Medical Diagnoses with a Cartographic Oriented Model

Elizabeth S. Carvalho[1], Adérito F. Marcos[1], Maribel Y. Santos[1], João Espregueira-Mendes[2], Rogério B. Pereira[3]
[1]University of Minho, School of Engineering, Information Systems Department
[2]University of Porto, Faculty of Medicine
[3]Fernando Pessoa University, Faculty of Health Science

ABSTRACT

The human body is composed of several systems and organs that have a specific and well located position within it. Each organ is usually related to one or more physiological data. There is a subtle spatial interdependency on human's body structure and behaviour. Because of this, doctors usually execute a spatial analysis when diagnosing a disease in a patient. The doctor has to combine patient's medical data performing some "implicit" algebraic map operation. Although this is true, most of the models used to analyze, to process and to visualize these data, do not take into account the strong spatial interdependency inherent to human body's functioning. These models usually treat morphological and physiological data in a full autonomous and isolated way. This happens because they are not "spatially" oriented, and do not interpret the human body as a 3D map, being composed by different parts and layers of information. The possibility of combining these layers using spatial algebraic operations, introduces a new degree of information insight. The main goal of the CHUB (Cartographic Human Body) model is to introduce a cartographic approach to help doctors to analyse, visualize and diagnosis human's body illnesses.

1. INTRODUCTION

There are several ways of analyzing and modeling the human body and its associated morphological and physiological data. Most of the models, used to analyze, to process and to visualize these data, do not take into account the strong spatial interdependency inherent to human body's functioning. For instance, a disease in the liver might impact in several other organs. These models usually treat morphological and physiological data in a full independent and isolated way. This happens because they are not "spatially" oriented. The human body can be compared to a map, being composed by different parts and layers of information. The possibility of combining these layers using spatial algebraic operations, introduces a new degree of information insight. Because of these characteristics, it is important to consider and evaluate the development and usage of a cartographic oriented model to analyze, represent and visualize human body's data. This is the main goal of the CHUB (Cartographic Human Body) model (Carvalho et al,, 2007a) (Carvalho et al., 2007b), which will be introduced in this paper. This paper also presents the results achieved until now through the implementation of the CHUB's prototype.

This paper is organized as follows. Section 2 presents the main issues considered in the development of this model. In section 3, CHUB's model is objectively described, while section 4 the selected case study to evaluate and validate the CHUB model is briefly referred. Finally, in section 5 the implemented prototype is introduced and in section 6 the main conclusions and results are discussed.

2. BACKGROUND

Scientific information analysis and visualization (Tufte, 2001) offer a bunch of different visual techniques that can help us a lot to achieve information insight. It has been widely used and applied with proved success in several areas of knowledge. We can say that thanks to visualization, any illiterate computer user is able to process huge volumes of data with the simple effort of an eye look.

Medicine is a vast scientific area which main concern is Human Beings health and welfare. Many computer applications (Preim, 2007) focusing mainly image processing of X-Rays, ultrasound or MRI (Magnetic Resonance Imaging) has been produced. They help doctors to analyze these images, revealing details that sometimes our eyes can not easily detect. Besides these applications, many others have been created, regarding other important aspects and issues of this scientific area, such as: human body modelling, diagnosis decision support systems, data analysis or training systems (most in virtual reality environments). Computer graphics has been the essential key in all these applications or systems (Ware, 2004).

However computer graphics is a strong information communication tool, we cannot ignore that the success of any graphical application depends a lot on a well-tailored visualization pipeline. This means that data modeling, analysis and treatment must be very well conceived and personalized according the application goals and its data profile (type, nature, dimension, etc.).

A cartographic model (DeMers, 2007) is defined as a simplified representation of the Earth's surface or any celestial body that can be expressed in an analytical form. For many years, cartography was only associated to the production of analogical maps. Nowadays, its domain grew (Peuquet, 2002) and other fields of knowledge start to use it as a way to express information (Skupin, 2000) (Skupin, 2002). Its key feature is the decomposition of information (Harmon, 2003) into layers that are geo-referenced and that can be easily combined through diverse algebraic spatial map operations (intersection, union, etc.).

Human's body data has a strong spatial interdependency and characteristic and might be stated as being "human-referenced" (referenced to the median mass centre of the human body, for instance). On the other hand, when a doctor or any healthcare specialist analyzes this data, he/she always performs some kind of algebraic map operation in order to evaluate the patient and achieve some diagnosis. Algebraic spatial map operations are implicitly performed by doctors when evaluating patient's health data. Taking this into account, it is reasonable to say that a cartographic based model might also help to solve (Carvalho, 2007b) the existing limitations usually present in human body data models (Sato, 2001).

