers engage in is exploration and evaluation of alternatives, often adapting and merging several possibilities to create a solution to a new problem. I propose a process model of this activity and discuss the requirements it puts on case representations and case-based and other reasoning methods. Some examples from a prototype program will be shown.

Kolodner, J.L. A Case-Based View of Case-Based Reasoning, Invited talk, *AAAI Case-Based Reasoning Workshop*. Washington, D.C., July, 1993.

Kolodner, J.L. Keynote Address: Understanding Creativity: A Case-Based Approach, *First European Workshop on Case-Based Reasoning*, University of Kaiserslautern, Germany, Nov. 1993. J.L. Kolodner will also presented invited talks in Holland and Belgium during her trip to Europe in Oct-Nov., 1993.

Abstract: Case-based reasoning has a great deal to offer in modelling creativity, especially the key processes of problem framing and idea exploration and evaluation. We hypothesize that creativity derives from brainstorming procedures involving enumeration of ideas (through memory search), redescription and elaboration of problem specifications (facilitating enumeration and memory search), and evaluation of proposed solutions that went beyond the stated constraints on a solution. This talk describes our research in understanding the processes of creating interesting solutions, investigating the role of cases and case-based reasoning processes in this kind of problem solving, and constructing a framework that supports more creative case-based reasoning.

Kolodner, J.L. Conceptual Foundations of Case-Based Reasoning, two invited talks at GMD and University of Kaiserslautern, Germany, Oct-Nov., 1993.

Abstract: Case-based reasoning has matured in the past several years from a research idea to an approach to building applications and on to providing an approach to addressing research problems that have been otherwise inaccessible. Doing a good job of either of these tasks requires intimate knowledge of CBR's conceptual underpinnings. Unfortunately, the CBR community has done a poor job of articulating these. In particular, there are major misconceptions about indexing and about the role of rules and general knowledge in reasoning. I address those issues, beginning by illustrating the results of these misconceptions, continuing by making clear the approach CBR puts forth as a paradigm, ending by discussing indexing and knowledge issues in some detail.

[Ram 1993a]
Ram, A. Creative Conceptual Change, *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society*, pp. 17-26, June 1993.

Abstract: Creative conceptual change involves (a) the construction of new concepts and of coherent belief systems, or theories, relating these concepts, and (b) the modification and extrapolation of existing concepts and theories in novel situations. I discuss these and other types of conceptual change, and present computational models of constructive and extrapolative processes in creative conceptual change. The models have been implemented as computer programs in two very different task domains, autonomous robotic navigation and fictional story understanding.

Publications

[Bhatta 1993a]
Bhatta, S. and Goel, A. Discovery of Physical Principles from Design Experiences. To appear in a Special Issue on Machine Learning in Design of the International Journal *AI in Engineering Design, Analysis, and Manufacturing*, 1993.

> **Abstract:** One method for making analogies is to access and instantiate abstract domain principles, and one method for acquiring knowledge of abstract principles is to discover them from experience. We view generalization over experiences in the absence of any prior knowledge of the target principle as the task of hypothesis formation, a subtask of discovery. Also, we view the use of the hypothesized principles for analogical design as the task of hypothesis testing, another subtask of discovery. In this paper, we focus on discovery of physical principles by generalization over design experiences in the domain of physical devices. Some important issues in generalization from experiences are what to generalize from an experience, how far to generalize, and what methods to use. We represent a reasoner's comprehension of specific designs in the form of structure-behavior-function (SBF) models. An SBF model provides a functional and causal explanation of the working of a device. We represent domain principles as device-independent behavior-function (BF) models. We show that (i) the function of a device determines what to generalize from its SBF model, (ii) the SBF model itself suggests how far to generalize, and (iii) the typology of functions indicates what method to use.

[Bhatta 1993b]
Bhatta, S. and Goel, A. Learning Generic Mechanisms from Experiences for Analogical Reasoning. In the *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society*, June 18-21, 1993, Boulder, CO.

