A cloud-oriented architecture for the remote assessment and follow-up of hospitalized patients

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***Abstract*—During the last months the dramatic COVID-19 outbreak has exposed the fragility of our healthcare system, as well as the need for a smart remote follow-up system for the patients, in order to less the burden on the healthcare service and reduce the average hospitalization time. In this paper we proposed a solution designed to grant maximum flexibility by means of the allocation of resources on a cloud service for the remote follow-up of patients. Such resources can be used as a remote support for the caregiver both when planning or enforcing a therapeutic path. A major explanation behind follow-up regards the location and treatment of potentially adverse reactions after treatments. Physical side effects of the different modalities of treatment might be various and crippling after chemotherapy and radiotherapy. Moreover remote follow up can be a life-changing solution also on the economical side, due to the implication of therapeutic attendances for patients as far as missed work and travel costs that must likewise be comprehended in the overall economical burden. In an investigation of patients with testicular disease, Campbell et al. Finally such a solution could effectively improve the patient's adherence to the therapeutic plan. The ability to remotely follow follow-up is therefore a monetarily alluring choice as far as investment funds, also given the improved efficiencies, reduced cost and number of missed working days for the patient. Patients with a patient-held record may also take advantage of a more conscious and motivated interest over their own wellbeing, illness and treatment, with a direct impact on patient's adherence to the therapeutic plan.**

I. Introduction

During the last months the dramatic COVID-19 outbreak has exposed the fragility of our healthcare system. Moreover it gave use the possibility to rethink different therapeutic procedures as well as cure protocols. The activities of the healthcare operators in hospital wards have been extensively remodeled, so as to ensure greater safety for the entire staff operating in the facility as well as to enforce the required sterilization protocols to ensure the patients well being. The hospital facilities had been required to enforce massive use of personal protective equipment, install sanitizing gel dispensers in every hallway and waiting room, determine a maximum limit of people at the same time in the same room, and, above all to apply social distancing. It follows that hospitalized patients have been subjected to limitations, in order to maintain the correct social distancing, involving their permanence as well of their relatives, also avoiding gatherings, and, sometime, limiting the entrances in the ward. The effect of these necessary limitations is to increase the isolation effect on the hospitalized patient. Therefore, while the patient follows a cure protocol, he must also be helped, with the same accuracy, by means of a parallel protocol that takes care also of the solitude experienced by the person.

Isolated patients are visited fewer times than non-isolated patients, moreover such isolated patients generally benefit of a shorter time span with their physicians. Because of the significantly lower contact time observed, particularly among the most severely ill of floor patients, a reexamination of the risk-benefit ratio of this infection control method has been proposed. In facts the attending physicians are about half as likely to examine patients in contact isolation compared with patients not in contact isolation [7]. Similarly, other studies

