A Survey on the Research Lines of the Applications of Fuzzy Logic and Evolutionary Algorithms Research Unit at the European Center for Soft Computing

Oscar Cordón, Sergio Damas, Raúl del Coso,
Oscar Ibáñez, Carmen Peña
European Center for Soft Computing, Mieres, Spain
{*oscar.cordon, sergio.damas, raul.delcoso, oscar.ibanez, carmen.pena*}*@softcomputing.es*

Abstract

This contribution is devoted to review the outcomes of some of the research lines developed at the European Center for Soft Computing since its creation by the beginning of 2006[1]. In particular, the activities performed by the Applications of Fuzzy Logic and Evolutionary Algorithms research unit will be described. We will specially focus on two challenging research projects, at different stages of development, which actually show the potentials of soft computing in two different medical scenarios: forensic identification and medical imaging.

Keywords: *Soft Computing*, *Medical Imaging*, *Forensic Identification*, *European Center for Soft Computing*.

1 Introduction

Soft Computing (SC) [11] is an area of artificial intelligence research focused on the design of intelligent systems to process uncertain, imprecise and incomplete information. SC methods applied to real-world problems frequently offer more robust, tractable and less costly solutions than those obtained by more conventional mathematical techniques [56].

The main constituents of SC are fuzzy logic [57], neural networks [69], evolutionary computation [7] and probabilistic reasoning [62]. Since Lotfi A. Zadeh coined the term in 1991 [86], this technological area has developed rapidly both in its theoretical aspects and in its business applications. SC techniques address different types of problems both in typology (modeling, optimization, planning,

[1]This contribution is an extended and updated version of [24].

control, forecasting, data mining, etc.) and in the areas of application (industrial production, logistics, energy, banking, food industry, etc.).

One of the consequences of the significant development experienced by the SC area has been the creation of the European Center for Soft Computing (ECSC), an international research center specifically devoted to the topic, in Mieres (Asturias), Spain by 2006. The aim of the current contribution is to briefly describe the research lines developed and under development in the Applications of Fuzzy Logic and Evolutionary Algorithms (AFE) research unit at the ECSC. In particular, a strong focus will be put on the description of two representative research projects.

On the one hand, we will present the successful results obtained in a three-year multidisciplinary project entitled "Soft Computing and Computer Vision in Forensic Identification", which was granted by the Spanish Ministry of Education and Research in 2006 and finished at the end of 2009. It was aimed to develop an intelligent system based on SC techniques to assist the forensic anthropologist in the identification of a missing person. The underlying forensic identification technique is called craniofacial superimposition. It is based on overlaying a scanned 3D model of the skull found against a subject's face photo trying to establish whether this is the same person through the partial matching of two sets of radiometric points. We will show how evolutionary algorithms and fuzzy logic can become powerful supporting means for the forensic expert in this identification procedure by reporting its superb performance when solving some real-world identification cases from the Physical Anthropology lab at the University of Granada, Spain.

On the other hand, we will also introduce a recently launched research project entitled "Medical Imaging Using Bio-inspired and Soft Computing", coordinated by the AFE research unit head, Dr. Cordón, and funded by the European Commission under the Marie Curie International Training Network action within the Seventh Framework Program (FP7-PEOPLE-ITN-2008). The main goal of this second project is to set up a high quality interdisciplinary training program for 16 young researchers in order they can develop their doctoral dissertations in the application of intelligent systems constituted by SC and bioinspired computing techniques to real-world medical imaging applications. To do so, a multidisciplinary partnership composed of 12 institutions (research centers, universities, companies, and hospitals) has been established including prestigious researchers in the SC-bioinspired computing (e.g., Prof. Kerre from Gent University in Belgium, Prof. Herrera from University of Granada in Spain, and Dr. Dorigo from Université Libre de Bruxelles in Belgium) and medical imaging fields (e.g., Prof. Henning from Universitätsklinikum Freiburg in Germany and Prof. Li from the University of Nottingham in the UK).

The structure of the paper is as follows. The next section will briefly introduce the ECSC by reviewing its current structure, vision, goals, scientific committee, and main research and training activities. Section 3 will focus on the AFE unit by reporting its current main research lines and recent developments. Section 4 will be devoted to describe the two said research projects. Finally, some concluding remarks will be pointed out in Section 5.

2 The European Center for Soft Computing

The ECSC is a young international research and development center located in Mieres (Spain) with the purpose of serving as a world-class institution focused on basic and applied research in the area of SC. It was launched by the beginning of 2006, supported by a private non-profit foundation (Foundation for the Advancement of Soft Computing).

The main ECSC goal is the basic and applied research in the SC area as well as the technology transfer in industrial applications of intelligent systems design for the resolution of real-world problems. Besides, the Center wants to become a meeting point for worldwide experts and also a place where PhD students and young researchers can develop advanced research. The official language of the ECSC is English. Since its creation, non-Spanish researchers have worked at the ECSC. Currently, approximately 40% of the researchers of the Center are from abroad (India, Germany, France, Poland, Netherlands, etc.).

The motivation for creating the ECSC is based on the vision of SC research as a high potential tool for innovation and economic development. This vision is developed in a mission that involves three basic elements:

- To carry out first level research on the fundamentals and applications of SC aiming to reach a leading scientific position in Europe.
- To become a meeting place for worldwide experts in SC and to offer the best training and development opportunities for young researchers.
- To promote technology transfer and innovation based on the research activities of the Center.

Furthermore, the latter mission can be summarized into four strategic lines that guide the activity of the ECSC:

- Contribute to scientific advancement.
- Improve business competitiveness.
- Enhance the technological image of Asturias (the Spanish region where the ECSC is located).
- Disseminate science and new technologies to society.

In the context of these strategic lines, the main objectives of the ECSC are focused on the generation of new scientific knowledge and on the application of information technologies. These objectives include both theoretical approaches and the application of SC to solve real-world problems of industry, economy, and society. The Center interacts with its stakeholders by cooperating with universities, research organizations and companies in R&D activities, providing specialized training and the social dissemination of research results.

In order to accomplish the previous objectives, the ECSC is currently comprised by five research units:

- Applications of fuzzy logic and evolutionary algorithms, headed by Dr. Oscar Cordón.
- Intelligent data analysis and graphical models, headed by Dr. Christian Borgelt.
- Computing with perceptions, headed by Dr. Gracián Triviño.
- Collaborative intelligent systems, headed by Dr. Enrique Ruspini.
- Fundamentals of soft computing, headed by Dr. Claudio Moraga and Dr. Enrique Trillas.

