A Neural Network Approach to Assess Myocardial Infarction

by

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The assessment of myocardial infarction is a complex, information intensive process that involves the analysis and interpretation of cardiovascular nuclear medicine images. For a number of years, a knowledge-based approach has been under development jointly between Georgia-Tech and Emory University to assist in making this clinical assessment, using images obtained from Thallium-201 single-photon emission computed tomography (SPECT) images. This paper discusses recent attempts to extend this knowledge-based system to incorporate the concept of myocardial thickening as a possible measure of myocardial viability, using Tc-99m and connectionist methods. The implementation of neural networks, its linkage to the knowledge-based system, and the use Sestamibi Tc-99 (instead of Tl-201 imagery), introduce novel informatics methods to diagnostic cardiology.

1. Introduction.

Since the early days of computer science, there has been an even increasing interest in elaborating models trying to relate computers and human cognition. In this way, the seminal papers by McCulloch and Pitts [1], and Turing [2] may be considered among the most influential works exploring this relationship.

It is possible to identify, historically, two branches of computing that have become separated: one trying to simulate the physical components of the brain and the other trying to imitate its symbolic-logic functioning. The former, or "connectionist", branch can be traced to the 1940s [1] and, after some years of relative inactivity, due to the limitations of the existing models on that time [3], research in connectionist approaches has resurged with the development of artificial neural networks. The symbolic-logic branch is closely associated with knowledge engineering, which has been one of the most active areas of computer science, leading to the emergence of expert systems: programs that try to capture and imitate the knowledge that an expert holds in a specific field.

Traditionally, these two branches have evolved in separate directions primarily due to the nature of the underlying hypotheses: one is inspired by brain structure while the other by human or "expert" reasoning. However, the lack of complete and explicit knowledge of the underlying mechanisms of apparently simple cerebral processes, has caused connectionist and symbolic approaches to remain relatively independent, almost mutually exclusive, research directions. Nontheless, there are a number of instances where both connectionist and symbolic approaches can combine in a unified and complementary fashion. This is the case in the interpretation of medical imagery, wherein visual information can benefit from the respective strengths of both approaches: the usefulness of explicitly representing experiential knowledge to interpret the imagery, and the power to identify meaningful patterns on a structural basis, without requiring prior knowledge. With this in mind, it would be worthwhile to examine the characteristics of each method in general, and their application to interpretation of myocardial perfusion images in particular.

2. PERFEX: A Knowledge-based system for the interpretation of myocardial perfusion images.

PERFEX is a rule-based expert system for interpreting 3D myocardial perfusion distributions, obtained from Thallium-201 tomographic imagery and developed between Georgia Institute of Technology and Emory University [4]. PERFEX incorporates more than two hundred heuristics for evaluating coronary artery disease from stress and delayed (redistribution or "at rest") perfusion studies, and it also incorporates other clinical information such as age, sex, chest pain symptoms, and EKG s-t segment depression.

Figure 1 illustrates the information flow of this knowledge-based diagnostic system. The short-axis slices reconstructed from Tl-201 SPECT acquisition are mapped to a 2D-polar representation. An automatic feature extraction program uses searching and edge- hugging techniques to identify and localize all existing perfusion defects in this polar presentation. These regions are then assigned a certainty factor value based on comparisons with data acquired for normal patients. Finally, this information is introduced to the knowledge-based system for diagnostic interpretation. The Nexpert © object-oriented expert system shell has been used for implementing the system on a SUN 3/260 workstation.

The output from the expert system is a patient condition report which provides the relative likelihood associated with the location and shape of each myocardial perfusion defect, as well as suggestions regarding the presence or abscense, and location and shape, of each coronary lesion. The report also hints at the presence of any imaging artifact that might have contributed to the patient condition evaluation. Pilot studies have shown that the results agree very favorably with experts' interpretations [5]. This system is currently undergoing testing and evaluation in an actual, routine clinical setting.

