Personalized Dietary Counseling System Using Harmony Rules in Tele-Care

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Abstract

Introduction: Lifestyle assessment, especially nutrition counseling may have a great impact on the health state of everybody. The MenuGene expert system provides services for the logging and assessment of nutrition and physical activity.

Aim: This paper focuses on how the harmony of a dietary log can be analyzed using harmony rules. Such an assessment can be used to assess a log as well as drive an evolutionary search process that constructs a personalized menu.

Methods: Expert knowledge is formalized in two parts, sets of foods and dishes and rules that fire at a pre-defined pattern of sets. To tackle the large rule search space, a simple conflict resolution strategy is used.

Results: We implemented several hierarchies of sets to support the definition of rules, and also an Android based lifestyle assistant application. We validated the completeness of the dietary database in a survey.

Conclusion: The system may prove very useful for a real improvement of the quality of life and general health state especially for patients with chronic diseases like diabetes. We plan to conduct clinical trials to prove this early next year.

Keywords

Dietary menu planning, harmony rules, nutrition counseling

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1 Introduction

Nutrition has severe impact on the probability of cardio-vascular ant other diseases, so bringing tailored advice to the general population on nutrition and lifestyle, including physical activity can improve life expectancy. An important task of personalized lifestyle counseling is dietary menu planning and analysis. The paper describes the architecture and results produced by an automated dietary menu generator MenuGene, applied now in a diabetes home monitoring project. Our solution is intended to support, not to substitute the human dietary expert.

Computer-aided menu planning and analysis is a traditionally hard problem since it is characterized by i) a very large search space and ii) hard-to-formalize expert dietary knowledge on the harmony assessment of a menu. Human experts probably build better meal plans than computers even now, although research on computerized methods has been ongoing since the 1960's. In 1964 Balintfy developed a linear programming method for menu optimization [1], while Eckstein used random search to satisfy numerical nutrient constraints [2]. Later more advanced artificial intelligence methods were developed using Case-Based Reasoning (CBR) or Rule-Based Reasoning (RBR) or by combining the two methods with other techniques [3]. A web based system called DietPal has been built in Malaysia that models the workflow of dietetic experts in order to support their work [4]. There are solutions for parts of a nutrition counseling expert system, but so far there were no complete solutions published and validated. Our system implements all aspects of this area in a user friendly and effective way.

For the first problem i.e. search satisfying numerical constraints, we apply multi-level, multi-objective genetic algorithms that calculate the fitness of candidate solutions using personalized target values of various nutrients. The objectives for the menu planning process are obtained from personal medical data, entered manually

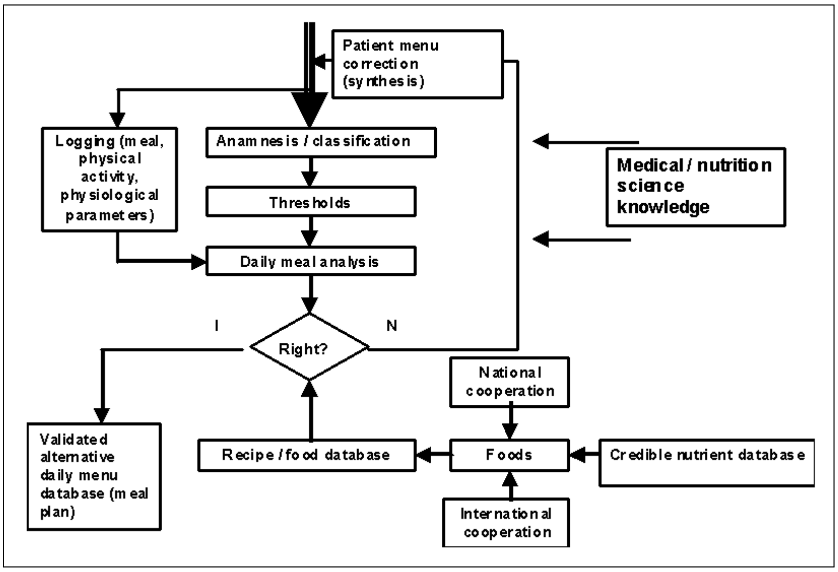

Figure 1: Work flow of the dietary log assessment process.

or measured by sensors of the tele-care system. Another source of information is the aim of the patient like "losing weight" and the user's daily dietary log (essentially a smart phone application) which can be analyzed for food composition and completeness. Then we apply general nutritional guidelines to compute the personalized numerical constraints at different levels. An example constraint is the daily minimum, optimum and maximum value for carbohydrate content. For the details of the Genetic Engine, see [5]. A similar approach based on evolutionary computing is reported in [6]. In this paper, however, we will focus more on the second problem, i.e. on the representation of the dietary expert knowledge.