The ECSC is supported by a Scientific Committee composed of ten renowned international researchers. Its functions include the definition of the main lines of research, the advice in the recruitment of top researchers, and the periodical assessment of scientific and technical performance of the Center. Prof. Lotfi A. Zadeh (Univ. Berkeley, USA) is the Honorary Chairman of the Scientific Committee, which is currently chaired by Dr. Piero P. Bonissone (General Electrics Research, USA) and vice-chaired by Prof. Ramón López (Superior Council of the Scientific Research, Spain), with the support of Prof. Antonio Bahamonde (Univ. of Oviedo, Spain) in the secretary role. In addition, it is comprised by the following seven members: Prof. Bernadette Bouchon-Meunier (Univ. Paris 6, France), Prof. Christer Carlsson (Univ. Abo Akademi, Finland), Prof. Janusz Kacprzyk (Intelligent Systems Laboratory, Poland), Prof. Rudolf Kruse (Univ. Otto-von-Guericke Magdeburg, Germany), Prof. Xin Yao (Univ. of Birmingham, UK), Dr. Henri Prade (Centre National de la Recherche Scientifique, France), and Prof. Javier Montero (Complutense Univ., Spain). Dr. Enric Trillas (ECSC), Prof. María de los Ángeles Gil (Univ. Oviedo, Spain), Prof. Senén Barro (Univ. Santiago de Compostela, Spain), Prof. Ebrahim Mamdani (Imperial College London, UK), and Dr. Gianguido Rizzotto (SST Group, Italy), were also members of the Scientific Committee during the ECSC first four years of activity.

The ECSC has established numerous collaborations with the industry to apply SC techniques in order to improve business productivity and create new products and services. In this context, the Center has developed and is developing around 17 R&D projects with companies including a small company in the agricultural sector, technological high-growth small and medium enterprises (SMEs), 6 large national public-private consortia, and 3 projects with large multinationals such as EDP (an energy company from Portugal), Tenneco (an American automobile components company), and the PMG Group.

Currently, the ECSC participates in 5 basic and applied research projects funded by the Government of Spain and the regional government of Asturias. In terms of EU funding, the ECSC is coordinating the Seventh Framework Program (FP7) Marie Curie Initial Training Network "Medical Imaging Using Bio-inspired and Soft Computing" (see Section 4.2) and the COST Action "Combining Soft Computing Techniques and Statistical Methods to Improve Data Analysis Solutions". In addition, the ECSC participates in the FP7 ICT FET project "Bisociation Networks for Creative Information Discovery" and has recently received a

Marie Curie International Incoming Fellowship on "Soft Collaborative Intelligent Systems".

Furthermore, the Center shows an active participation in SC training activities [60]. It organizes a yearly summer course in SC that is taught by international renowned researchers. Besides, the ECSC, in collaboration with the University of Oviedo, coordinates an official Master (new European denomination for PhD program) in "Soft Computing and Intelligent Data Analysis" taught in English and adapted to the European Higher Education Area (`http://www.softcomputing.es/master`).

3 The Applications of Fuzzy Logic and Evolutionary Algorithms Research Unit

The main aim of this ECSC research unit is to propose new methodologies to tackle complex real-world problems by means of evolutionary algorithms (EAs) [7], fuzzy logic (FL) and fuzzy systems (FSs) [57], either in isolation or by their hybridization. Among these problems, we find those in the optimization, system identification (modeling, classification, and forecasting), data mining, and intelligent data analysis domains.

FL extends classical logic to provide a conceptual framework for knowledge representation under imprecision and the consequent uncertainty, while a FS is any kind of FL-based system using FL for knowledge representation and approximate reasoning. On the other hand, EAs are a kind of learning and optimization algorithms based on computational models of evolutionary processes.

To our mind, the combination of FL and FSs ability to model real-world phenomena presenting uncertainty and vagueness, and the search and knowledge discovery capability of EAs can be of help to solve some problems where either classical techniques can not been applied or they can be outperformed by intelligent techniques of the latter kind.

This research unit is active at the ECSC since the Center's creation by April, 2006. It is currently composed of nine researchers: Dr. Oscar Cordón (Principal researcher); Dr. Sergio Damas (Associate researcher); Drs. Arnaud Quirin, Prakash Shelokar, and Oscar Ibáñez (Postdoctoral researchers); and Ms.Rosario Campomanes, and Mrs. Krzysztof Trawinski, Andrea Valsecchi, Nicola Bova (Research assistants). Dr. José Santamaría from the Univ. of Jaén (Spain) and Mr. Manuel Chica from Inspiralia Tecnologías Avanzadas in Madrid (Spain) also belong to the unit as external affiliated researchers.

The following four subsections are devoted to briefly describe the research lines being developed by the AFE unit, enumerating the collaborations established with other research groups. Besides, the fifth subsection will provide a list of the currently active research project and contracts.

3.1 Multi-objective Graph-based Data Mining. Design and Mining of Visual Science Maps

In spite of the fast and huge development experienced by the data mining and knowledge discovery field in the last few years, current tools and techniques to examine the content of large databases are still hampered by their inability to support searches based on criteria that are meaningful to users of those repositories. The increasing need of mining multi-relational data in the form of graphs has resulted into the creation of graph-based data mining (GBDM) [48, 23, 1]. There are a large number of applications requiring analysis of structural data, such as microarray data in bioinformatics, social networks, transportation networks, web data, scientific data, satellite maps, and CAD circuits, among many others.

Many GBDM methods have been proposed in the specialized literature [48, 23]. These methods incorporate a search process (either exact exhaustive or approximate heuristic) in the possible sub-graph lattice, which is guided by a single objective representing a unique and specific user preference [85]. For example, mining sub-graphs which are present in at least m graphs is a typical choice.

The use of such simple thresholds for frequent sub-graph mining has important limitations [61]. The number of mined sub-graphs is large (respectively, few or nil) in the cases of weak (respectively, strict) thresholds. Moreover, in real-life applications a user is generally interested in mining a graph-based repository using several objectives that are actually meaningful to her/him. For example, users prefer obtaining sub-graphs with both high frequency and large size. However, these objectives are conflicting as simpler descriptions are usually the most frequent ones and vice versa.

We have introduced a multi-objective GBDM framework to handle the simultaneous optimisation of several conflicting goals representing different user preferences. It can deal with different multi-objective frequent sub-graph mining tasks by customising the tackled objectives, which may be based on the size of the sub-graph being explained, the number of retrieved sub-graphs, and their diversity, among others. Our approach permits uncovering sub-graphs comprising even a small number of observations that describe the underlying phenomena from different angles, revealing novel information that otherwise would be concealed by uninformative frequent descriptions.

On the one hand, we have proposed the incorporation of Pareto-based multi-objective search strategies from the evolutionary multi-objective optimization (EMO) field [21] to classical graph mining techniques such as Subdue [22] (MO-Subdue) [78, 77]. On the other hand, we have designed pure multi-objective graph mining methods algorithms [41] for both sub-tree [68] and sub-graph mining [32, 79] based on EMO algorithms and multi-objective ant colony optimization.