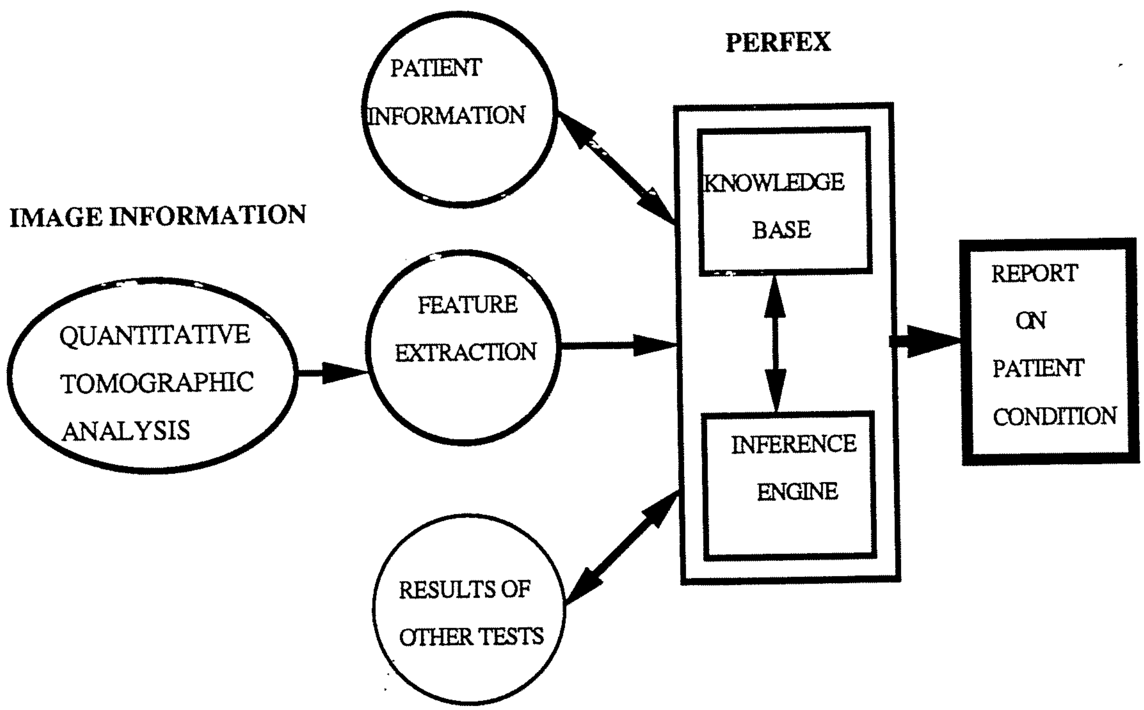

Figure 1.- Information flow of knowledge-based system

Although PERFEX has demonstrated diagnostic accuracy, several issues need further consideration. As in the case of most other expert systems, there are limited explanation capabilities, as well as questions regarding knowledge acquisition and robustness. In addition, there also are certain inadequacies in dealing with predictive or prognostic features. Independent of these limitations, there was also some interest within our group in changing the knowledge base to consider Sestamibi Tc-99-m instead of Thalium-201 images, and to explore the use of myocardial thickening-information. As a result of these considerations, an investigation was undertaken to consider myocardial thickening during systole, which is a possible predictive factor with some clinically attractive characteristics.

3. Myocardial thickening and its implications.

A number of reports have shown that, in dogs, thickening of left ventricular myocardium during systole is reflective of myocardial perfusion [6][7]. Dynamic features of normal left ventricular myocardium include end-diastolic thickness of approximately 1 cm and thickening during systole of approximately 50%. With myocardial infarction, wall motion abnormalities are observed and systolic wall thickening is dramatically reduced. The principal anatomic difference between remote and acute infarction is the absence of end-diastolic wall thinning in acute myocardial infarction.

Thallium-201, and more recently Sestamibi Tc-99-m, have proved to be excellent methods to assess myocardial perfusion. Clinical researchers at Emory University [8] have also shown that, in humans, the assessment of wall thickening during systole, using Sestamibi Tc-99-m, could provide information as to (1) tissue viability, and (2) myocardial perfusion. If myocardial thickening at rest could be measured simultaneous to assessing myocardial perfusion at peak stress, then determination of ischemia, scar and viable myocardium in a single setting would be possible.

