Decision Making System Based on Bayesian Network for an Agent Diagnosing Child Care Diseases

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Abstract. In some cases a pediatrician seeks help from super specialist so as to diagnose the problem accurately. In a Mutli-agent environment, an agent called Intelligent Pediatric Agent (IPA) is imitating the behavior of a pediatrician. The aim is to design a decision making framework for this agent so that it can select a Super Specialist Agent (SSA) among several agents for consultation. A Bayesian Network (BN) based decision making system has been designed with the help of a pediatrician. The prototype system first selects a probable disease, out of 11; and then suggests one super specialist out of 5 super specialists. To verify the results produced by BN, a questionnaire containing 15 different cases was distributed to 21 pediatricians. Their responses are compared with the output of the system using KS test. The result suggests that 91.83% pediatricians agree with the result produced by the system. So, we can conclude that BN provides an appropriate framework to imitate the behavior of a pediatrician during selection of an appropriate specialist.

Keywords: Multi-agent System, Decision making, Bayesian Networks, Child care.

1 Introduction

Medical problems inherent uncertainty and Bayesian Network (BN) provides a strong basis to deal such problem as it is based on rigorous mathematical fundamentals. This paper presents the decision making based on BN for an agent called Intelligent Pediatric Agent (IPA).

1.1 Scope of the Paper

This paper presents the design and preliminary evaluation of a decision making for an IPA that chooses among super specialist agents (SSA) for tackling childhood diseases that are beyond its scope. The decision making system is built using Bayesian Network, an inference mechanism to build an uncertain-reasoning system. The IPA is to decide the probable disease and the suitable SSA as per the sign symptoms provided to it. The following super specialists are under consideration:

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- *Endocrinologist:* Deals with diseases of endocrinal glands which secrete hormones e.g. Thyroid, Pancreas, and Pituitary etc.
- *Cardiologist:* A specialist who deals with diseases due to malfunctioning of heart.
- *General Surgeon:* A doctor who treats diseases through surgery.
- *Pulmonologist:* A specialist who is required in lung diseases.
- *Gastroenterologist:* A specialist who is required in intestinal and liver diseases.

The decision making system in this paper is to be integrated with the Multi-agent medical system presented in [1] so as to decide communication path among agents. A concise introduction of the larger MAS has been discussed in section 1.3.

1.2 Problem Definition

There are around 65% Indians who live in rural or remote areas where medical facilities are in dire state. The main contributors to this dismal situation are lack of infrastructure and inadequate trained staff. The government is helpless in providing ample amount of funds to improve the situation. Due to this, the infant mortality rate is 68/1000 live births.

The General Doctor (GD) who is posted in rural/remote centers is not qualified enough to tackle critical childhood diseases. Whenever he encounters a case that is beyond his knowledge, he refers the ailing child to a pediatrician. A pediatrician usually lives in cities/urban areas.

A pediatrician is capable to solve most of the cases himself but in some particular cases he needs help from super specialists. He may transfer such patients to super specialist also or may seek guidance to cure the patient. This paper studies the way a pediatrician chooses the super specialist for reference.

1.3 Overview of the Multi-agent Medical System

The decision making system described in this paper is incorporated in a larger medical system that authors and their collaborators are currently developing. The medical system will help rural healthcare professional in tackling childhood diseases more effectively with the use of this system. The system developed so far utilizes childhood disease ontology developed for understanding the meanings of the messages exchanged by User Agent (UA) and the IPA. The abstract model of these agents is depicted in Fig. 1.

The agent at rural site is called User Agent (UA), the agent at pediatrician level is named as Intelligent Pediatric Agent (IPA) and the agent at super specialist level is termed as Super Specialist Agent (SSA).The ontology shared by UA and IPA has been developed as per the guidelines stated in [2]. If the UA informs the IPA that the patient, aged above 2 years, is suffering from cough, then IPA posses the following queries to be answered by UA:

- For how long the patient is suffering from cough?
- Is the patient suffering from wheeze, chest in-drawing?
- Specify the breaths in 1 minute.

This information is sufficient for diagnosing the problem and its treatment plan. The same information, in presence of few more symptoms like swelling of feet and easy exhaustiveness, makes it a complex problem that is supposed to be passed onto a Cardiologist. So there is a need to tackle such uncertainty, and BN provides a suitable environment.

