01 Feb 2009

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Recommended Citation

G. K. Venayagamoorthy, "A Successful Interdisciplinary Course on Computational Intelligence," *IEEE Computational Intellience Magazine*, Institute of Electrical and Electronics Engineers (IEEE), Feb 2009.
The definitive version is available at https://doi.org/10.1109/MCI.2008.930983

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A Successful Interdisciplinary Course on Computational Intelligence

 1556-603X/09/$25.00©2009IEEE

Abstract: This article presents experiences from the introduction of a new three hour interdisciplinary course on computational intelligence (CI) taught at the Missouri University of Science and Technology, USA at the undergraduate and graduate levels. This course is unique in the sense that it covers five main paradigms of CI and their integration to develop hybrid intelligent systems. The paradigms covered are artificial immune systems (AISs), evolutionary computing (EC), fuzzy systems (FSs), neural networks (NNs) and swarm intelligence (SI). While individual CI paradigms have been applied successfully to solve real-world problems, the current trend is to develop hybrids of these paradigms since no one paradigm is superior to any other for solving all types of problems. In doing so, respective strengths of individual components in a hybrid CI system are capitalized while their weaknesses are eliminated. This CI course is at the introductory level and the objective is to lead students to in-depth courses and specialization in a particular paradigm (AISs, EC, FSs, NNs, SI). The idea of an integrated and interdisciplinary course like this, especially at the undergraduate level, is to expose students to different CI paradigms at an early stage in their degree program and career. The curriculum, assessment, implementation, and impacts of an interdisciplinary CI course are described.

1. Introduction

The IEEE Neural Network Society changed its name in 2004 to IEEE Computational Intelligence Society (CIS) – *mimicking nature for problem solving*. Computational intelligence (CI) is one of the most active research areas today in information science and engineering. Initially, CI was defined as the combination of fuzzy logic, neural networks, and genetic algorithms. A broad definition of computational intelligence is the study of adaptive mechanisms to enable or facilitate intelligent behavior in complex, uncertain and changing environments. These adaptive mechanisms include those artificial intelligence (AI) paradigms that exhibit an ability to learn or adapt to new situations, to generalize, abstract, discover and associate [1]. The paradigms of CI mimic nature for solving complex problems. In other words, inspired from biology and nature, and these paradigms include neural networks, evolutionary computing, swarm intelligence, fuzzy systems and artificial immune systems. Together with case-based reasoning, deductive reasoning, expert systems, logic and symbolic machine learning systems, these intelligent algorithms form part of the field of AI [1]. AI with its numerous techniques is a combination of several research disciplines, for example, biology, computer science, engineering, neuroscience, philosophy, sociology. AI is claimed as *the way of the future*. Computational intelligence is successor of AI and *is the way of the future computing. Intelligence without computing is like birds without wings. Computing with intelligence can make imaginations and dreams a reality.* CI has links to and differences from AI. Some of the techniques are common to CI and AI. Traditional AI techniques are developed in a top-down approach, by imposing structure and order of processing solutions from the top. In contrast, CI techniques are applied in a bottom-up approach through emergence structure and order.

The field of CI has applications and contributions to make in several disciplines including biology, chemistry, computer science, economics, electromagnetics, engineering, immunology, information science, linguistics, material science, music and physics. Many new educational programs are introduced at colleges and universities including an MSc program in computational economics with a focus on CI at the Erasmus University, Netherlands [2] and an MSc program in natural computation at the University of Birmingham, UK [3].

This article presents the design, implementation and experiences of a three hour interdisciplinary course on computational intelligence created and taught by the author at the Missouri University of Science and Technology (Missouri S&T), USA for the past five years at the undergraduate and graduate levels. This course is unique in the sense that it covers the main paradigms of CI and their integration to develop hybrid intelligent systems. The idea to introduce a classroom course on CI originated in the author's National Science Foundation (NSF), USA, CAREER proposal, which was submitted in July 2003 and awarded effective 2004 [4]. The author introduced the CI course for the first time as an experimental course and eventually became a permanent one in computer engineering, electrical engineering and systems engineering. The following sections describe the curriculum, which has evolved in the last five years and continues to, assessment, implementation, projects and impacts of this interdisciplinary CI course.

2. Course Curriculum and Implementation

The CI course was implemented for the first time at the Missouri S&T in the Spring Semester of 2004 as an experimental course in the following departments: 1) computer engineering 2) electrical engineering 3) mechanical engineering and 4) systems engineering. This course is of an introductory nature, thus, the course is offered at the 300 level allowing both the undergraduate and graduate students to enroll. The course was offered for the second time as an experimental course in the Fall Semester (FS) of 2005. Thereafter, the course was listed as a permanent course in three disciplines, namely computer engineering (CpE), electrical engineering (EE) and systems engineering (SysEng) and given the course numbers – CpE 358, EE 367 and SysEng 367 respectively. The course has been offered with these course numbers in the FS 2006, FS 2007 and FS 2008, and is scheduled to be offered every Fall Semester. The advantage of offering at the 300 level is that undergraduate students are exposed to the emerging field of computational intelligence; and for graduate students, the course introduces them to dominant CI

