An Artificial Intelligence Approach to Individuals' Age Assessment

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Abstract: - A link between patterns of pelvic growth and human life history is supported by the finding that, cross-culturally, variation in maturation rates of female pelvis are correlated with variation in ages of menarche and first reproduction, i.e., it is well known that the human dimensions of the pelvic bones depend on the gender and vary with the age. Indeed, one feature in which humans appear to be unique is the prolonged growth of the pelvis after the age of sexual maturity. Both the total superoinferior length and mediolateral breadth of the pelvis continues to grow markedly after puberty, and do not reach adult proportions until the late teens years. This continuation of growth is accomplished by relatively late fusion of the separate centers of ossification that form the bones of the pelvis. Hence, in this work we will focus on the development of an intelligent decision support system to predict individual's age based on a pelvis' dimensions criteria. Some basic image processing techniques were applied in order to extract the relevant features from pelvic X-rays, being the computational framework built on top of a Logic Programming approach to Knowledge Representation and Reasoning that caters for the handling of incomplete, unknown, or even self-contradictory information, complemented with a Case Base approach to computing.

Key-Words: - Individuals' Age Prediction; Pelvis X-ray Images; Logic Programming; Knowledge Representation and Reasoning; Case Based Computing; Decision Support Systems

1 Introduction

The individual's age estimation is a difficult task, but it is essential in physical anthropology, clinical forensic medicine, osteoarchaeological sciences and for various civil and criminal purposes. In developing countries or in current migrant crisis the paucity of reliable documentary evidences like birth certificate, board certificates makes this job even more important [1]. Skeletons are good age markers because teeth and bones mature at fairly predictable rates. To determine age in young people, i.e., toddlers to teenagers up to age 21, the most commonly used radiological studies are teeth, hand-wrist radiographs and elbow, and shoulder. However, for adult age, some of the best indicators are related with pelvis and can be obtained from pelvic radiographs that depict the iliac and ischial borders [1-3]. Pelvis is the lower part of the trunk, between the abdomen and the thighs. Each side of the pelvis is formed as cartilage, which ossifies as three main bones and stays separate through child-hood, i.e., ilium, ischium and pubis. At birth the whole of the hip joint (the acetabulum area and the top of the femur) is still made of cartilage (but there may be a small piece of bone in the great trochanter of the femur).

According to [4] the techniques to evaluate skeletal aging focused on the os coxae have demonstrated low accuracy and high bias when the methodology is used on different populations. The authors highlighted the necessity of increasing research to better understand age markers related to biology, designing new predictive models, and finding new age markers. Thus, this paper addresses the theme of *Individuals' Age Prediction* based on *Pelvis X-Ray Images* using a *Case-Based* (*CB*) approach to computing [5, 6]. To set the structure of the environment and the associate inference mechanisms, a computational framework centred on a *Logic Programming* (*LP*) based approach to knowledge representation and reasoning was used [7]. It may handle unknown, incomplete, or even contradictory data, information or knowledge. Clustering methods centered on an analysis of attribute's similarities were used to distinguish and aggregate historical data according to the context under which it was added to the *Case Base*, therefore enhancing the prediction process.

2 Background

2.1 Case Based Computing

The *Case-Based* (*CB*) approach to computing stands for an act of finding and justifying a solution to a given problem based on the consideration of the solutions of similar past ones, either using old solutions, or by reprocessing and generating new data or knowledge from the old ones [5, 6]. In *CB* the *cases* are stored in a *Case-base*, and those cases that are similar (or close) to a new one are used in the problem solving process.

The typical *CB* cycle is given in Fig. 1, which presents the mechanism that should be followed to have a consistent model. The first stage entails an initial description and a reprocessing of the problem's data or knowledge. The new case is defined and it is used to retrieve one or more cases from the repository. At this point it is important to identify the characteristics of the new problem and retrieve cases with a higher degree of similarity to it. Thereafter, a solution to the problem emerges, on the *Reuse* phase, based on the blend of the new case with the retrieved ones. The suggested solution is reused (i.e., adapted to the new case), and a solution is provided [5, 6]. However, when adapting the solution it is crucial to have feedback from the user, since automatic adaptation in existing systems is almost impossible. This is the *Revise* stage, in which the suggested solution is tested by the user, allowing for its correction, adaptation and/or modification, originating the test repaired case that sets the solution to the new problem. The test repaired case must be correctly tested to ensure that the solution is indeed correct. Thus, one is faced with an iterative process since the solution must be tested and adapted, while the result of considering that solution is inconclusive. During the *Retain* (or *Learning*) stage the case is learned and the knowledge base is updated with the new case [5, 6].

There are numerous examples on the literature that make use of *CB* as a problem-solving methodology in Medical Domain. Different researchers have reviewed more than thirty *CBR* systems showing that they have been widely employed in medicine, including disease diagnosis, classification, treatment and management [8, 9].