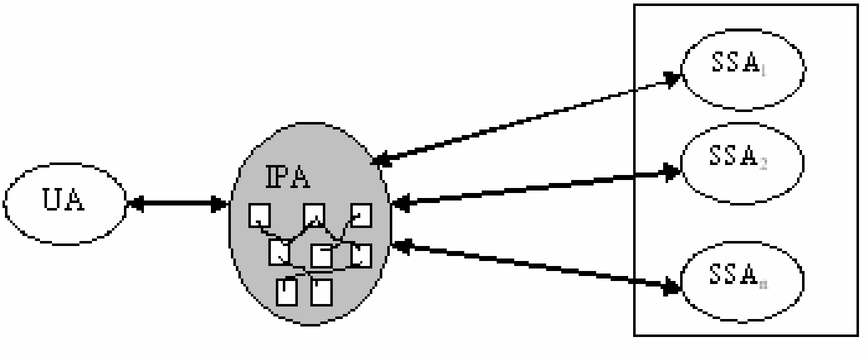

Fig. 1. Abstract model of MAS for Child Care

This paper is concerned with the decision making process based on BN for IPA. The aim is to initially decide a probable disease and then appropriate SSA as per the sign symptoms provided by UA. Our previous work [1] presents a prototype MAS that enables UA and IPA to form a client server architecture and handle diseases that are within the scope of a pediatrician.

2 Related Works

The usefulness of Bayes's theorem has been accepted in medical domain long time back. It suits to medical domain since information needed in decision making is probabilistic [3]. The Bayes's theorem delivers accurate results where specific manifestations have high frequency and high specificity [4]. Lot of experimentation is undergoing to utilize BNs in current scenarios also. For example, discovering temporal-state transition patterns during Hemodialysis has been discussed in [5]. But there has been criticism of Bayesian based probabilistic systems also. The main limitation is to obtain realistic prior probabilities. This can be tackled by involving domain experts for deciding probabilities or utilizing statistical data as being done in [6], for diagnosing hypertension.

Software agents are proving to be promising solution in medical domain because of their reactive, proactive, autonomous, collaborative and knowledge-sharing capabilities. For instance, [7] discusses management of diabetic patient, and [8] highlights a case study for community surgery where agents need to collaborate for appointment scheduling, monitoring and recording data, etc.

To make the agents demonstrate the requisite behaviors, probabilistic networks, rule based system and Markov decision making process can be utilized. But probabilistic networks are more appropriate in our domain. For instance, the negotiation algorithm for agents when information is incomplete has been discussed in [9].The core of this algorithm is based on Bayesian learning process. Similarly, with passage of time, the behavior of an agent tends to modify. To tackle such a case, influence diagrams and BNs have been used in [10]. Although, a Markov Decision making process to aid people who are suffering from Dementia has been discussed in [11], yet BN is more promising.

The Contract Net Interaction protocol [12] specifies communication protocol among agents. One agent behaves as an initiator and others as participants. The initiator broadcasts a requirement that can be met by one or more agents. This negotiation concludes with the initiator behaving as a server and the most promising agent as a client. This kind of interaction is not feasible in our case, for instance, if the IPA broadcasts 'Constipation' as a sign symptom then SSA Surgeon, SSA Cardiologist and SSA Endocrinologist would respond, sensing the probable diseases. Now IPA, using contact net protocol, would respond to all SSAs'. This would lead to high density of messages. On the other hand if UA supplies Constipation and Abdominal Distention, IPA using the proposed BN can first decide the probability of a disease (Intestinal Obstruction) and finally the SSA, Surgeon in this case.

The discussion above concludes that BNs can work well in the Multi-agent systems for health care domain. In this paper, we design and evaluate the BN for selection of appropriate super specialist agent for communication with user agent. This decision making is a functional part of IPA.

In the subsequent sections we introduce the fundamentals of BN. The basics of BN, specific to our problem, will also be discussed and then we will design the probabilistic network with the help of GeNIe [13]. This tool has been used to verify the results too.

3 Basis of Bayesian Network

A BN is composed of a qualitative and a quantitative part. The qualitative part is an acyclic directed graph reflecting typically the causal structure of the domain; the quantitative part represents the joint probability distribution over its variables/nodes. Every variable consist of a conditional probability table (CPT) representing the probabilities of each state given the state of the parent variable. If a variable does not have any parent variable in the graph, the CPT represents the prior probability distribution over the variable. A BN is capable of calculating the posterior probability distribution over an uncertain variable given some evidence obtained from related variables. This capability of BNs makes it a very suitable technique for building diagnostic models. Diagnosis is probably the most successful practical application of BNs.

The proposed BN uses the following three sets:
SSA= {Pulmonologist, Cardiologist, Endocrinologist,…},
D= {Tuberculosis, Asthma, Pneumonia, Heart malfunctioning,…}
Sym= {Wheeze, Loss of weight, Fever, Appetite loss,…}

Network chooses the SSA as per the following relationship:

$$\Pr(SSA) \leftarrow \Pr(D) \leftarrow SYM$$

The relationship states that depending on the presence of symptom(s) the probability of a disease is calculated and hence depending on the probability of disease a SSA is decided. The probabilistic inference is governed by the Bayes' theorem. That is,

$$\Pr(SSA \mid D) = \frac{\Pr(D \mid SSA).\Pr(SSA)}{\Pr(D)}$$

In this experimental work the CPTs are estimated with the help of a pediatrician. This ensures that the estimations are accurate.

