DEVELOPING AND TEACHING GRADUATE COURSES IN COMPUTATIONAL INTELLIGENCE

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ABSTRACT:
This paper discusses the first-hand experiences of the author in developing and teaching courses in neural networks, evolutionary computing and fuzzy logic. While these courses are offered at the graduate level in a school of engineering, they have attracted a variety of students from many engineering disciplines, from medical studies, from business school, from mathematics and statistics, and from information sciences. The paper discusses course content, textbooks and written material, software and computer projects, and grading and evaluation.

INTRODUCTION

The advent of new computational techniques inspired by nature has resulted in the publication of many new books and journals, new organizations and conferences, and a new group of graduate students who want to learn about these techniques. Developing new courses at the graduate level is time consuming and challenging. For new courses in computational intelligence, development is complicated because the fields are rapidly changing, few comprehensive textbooks exist, students with a wide variety of backgrounds and interests are attracted, and software implementation is an open issue. This paper will focus on traditional university courses with the main emphasis on graduate education. However, it must be noted that there are many non-traditional means of instruction in computational intelligence. There are short courses presented by experts from both academia and industry, there are instructional video tapes, and there are tutorial sessions during many conferences.

A very few papers in the literature have addressed computational intelligence education or courses. Winston describes a course in neural networks designed for working engineers [32]. Lee and Edwards write about a course in power plant control that emphasizes techniques from computational intelligence including fuzzy systems, neural networks and expert systems at the Pennsylvania State University [19]. Fowler and Hudson of Kansas State University describe a distance learning course for electrical engineering students on fuzzy logic and neural networks [6]. Another course focusing on electrical engineering was described by Ribeiro and Rogers at Dordt College in Iowa [26]. This course covers the analysis of power signals (currents and voltages) using wavelets, genetic algorithms, expert systems, fuzzy logic and neural networks. The rest of the paper describes courses developed by the author in neural networks, heuristic optimization and fuzzy logic.

NEURAL NETWORKS

The course, Neural Networks and Industrial Applications, has been taught three times (1993, 1995, 1997). This three credit graduate course has no prerequisites and has attracted Masters and PhD students from the following engineering departments; industrial, civil, chemical, electrical and mechanical. It has also attracted business school students, mathematics and statistics students, and medical school students. Most students have been full time graduate students, but some were working in industry pursuing a Masters degree part time. The course has been taught using Zurada's *Introduction to Artificial Neural Systems* (first time) [34] and Fausett's *Fundamentals of Neural Networks* (last two times) [4]. Other possible textbooks are Schalkoff's *Artificial Neural Networks* [28], Mehrotra, Mohan and Ranka's *Elements of Artificial Neural Networks* [22], Hassoun's *Fundamentals of Artificial Neural Networks* [11], Freeman and Skapura's *Neural Networks: Algorithms, Applications, and Programming Techniques* [7], Hagan, Demuth and Beale's *Neural Network Design* [10] and Haykin's *Neural Networks: A Comprehensive Foundation* [12]. The Haykin book is more advanced and detailed than the others, and is probably more appropriate for advanced students. A new book aimed at civil engineers is *Artificial Neural Networks for Civil Engineers: Fundamentals and Applications* edited by Kartam, Flood and Garrett [14]. Another focused book is *Pattern Recognition Using Neural Networks* by Looney [20].

The syllabus starts with simple and historic neural network paradigms including Hebbian learning and perceptrons. Then backpropagation and its variants are discussed, followed by pattern association (Hopfield, bi-directional associative memory). Self organization come next (Kohonen's networks, counterpropagation and adaptive resonance theory (ART) I). Using neural networks for optimization (Hopfield, Kohonen, elastic net) is presented. Radial basis function networks are covered, then a brief introduction to cascade correlation and the neocognitron is made. The semester concludes with lectures on model building and validating, and hardware (analog, digital and optical) implementations of neural networks. For each network paradigm, the motivation, mathematical algorithm and associated theory are presented along with applications from the literature. Comparisons between paradigms, including their relative advantages and disadvantages, are made.

Software is necessary for any course in neural networks. Where possible, students should be encouraged to code their own neural networks as this greatly enhances algorithm understanding. However, for many students, coding a variety of network learning algorithms and architectures is burdensome and detracts from their learning experience. For these students, commercial software such as the NeuralWorks Explorer package [23], can be very useful. The author has developed a software package, Pittnet, to be used for neural network education and academic research [3]. It is coded in C++ and includes backpropagation, the Kohonen self organizing map, ART 1 and the radial basis function network. Students in the author's course have used the Explorer package [23], the Pittnet package [3], the Brainmaker package for backpropagation [2] and coded their own. The Explorer has the most breadth but is harder to use (many options and settings are available).