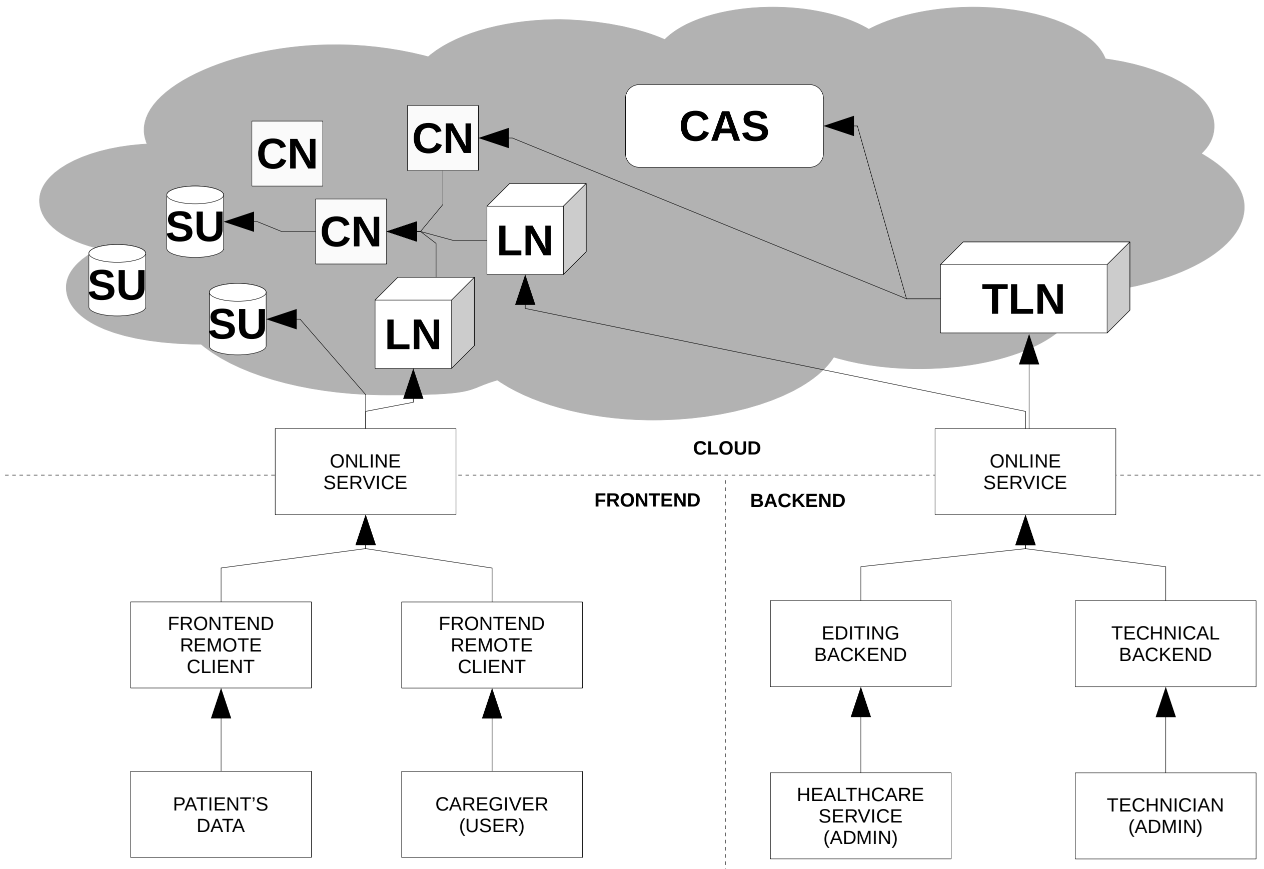

Fig. 1: A general schema of the system developed in this work. Clockwise: a representation of the cloud and its resources, the administrative and test design backend, and, finally, the users' frontend.

have pointed out the concern that isolation may negatively affect not only the perceived quality of service but also the patients' mental health [8], [9], with a substantial increase in anxiety and stress-related disorders [10], [11]. Finally [12] shows that isolation precautions are associated with adverse effects which may result in poorer hospital outcomes, a longer hospitalization, an higher cost of care, as well as an higher rate of readmission to hospital within a month.

Differently from direct intervention, follow-up medicine does not base its protocol only on drugs and prescriptions, on the contrary it build the intervention around the patient [13]. Trough standardization the caregivers are guided in making decisions regarding the more appropriate therapeutic plan for a specific conditions, while the medical practices can be rationalized improving, in the end, the general outcome for the therapy at full advantage of the patient's well being. Other fields of medicine can rely on very effective clinical prediction rules in order to reduce the uncertainty inherent the medical practice by defining how to use clinical findings to make predictions [14]. Finally, it must be said that in certain cases it is uttermost difficult to draw methodology-proof clinical practice guidelines due to the extreme statistical and subjective variability of the matter at hand [15].

In the work presented on this paper we developed a unified cloud-based resource for the management and execution of all the task related to the patient's follow-up from the creation of the medical record, to its use, update and management. The solution has been designed to grant maximum flexibility allocating resources on a cloud service. Such resources can be used as a remote support for the caregiver both when planning or enforcing a therapeutic path.

The paper is organized as follows. After this brief introduction, in the following Section II the designed system is described in its constituent parts. In Section III we will focus on the management of the cloud services giving further details on the resource allocation policies. Finally in Section IV we will draw our conclusions.

