Classification of Interaction Participants in the Formation of the Trajectory of Diagnosis and Treatment of Bronchopulmonary Diseases to Design Agents of a Multi-agent System

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Abstract. The article deals with the formation of a rational trajectory of diagnosis and treatment of bronchopulmonary diseases of patients in hospital conditions. The description of the process of treatment taking into account various factors is given. The task of forming effective trajectory of diagnostics and treatment of bronchopulmonary diseases is considered in the context of clinical guidelines describing the process of treatment, individual characteristics of patient's health, and available diagnostic equipment and medicines. To solve this problem it is proposed to use a multi-agent approach. This approach will take into account clinical guidelines describing the treatment process, the individual characteristics of the patient's health, and the available diagnostic equipment. The interaction of real participants in the process can be modeled as the interaction of corresponding prototypes—the agents of a multi-agent system. To design the agents of a multi-agent system, a classification of the participants of such interaction for forming a diagnostic and treatment trajectory is proposed. At the first stage digital platform AnyLogic is proposed to be used as a tool for modeling the interaction processes. A formal statement of the problem of forming a trajectory for diagnosing and treating a patient, the results of primary data processing necessary for subsequent modeling, state diagrams of the main agents of the future model are presented, and directions for further research are determined #COMESYSO1120.

Keywords: Diagnostic and treatment trajectory · Agent · Multi-agent system · Agent-based modeling

1 Introduction

The problem of shaping a patient's diagnostic and treatment trajectory, taking into account his/her personal characteristics and the interests of all stakeholders in this process, using artificial intelligence technologies to improve the efficiency of medical data processing, reduce risks and improve the quality of life of the patient for implementing the transition to personalized medicine and high-tech health care, is topical today.

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Research in the application of information technologies, including intelligent technologies, to medical data processing is being actively pursued by many researchers in various countries [1–4]. However, some questions remain unresolved, in particular the consideration of the interests of participants in the process of diagnosis, treatment, and patient follow-up, and have not been fully explored.

This article is devoted to the development of a model for shaping the trajectory of diagnosis and treatment of patients, taking into account all stakeholders. Section 1 describes the problem situation and presents the problem statement. Section 2 is devoted to the analysis of known approaches for solving such problems. Section 3 classifies the participants of interaction in the process of patient treatment, presents a multi-agent model for forming a rational trajectory of diagnosis and treatment of a patient and its implementation using the digital platform AnyLogic. Section 4 presents the results of primary processing of statistical data for subsequent modeling and their interpretation.

2 Problem Description and Problem Statement

Forming a diagnostic and treatment trajectory is a complex process, often poorly formalized, that can have many alternatives depending on a variety of factors. Such factors include the patient's health status, the presence of certain comorbidities, allergic reactions to certain medications, the resources available to the medical institution (availability of diagnostic equipment, available medications), and many others. The person who decides on the choice of a particular diagnostic and treatment trajectory is the treating physician-therapist.

There are clinical guidelines that describe the treatment process for various conditions. These guidelines may change (improve) over time. And undoubtedly, the treating physician needs information support when choosing one or another diagnostic and treatment trajectory.

The task is to use the available clinical guidelines describing how to treat a patient, the individual characteristics of the patient's health and the resources available to the medical institution in the form of diagnostic equipment and medications to form the most effective diagnostic and treatment trajectory designed to improve the patient's condition as much as possible. The aim of this work is to build a model reflecting the patient's diagnostic and treatment trajectory and to determine the parameters of this model.

The aim of the study is to build a multi-agent model reflecting the patient's diagnostic and treatment trajectory, to determine the parameters of this model and the primary processing of the data required for subsequent modeling.

3 Known Approaches to Solving Such Problems

Among domestic developments using a multi-agent approach in healthcare, we can highlight [5], which considers the implementation of a portal using multi-agent technology in healthcare. The multi-agent system developed and presented in [5, 6] simulates the interaction between general practitioners, the head doctor of a clinic, specialists of a hospital, ambulance service, medical university, managers of the regional Ministry of Health, territorial compulsory medical insurance fund, authorized pharmacological

enterprise, patient of medical institutions. In [7] an overview of the application of multi-agent systems for various tasks in the field of health care is given. The authors highlight such areas of application of multiagent systems as: investigating the effectiveness of different mechanisms ensuring the interaction of agents, different scheduling heuristics, etc.; using a multiagent system for operational planning of the treatment process in real hospitals; the multiagent structure is used to build a simulation model of a particular hospital. Such a model reproduces as accurately as possible the organizational structure of the hospital (or its part), available resources (wards, beds, equipment, staff), the mechanism of interaction between units during the treatment process, and actual statistical characteristics of the patient flow. The simulation model makes it possible to improve the organization of the treatment process itself.

