Research Group on Artificial Intelligence at Universitat Rovira i Virgili (Tarragona)

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Abstract—**This paper describes a selection of some of the most representative research lines of the Research Group on Artificial Intelligence (BANZAI) at the Universitat Rovira i Virgili (Tarragona) in the area of Artificial Intelligence in Medicine and the main results achieved. These research interests are: the induction of clinical algorithms, the representation of knowledge to train clinicians, and the study of multimorbidity. Moreover, the paper describes the current and future research interests of the group.**

Keywords—Research Group on Artificial Intelligence (BANZAI); artificial intelligence in biomedicine; description of research lines and projects.

I. Introduction

The Research Group on Artificial Intelligence BANZAI[1], at the Universitat Rovira i Virgili (Tarragona), was founded in 1998. In the last two decades, the work of the group has been centered in the topics of Intelligent Data Analysis, Knowledge Representation in Health Care, and Clinical Decision Support Systems, in collaboration with several hospitals in Barcelona, Tarragona, and Reus.

In 2000 the group collaborated with the Hospital Universitari Joan XXIII (Tarragona) in the project *COSYS: Sistema de Información Hospitalaria de Ayuda a la Adaptación de Pesos Relativos a los GRD*. In this project, a tool was developed to classify patients in order to simplify the comparison between the real costs of inpatients and the relative weights of the Diagnostic Related Groups (DRG) [1][2]. In 2003, they worked with the Palliative Care Unit at the Hospital de la Santa Creu i Sant Pau (Barcelona) in the project *Palliasys: Use of new ICT to facilitate the treatment of palliative patients* in order to implement a eHealth system to assist patients requiring palliative care at home, but also in the analysis of retrospective data about patients attended in the unit in order to find out medical protocols of efficient medical practices [3]-[10]. In 2006, they coordinated the project *Hygia* with the Hospital Clínic de Barcelona, the University of Santiago de Compostela and Universitat Jaume I. The contribution of BANZAI in the project was the analysis of retrospective data to construct treatment models for chronic patients [11]-[13]. Later on, in 2006, they coordinated the project *K4CARE: Knowledge-Based Home-Care eServices for an Ageing Europe* that counted on several hospitals in Europe, apart of some technological partners [14]. The project combined healthcare and ICT experiences of several western and eastern EU countries to create, implement, and validate a knowledge-based health-care model for the professional assistance to senior patients at home [15]-[17].

In the last eleven years, this research group has organized international workshops every year in the field of health-care knowledge representation. Since 2009, this workshop is called *K4CARE: Knowledge Representation for Health-Care* and, in 2018, it was the tenth edition. They are also editors of the Springer LNAI book series on "Knowledge Representation for Health Care" (eight books published until 2018) containing the extended versions of a selection of the best papers in those workshops.

The rest of the paper is organized in two sections: in the first one, three research lines showing the current interests of the BANZAI group are described. In the second one, a short discussion of the future interests is provided with conclusions.

II. Research Lines and Results

A. *Induction of Clinical Algorithms*

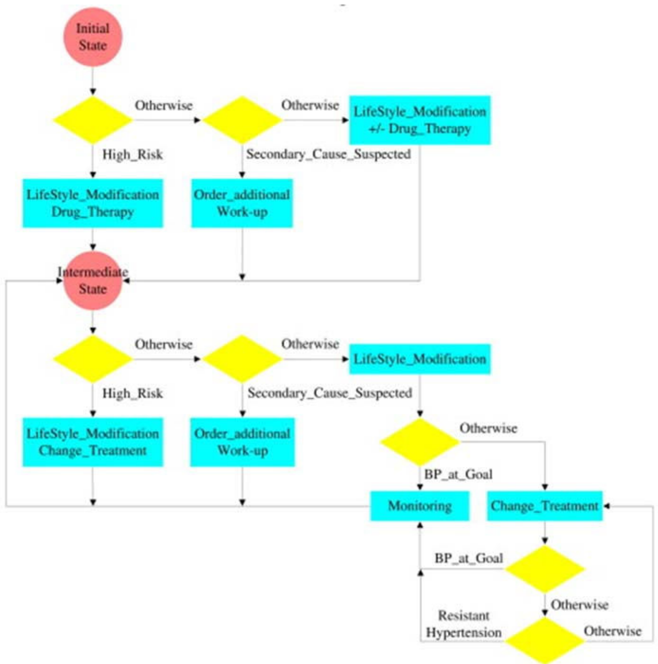
Chronic patients are characterized by requiring continuous follow-up for long periods of time, years, or even for lifetime. This timeline process is described by the clinical concept of Episode of Care (EOC) which can be defined as the services provided to a patient within a specific problem during a certain period of time. The EOC are based on the idea of clinical encounter in which the health-care professional (physician or nurse) observes the clinical condition of the patient (state), decides which issues require attention, and suggest clinical actions to address these issues. An EOC is then a sequence of encounters, and each encounter simplified as a vector (S, D, A) where S stands for the state of the patient, D are the decided issues requiring attention, and A the clinical actions performed or started in that particular encounter to address D.