Although in the past we have dealt with bioinformatics problems, our current main application is the mining of visual science maps, a very novel, useful tool for the analysis of scientific information. These scientograms are built from co-citation information using classical methods from the area of bibliometrics such as citation analysis, as well as social networks analysis and information visualization techniques [83]. We are performing scientogram mining in order to analyze and compare the structure of scientific fields and research fronts in maps of the same (taken at different periods of time) or different domains (looking for similarities between different countries scientific productions) using single- and multi-objective GBDM techniques [66].

This work is done in cooperation with the Scimago research group (`http://www.scimago.es/`) headed by Prof. Felix de Moya at the CSIC-Univ. of Granada, which has developed two very ambitious projects: The Atlas of Science (`http://www.atlasofscience.net/`), to create a web-based information system achieving a graphic representation of all the IberoAmerican Science Research; and the Elsevier SCImago Journal & Country Rank (`http://www.scimagojr.com/`), which provides new scientific journal quality indicators to assess and analyze scientific domains. We have developed novel methods in the latter two web information systems, such as new variants of the Pathfinder network pruning algorithm [75] permitting the on-line generation of scientograms of very large scientific domains (even of the whole World production) [65, 64], and new network visualization approaches achieving closer representations to human beings' understanding [63]. The former pruning methods have been incorporated to the last release of the Network Workbech software (`http://nwb.slis.indiana.edu/`) developed by Prof. Katy Borner's team at the Univ. of Indiana. In addition, we have applied our scientogram design methods to other domains such as multi-agent systems debugging, in collaboration with Dr. Juan Botia's research team at the Univ. of Murcia [76].

3.2 Genetic Fuzzy Systems. Fuzzy Classifier Derivation for High Dimensional Problems

System identification involves the use of mathematical tools and algorithms to build dynamical models describing the behavior of real-world systems from measured data. There are always two conflicting requirements in the modeling process: the model capability to express the behavior of the real system in an understandable way (interpretability) and its capability to faithfully represent the real system (accuracy) [14, 15]. Obtaining high degrees of interpretability and accuracy is a contradictory purpose and, in practice, one of the two properties prevails over the other.

FSs have demonstrated their outstanding capability as system identification and control tools. FL has proven its ability to generate different kinds of fuzzy models/classifiers/controllers, with a different accuracy-comprehensibility trade-off, and to permit the incorporation of human expert knowledge; as well as to integrate numerical and symbolic processing into a common scheme.

We are world-wide recognized experts on the design of FSs by means of EAs, the so called genetic fuzzy systems [28, 29]. Among other real-world applications, we have used them to build fuzzy models for the estimation of maintenance costs of electricity distribution networks in Asturias [30] (outperforming other approaches such as neural networks and classical and symbolic regression), in collaboration with the head of the "Metrología y Modelos" research group at the University of Oviedo (Spain), Dr. Luciano Sánchez. Moreover, they were also applied to derive fuzzy controllers for HVAC systems for large buildings, simultaneously optimizing several design criteria [2, 3].

We have developed a new approach to design fuzzy classifier ensembles for high dimensional problems by considering data re-sampling, feature selection, and multi-criteria EAs for classifier selection to get an appropriate accuracy-interpretability trade-off [31, 80, 81]. Besides, we have proposed the use of a genetic fuzzy system to jointly perform classifier fusion and reduction [70]. Currently, we are applying EAs to design fuzzy finite state machines for real-world applications such as human gait modelling and body posture recognition [5, 6]. Finally, we have recently proposed a new methodology to measure fuzzy system interpretability based on the use of scientogram design methods [4].

3.3 Soft Computing for Medical Image Processing

In the last few years there is an increasing interest on using SC techniques to solve real-world image processing problems covering a wide range of domains. In particular, one of the application fields that has suffered a large development is that of image registration (IR) [45]. IR is a fundamental task in computer vision used to achieving the best fitting/overlaying between two (or more) different images taken under different conditions (at different times, using different sensors, from different viewpoints, or a combination of them). Over the years, it has been applied to a broad range of situations from remote sensing to medical images or artificial vision and CAD systems, and different techniques have been independently studied resulting in a large body of research.

In this way, evolutionary IR is a very promising application area nowadays. Thanks to their global optimization techniques nature, EAs aim at solving the drawbacks presented by traditional IR methods, which usually get stuck in local optima when dealing with large misalignments between the images to be registered [10]. Our team has developed a large number of robust evolutionary IR approaches able to overcome the latter problems based on the use of advanced EAs including domain knowledge, such as [25, 26] among others. They have achieved a successful performance on both medical IR (human MR and CT images) and on 3D model reconstruction (range images). Besides, we have developed a wide experimental survey on different state-of-the-art evolutionary IR approaches for the 3D modeling of forensic objects application [34, 71].

Specifically, we have dealt with a challenging real-world problem in the field of forensic medicine. In cooperation with the Physical Anthropology Lab of the Univ. of Granada, headed by the prestigious forensic anthropologist Dr. Miguel Botella, we have developed an intelligent system to assist the forensic anthropologist in the identification of a missing person by a technique called craniofacial superimposition. This technique is based on overlaying a scanned 3D model of the skull found against a face photo to try to establish whether this is the same person through the partial matching of two sets of radiometric points. While EAs and image processing techniques are used to automatically build the skull 3D model and perform the skull-face overlay, FL is considered for the landmark location and matching. The system is supported by an international patent and has already been used by the Spanish scientific police to solve real-world identification cases. This project will be described in detail in Section 4.1. Currently, we are designing advanced evolutionary models for the 3D modelling of forensic objects.

We also coordinate a Marie Curie International Training Network entitled "MIBISOC: Medical Imaging Using Bio-inspired and Soft Computing" granted by the European Commission within the Seventh Framework Programme (FP7-PEOPLE-ITN-2008). We are working in the design of evolutionary deformable medical IR models and genetic fuzzy systems for medical image segmentation based on deformable models such as topological active nets. A description of this project will also be provided in Section 4.2.

3.4 Real-World Applications of Single and Multi-objective Metaheuristics

Many complex combinatorial and numerical optimization problems arise in human activities, such as Economics (e.g., portfolio selection), Industry (e.g., scheduling or logistics), or Engineering (e.g., routing). The impracticability to get optimal solutions for these kinds of problems in reasonable time using classical algorithmic techniques has caused the successful development of different approximate algorithm methodologies called metaheuristics [42] in the last two decades, able to quickly provide high quality solutions to them. Their success when solving a large number of real-world optimization problems is due both to the powerful heuristic search they apply in complex, ill-defined solution spaces of huge dimension, and to their flexibility, which allows them to handle problem restrictions in an easier way or to be able to simultaneously optimize multiple, conflicting objectives, which are usually present in these problems.

Metaheuristics constitute a very diverse family of optimization algorithms. Our staff owns a large expertise on the single- and multi-objective variants of many of them, mainly on EAs, ant colony optimization (ACO) [38], scatter search, simulated annealing, tabu search, GRASP, and iterated local search. We have both used them in different applications such as medical IR, bioinformatics (genetic regulatory networks knowledge discovery), or information retrieval, as well as we designed new hybrid designs in the field of ACO aiming to obtain better performing algorithms [27, 13].