3. CHUB – THE CARTOGRAPHIC HUMAN MODEL

CHUB is a model that was developed taking into consideration the main principles of cartographic modelling. It structures data according to different layers of information. Each layer is associated to a specific organ and/or system, and might contain geometric data or attributes that are "human-referenced". CHUB has not been developed as a dynamic model. It is considered that dynamic issues related to human's body data, such as body movement, blood flow or heartbeat (besides others) will be accomplished by other models that should be used as a specialized extension to CHUB. Figure 1 shows CHUB's general architecture. CHUB's architecture includes three main components: i) Data repository; ii) Data analysis, and iii) Data Visualization.

The Data Repository Component is responsible for the management and storage of the qualitative and quantitative data related to the human body, the geometry 3D files describing different human organs and/or systems, the raster images from resulting exams (like, for instance, a X-Ray) and the heuristics that are used to evaluate and compare layers by the model. Both geometry 3D files and raster images are considered to be "human-referenced". In its management level, this component integrates stages such as creation, edition, querying, and deletion of records in the Qualitative and Heuristics Database, creation, reading and deletion of records in the Quantitative Database, reading and deletion of raster files from the Raster Database, and reading of geometries from the Geometric Database.

The Data Analysis Component is composed by the following stages: Data Selection, Data Treatment, Layers Creation, Layers Processing and Results Interpretation. It uses as input the data from the previous component, and sends its results to the Data Visualization component. It is basically in charge for the treatment, processing and analysis of the data. In this component algebraic cartographic operations are performed on data in several different ways in order to merge it diversely. Finally, the Data Visualization Component holds the results repository databases (from statistical and/or mathematical data analysis and algebraic map operations on it), and typical stages of the visualization pipeline and database management.

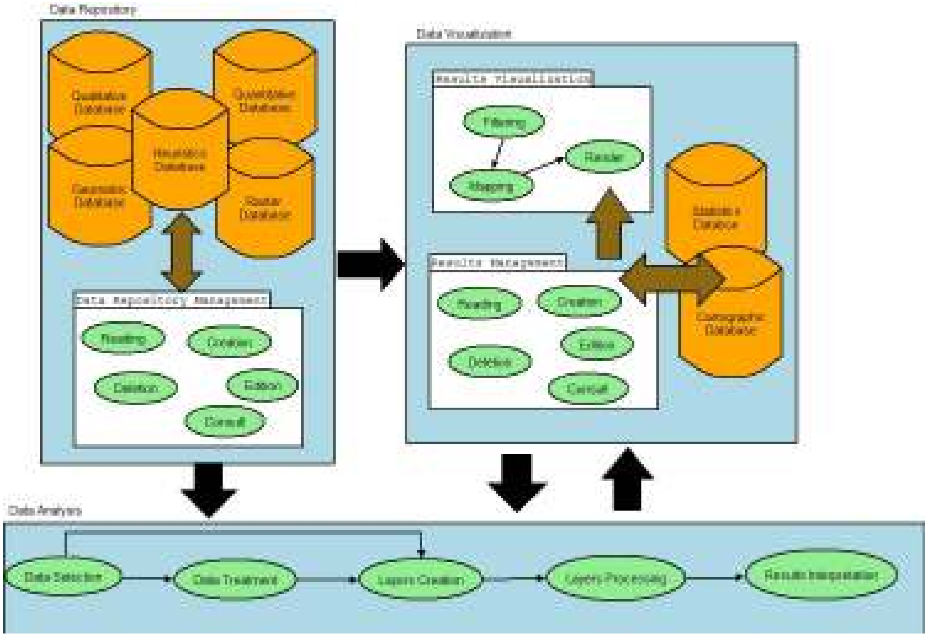


Figure 1: CHUB's general architecture

4. CASES STUDY

A case study to validate and evaluate our model is required. Because of the model complexity, two different scenarios and cases study were taken into consideration: hydrokinetic therapy sessions and knee osteoarthritis diagnosis. Considering this approach, besides a more robust evaluation of our model, it will be possible to exploit better each of its potentialities. We are particularly interested in evaluating our model capability to work as a diagnosis support tool (in this case, knee osteoarthritis) and as an analytical tool (in this case, hydrokinetic therapy sessions). In both situations the cartographic oriented approach available in our model should proof its effectiveness. In this section, it will be presented the applied/adapted model architecture.