A high correlation of thickening with resting perfusion has been shown [8]. This finding represents a possible marker of myocardial functioning, since the predictive value of absent systolic wall thickening (SWT) for fixed segments has been reported to be 100%. Thus, the presence or absence of SWT appears to be an extremely reliable indicator of myocardial viability.

At this moment, two clinical tests are made routinely using Sestamibi Tc-99-m, to measure stress perfusion and resting perfusion. The appeal of the aforementioned findings is that it would be possible to infer the results of the resting perfusion test using only the stress perfusion test and myocardial thickening. In this ideal case, it would be feasible to obviate the need to perform resting perfusion imaging.

The clinical importance of this assumption, if proved, would be significant, since aspects such as time, cost and morbidity could be considerably reduced using this approach. Therefore, we considered the inclusion of myocardial thickening information in the PERFEX knowledge base as an additional and powerful extension of the diagnostic tool. In this context, a new knowledge acquisition process was carried out, in order to acquire and represent this body of knowledge into the system. Here are some examples of the rules obtained:

IF Stress_perfusion is decreased and Resting_thickening is normal
THEN myocardium_is_ischemic_but_viable

IF Stress_perfusion is decreased and Resting_thickening is decreased
THEN myocardium_is_viable

IF Stress_perfusion is decreased and Resting_thickening is present
THEN myocardial_non_transmural_infarction

A preliminary decision tree was built, in order to try to represent the general structure of this new knowledge module, as shown in Figure 2. However, it became early clear that, since the clinical aspects of these findings were still under development, it was not possible to represent knowledge explicitly and, furthermore, it was not clear how to link the new knowledge to the remainder of the knowledge-based system.

Hence, it was obvious that symbolic methods were not the best approach. On the other hand, the use of artificial neural networks not only seemed correct but also provided an exceptional opportunity to try to demonstrate the intimate relationship that can be established between a rule-based system and a connectionist system. Besides, the neural net is not only appropriate for recognizing relevant patterns in the imagery, but, if properly designed, it could also be used to provide insight into interrelationships in the imagery, and thereby facilitate the acquisition of explicit knowledge. These considerations led to connectionist models in a very natural manner.

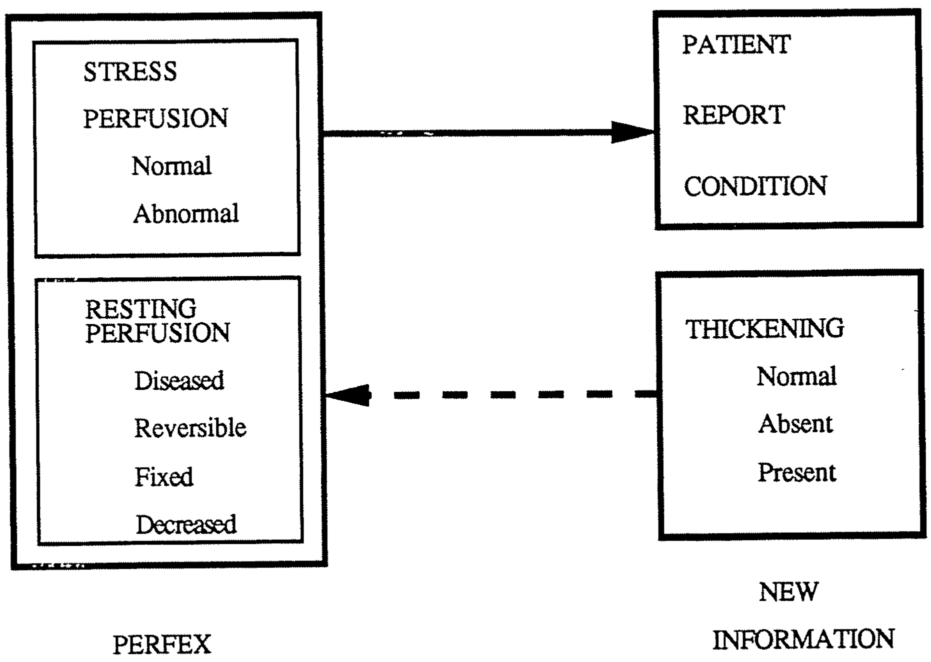

Figure 2.- Preliminary knowledge structure to incorporate Thickening Information.