2 Methods

For the assessment of harmony, we defined dietary concept sets e.g. 'fruits with a high glycemic index', and we use a simple mechanism for enforcing harmony rules over them. The rules are used to score candidate solutions e.g. a daily menu, and the score is combined with the numerical fitness of the solutions at different levels (dish, meal, daily menu). Rules assign a positive or negative score to a co-occurrence pattern of two or more sets. Positive scores mean recommended patterns, like "muesli and any drink for breakfast", while negative scores mean detrimental combinations, like "beer and water-melon in the same meal". The fitness value of a candidate solution is multiplied by the factor that appears in the consequence part of the applied rule, so "negative" scores mean fitness factors in the range of 0..1. Fig. 1 shows an overview on the dietary log assessment process.

We support harmony rules on the meal, daily and weekly level. The condition part of a rule may contain one or more sets in an AND construct. For a meal level rule, this means that the rule will be fired if the meal contains all of these sets, or dishes/foods in their subsets. For example, the set "fruits" contains the set "fruits with a high glycemic index" so if the rule contains "fruit" in the condition part, then all elements of the set "fruits with a high glycemic index" will match, such as ripe banana.

Due to this generalized method of rule matching, several (contradicting) rules may match a meal or a day, so conflict resolution is inevitable. Our strategy is based on the following principles.

- Rules with a more elements in their condition part are preferred over simpler rules because they match the actual meal/day/week more precisely
- Concrete rules with less general sets in their condition parts are preferred over more general rules, for the same reason. For the case of ripe banana, the set "fruits with a high glycemic index" is a stronger reference, than "fruits".
- If two or more rules have the same complexity or generality, we apply the stricter one. A rule is stricter if in the consequence part it contains a lower fitness factor in the case of a negative rule or a higher fitness factor in the case of a positive rule.

When assessing a weekly menu, or alternative weekly menus, the harmony factors of a lower level can be expressed as a vector. The computational complexity of the calculation of this vector is exponential in time in the function of the number of the slots (n), because each subset of the objects associated with slots should get evaluated according to harmony. The harmony of each subset will be expressed through the harmony payloads. Not including the empty set, the number of subsets is 2n ? 1, and this many checks are needed to calculate the value of each harmony payload. This makes the proof of the decision problem 'whether the assignment's payloads are within the constraints' verifiable in exponential time. For NP