4.1. Selected Scenarios

Knee Osteoarthritis Disease

The knee (Espregueira-Mendes, 2006) is the intermediary articulation of the leg. It has possibly the most important role in the human motion. It is not easy to have the complete knowledge of everything that is related to this articulation and might affect it. It requires a combined effort between different disciplines such as the anatomy, the biomechanics and the physiology surgery, with special emphasis on orthopaedic surgery. The muscle-skeletal evaluation of the knee aims to detect problems and has three distinct phases: visual examination, touch examination and movement analysis.

The osteoarthritis (Russel, 2004) is a disease normally caused by the natural aging articulation degeneration. The pain in the knee triggered by any movement is a significant symptom. The patient slowly loses his/her knee motion, and it usually becomes swelled. The X-Ray exams of the knee allow the evaluation of its inner space loss and any sclerosis or osteopathy formation. The osteoarthritis diagnosis is achieved after the muscle-skeletal evaluation of the knee and complementary exams such as X-rays, blood tests and MRIs.

Hydrokinetic Therapy Sessions

Hydrokinetic (Fiorelli, 2002) therapy sessions are composed of several and different techniques that are applied and based on submersed human body movement. As a matter of fact, it is a kind of hydro physiotherapy. Patients should perform several different therapeutic exercises and movements under water, according to their health needs and handicaps.

A special suit provided with electronic sensors is being developed to maximize session performance and allows an accurate monitoring and evaluation of patient’s treatment response. It is clear the need of a well tailored computer application that process and records properly all data sent by sensors in real time. This computer application should also be able to offer effective and straightforward different data visualizations, which help therapists and doctors to have information insight, and easily evaluate patient’s condition during a session and/or between sessions, working as a tool for diagnosis and decision support.

All captured data during a session will be sent to a computer in order to be properly processed. It is of great importance the creation of a suitable computer application that guarantees accurate and reliable data treatment. Besides that, the huge amount of information demands powerful and comprehensive data visualization tools.

4.2. Adapted Model Architecture

Considering the two scenarios described in the previous section, our adapted architecture should process, treat and visualize properly hydrokinetic therapy sessions and knee osteoarthritis diagnosis. In the first case, it is considered to be also interesting to perform different statistical and historical evaluation on data, while in the knee osteoarthritis, the focus should be the usage of algebraic map operations to achieve the proper diagnosis.

The writing databases hold results of statistical evaluation of the hydrokinetic sessions (*Statistic Database*) and algebraic maps operations (*Cartographic Database*) performed on human-referenced information layers.

Data Repository Component

The *Qualitative Database* holds both patients personal information besides blood exams and X-rays graduations in terms of Alhbäck scale (it classifies the osteoarthritis gravity) while the *Quantitative Database* stores the hydrokinetic session’s recording. All the geometry used by the prototype is kept inside the *Geometric Database* and is “human-referenced”. The X-rays imagery of the patient is hold by the Raster Database and is also “human-referenced”. Inside the *Heuristics Database* are the logical descriptions of the decision tree that the doctor “mentally” and “implicitly” uses while diagnosing the knee osteoarthritis. As a matter of fact, these descriptions are rules that identify how information layers should be matched and combined.

Patient’s records are stored into a relational database with four tables. Patient’s data include general information about the patient, such as his/her therapist, disease or age, and personalized physiological parameters such as his/her maximum permitted heartbeat value. These parameters are used for alarmist purposes. Hydrokinetic session recordings include patient’s heartbeat, breathing frequency, hips, shoulders and spine rotations (in terms of pitch, yaw and roll) at each millisecond, besides suit identification number, patient’s name and date and time. Each session might last 30 minutes. Figure 2 illustrates the structure of a recording file.