4. Incorporation of a Neural Network Model.

As outlined in the previous discussions, an artificial neural network (ANN) would enable interpretation of the images associated with myocardial thickening without requiring explicit knowledge. It should be pointed out that the net would not be expected to produce a diagnosis, but rather an image: namely, the redistribution image. Hence, the underlying hypothesis of our approach is that a neural network can be trained, given stress and thickening images as input, to produce as output the associated redistribution image. The net would thus act not so much as a classifier, but as a predictor: two images are inputs, and another image is "predicted". In turn, this predicted redistribution image would serve to replace an actual resting perfusion image that presently requires a second clinical test. The predicted image would then he used by PERFEX as show in Fig. 2.

With this in mind, the current goal is to train the ANN to accept images associated with stress and thickening as input, and provide redistribution ("resting perfusion") as output, as shown in figure 3.

Specifically, the output of the ANN consists of numerical values (akin to certainty factors) of resting perfusion, whereas the input consists of similar numerical values of stress perfusion and myocardial thickening. 32 values were considered for each case (32 stress perfusion + 32 myocardial thickening -----> 32 resting perfusion).

The current neural network is described topologically as a three-layer network with one hidden layer with 37 processing elements, one input layer consisting of 64 nodes (32 stress values and 32 thickening values), one 32-node output layer, and a bias connected with all processing elements of hidden and output layers. The neural network is constructed as a feed-forward backpropagation. The input and hidden layer are not fully connected, but rather each input node is connected to five nodes of the hidden layer, thus allowing for double overlapping connections. A hyperbolic-tangent transfer function and a cumulative-delta learning rule were used.

Given that Sestamibi Tc-99 is a relatively new technique, limited data are available. With a reduced training set of 25 patients cases, the neural net has been succesfully trained. Training was performed using 8.000 cycles, taking 75 minutes to reach convergence at the level of 0.02 error. This is errors smaller than 0.02 were obtained when comparing the expected and predicted output values for all nodes in the output layer)

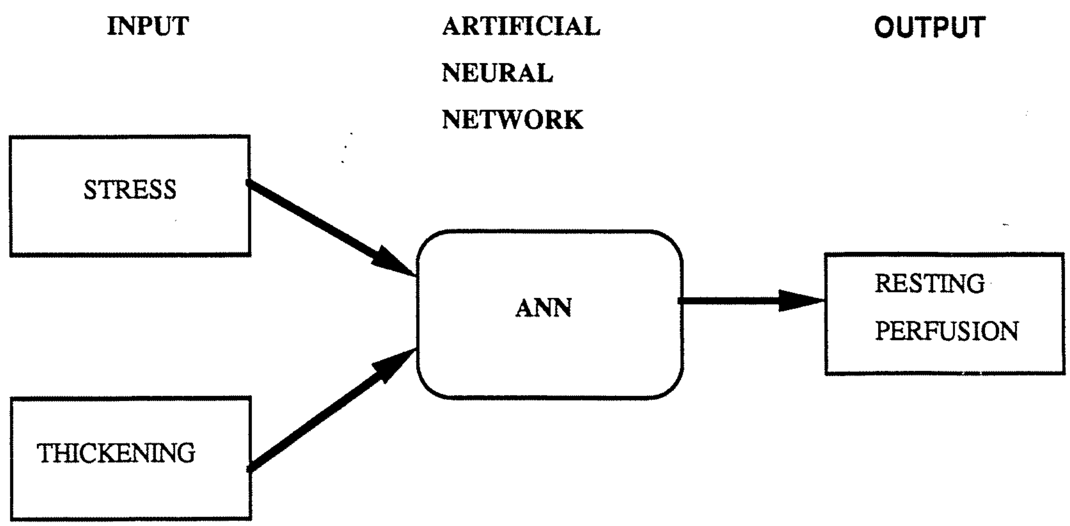

Figura 3.-Incorporation of a neural network model

Testing has been conducted in two phases: with the training set, and with a testing set consisting of actual patients cases not included in the training set. (The errors associated with both testing set ranged between 0.001 and 0.4 of all output nodes.)

