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## A Portable Decision Making Tool for Health Professionals Based on Neural Networks


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# A portable decision making tool for health professionals based on neural networks

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**The article presents a fast portable system to provide health professionals with solutions for pre-operative surgical planning and decision making in real time. The system employs an effective computational environment for solving partial and ordinary differential equations based on neural networks. This approach is implemented partially on a specialized hardware board to exploit the fact that neural networks constitute massively parallel systems. The system also contains a powerful and convenient graphical user interface. There are tools to visualize and/or animate 2-D and 3-D data, and a customized interactive environment where particular biomedical problems can be easily processed and formulated.**

### Keywords

neural networks, parallel computing, portable decision making tools, surgical planning

## Introduction

In the medical profession, modelling and simulation are used to advance the quantitative understanding of biological functions and to improve medical practice by utilizing the acquired knowledge. Surgeons have to make decisions during operations and they need a fast and reliable environment in which they can perform simulation of the actual conditions in real time. Biological systems can be formally expressed using appropriate mathematical models to analyse and explain their complex properties and functions. The resulting mathematical models emulate the observed functional behaviour of the system under experimental conditions when simulated on the computer. It is usually the case that when a complex model is specified using partial differential equations with rich parameterization, the computational effort needed is extremely high. In order to overcome such computational restrictions a set of assumptions can be applied that reduce the complexity of the model but also its accuracy.

The system proposed in this work combines an advanced software and hardware platform able to solve ordinary or partial differential equations using techniques based on neural network models. It introduces a computational framework that assists medical professionals in studying and analysing complex biomedical models in an easy-to-use, efficient and cost-effective manner.

## System functionality

### *Target audience*

The system provides a useful tool for studying a wide range of mathematical models used to describe the behaviour of many biomedical systems. The complexity of these models increases with the quantity of differential equations. The proposed platform provides researchers and professionals in the medical arena with a fast and highly accurate differential equation solver that accelerates their laboratory experiments and allows the development and testing of more sophisticated detailed models. In addition, it helps them to better understand the normal functions of organisms, to predict changes due to alterations and to propose efficient methods of artificial intervention.

The proposed system functionality will be of immediate interest to several types of users, who can be classified into the following categories. From the *health professional* point of view:

- *Orthopaedists*: in most cases orthopaedists must choose among different endoprostheses or implants, which vary in shape, size and properties. Different implants can be placed inside the bone, and the set of differential equations with the appropriate boundary conditions must be solved in order to provide the optimum choice of implant [1].
- *Cardiologists*: they can use the proposed system in cardiovascular diseases when the simulation of the artery and the blood flow will greatly improve the efficiency of the specific type of operation (e.g. choice of the appropriate stent) [2].
- *Other medical professionals*: other medical doctors of several specialities will benefit from the proposed system as long as further models are developed and incorporated by bioengineers. The customized visualization capabilities of the system will help them in the decision making process.

From the *organizational* point of view:

- *Public or private biomedical research institutes*: their researchers must be provided with an efficient computational framework for modelling complex biological problems [3, 4]. Within the system workbench new experiments can be developed and new models and methods can be explored.

From the *industrial* point of view:

- *Biomedical engineering companies*: they may benefit from the proposed system by exploring its software modules and using it as embedded hardware for their diagnostic procedures. The portability of the system allows its easy incorporation in existing systems which are dedicated to biomedical engineering modelling. They could also invest in the proposed platform and exploit the computational framework in all sectors of biomedical engineering, but also in other sectors such as robotics, control and areas with various modelling and simulation needs.