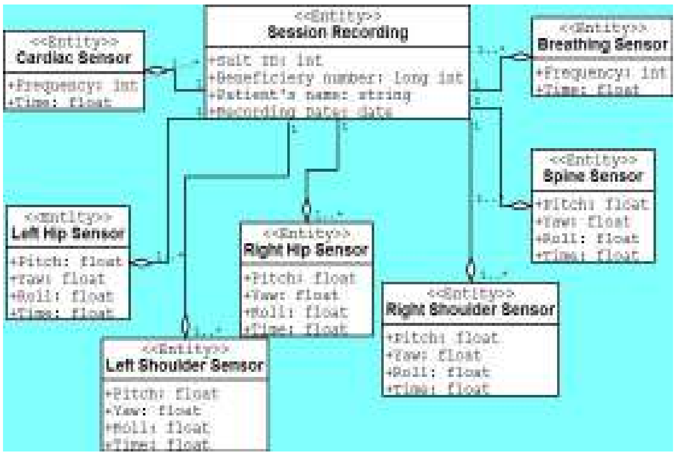


Figure 2: Hydrokinetic session recording file

Seven tables compose the *Heuristics Database*. The table Diagnosis is used to define the rules to be used in the knee osteoarthritis diagnosis. The tables *Causes, Symptoms* and *ClinicalExams* hold respectively causes, symptoms and clinical exams that are directly related to the osteoarthritis disease diagnosis. Each of these tables associates an entry to some punctuation/score. By this process, the logical “mental” decision tree used by the doctor, with all its possible paths, is suitably represented. In addition to these tables, and in order to be feasible to establish the correspondence between the diseases, the diagnosis and its location within the human body (system, organ and physiology), additional tables are also present to hold this information. Figure 3 shows the table’s scheme inside the *Heuristics Database*.

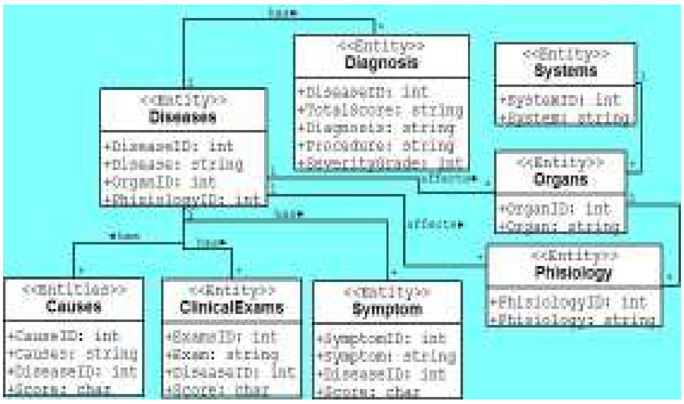


Figure 3: Heuristic database

Data Analysis Component

In the *Data Analysis* component is executed the statistical processing of data gathered along one and/or several hydrokinetic sessions and evaluated the quantitative and qualitative patient data according the heuristics defined to diagnosis knee osteoarthritis. The layers are resultant of algebraic maps operations (reclassification and overlapping) and are "human-referenced". Because a hydrokinetic session should also be analysed and visualized in real time, data processing must attend the synchronism characteristics of a communication port reading. These aspects must be considered in both the *Data Analysis* and *Results Visualization* components.

If it is an analysis of a hydrokinetic therapy session, in the *Data Selection* stage, the patient and his/her related recording session files are chosen in order to be analyzed. Several sessions recordings and periods of time are available. If more than one session file is chosen, a historical evaluation of patient's data is performed; otherwise, a unique session is analyzed. In the *Data Treatment* stage, the noise is deleted and the data clustered according to the chosen granularity (in previous stage).

Otherwise, if it is a knee osteoarthritis diagnosis, in the *Data Selection* stage the patient should also be selected besides the causes, the symptoms and/or the clinical exams chosen. These supplementary data indicates how is actually the stage of the disease in the patient. In the *Data Treatment* stage, this data is combined and matched according to what is specified within the *Heuristics Database*.

