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Distributed Constraint Satisfaction based scheduling of nurses

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Abstract: In Indian hospitals, the number of nurses is inadequate. Due to a shortage of hospitals to accommodate India's expanding population, the problem has gotten worse. Generally speaking, hospitals treat more patients than they can manage. Nurses are a vital human resource for every hospital's day-to-day operation. This human resource, which is typically limited, must be used as efficiently as feasible. Manually scheduling nurses is difficult and time-consuming as nurse scheduling is extremely constrained and labour-intensive to do by hand. This work formulates the Nurse Scheduling Problem (NSP) as a distributed Constraint Satisfaction Problem (DCSP) that may be automated using any object-oriented programming language.

Keywords: Nurse Scheduling Problem, NSP, Distributed Constraint Satisfaction Problem, DCSP

1. Introduction

It is not possible for doctors to take care of every need of patients. Doctors are specialized in their respective domains. It is a waste of advanced skill of doctors to do all the such needs that can be done with less training. These types of medical care which are common and does not need advanced doctoral skills can be acquired by individuals. Nurses are skilled with these types of medical care. Numerous departments, such as Obstetrics and Gynaecology, radiology, Pathology, neurology, orthopaedics, paediatrics, ENT, etc. are commonly found in hospitals. There is very little variation in the nursing needs of the various departments. As a result, departments with comparable nursing requirements are grouped together so that respective specialized nurse allotment would be easier. There are four categories of nurses that are available in India. These are Master's degree nursing graduates, Auxiliary Nurses and Midwives (ANM), General Nurses and Midwives (GNM), and Graduate Nurses. General nursing midwife (GNM) nurses provides more integrated health care in hospitals; graduate nurses (BSc Nursing) have advanced level of patient care skills and handle adverse situations like ICU etc.; master's in nursing graduate (MSN) are specialized in particular domain typically specializes in a particular field like education, management, Health policy etc. Seniority is another factor that is used to categorized nurses. Hospitals have their own terminology for seniority among nursing staffs. For instance, Chief Nursing Officer (CNO) → Nursing Superintendent (NS) → Deputy Nursing Superintendent (DNS) → Assistant Nursing Superintendent (ANS) → Senior Nursing Officer (SNO) → Nursing Officer (NO) is the hierarchy of nursing services at AIIMS, New Delhi.

Majority of patients needs only medical advice from doctors, only a few needs specialized medical care and required to be administered by admitting in hospitals. On the basis of this, hospitals provide two types of services, namely out patients departments (OPDs) and in patients departments. Thus, hospitals in India required the services of nurses for OPDs and for patients admitted in hospitals. OPDs provide only advices to patients, it is not required to be opened for 24 hours a day but critical patients require to be in continuous observation. So, usually there are four types of shifts for nurses. One for OPDs which is about 8 to 10 hours a day and another for continuous observations of patients. Since a nurse can not work for 24 hours, the 24 hours is divided into three shifts of 8 hours each. The morning shift usually starts between 6 to 7 AM in the morning and last between 2 to 3 PM. The next shift, evening shift starts between 2 to 3 PM in the evening and ends between 10 to 11 PM. The night shifts usually start between 10 to 11 PM and ends between 6 to 7 AM the next morning. For instance, AIIMS scheduled 6AM – 2PM, 2PM – 10PM and 10PM – 6AM for these three shifts. Let's termed these morning, evening and night shifts as shift1, shift2, shift3 and for the shift for OPD, let's call it OPDshift. Nursing personnel are needed to be assigned to these shifts.

Since there are rules and regulations set up by medical council of India that regulates the working hours and conditions of nurses in hospitals of India, the nursing schedule required to satisfies these conditions. For example, nursing personnel can work up to 40 to 42.5

hours a week. Usually, they require to do 22/23 such shifts a month. Responsibilities of nursing personnel depends upon their seniority. For example, The Senior Nursing Officer oversees the Nursing Officer and is answerable to the Assistant Nursing Supervisor for the overall care of the patients in the wards. So, adequate number of senior nursing personnel needed to be deployed against junior nursing personnels. The specifications of deployment of senior nursing personnel with respect to junior nursing personnel depends upon hospitals. For AIIMS it is mentioned in their NURSING SERVICES MANUAL AIIMS, New Delhi [5].

***Problem Statement*:**

An NSP is a problem of allotment of nurses to wards and OPDs satisfying the following scheduling constraints:

1. A nurse cannot be assigned to two different wards at the same time.

2. A nurse can be assigned up to 5 shifts of 8 hours each in a week.

3. Number of shifts assigned to nurses should be rational. Every nurse gets equal number of shift1, shift2, shift3 and OPDshifts.

4. Specialized nurses needed to be allotted to specific wards as per the requirement of the hospital.

5. Nursing personnel can be engaged for two consecutive shifts and no more.

6. Adequate number of senior nursing personnel to be deployed against junior nursing personnels as per the hospital norms.

