# Integrating CBR and RBR for Nutritional Menu Design

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### Abstract

An integrated approach is presented, in which a primarily case-based reasoning (CBR) system for nutritional menu design is enhanced by rule-based reasoning (RBR). In nutritional menu planning, a nutritionist plans a daily menu for a single individual, taking dietary requirements and personal preferences into account. This task requires satisfaction of multiple numeric nutrition constraints plus personal preference goals and aesthetic criteria. In our approach, CBR is used to satisfy multiple numeric constraints, while RBR allows the introduction of new foods into menus and the performance of "what if" analysis needed for creative design. We developed our approach by combining the strengths of independent CBR and RBR menu planning systems. We believe the approach would extend to other design domains in which both physical constraints and aesthetic considerations are important, such as college course advising, architecture, and new product design.

## Introduction

Nutritional menu planning is a task which has defied computerization for over thirty years (Eckstein 1978; Spears 1995). The task is to design a daily menu for an individual in accordance with nutrition guidelines, personal preferences, and aesthetic standards for color, texture, temperature, taste and variety (Food and Nutrition Board 1989; U.S. Departments of Agriculture and Health and Human Services 1995). We have developed a hybrid system to perform this task, in which CBR is used to satisfy multiple numeric constraints, while RBR allows the introduction of new foods into menus and the performance of "what if" analysis needed for creative design. We have previously described the system comparison and integration in (Marling, Petot, & Sterling 1998). The goal of this paper is to help situate our approach among other CBR integrations.

## The CAse-based Menu Planner Enhanced by Rules

The CAse-based Menu Planner Enhanced by Rules (CAMPER) plans daily menus to meet individual nutrition and personal preference requirements. A nutritionist would use CAMPER to assist clients who must learn to adjust their diets to constrain intake of: calories, percentage of calories from fat, sodium, calcium, protein, cholesterol, or other nutrients. Personal preferences are included to ensure that the clients willingly eat the foods prescribed, thereby deriving the intended benefits.

CAMPER was built by combining the best features of independent CBR and RBR nutritional menu planning systems. These systems are the CAse-based Menu Planner (CAMP) and the rule-based Pattern Regulator for the Intelligent Selection of Menus (PRISM). CAMP is a canonical CBR system, which operates by storing, retrieving, and adapting daily menus. PRISM is a traditional rule-based system, which produces menus through a process of generate, test and repair. It relies on menu patterns, an extensive ontology of foods, and common sense knowledge of the ways in which foods may be combined. Additional information about these systems is available in (Marling, Petot, & Sterling 1998; Marling & Sterling 1996; Marling, Petot, & Sterling 1996).

One thing we learned from building, comparing and contrasting CBR and RBR systems is that, in our domain, CBR excelled at meeting multiple numeric constraints, while RBR facilitated creative design. We built CAMPER to combine the strengths of both paradigms. A flow chart for CAMPER is shown in Figure 1. Solid lines represent functionality taken intact from CAMP. Rule-based enhancements taken from PRISM are shown by dotted lines.

As shown in the figure, CAMPER begins by obtaining the menu planning criteria and selecting the best daily menu from its case base. The retrieval metric selects a menu based on the ease of adapting it to meet current criteria. The best menu is then adapted to meet any unmet goals, using strategies based on a human expert's approach to fine tuning menus manually. Both snippets, or parts of other menus, and domain specific adaptation rules are employed. The retrieved and adapted menu is then displayed to the user, a qualified nutritionist. The user may use "what