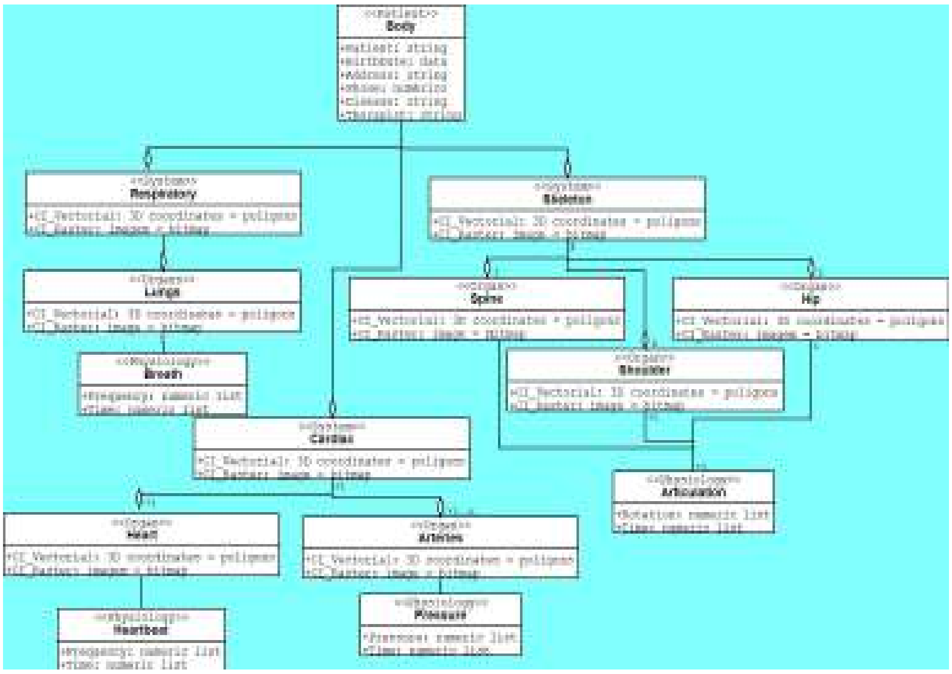


Figure 4: Information layers in hydrokinetic therapy session(s) analysis

In the *Layer Creation* stage data is arranged into layers. Figure 4 shows several layers of information and their interdependency when a hydrokinetic session is being evaluated. These layers are being processed in the *Layer Processing* stage. Maximum, minimum, medium, standard deviation and linear regression values both for clustered and global data are being calculated. The healthcare specialist might extract valuable information both from the treated data and the results obtained from this phase. He/She can also perform implicitly overlapping and reclassification spatial operations (algebraic maps operation) on data in order to achieve a knee osteoarthritis diagnosis evaluation.

At last, in the *Results Interpretation* stage, all the results from previous stages are consolidated and data is sent to the *Statistical Database* if it was a hydrokinetic therapy session(s) analysis or to the *Cartographic Database* if it was a knee osteoarthritis diagnosis (the structure "*Result*" is therefore recorded for further reuse).

Data Visualization component

Transparency is only used when it is a knee osteoarthritis diagnosis, so that the doctor may see inner parts of the articulation. Textures and colours are used to express the severity of the disease. Raster images of the radiographies are mapped with different hue, saturation and grey levels, so that some details might be better enhanced in the image. In order to emphasize visually the cartographic oriented nature of the underneath model, we tried to represent information with a visual layer approach and other typical geographic metaphors as far as possible (such as contour lines and hachured areas with texture).

5. CHUB'S PROTOTYPE

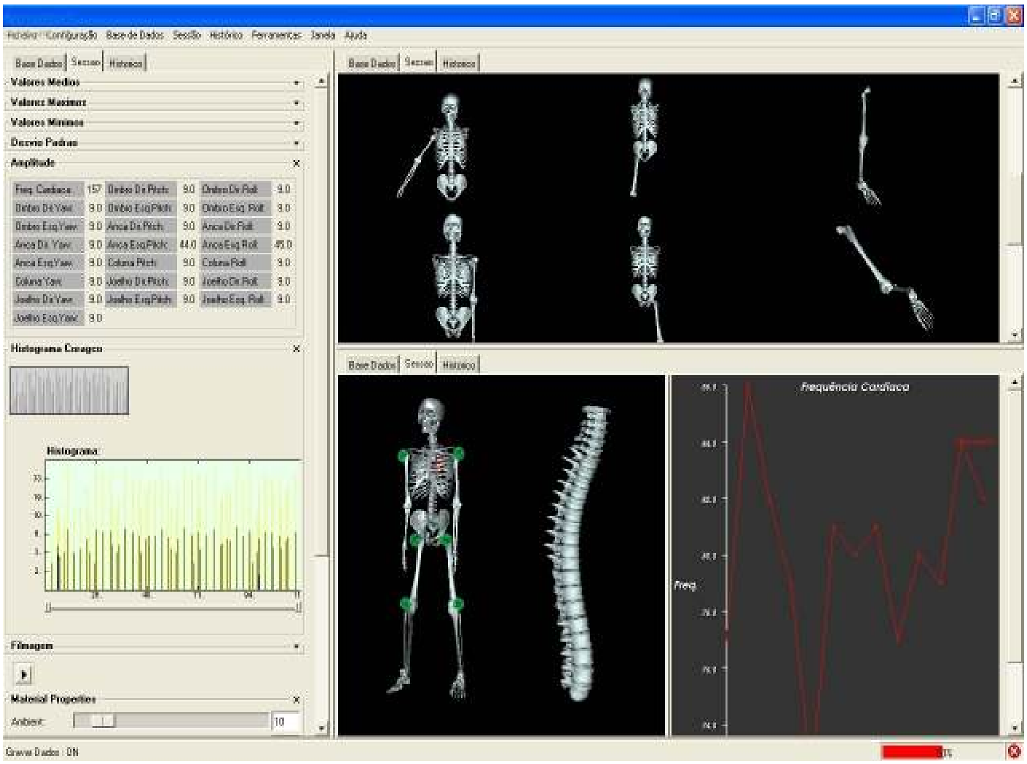
The implemented prototype integrates several probable causes, symptoms and medical exams outputs of diseases. This information is kept inside the *Heuristics* database and is "human-referenced". According to the choices that the user does, firstly a logical operation is performed in order to decide what possible(s) disease(s) is(are), followed by a spatial analysis in order to find where the possible(s) location(s) is(are). The logical used to diagnosing the disease is based on the mental decision tree used by a doctor. Accordingly, the heuristics are a logical mapping of the decision model applied by a doctor when diagnosing. Figures 5 and 6 illustrates the prototype's environment and interface while a hydrokinetic therapy session analysis and knee osteoarthritis diagnosis, while Table 1 shows the correlation between visualization techniques and each situation available in the prototype.