> **Abstract:** Humans appear to often solve problems in a new domain by transferring their expertise from a more familiar domain. However, making such cross-domain analogies is hard and often requires abstractions common to the source and target domains. Recent work in case-based design suggests that generic mechanisms are one type of abstractions used by designers. However, one important yet unexplored issue is where these generic mechanisms come from. We hypothesize that they are acquired incrementally from problem-solving experiences in familiar domains by generalization over patterns of regularity. Three important issues in generalization from experiences are what to generalize from an experience, how far to generalize, and what methods to use. In this paper, we show that mental models in a familiar domain provide the content, and together with the problem-solving context in which learning occurs, also provide the constraints for learning generic mechanisms from design experiences. In particular, we show how the model-based learning method integrated with similarity-based learning addresses the issues in generalization from experiences.

[Bhatta 1992]
Bhatta, S. A Model-Based Approach to Analogical Reasoning and Learning in Design. Technical report GIT-CC-92/60, Ph.D. Proposal, Nov. 1992.

Abstract: Analogy is often believed to play an important role in the reasoning underlying innovation and creativity. The ability to make analogies between distant situations or domains (i.e., cross-domain analogies) appears to be crucial for innovation and creativity. However, making cross-domain analogies often involves learning shared abstractions as well as reasoning mediated by the abstractions. We hypothesize that structure-behavior-function (SBF) models at different levels of abstraction provide the right knowledge to facilitate analogical reasoning, ranging from within-domain to cross-domain analogies. We call such analogical reasoning *model-based analogy*.
A mental model is characterized by the types of information it captures such as causal, functional (teleological), and structural relations between the entities in a system or a situation. We represent device-specific models (i.e., models of specific designs) as SBF models and device-independent models (i.e., models of physical principles, processes, and generic mechanisms) as behavior-function (BF) models.
An important issue concerning mental models is their origin. One method for acquiring knowledge of these models is to "discover" them from experience. We hypothesize that SBF models at a lower level of abstraction (e.g., device-specific models) provide both the content and constraints for learning BF models at higher levels of abstraction (e.g., device-independent models) by generalization.
We propose an integrated architecture for design by model-based analogy and for learning of shared abstract models. We are currently implementing the architecture in a system called IDEAL (Integrated "DEsign by Analogy and Learning"). We plan to evaluate it in the context of the design of physical devices, such as heat exchangers and electric circuits.

[Griffith, et al. 1994]
Griffith, T., Wills, L., Ram, A., Nersessian, N. Theory Based Representation: A Framework for Modeling Conceptual Change, submitted to *The Sixteenth Annual Conference of the Cognitive Science Society.*

Abstract: This paper develops a knowledge representation system that provides a framework for modeling conceptual change. We view conceptual change as a kind of theory change. We present a theory-based representation for modeling theory changes, and show how the constituents of theory-based representation capture the processes of theory change. We argue that a representation for theories is adequate for representing concepts and objects as well. In the presented research, we examine conversation protocols taken from an engineering design project and use theory-based representation to model the results in an effort to uncover the representations that facilitate the theory changes evidenced in the protocols.

[Kolodner 1993bk]
Kolodner, J.L. *Case-Based Reasoning.* Morgan-Kaufman Publishers, Inc., San Mateo, CA, 1993.

[Kolodner 1993a]
Kolodner, J.L. and Wills, L.M. Case-Based Creative Design, *AAAI Spring Symposium on AI and*

Creativity. Stanford, CA. March 1993. Reprinted in a special Autumn 1993 issue (no. 85) of *AISB Quarterly* on AI and Creativity, edited by Terry Dartnall. Also to be reprinted in an edited book based on the papers presented at the Spring Symposium.

Abstract: Designers across a variety of domains engage in many of the same creative activities. Since much creativity stems from using old solutions in novel ways, we believe that case-based reasoning can be used to explain many creative design processes.

[Kolodner 1993b]
Kolodner, J.L. and Wills, L.M. Paying Attention to the Right Thing: Issues of Focus in Case-Based Creative Design, *AAAI Case-Based Reasoning Workshop*. Washington, D.C., July 1993.