We are applying multi-objective ACO algorithms [41] to solve a challenging real-world application, the time and space assembly line balancing problem (TSALBP) [8]. It involves to achieve optimal assignments of a subset of tasks to each station of the assembly line of a plant with respect to two or three conflicting objectives to be minimized: its cycle time, its number of stations, and their area [17, 19, 20]. This framework emerged thanks to the observation of a real automotive industry plant belonging to Nissan and located in Barcelona (Spain), as this research is being performed in collaboration with the Nissan Endowed Chair of the Technical University of Catalonia (`http://www.nissanchair.com/`), headed by Prof. Joaquín Bautista. Besides, we have proposed an EMO algorithm [16] and hybridized it with local search optimizers in order to achieve an improved performance in the TSALBP [18].

3.5 Active Research Projects and Contracts

A detailed list of the currently active research projects and contracts at the AFE unit is provided as follows:

- Technologies for Providing Services under Mobility in the Future Intelligent Universe. Spanish Ministry of Science and Innovation. Research project CENIT-2008-1019. January 2008-December 2011. Budget: 143,750€.
- Energy Production Forecasting Model for WindFarms. Research contract between NEO Energia and the ECSC. August 2009-April 2011. Budget: 90,000€.
- Medical Imaging Using Bio-inspired and Soft Computing. European Commission. Marie Curie International Training Network FP7-PEOPLE-ITN-2008. Grant Agreement number 238819. October 2009-September 2013. Budget: 3,400,000€.
- Single- and Multi-objective Metaheuristics for Real-world Applications: Assembly Line Balancing, Visual Science Map Mining, and 3D Forensic Modeling. Spanish Ministry of Science and Innovation. Research project TIN 2009-07727. January 2010-December 2012. Budget: 147,400€.
- Real time video analysis for security applications. October 2010-December 2012. Science, technology and innovation plan of the Asturias Principality. Budget: 21,240€.

4 Two challenging projects at the AFE research unit

A brief description of two of the projects tackled by the members of the AFE research unit follows. Both projects have been selected as good representatives of the goals of this research unit. In particular, they demonstrate the chances to apply SC to challenging problems for the society. Moreover, they are an opportunity to join the forces of world-wide recognized researchers as a step forward in the development, application, and knowledge transfer of SC concepts.

4.1 SOCOVIFI: Soft Computing and Computer Vision in Forensic Identification

The first one, entitled "Soft Computing and Computer Vision in Forensic Identification", is a research project founded by the Spanish Ministry of Education and the . It has recently finished (December 2009) with promising achievements in the filed of forensic identification.

Our main objective was to develop an intelligent system to assist the forensic anthropologist in the identification of a missing person by a usual forensic identification technique called craniofacial superimposition [54, 58]. This technique is based on overlaying a scanned 3D model of the skull found against a face photo to try to establish whether this is the same person through the partial matching of two sets of radiometric points. In order to do so, we cooperated with the Physical Anthropology Lab of the University of Granada (Spain), headed by the prestigious forensic anthropologist Dr. Miguel Botella. His team is internationally recognized by its participation in forensic anthropology activities such as the identification of Christopher Columbus' skeletal remains, the identification of the women killed at Ciudad Juárez (Mexico), or the identification of victims of the dictatorial repression at Chile, among many others.

Our research was based on the use of three main techniques: EAs, FL, and image processing (especially, IR). While EAs and image processing techniques have been successfully used to automatically build the skull 3D model and perform the skull-face overlay, FL was considered for tackling the different sources of uncertainty inherently to the problem. Specifically, we extended our previous evolutionary IR methods (see Section 3.3) for classical medical imaging environments (magnetic resonance and computer tomography images) to deal with this challenging real-world problem from the field of forensic medicine.

All the information about this project can be found at `http://www.softcomputing.es/socovifi/en/home.php`.

4.1.1 Description

One of the main goals of forensic anthropology [12] is to determine the identity of a person from the study of some skeletal remains. In the last few decades, anthropologists have focused their attention on improving those techniques that allow a more accurate identification.

Before making a decision on the identification, it is necessary to follow different processes that let them assign a sex, age, human group, and height to the subject from the study of bones found. Different methodologies have been proposed, according to the features of the different human groups of each region [44, 55, 36, 37, 40, 84].

Once the sample of candidates for identification is constrained by these preliminary studies, an identification technique is applied. Among them, craniofacial superimposition [54] is a complex and uncertain forensic process where photographs or video shots of a missing person are compared with the skull that is found. By projecting both photographs on top of each other (or, even better, matching a scanned three-dimensional skull model against the face photo/series of video shots), the forensic anthropologist can try to establish whether that is the same person [58].

The said process is guided by a number of landmarks located in both the skull and the photograph of the missing person (see Figures 1 and 2). The selected landmarks are located in those parts where the thickness of the soft tissue is low. The goal is to ease their location when the anthropologist must deal with changes in age, weight, and facial expressions.

Figure 1: From left to right, principal facial landmarks: lateral and frontal views

Figure 2: From left to right, principal craniometric landmarks: lateral and frontal views

4.1.2 Computer-aided 3D/2D Craniofacial Superimposition Procedure

After one century of development, craniofacial superimposition has become an interdisciplinary research field where computer sciences have acquired a key role as a complement of forensic sciences. Moreover, the availability of new digital equipment (as computers and 3D scanners) has resulted in a significant advance in the applicability of this forensic identification technique [33].

In our view, the whole craniofacial superimposition process is composed of the following three stages (see Figure 3):

1. The first stage involves achieving a digital model of the skull and the enhancement of the face image. Obtaining an accurate 3D cranial model has been considered a difficult task by forensic anthropologists in the past. However, it is nowadays an affordable and attainable activity using laser range scanners (Figure 4) like the one used by our team, available in the Physical Anthropology Lab at the University of Granada (Spain). The subject of the

