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Adaptive Business Intelligence platform and its contribution as a support in the evolution of Hospital 4.0

João Lopes[a,*], João Braga[a], Manuel Filipe Santos[a]

[a]*Centro ALGORITMI, University of Minho, Braga, Portugal*

Abstract

For many years there has been debate about what healthcare systems will look like in the future. Covid-19 has caused all Healthcare organizations to quickly adopt new solutions and evolution in this sector is a certainty. This research looks at the role that an Adaptive Business Intelligence (ABI) system can play in the evolution to a Hospital 4.0 and how it needs to evolve to achieve full integration between hospital services and the technological solutions. Thus, the first version of this system is explained and that will serve as a basis for the development of a more robust platform, with a view to a more effective environment, both for the professionals and for the main beneficiary of this type of service, the patient.

Keywords: Adaptive Business Intelligence; Big Data; Cloud Computing; Healthcare; Hospital 4.0

1. Introduction

The beginning of 2020 has seen the emergence of a coronavirus outbreak caused by a novel virus called SARS-CoV-2. The sudden explosion and uncontrolled worldwide spread of this virus show the limitations of existing healthcare systems to timely handle public health emergencies [16]. Preparing a post-covid era, they must strengthen all existing digital domains with one main goal: to make up for a lost time, both at the medical level with treatments

* Corresponding author. Tel.: +351934373667
E-mail address: lopesit@outlook.pt

that went unmet and at the organizational level with rebuilding hospital management goals that may have gone unmet [23]. In order to respond to the demands of healthcare and to improve the quality of treatments of its patients, some studies have been carried out to make technological systems more and more intelligent, with the clear aim of improving the quality of decisions that have to be made every day. In a recent research [14], some progress has been made towards the integration of an Adaptive Business Intelligence (ABI) system in a hospital organization that thanks to the connection with the hospital data, would use predictive and optimization models to increasingly adopt the different sectors to the reality of the organization. The framework of this architecture developed so far with everything that concerns a Hospital 4.0 will be reflected in the clear identification of the technologies that must be used to make this system more robust and complete, with a view to full integration with existing systems that are critical to the proper functioning of a hospital. In the following topics, the principles of a Hospital 4.0 will be addressed, mentioning technologies that are essential for the development of this research.

2. ABI System: Developments and Restrictions

The concept of adaptability is emerging in a wide variety of markets. In organizations, data is collected and accumulated at a very fast pace, and under these circumstances, there is an urgent need to develop advanced Intelligent Systems to help people extract useful information and knowledge to make accurate decisions in real-time [3]. An ABI system combines predictive layers to identify possible future scenarios [19] [8] and an optimization base that uses the predicted scenarios to search for even broader scenarios, according to the existing constraints in each problem [5] [15]. Following these topics already presented, the first prototype of this system has already been developed [14]. In this first phase, the architecture relied entirely on the Docker concept, which runs applications in a distributed manner. The adoption of this technology was critical to the execution of this first phase and essentially allowed for increased speed, scalability, and consistency of the developed system. Figure 1 shows the relationships that exist in the developed architecture. Although the implementation was efficient, some limitations have been identified with this architecture. First, relates to the high dependency on powerful and efficient databases to run these processes. Considering a large amount of data available [6], just the use of databases in this architecture becomes counterproductive when considering the results expected from this system. Moreover, the entire system depends too much on a single virtualized process in Docker. Therefore, the system needs a better tolerance to possible failures and a better efficiency in the management of existing users. Finally, difficulties are also identified in the management of processes in the system, at the level of the existing data, as well as in the execution of the scripts. Further study of the principles of a Hospital 4.0 will allow us to respond to these limitations and understand what technologies can and should be used to make the system more robust, secure, and accessible to any user.

