A CBR/RBR Hybrid for Designing Nutritional Menus

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Abstract

The task of designing nutritious, yet appetizing, menus is one at which human experts consistently outperform computer systems. Tailoring a menu to the needs of an individual requires satisfaction of multiple numeric nutrition constraints plus personal preference goals and aesthetic criteria. We have combined case-based reasoning (CBR) and rule-based reasoning (RBR) in a hybrid system which designs a daily menu for an individual, in accordance with nutrition guidelines, personal preferences, and aesthetic criteria. The hybrid system incorporates the strengths of independent CBR and RBR systems built to perform the same task. CBR is used to satisfy multiple constraints, while RBR allows the introduction of new foods into menus and the performance of "what if" analysis needed for creative design. The CBR/RBR hybrid outperforms either single strategy system. It provides a new framework for planning special purpose therapeutic menus, such as those for diabetics and cardiac patients. We believe that the hybrid approach would extend to other design domains in which both physical constraints and aesthetic considerations are important.

Introduction

Case-based reasoning (CBR) was originally introduced as an alternative, rather than a complement, to rule-based reasoning (RBR) (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). While CBR/RBR hybridization fit the legal domain well (Branting 1991; Zeleznikow & Hunter 1994), it was slow to catch on in other fields. Pioneering efforts included Golding's work on pronouncing American surnames (Golding 1991), and Navinchandra's work on landscape design (Navinchandra 1991).

We have built a hybrid system for nutritional menu planning[1] by combining the strengths of independent CBR and RBR systems built to perform the same task. 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. This task is one at which human experts (nutritionists) consistently outperform computer systems. Unsuccessful attempts to automate the task date back thirty years (Eckstein 1978). While we owe a debt to early CBR research on planning menus for dinner parties (Hinrichs 1992), our focus is on producing menus which satisfy multiple numeric energy and nutrient constraints as well as personal preference goals and aesthetic criteria. In our hybrid system, CBR is used to satisfy multiple constraints, while RBR allows replacement of food items in menus and the performance of "what if" analysis needed for creative design. We believe our approach is applicable to other design tasks in which both physical constraints and aesthetic criteria must be met, such as college course advising, new product design, and architecture.

[1] Menu *planning* is the unfortunate vernacular term for a process which is quintessentially one of design.

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. Its case base contains 84 menus, each of which was designed to satisfy the Recommended Dietary Allowances (Food and Nutrition Board 1989), the Dietary Guidelines for Americans (U.S. Departments of Agriculture and Health and Human Services 1995), and aesthetic standards for color, texture, temperature, taste and variety. Features which indicate the usefulness of a menu for a particular individual include: its nutrient vector of data for 24 nutrients, the types of meals and number of snacks included, and included foods. Cases are selected based on the ease with which they can be adapted to meet all of a healthy individual's requirements. Both snippets, or parts of other menus, and domain specific adaptation rules are used for adaptation. Unlike some CBR systems, CAMP does not store adapted menus for reuse, as all menus produced can be easily regenerated. CAMP was first described in (Marling, Petot, & Sterling 1996). A demo version is available on the World Wide Web at *http://pearson.cwru.edu/camp*.

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. It generates an initial menu by successively refining patterns for meals, dishes and foods, filling general pattern slots, such as *breakfast bread dish*, with specific foods, such as *1 slice of cinnamon raisin toast with 1 teaspoon of butter*. Its rules, in effect, implement a context-free grammar for the production of well-formed menus. Menus are generated in compliance with both user specifications and common sense expectation as to form. Generated menus are tested to see if they meet all nutrition constraints. As these constraints are not context-free, they can not always be built into a menu up front, so repair is undertaken. Repair is a backtracking process of substituting new foods, dishes, or meals for those found to be nutritionally lacking. Menus produced by PRISM may be interactively modified by the user to try out alternatives which might better suit individual preferences. PRISM reports the effects on nutritional quality of any such changes. PRISM is fully documented in (Kovacic 1995).

CAMP and PRISM were tested, evaluated, and compared, in conjunction with our own experts, other practicing nutritionists, and nutrition students who had recently learned to plan menus. A full account of the system comparison is presented in (Marling & Sterling 1996). In brief, both systems were judged to produce useful menus, but they had different strengths and weaknesses. CAMP's biggest advantage was its ability to satisfy multiple nutrition constraints, while PRISM excelled at creative design. It was easier to find and modify a menu that almost met constraints than to create a menu meeting all constraints from scratch. Because backtracking to repair one deficiency could potentially introduce new deficiencies, PRISM could handle fewer constraints at once than could CAMP. However, PRISM generated a wider variety of menus, and its interactive "what if" analysis allowed users to propose and evaluate their own creative food combinations as well. "What if" analysis is a useful thinking process, naturally employed by nutritionists, which is not easily supported by CBR, with its alternate emphasis on "what did." Creativity and variety are highly valued in this domain, where today's perfect menu becomes tomorrow's leftovers.