[1] http://banzai-deim.urv.cat

Primary care services register all this information in their databases or in the patients EHRs.

In modern medicine, clinical quality is related to the sort of evidences registered in the clinical practice guidelines. These are documents gathering all the clinical knowledge available for specific diseases. Therefore, the quality of medical practice uses to be related to the level of adherence of clinicians and patients to the evidences in these guidelines. Unfortunately, it is not easy to check adherence. However, in order to promote adherence, clinical processes can be simplified and represented as intuitive clinical algorithms such as the one in Fig. 1, and finally incorporated to the guidelines.

FIGURE I. CLINICAL ALGORITHM



In this context, BANZAI and SAGESSA[2] worked together to automate the process of clinical algorithm extraction from EOC databases. Clustering technologies were developed to isolate relevant states and treatment blocks (circles and squares in Fig. 1) from EOC data, and combined algorithms to induce decision trees were proposed to intertwine states and actions with decisions (diamonds in Fig. 1) [18]. These algorithms were used to compare clinical procedures across institutions and in contrast with clinical algorithms recommended in different clinical practice guidelines [19].

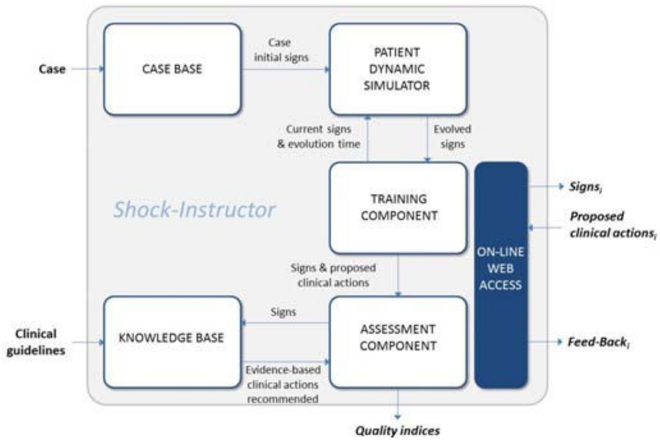
B. Knowledge Representation for Clinical Training

Clinical practice is a complex task in which several decision problems combine in sophisticated models, as the one proposed by BANZAI [20]: the MPM. Three of the main decision problems in these models are diagnosis, treatment, and prognosis, though these can comprise multiple subtypes. Representing medical knowledge with AI structures to support decisions for these three decision problems starts with the selection of appropriate representation models. One of these models are decision tables [21][22]. Interestingly, once constructed and validated, these knowledge structures are not only useful to support decision making, but also to train novel clinicians to make the right decisions.

[2] SAGESSA is an entity that manages all the clinical services in the south of Tarragona, including four hospitals, five primary care centers, and four rehabilitation centers.

In collaboration with the Emergency Department of the Clinical Hospital in Barcelona (HCB), the BANZAI group worked to formalize the knowledge available in multiple clinical practice guidelines as grouping decision tables. These tables were wrapped by a web-based system to train residents of the HCB and to analyze the benefits of this sort of computer-based learning in medicine. The training system, whose functional architecture is shown in Fig. 2, was used to improve residents skills in (1) applying differential diagnosis to secondary causes of hypertension [23], (2) providing the right treatment of circulatory shock in ERs and ICUs [24], and (3) simulating emergency shock to prognosticate patient evolutions [25].

FIGURE II. SHOCK-INSTRUCTOR TRAINING TOOL ARCHITECTURE

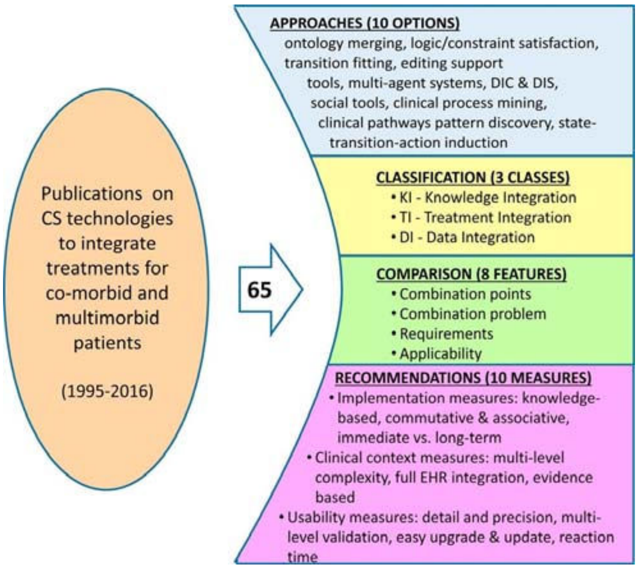


These studies concluded that the use of knowledge-based e-learning computer tools can significantly improve the learning curve, the adherence, and the clinical results of novel residents beyond traditional formative programs in schools of medicine, and hospitals.