CB approach was used in mental diseases, in order to predict the effect of treatments of patients with anxiety disorders [10]. This study showed 65% of correct predictions in the absence of similarity restrictions, while in the presence of similarity restrictions (i.e., prediction based only on cases with a similarity higher than 0.62), the accuracy increased to 80%. Another study presents a fuzzy ontology-based semantic *CB* system for a decision support system to answer complex medical queries related to semantic understanding of medical concepts and handling of vague terms in diabetes diagnosis [11]. The overall accuracy attained with the proposed system was 97.7%, higher than the accuracies obtained with another artificial intelligence based tools like the k-nearest neighbour, with $k = 3$ (68.3%), artificial neural networks (71.7%), support vector machines (76.7%), Bayesian classifier(76.7%) and decision trees (90.0%).

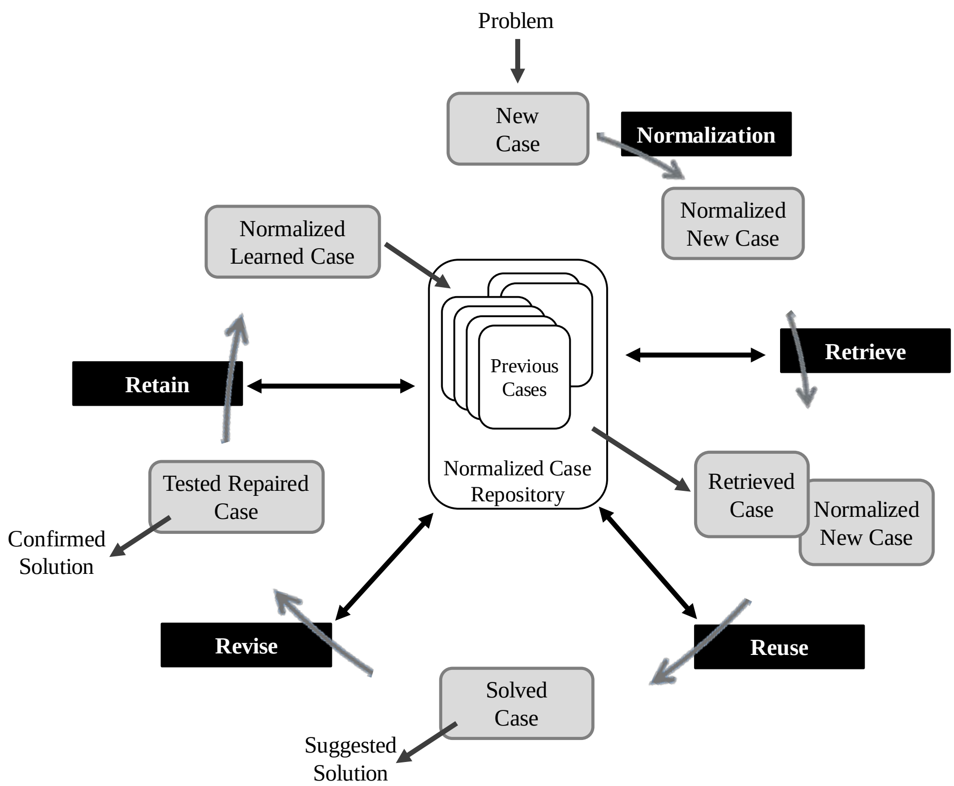

Figure 1: The typical *CB* cycle (adapted from [5])

A recent study combines *CB* methodology and multi-agent systems [12]. The multi-agent architecture intends to take into account the whole cycle of clinical decision-making, in order to obtain an adaptable system that includes different medical aspects such as the diagnosis, prognosis, treatment and therapeutic monitoring of gastric cancer. In the multi-agent architecture, the ontological agent type uses the knowledge domain to ensure proficiency in the extraction of similar clinical cases and provide treatment suggestions to patients and physicians. *CB* methodology is used to memorize and to restore experience data in order to solve similar problems.

Undeniably, despite promising results, the current *CB* systems are neither complete nor adaptable enough for all domains. In some cases, the user cannot choose the similarity(ies) method(s) used in the retrieval phase and is required to follow the system defined one(s), even if they do not meet their needs. Moreover, in real problems, the access to all necessary information is not always possible, since existent *CB* systems have limitations related to the capability of dealing, explicitly, with unknown, incomplete, and even self-contradictory information. To make a change, a different *CB* cycle was induced (Fig. 2). It takes into consideration the case's *QoI* and *DoC* metrics, matters that will be explained in the next section. It also contemplates a cases optimization process present in the *Case-base*, whenever they do not comply with the terms under which a given problem as to be addressed (e.g., the expected *DoC* on a prediction was not attained). In this process can be used *Statistical Tests* [13, 14] or *Artificial Neural Networks* [15, 16], *Particle Swarm Optimization* [17] or *Genetic Algorithms* [18], just to name a few. Indeed, the optimization process generates a set of new cases which must be in conformity with the invariant:

$$\bigcap_{i=1}^{n}(B_i\,,\,E_i) \neq \emptyset \qquad (1)$$

i.e., it states that the intersection of the attribute's values ranges for the cases' set that make the *Case-base* or their optimized counterparts ($\boldsymbol{B_i}$) (being n its cardinality), and the ones that were object of a process of optimization ($\boldsymbol{E_i}$), cannot be empty (Fig. 2).

