# Development of software in the study of carotid artery in the neck

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## SUMMARY

The aim of this work was to develop and employ software for the study of the common carotid artery and its branches in the neck. We first constructed geometric models of anatomic components, for the building of knowledge bases to be used in automatic feature extraction techniques from images. Then, we developed a software system characterised by three-dimensional visualisation, image processing functions, knowledge base and a programming language to describe classification processing by means of fuzzy logic. The software system was used to perform automatic reconstruction of three-dimensional models of carotid arteries from contiguous CT scans of the neck. These findings suggest that such software systems represent a useful help in the study of image based diagnosis of carotid arteries.

## INTRODUCTION

The importance of a correct and early diagnosis and how many and sophisticate instruments are disposable to perform this target is well known. The great amount of data provided by such instruments can be processed by computer to extract useful data in image based diagnosis. The extraction process can be either supervisioned by an operator or, hopefully, automatic. The last case requires building knowledge bases of the geometric relations among anatomic components and logic rules to process experimental data accordingly to it that could be used by automatic reasoning systems. Importantly, the target of this research is to develop software for physiologic and pathologic study of common carotid artery and its branches. The importance of this anatomic area is due to the relevance in the blood brain supplying and in the frequent pathologies involving the system. The work was done in collaboration with the Department of Electric Engineering of the University of Palermo.

## MATERIALS AND METHODS

*Information sources are:*

— anatomic specimens obtained by macro and micro dissection techniques (Fig. 1 A-H)

— plastination (Fig. 1 I)

— digitised images of sections from the Visible Human Dataset (male); the region of the neck they refer to is comprised from the mm 1630 to 1660; each image refers to a section 1 mm thick; a section out of three has been taken;

— CT scan images from V. H. D.; the region of the neck they refer to is comprised from the mm 1629 to 1659; each image refers to a section 3 mm thick; the grey level window was set to show soft tissues;

— CT and MR scans from clinical examinations (Fig. 1 J-K).

## RESULTS

Results are constituted by geometric models and a software system to process CT scan images. One class of geometric models has been built by three-dimensional modelling software after observation of anatomic specimens and CT and MR scan images. These models have been used to produce two-dimensional images by rendering techniques. The models describe sternocleidomastoidea region as a succession of planes: cutaneous, subcutaneous with musculus platisma and external jugular vein, muscolus fascialis superficialis plane with muscolus sternocleidomastoideus and fascia cervicalis superficialis, muscolus fascialis profundus plane with musculi omohyoideus, sternohyoideus and fascia cervicalis media, vasculonervosum space with carotis communis, internal jugular vein, nervus vagus and vagina vascularis, visceralis space with larynx trachealis canal, glandula thyroidea and vagina visceralis, deep plane of vascular and visceral spaces with the columna vertebralis, musculi vertebrali and fascia cervicalis profunda. The models show the division of the arteria carotis. (Fig. 2 A-K)

Another class of geometric models has been built by manual sampling of points on the Visible Human Dataset images of anatomic sections. For each components of interest, that were sternocleidomastoideus musculus, jugular vein and carotid artery, a series of points of the contour were traced. The software system processed these points to build a sliced model of the region by extrusion of polylines along the normal to the section plane with the same thickness of the sections (1 mm) (Fig. 4 A-Q).