In [8], the authors return a multi-agent system for the formation of a schedule for the execution of a procedure in a sanatorium-and-health work.

Among foreign sources, it is possible to highlight the following areas of application of MAS in healthcare: decision-making support for healthcare managers, balancing and maximizing the use of available resources [9]; MAS-based DSS for managing hospital resources [10]. In [11–13] the main directions applications of MAS in the health care sphere.

4 Proposed Approach

4.1 Classification of Interaction Participants in the Formation of the PATient's Treatment Trajectory

The proposed classification of participants in the interaction of the process of the patient's treatment in a hospital, which includes not only the patient and the nursing staff, but also other stakeholders, with description of the main roles is presented in Table 1.

4.2 Choosing a Digital Platform for Multi-agent Modeling

To obtain the best trajectory of in-depth diagnosis and treatment, a multi-agent approach is proposed [14–16]. A multi-agent system (MAS) unit is planned for development, which simulates the interaction of the main participants: patient, diagnostic doctor, therapist, specialized doctors, pharmacist and others. The prototypes of the participants will be the corresponding agents of the MAS, which communicate with each other. As a result of the MAS functioning, the search for the most rational combination of therapeutic (medicinal) and physical influences on a specific person (treatment pathway) and the issuance of personalized recommendations taking into account such characteristics as the patient's health features, lifestyle, demographic data, contraindications to certain groups of drugs, development and severity of disease, associated diseases, personal preferences, characteristics of drugs, their side effects, interaction with drugs, etc., will take place. For this purpose, it is planned to give the appropriate knowledge and target functions to the MAS agents.

The interaction of real participants in the process can be modeled as the interaction of the corresponding prototypes—the agents of the multi-agent system.

Table 1. Classification of participants in the interaction of the process the patient's treatment in the hospital

No.	Participant	Role in the treatment process
1	Patient	Directly passes all diagnostic procedures and treatment
2	Attending doctor	Monitors the patient's health status and is responsible for the choice of methods and means of treatment
3	Diagnostic doctors	Provide diagnostic procedures and interpretation of results
4	Specialized doctors	Carry out a more detailed study and description of the patient's condition, can perform a specific appointment to the patient
5	Pharmacists	Participate in the provision of medicines for the process of diagnosis and treatment of the patient
6	Paramedical personnel	Ensure that the patient undergoes treatment and necessary diagnostic procedures
7	Head of department (administrative person)	Carries out general administrative management of the process of diagnosis and treatment of patients in the department, taking into account the available resources (material, financial, human, etc.)
8	Relatives, patient's surroundings	Participate in the process of interaction between the patient and the attending physician, which is necessary for making decisions in the process of diagnosis and treatment

At the initial stage it is supposed to use digital platform AnyLogic [17] as a simulation tool, which allows building an agent-based model describing the trajectory of patient diagnosis and treatment. Digital platform AnyLogic allows you to build models using three approaches: discrete event, agent-based and system dynamics. The capabilities of multi-approach simulation modeling allow you to develop complex models of phenomena, processes, systems within a single concept and single digital platform.

4.3 Multi-agent Model for the Formation of a Rational Trajectory for the Diagnosis and Treatment of a Patient

In accordance with the previously proposed methodology for solving resource management problems in complex socio-economic systems [18, 19], the multi-agent model for the formation of a rational trajectory for diagnosing and treating a patient can be represented as follows:

$MAS = < A, States, Acts, KB, Constraints, F >$, where:
$A = \{a^i{}_j\}$—the set of agents of class i;
$States = \{states^i{}_j\}$—the set of states of the agents of class i;
$Acts = \{acts^i{}_j\}$—the set of possible actions of the agents of class i;
$KB = \{KB^i{}_j\}$—the set of knowledge bases of the agents of class i;
Constraints—the set of domain constraints;
$F = \{F^i\}$—the set of performance evaluation criteria for each class of agents.

