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ORIGINAL

Optimization and designing a hospital using distributed AI

Optimización y diseño de un hospital mediante IA distribuida

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ABSTRACT

The COVID crisis has demonstrated the fragility of hospital health systems. Patients monitored for chronic illnesses have had to stop monitoring their illness. The aims of this article is to present an intelligent and dynamic system that allows patients to be redirected to other care units to ensure their medical care and to prevent inequality between the provision of care and the need depending on the region. An interconnected hospital system will restore a better balance between supply and demand for care. In this article, we present the design and architecture of a hospital using distributed AI and especially multi-agent system that has proved its worth in several distributed systems.

Keywords: Digital Hospital; Health System; Hospital System; Multi Agent System; Primary Care Health System.

RESUMEN

La crisis de COVID ha demostrado la fragilidad de los sistemas sanitarios hospitalarios. Los pacientes controlados por enfermedades crónicas han tenido que dejar de seguir su enfermedad. El objetivo de este artículo es presentar un sistema inteligente y dinámico que permita redirigir a los pacientes a otras unidades asistenciales para garantizar su atención médica y evitar la desigualdad entre la oferta de asistencia y la necesidad según la región. Un sistema hospitalario interconectado restablecerá un mayor equilibrio entre la oferta y la demanda de asistencia. En este artículo presentamos el diseño y la arquitectura de un hospital que utiliza IA distribuida y, sobre todo, un sistema multiagente que ha demostrado su eficacia en varios sistemas distribuidos.

Palabras clave: Hospital Digital; Sistema Sanitario; Sistema Hospitalario; Sistema Multiagente; Sistema Sanitario de Atención Primaria.

INTRODUCTION

Access to primary health care is the foundation of a resilient health system. It makes it possible to define the main role of the hospital centered on the management of acute care and vital or serious emergencies. The aging of the population and the constantly increasing number of chronic illnesses around the world, combined with a shortage of healthcare professionals, are making the hospital system even more fragile.

Access to primary care has deteriorated sharply, and this systematically leads to delays in patient care, which in turn can result in treatment being abandoned, or a complication in the patient's state of health

leading to hospitalization. Access to primary healthcare must be optimized to ensure better follow-up and care for patients.

It is therefore important to strengthen patient pathway management to better prevent hospital saturation. Digitizing the patient pathway will enable better analysis of the patient's care pathway (AI, Big data, etc.) and thus optimize the care chain. The use of digital tools will also enable patients to be directed towards which establishment get there (town medicine, dispensary, telemedicine, teleconsultation, etc.)

It is important to have a single, interoperable platform shared by the entire medical profession (care centers, local and university hospitals, etc.). Coordination between the various players around a single, shared, and interoperable data collection system is the key to better optimization of hospital system management. This confirms the need to digitize the care pathway.

Several technological and IT solutions could optimize the hospital system. Within the hospital, the solution that consists in managing the flow of patients according to the performance level of each care department and redirecting the patient to another hospital or teleconsultation in a dynamic and intelligent way remains the most suitable and appropriate in our case.

Research work is mainly based on crisis management in hospital emergency departments. However, the covid pandemic and increasingly frequent epidemics show that current hospital management is rigid and can no longer deal effectively with emergency situations. It is crucial to optimize the management of patient flows in hospitals in an agile, dynamic and instantaneous way. An intelligent system that focuses not only on the patient, but also on doctors, who find themselves overworked and working under constant strain.

The proposed system is intelligent, dynamic and agile, focusing not only on the patient to ensure better patient follow-up, but also on the doctor so that can work in the best possible conditions and avoid stressful situations.

The aim of our work is to optimize timely patient care and rescheduling appointments in the event of tension in a hospital department. This agile system will not only focus on the patient, but also on the medical staff, so that they can concentrate as much as possible on their main mission: "providing patient care" in the best possible conditions for both patients and medical staff. The proposed system is based on the multi-agent approach, which is the closest to the hospital system, and is also distributed.

1. Related work in hospital healthcare systems based on multi-agent systems
2. Why we chose a multi-agent system to model our system
3. Define, design and optimize a multi-agent system for managing a hospital system.

Related work

Several studies and research works have been presented for the optimization and management of hospital systems.