### *User scenario*

An orthopaedist before surgery has to examine image data in order to select the most appropriate endoprosthesis or implant. These are commercial products and they are available in a wide variety of shapes, sizes and materials. Usually the orthopaedist must select one of the available items following an empirical procedure. He combines previous medical findings, patient records, patient data (patient age, sex and weight) and medical images. However, this procedure is slow and unreliable. For this reason, several hospitals have chosen to cooperate with a CAD/CAM company. Someone from the radiology department delivers medical images and other patient data to the company. They use image-processing techniques to extract regions of interest for the bone, 3-D reconstruction algorithms to visualize the bone in 3-D, and finite elements to perform computations, using the appropriate boundary conditions, in order to access the bone performance with and without the implant. This leads to a decision for the appropriate implant. The whole procedure takes 3–4 weeks and the treatment of the patient strongly depends on the availability of the doctor and the software expert. Sometimes the doctor cannot communicate with the software expert, and the obtained shape might perform correctly under mechanical loading but is not good from the medical point of view.

The use of the proposed system, which looks like a PC card, makes the procedure much faster and more effective. The system is a special purpose computer, which can reconstruct human tissues in three dimensions, perform the computations almost in real time, and provide the orthopaedist with an accurate and reliable decision. The system is fully portable and it can be used with several imaging devices in the hospital. Now the doctor can easily work close to the patient, avoiding delays and the use of software experts who in some cases are not readily available.

## Functional specifications

The proposed system exploits the parallelization and generalization characteristics of artificial neural networks, and technological advantages in software and hardware, to offer healthcare professionals and biomedical engineers a flexible, advanced and easy-to-use computational platform for solving biomedical problems and to experiment on biological models that can be described by partial and/or ordinary differential equations. Owing to the great difference in the expertise of the two above-mentioned target user groups, two different versions of the proposed computational environment, in respect of the definition of the problem, have been developed.

In the following, the graphical user interface and the high-level language, the execution environment, the portability and the hardware function utilities are described.

## *Graphical user interface and high level language for biomedical engineers*

The graphical user interface for biomedical engineers is supported by a powerful toolbox with specialized editors [5, 6]. The toolbox editors are used to create or modify the objects which specify the biomedical problem and describe the necessary parameters for solving it. The editors provide both visual tools which will assist in every step of the process, and a high-level language text editor for direct program definition of the problem. As a first step, the biomedical engineer defines the differential equations that are related to the problem that he wants to solve. The selection takes place either through a selection box, or by directly typing into the editor. The next step in the process is the designation of the domain of definition (DoD) of the problem. After entering the DoD, the user has to define the number of points (samples) for the discretization of the DoD. When the user enters the required numbers it is up to the software to distribute these points on the whole of the DoD and the boundaries. The resulting set of points will be stored for later use since it constitutes the training set of the neural network that calculates the solution of the problem. Then, the toolbox editors will guide the user in inputting the boundary conditions for the specific biomedical problem. Parameters related to the neural network will be defined in order to achieve the best approximation to the real solution. It should be noted that the toolbox will only allow the user to ender 'meaningful' values in these parameters. The final step in this long definition process is to select the optimization method that will be used by the execution environment in order to calculate the solution. In fact, this is the method that is used to train the neural network.

In addition to the above-described functionality the user is able to directly manipulate scripts written in a high-level language in order to define a problem.

## *Graphical user interface for healthcare professionals*

The second version of the computational environment targets orthopaedists, cardiologists and other healthcare professionals [6]. They handle specialized biomedical problems that are solved using differential equations but they do not have the necessary knowledge to define a problem 'from scratch' and are not interested in doing so. The proposed system guides these users through a customized interface with a more problem-oriented than equation-oriented approach. This facilitates the use of the platform as well as eliminates the possibility for input errors from the non-expert users.

The user interface has a 'wizard'-like structure to make user input as easy as possible. The proposed system includes predefined problems, such as blood flow or implant placement. The user selects the problem without the need to compose the required differential equations. The system then automatically loads the appropriate equations.

The next step is the designation of the DoD via the direct retrieval of CTI or MRI images. The user has the option to execute specialized algorithms on these images to automatically obtain the boundaries of the DoD. Since the above algorithms do not have 100 per cent accuracy, the user is given an interface in which the results of the algorithms are displayed. The user has the ability, with simple mouse click functionality, to lead the algorithm by inserting points that belong to the boundary in order to achieve high precision.

The software, with no user intervention, automatically handles the discretization of the DoD using grid generation methods.