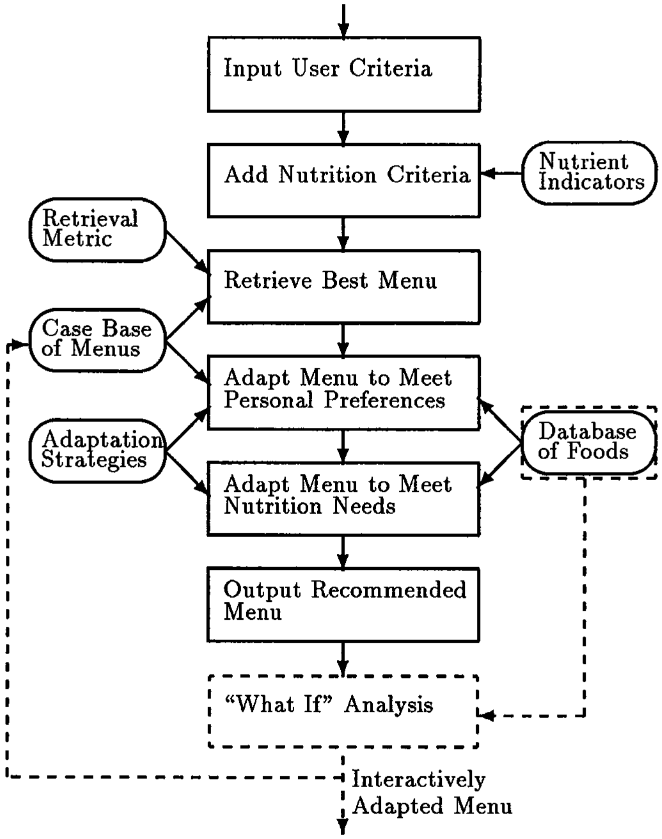


Figure 1: A Flow Chart for CAMPER

if" analysis to add, delete or replace foods, to greater customize the menu to the needs and desires of an individual. Rules guide the allowable changes, ensuring that modified menus still meet the established criteria. Menus which are significantly different from those already stored in the case base can be saved for future use. From a nutrition standpoint, this adds variety, providing more menu options for individuals. From a system standpoint, this expands system coverage, enabling the system to improve its performance over time. This feature was not part of CAMP or PRISM, but was made possible by the synergy between them. While CBR-only systems may save adapted cases, this did not prove productive for CAMP, because all new menus were derivative of old ones and they could easily be regenerated. RBR provided the means of generating cases which could extend system capabilities.

The new rules in CAMPER are unlike those of CAMP, which support CBR during retrieval and adaptation. CBR systems have long used rules for support, and this is not what is meant by CBR/RBR integration. CAMPER's rules expand the traditional role of the case as a specific experience, or precomposed solution, to be recalled and reused. Roast beef, roast potatoes and brussels sprouts go together in CAMP because the entire combination was once deemed satisfactory, *not* because a well-formed dinner may be composed of meat, potato and vegetable. Rules in PRISM, on the other hand, compose menus by configuring components stored in the database. Foods in PRISM's database are the building blocks of menus, whereas CAMP's database plays a minor role, as foods derive context from cases, instead. CAMPER's database supplies PRISM-like context for foods. A case in CAMPER, then, may be viewed as one instantiation of a menu pattern. The components of the underlying menu pattern may vary in accordance with the rules of a grammar for well-formed menus. CAMPER derives benefit from cases in two different ways. A case may provide a specific reusable solution, and it may also provide a useful abstraction, or framework, for defining a range of possible solutions.

A menu planned by CAMPER is shown in Figure 2. The user-specified constraints were to include: 1,600 calories, at most 30% calories from fat, at least 1,000 milligrams calcium, a cereal breakfast, sandwich lunch, pasta dinner, and fruit snack; and to exclude nuts and shellfish. While the menu meets all constraints, the user may still want to experiment to find an even better menu. For instance, the user might try to substitute American cheese for the roast beef at lunch, but would find that fat and calories rise, while zinc and Vitamin B12 fall to unacceptably low levels. On the other hand, substituting two chocolate chip cookies for the cantaloupe would not violate any nutrition constraints, should an individual decide that cookies would be preferable to fruit.

## CBR/RBR Integration

Case-based reasoning was originally introduced as an alternative, rather than a complement, to rule-based reasoning (Kolodner 1993; Riesbeck & Schank 1989). Among the first to recognize the power of combining the two paradigms were Rissland and Skalak, whose legal domain naturally included both cases (legal precedents) and rules (statutes) (Rissland & Skalak 1989). Their system, CABARET, featured independent coreasoners, each capable of solving problems on its own and each called as needed. Golding introduced the idea of using CBR to improve RBR in ANAPRON, a system for pronouncing American surnames (Golding 1991). In ANAPRON, most of the work was accomplished by an RBR master, while CBR served as a slave to handle exceptions to the pronunciation rules. We introduced the idea of using RBR to enhance CBR in CAMPER. The CBR master produces goal compliant menus, and an RBR slave adds creative flair by moving beyond "what did" through "what if" analysis of future possibilities.