Digital Object Identifier 10.1109/MCI.2008.930983

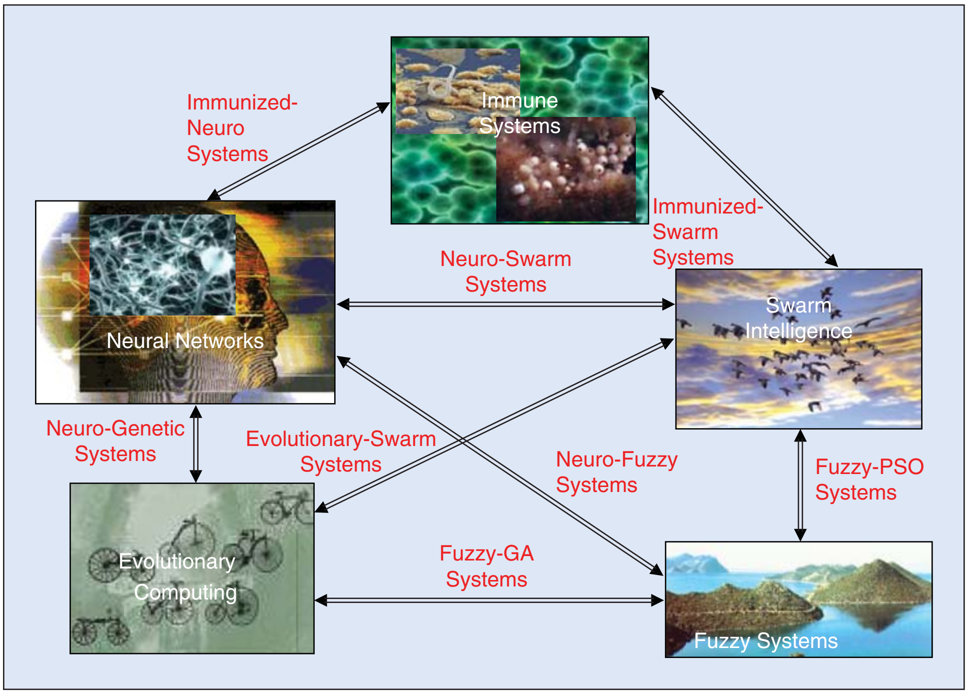

FIGURE 1 Five dominant paradigms of CI and typical hybrids.

paradigms and their interest in any of these paradigms can be broaden by enrolling in a full semester course on either neural networks, fuzzy logic for control or evolutionary computation, which are offered at the Missouri S&T. Missouri S&T undergraduate and graduate catalogs' description for this course is:

> "Introduction to Computational Intelligence (CI), Biological and Artificial Neuron, Neural Networks, Evolutionary Computing, Swarm Intelligence, Artificial Immune Systems, Fuzzy Systems, and Hybrid Systems. CI applications case studies covered include digital systems, control, power systems, forecasting, and time-series predictions."

The CI course is designed around five dominant paradigms, namely, artificial immune systems (AIS), evolutionary computing, fuzzy systems, neural networks (NNs) and swarm intelligence as illustrated in figure 1. To the author's knowledge, similar courses taught elsewhere do not cover all these paradigms in a single semester course.

These paradigms can be combined to form hybrids (as shown in figure 1) resulting in Neuro-Fuzzy systems, Neuro-Swarm systems, Fuzzy-PSO (particle swarm optimization) systems, Fuzzy-GA (genetic algorithms) systems, Neuro-Genetic systems, etc. Designs and developments with hybrid algorithms already exist in literature [5, 6].

The following sections describe the above mentioned five paradigms currently covered in the CI course. Hybrid intelligent systems are developed by the integration of two or more of these paradigms. Hybrid systems are able to capitalize on individual strengths and eliminate weaknesses of the different CI paradigms, thus, offering powerful algorithms for solving complex problems.

2.1. Artificial Immune Systems

The biological immune system is a highly parallel and distributed adaptive system. It uses learning, memory, and associative retrieval to solve recognition and classification tasks. Artificial immune systems are fairly new computational approaches for the CI community [7]. The design of robust controllers using AIS technology is covered among other applications in the course [8]. The clonal selection algorithm (CSA) is good optimization technique [7].

2.2. Evolutionary Computing

Evolutionary computing algorithms are modeled after nature. The algorithms covered include genetic algorithms, genetic programming, evolutionary programming, evolutionary strategies (ESs) differential evolution (DE) and cultural evolution. These algorithms are introduced, with their differences, when and where these algorithms are applicable and a number of case studies in different applications are presented in class [1].

2.3. Fuzzy Systems

Fuzzy logic and systems allow approximate reasoning and modeling of common sense. In this paradigm, the topics covered include fuzzy logic, fuzzy systems, fuzzy interference systems, fuzzy controllers and rough sets. The design of a fuzzy room temperature controller and fuzzy cruise controller is taught in the course in a step by step fashion, taking students through the fuzzification process, interference engine, rule set and the defuzzication process [1].