4 System Design

In this section we describe the design of BN and briefly discuss the diseases for which BN has been constructed.

4.1 Childhood Diseases

Some of the childhood diseases are not diagnosed properly by health care workers in rural India, as discussed earlier in section 1.2. Using the proposed system, the health-care practitioner is to send the sign and symptoms to the IPA. The IPA is supposed to

Table 1. Diseases and its description

DISEASE	DESCRIPTION
Asthma	Chest disease, in which there is allergic cough coming in bouts associated with breathlessness and a wheezing (whistling) sound.
APD (Acid Peptic Disease)	Common gastritis/Acidity.
Calculi	Stones e.g. kidney stone, gall stone
Diabetes	Metabolic disease in which insulin is decreased resulting in high blood glucose levels.
Hiatus Hernia	Upper end of stomach herniates through diaphragmatic opening.
Heart Failure	Disease in which pumping action of heart is compromised due to various causes.
Hypothyroidism	Hormonal disease in which thyroid-hormone levels decrease, resulting in altered metabolic functions of body.
IHD (Ischemic Heart Disease)	Decreased blood supply to heart muscle.
Intestinal obstruction	When there is a block in gut-passage.
Pneumonia	Inflammation of lung parenchyma.
Tuberculosis	Infection caused by Mycobacterium tuberculosis.

tackle cases that are within its scope. But if IPA wishes to consult the super specialist then it first decides the probable disease and then the concerned super specialist. A few diseases that can be diagnosed by IPA using the BN are shown in table 1.

Some of these diseases are critical and may lead to infant mortality if not taken care.

4.2 Bayesian Network for IPA

We are now illustrating the BN developed for IPA. The BN, shown in Fig. 2, is constructed with the help of GeNIe, an interactive tool for development of BN. This tool has been used to model and test the network.

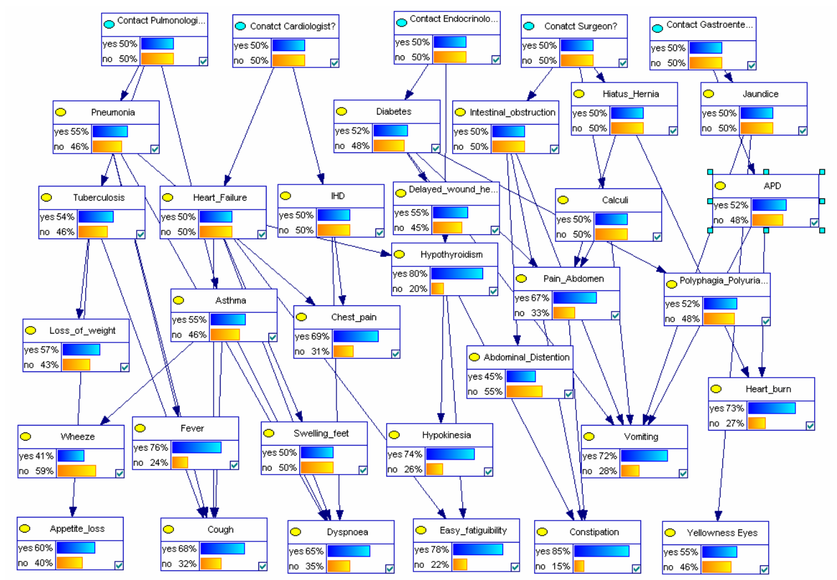

Fig. 2. Bayesian Network for Intelligent Pediatric Agent

There are 34 nodes in the BN out of which 11 nodes are dedicated to different diseases to be handled by 5 specialists. For instance, Breathlessness as a clinical symptom may be caused by Asthma, Pneumonia, Heart failure or IHD. The details of these diseases are given in table 1. These diseases are ideally to be tackled by either a Pulmonologist or a Cardiologist.

In the next section the results produced by BN and opinions of a Pediatrician and general doctors have been analyzed.