Abstract: Case-based reasoning can be used to explain many creative design processes, since much creativity stems from using old solutions in novel ways. To understand the role cases play, we conducted an exploratory study of a seven-week student creative design project. This paper discusses the observations we made and the issues that arise in understanding and modeling creative design processes. We found particularly interesting the role of imagery in reminding and in evaluating design options. This included visualization, mental simulation, gesturing, and even sound effects. An important class of issues we repeatedly encounter in our modeling efforts concerns the focus of the designer. (For example, which problem constraints should be reformulated? Which evaluative issues should be raised?) Cases help to address these focus issues.

[Moorman 1994]
Moorman, K. and Ram, A. A Functional Theory of Creative Reading, Technical report GIT-CC-94/01. Also to appear in *Psychgrad Elec. Journal.*

Abstract: Reading is an area of human cognition which has been studied for decades by psychologists, education researchers, and artificial intelligence researchers. Yet, there still does not exist a theory which accurately describes the complete process. We believe that these past attempts fell short due to an incomplete understanding of the overall task of reading; namely, the complete set of mental tasks a reasoner must perform to read and the mechanisms that carry out these tasks. We present a functional theory of the reading process and argue that it represents a coverage of the task. The theory combines experimental results from psychology, artificial intelligence, education, and linguistics, along with the insights we have gained from our own research. This greater understanding of the mental tasks necessary for reading will enable new natural language understanding systems to be more flexible and more capable than earlier ones. Furthermore, we argue that creativity is a necessary component of the reading process and must be considered in any theory or system attempting to describe it. We present a functional theory of creative reading and a novel knowledge organization scheme that supports the creativity mechanisms. The reading theory is currently being implemented in the ISAAC (Integrated Story Analysis And Creativity) system, a computer system which reads science fiction stories.

[Prabhakar 1992]
Prabhakar, S. and Goel, A. Performance-Driven Creativity in Design: Constraint Discovery, Model Revision, and Case Composition. In *Proceedings of the Second International Conference on Computational Models of Creative Design*, Dec. 1992, Heron Island, Australia.

Abstract: Creative Design can be defined as introducing new design variables into the existing design problem space. Many devices fail to perform normally in a new operating environment. This is because the environment imposes new constraints on the device which may not be addressed in the design knowledge. We present a model, Performance-Driven Creativity (PDC), for creative design that introduces new variables into design problem space by discovering and addressing new constraints on the design knowledge. PDC is an extension of KRITIK [Goel, 89] which integrates model-based reasoning and case-based reasoning to come up with creative designs. We have identified three case-bases that help in PDC: (i) Case-base of design experiences that were encountered in the past, (ii) Case-base of previous experiences of failure output behaviors, and (iii) Prototypical behaviors. The knowledge in these cases is modeled using a Structure-Behavior-Function (SBF) model. The PDC task has been decomposed into: (i) Discovery of New Constraints, (ii) Formation of Behaviors for the Constraints, and (iii) Composition of Behaviors to arrive at the final design that satisfies all the constraints identified. In the process of creative design, different models get composed into a single model that represents the final design knowledge. We illustrate our ideas in the design of coffee-maker that can withstand cold environmental conditions.

[Ram, et al. 1993b]
Ram, A., Domeshek, E., Wills, L., Nersessian, N. and Kolodner, J. Creativity is in the Mind of the Creator: Review of Boden's *The Creative Mind.* Accepted for publication in *Behavioral and Brain Sciences*, Princeton, NJ.

[Ram, et al. 1994]
Ram, A., Domeshek, E., Wills, L., Nersessian, N., and Kolodner, J. Creativity is in the Mind of the Creator. Accepted for publication with revisions in *Artificial Intelligence.* This is a review of Boden's book *The Creative Mind*, which is longer and more detailed than our *BBS* review.