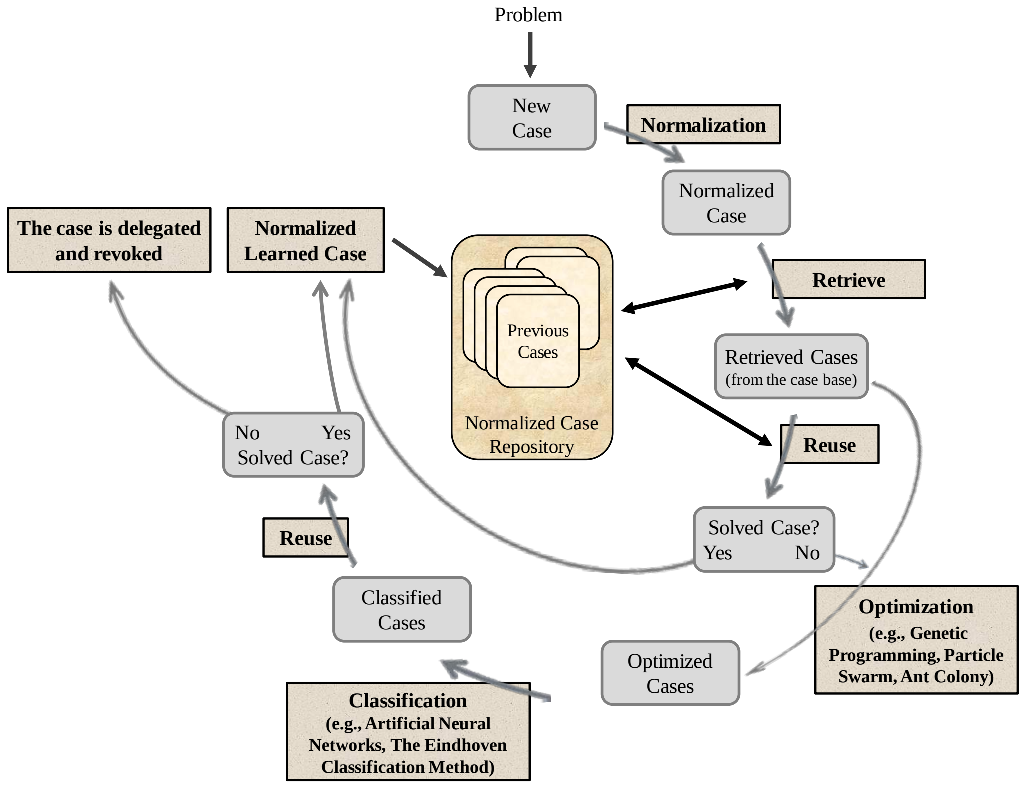

Figure 2: The extended view of the *CB* cycle

2.2 Knowledge Representation and Reasoning

Logic Programming (*LP*) has been used for knowledge representation and reasoning, representing a point of convergence in the disciplines of *Logic*, *Mechanical Theorem Proving* and *Computer Science*. It may be given in terms of elements of *Model Theory* [19, 20] or *Proof Theory* [7, 18]. In the present work the *Proof Theoretical* approach is followed as an extension to *LP*. Indeed, an *Extended Logic Program* is a finite set of clauses in the form:

$$\{$$
$$\neg p \leftarrow not\ p \wedge not\ exception_p$$
$$p \leftarrow p_1 \wedge \cdots \wedge p_n \wedge not\ q_1 \wedge \cdots \wedge not\ q_m$$
$$exception_{p_1}$$
$$\ldots$$
$$exception_{p_j} \quad (0 \le j \le k), \quad being\ k\ an\ integer\ number$$
$$\} :: scoring_{value}$$

where the first clause stand for predicate's closure, "$\wedge$ " denotes *logical and*, while "*?*" is a domain atom denoting falsity. The p_i, q_j, and p are classical ground literals, i.e., either positive atoms or atoms preceded by the classical negation sign $\neg$ [7]. Indeed, $\neg$ stands for a strong declaration that speaks for itself, and *not* denotes *negation-by-failure*, or in other words, a flop in proving a given statement, once it was not declared explicitly. Under symbols' theory, every program is associated with a set of abducibles [19, 20], given here in the form of exceptions to the extensions of the predicates that make the program, i.e., clauses of the form:

$$exception_{p_1}$$
$$\ldots$$
$$exception_{p_j} \quad (0 \le j \le k), \quad being\ k\ an\ integer\ number$$

that stand for data, information or knowledge that cannot be ruled out. On the other hand, clauses of the type:

also named invariants or restrictions, allows one to set the context under which the universe of discourse has to be understood. The term $scoring_{value}$ stands for the relative weight of the extension of a specific *predicate* with respect to the extensions of peers ones that make the inclusive or global program.

In order to set one's approach to knowledge representation, two metrics will be set, namely the Quality-of-Information (*QoI*) and the Degree-of-

Confidence (*DoC*). The *QoI* of a logic program should be understood as a mathematical function that will return a truth-value ranging between 0 and 1 [21, 22], once it is fed with the extension of a given predicate, i.e., $QoI_i = 1$ when the information is *known* (*positive*) or *false* (*negative*) and $QoI_i = 0$ if the information is *unknown*. For situations where the extensions of the predicates that make the program also include *abducible* sets, its terms (or clauses) present a $QoI_i \in]0, 1[$, in the form:

$$QoI_i = 1/Card \quad (2)$$

if the *abducible* set for *predicates i* and *j* satisfy the *invariant*:

$$?\left(\left(exception_{p_i} \vee exception_{p_j}\right) \wedge \neg\left(exception_{p_i} \vee exception_{p_j}\right)\right)$$

where "$\vee$" denotes *logical or* and "*Card*" stands for set cardinality, being $i \neq j$ and $i, j \geq 1$ (a pictorial view of this process is given in Fig. 3(a), as a pie chart).