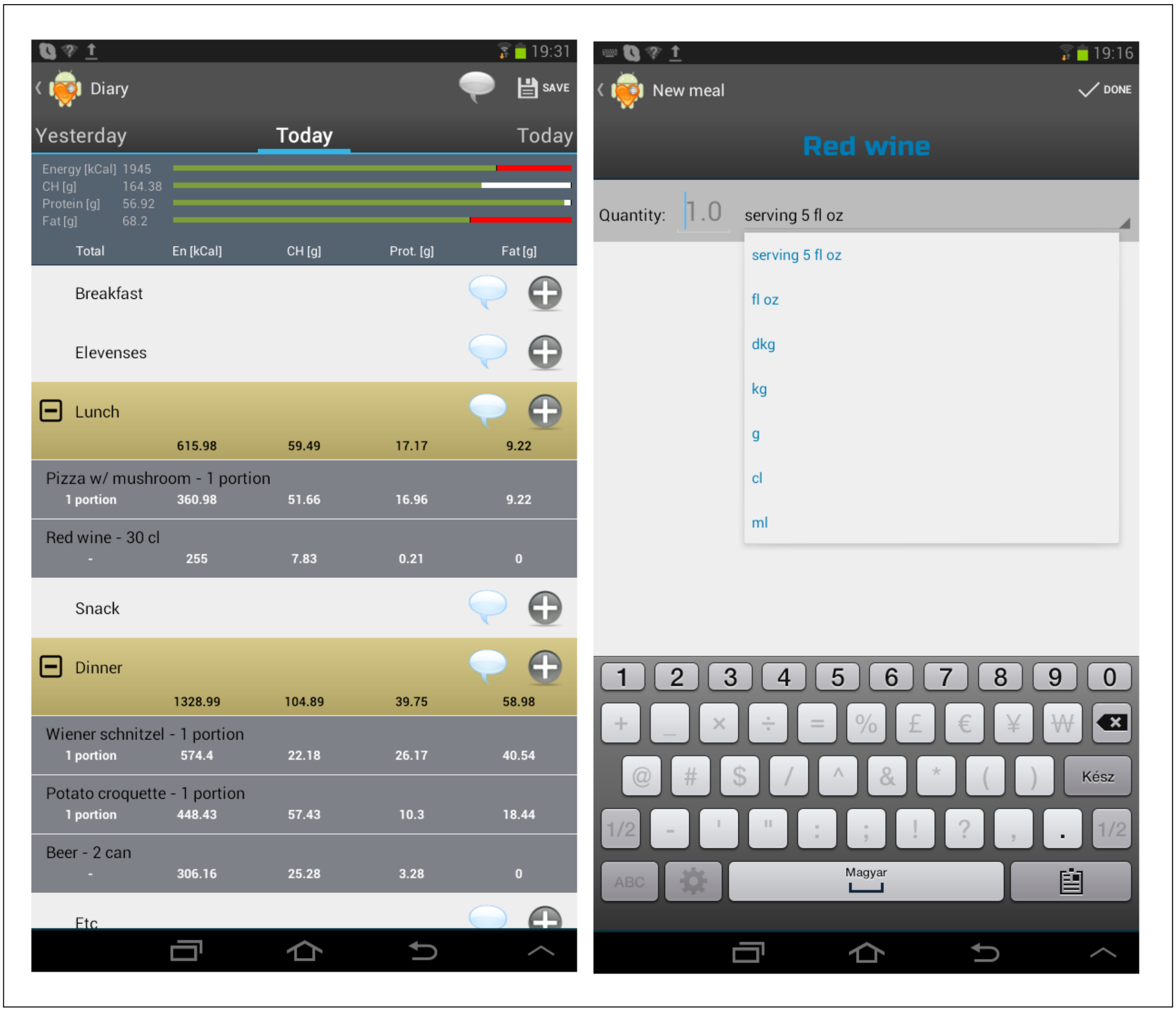

Figure 2: Logging example screen shots of the Lavinia lifestyle mirror application.

complexity the proof would have to be verifiable in polynomial time by a deterministic Turing machine. Therefore, the introduction of harmony makes the decision problem harder than NP, a good candidate for evolutionary solving methods. A similar extension of the Mixed Integer Linear Problem with first-order logic is presented in [7].

Due to the large number of concrete or general, possibly applicable rules for every single meal, we store the sets and the rules in a pre-processed form that can be searched easily. The final goal of the development is to ensure real time harmony assessment of user-logged of system generated menus.

3 Results

The Hungarian version of the MenuGene data base currently stores 9500 food items along with their nutrient contents and 1373 dishes composed from the foods, but on the user interface we show only the most important 299 dishes and 360 foods, organized in 195 sets, to simplify the search. In a recent survey, we evaluated the completeness of our food and dish data base by manually entering 110 days of menu planned by human dietetians in a Hungarian rehabilitation hospital. The results showed that the database contained ca. 74% of the total 194 dishes that occurred in the menus, but most of the missing dishes occurred rather rarely, so if we consider the dish coverage by food diary item, the coverage ratio is 84%. This means that we could support the most common items. For the foods, these ratios are 84% and 96.5%, respectively. For this trial, we used the Lavinia lifestyle mirror application with an android based GUI (Figs. 2 and 3). This application uses the central MenuGene database and related services in a service oriented open architecture. A distinguishing feature of Lavinia compared to other lifestyle logger applications e.g. [8, 9, 10] is its integration with physiological sensors and its enhanced medial intelligence.

The set hierarchy was developed manually by our dietitian expert such that it should be in line with recent professional recommendations and also support the easy construction of harmony rules. We now have a total of 1409 sets in several hierarchical structures or ontologies.