At present additional cases are being generated for further training and testing. Obviously, a much larger number of cases would be necessary to enhance reliability and provide the necessary base for formulating additional medical hypotheses concerning myocardial viability in the context of thickening.

5. Conclusions and future directions.

A connectionist approach has been developed and implemented to enhance the capabilities of a rule-based expert system.

Some applications are apparent. These include the possibility of processing visual information without explicit knowledge, the possible elimination of the resting perfusion clinical test, and the integration of a rule-based system with a neural network model.

These preliminary results show the viability of this approach, and our current efforts are aimed at further refining and testing the net, and at exploring the linkages and interrelationships between various branches of medical informatics, including symbolic, connectionist, and image understanding methods.

Acknowledgements:

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This work has been supported, in part, by the NIH grant R29LM04692, and by personal grants of the Spanish Government for Dr. Maojo and Dr. Martin, and from the Xunta de Galicia (Spain) for Dr. Pazos.

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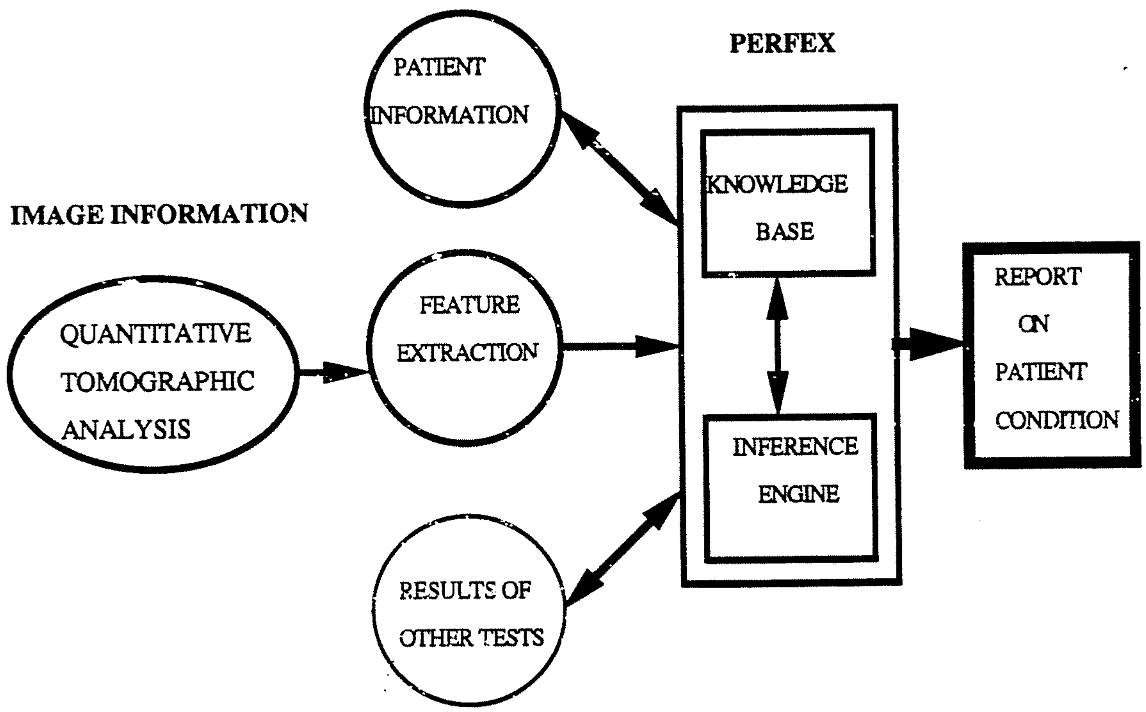