5 Implementation

The BN has been designed using GeNIe while Java has been used for developing graphical user interface. The algorithm for selecting most appropriate super specialist is discussed below. In Fig. 3, sign-symptoms: Fever, Loss of Weight and Wheeze has been checked. The system suggests that the patient should consult Pulmonologist, shown in Fig. 4.

```
function GetRecommendedTreatment is
input:    network N,

          symptom Si,
          treatment Ti
output:   treatment Ti
for each Selected(Si) as evidence in N do
  SetEvidence(Si)

      while (there exists a treatment Ti which is ef-
    fected by above operation) do
      if(GetMaxValueOfTraetment(Ti))
        return Ti
      end if
    end while
  end function
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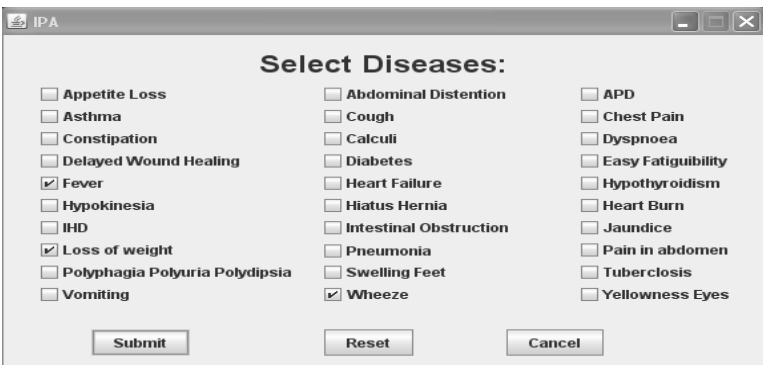

Fig. 3. Interface for selecting Disease or Sign-Symptoms

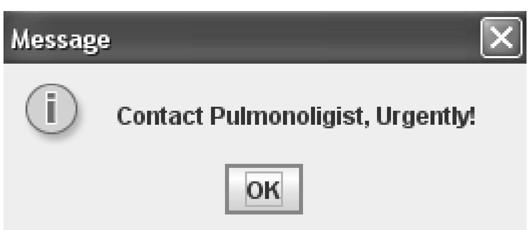

Fig. 4. Bayesian Network based outcome

6 Evaluation

To evaluate the results produced by our system, we contacted 21 pediatricians. These specialists were supplied a questionnaire that contained 15 test cases. Table 2 shows 5 such test cases. A couple of test case was erroneously skipped by pediatricians; hence we received 313 valid results.

To determine if the two samples (one produced by our system and other received from pediatricians) are significantly different or not, we applied Kolmogorov-Smirnov (KS) test. Result is summarized in Fig. 5 and 6. The advantage of this test is that it's a non-parametric method and it makes no assumptions about the underlying distributions of the two observed data being tested.

Mean of the observation produced by pediatricians is 20.867 and the Standard deviation is 1.47. The result of the test suggests that the BN is producing 91.83% accurate result. The significance level assumed in the test is 5%. Clearly BN has been successful in encoding the behavior of a pediatrician for selecting super specialist in case of consultation.

Two-sample Kolmogorov-Smirnov test / Two-tailed test:

D	0.333
p-value	0.082
alpha	0.05

Fig. 5. Result of the KS test

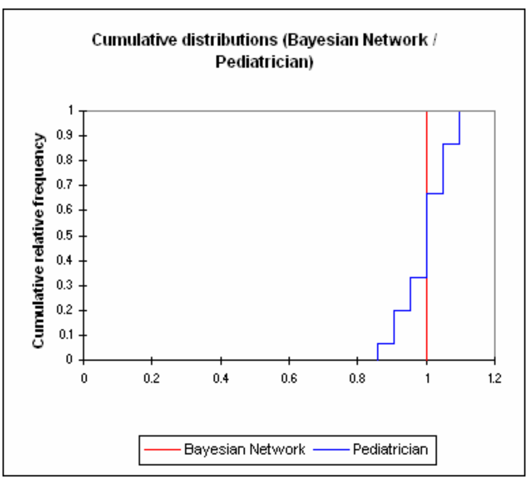

Fig. 6. Analysis of the outcomes

Table 2. Test Cases distributed among Pediatricians

Case No.	Sign Symptoms	Contact Specialist				
		Cardiologist	Endocrinologist	Pulmonologist	Surgeon	Gastroenterologist
1.	Chest pain, Dyspnoea	☐	☐	☐	☐	☐
2.	Loss of Weight, Appetite Loss, Cough	☐	☐	☐	☐	☐
3.	Appetite Loss, Vomiting, Pain Abdomen	☐	☐	☐	☐	☐
4.	Easy fatigability, Cough, Fever	☐	☐	☐	☐	☐
5.	Polyphagia, Loss of Weight	☐	☐	☐	☐	☐

7 Conclusion

The aim of this paper is to design a framework that imitates the behavior of a pediatrician whenever there is a need to consult super specialist. This has been achieved by constructing a BN that encodes the behavior of a pediatrician in such a scenario. The outcomes of the system were evaluated by pediatricians and the results suggest that the system is behaving accurately to an acceptable extent.

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