II. The Developed System

In Figure 1 a gross schema of the designed system is reported, this is composed by the following agents and components:

A. Frontend:
- *Online interface*
- *Frontend remote clients*

B. Backend:

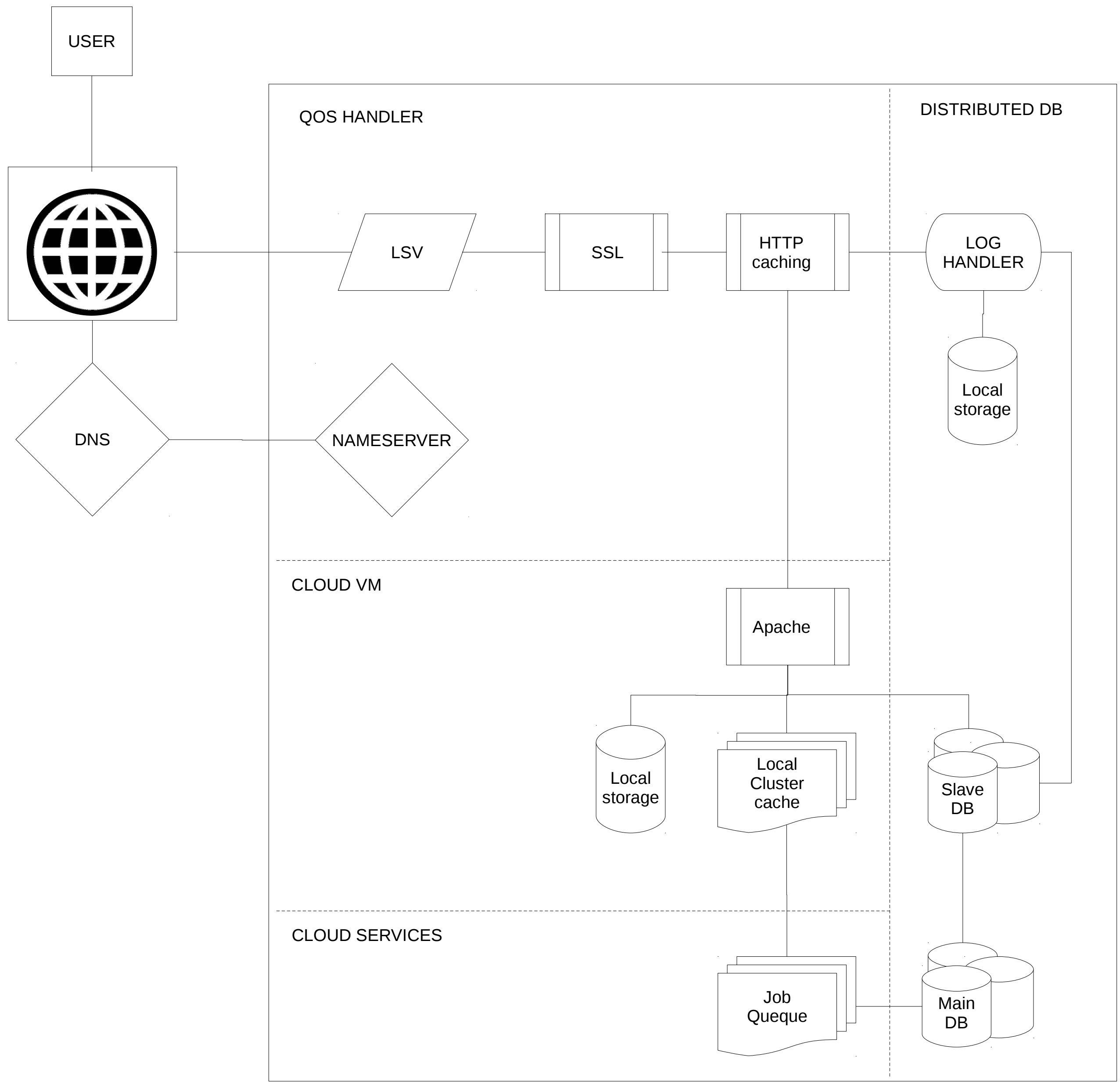

Fig. 2: Schematics of the services involved in developed system and the respective dependencies.