2.4. Neural Networks

Neural networks are inspired by the biological brain. The topics covered under this paradigm include the biological and artificial neuron models, and supervised and unsupervised learning neural networks. The students are introduced to different NN architectures and types. The differences between static and dynamic neural networks are discussed. More emphasis is given to feedforward networks. A feedforward NN is illustrated in figure 2a and the conventional training algorithm is the backpropagation algorithm [9-12]. Incremental (online) and batch (offline) training modes for neural networks are also introduced.

A feedforward neural network can consist of many layers, namely: an input layer, a number of hidden layers and an output layer. The input layer and the hidden layer are connected by synaptic links called weights and likewise the hidden layer and output layer also have connection weights. When more than one hidden layer exists, weights exist between the hidden layers. The determination of optimal number of weights for a given application is an optimization problem.

NNs use some sort of "learning" rule by which the connections weights are determined in order to minimize the error between the NN output and the desired output. The learning gain and momentum gain have to be carefully selected to maximize accuracy, reduce training time and ensure global minimum. A JAVA based software to illustrate training for a multilayer perceptron (MLP) neural network was developed by the author (screen shot shown in figure 2b) and is used to illustrate the need to carefully select these parameters and their effects [13].

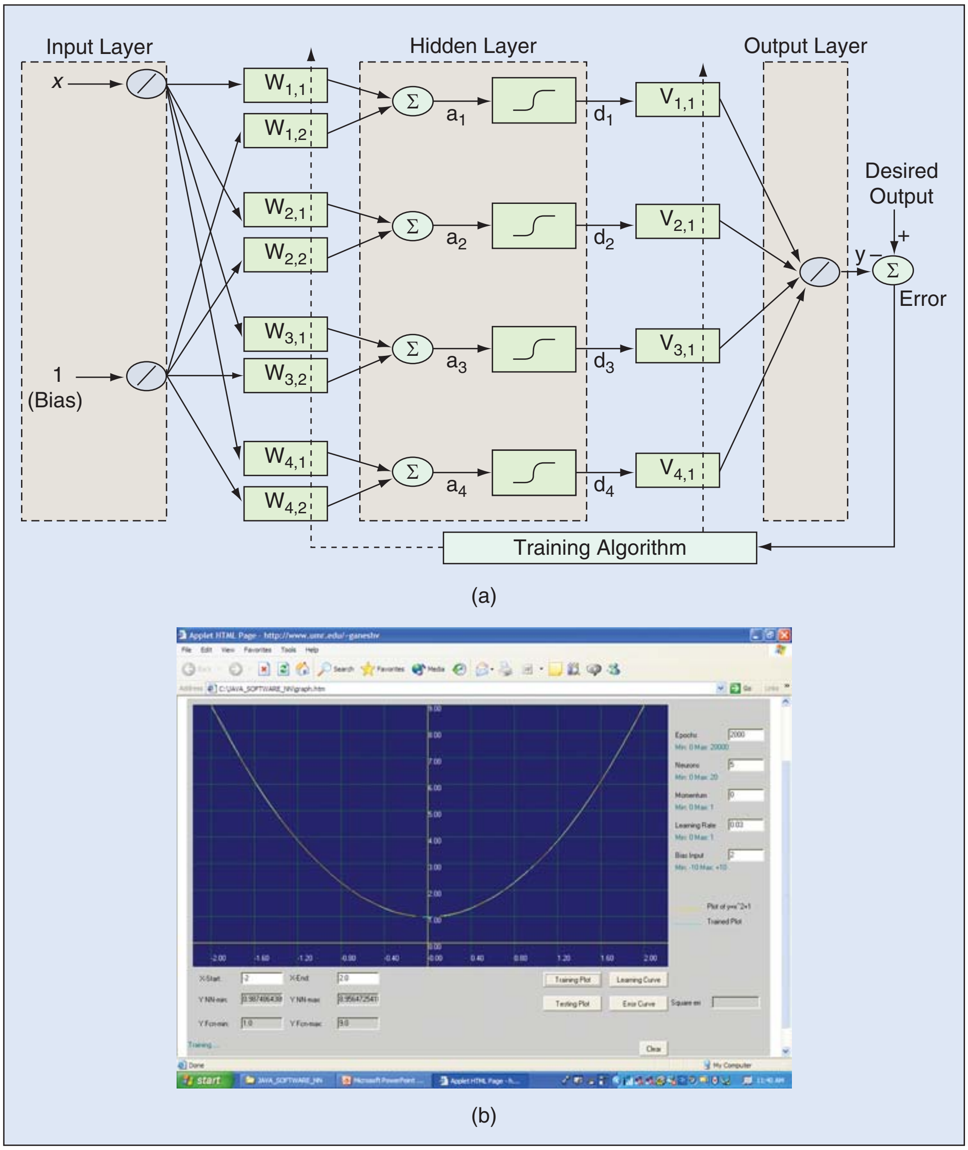

FIGURE 2 (a) Feedforward neural network with one hidden layer and (b) JAVA applet demo for neural network training.