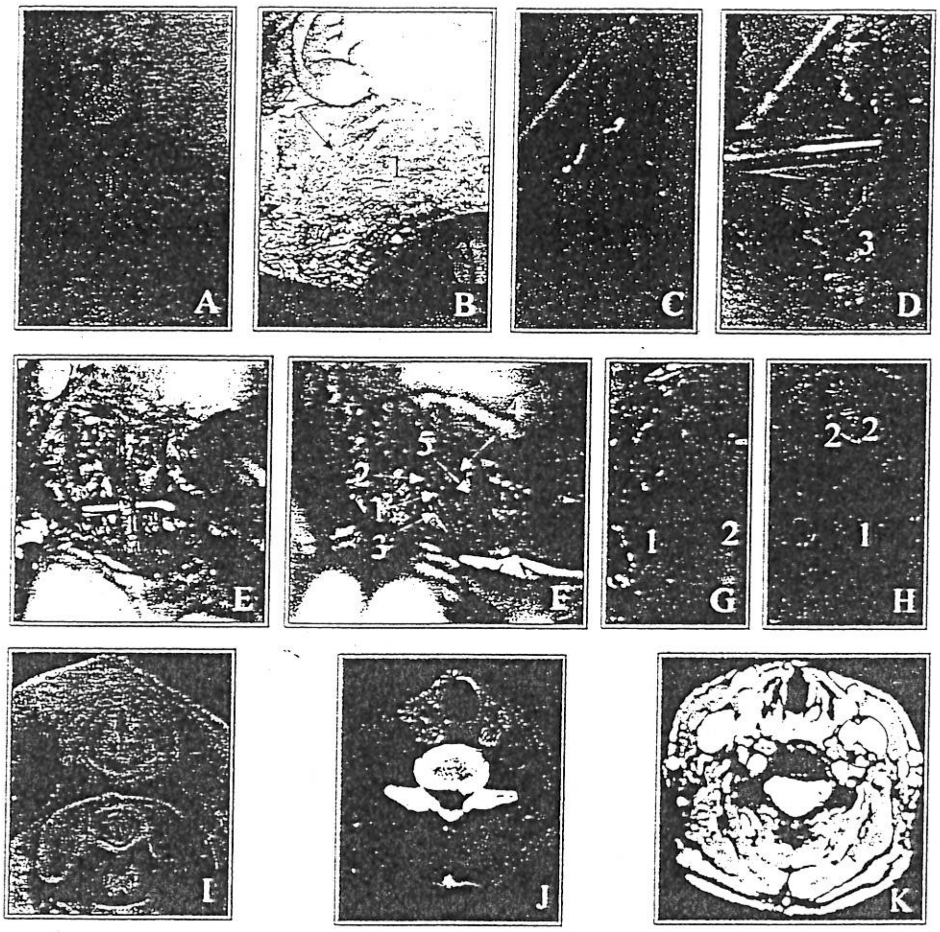


Fig. 1 — Sternocleidomastoidea region and its content: A) 1 cutaneous plane; B) subcutaneous plane: 1 m. platisma, 2 external jugular v.; C) muscolus fascialis superficialis plane: 1 m. sternocleidomastoideus, 2 fascia cervicalis superficialis; D) muscolus fascialis profundus plane: 1 m. omohyoideus, 2 m. sternohyoideus, 3 fascia cervicalis media; E) fascium vasculonervosum and vagina vascularis (1); F) vascular and visceralis space: 1 common carotid a., 2 internal jugular v., 3 n. vagus, 4 larynx trachealis canal, 5 glandula thyroidea; G) deep plane of vascular and visceral spaces: 1 mm. vertebrali, 2 columna vertebralis and fascia cervicalis profunda; H) common carotid artery and its bifurcation branches; I) plastinated section: fascium vasculonervosum (in the circle); J) CT scan section: fascium vasculonervosum (in the circle); K) MR scans: fascium vasculonervosum (in the circle);

In detail, points were sampled on 10 sections from V.H.D. starting from the section corresponding to mm 1630 to section corresponding to mm 1660 taking a section out of three. These models served as a comparison during the phase of automatic reconstruction of carotid arteries.

The software system is constituted by a knowledge base running in a Prolog environment (SWI Prolog) which allows to operate on entities with a wide freedom degree. Its declarative nature permits to describe facts and operators in a way similar to natural language (Norvig P, et al., 1995).