C. Dealing with Multimorbidity

Multimorbidity is the simultaneous observation of more than one disease in the same patient. This is a common clinical condition of elderly patients, more inclined to suffer several chronic ailments. The management of multimorbid patients is challenging because of many reasons such as some issues related to polypharmacy or the lack of evidence about multi-morbid cases. On the contrary, the number of multimorbid cases increases year after year, and consequently the amount of clinical data generated about the treatment and evolutions of these cases is large and growing rapidly. We performed a review of CS technologies applied to the management of multimorbid patients [26] whose results are summarized in Fig. 3. Three alternative technologies were identified: knowledge integration, treatment integration, and data integration.

FIGURE III. Comparison of CS Technologies for multimorbidity



Knowledge integration is about the combination of single-disease knowledge structures (and additional clinical knowledge) to generate multimorbid knowledge structures. Several works exist following this approach, among which the BANZAI group proposed a technology that adapts general Formal Intervention Plans (similar to clinical algorithms, seen in Fig. 1) into Individual Intervention Plans according to the constraints of an ontology containing complementary clinical knowledge and the EHR of the patient. Individual Intervention Plans of different diseases for the same patient can be combined into a Unified Intervention Plan to define holistic personalized treatment for that multimorbid patient.

Treatment integration is seen as the combination of clinical lists of actions (including prescriptions and procedures) by solving cross interactions between actions for different diseases. In [27], a rule-based system to combine treatments of hypertension and/or diabetes mellitus and/or heart failure was proposed and tested on twenty multimorbid patients. In a later work [28], we also proposed a semi-automatic methodology to combine treatments that are expressed under a "global" structure of patient management in primary, secondary, and tertiary care.

Data integration is based on the idea of extracting knowledge about the treatment of multimorbid patients, from the intelligent analysis (machine learning) of databases about the management of this sort of patients. Our approach, different from other process mining approaches, is a machine learning process in which EOC about multimorbid patients are transformed into SDA clinical algorithms (Fig. 1) [12][29].

III. Future Lines and Conclusions

Today, some of the above described research lines of the Research Group on Artificial Intelligence (BANZAI) have converged in some interesting and challenging issues that will determine the course of our future research. Here, we describe four of them, broadly.

The analysis of ICU data: Intensive Care Units are singular services in the sense that they produce a huge amount of data per patient, the related costs are high, the patients are very sensitive and they may require rapid interventions by coordinated (sometimes multidisciplinary) expert teams. We are in close collaboration with the ICU of the Hospital Universitari Joan XXIII (Tarragona) in order to define a big data for scientific exploitation, similar to the USA database MIMIC III. In this collaboration, our main contribution is the analysis of these data with data mining technologies and the construction of descriptive and predictive models to solve important medical questions such as the length of stay, the parameters affecting the length of stay, advanced detection of patient's complications and changes of state, the accurate use of antibiotics and the pharmacological consumption in general, or the adherence to ICU guidelines.

The analysis of cancer data: We are concluding a preliminary longitudinal study on breast cancer data coming from the SEER database. We are also participating in the *P-BreasTreat* project, one of whose objectives is the combination of visual data extracted from the analysis of images, with clinical data taken from the patient EHR to classify cancer's typology. This work is in conjunction with the Oncology Service of the Hospital Sant Joan (Reus).

Multimorbidity: Although, we achieved considerable results in this topic in the past, there are still some open questions that we would like to address in our close future. Just to mention some, we are interested in determining whether there are significant differences in the interactions detected by different publicly available drug interaction checkers, or the automatic construction of diagrams to evidence the differences between the treatments of one disease for monomorbid patients, in comparison with the treatment of this same disease in multimorbid patients. Gaining insight in multimorbidity management will influence the next research line for the future.

Data synthetization: Data about clinical processes and patients are highly sensitive and subject to strict legal restrictions. Anonymization is a way to exempt the data analyzer from legal issues, but it does not solve the case of disambiguation by crossing databases. An alternative approach is to construct mechanisms for data synthetization. In one preliminary study [30] we identified three alternative methods for clinical data synthetization: statistical, knowledge representation, and simulation. The *statistical method* uses the available data about real patients to construct a statistical model of the clinical parameters, and then a generator uses this model to synthesize treatments about fictitious patients. The *knowledge representation method* integrates the available knowledge (in clinical guidelines, health-care ontologies, electronic books, web sites, etc.) into a knowledge base and then it synthesizes fake treatments that are consistent with the knowledge base. Finally, the *simulation method* depends on the availability of a patient (or signs) simulator that emulates the evolution of that patient or signs when a treatment is carried out. Combining the simulator with a treatment recommender system, and making these elements to loop, a database can be synthesized containing specific fictitious treatments.

In conclusion, the Research Group in Artificial Intelligence at the Universitat Rovira i Virgili (Tarragona) has been working in the area of medical informatics since 1998 with two main technological focuses: intelligent data analysis and knowledge representation. We have a wide trajectory collaborating with multiple hospitals and health-care centers in general. Our current and future interests are in the analysis of ICU and cancer data, and the synthetization of EHR data for multimorbid conditions.

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