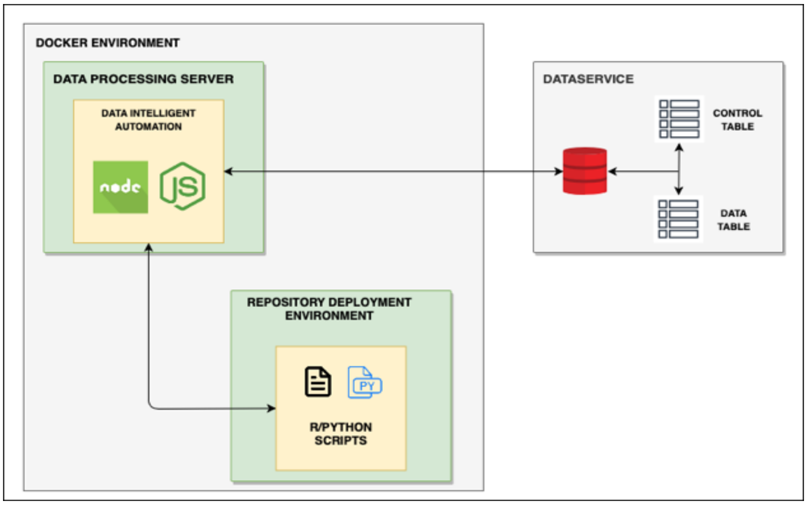

Fig. 1. Main Architecture of ABI System. Withdrawn from [13]

3. Principles in Hospital 4.0

Healthcare now is driven by statistical averages, which reflect in the values that define normality (e.g., the type and dose of medication or the surgical approach to be chosen). Future practice will move towards individualized treatment. The idea is to manage especially chronic and non-communicable diseases in a more precise manner by collecting information ideally in real-time from patients and process them with smart algorithms in order to describe the actual state of a patient more precisely [22]. According to Hermann et al. [9], Hospital 4.0 is closely linked to these design principles: (1) Interoperability, to enable the seamless flow of contextual information; (2) Virtualization, enabling the monitoring of physical health processes; (3) Decentralization, moving toward to a distributed patient-centered model with patients and professionals; (4) Real-time capability, to ensure proper orchestration of processes; (5) Service orientation, with a high-level overview of customer-centered service aggregation; (6) Modularity, producing a system able to flexibly adapt to changing requirements. The fundamental components arise from a mix of enabling technologies and approaches, including the Internet of Things (IoT), Big Data, Cloud Computing (CC), and Artificial Intelligence (AI). In a medical organization, Physical Healthcare Systems (PHS) are precisely modeled by a vast number of digital models and automation processes, also known as the Cyber Healthcare Systems (CHS). The PHS generates data in real-time to the CHS, this data is formerly processed and interpreted with the help of Big Data technologies, and all the software components are deployed over Cloud Computing platforms in a fully distributed fashion. Both the PHS and CHS are powered by AI for not only data analytics but all decision-making and execution so that manual intervention is minimized [13] [7].

3.1. The role of Big Data

Big Data in Healthcare is concerned with meaningful datasets that are too big, too fast, and too complex for healthcare providers to process and interpret with existing tools. It is driven by continuing effort in making health services more efficient and sustainable given the demands of a constantly expanding population with an inverted age pyramid, as well as the paradigm shift of delivering health services toward prevention, early intervention, and optimal management. This trend is due to the fact that multiscale data generated from individuals are continuously increasing, particularly with the new high-throughput sequencing platforms, real-time imaging, and point of care devices, as well as wearable computing and mobile health technologies [11]. Table 1 presents a set of important tools for implementing Big Data components in technological architectures. The technologies were selected according to the fundamentals in Hospital 4.0 and the objectives to be met in the new architecture.

Table 1. Open-Source Big Data Tools and Technologies

Technologies	Description
Apache Spark [2] [18]	An open-source tool for processing large data sets. Supports several programming languages for processing large volumes of data. Runs anywhere, meaning we can access data from HBase and Hive. It consists of several APIs, among them, Spark SQL, Spark Streaming, MLlib, and GraphX.
Apache Storm [2]	Open-source distributed real-time computation system for the processing of big data. Is beneficial to YARN for machine learning, ETL, and continuous monitoring of operations. Its scalability, fault tolerance, reliability, speed, and ease of operation.
Apache Kylin [17]	Apache Kylin is an open-source Distributed Analytics Engine designed to provide SQL interface and multi-dimensional analysis (OLAP) on Hadoop
Hadoop Distributed File System (HDFS) [20] [18]	File system based on the master-slave architecture. It breaks the large files into default 64 MB blocks and stored them into a large cluster in a very efficient manner.
Apache Kafka [20]	Open-source distributed event streaming platform optimized for ingesting and processing streaming data in real-time. A streaming platform needs to handle this constant influx of data and process the data sequentially and