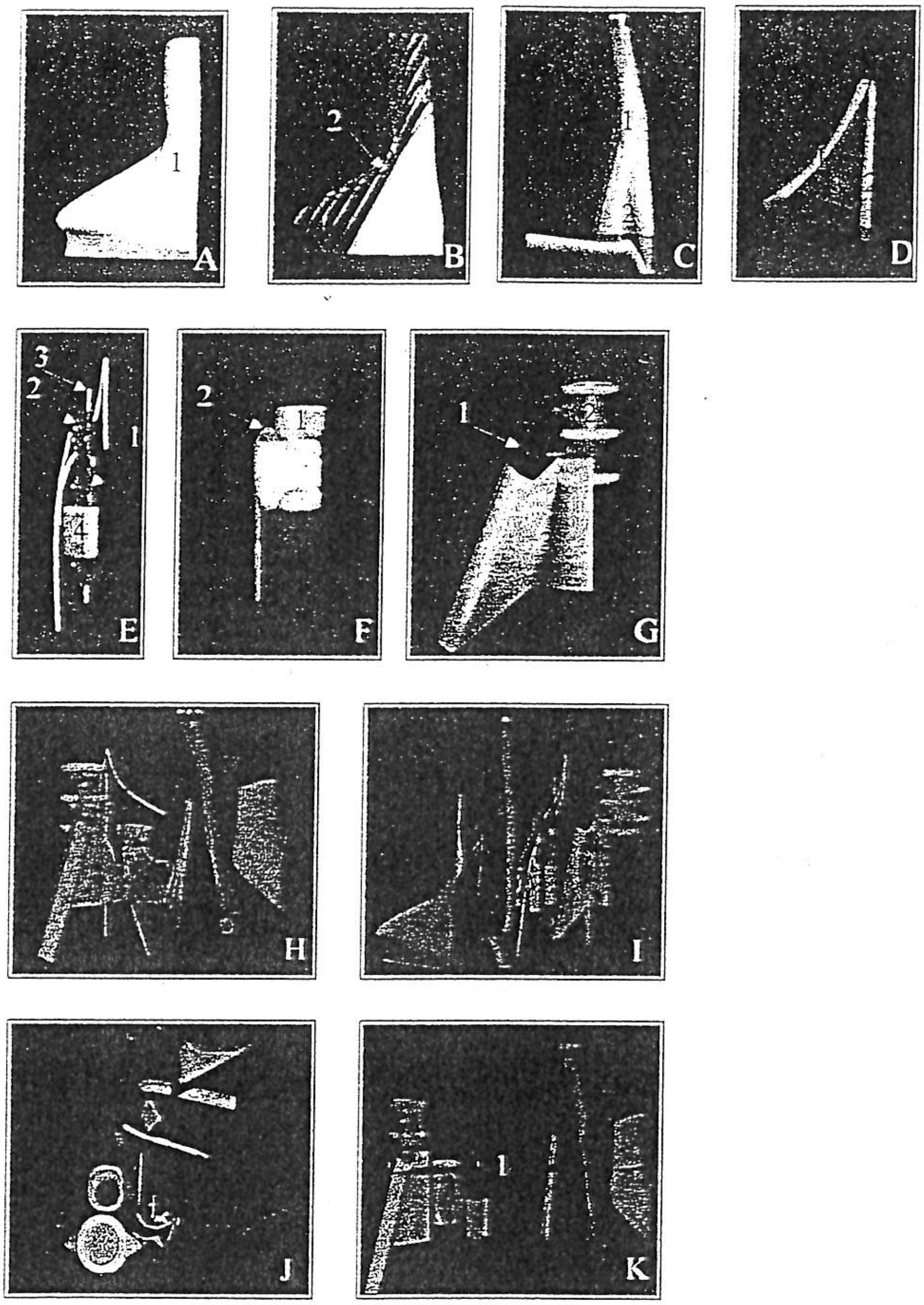


Fig. 2 — Geometric models of sternocleidomastoidea region and its content: A) cutaneous plane; B) subcutaneous plane: 1 m. platisma, 2 external jugular v.; C) muscolus fascialis superficialis plane: 1 m. sternocleidomastoideus, 2 fascia cervicalis superficialis; D) muscolus fascialis profundus plane: 1 m. omohyoideus, 2 m. sternohyoideus, 3 fascia cervicalis media; E) fascium vasculonervosum: 1 common carotid a., 2 internal jugular v., 3 vagus n., 4 vagina vascolaris; F) visceralis space: 1 larynx trachealis canal, 2 glandula thyroidea, 3 vagina visceralis; G) deep plane of vascular and visceral spaces: 1 mm. vertebrali, 2 columna vertebralis, 3 fascia cervicalis profunda; H) whole model: lateral view; I) whole model: medialis view; J) whole model: top view; K) whole model: 1 plane at the level of the artery bifurcation.

Several predicates implement operations of image processing and three dimensional representation to operate on CT and MR scan images and to visualise geometric data in a three-dimensional environment which is possible to interact in real time with.

Other predicates implement objects and operators of fuzzy logic that have been employed in the application of three-dimensional reconstruction of carotid arteries from CT scan images of V.H.D.

Three dimensional visualisation has been implemented by graphic subsystems of the programming environments used (OpenGL and Mesa). The set of the system's predicates allows definition of bidimentional curves, voxel objects, bitmap images, extrusion of curves and generation of solids.

The system operates on series of CT scan images. Each image is segmented and the result processed to perform the classification. Segmentation extracts areas of the images on the basis of low-level features of their pixels. These features are local properties of every single pixel such as intensity and connection with the neighbouring pixels. The image areas extracted by segmentation are then processed by classification. This processing is based upon high level features of the areas that are related to spatial relations of areas. In this two layer processing scheme, segmentation provides the classification layer, the higher level one, with just spatial relations about image areas that could belong to the searched components.