There are patient-oriented parameters, along with the DoD, in each given scenario that must be entered by the non-expert user at runtime. However these parameters are expressed in terms that are easy for the medical professional to understand, such as height and weight for the orthopaedic application, and not in mathematical terminology as is the case for the biomedical engineers.

The parameters related to the neural network architecture and the optimization technique are automatically loaded by the system.

The medical user will have a system of online help at his/her disposal at all times to offer a better understanding of each step of the process. To avoid confusion and complications the medical user will not be allowed to interact with the high-level language.

### *Execution environment*

The biomedical engineers and the healthcare professionals use the GUIs of the system to define the biomedical problem that needs to be solved. This problem is described in terms of a symbolic mathematical form, namely differential equations, a domain of definition, boundary conditions, neural network parameters and a variety of other parameters. The system needs to translate this information and create an executable library and a system file, which will be used by the execution environment for the calculation of the problem's solution. Figure 1 shows the procedure that is followed in the execution environment.

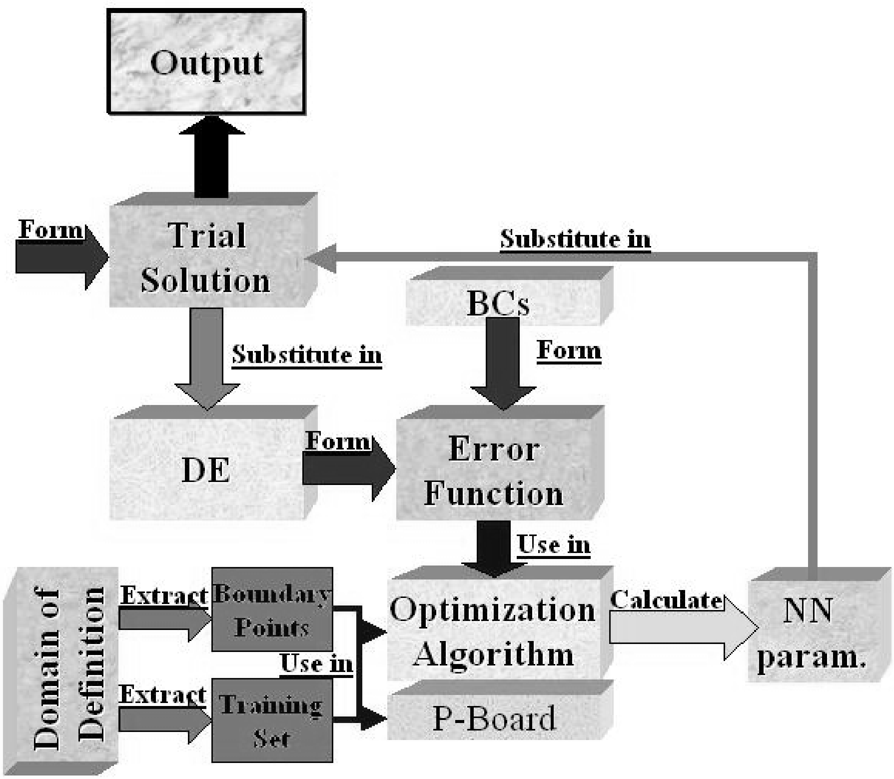


**Figure 1** The execution environment of the proposed system

As it is mentioned above, in the proposed system an effective approach is used for solving both ordinary differential equations (ODEs) and partial differential equations (PDEs) [7, 8]. The aforementioned approach relies on the creation of a trial solution that involves a neural network to be trained so as to satisfy the differential equation. Using symbolic manipulation techniques [9], the trial solution is incorporated in the differential equation to be solved and an error function is formed. The latter takes its final form via the appropriate use of the boundary conditions and is used to train the neural network. To train the network, we employ optimization techniques [10, 11], which in turn require a training set for the neural network. The execution of the optimization algorithm is a heavy task and for that reason the proposed system employs an advanced specialized hardware board.