	incrementally.
Apache Hive [20]	Data warehouse infrastructure allows querying of data from HDFS and these queries are converted into map-reduce jobs.
Apache HBase [20] [2] [18]	Non-relational or column-oriented database which runs on top of HDFS. It is open-source and allows reading and writing data on HDFS in the real-time scenario.

3.2. The Role of Cloud Computing

Cloud Computing (CC) can play a critical role in containing healthcare integration costs, optimizing resources, and ushering in a new era of innovations. Current trends aim towards accessing information anytime, anywhere, which can be achieved when moving healthcare information to the cloud. This new delivery model can make healthcare more efficient and effective, and at a lower cost to technology budgets [10]. CC gives opportunities for clinics, hospitals, insurance companies, pharmacies, and other healthcare companies to agree in collaborating between them and share healthcare information to offer a better quality of service and reduce costs. Physical data storing in a hospital may not be possible in every situation so, an emerging technology, CC can handle the situation easily [1]. Thus, FC made several contributes [21]: (1) Ease the burden of the infrastructure and number of people associated; (2) Health records of the patient whenever needed, helping patients, clinics, and insurance providers to access their data; (3) Reducing latency, giving a better performance against delay in real-time response; (4) Better security of data, providing computing redundancy and backup in case the link to the cloud is faulty.

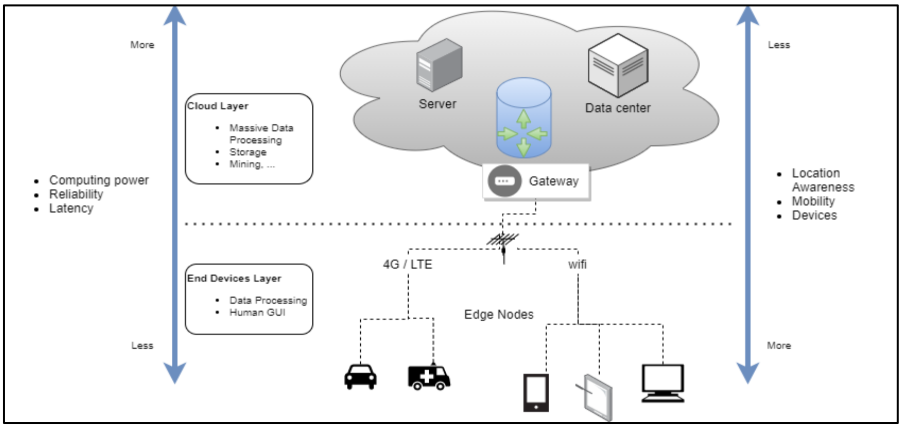

Fig. 1. Principles of Cloud Computing.

CC presents a hierarchical distributed architecture with the support of the integration of technological components and services that might be in near future like smart hospitals. Figure 1 represents an example of this architecture and is represented by End Devices Layers such as sensors, actuators, or things (e.g., mobile smartphones, PCs). Above is the Cloud layer where physical data center nodes are placed, it consists of software and applications running on the central server having a Big Data cluster. Table 2 presents a set of important tools for implementing Cloud Components.

Table 2. Cloud Tools and Technologies

Technologies	Description
Docker [4]	Open-source system tool of software containers. Containers help software to run while it is being moved from one environment to another. All the components are inside an isolated environment. Docker makes it possible to virtualize the operating system itself along with the application.
Kubernetes [4]	Open-source platform portable and extensible, for managing containerized workloads and services,

	that facilitates both declarative configuration and automation. Kubernetes became the replacement for proprietary virtual machine managers.
Apache CloudStack [12]	An open-source cloud computing software, which is used to build private, public, and hybrid Infrastructure as a Service (IaaS) clouds by pooling computing resources.