On the other hand, the clauses cardinality (*K*) will be given by $C_1^{Card} + \cdots + C_{Card}^{Card}$, if there is no constraint on the possible combinations among the abducible clauses, being the *QoI* acknowledged as:

$$QoI_{i_{1 \leq i \leq Card}} = 1/C_1^{Card}, \cdots, 1/C_{Card}^{Card} \quad (3)$$

where C_{Card}^{Card} is a card-combination subset, with *Card* elements. A pictorial view of this process is given in Fig. 3(b), as a pie chart.

However, a term's *QoI* also depends on their attribute's *QoI*. In order to evaluate this metric, look to Fig. 4, where the segment with bounds 0 and 1 stands for every attribute domain, i.e., all the attributes range in the interval [0, 1]. [*A*, *B*] denotes the range where the unknown attributes values for a given predicate may occur (Fig. 4). Therefore, the *QoI* of each attribute's clause is calculated using:

$$QoI_{attribute_i} = 1 - \|A - B\| \quad (4)$$

where $||A–B||$ stands for the modulus of the arithmetic difference between *A* and *B*. Thus, in Fig. 5 is showed the *QoI's* values for the abducible set for $predicate_i$.

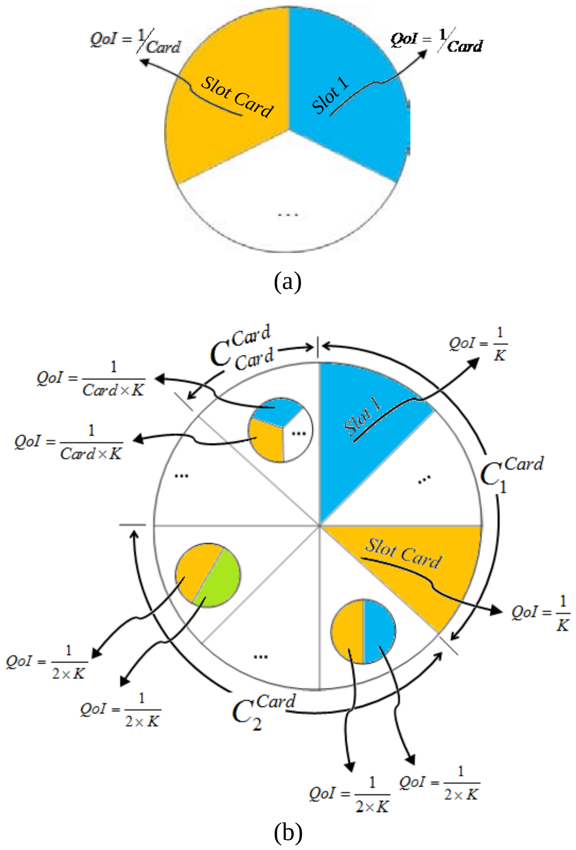

Figure 3: *QoI's* values for the abducible set for $predicate_i$ with (a) and without (b) constraints on the possible combinations among the abducible clauses

Under this setting, another metric has to be considered, which will be denoted as *DoC*, that stands for one's confidence that the argument values or attributes of the terms that make the extension of a given predicate, having into consideration their domains, are in a given interval [23]. The *DoC* is figured using , where Δl stands for the argument interval length, which was set to the interval [0, 1] (Fig. 6).

Thus, the universe of discourse is engendered according to the information presented in the extensions of such predicates, according to productions of the type:

$$predicate_i - \bigcup_{1 \leq j \leq m} clause_j\left(\left(\left(A_{x_1}, B_{x_1}\right)\left(QoI_{x_1}, DoC_{x_1}\right)\right), \cdots, \left(\left(A_{x_l}, B_{x_l}\right)\left(QoI_{x_l}, DoC_{x_l}\right)\right)\right) :: QoI_j :: DoC_j \quad (5)$$

where *U*, *m* and *l* stand, respectively, for *set union*, the *cardinality* of the extension of $predicate_i$ and the number of attributes of each clause [23]. On the other hand, either the subscripts of the QoI_s and the DoC_s, or those of the pairs (A_s, B_s), i.e., $x_1, \ldots, x_l$, stand for the attributes' clauses values ranges.