2.5. Swarm Intelligence

Swarm intelligence algorithms like the evolutionary computing ones are modeled after nature. In this paradigm, the topics covered include particle swarm optimization [14, 15], ant colony optimization [16] and bacteria foraging [17]. These algorithms are introduced and their numerous applications are demonstrated in class through examples. The differences between these algorithms, when and where these algorithms are applicable is emphasized. More emphasis and coverage is given to the PSO algorithm and its variants [6]. PSO is an evolutionary-like computational technique (a search method based on natural systems) developed by Kennedy and Eberhart [14, 15]. PSO like a genetic algorithm is a population (swarm) based optimization technique. However, unlike GA, the classical PSO has no evolution operators such as crossover or mutation, and moreover PSO has less number of parameters to tune. PSO is the only evolutionary-like algorithm that does not implement survival of the fittest and unlike other evolutionary algorithms where evolutionary operators are manipulated, the velocity and positions are dynamically adjusted [6].

The CI course is implemented and taught as a semester course, usually within sixteen weeks. The entire course material is delivered in twenty four lectures (12 weeks), with each lecture lasting for 75 minutes. The remaining four weeks of the semester are spent on examinations and project technical presentations and report writing. The prescribed textbook for this course is "Computational Intelligence" by A P Engelbrecht [1] and a suggested reading list is [5-7, 9-11, 13-26].

Based on the growing need of this course, the course was introduced in FS07 as a distance-learning course for off-campus students. All lectures are available for remote live or offline viewing over the internet. Based on the success of this initiative, it is now scheduled as a regular distance-learning class. With this kind of setup, the instructor can remotely teach the class. The author once did this from a hotel room at 2.30 am in Melbourne, Australia in December 2007 while at the

International Conference on Intelligent Sensors, Sensor Networks and Information Processing.

In addition to the regular class instruction, the students are encouraged to attend the IEEE CIS St. Louis Chapter activities and seminars. Many distinguished lecturers of the IEEE CIS Society and other pioneers in the field of CI and its applications are invited to deliver lectures to the Chapter. The author is a founding and current chair of the IEEE CIS St. Louis Chapter. The Chapter's events is an additional resource to CI course students outside the classroom environment. The students participate at such events and benefit from the presentations and the interactions with the distinguished speakers. In order to motivate attendance at such seminars and events, some bonus points that count towards the final course marks are given to the students.

3. Course Assessment

The performance of the students in this course is assessed by several ways including the traditional classroom examinations and quizzes, a semester duration project, a technical presentation(s) and a number of assignments. The typical score distribution is given below.

- 20% Homework/Assignments
- 40% Tests
- 30% Project
- 5% Class presentation
- 5% Quizzes & IEEE CIS St. Louis Chapter seminar attendance

The course typical has eight assignments where students write programs (in MATLAB/C) to train MLP neural networks using supervised learning methods, online and offline, using the standard backpropagation algorithm, CSA, DE, DEPSO (hybrid of PSO and DE) GA, ES and PSO, and learning vector quantization networks using unsupervised (competitive) learning. Tests are usually given every month to evaluate the students' learning and understanding of the concepts and applications of CI. Each test has a defined scope and the students on average demonstrated an 'entirely satisfactory' performance. Typical projects undertaken in this course are described in Section 4. Students make class presentations on their projects, thus, developing their communication and presentation skills. For many undergraduate students, this is their first presentation. Different course grading scheme is used for undergraduates and graduate students.

4. Course Projects

Projects usually involve at least two of five CI paradigms. Projects contributing to the development of CI paradigms and the applications of CI are selected. Depending on the makeup of the class enrolment, groups of two are encouraged among the undergraduate students. Within the first two weeks of the semester, projects are identified by students in consultation with the instructor based on the students' strengths and interests. Industrial projects identified to fall within the scope of the class project are selected and proposed to the students. The students are requested to write a project proposal outlining a) the