2. Literature Review

Assigning a set of shifts to the group of nurses over the course of the schedule period is the goal of the NP-Hard scheduling problem known as the NSP [1,2,3,4]. Healthcare researches into staffing skills, allocation capacity, scheduling cycles, and nursing assignment were categorized by Warner [11]. Several scholars have examined the best way to distribute nurses in healthcare systems using various methodologies. Warner [6] employed mathematical programming ideas to plan nursing staff according to their choices about off-duty days, shift patterns, and length of stay on duty. Bard and Purnomo [7] used a column generation strategy that integrates both integer programming and heuristic models to tackle the multi-objective problem of preferred nurse scheduling. In order to handle the uncertainty in the scheduling problem, Topaloglu and Selim [8] utilized fuzzy set theory to nurse scheduling and created a multi-objective integer programming model using three distinct fuzzy sets. Warner and Prawda [9] employed mixed-integer programming to maximize the quantity of nursing staff with different ability groups in different hospital wards and shifts. Fei et al. [10] planned and scheduled a hospital theater operating room using a hybrid genetic algorithm technique and a heuristic-based approach.

3. Methodology

A variety of constraints needed to be taken care of while scheduling nurses. So, if the problem is reduced into constraint satisfaction problem (CSP), then the automation of scheduling process can be achieved using backtracking. Using heuristics the search time of a feasible solution can be further reduced. One more advanced consideration would be to use distributed CSP. If we are able to reduce the NSP into an equivalent distributed CSP, then using asynchronous backtracking search time for a feasible solution will further be reduced.

A CSP is a three tuple consists of the set of variables – X, set of constraints – C, and set of domains of variables – D. For example, a 4x4 queens' problem which is to place 4 queens on a 4x4 chess board such that no two queens attack each other, can be stated as a CSP as follows:

X = {q1, q2, q3, q4}, be the set of four queens such that q1 will be placed at one of the four boxes of first row. Similarly, the second, third and fourth queen will be placed in one of the four boxes of second, third and fourth rows respectively. Let their respective domains be d1, d2, d3, d4, then D = {d1, d2, d3, d4}, where d1 = d2 = d3 = d4 = {1, 2, 3, 4}. There are two types of constraints namely c1 and c2 avoiding vertical and diagonal clashes between queens. If queen qi is assigned a value x and queen qj is assigned a value j then the set of constraint will be C = {c1, c2}, where c1 is $x \neq y$ if $qi \neq qj$ and c2 is (x-y) should not be divisible by mod(i-j).

A distributed Constraint Satisfaction Problem (DCSP) is a CSP where constraints and variables are distributed among autonomous agents. Asynchronous backtracking is used to solve DCSP. There are some assumptions will be made to solve a DCSP using synchronous backtracking. The first assumption is to

consider that all the autonomous agents contain only one or more variables, another assumption is that the constraints are of binary or unary in nature means to say that no more than two agents(variables) are involved in a constraint. The knowledge of constraints is limited to the variables involved in the constraints as against in CSP where all the constraints are managed centrally. Out of the agents who have the knowledge of constraint among involved agents, not all tries to evaluate the constraints. The agents are categorized as constraint evaluating agents and value sending agents. So, we choose one of the agents as constraint evaluating agent and others as value sending agents who sends the values assigned of their component variable to the constraint evaluating agent. Thus, there is a need of communication among constraint evaluating agents and value sending agents. A two – way communication protocol is imposed for this communication. A value sending agents send its value to the constraint evaluating agent with the OK? Message having form {(variable → assigned value)} OK? . All the (variable, assigned value) pairs received to constraint evaluating agents constitute its agent view. Upon receiving the values from different agents, the constraint evaluating agent communicate with value sending agent with a nogood message having the form nogood{(variable → assigned value)} indicating the assignment made by the particular variable is not consistent. It is to be noted that an agent can be viewed as both value sending agent as well as constraint evaluating agent. Once a nogood is received by some agent it will change its value and again communicate with the constraint evaluating agent. Here assignment of agents is carried out simultaneously. So, there is chance of the process to get stuck in a loop as change in agents values always violates constraints. To avoid such loops, a total order relation among agents is to be established before asynchronous backtracking starts.

4. DCSP compatible design of Nurse Schedular

The number of nursing personnels for a hospital depends upon the number of wards, number of beds, number of OPDs and regulations of the respective country. The nursing personnel requirements can easily be calculated manually. These nursing personnel needed to be placed at one of these wards, OPDs. For simplicity, wherever shift1(Morning), shift2(evening), shift3(night) duties are needed, we call them wards and wherever straight shift (9AM to 5PM) are needed, we call them OPDs. So, there are basically two types of rooms, wards and OPDs where nursing personnels are needed to be placed.