Figure 4: Setting the *QoIs* of each attribute's clause

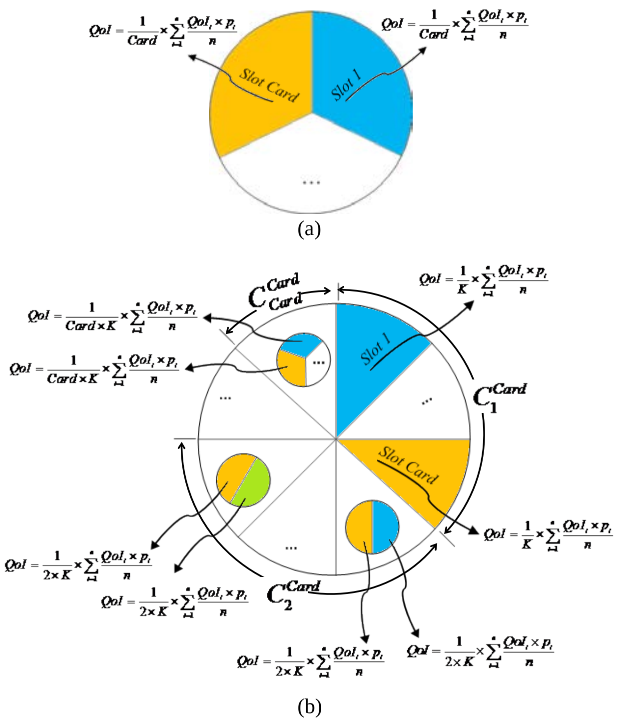

Figure 5: *QoI's* values for the abducible set for *predicate*$_i$ with (a) and without (b) constraints on the possible combinations among the abducible clauses. $\sum_{i=1}^{n} (QoI_i \times p_i)/n$ denotes the *QoI's* average of the attributes of each clause (or term) that sets the extension of the predicate under analysis. n and p_i stand for, respectively, for the attribute's cardinality and the relative weight of attribute p_i with respect to its peers (

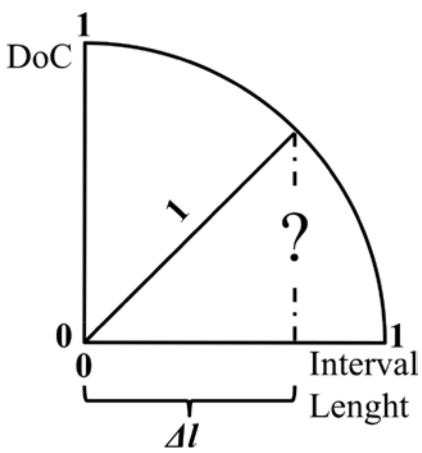

Figure 6: Evaluation of the attributes' *Degree of Confidence*

3 Materials and Methods

3.1 Source of Data

Aiming to develop a predictive model to estimate the individual's age based on pelvis' dimensions criteria a database was set. The data was taken from the health records of patients at a major health care institution in the north of Portugal (Centro Hospitalar do Porto). University of Minho researchers developed a computational platform, denoted as **AIDA**, which stands for an **A**gency for the **I**ntegration, **D**iffusion, and **A**rchive of patient information [24]. The AIDA platform aims to allow/facilitate the dissemination and integration of information generated in hospital environments (Fig. 7). It incorporates various integration capabilities through technologies like Service Oriented Architectures and Multi-Agent System, which ensure the interoperability in a specific and distributed environment. It respects standards requested by services providers that constitute a healthcare institution. AIDA is characterized by electronic applications that provide intelligent workers, intended as software agents that have a proactive comportment. They are responsible of tasks like the communication between different systems, the send and receipt of information (e.g., clinical or medical reports, images, collect of data, prescriptions), the management of information and the responses to requests correctly and timely [24, 25].

3.2 Participants

A set of 736 pelvis X-ray DICOM images with dimensions of 2140×1760 pixels was collected, in order to perform this study. The patients included in this study aged between 21 to 83 years old, with an average of 41±15 years old. The gender distribution was 47.8% and 52.2% for male and female, respectively.

3.3. Image Processing

Image processing is an essential component of tomographic and non tomographic medical imaging, and it is based on systems that are capable of performing operations on digital images. Usually the information contained on medical images is too large and unorganized. Therefore, some steps must be followed in order to extract the most relevant features for the case study and eliminate some artefacts that can cause some impairment on the results that one is trying to obtain.