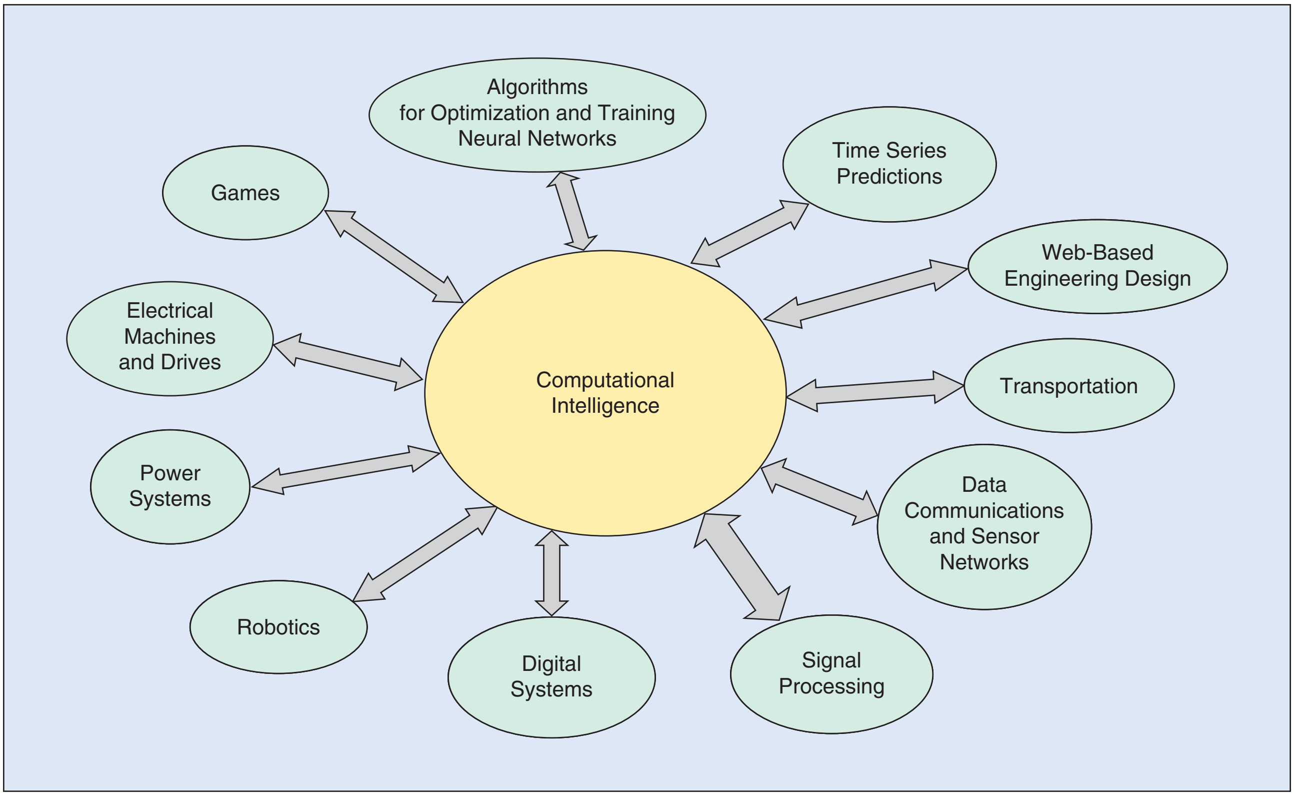

FIGURE 3 Typical CI course project application areas.

problem to be solved; b) some background covering the state of the art solutions; c) the proposed CI techniques based solution; d) a time management plan with milestones; and e) a list of references. A final presentation is given and a technical report is submitted at the end of the semester for project evaluation. Typical projects carried out since the course was introduced fall into many application areas as illustrated in figure 3 and some of these projects are briefly described below. In general, many students were on target with their respective milestones and completed their projects getting some concrete results with the CI algorithms. Some of the project results were publishable while others needed more work to do so.

A number of projects have been carried out to develop new algorithms for training neural networks and solving benchmark optimization problems. Quantum inspired evolutionary algorithms were developed and compared with binary particle swarm optimization for training feedforward and recurrent neural networks on complex problems [27]. Random functions were generated by feedforward neural networks, and learned by feedforward and simultaneous recurrent networks (SRNs), and vice-versa. It is found that functions generated by SRNs were difficult to be accurately mapped by feedforward networks even with a powerful training algorithm, On the contrary, SRNs were able to learn the functions generated by feedforward networks better as the power of training algorithms grew [18, 28].

In the area of digital systems, a project on evolution of digital logic circuits using PSO and DE was carried out [29]. The objective of the evolution was to discover feasible circuits (functional) with minimum number of logic gates. Novel circuits were evolved by PSO and DE and some of these circuits used less number of gates than those found with techniques like the Karnaugh Map. Hybrid algorithms were developed using PSO and DE – DEPSO to yield solutions of better quality than those obtained separately with PSO and DE as the complexity of circuit to be evolved increased [19].

A large number of elephants (figure 4) can be found on small wildlife reserves. When confined to enclosed reserves increases in elephant densities are higher than that observed in the wild. The large nutritional demands and destructive foraging behavior of elephants can threaten rare species of vegetation. If conservation management is to protect threatened species of vegetation, it is essential to know how long elephants stay in one part of the reserve as well as which part they move to next.

A project was carried out to train feedforward and recurrent neural networks to predict an elephant herds' next position in the Pongola Game Reserve in South Africa. Accurate predictions would provide a useful tool in assessing future impact of elephant populations on different areas of the reserve. Particle swarm optimization, PSO initialized backpropagation (PSO-BP) and PSO initialized backpropagation through time (PSO-BPTT) algorithms are used to adapt the neural networks weights. The effectiveness of PSO, PSO-BP and PSO-BPTT for training neural networks for elephant migration prediction was compared and PSO-BPTT produced the most accurate predictions at the expense of more computational cost. The project study is reported in [30-32].

Swarm intelligence has been demonstrated to be a useful tool in target search applications such as collective robotic search (CRS). A number of students liked this application area and several projects have been carried out in robotics. A group of unmanned mobile robots are able to locate a specified target in a high risk environment with extreme efficiency when driven by an optimized PSO based navigation algorithm. A project to incorporate obstacle avoidance algorithms into the PSO approach based navigation for CRS application (figure 5) was carried out. Obstacles represented by basic geometric shapes to simulate perilous ground terrain are introduced to the search area to observe their effect on the performance of the PSO algorithm. The results of this project were reported in [33, 34].

In the area of power systems, and power electronics and drives, there are several CI course projects that have been carried out and a couple of these are briefly described below.

FIGURE 4 African elephant herd in a game reserve.