## *Hardware implementation*

The specialized hardware board exploits the parallelization characteristics of the neural networks. One of the main constraints of the neural network approach for solving differential equations is the need to handle floating-point double-precision data. Most of the hardware developed for neural networks is designed for single-precision floating or integer data. So, even if the market offers neuro-chips able to solve the neural networks, these solutions are not suitable for the system under consideration. The possibility of using DSP modules has not been selected for a similar reason: to implement a floating-point double-precision calculation a DSP needs more than one clock cycle, so the total computing time increases.

We have chosen to use field programmable gate array (FPGA) modules [6]. These are general-purpose programmable devices that can be configured for a wide variety of applications. The advent of high performance FPGAs offers new potentialities for HW and HW–SW implementations of neural networks. The FPGAs provide the benefits of custom ASIC, while avoiding the initial cost, time delay and inherent risk of a conventional masked gate array. Moreover, the FPGA takes advantage of hardware parallelism and reduces the timing overheads needed for general-purpose microprocessor applications. For example the time taken by load/store operations and instruction decoding can be eliminated. FPGAs are cost-effective devices that can allocate a large number of system gates, and are specialized in the configuration of DSP data paths suitable for implementing the neural network parallelism.

## *Graphical representation of the problem and solution*

The solution visualization is the output user interface of the proposed system [6]. It visualizes the solution data resulting from the problem that was defined by the user and submitted to the hardware board.

The graphical tool presents the solution data in the appropriate mode, 1-D, 2-D or 3-D. It allows full control over the displayed graph such as rotation, zooming in and out and colour scheme selection in order to enable the user to fully comprehend the meaning of the solution data. Scale changes are also possible. The visualization method and the initial zoom and positioning of the graph are automatically calculated by the software. The user is also able to get the solution data in textual format and save it.

In addition to data directly related to the solution, the user interface provides additional data such as the total processing time, the hardware board's processing time and other info, which can be used for the overall evaluation of the platform and/or the optimization algorithm.

### *Portable system*

The proposed system can be used in a computer system (PC or workstation) by:

- researchers and analysts, as a stand-alone support package, for experimentally studying different biomedical modelling and simulation processes
- healthcare professionals as a decision making tool.

Therefore, the proposed system consitutes a complementary equipment within a scientific computing environment, which can accelerate experimental procedures and development processes.

Overall, the proposed system supports four major functionalities:

- Efficient representation of the problem solving processes that will allow the user to specify differential equation problems and their solution frameworks textually in an appropriate form.
- An execution environment that will help users to compile and execute programs written in the high level language on the hardware platform.
- Visualization of the scientific data generated by the system solvers. This is based on customized tools used to visualize and/or animate 1-D, 2-D and 3-D solution data.
- Compatibility with standardized modelling processes, data structures and interfaces in order to carry on experimental studies with the proposed tool.

## Overall system architecture

Figure 2 shows the system architecture. The hardware part of the system includes:

- *P-board*: the system board (P-board) is the major hardware part of the system. It implements the neural network used in the trial solution of a partial or ordinary differential equation. The P-board communicates with a PC-based platform via a PCI bus.
- *Commercial PC*: the P-board is embedded in a PC-based platform that incorporates a general-purpose processor and runs a commercial operating system. This is also the platform that incorporates the software part of the system.

The software part of the system consists of:

- *Power user GUI*: using the power user GUI the user can (1) specify the problem, (2) visualize the solution.
- *Medical user GUI*: this is the customized graphical user interface specially designed for orthopaedists and cardiologists.

- *High-level language and compiler*: this module provides the biomedical engineer with the high-level language that is used for the definition of the problem. A compiler is used to effectively translate the given scripts.
- *Runtime environment*: this includes all those mechanisms that receive input from the user interface and formulate the solving procedure and the execution files for the defined problem.
- *Optimization layer*: this is responsible for the implementation of the optimization algorithms. It interacts with the runtime environment in order to acquire the system file that describes the procedures to be followed and the P-board in order to 'feed' it with the updated neural network weights.