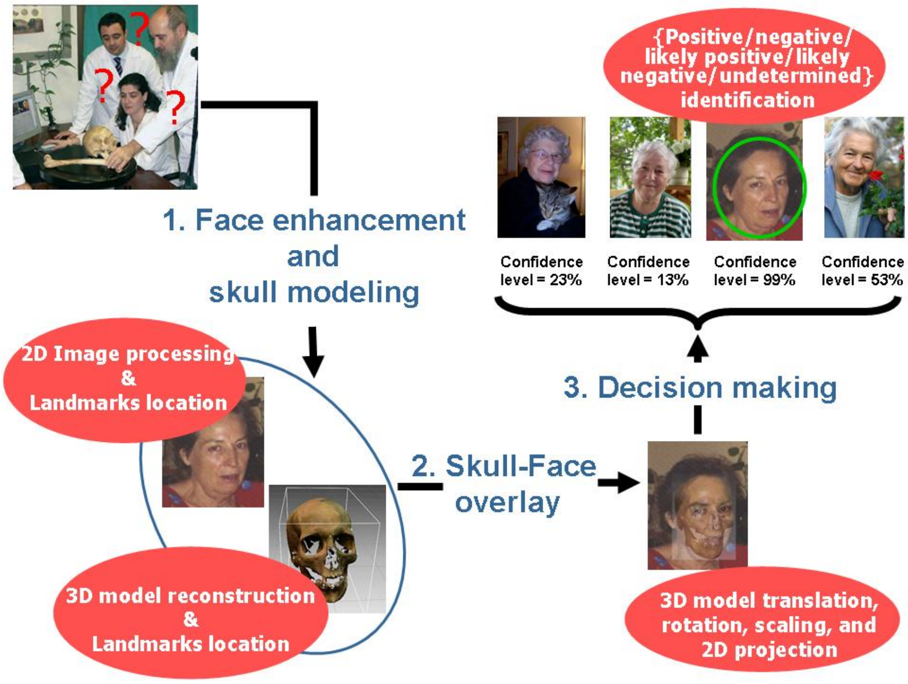

Figure 3: The three stages involved our proposal for the 3D/2D computer-aided craniofacial superimposition process

identification process, i.e. the skull, is a 3D object. Hence, the use of a skull 3D model instead of a skull 2D image should be preferred because it is definitively a more accurate representation. It has already been shown that 3D models are much more informative in other forensic identification tasks [35]. Concerning the face image, the most recent systems use a 2D digital image. This stage aims to apply image processing techniques [43] in order to enhance the quality of the image corresponding to the face photograph that was typically provided by the relatives when the person disappeared.

2. The second stage is the skull-face overlay. It consists of searching for the best overlay of the skull 3D model and the face 2D image achieved during the first stage. The achievement of the right overlay involves two different factors: i) the determination of the real size of the figures (scaling), since it would be impossible to overlay images with a different relative size; and ii) the orientation method for the skull, to make it correspond to the face position in the photograph. There are three possible moves to put that into effect: inclination, extension, and rotation. The overall procedure is usually done by bringing to match some corresponding landmarks on the skull and the face.

Figure 4: Acquisition of a skull 3D partial view using a Konica-Minolta™laser range scanner

3. Finally, the third stage of the craniofacial superimposition process corresponds to the decision making. Based on the skull-face overlay achieved, the identification decision is made by either judging the matching between the corresponding landmarks in the skull and in the face, or by analyzing the respective profiles. Notice that, the use of computers in this stage aims to support the final identification decision that will be always made by the forensic anthropologist.

4.1.3 Why Should We Use Soft Computing for Craniofacial Superimposition?

In view of the tasks to be performed in the first two craniofacial superimposition stages, it can be seen the relation of the desired procedure with the IR problem in computer vision (see Section 3.3). Besides, from the second and the third stages, we can also draw the underlying uncertainty involved in the whole process. The correspondence between facial and cranial anthropometric landmarks is not always symmetrical and perpendicular (see Figure 5), some landmarks are located in a higher position in the alive person face than in the skull, and some others have not got a directly related landmark in the other set. So, we found a clear partial matching situation and a need for automatic techniques. As a final result, the identification decision can be expressed according to several confidence levels, depending on the chances of the sample (degree of conservation) and of the analytical process put into effect (see Figure 3): "absolute matching","absolute mismatching", "relative matching", ... Hence, we again find the uncertainty and partial truth involved in the identification process.

As seen, different kinds of uncertainty are associated to the current process making the use of FL particularly appealing: the association of the facial and skull anthropometric landmarks is a partial matching process, there is uncertainty on the available knowledge and materials (different degrees of decomposition can affect to

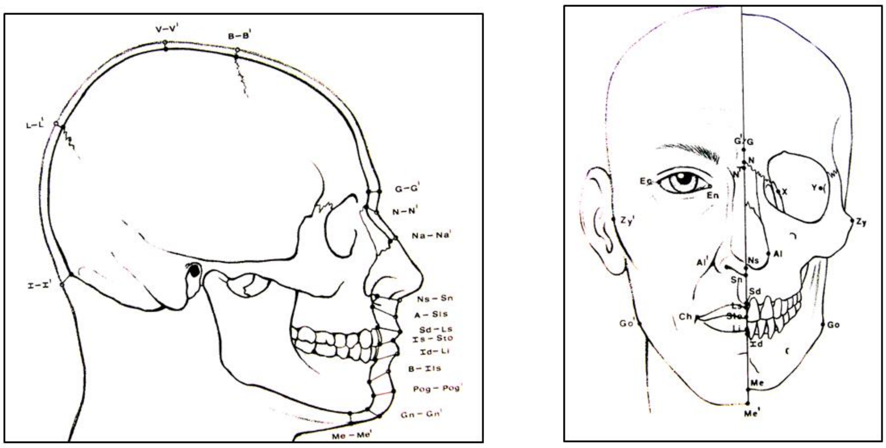

Figure 5: From left to right, correspondences between facial and craniometric landmarks: lateral and frontal views.

the skeleton), partial degrees of truth are present in the resulting final decision, and different information sources must be aggregated to take it.

On the other hand, the whole craniofacial procedure is very time consuming as it is performed by the forensic expert in a iterative trial-and-error way. Besides, there is not a systematic methodology but every expert usually applies his particular knowledge-based process. Hence, there is a strong interest in designing automatic methods to support the forensic anthropologist to put it into effect [82].

In summary, we clearly identify a potential field for the application of SC due to the following reasons:

- No systematic craniofacial superimposition method exists (whole procedure).
- The forensic anthropologist is usually not very skillful neither to calibrate the scanner nor to properly match the different views of the skull (stage 1).
- The scanner software only determines the correct alignment if a rotary table is available (stage 1).
- Manual skull-face overlay is very time consuming (stage 2).
- There is a clear situation of partial landmark matching: landmarks are located in a different location in the skull and the face, some of them do not have a correspondence, etc. (stage 2).
- Uncertainty and degrees of confidence are inherent to the final identification result (stage 3).
- There is a need of automatic techniques able to deal properly with incomplete information (whole procedure).

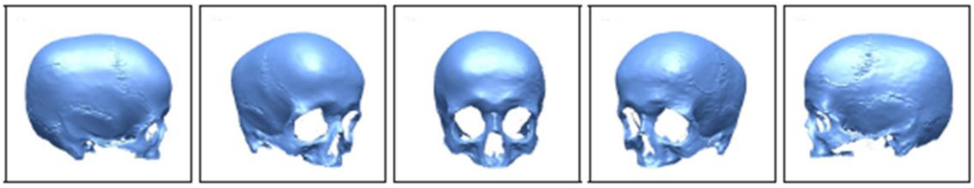

Figure 6: An example of a 3D skull model reconstructed by means of the designed evolutionary range IR methods.