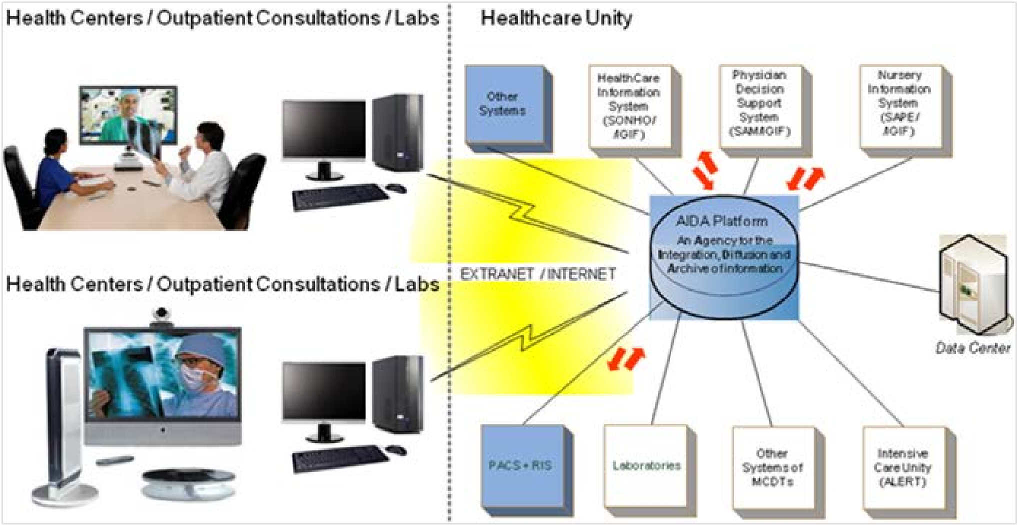

Figure 7: The computational platform architecture

Although pelvis X-ray DICOM images show noise, it is not relevant for the study since the image measurements that will be used only have to do with linear dimensions, which can be extracted from a noisy image. A Java-based image processing framework named *imageJ* [26] was used to extract the necessary features from the X-ray images. As may be seen in the X-ray image presented in Fig. 8, there is much space besides the pelvis bone. In order to remove this extra space a *Region-Of-Interest* (*ROI*) was defined. Then, the *Image* > *Show Info* option of *imageJ* was used to acquire the DICOM information about the image plus the height and width of the *ROI* in pixels and millimetres. The data obtained (i.e., pelvis height and width and patient's gender and age) was exported to a *Microsoft Excel* file for posterior processing.

3.4. A Logic Programming Approach to Data Processing

It is now possible to build up a knowledge database given in terms of the extensions of the relations depicted in Fig. 9, which stand for a situation where one has to manage information aiming to estimate the individual's age based on gender, pelvis height, and pelvis width. The column *Gender* of *Age Prediction* table are populated with 0 (zero) and 1 (one) denoting, respectively, *Female* and *Male*. Under this scenario some incomplete and/or default data is present. For instance, the *pelvis height* in case 2 is unknown, which is depicted by the symbol $\perp$, while the *pelvis width* in case 1 ranges in the interval [365, 382].

Applying the algorithm presented in [23] to the fields that make the knowledge base for *Individual's Age Prediction* (Fig. 9), excluding at this stage of such a process the *Description* ones, and looking to the DoC_s values obtained, it is possible to set the arguments of the predicate *age prediction* ($age_{prediction}$) referred to below, that also denotes the objective function with respect to the problem under analysis:

$$age_{prediction}: Gender, Pelvis\ Height, Pelvis\ Width \rightarrow \{0, 1\}$$

where 0 (zero) and 1 (one) denote, respectively, the truth values *false* and *true*.

Figure 8: A pelvis X-ray image showing region-of-interest

	Age Prediction				
Attributes of the Feature Vector:	#	Gender	Pelvis height (mm)	Pelvis width (mm)	Description
Feature Vector Attributes:	1	1	270	[365, 382]	Description 1
	2	0	⊥	363	Description 2
	…	…	…	…	…
	736	0	[235, 250]	342	Description 736
Feature Vector Domains:		[0, 1]	[200, 300]	[200, 400]	

Figure 9: A fragment of the knowledge base for individual's age prediction

The application of the algorithm presented in [23] comprises several steps. In the former one the clauses or terms that make extension of the predicate under study are established. In a second step the boundaries of the attributes intervals are set in the interval [0, 1] according to a normalization process given by the expression $\frac{Y - Y_{min}}{Y_{max} - Y_{min}}$, where the Y_s stand for themselves. Finally, the *DoC* is evaluated as described in section 2.2. Exemplifying with a term (patient) that presents feature vector $G_{ender} = 0$, $P_{elvis}H_{eight} = \perp$, $P_{elvis}W_{idth} = [320, 330]$, one may have:

Begin *(DoCs evaluation)*

The predicate's extension that sets the Universe-of-Discourse for the term under observation is fixed

$$\{ \quad \neg\, age_{prediction}\left(\left((A_G, B_G)(QoI_G, DoC_G)\right), \left((A_{PH}, B_{PH})(QoI_{PH}, DoC_{PH})\right), \left((A_{PW}, B_{PW})(QoI_{PW}, DoC_{PW})\right)\right)$$

$$\leftarrow not\ age_{prediction}\left(\left((A_G, B_G)(QoI_G, DoC_G)\right), \left((A_{PH}, B_{PH})(QoI_{PH}, DoC_{PH})\right), \left((A_{PW}, B_{PW})(QoI_{PW}, DoC_{PW})\right)\right)$$

$$age_{prediction}\left(\left((0, 0)\left(1_{[0,0]}, DoC_{[0,0]}\right)\right), \left((200, 300)\left(1_{[200,300]}, DoC_{[200,300]}\right)\right), \left((320, 330)\left(1_{[320,330]}, DoC_{[320,330]}\right)\right)\right) :: 1 :: DoC$$

$$\underbrace{[0, 1] \qquad\qquad [200, 300] \quad [200, 400]}_{attribute`s\ domains}$$

$$\} :: 1$$

The attribute's boundaries are set to the interval [0, 1], according to a normalization process that uses the expression $\frac{Y - Y_{min}}{Y_{max} - Y_{min}}$

$$\{ \quad \neg\, age_{prediction}\left(\left((A_G, B_G)(QoI_G, DoC_G)\right), \left((A_{PH}, B_{PH})(QoI_{PH}, DoC_{PH})\right), \left((A_{PW}, B_{PW})(QoI_{PW}, DoC_{PW})\right)\right)$$