A LAN connection can be used for the interaction of the system with external equipment and systems such as MRI and CT scanners or image databases. For the smoother operation of such cases, an interoperability mechanism has been implemented.

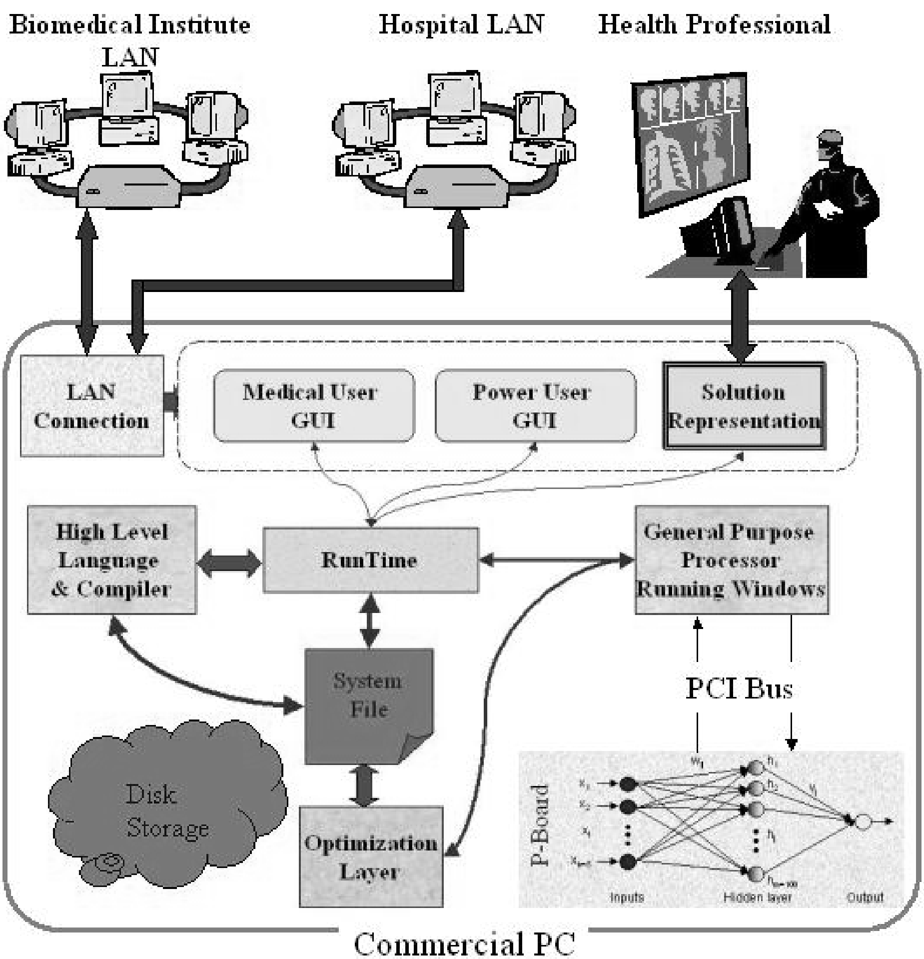


**Figure 2** The system computation platform

## Conclusions

We have developed an advanced high-performance computational environment for solving complex medical problems using a method based on artificial neural networks. The system is portable, it has embedded system capabilities and it can be easily used by health professionals.

The system aims to improve the performance of existing embedded systems, which are based on advanced biomedical signal processing applications, and at the same time to stimulate support for related hardware and software technologies. We have developed a specialized, FPGA-based hardware board. The purpose of this board is twofold: first, to exploit the parallelization characteristics of the neural networks, and second, to efficiently handle floating-point double-precision data so that optimum performance can be achieved. The success of this attempt offers the opportunity to tackle in real time difficult differential equation problems arising in many engineering applications. Concerning software technologies, the system offers:

- an efficient problem-solving environment for bioengineers
- a customized environment for healthcare professionals.

Overall, the system aims to constitute the computational framework that assists both doctors and bioengineers in experimentally studying and analysing complex biomedical models in an easy-to-use and efficient way.

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