4.1.4 Our Approach to Soft Computing-based 3D/2D Computer-aided Craniofacial Superimposition

Our approach to deal with the challenge of designing an intelligent system to support the forensic anthropologist in the identification procedure by craniofacial superimposition is based on the use of the following SC techniques in each of the three existing process stages:

Stage 1: Face enhancement and skull modeling

In order to accomplish the 3D model of the skull, laser range scanners are equipped with an additional positioning device named rotary table and an appropriate software that permits the 3D reconstruction. Some anthropologists are skilled enough to deal with the set of 3D views and they supervise the procedure of commercial software like RapidForm^{TM}. Nevertheless, these software packages do not always provide the expected outcomes and the anthropologists even have to stitch up manually every couple of adjacent views. Moreover, there are scenarios where it is not even possible to use the rotary table. Hence, a 3D image robust reconstruction method is a real need. However, these is a really complex optimization task, with a huge search space (exhaustive search methods are not useful) that has many local minima (multimodality), but forensic experts demand highly robust and precise results. This complex landscape lead us to propose different evolutionary methods [72, 73], achieving really good results in the automatic alignment of skull range images. A two step pair-wise range IR technique [9] was successfully applied to such images. The approach includes a pre-alignment stage, that uses a scatter search-based algorithm [59], and a refinement stage based on the classical iterative closest point algorithm [10]. The method is very robust, indeed it reconstructs the skull 3D model even if there is no turn table and the views are wrongly scanned. An example of a 3D skull model from the Physical Anthropology lab, automatically reconstructed from five partial views by using our evolutionary methods, is shown in Figure 6.

Stage 2: Skull-face overlay

The success of the superimposition technique requires positioning the skull in the same pose of the face as seen in the given photograph. The orientation process is a very challenging and time-consuming part of the craniofacial superimposition technique [39]. Most of the existing craniofacial superimposition methods are guided by a number of landmarks of the skull and the face. Once these landmarks are available, the skull-face overlay procedure is based on searching for the skull orientation leading to the best matching of the set of landmarks. However, this is again a really complex optimization task, with a highly multimodal landscape (exhaustive search methods are again not useful), and forensic experts again demand highly robust and precise results. This complex landscape lead us to propose different evolutionary methods [49, 50] such as CMA-ES [46] and different real-coded genetic algorithms [47], achieving really good results both in performance, competitiveness with human-obtained ones (see some overlay results in Figures 7 and 8), and robustness (almost the same overlay results over 30 runs). We have also designed a fast variant based on scatter search [52].

Moreover, since in this process the goal is to match two sets of landmarks that belong to two different objects (the face and the skull), there is an inherent uncertainty that must be taken into account. On one hand, the landmark matching uncertainty (not yet modeled in any of our works) will refer to the imprecision involved in the matching of landmarks corresponding to the two different objects, since every pair of landmarks has a different and not fixed matching correspondence. On the other hand, the location uncertainty is related to the extremely difficult task of locating the landmarks in an invariable place [67], with the accuracy required for this application. Indeed, every forensic anthropologist is prone to locate the landmarks in a slightly different position. The ambiguity may also arise from reasons like variation in shade distribution depending on light condition during photographing, unsuitable camera focusing, poor image quality, etc. We have proposed the use of fuzzy landmarks [51, 53] to model this kind of uncertainty. This new approach is also relevant to solve the co-planarity problem presented in many overlay cases [74].

Figure 7: From left to right, best skull-face overlay results achieved by the forensic experts and using our automatic evolutionary-based method.

Overall, the proposed method is fast (it takes around 2 minutes) and automatic, and therefore very useful for solving one of the most tedious works performed by the forensic anthropologists (requiring up to several hours). In addition, this method supposed a systematic approach to solve the superimposition problem and in spite of the fact it could need additional improvement, it can already be used in many cases, since it has demonstrated competitive results with the ones achieved by

Figure 8: From left to right, best skull-face overlay results achieved by the forensic experts and using our automatic evolutionary-based method.

the forensic experts following a manual approach as Figures 7 and 8 show (see [49, 52, 74] for some additional results in other real-world identification cases).

Stage 3: Decision Making

Once the skull-face overlay is achieved, the decision making stage can be tackled. The straightforward approach would involve measuring the distances between every pair of landmarks in the face and in the skull. One more time, we have different sources of uncertainty to be tackled in this stage. On the one hand, errors are prone to be accumulated during the process of calibrating the size of the images. On the other hand, we have to propagate the uncertainty of the previous stage and incorporate it in this decision stage. In addition, the final decision will be given together with a confidence degree, resulting in decisions such as: likely positive, likely negative, positive, negative and also undetermined identification. The best way of model this decision making support system is using FL/FSs. We have not modeled this stage yet but we aim to do so in the short future.

The novelty and importance of this research line together with the really good results achieved by the proposed methods lead us to ask for an international PCT patent, which was granted by the European Agency on February, 2011[2]. In addition, we have applied for a research project on December 2010 within the FP7 Security Call (Topic SEC-2011.1.4-3 - Advanced forensic framework - CSA). It is called "MEPROCS" (New MEthodologies and PROtocols of forensic identification by Craniofacial Superimposition) and its main goal is to promote and standardize the use of computer-aided craniofacial superimposition throughout experts in the

[2] http://www.wipo.int/pctdb/en/fetch.jsp?SEARCH_IA=ES2010000350&DBSELECT=PCT&C=10&TOTAL=1&IDB=0&TYPE_FIELD=256&SERVER_TYPE=19-10&SORT=41327081-KEY&QUERY=\%28WO\%2FWO2011\%2F012747\%29+&START=1&ELEMENT_SET=B&RESULT=1&DISP=25&FORM=SEP-0\%2FHITNUM\%2CB-ENG\%2CDP\%2CMC\%2CAN\%2CPA\%2CABSUM-ENG&IDOC=2600594&IA=ES2010000350&LANG=ENG&DISPLAY=STATUS

field.

4.2 MIBISOC: Medical Imaging Using Bio-inspired and Soft Computing

We also coordinate a Marie Curie International Training Network entitled "MIBISOC: Medical Imaging Using Bio-inspired and Soft Computing" which has been recent granted by the European Commission within the Seventh Framework Program (FP7-PEOPLE-ITN-2008).

The general area of this project deals with the application of intelligent systems constituted by Bio-inspired and Soft Computing (BC-SC) techniques to real-world Medical imaging (MI) applications. MI is at the heart of many of today's improved diagnostic and treatment technologies. Computer-based solutions are vastly more capable of both quantitative measurement of the medical condition and the pre-processing tasks of filtering, sharpening, and focusing image detail. BC-SC techniques have been successfully applied in each of the fundamental steps of medical image processing and analysis (e.g. restoration, segmentation, registration or tracking). The natural partnership of humans and intelligent systems and machines in MI is to provide the clinician with powerful tools to take better decisions regarding diagnostic and treatment. This project aims to surpass the state of the art approaches applying intelligent systems constituted by SC-BC techniques to real-world MI applications.