$$\leftarrow not\ age_{prediction}\left(\left((A_G, B_G)(QoI_G, DoC_G)\right), \left((A_{PH}, B_{PH})(QoI_{PH}, DoC_{PH})\right), \left((A_{PW}, B_{PW})(QoI_{PW}, DoC_{PW})\right)\right)$$

$$age_{prediction}\left(\left((0, 0)\left(1_{[0,0]}, DoC_{[0,0]}\right)\right), \left((0, 1)\left(1_{[0,1]}, DoC_{[0,1]}\right)\right), \left((0.2, 0.3)\left(1_{[0.2,0.3]}, DoC_{[0.2,0.3]}\right)\right)\right) :: 1 :: DoC$$

$$\underbrace{[0,1] \quad [0,1] \quad [0,1]}_{attribute`s\ domains\ once\ normalized}$$

$\}:: 1$

The DoC's values are evaluated

$$\{ \neg\, age_{prediction} \left(\left((A_G, B_G)(QoI_G, DoC_G)\right), \left((A_{PH}, B_{PH})(QoI_{PH}, DoC_{PH})\right), \left((A_{PW}, B_{PW})(QoI_{PW}, DoC_{PW})\right)\right)$$

$$\leftarrow not\ age_{prediction} \left(\left((A_G, B_G)(QoI_G, DoC_G)\right), \left((A_{PH}, B_{PH})(QoI_{PH}, DoC_{PH})\right), \left((A_{PW}, B_{PW})(QoI_{PW}, DoC_{PW})\right)\right)$$

$$age_{prediction} \underbrace{\left(\left((0, 0)(1, 1)\right), \left((0, 1)(1, 07)\right), \left((0.2, 0.3)(1, 0.99)\right)\right)}_{attribute`s\ values\ ranges\ once\ normalized\ and\ respective\ QoI\ and\ DoC\ values} :: 1 :: 0.67$$

$$\underbrace{[0,1] \quad [0,1] \quad [0,1]}_{attribute`s\ domains\ once\ normalized}$$

$\}:: 1$

End

4 Results and Discussion

4.1. A Case Based approach to Computing

In the present section is set the model of the universe of discourse, where the computational part was grounded in a *CB* approach to computing. Contrasting with other problem solving tools (e.g., those that use *Decision Trees* or *Artificial Neural Networks*), relatively little work is done offline [27]. Undeniably, in almost all the situations the work is performed at query time. The main difference between this approach and the typical *CB* one relies on the fact that not only all the cases have their arguments set in the interval [0, 1], a situation that is complemented with the prospect of handling incomplete, unknown, or even self-contradictory data, information or knowledge. Thus, the classic *CB* cycle was changed (Fig. 2), being the *Case-base* given in terms of the pattern:

$Case =$

where the $Description_{data}$ field will not be object of attention in this study. Undeniably, when confronted with a new case, the system is able to retrieve all cases that meet such a case structure and optimize, such a population, having in consideration that the cases retrieved from the *Case-base* must satisfy the invariant present in equation (1), in order to ensure that the intersection of the attributes range in the cases that make the *Case-base* repository or their optimized counterparts, and the equals in the new case cannot be empty. In this study *Artificial Neural Networks* (*ANNs*) were used, in the *CB* cycle, for case's optimization in the following way:

- The extremes of the attribute's values ranges, as well as their *DoCs* and *QoIs* are fed to the *ANN*; and
- The outputs are given in a form that ensures that the case may be used to solve the problem (*no* (*0*), *yes* (*1*)), and a measure of the system confidence on such a result (Fig. 10).

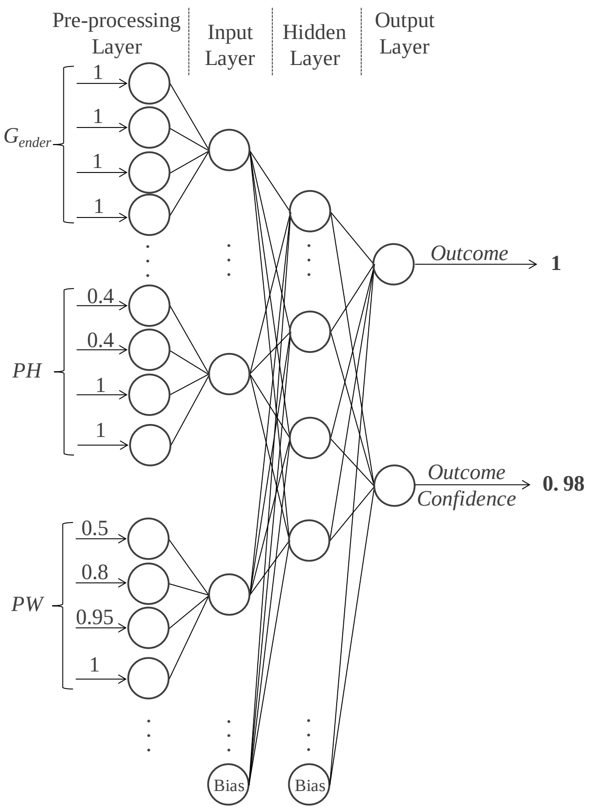

Figure 10: A case's optimization procedure based on *ANNs*

Having this in mind, the algorithm given in [23] is applied to a new case that presents the feature vector $G_{ender} = 1$, $P_{elvis}\ H_{eight} = [240, 270]$, $P_{elvis}\ W_{idth} = [350, 380]$. Then, the computational process may be continued, with the outcome:

$$age_{prediction_{new\ case}}\left(\left(\left((1,1)(1,1)\right),\ \left((0.4,0.6)(1,0.98)\right),\left((0.5,0.8)(1,0.95)\right)\right)\right) :: 1 :: 0.98$$