Images of the input set are processed one by one and each one is segmented in pixel groups. As each image represent a slice whose thickness was set when the image was taken, working on image pixels means working on their correspondent elementary volumes. Features used to segment images are elementary volumes density, which have to stand in the range presumed for the searched component, and connection with neighbouring volumes (8-connection) (Gonzales RC et al., 1993). These two kind of features represent the two operations that, performed in sequence, segment the image. In the former a threshold operator is applied to each image of the input set. This operator produces a new image in which points have just two values in dependance of the value of the corresponding point of the input image have a value in the threshold range or not.

The search algorithm starts from the centre of the image scanning each line to find points with the expected low level feature. When a point is detected a region growing operation is performed. Region growing finds the set of 8-connected points that the starting point belongs to. The connection criteria are the same for the search of the starting point. If the region is greater than the specified number of pixels, it is discarded. Search continues until the whole image is scanned.

The output of segmentation processing is a set of connected pixel areas that could be, for their low level features, the sections of searched anatomic components. This set, which expresses the facts of the knowledge base, is then processed by the rules of classification that are based upon spatial relations among sections of the components of the region. These rules are expressed by fuzzy logic linguistic variables (Visible Human Dataset) as this logic, working on possibilities, seamed effective to represent uncertain geometric relations in a way close to natural language. A simple way to express uncertain relations showed itself useful whether in low or high level processing.

Operators used to express fuzzy logic truth expressions are and, or, not»; their definitions are:

$$\text{fespr}_1 \text{ and } \text{fespr}_2 = \min(\text{fespr}_1, \text{fespr}_2)$$
$$\text{fespr}_1 \text{ or } \text{fespr}_2 = \max(\text{fespr}_1, \text{fespr}_2)$$
$$\text{not fespr} = 1\text{-fespr}$$

in which fespr, $\text{fespr}_1$ e $\text{fespr}_2$ are fuzzy expressions obtained combining fuzzy operators and atomic expressions of the form:

fvar(val) is term,

in which *fvar* is a fuzzy linguistic variable, term is one of its terms and "*is*" the evaluating operator.