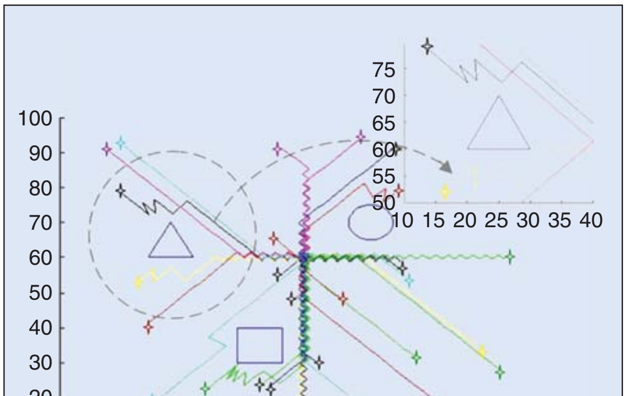

FIGURE 5 Trajectories of a swarm of PSO robots converging on a target with enlargement of one PSO path.

Power system stabilizers (PSSs) are used to damp out low frequency system oscillations occurring as a result of a change in operating condition or a disturbance. How well the oscillations are damped over a wide range of operating conditions and disturbances is dependent on parameters of the PSS and other stabilizing controllers in the system. It is often a challenging task to find these parameters as the size of the power system grows and it becomes necessary to retune the PSS parameters over time. A project was carried out using a small population based PSO (SPPSO) algorithm for optimizing/tuning the parameters of several PSSs simultaneously in power systems. A small population reduces computational cost of the algorithm drastically and thus can be considered as a first step towards online optimization with PSO. A regeneration concept is introduced in SPPSO to retain the 'fast convergence in the first few iterations' property of classical PSO. Results on the PSS design and its performance is elaborated in [17, 35].

Electric ship power system often suffers from severe power quality problems due to high-energy applications such as radar, railguns, and advanced weapons. The dip in bus voltage and the subsequent oscillations are detrimental for navy ships under battle conditions. A project was carried out to design and implement in hardware (figure 6) an optimal excitation controller using PSO to minimize the effects of high energy demand loads. The PSO algorithm was implemented on a digital signal processor. Laboratory results show that the PSO designed excitation controller provides an effective control of a generator's terminal voltage during such high energy loads, restoring and stabilizing it quickly [36].

FIGURE 6 Laboratory setup of a typical ship power system for CI based design of an optimal excitation controller.

Facial expression recognition (FER) has potential applications in different aspects of day-to-day life which has not yet been realized due to the absence of effective expression recognition techniques. A project was carried out on the application of Gabor filters based feature extraction in combination with learning vector quantization (LVQ) for recognition of seven different facial expressions from still pictures of human faces (figure 7). The details and results are presented in [20] and are better in several aspects from earlier work in FER. This study has shown that there is potential for computer based FER for practical applications like surveillance and human computer interaction.

5. Course Challenges, Student Responses and IMPACTS

The introduction of this interdisciplinary computational intelligence course at Missouri S&T has impacted a number of students who have successfully completed the course. However, there have been a lot of challenges in making it successful. Eighty-one students, from nine disciplines, have enrolled for the CI course since it was introduced, namely from aerospace engineering (AE), computer engineering, computer science (CS), electrical engineering, mathematics (Math), mechanical engineering (ME), metallurgical engineering (MET), physics (Phy) and systems engineering. Of the eighty-one students, eighteen of them are undergraduate students.

Every semester, the types of students enrolled are from different backgrounds and levels. The only requirement for students to take this course is a prior course on statistics and some programming background. The instructor's teaching styles and methods come into play to make an integrated and an interdisciplinary class an efficient learning environment. Grasha [37] lists five teaching styles, namely – expert, formal authority, personal model, facilitator and delegator. The primary style that worked well for this class is a mix of the expert, formal authority and personal model and the secondary style that worked is a mix of personal model, facilitator and delegator. Associated with the teaching styles are the teaching methods and the ones that are recommended based on the author's experience for such an interdisciplinary class include involving case studies, critical thinking discussion, emphasizing graded exams, inviting guest

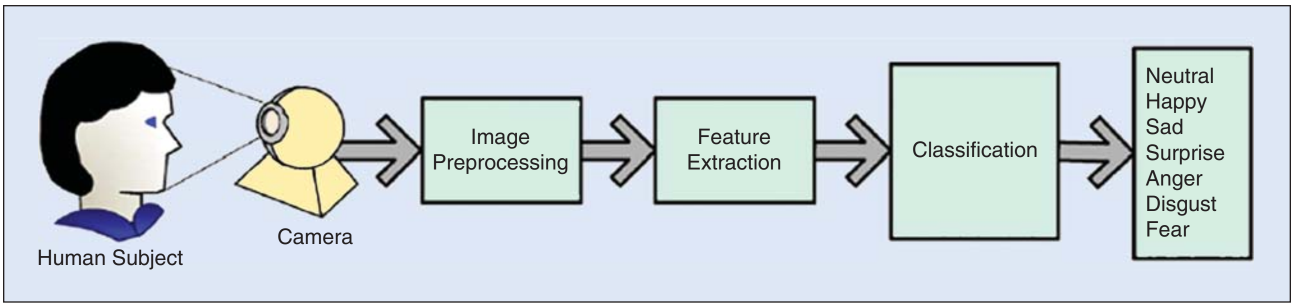

FIGURE 7 An overview of a facial expression recognition system [20].

speakers, provided guided readings, delivering lectures, integrating problem based learning, sharing personal experiences, having teacher-centered questioning and discussions, requiring term papers and mandatory technology-based presentations. In addition to the formal classroom contact hours, office hours were set for students needing assistance to contact the instructor outside the classroom environment. Students that did not hope well just on the formal classroom methods took advantage of the office hours. A mix of formal and informal instructor-student contact is highly recommended to enhance student learning especially in an interdisciplinary course of this nature.