Amani Daknou proposed a distributed agent-based architecture to optimize the care of patients in hospital emergency services. The proposed system ensures better care of patients in emergency services and ensures dynamic rescheduling when an unforeseen event or disruption are encountered in emergencies such as the arrival of a patient with a degree of vital urgency.[1]

Hanen Jemal, Zied Kechaou, Mounir Ben Ayed, Adel M. Alimi presented a connected health system to improve access to health care. This article presents the interaction in a multi-agent architecture within a hospital. This system promotes interaction and communication between and within services.[2]

Wided Chandoul suggest the design and implementation of a support system for management of tensions in pediatric emergency departments. This system can anticipate and avoid tension in pediatric emergency departments thanks to fuzzy logic.[3]

Noura Benhajji presented a multi-agent system for reactive management of patient pathways within hospital systems. The architecture of the system is heterarchical focused on the patient as the central agent. The human and material resources of the hospital at a lower level which interact with patient agent.[4]

Sara Ben Othman focuses on Collaborative system to help with the scheduling and orchestration of multi-skill care tasks. This system based on a multi-agent system (human and software) allows patient care according to the patient's condition as well as queue management. It also allows you to know the state of tension of the emergency system, to reschedule the system and to notify doctors.[5]

The optimization and design of hospital health systems at the literature level are focused on emergency services, bed management and operating theaters. Several causes require optimization of the hospital health system:

- The aging of the population
- Increased monitoring of chronic diseases
- The growth of epidemics
- The shortage of medical professions
- Covid

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- The existing hospital system is rigid.
- Thus, it is crucial to optimize the hospital health system which will have the following advantages:
- A system focused both on patient and medical profession,
- An agile system,
- A system that will be able to overcome periods of crisis (pandemic/epidemic),
- A system that approaches patient care as closely as possible,
- A system that allows the medical profession to concentrate on its main mission: Providing good quality care.
- A system that allows the patient to be redirected to another doctor in the event of a crisis in the hospital.
- A system that allows the medical profession to be reassigned to another service according to skills management in the event of a crisis.

DEVELOPMENT

Proposed system

In this article, we have proposed the architecture of a dynamic, agile and distributed system which will allow the management of patient appointment flows and the reordering of appointments in the event of proven tension in a care unit.

We based ourselves on a decentralized architecture of the hospital health system which has proven itself in the Nordic countries and which the Kingdom of Morocco tends to achieve in the coming years to come following the reform of the health system which was launched in this country.

To summarize, the patient should consult a general practitioner at the health center (HC) which is close to his home. The latter should decide whether or not he should be redirected to a specialist doctor. The patient is redirected to the center local hospital (CHP) first then towards the regional hospital center (CHR) and towards the university hospital center (CHU) lastly depending on the reception capacity of the centers, the availability of the specialist doctor and the reference letter from the specialist doctor.