[Wills and Kolodner 1994a]
Wills, L. and Kolodner, J. Towards More Creative Case-Based Design Systems, *Twelfth National Conference on Artificial Intelligence (AAAI-94)*, Seattle, Washington.

Abstract: Case-based reasoning has a great deal to offer in supporting creative design, particularly processes that rely heavily on previous design experience, such as framing the problem and exploring and evaluating design alternatives. However, most existing case-based reasoning systems are not living up to their potential. They tend to adapt and reuse old solutions in routine ways, producing robust but uninspired results. Little research effort has been directed towards the kinds of situation assessment, evaluation, and assimilation processes that facilitate the exploration of ideas and the elaboration and redefinition of problems that are crucial to creative design. Also, their typically rigid control structures do not facilitate the kinds of strategic control and opportunism inherent in creative reasoning. In this paper, we describe the types of behavior we would like case-based design systems to have, based on a study of designers working on a mechanical engineering problem. We show how the standard case-based reasoning framework can be extended to achieve the desired behaviors. We also describe an architecture we are developing to experiment with these ideas.

[Wills and Kolodner 1994b]
Wills, L. and Kolodner, J. Explaining Serendipitous Recognition in Design, submitted to *The Sixteenth Annual Conference of the Cognitive Science Society.*

Abstract: Creative designers often see solutions to pending design problems in the everyday objects surrounding them. This can often lead to innovation and insight, often revealing new functions and purposes for common design pieces in the process. We are interested in modeling serendipitous recognition of solutions to pending problems in the context of creative mechanical design. This paper characterizes this ability, analyzing observations we have made of it, and placing it in the context of other forms of recognition. We propose a computational model to capture and explore serendipitous recognition which is based on ideas from reconstructive dynamic memory and situation assessment in case-based reasoning.

4 Transitions and DoD Interactions

Because our exploratory study involved a team of students collaborating on a design, it is of considerable interest to researchers studying human-computer collaboration. We are sharing the transcripts and data collected from our exploratory study with researchers at the DEC-Cambridge Research Laboratory who are studying cooperation among heterogeneous agents. In addition, we were invited to participate in the AAAI-93 Fall Symposium on Human-Computer Collaboration last October.

5 Software and Hardware Prototypes

We are developing an experimental case-based system that emphasizes the processes of situation assessment, evaluation, and assimilation, integrating them with the usual CBR processes of retrieval, elaboration (case manipulation, adaptation, merging, prediction), and learning. It has a flexible, opportunistic control structure which allows us to keep focus tactics separate, explicit, and modifiable. With this system, we plan to experiment with a variety of control strategies, causing complex and interesting interactions among the basic mechanisms from which creative processes emerge. This will allow us to test our hypotheses about the cognition of creativity.

The processes within our system are not applied in a strictly linear succession. Rather, the system has a blackboard-style architecture. The processes are centered around and act upon data structures that represent the evolving problem specification and the set of design alternatives under consideration.

Situation assessment procedures act on the problem specification to evolve it along multiple directions. Evaluation examines design alternatives, checking them against the current specification, which may reveal inconsistencies, ambiguities, and incompletenesses in the specification that suggest new redescriptions. Evaluation also brings up new evaluative issues, criteria, and constraints which are incorporated into the problem specification.

The design specification that is being evolved by the primary mechanisms is used in two ways. One is as a probe to flexibly retrieve relevant design cases. The other use is as a dynamically changing indexing vocabulary with which to interpret and organize the pool of alternatives under consideration. Not only are intentionally proposed solutions accumulated and assimilated (i.e., those that are recalled and elaborated), but alternatives observed in the external environment are as well. This will be used to model the serendipitous recognition of solutions to pending problems as a process of re-interpretation in the context of the current problem.