Situation	Visualization technique
Heartbeat	Line graph
Breathing frequency	Line graph
Rotations in articulations	3D hedgehogs, 3D stereoscopic human body with animation and sensors tagged as symbols.
Distribution of frequencies	Histogram
Distribution of rotations	3D Human Body, hedgehogs
Knee osteoarthritis diagnosis Overlapping operation	Texture, pseudo color, segmentation, transparency and zooming of a 3D stereoscopic human body
Knee osteoarthritis diagnosis Reclassification operation	Texture, pseudo color, segmentation, transparency and zooming of a 3D stereoscopic human body
Locations (x, y, z) in the human body model	Contour lines, pseudo color, rotation and transparency of a 3D stereoscopic human body
Alarms of danger situations	Sound, text and blinking effect
Radiographies	Pseudo-color and filtering

Table 1: *Situation versus visualisation techniques*

Once the choices are done, a list of the potential diseases, sorted by the severity level is displayed, with the total weight each choice contributed to each result. If the user has chosen only causes or symptoms and causes, the result is considered inconclusive and further exams are suggested. If he/she chose at least one exam, a standard medical procedure is also recommended to the user.

In terms of graphics, the user visualizes the likely sick parts of the human body in 3D mapped with diverse textures and colors according to the gravity of the diagnosis (by default, the visualization represents automatically the most critic situation), and levels of transparency.



Freq. Cardiaca	157	Ombro Dir Pitch	9.0	Ombro Dir Roll	9.0
Ombro Dir Yaw	9.0	Ombro Esq Pitch	9.0	Ombro Esq Roll	9.0
Ombro Esq Yaw	9.0	Anca Dir Pitch	9.0	Anca Dir Roll	9.0
Anca Dir Yaw	9.0	Anca Esq Pitch	44.0	Anca Esq Roll	45.0
Anca Esq Yaw	9.0	Coluna Pitch	9.0	Coluna Roll	9.0
Coluna Yaw	9.0	Joelho Dir Pitch	9.0	Joelho Dir Roll	9.0
Joelho Dir Yaw	9.0	Joelho Esq Pitch	9.0	Joelho Esq Roll	9.0
Joelho Esq Yaw	9.0				

Figure 5: Information layers in hydrokinetic therapy session(s) analysis

An extra important point is the possibility of executing some statistical analysis on patient's physiological data. It is not pertinent to the cartographic issue, but it is a relevant compliment tool that allows the user to evaluate better human's body data. Because of this, CHUB's prototype also includes statistical analysis.

In order to be able to cover these two topics – spatial operations and statistical analysis of physiological human's body data, the prototype was implemented having two basic goals: the diagnosis of the osteoarthritis disease and the statistical evaluation of hydrokinetic therapy session data (specially from patients also suffering from bone diseases). In the later case, physiological data is composed of a dataset containing several articulations rotations and patient's heartbeat and breath frequency. This data is collected while the patient performs a hydrokinetic therapy session.

The prototype was implemented with VTK 5.0 (VTK, 2007) and KWWidgets both open sources from Kitware Inc. The VTK is a three-dimensional (3D) computer graphics, image processing and visualization object oriented library. KWWidgets is an interface widget library. Both can be installed on different platforms, such as Windows, Mac and various types of Unix/Linux. C++ was the programming language.

Since our main concern is the visualization output, we used the GEM – Generic Evaluation Model, proposed by Irene Buvat et al. (Buvat , 1999), as a basic guideline to structure tests and evaluations. This model is specially oriented to the visualization in the medicine field of knowledge; however it can be used in much broader situations.