- *Online interface*
- *Administration backend*
- *Technical backend*

C. Cloud

- *Trusted Login Node* (TLN)
- *Cloud administration service* (CAS)
- *Login nodes* (LN)
- *Computing nodes* (CN)
- *Storage Units* (SU)

The components are better described in the following.

A. *Frontend*

The frontend of the system has been developed by means of the Angular JS [18], [19] framework in order to grant portability and compatibility with almost all the available hardware and software systems. In this manner there are no particular requirements to interface with the developed system, granted the ability to execute JavaScript on a browser-like application. Although a web browser would have sufficed to interface with the online service, we developed a simple ad-hoc application to oversimplify the interface. In this manner it is possible to avoid unnecessary complication for the caregivers that will benefit of this application. The *frontend remote client* only

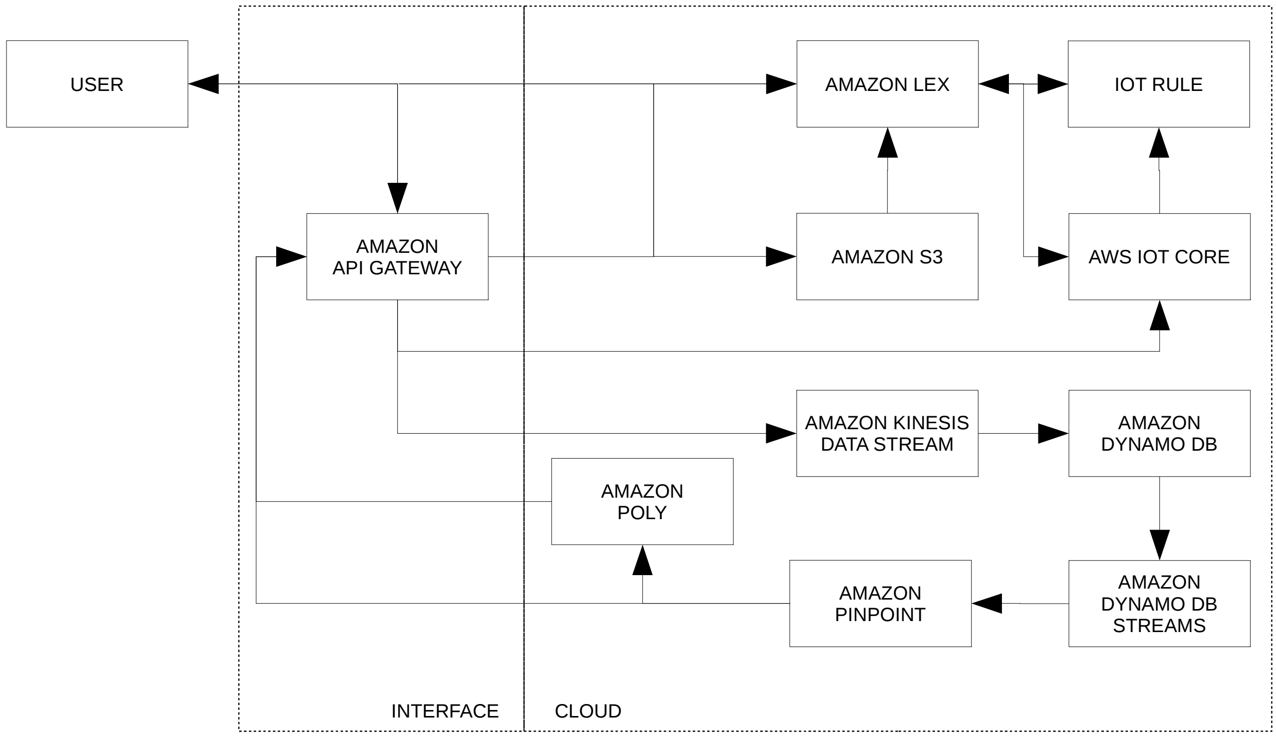

Fig. 3: The adopted Amazon Web Services (AWS) configuration and the relative data flow among the different component and services within the cloud environment

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provides the interface for the final *users*, but it is not designed to create a new task or operate for its standardization, since these latter procedures are related with the backend.