The partnership is composed of high quality scientific members, looking for world-wide recognized researchers and high quality technical partners on each area (see Table 1). Direct links between the ITN topics (MI, SC-BC, and SC-BC for MI) and the project partners' expertise were established, to get together capabilities to face some of the most challenging MI problems by using SC-BC. The network properly balances the presence of research and technical partners, including companies and hospitals, as well as two SMEs, one of them as full network participant.

The network clearly promotes the transverse exchange of knowledge among three different disciplines: medicine, imaging, and computing. Such interdisciplinary approach is show in Figure 9, where the different research areas are linked throughout the MI process as well as the role of every research and technical partner.

The main goal of the network is to integrate 16 Early Stay Researchers (ESRs) for 36 months in eight leading research groups under the umbrella of a formation program in MI using BC and SC to obtain their PhD degree. The ESRs will learn about a number of important MI problems as well as about the tested and emerging BC and SC techniques, and how to develop methods to solve the former problems by means of the latter techniques as well as to design the associated experiments in a rigorous way. In addition, they will be taught in other complementary skills such as project management, industrial property, etc., by means of the participation in a strictly coordinated international team activity.

The methodology to be followed involves both a theoretical and a practical side. Even though in most cases doctoral studies involve training for research, in this project we would like to focus on training by research. In this way, the outstanding

Table 1: List of the project participants.

Network Participants	**Technical Associated Partners**	**Support Associated Partners**
European Center for Soft Computing (Spain) (ECSC)	Center National de la Recherche Scientifique (France) (CNRS)	Treelogic (Spain)
Ghent University (Belgium) (UGent)	General Electric Healthcare Europe (UK) (GE-Europe)	
Université Libre de Bruxelles (Belgium) (ULB)	Hospital Universitario Central de Asturias (Spain) (HUCA)	
University of Nottingham (UK) (UNott)		
Universita degli Studi di Parma (Italy) (UNIPR)		
University of Granada (Spain) (UGR)		
Henesis (Italy)		
Universitätsklinikum Freiburg (Germany) (UKL-FR)		

research expertise of the different partners in their respective areas, the practical know-how and the "hands on" scenarios provided by the industrial partners (companies and hospitals), and the experience of all the network participants and associated partners in organizational activities will allow us to implement a high quality training program allowing the exchange of knowledge between the different ESRs selected. The trained ESRs will acquire a strong background for the development of intelligent systems based on BC-SC providing more sophisticated and flexible application-oriented solutions to current MI problems in the clinical and research field. Furthermore, it also aims to provide a transverse research formation from different industrial sectors: scientific research, technology development, practical uses in hospitals, and companies.

With this aim, a personalized, exhaustive and complementary career development plan (PCDP) has been designed for each of the ESRs (see Figure 10), consisting of: i) a personalized research plan based on individual research projects; ii) local and network-wide specific training courses, both in face-to-face and virtual modalities; iii) network's complementary skills courses, workshops and final conference; and iv) international research stays among the different partners.

The individual research projects of the ESR are based on novel and attractive research topics of the main research lines of the partners involved and on their collaboration with other research and technical partners. The network will promote the co-supervision of the ESRs' research training projects and PhD studies. The additional co-supervision from another participant or associated partner will enrich the multidisciplinary and intersectorial aspects of the research carried our by the ESRs and will enhance the collaboration between the network partners. Table 2 shows the individual projects foreseen by the each of the recruited early stage researchers.

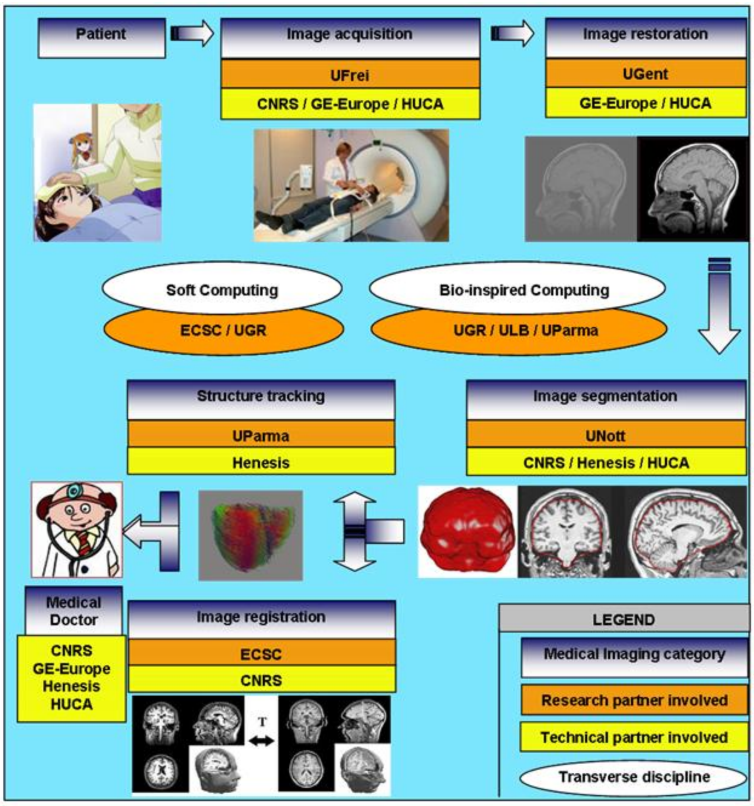

Figure 9: Graphical representation of the MI domain subdivided into categories and the assignments of partners and categories according to the partners' expertise and research plan.

The personalized training stage will be started by each of the ESRs once they become contracted in a specific network participant. The core of this first stage will be the academic courses organized locally by her/his hiring partner (mainly its local PhD program), to become trained in that partner's main topic of expertise. They will be coordinated with two personalized networking activities:

1. either a first short stay (1-2 months) in other network participant or a secondment (1 month) in a technical associated partner, which in both cases will own a different expertise (e.g., an ESR contracted by an MI partner will do her/his stay either in a SC-BC or SC-BC for MI partner). The ESR will thus complement the concepts acquired by either attending to that other participant's local courses or benefiting from the associated partner's technical expertise and "hands-on" scenario; and

2. an on-line course, available as soon as the ESR joins the network, whose first year will be devoted to introduce her/him in the fundamentals of the two ITN