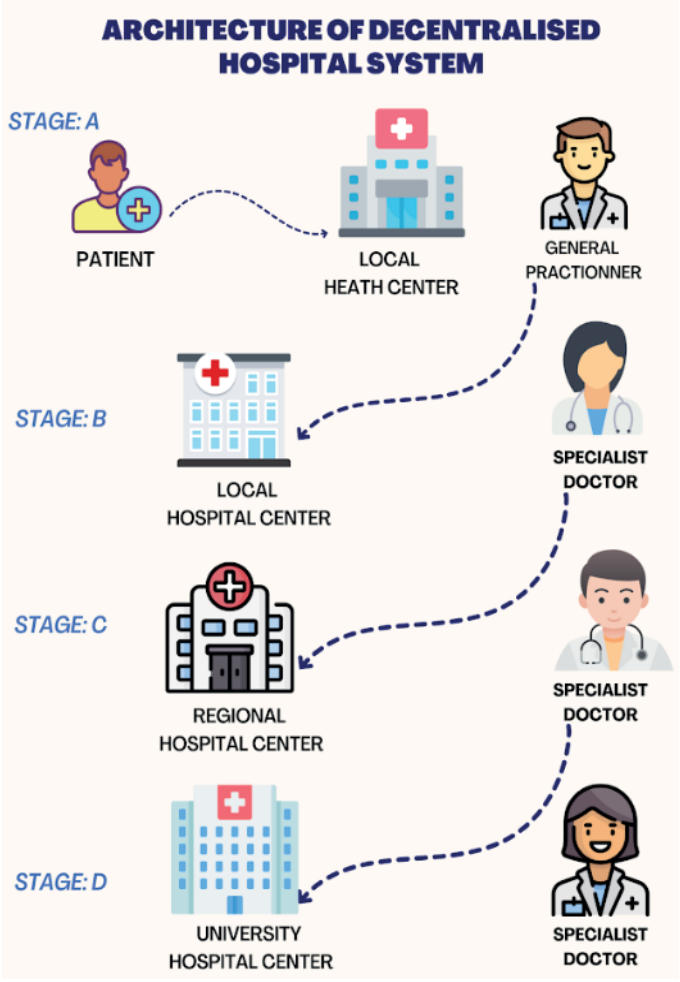

Figure 1. Architecture of decentralized hospital system proposed

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In this article, we will focus on the optimization of a hospital center. The optimization of the hospital health system will be the subject of a future article.

Architecture of a hospital center

The architecture of a hospital center is like an industrial company. The hospital center is divided into several health care departments (pediatric department, cardiology department, rheumatology department, emergency department, etc.). Each department includes human resources (doctors, nurses, nursing assistants, stretcher bearers, etc.) and shared material resources (beds, operating theaters, recovery rooms, consultation rooms, etc.).

The management of each service is done independently by a doctor in charge of the department who manages his department (scheduling, guard duty, leave management, etc.). By analogy with an industrial company which ensures the manufacture of a product, a hospital must provide health care services. Production units are similar to health care services which produce specific health care services. Health care services are managed autonomously but interact with other services (imaging, emergencies, blood analysis laboratory...) or on a larger scale with the health care service of another hospital.

Multi agents systems

Multi-agent systems (SMA) are distributed computing systems. They are part of the field of distributed artificial intelligence (IAD). Unlike distributed systems, the entities that interact within an SMA are intelligent and autonomous. They allow us to design complex computer systems. They are based on interaction and communication between different agents.

According to Yuan et al.[6] SMAs make it possible "to model the behavior of a set of expert entities, organized according to social type laws. These entities or agents have a certain autonomy and are immersed in an environment in which and with which they interact."

A multi-agent system can be defined as a set of agents, evolving in an environment who communicate with each other within an environment.[7]

Agents Definition

Ferber[8] defines an agent as follows, an agent is a physical or virtual entity:

- who can act in an environment.
- who can communicate directly with other agents.
- which is driven by a set of trends (in the form of individual objectives) or a function of satisfaction, or even survival, which it seeks to optimize.
- which has its own resources.
- who is capable of perceiving, but in a limited way, his environment.
- which only has a partial representation of this environment (and possibly none);
- who has skills and service offerings.
- which can possibly reproduce.
- whose behavior tends to satisfy its objectives, considering the resources and skills at its disposal, and depending on its perception, its representations, and the communications it receives.

Typology of agents

An agent is endowed with an intelligence that allows it to react, take initiatives, understand and interact with its environment.

We can distinguish the degree of intelligence of agents into three categories:

1. Reactive agents: This type of agent reacts to a stimulus, they are not capable of reasoning. We can call them "passive" agents.
2. Cognitive agents: This type of agent can reason to achieve a specific goal. We can call them "intelligent" agents.
3. Hybrid agents: type of agent with the joint capabilities of reactive and cognitive agents.
4. We therefore find 3 main architectures of multi-agent systems: reactive agent architectures, cognitive agent architectures and hybrid agent architectures.

System components

The design of the system we are about to present was carried out in collaboration with several doctors working in different hospitals in the Kingdom of Morocco, the aim being to obtain as much feedback as possible in order to design a system that best meets the requirements and weaknesses of the current Moroccan hospital system. The figure below shows the overall architecture of the proposed system.