B. Backend

While the frontend for the proposed system is constituted by the final interface that the users and patients can use for the only purpose of entering certain data, the the backend of the developed system provides the necessary support for the design of new task and follow-up protocols as well as their standardization, finally it implements the tools for the technical administration of the overall platform. Differently from the frontend, the backend provides two separated consoles for caregivers and technicians. The first allows the caregiver to design a new task or protocol, insert the item, provide the validation rules, and request to the system to analyze the validation data. The second console is reserved for technical administration in terms of resource allocation, cloud management policies, etc...

C. Cloud

The cloud resources are allocated both for computational and provisional purposes. Complete standardized procedures can be used and implemented by means of the frontend interface. In this case a simple set of queries can do the job, by selecting and extracting the required data from the databases, distributed on several *storage units* (SU), as well as by uploading data for further use. On the other hand the standardization of a new test, due to the required statistical analysis, also makes use of the *computing nodes* (CN). The cloud system is also provided with several login node in order to avoid direct interactions with the allocated computing nodes and storage units, excepted for the storage units containing the public database useful to run the fronted interface. Finally the technical administration of the cloud, due to the criticality of the matter, makes use of a *trusted login node* that ensure a grater security level. The details on the cloud policies are given in the following Section III.

III. The Cloud Environment

In our proposal the cloud environment is administered on a technical level by expert users. Moreover the system has been studied in order to adapt to the total load by allocating or freeing resources. For the implementation we supported our system with the Amazon Web Services (AWS) [20], and particularly on the AWS ECS and S3 service [21]. The main component for the administration of the cloud environment is the Cloud Administration Service (CAS) depicted in Figure 4. The Cloud Administration Service analyzes the provided application and estimate the computational burden by means of a XML application requirement descriptor. Along with the single application (e.g. a meta-analysis by means of factorial

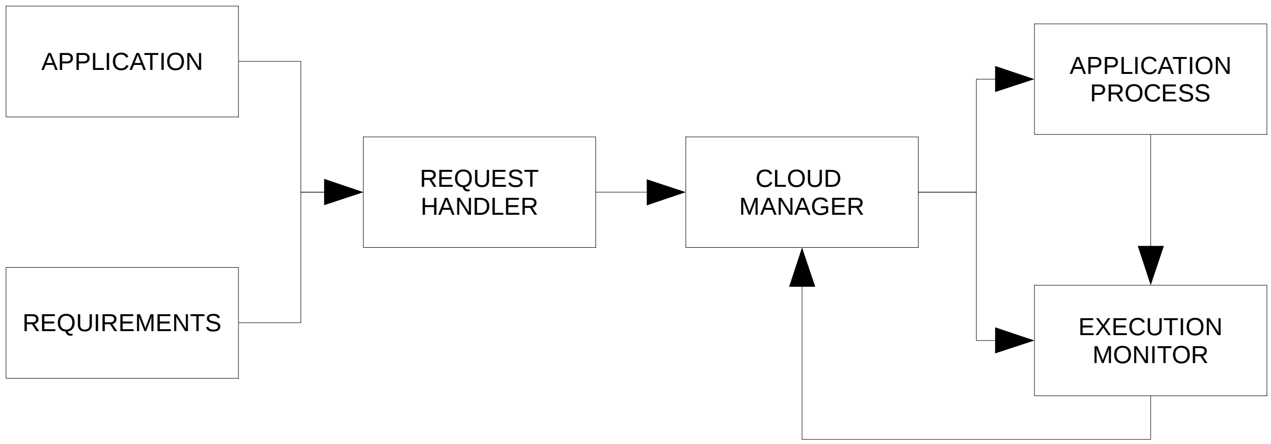

Fig. 4: Schematics of the Cloud Administration Service (CAS).

analysis, multidimensional scaling, etc...), the psychologist administrator also submits a set of requirements (e.g. the desired deadline or throughput, etc...). Both the application descriptor and the submitted requirements, are then analyzed by the *request handler* module. The request handler has the responsibility to determine the correct allocation request mediating between the application requirements, the user defined constraints, and the effective resource availability on the cloud system (see Figure 3).