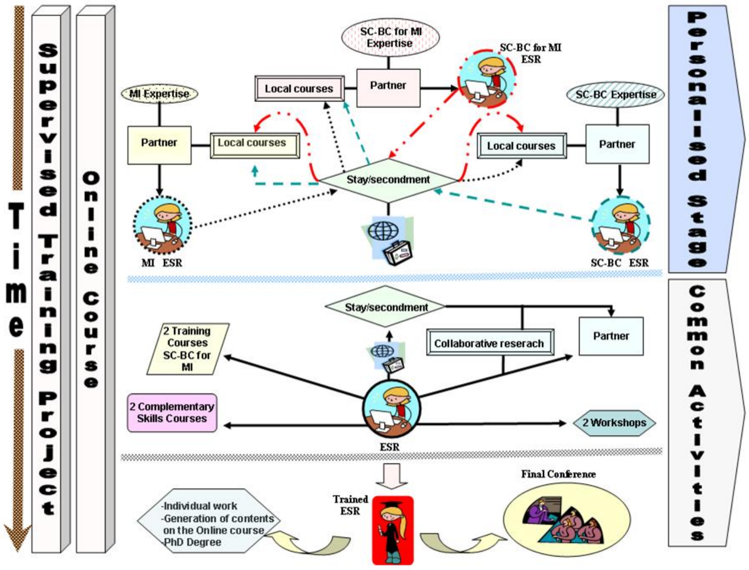

Figure 10: Draft template of the described CDP plans.

basic disciplines, MI and SC-BC. The syllabus of that first part of the on-line course is coordinated with the local courses and includes all the basic MI and SC-BC concepts required to face the next learning stage and the development of the personalized research training projects, thus properly complementing the skills acquired through the face-to-face modality (i.e., blended learning). Besides, it allows us to establish an active learning modality for the ESR through a virtual community of learners.

The latter two activities are very important for the ESR since, from the perspective of a PhD student, working in an existing topic that is of interest to other researchers in the field is positive. Contact with these researchers early in the study can help in guiding her/his formation by focusing on what other researchers deem important. It is also important for the ESRs' social network, which will become vital for choosing the step following their PhD. Complementary physical and virtual mobility modalities are considered to be implemented through the short secondment and the on-line course.

The network-wide training activities will become the second ESR training stage, mainly starting after the first ESR contract year. They will be coordinated with the basic training themes and the skills taught locally (either at the hiring or the hosting partner) in order the ESR can widen the scope of her/his research interests and knowledge and obtain her/his PhD. The ESRs will: i) enroll in two training courses introducing her/him in different MI application domains solved by SC-BC approaches to get the additional skills needed for his research project; ii) attend to two workshops where (s)he can interact with her/his mates and all the members of the network; iii) enroll in two additional skills courses to complement her/his

Table 2: Individual research projects offered by the host organizations.

Individual Project	Host Institution
Deformable Registration of Medical Images Using Soft Computing	ECSC
Genetic Fuzzy Systems and Deformable Models for Medical Image Segmentation	ECSC
Image Restoration: Noise Reduction	UGent
Image Restoration: Similarity Measures	UGent
Application of Automatic Algorithm Configuration in Image Analysis	ULB
Development of Tools for Automatic Algorithm Configuration	ULB
Manifold Learning for Medical Imaging: developing a 3D interactive MR image segmentation system	UNott
Manifold Learning for Medical Imaging: developing methods for identifying non-linear structures in medical imaging data	UNott
Detection and analysis of anatomical structures in multidimensional image sets	UNIPR
Bio-inspired techniques for multi-dimensional image analysis	UNIPR
Multi-objective Genetic Fuzzy Systems	UGR
Evolutionary Algorithms for continuous optimization	UGR
Vision-based assisted flexible endoscopy	Henesis
Multimodal behavioural assessment and prediction in rehabilitation	Henesis
Development of novel image analysis techniques for preclinical and clinical studies, involving the problems of segmentation and non-rigid registration in real time medical imaging data	UKL-FR
Development of novel image analysis techniques for preclinical and clinical studies, monitoring preclinical or clinical pharmaceutical studies with imaging	UKL-FR

formation; and iv) attend to a final conference to present her/his research results.

The on-line course will keep on running in this second period for two additional years. During the first of them, the contents taught in the two training courses on MI applications of SC-BC are complemented with a whole syllabus on that topic. The last year is devoted to additional ESR's active personalized learning through individual and collaborative virtual activities such as new content development resulting from her/his research results, and the maintenance of an Internet portal and of a virtual community of experts on the ITN topic by the ESRs. Finally, we also plan to exchange the hired ESRs among labs for at least a second time in this stage to give them the chance to collaborate with high quality European experts on different MI problems and SC-BC methods helping them to advance in their personalized research training project.

The exhaustive and interdisciplinary proposed training program will provide the European industry with highly qualified researchers able to solve complex MI problems. These researchers will promote new scientific knowledge and technological applications in hospitals, healthcare providers, and technological companies.

Last July 2010 the recruited ESRs started joining their corresponding host institutions, with the recruitment process being finished by mid October. Andrea Valsecchi and Nicola Bova were the two researchers selected by the ECSC. Mr. Valsecchi is being supervised by Dr. Damas and Dr. Santamaría, in the research project "Deformable Registration of Medical Images Using Soft Computing". Mr. Bova, supervised by Dr. Cordón and Dr. Ibáñez, is involved in the project "Genetic Fuzzy Systems and Deformable Models for Medical Image Segmentation". Currently they have already started their personalised training, including the "aster in Soft Computing and Intelligent Data Analysis" PhD program, taught by the ECSC in collaboration with the University of Oviedo.

The first common activity of the MIBISOC research training programme was the online course, focused on providing the ESRs with a very brief global introduction to all the ITN topics. It was held between the first of July and the 25th of September 2010. The second one was the first complementary skills course that was held in Granada from 1 to 2 February 2011. The course contents were divided into five modules: Research Methodology and Policy, Search of scientific and technical information, Specialised scientific writing and oral communication, Creative thinking and problem resolution, General public dissemination, and Gender issues. These modules were taught by outstanding professionals, among which we can highlight Dr. José M. Labastida, recently appointed Director of the Scienctific Division of the European Research Council (ERC), and Dr. Damini Kumar, Director of Design and Creativity, NUI Maynooth, Ireland, and European Ambassador of Creativity and Innovation.

The next common activity where the ESRs will be enrolled will be the first technical course that will be organised by the ECSC in July 2011, and which will be focused on teaching real-world applications of SC and BC-based intelligent systems in the field of MI. Along 2011, the ESRs will also develop his/her first short stay at another partnering institution that holds a complementary background and experience, (e.g., an ESR contracted by an MI partner will do her/his stay either in a SC-BC or SC-BC for MI partner).

For further information about the MIBISOC project, the interested reader is kindly asked to visit: `http://www.mibisoc-itn.eu`.

5 Concluding Remarks

We have devoted the present manuscript to review some of the research lines developed at the ECSC. After describing the general aspects of the creation and current structure of the Center and of its main research and training activities, we have focused on one of the five research units composing it, the AFE unit. The main resarch lines of the AFE unit has been introduced. Then, two challenging research projects dealing with the computer vision and medicine fields have been reviewed, showing the potentials and the beneficial characteristics reported by the use of SC to solve different problems in their application domains.

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