It is important to note that CAMPER's approach to integration arose through a systematic study of the strengths and weaknesses of CBR and RBR in one domain. Nutritionists naturally employ both reasoning

**Breakfast**
1 cup orange juice
1 cup ready-to-eat cereal
1/2 cup skim milk
2 slices toast with
2 tsp. margarine

**Lunch**
Sandwich
• 2 slices whole wheat bread
• 2 oz. roast beef
• 1 leaf lettuce
• 2 tsp. mayonnaise-type salad dressing
10 carrot sticks
1 1/2 medium oranges
1 cup skim milk

**Dinner**
Salad
• 1/2 cup lettuce
• 1/2 medium tomato, sliced
• 1/4 cup chopped celery
• 1/8 cup carrots
• 1 Tbsp. Italian dressing
1 cup spaghetti with tomato sauce
3/4 cup cooked green peas
2 slices Italian bread with
2 tsp. margarine
1 cup skim milk

**Snack**
1 wedge cantaloupe

Figure 2: A 1,600 Calorie Menu Planned by CAMPER

processes while planning menus manually, so it made sense that an automated system would also employ both processes. We did not begin with a preconceived notion of how integration should proceed, but aimed to capitalize on the strengths of both paradigms. This seems different from integration driven by a need to ameliorate some specific deficiency of one approach or another, and may prove relevant as we try to characterize different multimodal reasoning architectures.

There are at least three factors which make nutritional menu planning difficult. First, there are many numeric constraints, some of which conflict with others. For example, if you cut back on red meat, in accordance with the Dietary Guidelines for Americans (U.S. Departments of Agriculture and Health and Human Services 1995), it becomes hard to meet the minimum daily requirement for zinc set forth in the Recommended Dietary Allowances (Food and Nutrition Board 1989). Second, the constraints are not constructive in nature. They allow you to evaluate a menu, but they do not specify how to produce a good menu. Furthermore, it is not possible to fully evaluate a menu before it is entirely constructed. A nutritionist does not evaluate menus on a food-by-food or meal-by-meal basis. The goodness of having egg salad for lunch depends on whether or not scrambled eggs were already part of breakfast and on whether or not an omelette will be part of dinner. Any one of these dishes would be fine, but together they form a monotonous menu which exceeds the daily cholesterol limit. Third, there is a large amount of common sense involved. There's a *sense* that some meals appeal while others don't. There's a sense that some foods go together, like roast turkey with stuffing, and a sense that some foods don't, like roast turkey with ketchup and pickles. Early automated menu planners proposed things which looked nonsensical, like eating a single carrot stick, drinking a gallon of lemonade, or having chocolate covered almonds and stewed tomatoes for breakfast (Sterling *et al.* 1996). Nonsensical menus may well meet nutrition constraints, however, and it is not easy to describe the other kinds of constraints involved.

While recent CBR integrations have shown that multimodal reasoning is useful in many different domains (Freuder 1998), it seems likely that different types of domains will benefit from different modes of integration. For example, Branting has shown how a CBR/MBR approach, approximate-model-based adaptation, is especially well suited to prediction and control planning in complex physical systems having incomplete models and limited empirical data (Branting 1998). We believe our approach would extend to other design domains in which both physical constraints and aesthetic considerations are important. Such domains include college course advising, architecture, and new product design.

Work which parallels ours in many respects has recently been reported in the domain of harmonizing melodies (Sabater, Arcos, & López de Mántaras 1998). The domain parallels ours in that there is a definite structure to musical composition, but there is a *sense* that some compositions are pleasing while others are not. There are well-established harmonization rules, which reflect the organization and structure of musical composition, but which are not constructive in nature. Sabater *et al.* wrote, "... the rules don't make the music; it is the music which makes the rules." Their system, GYMEL, uses cases, which are musical phrases from Catalan folk songs, and general harmonization rules. As in CAMPER, GYMEL's predominant reasoning mode is CBR while RBR serves as a slave. Unlike CAMPER, GYMEL uses rules when CBR can not supply a solution. CAMPER's CBR module can always supply a solution, but its RBR module can improve that solution. Like CAMPER, GYMEL stores the new solutions generated using RBR in its case base to improve future performance. Sabater *et al.* believe that their approach is especially well suited to domains where it is difficult to find enough cases and where it is unsuitable to work with rules alone. As we have previously reported, finding enough cases was a major obstacle in building our CBR module (Marling & Sterling 1996). While we agree that rules can compensate for a paucity of cases, we suggest that the creative and aesthetic aspects of harmonizing melodies may play a role in the success of this approach to CBR/RBR integration.

One aspect that has been identified by Branting as important for integration is the degree of structure present in a domain (Branting 1998)[1] An integrated approach made sense for Carma, a system that helps ranchers manage grasshopper infestations, in part because useful numerical models existed which were not complete enough for full problem solving. There were not enough cases available for full problem solving, either, but cases could supplement the structured models. Although the domains and tasks are quite different, the degree of structure seems similar to that of harmonizing melodies and planning menus. Harmonizing melodies involves structure, expressed by rules, but the structure can not entirely define pleasing harmonies. Menu planning may be viewed as semi-structured as well, in that there are many rules and constraints, but these can not entirely define pleasing menus.