The rules used in the classification process are expressed in the following way:

R: $p_1$(M, N, $\text{val}_1$), $p_2$(M, N, $\text{val}_1$), if (x($\text{val}_1$) is $A_1$ and y($\text{val}_2$) is $B_1$) > 0.5 then N($\text{Class}_1$)

In which $p_1()$ and $p_2()$ are relations that associate to objects M and N respectively $val_1$ and $val_2$, the "*if.. then*" group defines a fuzzy condition between A and B terms respectively of linguistic vars $x$ and $y$ valuated with values $val_1$ and $val_2$, and $Class_1$ specifies object class N for which the fuzzy truth value is greater than 0.5

Another possibility of classification is the maximisation of a fuzzy truth expression:

$\text{Class}_2$=(M(: max(tval) $p_3$(N,M,$\text{val}_1$), $p_4$(N,M,$\text{val}_2$), tval= x($\text{val}_1$) is $A_1$ and y($\text{val}_2$) is $B_1$

In which $Class_2$ is constituted from M object for which *tval* value is maximised.

The system was implemented on a Silicon Graphics Indigo2 workstation and on a Linux system with a AMD K6 233 MHz processor. The software tools and environment used were C compiler, Tcl/Tk 8.0, GNU Bison, GNU Flex, SWI Prolog 3.52, OpenGL (Indigo2), Mesa (Linux).

The system was employed to recognise and reconstruct carotid arteries from the set of CT scan images taken from V. H. D. A set of rules of formal description of components features was developed.

The rules set the conditions to be satisfied from the image areas that belongs to carotid and vertebral arteries (Fig. 3 A-F). These conditions, expressed in the possibility distribution of fuzzy linguistic variables, are based upon distance and angles values. In detail geometric relations used in the rules are distance and angles among centroids of the segmented areas (Fig. 3 G). Regarding angles, they were represented as positive values in 0-360° or 0-2π ranges, in the counter-clockwise way.