The coordination of the various processes is controlled by explicit strategic control mechanisms. There are a set of monitoring procedures, called "noticers," associated with each of the processes, which watch for opportunities for some task to be performed. The opportunities noticed are placed on an "opportunity agenda." Opportunities are chosen and pulled from the agenda by strategic control heuristics. For example, a noticer associated with the assimilation process watches for an alternative to be added that is much better than any other alternative proposed so far, along some desired criterion. This yields an opportunity to change the problem description by increasing the priority of that criterion and/or by relaxing constraints that are not met by that proposal. This simulates the behavior of changing the relative importance among criteria to accommodate an unexpectedly good solution that is stumbled upon. An example strategic control heuristic would be to pursue elaboration opportunities for alternatives that satisfy a desired criteria extremely well before pursuing evaluative processes that would negatively critique the alternatives. This simulates the behavior of optimistically pursuing an idea, suspending all but constructive criticism.

6 Photographs, Vugrafs or Videotapes

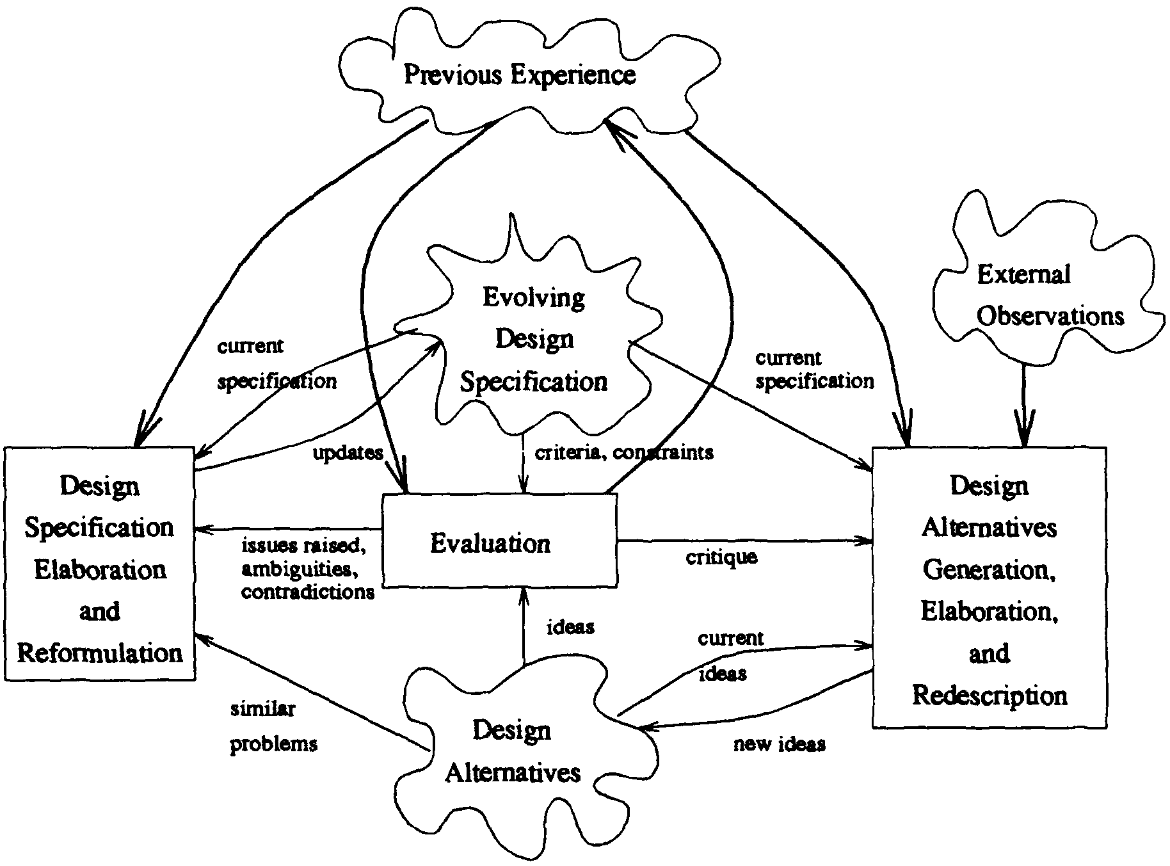

Figure 1: Our model of the creative design process.