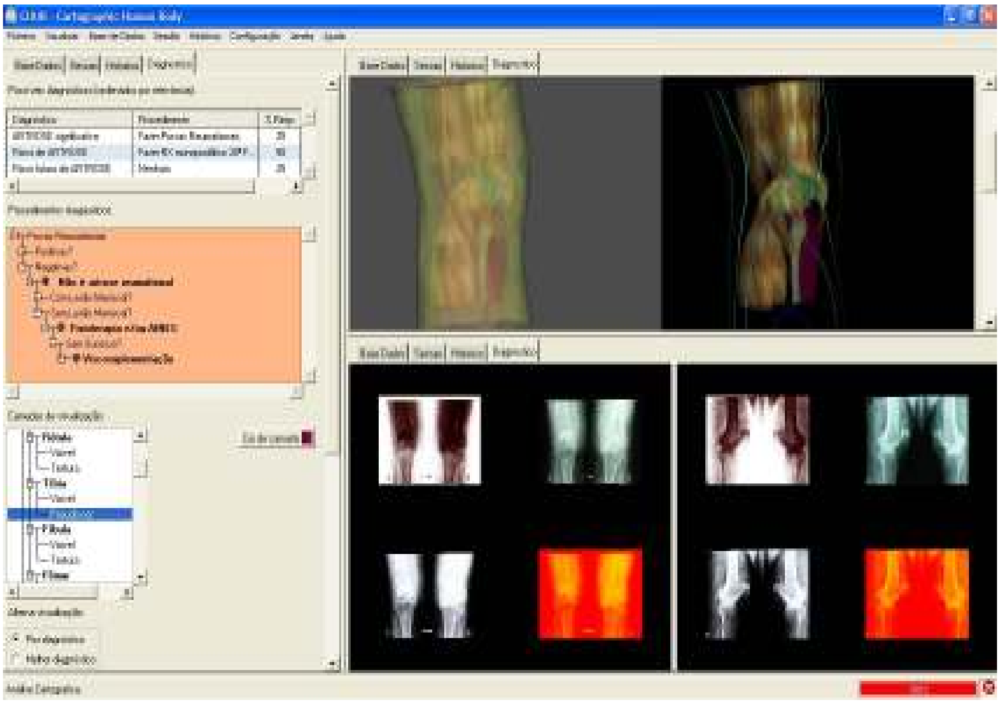


Figure 6: Knee osteoarthritis diagnosis

Adapting and applying GEM rules and levels to our situation, we identified six hypotheses that should be tested and estimated in order to evaluate our model and consequently its prototype. For each of these hypotheses we also defined the observer profile, the input data, the method and tasks to be applied and finally the quality index and a reference for results evaluation. These hypotheses were the following:

- Hypothesis 1 – The appliance of cartographic and spatial operations on human-referenced information layers, allow knee osteoarthritis detection.
- Hypothesis 2 – Besides what is referred in hypothesis 1, we can also properly achieve osteoarthritis diagnosis (severity grade).
- Hypothesis 3 – Cartographic metaphors in results deliverance can help doctor to gain information insight.
- Hypothesis 4 – CHUB can work properly as a diagnosis support tool.
- Hypothesis 5 – CHUB usage actually eases the osteoarthritis knee diagnosis through its algebraic map operations and “human-referenced” data structures.

- Hypothesis 6 – The CHUB can be successfully applied and used for the identification of other illnesses that can molest the knee.

A questionnaire divided into two parts was elaborated. It was completely based on GEM-oriented rules and levels and aimed our hypotheses assessment. In the first phase of the evaluation process, doctors had to fulfill the first part of the questionnaire while interviewing and diagnosing a patient. In the second phase, doctors and therapists manipulated the prototype by exploring the different available features and functionalities and answered the missing part of the questionnaire. Thirty patients, presenting or not symptomatic knee osteoarthritis symptoms, were considered as test bay. Several patients and therapists were ours potential prototype's users.

6. MAIN RESULTS AND CONCLUSIONS

Human's body data has actually a very strong spatial interdependency. We could validate clearly this consideration while capturing the doctor's mental decision tree for knee osteoarthritis diagnosis or evaluating the sensors received data. For instance, according to the degree and strength of an articulation rotation, a significant variation occurs in patient's heartbeat. On the other hand, the standard procedure that any healthcare specialist follows while examining a patient is a combination of several algebraic map operations.