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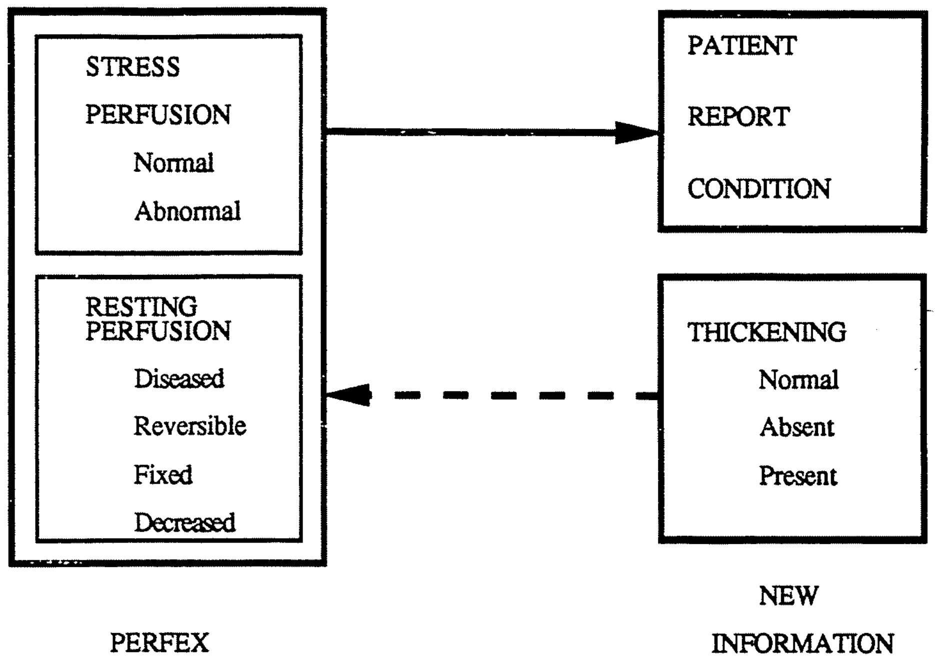

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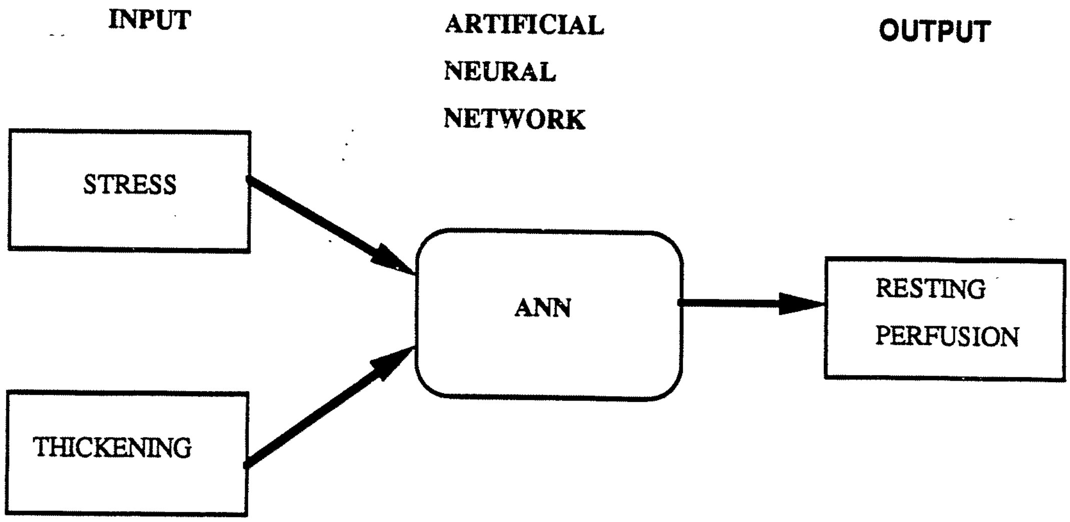

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