Classes of agents are defined on the basis of the above classification in Table 1. By the trajectory of diagnosis and treatment of the patient we will understand the sequence of transitions between the states of the agent «Patient» from the initial to the final one. The transitions between agents' states can depend not only on their own actions, but also on the actions of agents of other classes from the «Acts» set. The functions F allow us to numerically estimate the state the agent is in at a given moment.

To form a rational diagnostic and treatment trajectory, it is required to determine the sequence of actions that would eventually lead the agent «Patient» to one of the final states with the best values of performance criteria from F for each class of agents.

4.4 Development of a Multi-agent Model for the Formation of a Trajectory for the Diagnosis and Treatment of a Patient in the Digital Platform AnyLogic

A multi-agent model using the digital AnyLogic platform is a set of state diagrams for selected classes of agents that describe the behavior of agents and their interaction.

The developed simplified model includes the processes of selection and pre-sorting of patients coming to the hospital. Then the treatment process itself takes place, at the end of which a new triage takes place. Based on the results of this triage, the patient is either discharged or, if the treatment was ineffective, can go through all the stages of diagnosis and treatment again with new prescriptions, that is, according to a new trajectory.

The passage of all stages of diagnosis and treatment of patients is represented as a process of transition of an agent from one state to another. Thus, in order to complete the whole process of treatment in the hospital, it is necessary for the agent «Patient» to move to the final state. Such a representation is quite convenient for modeling, as it makes the model itself extensible in terms of greater detail and subsequent refinement and complication. In addition, it greatly simplifies the processes of correct description of the interactions of the main participants at any of the stages of treatment.

Figures 1 and 2 show, as an example, the developed simplified diagrams of the states of the agents «Patient» and «Attending doctor», describing the treatment process.

Interaction of agents «Patient» and «Attending doctor» is implemented by exchanging messages between the agents of the corresponding types. For example, the attending doctor, when a patient comes to him or her, has to examine the patient, confirm the pre-established diagnosis, and prescribe a set of diagnostic and therapeutic procedures in accordance with the current regulations. This interaction is implemented by sending the «Patient» agent sends a message to the «Attending doctor» agent. The «Attending doctor» agent, receives the corresponding message, carries out a set of necessary actions for prescribing a certain treatment.