The introduction of a distance-learning class for this course posed different challenges. Students from industries enrolled in the course from different parts of the United States. Different exams were set and a time window for taking the exam was arranged through the blackboard tool.

5.1 Class Size and Course Evaluations

At Missouri S&T, every course and instructor is evaluated by students enrolled in it at the end of semester. Some extracts from the CI course evaluations and size of each semester class enrollments are mentioned below.

(first) CI offering-Spring Semester 2004: Twelve students (two undergraduates and ten graduates) from six disciplines enrolled in the course, namely from AE, CpE, CS, EE, ME and MET. All except the AIS paradigm was taught this semester. The twelve students were grouped into six teams (1 team of undergraduate students and five teams of graduate students) for carrying out the class projects. Here are some of the comments from these students: "Course is well organized, excellent use of research papers and keeping abreast with the ongoing research"; "Great and effective course in CI. It is broad and covers a lot of great topics and relates everything"; "too much of material for a semester course", "the course covers a wide range of paradigms and gives a good understanding of different algorithms", "is better to have students work on projects separately rather in teams", and "the professor is turning his research into instruction".

(second) CI offering-Fall Semester 2005: Sixteen students (four undergraduates and twelve graduates) from three disciplines enrolled in the course, namely from CpEng, EE and Math. All five paradigms mentioned in Section 2 were covered. The project teams were only made for undergraduate students. Comments from some of these students include "the course provides a complete overview of computational intelligence paradigms"; "interesting course material with a good mix of instruction and applications"; "awesome course, needs to be longer!"; "the semester is over and subject is beginning", and "excellent course, learnt a lot".

(third) CI offering-Fall Semester 2006: Eighteen students (four undergraduates and fourteen graduates) from four disciplines enrolled in the course, namely from CpEng, CS, EE and Phy. Undergraduate students were allowed to work individually on their projects or in groups of two but all students chose to work separately. Comments from some of these students include "… it was probably the single best course I have had in college"; "the course is illuminating towards computer engineering, intelligence & psychology. It holds the students' interest & informs them on state-of-the-art technology all at once"; "state-of-the art discussion"; "time runs out fast and there is a lot more to learn in CI", and "… it's a great learning course".

(fourth) CI offering-Fall Semester 2007: Sixteen students (three undergraduates and thirteen graduates) from four disciplines enrolled in the course, namely from CpE, CS, EE and SysEng. One of the students in CpE was a distance student. Here are some of the comments from these students: "evolving, one can think of linking his main project with computational intelligence thus giving it touch of automation"; "course is crisp and sound"; "new algorithms are learned to solve classic problems, high practical value"; "one semester is too short for CI … topics are crammed together…, it is field by its own right" and "very interesting topics focused on".

(fifth) CI offering-Fall Semester 2008: Nineteen students (five undergraduates and fourteen graduates) from five disciplines enrolled in the course, namely from CpE, CS, EE, ME and SysEng. Five of these students were distance students. Evaluations are yet to be released for this semester at the time this article was written up.

Overall, the students in the last five years liked all the paradigms of CI. Their excitement about the field of CI grew as they were introduced to the different paradigms in class. Every time the course is offered, highlights of recent innovations in the theory of CI and new applications are presented in class. The students always look forward to their peers' project presentations, and to see what solutions have been obtained and contributions made as result of applying CI to their specific problems.

5.2 Conference Proceedings and Journal Publications

Some of the course projects, briefly described in Section 4, are topics researchers in different disciplines are investigating and definitely breakthroughs in these areas are publishable. Many project technical reports have resulted in refereed conference papers [18, 27, 28, 30, 33, 35, 36] which have been presented at different conferences including the IEEE Swarm Intelligence Symposiums, International Joint Conference on Neural Networks, IEEE World Congress on Computational Intelligence, IEEE Congress on Evolutionary Computation, IEEE Power Engineering Society's General Meeting, and Neurocomputing and Evolving Intelligence. For many, if not, all students, this was their first paper. In addition, to learning the CI paradigms in this course, students learn how to write their first technical article and make their first presentation. A brief introduction to 'writing a technical paper and making a technical presentation' is given in class. The spirit for learning for many spirits is fueled especially when they realize they are about to adventure into a project that can possibly make a new contribution. Students burning with passion to pursue their projects further have done so and published in refereed journals [17-21, 32, 38] and edited books [34].