We collect the details of nursing personnels and wards/OPDs nursing requirement in tables as below:

Table of Nursing Personnels: It contains the details of nursing personnel of the hospital. The last column of the table creates a unique code for each nursing personnel. The coding scheme for this is: (Serial No)-(Type of nursing personnel)-(seneority).

Serial No.	Name of Nursing Personnel	Type of Nursing personnel (ANM/GNM/Graduate/Master)	Seniority (CNO/NS/DNS/ANS/SNO/NO)	Code
1	N_1	GNM	NO	1-GNM-NO
2	N_2	ANM	NO	2-ANM-NO
…	…	…	…	…

Table of Nursing Personnels

Table of OPD details: It contains the details of nursing personnel required to be placed at the OPD. The last row of the table creates a unique code for each OPD. The coding scheme for this is: O(serial Number)-(GEN/SPL)-(nursing personnel requirement details).

Serial Number	1	2	…
OPD Name	OPD_1	OPD_2	…
Is OPD General or Special?	General	Special	…
Type of Nursing Personnel Required (ANM/GNM/ Graduate/Master)	ANM	Graduate	…

Number of nursing requirements	2-ANM	1-Graduate, 2-ANM	…
Number of senior nursing staff	1-SNO	-	
Code for the OPD	O1-GEN-ANM-2-SNO-1	O2-SPE-G-1-ANM-2	…

Table of OPD details

Table of ward details: It contains the details of nursing personnel required to be placed at the ward. The last row of the table creates a unique code for each ward. The coding scheme for this is: W(serial Number)-(GEN/SPL)-(nursing personnel requirement details).

Serial Number	1	2	…
Name of WARD	W_1	W_2	…
General/ Special	General	Special	…
Type of Nursing Requirement (ANM/GNM/Graduate/Master)	ANM, GNM	ANM, Graduate	…
Number of Required Nurses	3-ANM, 2-GNM	1-Graduate, 2-ANM	…
Number of senior nursing staff	4-SNO, 1-ANS	-	
Code	W1-GEN-ANM-3-GNM-2-SNO-4-ANS-1	W2-SPL-G-1-ANM-2	…

Table of ward details

Once these tables are obtained for each OPD and for each ward, a table of timeslot codes for each OPD and for each ward is automatically be created. These timeslot codes are unique for each shift of each OPD and each ward. The format of timeslot Codes of OPD (OPDs are closed on sundays) are as under:

OPD – O1	OPDShift
Monday	O1-1-1-ANM-2-SNO-1
Tuesday	O1-2-1-ANM-2-SNO-1
Wednesday	O1-3-1-ANM-2-SNO-1
Thursday	O1-4-1-ANM-2-SNO-1
Friday	O1-5-1-ANM-2-SNO-1
Saturday	O1-6-1-ANM-2-SNO-1

timeslot codes of OPD O1

The coding scheme of timeslot for each OPDshift is: O(OPD Number)-(day number)-(shift number)-(nursing personnel requirements).

The format of timeslot codes of wards is as under:

Ward/OT – W1/O1	Shift1	Shift2	Shift3
Mon	W1-1-1-ANM-3-GNM-2-SNO-4-ANS-1	W1-1-2-ANM-3-GNM-2-SNO-4-ANS-1	W1-1-3-ANM-3-GNM-2-SNO-4-ANS-1
Tue	W1-2-1-ANM-3-GNM-2-SNO-4-ANS-1	W1-2-2-ANM-3-GNM-2-SNO-4-ANS-1	W1-2-3-ANM-3-GNM-2-SNO-4-ANS-1
Wed	W1-3-1-ANM-3-GNM-2-SNO-4-ANS-1	W1-3-2-ANM-3-GNM-2-SNO-4-ANS-1	W1-3-3-ANM-3-GNM-2-SNO-4-ANS-1
Thu	W1-4-1-ANM-3-GNM-2-SNO-4-ANS-1	W1-4-2-ANM-3-GNM-2-SNO-4-ANS-1	W1-4-3-ANM-3-GNM-2-SNO-4-ANS-1
Fri	W1-5-1-ANM-3-GNM-2-SNO-4-ANS-1	W1-5-2-ANM-3-GNM-2-SNO-4-ANS-1	W1-5-3-ANM-3-GNM-2-SNO-4-ANS-1
Sat	W1-6-1-ANM-3-GNM-2-SNO-4-ANS-1	W1-6-2-ANM-3-GNM-2-SNO-4-ANS-1	W1-6-3-ANM-3-GNM-2-SNO-4-ANS-1
Sun	W1-7-1-ANM-3-GNM-2-SNO-4-ANS-1	W1-7-2-ANM-3-GNM-2-SNO-4-ANS-1	W1-7-3-ANM-3-GNM-2-SNO-4-ANS-1

timeslot codes of ward W1

The coding scheme of timeslot for each ward shifts is: W(Ward Number)-(day number)-(shift number)-(nursing personnel requirements)