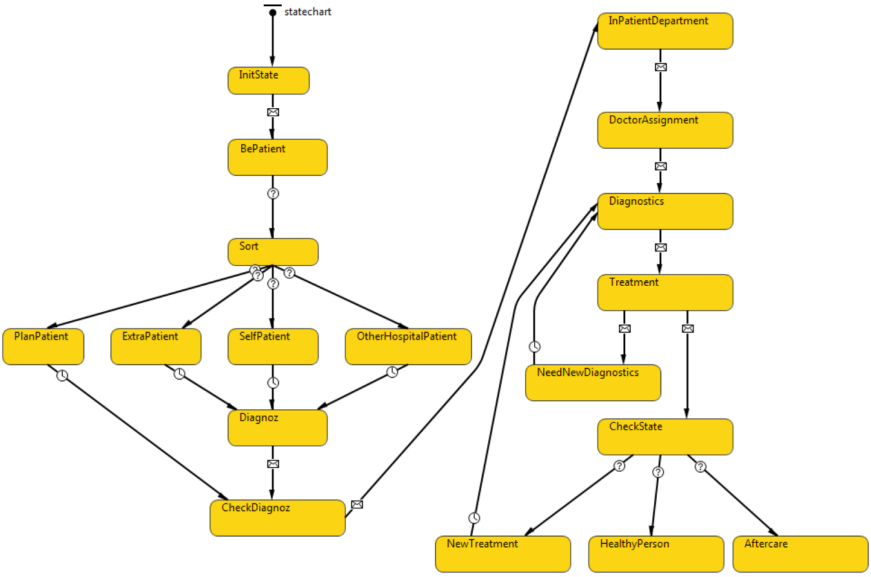

Fig. 1. Diagram of the «Patient» agent states

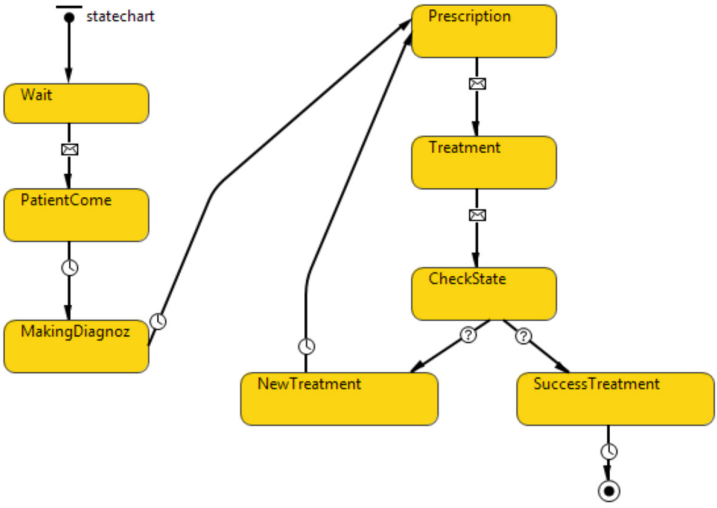

Fig. 2. Diagram of the states of the «Attending doctor» agent

5 Primary Data Processing for Subsequent Modeling

As parameters that characterize the process of treatment of bronchopulmonary diseases in patients hospitalized at the initial were the following:

The intensity of patients' admission to the hospital.

Parameters reflecting the distribution of patients admitted to the hospital (outpatient treatment or hospitalization).

Obtaining baseline data and their further processing is an important step for subsequent modeling. In our case, such data include the statistics of patients' admissions and their subsequent distribution.

As an example of initial data, we took real data on the admission of patients for 2021 to one of the clinics in the city of Ufa. Pre-processing consisted in collecting and processing data on inpatient admissions and subsequent sorting, which determines where the patient will be sent: to outpatient treatment or to one of the inpatient departments. We analyzed daily data reflecting patient admissions and their further distribution for the year 2021.

The results of the analysis are shown in Fig. 3.

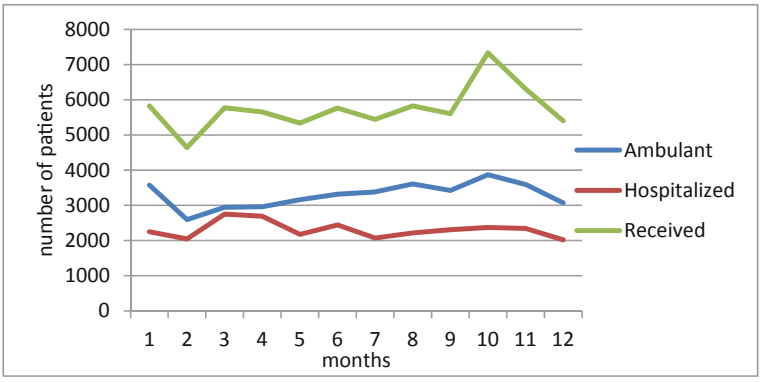

Fig. 3. Distribution of admitted patients.

The results of the analysis allow us to conclude that of the total number of inpatient admissions, most from 51 to 62% are sent for outpatient treatment, and about 32–48% of patients are hospitalized. At the same time, the variability of hospitalized patients is much higher, up to 1.5 times, while the variability of those patients who sent for outpatient treatment is only 1.2.

The analysis of admission schedules makes it possible to assume the presence of seasonality in this process. This circumstance requires a more thorough study and will be the subject of further research.

6 Conclusion

A classification of participants in the interaction in the formation of the trajectory of diagnostics and treatment of patients is proposed, which is used to design agents of a multi-agent system. It includes 8 main participants. A multi-agent model has been developed to form a rational trajectory for diagnosing and treating a patient. With the help of

the AnyLogic digital platform, the state diagrams of the agent's "Patient" and "Attending doctor" were developed—prototypes of the main participants in the interaction. The primary processing of the data necessary for modeling the process of diagnosing and treating patients was carried out. It showed the need for a more thorough analysis of the statistics of patient admissions in order to identify seasonal factors.

In the future, it is planned to develop formalized target functions of the agents and the whole system, which will make it possible to numerically evaluate their performance and compare different alternative trajectories, as well as to pay more attention to agent-based modeling directly the process of diagnosis and treatment.

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