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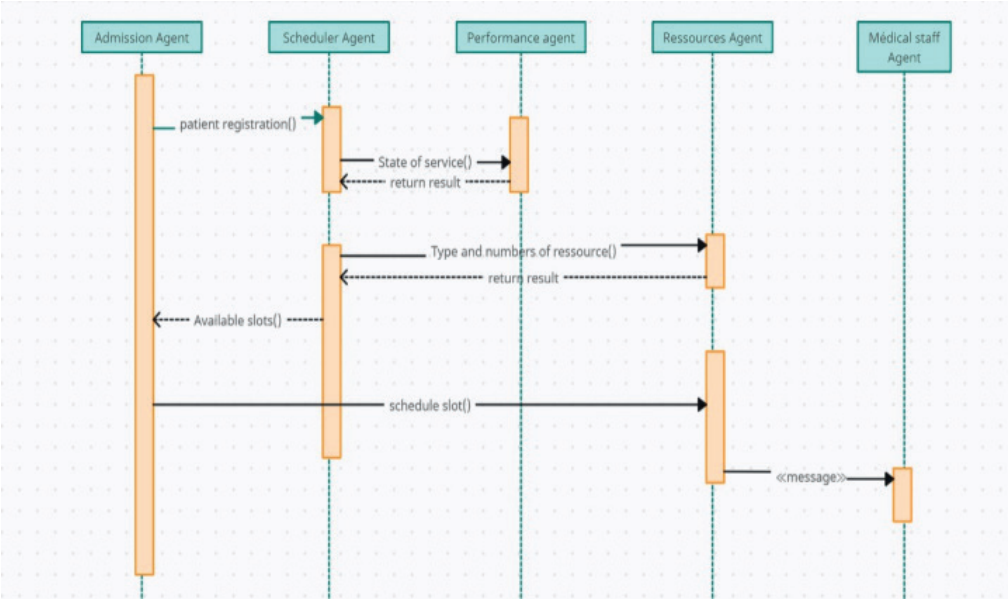

Figure 2. Sequence diagram

The patient accesses a healthcare service via the emergency department or the admissions office. The admission agent transfers the patient's data to the scheduler agent, which calculates the number of human and material resources required to care for the patient. It then sends a notification to the performance agent to inform it of the system's status. The scheduler then sends a request to the resource agent to find out the availability of resources. The resource agent updates the resource schedule and notifies the medical staff agent.

In the next sections of this article, we'll look in more detail at how each agent works, and how it interacts with its environment.

Admission agent

The admission agent is a reactive and software agent. It checks whether the patient already has a shared medical record (the admission agent has no access to the shared medical record, which is grayed out), otherwise it creates it. The admission agent is the patient's point of entry into a care department. In the case of a consultation or hospitalization, the admitting agent checks that the patient has a referral letter.

Next, the welcome agent will send the patient's shared medical file to the appropriate care department to check the "status" of the care department and receive the available slots (in the case of a consultation).

The patient will go to the welcome agent in the following cases:

- Medical consultation with a general practitioner.
- Medical consultation with a specialist.
- Patient hospitalized through medical emergencies.
- Hospitalization through another hospital.

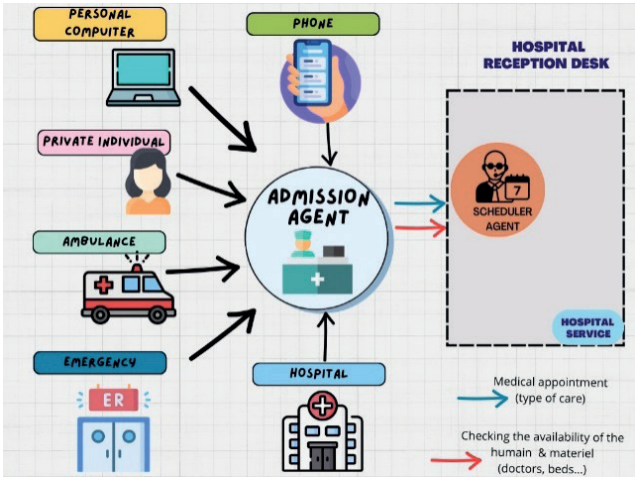

Figure 3. Admission Agent interaction

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Scheduler agent

The scheduler Agent is an intelligent, proactive hybrid agent. It represents the very heart of the system and interacts with several agents within the department. The scheduler receives patient information (shared medical record and type of care) from the admission agent. It determines the number of human and material resources to allocate to the patient, depending on the type of care (medical consultation, anesthetic consultation, stress test, hospitalization, etc.). Examples: For hospitalization, a patient needs a room, a bed, etc. (material resources) and a doctor, a nurse and a care assistant (human resources). For a medical consultation, the patient needs a consultation room and a doctor. This also provides an instant overview of allocated resources, which can then be used to improve future resource requirements (material and human). If a hospital department is under pressure, it can use the resources of another department which is not under pressure.