Now, the *new case* may be portrayed on the *Cartesian* plane in terms of its *QoI* and *DoC*, and by using clustering methods [28] it is feasible to identify the cluster(s) that intermingle with the *new one* (epitomized as a square in Fig 11). The *new case* is compared with every retrieved case from the clusters using a similarity function *sim*, given in terms of the average of the modulus of the arithmetic difference between the arguments of each case of the selected cluster and those of the *new case*. Thus, one may have:

$$\{\ \text{retrieved case}_1\left(\left((1,1)(1,1)\right),\left((0.4,0.4)(1,1)\right),\left((0.5,0.8)(1,0.95)\right)\right) :: 1 :: 0.98,\ \text{retrieved case}_2\left(\left((1,1)(1,1)\right),\left((0.6,1)(1,0.92)\right),\left((0.8,0.8)(1,1)\right)\right) :: 1 :: 0.97,\ \cdots,\ \text{retriev}$$

Assuming that every attribute has equal weight, for the sake of presentation, the *dis(imilarity)* between $new\ case$ and the $retrieved\ case_1$, i.e., $new\ case \rightarrow 1$, may be computed as follows:

$$dis^{DoC}_{new\ case \rightarrow 1} = \frac{\|1-1\| + \|0.98-1\| + \|0.955-0.95\|}{3} = 0.01$$

Therefore, the *sim(ilarity)* for $sim^{DoC}_{new\ case \rightarrow 1}$ is set as *1 – 0.01 = 0.99*. Regarding *QoI* the procedure is similar, returning $sim^{QoI}_{new\ case \rightarrow 1} = 1$. Thus, one may have:

$$sim^{QoI,DoC}_{new\ case \rightarrow 1} = 1 \times 0.99 = 0.99$$

These procedures should be applied to the remaining cases of the retrieved clusters in order to obtain the most similar ones, which may stand for the possible solutions to the problem. This approach allows users to define the most appropriate similarity threshold to address the problem (i.e., it gives the user the possibility to narrow the number of selected cases with the increase of the similarity threshold).

4.2. Model Validation and Performance Assessment

In order to evaluate the performance of the proposed model the dataset was divided in exclusive subsets through the ten-folds cross validation [15]. In the implementation of the respective dividing procedures, ten accomplishments were performed for each one of them. To ensure statistical significance of the attained results, 25 (twenty five) experiments were applied in all tests. The model accuracy was 94.7% (i.e., 697 instances correctly classified in 736). The model accuracy is higher than the accuracy obtained using the classical *CB* approach (Fig 1), i.e., 81.2% (598 instances correctly classified in 736). Thus, it is our claim that the proposed model is able to estimate the *Individuals' Age* through *Pelvis X-Ray* images, and can be a major contribution in this context.

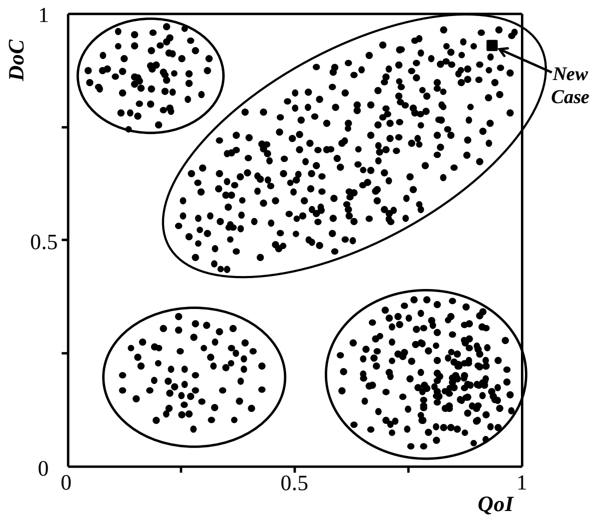

Figure 11: A case's set divided into clusters

5 Conclusions

This work presents an intelligent decision support system to estimate individuals' age based on pelvis X-ray images. It is centred on a formal framework based on *LP* for *Knowledge Representation and Reasoning*, complemented with a *CB* approach to computing that caters for the handling of incomplete, unknown, or even self-contradictory information. The proposed model is able to provide adequate responses once the overall accuracy is close to 95%. The methodology followed in this work may set the basis of an overall approach to such systems, susceptive of application in different arenas. Furthermore, under this line of thinking the cases' retrieval and optimization phases were heightened when compared with existing tactics or methods. Additionally, under this scenery the users may define the weights of the cases' attributes on the fly, letting them to choose the most appropriate strategy to address the problem (i.e., it gives the user the possibility to narrow the search space for similar cases at runtime).

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