Our prototype evaluation pointed out to the full acceptance of our proposed hypothesis. We can state that the cartographic approach of our model introduces a satisfactory level of quality. The quality references for each hypothesis were exceeded in general over 5%. This indicates clearly that the usage of a cartographic oriented model can effectively help illnesses diagnosis and doctors achieve a better data insight. Figure 7 shows the achieved results for each hypothesis.

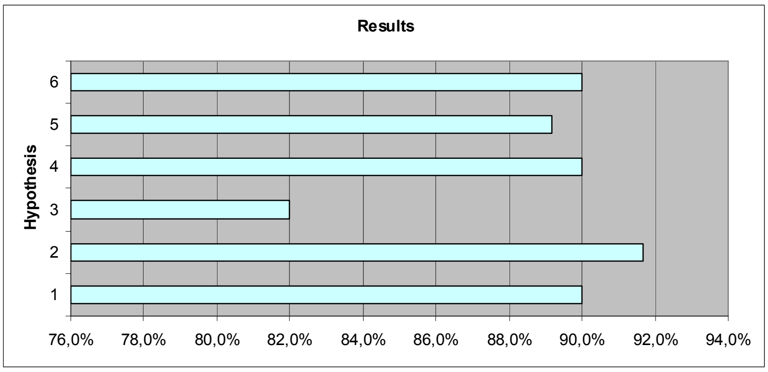


Figure 7: Positive results for each hypothesis

Lastly, based on the prototype evaluation results, we could state that CHUB is a fairly powerful model that would be successfully adapted and applied to analyze and visualize any kind of medical data or whichever one belonging to any alive being (such as animals, for instance). Its strength remains on the cartographic approach used to process, reference and visualize human data, and therefore reflecting properly the intrinsic spatial nature of it.

BIBLIOGRAPHY

Buvat, I., et al., 1999. The Need to Develop Guidelines for the Evaluation of Medical Processing Procedures. Procedures of the SPIE – Medical Imaging, vol. 3661, pp. 1466-1477.

Carvalho E., Marcos A., Santos Y. M., and Brito P., 2007a. Analysing and Visualizing a Human Body Cartographically. In proceedings of the 15º Encontro Português de Computação Gráfica. Lisbon, Portugal, 10-13 October, pp. 1-8.

Carvalho E., Santos Y. M., and Marcos A., 2007b. CHUB – Cartographic Human Body. In proceedings of IADIS – Multi Conference on Computer Science and Information Systems, Lisbon, Portugal, 5-7 July, pp. 27-34.

DeMers, M., 2007. Basic of Geographical Information System, Ed. John Wiley & Son Inc., ISBN 9780471152156.

Espregueira-Mendes, J., and Pessoa, P., 2006. O Joelho, Ed. Lidel, Portugal, ISBN 972-757-418-1, June.

Fiorelli, A., 2002. Hidrocinesioterapia: Princípios e Técnicas Terapêuticas. Colecções Plural, EDUSC, Santa Catarina, Brazil.

Harmon, J., and Anderson, S., 2003. The Design and Implementation of Geographic Information Systems, Ed. Wiley, ISBN 978-0471204886.

Peuquet, D. and Kraak, M., 2002. Geobrowsing: Creative Thinking and Knowledge using Geographic Visualization. In Information Visualization (2002), Volume 1, Nº 1, pp. 80-91.

Preim, B. and Bartz, D., 2007. Visualization in Medicine, Theory, Algorithms and Applications, The Morgan Kaufman Series in Computer Graphics, Ed. Elsevier, ISBN 978-0-12-370596-9.

Russel, R., Williams, N., and Bulstrode, C., 2004. Bailey & Love's Short Practice of Surgery, 24th. edition, Ed. Hodder Arnold, ISBN 0-340-808-19-5, Chapter 25, pp. 308-312.

Sato, M., 2001. Making a Human Body Map. In *NatureInterface*, nº 4, pp. 56-59.

Skupin, A., 2000. From Metaphor to Method: Cartographic Perspectives on Information Visualization. Proceedings IEEE InfoVis 2000 (2000), Utah, EUA, pp. 91-97.

Skupin, A., 2002. A Cartographic Approach to Visualizing Conference Abstracts. In IEEE CG&A, Volume 22, Nº 1, pp. 50-58.

Tufte, E., 2001. Principles of Information Display for Visualization Practioners, Ed. Graphic Press, ISBN 978-0961392147.

VTK, 2007. Visualization Toolkit, http://www.vtk.org (visited in 4-12-2007).

Ware, C., 2004. Information Visualization: Perception for Design (Interactive Technologies), Ed. Morgan Kaufman, ISBN 978-1558608191, April.