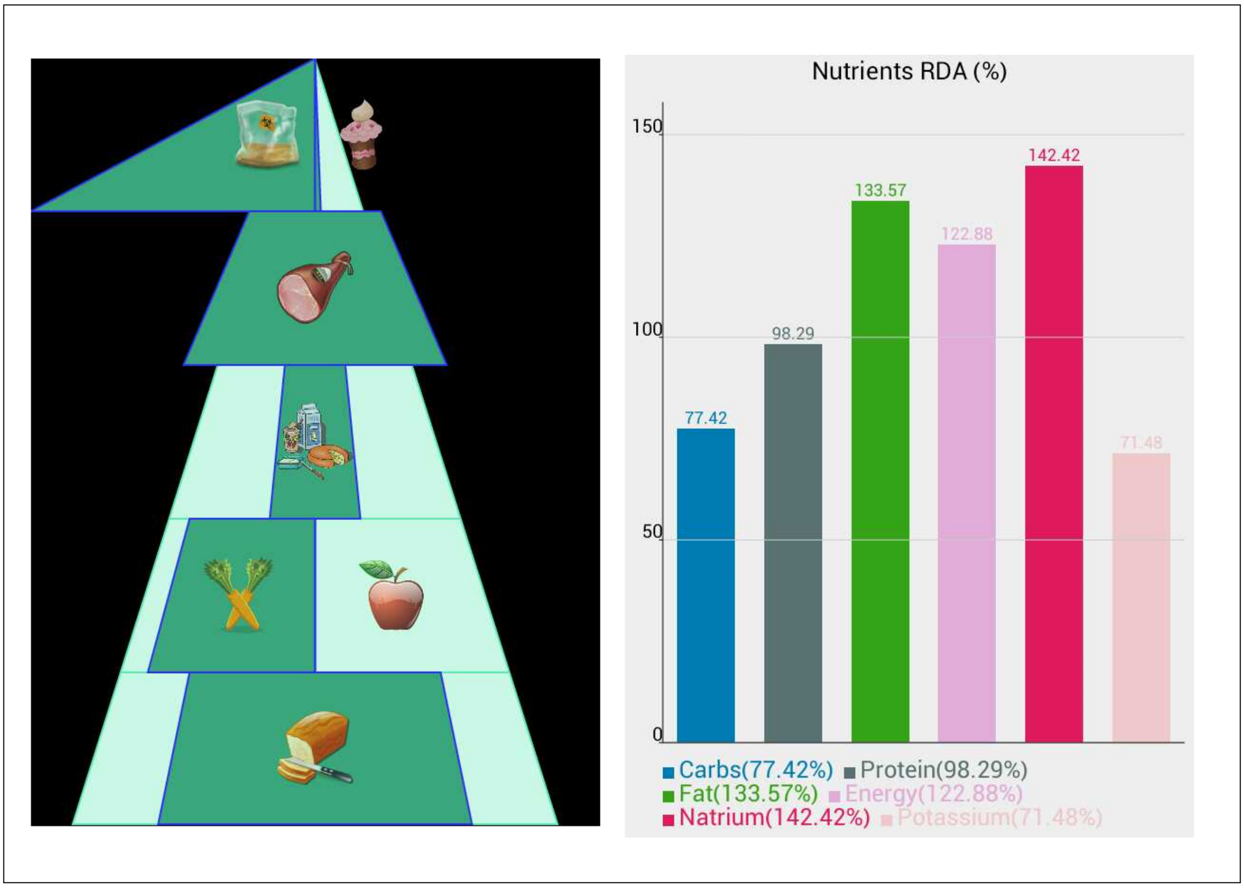

Figure 3: Evaluation example screen shots of the Lavinia lifestyle mirror application.

The reason of using multiple ontologies is the need to support different grouping and classification aspects of foods and dishes. The depth of the deepest hierarchy is 7 levels (Fig. 4).

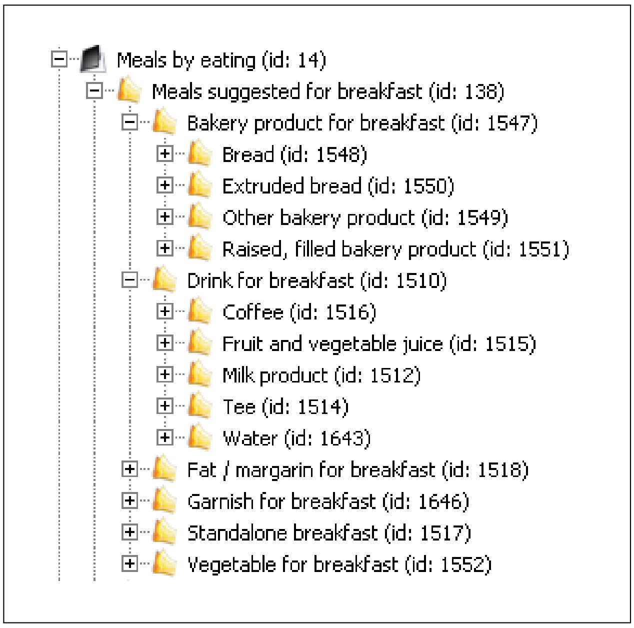

Figure 4: Part of the set hierarchy.