Scheduling Strategy:

The prime concern of Nurse Scheduling Problem is to allocate nursing personnel to each timeslot of wards and each timeslot of OPDs as per the nursing requirements of respective timeslot. Since, we can group wards and OPDs with similar requirements of nurses and the number of different types of nurses with different seniority can be evaluated easily. We create autonomous agents for each such groups with fixing the nursing personnel for each such groups as per the requirements. Let there be k such groups G1, G2, …, Gk and the group Gi has ri number of timeslots. We know a nurse can be allotted 5 shifts in a week, so if we denote n111, n112, n113, n114, n115 as nurse shift position of a nurse n1, denote n211, n212, n213, n214, n215 as nurse shift position of a nurse n2 and so on, then these shift positions are needed to be allotted to the timeslots of respective groups. In this way, there are separate nurse domain shifts say N1 = {n111, n112, n113, n114, n115, n211, n212, n213, n214, n215, …}, N2, …, Nk for each of the groups G1, G2, …, Gk respectively. There is an autonomous agent for each of these k groups and their respective domains are N1, N2, …, Nk.

With the above considerations we left to check only four types of constraints as first two types of constraints must be satisfied with this setup. The remaining four constraints are:

Scheduling Constraints:

1. Number of shifts assigned to nurses should be rational. Every nurse gets equal number of shift1, shift2, shift3 and OPDshifts.

2. Specialized nurses needed to be allotted to specific wards as per the requirement of the hospital.

3. Nursing personnel can be engaged for two consecutive shifts and no more.

4. Adequate number of senior nursing personnel to be deployed against junior nursing personnels as per the hospital norms.

5. The scheduling model

The specification of timeslot class will be:

Integer assignmentLevel=0;	Do the instantiated object is assigned or not?
Integer requiredNurses;	Contains number of nurses required in this timeslot.
String NurseCodesSlot[requiredNurses];	Array of NurseCodeSlot to store allotted nurse code slots.
Set and get functions for members of the class;	Use to set and get values of variables and functions of the class.

The specification of nurse shift class will be:

String Name;	Contains name of nurse
String NurseCode	Contains nurse code
Integer a;	Contains the number of shifts that can be allotted to the nurse per week.
String timeslots[a]	Array of strings to store the assigned timeslot.
Set and get functions for members of the class;	Use to set and get values of variables and functions of the class.

Every object of nurse class will also generate “a” (workload of the nurse) objects of NurseCodeSlot class. The specification of the NurseCodeSlot class is:

String NurseCode;	Contains nurse code for which this slot is to be created
String Assignment=null;	Contains assigned timeslot, If unassigned then it contains null string.
Int slot;	Contains slot number which a number from 1 to a, a being the workload of the nurse.
Set and get functions for members of the class;	Use to set and get values of variables and functions of the class.

The name of objects of the NurseCodeSlot class has the form: (NurseCode)-(slot), which is the value that is to be assigned to timeslot objects.

Two sets, assigned and unassigned each for NurseCodeSlot and timeslot is to be managed for each group. Once a timeslot is chosen for value assignment, that timeslot is removed from unassigned to assigned set. Similarly, for NurseCodeSlot. If the assignment of a timeslot is found to be inconsistent, then that value is removed from assigned to unassigned with respective changes in the object. The schedule offers an NSP solution once the list of unassigned timeslots is finished meeting all the requirements. The NSP cannot be solved otherwise.

Constraints:

1.There must be a nurse requirement particular to the domain. For instance, if ANM is required, then ANM should be choosen.

2.Prior to assigning a NurseCodeSlot to a timeslot, the timeslot to which the NurseCodeSlot is to be associated must be assigned to the NurseCodeSlot object.

3.It is important to confirm that the timeslot for which a NurseCodeSlot is to be selected from the unassigned set of NurseCodeSlot cannot be the third consecutive shift on the same day. Assuming that a nurse is to be assigned to timeslot W1-6-2-ANM-3-GNM-2-SNO-4-ANS-1, the difference between the timeslot's first three components and the first three components of any other timeslots that have already been assigned to the nursing code must be less than two.

4.A nurse's seniority would be compared to the needs of the wards for which it is being considered before being assigned.

6. Conclusion

The NSP in itself lack distributivity. The prototype presented here imposes distributivity in NSP, so that search time will be reduced using DCSP. One of the key advantages of this scheduling system is that it is simple to implement in any object-oriented programming language. Any hospital in India can use the idea with a few minor modifications. This scheduling mechanism is powerful and suitable for use in any hospital.

Once reduced as a DCSP, heuristics like ACO, ABC etc. can be used to further reduce the search time for a feasible solution.

7. Competing Interests

No competing interests.

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