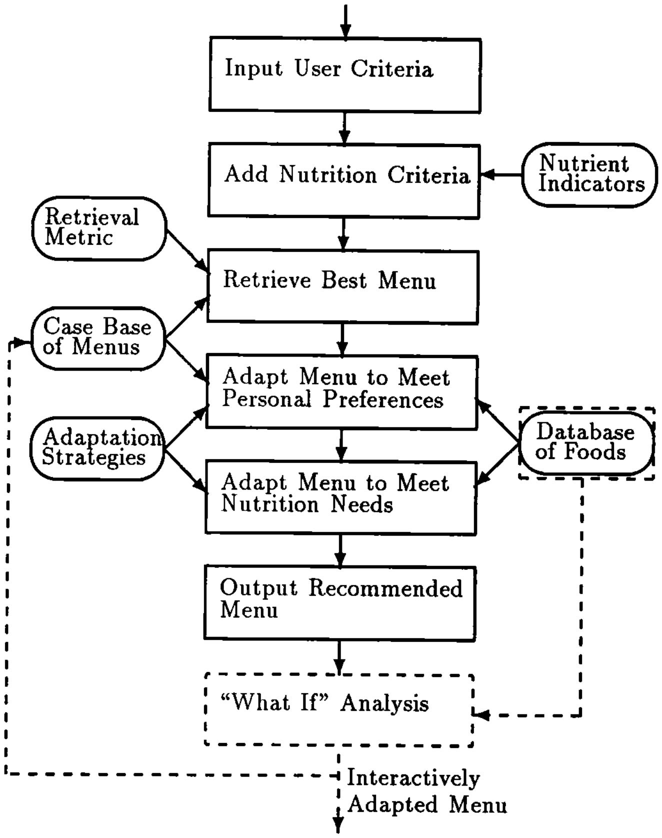

Figure 1: A Flow Chart for CAMPER

CAMPER was built by combining the best of CAMP and PRISM. 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. The enhancements expand the role of CAMP's database and add "what if" analysis functionality. Using "what if" analysis, a nutritionist may create menus which are significantly different from those already stored in the case base. These menus can be saved in the case base 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 either CAMP or PRISM, but was made possible by the synergy between them.

The new rules in CAMPER are unlike those of

CAMP, which are only used to support CBR during retrieval and adaptation. 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 a general outline, or prototype, for a menu, and its components may be varied broadly, 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 canteloupe is fine within the context of this menu, and might please the individual for whom the menu is prescribed. Menus which are extensively reworked can be saved for future use, at the discretion of the nutritionist.

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

Discussion

The first effort to build a computer-assisted menu planner, in the early 1960's, focused on constraint satisfaction (Balintfy 1964). Balintfy used a linear programming approach to optimize menus for nutrient content, cost and consumer satisfaction. While numeric constraints were successfully met, practicing nutritionists found the resultant menus aesthetically unacceptable, and did not use them. This approach remains in use, however, for planning nutritious, cost-effective animal feeds. The next effort, not long afterward, focused on menu form (Eckstein 1967). Eckstein planned only dinner menus, composing each of a randomly selected meat, starchy food, vegetable, salad, dessert, bread and beverage. Food items were evaluated based on cost, color, texture, shape, calories, variety and consumer acceptability, and unsatisfactory items were replaced. A straightforward extension of this approach was reported as recently as 1985 (Elazari, Bar-Chi, & Sinuany-Stern 1985). AI approaches to menu planning have been tried in the past decade. Both CBR and RBR menu planning systems have been built (Yang 1989; Hinrichs 1992; Ganeshan & Farmer 1995). Yet, practicing nutritionists still plan menus manually today, despite having embraced computer technology for a wide range of other tasks (Spears 1995).