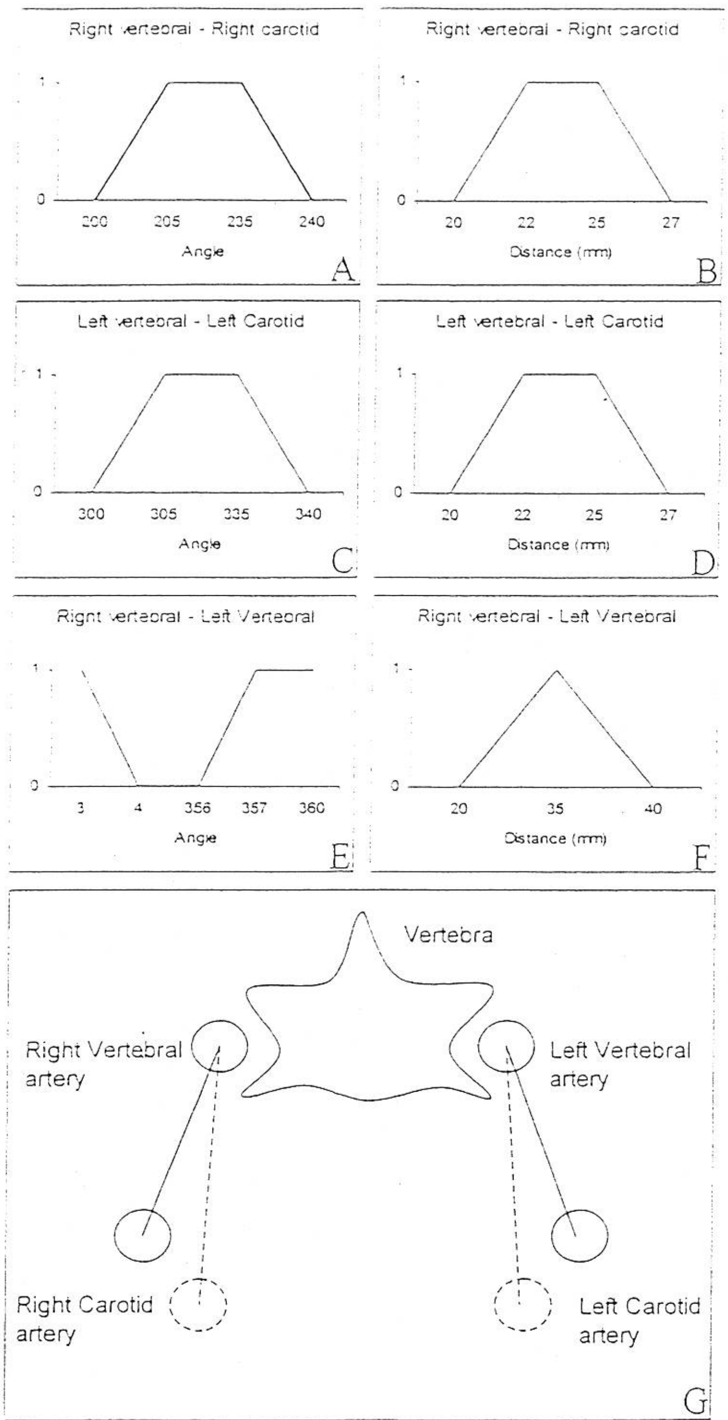


Fig 3 — A-F) functions of possibility distribution used in the classification process; G) relations among components used in the classification process: section of vertebra, sections of carotid arteries, sections of vertebral arteries.

