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A dynamic project allocation algorithm for a distributed expert system

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Abstract

One of the major concerns of a distributed expert system is to provide optimal solution to a business process characterized by an operations research model. Based on the concept of dynamic programming, the paper presents an efficient computer algorithm which solves an Integer Programming Model for optimally allocating Final Year Projects to more than 200 fourth year BSc students in Department of Civil Engineering (CE), National University of Singapore (NUS), subject to the operation constraints of students' ranking, personal preference and project availability. Having been implemented as part of a distributed project allocation system, the algorithm has improved tremendously the operation efficiency of FYP allocation, by a factor of more than 600 times with a flawless accuracy as compared to its counterpart generated by a previously-adopted manual processing procedure. In light of the dynamic programming pattern abstracted from this system, the allocation algorithm has the potential of being extended to building other distributed merit-based expert systems.

Keywords: Allocation; Dynamic programming; Expert systems; Integer programming; Optimization

1. Introduction

The latest development in internet/intranet server technology has empowered us to develop powerful distributed expert systems (Grove, 2000; Li, 2002) that have revolutionized the conventional way of information collecting, processing and decision-making. One of the key concerns of such an information system is its ability to collect the relevant data and to process them in such a way that generates the optimal solution to a business process characterized by an operations research model.

Traditionally in Department of Civil Engineering, National University of Singapore, the Final Year Project (FYP) allocation process was accomplished manually in three stages:

(1) Academic Staff contributed their FYP proposals and submitted them to Department Office before certain deadline;
(2) Fourth year students wrote down the titles of 10 FYP proposals in a form, prioritized and returned them to Department Office before certain deadline;
(3) Members of a committee manually allocated a FYP to a student based on the student's ranking number, his/her personal preference and the availability of the FYP. Then the committee would announce the allocation outcome to all the students.

The manual processing sequence was very time-consuming and very inconvenient to the parties involved. For instance, a student had to do a lot of manual search for finding the relevant projects and then prioritizing them in a form that was difficult to modify after submission. Academic Staff claimed it was troublesome for them to keep track of the FYP proposals submitted and make changes later on. For the committee members, it was very stressful and tedious to manually assign FYPs to students one by one, because they were under enormous pressure to do a good allocation job for several hundreds of students in a couple of days time. It was under such a circumstance that the request of developing a distributed expert system was studied, which aimed at computerizing all the three stages of FYP processing. The distributed expert system consists of (a) three user interfaces to support the system-user interactions in the above-mentioned FYP processing stages; (b) an expert engine to perform optimal FYP allocation based on the relevant data collected; and (c) a relational database management system for creating

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database tables and managing data transactions. At the core of such an expert engine is a computer algorithm based on dynamic programming concept, which applies expert knowledge (derived from an operations research model) to processing the content of backend database tables. This computer algorithm was intended to find an optimal allocation scheme that best matches a student's preference to the student's eligibility for the corresponding project, subject to the constraints in the student's ranking, his/her prioritized project selections and available project spaces. In other words, the implementation of the algorithm enables a student to be assigned to the most preferable project which the student's ranking and the associated project availability allow. In processing the relational database of students online-submitted FYP selections, the algorithm was applied uniformly across the whole student population to ensure the impartiality and fairness of the merit-based allocation mechanism. As compared to the results of manually processing of FYP assignment, the computerized allocation system had brought about tremendous improvement on operational efficiency (by more than 600 times) and achieved an impeccable accuracy as compared to the results of an independent manual processing procedure.

The paper aims at describing how an efficient computational algorithm had been developed and implemented, in light of a dynamic programming concept, to enable the optimal solution to the integer programming model which characterizes the FYP expert system mentioned above.

2. Problem statement

Let us begin with a description of the business process. Here in CE Department of NUS, several hundreds of fourth Year students are annually mandated to make (up to 20) prioritized FYP choices out of a pool of several hundreds of quota-fixed FYP proposals. Only one project will be assigned to each student. Majority of the projects only have one-person quota, with a dozen of group projects which can take $2 \sim 5$ students to accomplish. Each student has a unique ranking number which is used in the allocating process. *We need to find a allocation scheme such that it ensures overall that everyone gets a project which best matches the student's personal preference with his/her ranking, i.e. no other more qualified students can take the student's project allocated and the student is assured that the project assigned has the highest priority level among the projects he/she has chosen and is qualified to be allocated to*. To find the optimal solution to this problem of 'allocating most desirous projects to most qualified students', it is important to translate the problem statement into a mathematical model so that the optimal target of the problem can be clearly defined and its solution algorithm be thoroughly discussed.

3. Operations research model

Let us introduce some notation to facilitate the model setup.

P_j stands for a prioritized project set selected by a student whose ID is S_j;
P_j stands for the projectID of a project selected by S_j with priority level i, such that $p_i \in P_j$, $1 \leq i \leq$total of projects selected (≤ 20) and $1 \leq p_i \leq n$ (the upper bound of project ID). q_i stands for the students quota permitted to $p_{i.}$
F_j stands for the preference level assigned to p_j by S_j, with $F_j = 1$ designated as the first priority and $F_j =$ total number of projects selected by the student in the current session (≤ 20), designated as the last priority in P_j.
R_j stands for the ranking number of S_j, with highest ranking designated as $R_j = 1$ and lowest ranking designated as $R_j =$ total number of students.

Under the assumption that there are altogether m students whose FYPs are to be assigned by the model, the problem statement is translated into the following *Operation Research Model*, or more specifically *Integer Programming Model* in view that all the decision variables (F_j, S_j) for $j = 1$ to m must be of positive integer values.

Find the positive integer value pairs of $*(F_j, S_j)$ for $j = 1$ to m such that the following objective function has the minimum value:

$$\text{minimize objective function,}\quad Z_{\min} = \sum_{j=1}^{m} R_j F_j = \text{minimum}$$

Subject to: for $j = 1$ to m, F_j, S_j must be a positive integer, respectively, such that

(a) $1 \leq F_j \leq$number of projects selected by student S_j, F_j must be selected from P_j, where $P_j = \{(F_{1j}, p_{1j}), (F_{2j}, p_{2j}), \ldots, (F_{tj}, p_{tj}), 5 \leq tj \leq 20\}$, represents the prioritized project set selected by Student S_j during the student's latest FYP selection session with respect to a prescribed Student FYP selection cutoff date.
(b) F_j should be affected only by the assignment of F_i, where $i = 1$ to $j - 1$, i.e. a student's FYP assignment should be affected only by the FYP assignments of students whose ranking are higher than the student's.
(c) $1 \leq p_j \leq n$ (n represents the upper bound of projectID) and $p_j \in P_j$, P_j contains all the projects (≤ 20) selected by S_j and for every assignedp_j to be valid, the corresponding $q_j > 0$ must be ensured and updated.