Next, the scheduler checks the system status and sends a notification to the performance agent. This agent checks the status of the healthcare service (normal system, system under strain or system over-strain). If the healthcare service is not under strain or over-strain, the scheduler agent sends the number of resources to be allocated to the resource agent to check the availability of human and material resources. Once the patient has chosen the slot, the resource agent updates the schedules and sends a notification to the healthcare staff.

As covid has shown, a healthcare service can become overloaded very quickly, so the management of unforeseen events in a service must be taken into account to ensure the follow-up of scheduled patients and to prepare for a tense situation. In the event of tension within a healthcare service or unexpected absence of the doctor, the scheduler must notify patients of the cancellation of their appointment and offer them follow-up care in another hospital if there is availability in the first instance, otherwise if it's for the follow-up of a chronic illness they can consult a general practitioner or a teleconsultation to ensure the patient's follow-up.

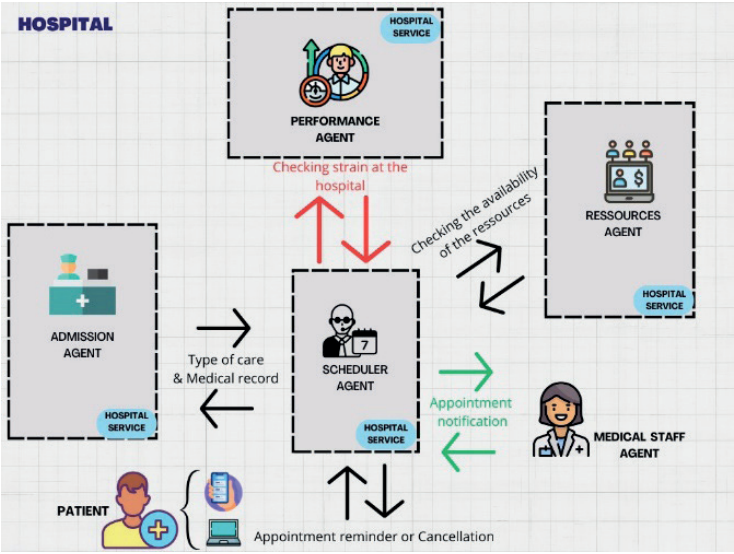

Figure 4. Admission Agent interaction

Performance agent

Indeed, a healthcare service can go into a state of strain at any moment, due to a number of unforeseen events: road accidents, earthquakes, floods, epidemics or pandemics on a larger scale. As a result, it is crucial to be agile and deal with crisis situations instantly, by notifying scheduled patients of the postponement of their consultations or their transfer to another hospital.

The performance agent is a reactive agent that can:

- Notify the planning agent in the event of a hospital crisis,
- Generate performance indicators for overall system evaluation,
- Responsible for overall system performance control,
- Verify and control performance indicators over a period of 1 month, 3 months, 6 months and 1 year.

In this article we focus on the design and optimization of a healthcare service. On a larger scale, each performance agent sends these statistics to the super performance agent of a hospital. This will help to relieve overcrowding in strain departments, by recovering their material resources (beds, rooms, oxygen cylinders, etc.) and even the human resources with the right skills to monitor patients in high-voltage departments.

In addition, the performance agent can be connected to ambulance drivers to route emergency patients directly to the relevant department without wasting time.