The resource request is provided to the *cloud manager* component which uses the Amazon AWS APIs to effectively request the allocation of new virtual machines. The cloud manager interfaces with the *AWS IoT Core* taking into consideration the *AWS IoT rule* component that determine the policies for the *Amazon Kinesis Data Stream*. The Amazon Kinesis Data Stream is a real-time streaming service that provides event-driven messaging and supports extended microservice architectures. This latter allows the processing requests trough the *Amazon API Gateway* once an admin has been logged and identified trough his credentials by the *Amazon Lex* component to access the *Amazon S3* service.

In our system design also the database is distributed on the cloud and supported by the *Amazon DynamoDB* services that allows data flow by means of the *Amazon DynamoDb Streams* component. Data transactions and session state are encrypted at-rest and securely managed in the high-performance and scalable NoSQL datastore offered by DynamoDB. The Amazon DynamoDB Streams is also able to trigger an *AWS Lambda function* in order to send notifications, by means of the *Amazon Pinpoint* and *Amazon Polly* services, to psychologist users when a patient has completed a test, as well as to send notification to a psychologist admin when the validation and standardization process advances or changes status.

IV. Discussion and conclusion

In order to check the developed system on the field, we simulated the small scale implementation on an oncology ward of an hospital subjected to personnel and visitors restriction due to an epidemic outbreak. In this scenario all members of the oncological staff have to carry out certain activities, where possible, in a smart working mode (e.g. the drafting of scientific articles, end-of-treatment reports and other internal reports, statistical analysis and supplementary clinical reviews). While all the measures adopted in such a scenario are necessary, as public health is always at risk, these measures evidently dilute the effectiveness of the treatment also remanding to the patient's responsibilities to follow the planned path. In such a scenario the remote follow-up of patients became a mandatory measure to both enforce the necessary sanitary safety protocols, as well as maintain an high level of therapeutic quality in order to ensure the patients' adherence to their therapeutic paths. In the case study at hands, therefore, we propose to implement and use the developed system in order to allow a remote follow-up of the patients. In this manner the hospitalization time can be reduced while preserving the patient's remission time and the therapeutic efficacy. A major explanation behind follow-up regards the location and treatment of potentially adverse reactions after treatments. In facts such reactions might be long lasting. Sometimes the need to inform the patient can be difficult to reconcile with the doctors' desire to encourage the latter: constant collaboration with psychologists will therefore allow them to better address these issues. Psychology responds to the need for specific reflection on the psychic processes involved in the adaptation of patients to the disease and on the evaluation of their quality of life. It must therefore provide useful tools for organizing the training of all the professional figures involved and propose effective strategies in psychological support to the patient. It is a set of knowledge and a series of skills in constant evolution, on which the professional identity of the psychologist is based.

Physical side effects of the different modalities of treatment might be various and crippling after chemotherapy and radiotherapy. Moreover remote follow up can be a life-changing solution also on the economical side, due to the implication of therapeutic attendances for patients as far as missed work and travel costs that must likewise be comprehended in the overall economical burden. In an investigation of patients with testicular disease, Campbell et al. [11] demonstrated that every center participation costs a normal of £61 per understanding for loss of profit, with an extra £11 in movement costs. A similar report indicated elevated levels of fulfillment, with a proposition to supplant up close and personal meetings with calls. Finally such a solution could effectively improve the patient's adherence to the therapeutic plan. The ability to remotely follow follow-up is therefore a monetarily alluring choice as far as investment funds, also given the improved efficiencies, reduced cost and number of missed working days for the patient. Patients with a patient-held record may also take advantage of a more conscious and motivated interest over their own wellbeing, illness and treatment, with a direct impact on patient's adherence to the therapeutic plan.

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