5.3 Research and Travel Grants

CI course alumni have received several research and travel grants from Missouri S&T Opportunities for Undergraduate Research (OURE) program, NSF and IEEE. The OURE grants are given to undergraduates who are interested in carrying out research possibly leading to graduate studies. Phillip Moore (2004 CI course alumnus), and Lisa Grant and Parviz Palangapour (2005 CI course alumni) are some of the recipients of such grants. Tridib Das and Parviz Palangpour, 2005 CI course alumni, were recipients of the IEEE CIS travel grants to attend the 2006 IEEE World Congress on Computational Intelligence in Vancouver, BC, Canada and presented their papers that were born from the CI course project [17, 31]. Furthermore, Tridib Das also received the IEEE Industry Applications Society (IAS) Myron Zucker travel grant (a highly competitive one) in order to attend the 2006 IEEE IAS annual meeting and present a second paper that originated from his CI course project [17].

Two of the CI course alumni, Tridib Das and Yusuf Yare won the 2006 and 2007 IEEE CIS Walter Karplus summer research grants for their research proposals "Bio-Inspired Algorithms for the Design of Optimal Controllers for Power System Stabilization" and "Optimal Maintenance Scheduling of Power Systems using an Algorithm Inspired by Swarm Intelligence and Quantum Evolution" respectively. The results of these proposals have been published in the *IEEE Transactions on Industry Applications* [17] and *IET Generation, Transmission and Distribution Proceedings* [38] respectively.

5.4 Design Competitions and Paper Contest

There are several competitions the alumni of CI course have competed in and won awards. A highlight on some of them is given here. Palangpour and Grant, alumni of FS 2005 CI class, participated in the 2006 Missouri S&T undergraduate conference, and won the first and third prize respectively among all papers in the Engineering oral presentations. Their papers were "Elephant Migration Prediction Using Neural Networks" and "Collective Robotic Search Using PSO" respectively. At the 2007 Missouri S&T undergraduate conference, Grant won the first prize among all papers in the Engineering oral presentations for her paper titled "Collective Robotic Search with Obstacle Avoidance Using PSO". Shishir Bashyal, an alumni of 2006 CI class, competed in the 2007 Missouri S&T Graduate Poster competition and won the third prize for his poster paper titled "Facial Expression Recognition Using Gabor Wavelets and LVQ". A team of three students–Grant, Palangpour and Parrott, undertook the hardware implementation of a PSO navigation algorithm for five iRobot Roomba robots for their undergraduate senior design project. When their project was successfully completed, they submitted their project report for the 2007 IEEE Industry Application Myron Zucker student design competition and won the first prize internationally. They were then invited to write an article for the *IEEE Industry Applications Magazine* [39].

5.5 Related Follow-on CI courses

In addition to the CI course, the author has introduced many other CI related courses to the CpE and EE curricula, namely – adaptive devices, circuits and systems (evolvable hardware), adaptive critic designs, CI methods in electric power, and advanced neural networks and hardware implementations. The first third are already implemented at Missouri S&T. In order for students to enroll in these courses, the requirement is that they have passed the course on CI. Many students have succeeded in the follow-on courses as a direct result of the CI course. The curricula of these courses and many other resources are available on the author's personnel website – http://web.mst.edu/~ganeshv.

5.6 Graduate Studies and Thesis

The CI and related follow-on courses have motivated many students to pursue graduate studies at Missouri S&T and elsewhere. Some of these students who are pursuing a PhD degree at Missouri S&T include Lisa Grant, Chris Hutson, Cameron Johnson, Parviz Palangpour, Curtis Parrott and Richard Welch. All these students are US Dept. of Education GAANN fellows [40] contributing to a GAANN project [41]. Besides, many CI course alumni focused their graduate thesis research on the development and application of CI to specific problems in their discipline of interest [42-50]. Missouri S&T is introducing a Graduate Certificate program in CI and one of the core courses is this course on CI.

6. Conclusions

This interdisciplinary computational intelligence course is unique in the sense that it introduces students to major paradigms of CI in a single semester. The students that took this course at the Missouri University of Science and Technology, USA over the last five years consisted of eighteen undergraduates and sixty-three graduate students from nine different disciplines across schools and colleges. The feedback received from students is mainly the great exposure to several paradigms of computational intelligence in one integrated semester course. Industrial and research oriented projects are encouraged so as to educate students that the field of CI has potentials and is promising for solving many real-world problems that cannot be tackled with conventional methods. Several CI course students have succeeded in publishing their projects in refereed conference proceedings and journals. Most of the graduate students who took the course ended up with a thesis topic involving one or more paradigm(s) of computational intelligence. Overall, the introduction of an interdisciplinary computational intelligence course at the undergraduate and graduate levels at the Missouri S&T has been a very successful and rewarding effort despite the challenges and time investment. Based on first hand experiences of the author, it is highly recommended that such a course on computational intelligence be introduced and taught regularly at colleges and universities across the world. The author has personally enjoyed developing and teaching this course on CI which has contributions to many disciplines.

Acknowledgments

The financial support from the National Science Foundation (USA) under the CAREER Grant: ECCS# 0348221 and CCLI Grant: DUE # 0633299 is gratefully acknowledged for the development of this course. The author is grateful for the following departments at the Missouri University of Science and Technology for offering the experimental course on computational intelligence to their students: Electrical and Computer Engineering, Mechanical Engineering and Systems Engineering.

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