We implemented the concept of the harmony rules described above as a plug-in in the MenuGene expert GUI. Figure 5 shows a positive rule that defines the possible sets of a 2 component standard breakfasts, like “a food from the Muesli/cereal set and a drink from the set of breakfast drinks”. Sets are also used to generate warning messages for the users with specific needs or illnesses. The MenuGene system currently supports 21 chronic illnesses like Crohn disease or diabetes, and various combinations of these provided the number of concurrent illnesses does not exceed 7. The interplay of illnesses is considered for the personalized RDA limits and additionally, users with certain illnesses receive a warning when logging certain types of food. For example, a user with diabetes will receive a warning when logging coke, even if she is within her RDA. Figure 6 shows the expert GUI for defining such message rules.

Another module that will allow the trace back of the rule firing process after the assessment of a menu is also in preparation.

4 Conclusion

The paper presented the MenuGene lifestyle assessment expert system with an emphasis on the rules expressing dietary harmony. A simple rule model, based

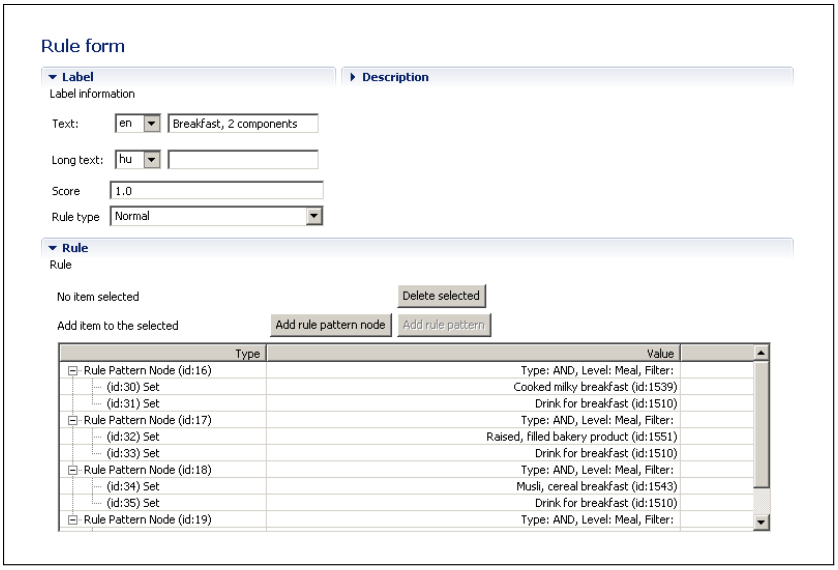

Figure 5: A breakfast structure based on sets.

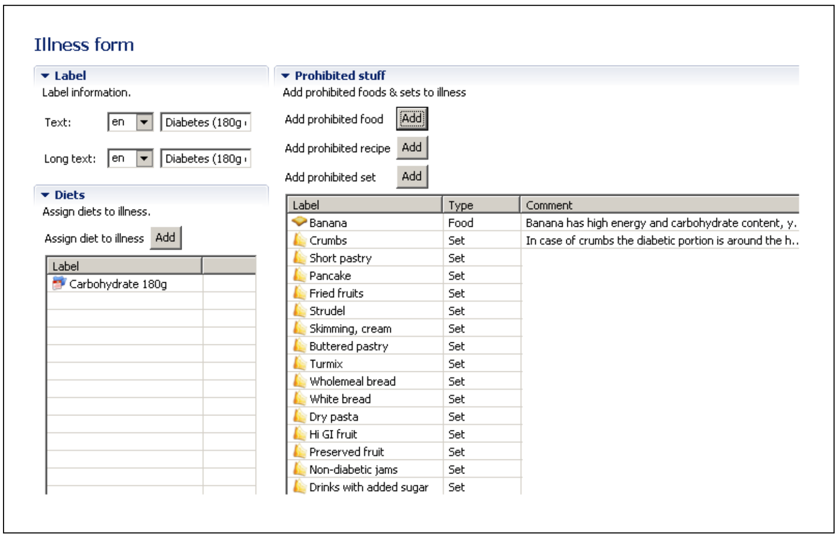

Figure 6: Sets used for generating warning messages on the expert GUI.

on a hierarchy of sets is used to represent domain knowledge. The system has an android-based user interface that supports logging and automated lifestyle assessment. We have already performed some trials to check the completeness of the data base and the usability of the user interface. We also plan to execute clinical trials early next year to examine whether the use of such services really improves patients' everyday life and general state of health, especially in such areas as diabetes and chronic kidney disease.

Acknowledgments

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