## Related Research

Computer-assisted menu planning systems have been built since the 1960's. Using linear programming techniques to build the first of these, Balintfy optimized a menu for nutritional adequacy, cost, and palatability (Balintfy 1964). Shortly thereafter, Eckstein adopted a "random" approach to satisfice, rather than optimize, menus (Eckstein 1967). Using a simple meal pattern, she composed each menu of a meat, starchy food, vegetable, salad, desert, bread and beverage. Within each category, a food item was selected randomly and evaluated with respect to constraints. The program would iterate until satisfactory items were found.

Two decades later, AI approaches to menu-planning were first tried. Yang built ESOMP to plan nutritionally sound menus for patients on a severely restricted low-protein diet (Yang 1989). Galotra *et al.* developed a Prolog expert system to plan therapeutic menus for patients in India (Galotra *et al.* 1991). They used Operations Research methods to match nutritional requirements to specific food items and heuristic rules and reasoning to convert the food items into complete menus. Hinrichs combined CBR with constraint propagation techniques to build JULIA, an interactive menu planner (Hinrichs 1992). JULIA plans meals for dinner parties, functioning in the role of caterer. It plans a meal to satisfy a group of guests, despite conflicting food preferences and evolving constraints. Ganeshan and Farmer have implemented an RBR catering system for a large Australian catering corporation (Ganeshan & Farmer 1995).

[1]This has been dubbed the "Branting continuum" by David Aha.

## Future Work

There is future work to be done, both in nutritional menu planning and in CBR integration. While CAMPER was built for essentially healthy adults, nutritionists plan menus in the real world to prevent, control and treat a variety of medical conditions. Special menus are planned for diabetics, cardiac patients, pregnant and lactating women, renal patients and burn patients. Metabolic diets are planned in clinical research centers to study the effects of nutrition on a wide range of medical conditions. By treating the CAMPER system itself as a case of reusable software, and adapting it to the needs of a particular condition, we believe we can provide practical support to nutritionists. We describe the adaptation needed to build a special purpose CAMPER for diabetics in (Marling, Petot, & Sterling 1998).

Now that CBR integration has been shown to be beneficial in many forms to solve many problems, it is important to better understand and to characterize the different integration architectures. It is neither practical, nor a good idea, to build independent CBR, RBR and/or XBR systems before deciding on the appropriate hybrid approach to solving each new problem we encounter. Workshops, like the one for which this paper is written, can help us to identify strategies which are ready for real world application and areas which require additional research.

## Conclusions

We have developed an integrated system for designing nutritional menus by incorporating the strengths of independent CBR and RBR systems. A CBR module to store, retrieve and adapt past menus contributes toward the design of menus which meet multiple numeric constraints. An RBR module to perform "what if" analysis contributes creativity in design. It allows the user to interact with the system, evaluating trade-offs and customizing menus. These customized menus can become new cases to improve system coverage in the future. We believe that our approach to CBR/RBR integration would be most useful in design domains in which both physical constraints and aesthetic considerations are important. Fuller characterization and understanding of multimodal reasoning architectures is an important research endeavor with strong potential impact on real world applications.

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## Appendix

1. **Integration Name**: CAMPER (CAse-based Menu Planner Enhanced by Rules)
2. **Performance Task**: To design a daily menu for an individual, in accordance with dietary requirements, personal preferences, and aesthetic criteria
3. **Integration Objective**: To combine CBR's capacity for handling multiple nutrition constraints with RBR's capacity for creative menu design
4. **Reasoning Components**: CBR for proposing a menu which meets specified goals. RBR for interactively evaluating creative alternatives, providing greater customization to individual tastes and new menu options for future use
5. **Control Architecture**: CBR as master
6. **CBR Cycle Step(s) Supported**: Reuse (customization beyond the adaptation provided by CBR), retention
7. **Representations**: Cases contain complete daily menus and features indicative of their suitability for particular individuals. The CBR module uses cases as precomposed solutions to be retrieved, adapted and reused. The RBR module generalizes cases, viewing them as instantiations of menu patterns. Rules define the roles foods play in menus, so that food items can be used as configurable components of menus by the RBR module. (The rules supporting case retrieval and adaptation in the CBR module serve their usual functions and are not considered to constitute integration.)
8. **Additional Reasoning Components**: The RBR module is used interactively by a nutritionist, so the nutritionist's natural reasoning processes are also involved
9. **Integration Status**: Applied and empirically evaluated
10. **Priority Future Work**: Application to design of menus to prevent, control or treat specific medical conditions. Investigation of CBR integration in other domains