4. The impact of the new ABI System

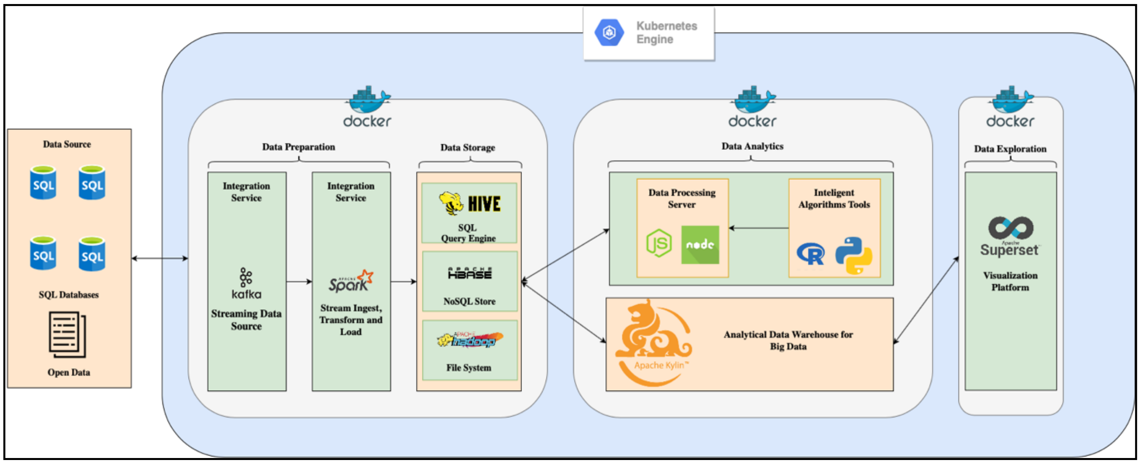

Fig. 3. Main Architecture of the new ABI System

After the background is carried out between the different technologies, it is possible to proceed with new developments for the ABI system in order to respond to the limitations described above. Figure 3 demonstrates the existing articulation between the different Big Data technologies and cloud architecture. The fundamental principles of a Hospital 4.0 are systems that manage various devices and software components with the constant relationship of data. The prototype of this system brings together three fundamental concepts: the capabilities of Big Data technologies for better warehousing and processing capabilities, preparing the system to handle all kinds of data. Cloud computing increase scalability and availability by accessing information at any place or time. Finally, adaptability, a concept that comes from the ability to analyze and include intelligent algorithms in real-time. Comparing the limitations existing in the previous architecture with the inserted technologies, the inclusion of HDFS, Storm, Kafka, Hive, and HBase [20] [2] [18] [17] respond to the high dependency on efficient databases, thus allowing better processing, distribution, and storage capacity. The difficulty of managing existing processes in the system is overcome with the integration of Kubernetes in cooperation with Docker and CloudStack [12] [4], allowing a better distribution of them to different users and system components. Data automation with the intelligent algorithms is achieved with the inclusion of Apache Spark [20], together with previously developed APIs, which can maintain a balanced flow of data at the same time as the data update information is saved.

5. Conclusions

The construction of an ABI system with a focus on a 4.0 Hospital foresees the digital and organizational development of several areas. From the patient's point of view, a technological system already prepared to perspective a type of treatment focused on the same is a significant advance, which thanks to the development of intelligent algorithms, analyzes historical data from that patient to identify different and more appropriate treatments. The mass storage of medical data in itself already represents a substantial improvement, which, thanks to Big Data technologies, makes it possible to improve the processing of medical data. From an organizational point of view, the reduction of time and costs associated with certain tasks is a highlight, as it will allow the maximization of productivity in different hospital specialties. The constant flow of data made possible by this architecture also makes it possible to envisage an Information System focused on the operation of the Hospital, allowing real-time monitoring of the different areas.

The new version of this system responds to the limitations detected in the first phase of this investigation. As future work, the development of this system is foreseen, with real implementation in the various systems of Health organizations.

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