Menu planning is a complex task, involving not only constraint satisfaction and menu form, but also a great deal of common sense (Sterling *et al.* 1996). There's a *sense* that some meals appeal, while others do not. Everyone *knows* that gravy goes well with roast turkey, while ketchup does not. Formalizing this type of common sense knowledge into rules was a formidable task for PRISM, while CAMP could capitalize on the common sense of an expert nutritionist being implicit in every case. On the other hand, RBR allowed us to take advantage of form to produce a wide variety of menus. Rather than the single menu form pioneered by Eckstein, PRISM has a rich grammar of allowable forms. It has over 1200 foods in its database, which it can configure in numerous ways to create a broad array of menus. While research in extending CBR to support creative design is underway (Wills & Kolodner 1996), CBR systems are presently better at reusing old solutions than at considering new possibilities. CBR was most helpful with the constraint satisfaction part of the task. Form is necessary, but not sufficient, in menu planning. The rules that tell us *if* a menu is satisfactory do not always tell us *how* to produce a satisfactory menu. Some constraints can not be evaluated before an entire menu is in place. For example, the goodness of an egg for breakfast depends on the amount of cholesterol present in the rest of the menu. Therefore, a certain amount of backtracking is inevitable when menus are generated step-by-step. As previously mentioned, backtracking is not always effective, especially if the initially generated menu is not already nearly goal compliant. CAMP had the simpler task of taking an almost-right menu, and adapting it to meet any unmet constraints. It had only to ensure that it did not introduce any new problems into menus via adaptation. Two things which helped in this regard were: (a) having a rich case base, so that the menu retrieved was as close to satisfactory as possible; and (b) using adaptation strategies which maintain the balance of the overall menu. For example, CAMP scales portion sizes to increase or decrease calorie level, rather than adding or subtracting food items. CAMP's adaptation strategies were based on the manual strategies employed by expert nutritionists, who regularly fine tune menus to meet individual needs.

It is interesting to note that nutritionists naturally employ both CBR and RBR while planning menus manually. For example, a manual CBR system is used for school lunch programs, which includes over 100 sample menus (a case base) and guidelines for customizing the menus to the needs of individual schools (adaptation rules) (American Heart Association 1992). Rules for planning menus are found in instructional texts for nutrition students and professionals (Spears 1995). One rule suggestive of hybridization is to keep old menus handy while planning new ones (Shugart & Molt 1989).

One significant aspect of the hybrid approach is its applicability to special purpose menu planning in medical settings. Nutritionists plan special diets 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. While CAMPER plans menus for essentially healthy adults, a special purpose CAMPER could be built using CAMPER's framework and methodology. A menu planner for diabetics could be built by incorporating menus published by the American Diabetes Association in a case base (American Diabetes Association 1989). Adaptation strategies would then be tuned to reflect the special needs of diabetics. For example, healthy individuals may "splurge" at one meal and then eat sensibly throughout the rest of the day to make up for it. Diabetics, on the other hand, must eat more consistently, maintaining a prescribed calorie level on a meal-by-meal basis. As adaptation strategies change to accommodate special needs, the retrieval metric would also be tuned to reflect changes in the ease of adaptation.

We believe our approach would extend to other design domains in which both physical constraints and aesthetic considerations are important. For example, in college course advising, a program of study is designed for an incoming freshman. Physical constraints include: being able to complete the program in four years; preceding each course by its prerequisites; taking only one course per time slot; fulfilling departmental regulations; and so on. Personal preference goals are also involved. The student must find the program "interesting," "challenging," but "not too difficult," in order to be motivated to undertake it. A case base could be constructed from programs of study completed by former students. Each case would represent one path toward graduation, which fulfills physical constraints, and which has already proven satisfactory for some individual. The student's goals could be used to retrieve a case as a starting point. The student could then custom tailor the program to his needs, guided by rules for maintaining the integrity of the entire four-year plan. Past experience is combined with analysis of alternative future scenarios to meet the student's needs.

Conclusions

We have built a CBR/RBR hybrid for designing nutritional menus by incorporating the strengths of independent CBR and RBR systems. A CBR module to store, retrieve and adapt potential menus contributes toward the design of menus which meet multiple nutrition, aesthetic, and personal preference constraints. An RBR module to perform "what if" analysis and to introduce new foods into menus 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. The two modules then function symbiotically, designing better menus in concert than either single strategy system could design. The CBR/RBR hybrid provides us with a new framework for future work in planning special purpose menus for therapeutic diets used in clinical practice. RBR "what if" analysis might also be used to enhance retrieval-only CBR systems for which fully automated case adaptation is infeasible. We believe our hybrid approach, as a whole, would extend to other design domains in which both concrete physical constraints and less tangible aesthetic goals must be met.

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