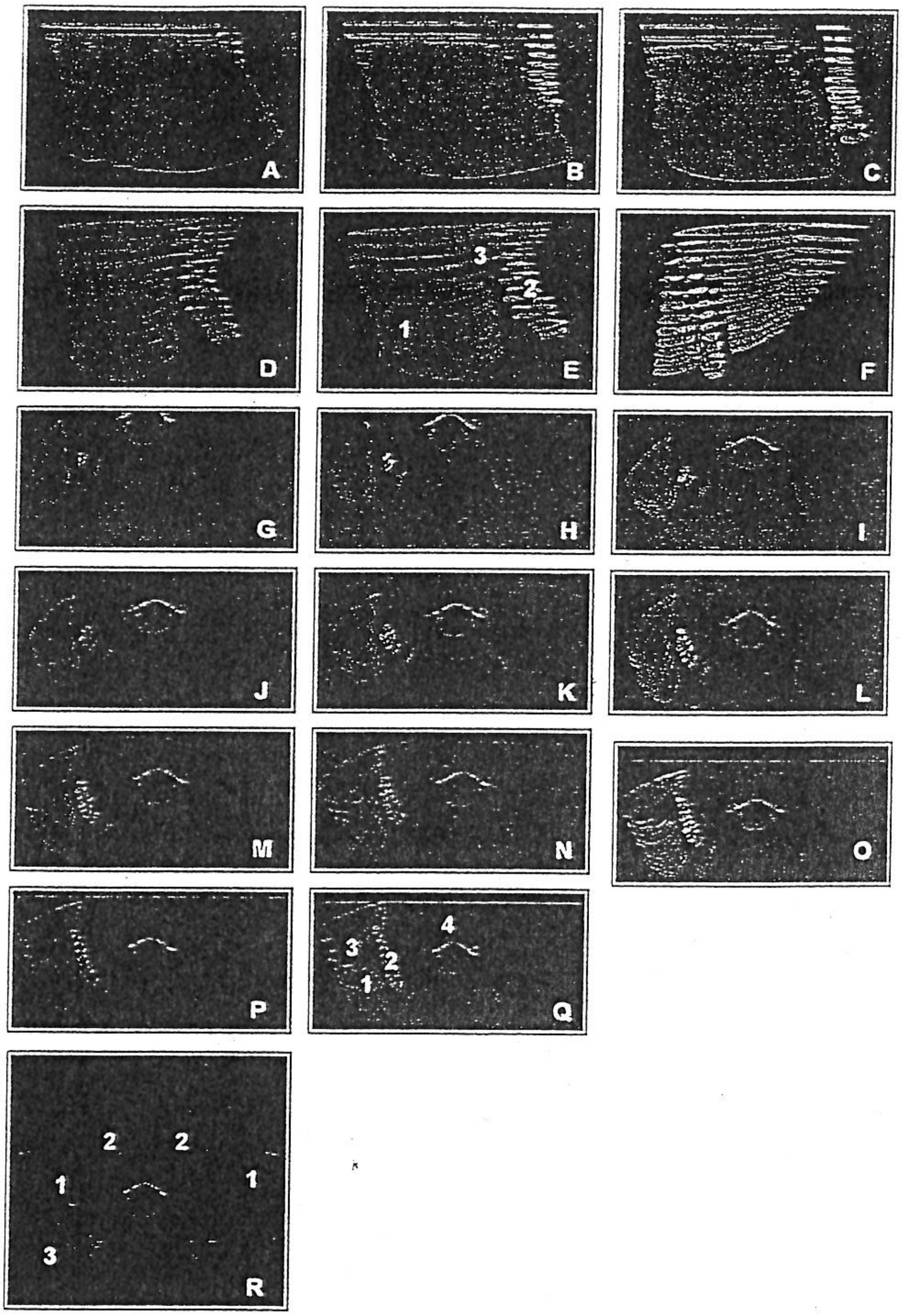


Fig 4 — A-F) model obtained by point sampling of m. sternocleidomastoideus (1), carotid artery (2), internal jugular v. (3): views obtained rotating the model from medialis to frontal position; G-Q) model obtained by point sampling of m. sternocleidomastoideus (1), carotid artery (2), internal jugular v. (3): comparison with the CT scan image of the section 1629 of V. H. D (4). R) Reconstruction of carotid (1) and vertebral (2) arteries; comparison with the CT scan image of the section 1629 of V. H. D (3).

Target of the classification is to recognise, among the areas of the images coming out from segmentation, first the two sections of vertebral arteries, that are more easily recognisable, and then, the sections of the carotid arteries. The last ones can be one or two on each side according to whether the section being processed lays above or below the artery's bifurcation or not. This possibility is indicated in the scheme with the dashed contour of sections. Lines that links arteries sections shows relations employed in the classification process. The system applies fuzzy logic rules searching, in each image, configuration that maximises the truth value of the set of rules. The distributions of possibility of the linguistic variables, that were found out empirically by the observation of the disposable data, are showed in the charts. Using these rules the system extracted from each CT scan image the sections of carotid and vertebral arteries reconstructing voxel models of them (Fig. 4 R).

## CONCLUSIONS

Results are constituted by models that represent the organisation of sternocleidomastoidea region and its content and by a software system of three-dimensional visualisation with integrated knowledge base, functions of image processing and a programming language to describe classification processing by means of fuzzy logic that yielded to automatic reconstruction of three-dimensional models of carotid arteries using CT scans as input data. These results led us to do the following considerations. Reconstructed models, even if expressing a virtual reality, showed themselves capable to reproduce, in ways close as much as it is possible to reality, the studied anatomical structures with their features, situation, position, spatial orientation and relations. Models, obtained by three-dimensional reconstruction, give a better way to visualise and understand the whole or every single part. Used alone or, even better, compared to anatomical specimens represent interesting didactic means in a period in which lack of anatomical material make more and more difficult for students to practise on corpses. Software systems similar to the one we realised can allow to extract from anatomical images or output of diagnostic devices information that can be employed whether in every single case or in wider statistical investigations. Employment of such software systems can lead to further studies about the structure and the relations among the components of the carotid arteries and their possible variations or alterations. Such software systems represent a great support in diagnosis, particularly in image based diagnosis, of carotid arteries pathologies.

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