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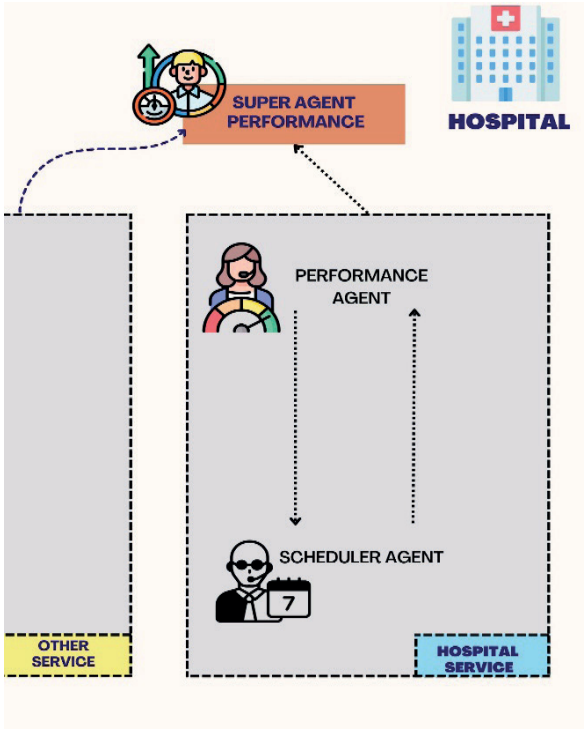

Figure 5. Performance Agent interaction

Ressources agent

The resource agent manages a department's resources. Human resources represent the doctors assigned to the department, according to their hierarchy: department head, interns, resident doctors, trainees, nurses, care assistants…Material resources represent beds, care equipment, rooms, treatment rooms... The resource agent is a cognitive device that enables you to:

- Monitor and manage a department's various material resources,
- Monitor the human resources schedules of a healthcare department,
- Detects stock shortages, medical staff bed shortages and informs the scheduler.

The human resources agent also interacts in the event of an unforeseen absence of a human resource, updating the schedule in real time, notifying the head of department, and notifying the patient. Also, thanks to an ergonomic interface, human resources can make their requests for vacation, make their administrative requests...enabling the head of department to validate the request directly without being interrupted each time, and to concentrate on his main mission of providing healthcare in the best possible conditions.

Medical staff agents

The personal medical agent represents a physical medical agent (doctor, nurse, care assistant, etc.) via a HMI integrated into hisorher smartphone.

- The medical staff can define or obtain information about the patient.
- They interact with the resource agent for requests for leave, unforeseen absences, and administrative requests.
- Real-time scheduling for improved time management.

CONCLUSION

The uncertainty of today's world, the high rate of chronic illness and the growing number of people living in old age are further weakening the current healthcare system. As the hospital is a distributed system, it is crucial to optimize the hospital healthcare system using new information technologies. Each department can experience a state of tension seasonally throughout the year (such as influenza, bronchiolitis, gastroenteritis...), during natural disasters (earthquakes, hurricanes, floods...) or on a larger scale during a pandemic. That's why the architecture proposed in this article focuses on managing each healthcare service autonomously.

To achieve this result, it is important to have a single interoperable platform shared by all the medical profession (doctors, hospitals, nurses...). Coordination between the different parties based on a single, shared and interoperable data collection system is the key to better optimize the hospital system.

The hospital's highly distributed architecture enabled us to optimize it using the multi-agent system architecture that has already proved its worth in distributed environments, particularly hospitals. In this

way, the hospital optimization presented in this article makes it possible to manage each health care service autonomously, notifying patients in the event of overload or tension in the hospital care service.

In future work, we will extend the hospital architecture proposed in this article to a country's entire hospital system, based on hospital hierarchy. The aim is to enable people living in remote areas to have access to healthcare, to enable small and medium-sized hospitals to focus on primary and secondary care, while large hospitals can concentrate on more advanced and complicated care. The aim is also to take the pressure off doctors and enable them to follow up their patients.

We will also be developing artificial intelligence-based algorithms for scheduling and rescheduling in the event of more urgent patient arrivals, during periods of crisis (flu epidemics, gastroenteritis), road accidents, natural disasters or pandemics. Patients are rescheduled according to their urgency and address, by sending an SMSto cancel the appointment, redirect them to a GP or a telemedicine consultation. We're also going to develop a medical skills management system to avoid bottlenecks in the health care department when it'sunder stress, and tobring in additional medical staff who are under-worked.

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