The course emphasizes hands-on learning with homeworks (6 assignments) and 1 exam. The homeworks are essential to learn each paradigm. A mix of manual problems (done by hand, calculator or spreadsheet) and software problems (data sets and functions to be explored through the use of software neural networks) are included. The manual problems are useful for the students to understand the micro-level of each paradigm while the software problems help the student appreciate the many "artful" issues in neurocomputing. For classification problems, simple alphabet recognition problems where letters are binary coded on a grid are useful. A small, but challenging function approximation problem is $y = 4.26(e^{-x} - 4e^{-2x} + 3e^{-3x})$. The students are asked to explore different network architectures, parameter settings, noise level in the data, data set sizes, etc. Semester projects that students have done include robotic control, financial and time series prediction, handwriting and Braille character recognition, and cellular manufacturing clustering.

HEURISTIC OPTIMIZATION

This course is an advanced industrial engineering graduate elective in operations research and has been offered twice. It covers many recent techniques in optimization that have been inspired by nature. The topics are simulated annealing (2 weeks), genetic algorithms (3 weeks), evolutionary strategies (1 week) and tabu search (2 weeks). Neural network optimization is not addressed as it is covered in the course discussed above. About 1 week each is spent on related heuristics, hybrid approaches and handling constraints. Both combinatorial and continuous optimization problems are addressed. The book *Modern Heuristic Techniques for Combinatorial Problems* by Reeves [25] has been used, but is supplemented heavily by papers, especially for the evolutionary algorithms. Other possible texts are *Evolutionary Algorithms in Theory and Practice* by Baeck [1], *Genetic Algorithms in Search, Optimization and Machine Learning* by Goldberg [9], *Evolutionary Computation* by Fogel [5], *Evolution and Optimum Seeking* by Schwefel [29], and *Genetic Algorithms and Engineering Design* by Gen and Cheng [8]. This last book is aimed at those in manufacturing systems, industrial engineering and operations research. None of these books are comprehensive, however, as is the Reeves book.

It is this author's opinion that none of the available software on these techniques should be used for teaching as each optimization problem requires its own encoding and approach. The techniques are straightforward to code, and the course starts with the simplest one (simulated annealing). The course is homework and project oriented with no exams. One homework assignment per each of the five modules (the general heuristic approach, simulated annealing, genetic algorithms, evolutionary strategies, tabu search) is made. Besides the homeworks, each student or group of two students produces a semester long project. The homeworks involve the students coding and testing the approaches on several well known problems. The quadratic assignment problem (QAP) is a good combinatorial study vehicle. It is easy to understand and has been thoroughly investigated in the literature using traditional techniques and the newer heuristics. The Nugent [24] test suite of problems ranges from 5 to 30 departments, providing nice scale-up testing. Another possible study vehicle is the traveling salesman problem (TSP). For continuous optimization, a good sized test problem is the six hump camelback function where x lies between ±3 and y lies between ±2. The objective is to minimize z. The global minimum lies at (-0.0898, 0.7126) where $z = -1.0316$.

$$z = [4 - 2.1x^2 + x^4/3]x^2 + xy + [-4 + 4y^2]y^2$$

This course has been well received, with a large percentage of students pursuing Masters or PhD theses in the area. Some projects include design of reliable networks, optimizing cellular manufacturing layouts and tooling, curve fitting and system identification, using space filling curves for TSP, and variations of the minimum spanning tree problem. The necessity of programming has discouraged some students from taking the class, however there does not seem to be any reasonable or effective way around this barrier.

FUZZY LOGIC

This course is a joint offering between Electrical Engineering and Industrial Engineering and is cross-listed. Because of this, the course has attracted electrical engineering students (about 60%), industrial engineering students (about 30%) and others, mainly biomedical engineers. The text used has been *Fuzzy Logic With Engineering Applications* by Ross [27]. This text is very comprehensive, however some of the problems at the end of the chapters are confusing and were not received well by the students. The text was supplemented with more details from other texts and papers, especially on control, clustering and real applications. A more mathematical and logic oriented text is Klir and Folger's *Fuzzy Sets, Uncertainty, and Information* [15]. Other possibilities are *Fuzzy Logic and Control*, edited by Jamshidi, Vadiee and Ross [13], *Fuzzy Set Theory and Its Applications* by Zimmermann [33], *A Course in Fuzzy Systems and Control* by Wang [31], *Fuzzy Set Theory* by Klir, St. Clair and Yuan [16], and *Fuzzy Engineering* by Kosko [18]. The first book includes some real, detailed applications.

The grading basis for the course consisted of a single exam, given midway through the course, a semester long project (individuals or pairs) and five homework assignments. The homeworks consisted of mostly manual problems with some that required software or spreadsheet implementation. Most students used some self-developed software for their projects while a few used the TilShell fuzzy logic software by Togai Infralogic [30]. Some students coded in languages such as C or Basic, but most used Matlab. The topics were covered in this order:

1. Motivation and basic description of fuzzy logic.
2. Membership functions, methods of composition, methods of fuzzification and defuzzification.
3. Expert systems and fuzzy logic.
4. Clustering and pattern classification and fuzzy logic.
5. Control systems and fuzzy logic.

Some time was spent interactively with the students motivating the need and utility of fuzzy logic at the course's onset. It was important to convince them of the relevance of fuzzy logic to current and future engineering problems. The basics were covered without much mathematical theory or formal logic constructs. The simplest and classic rules (max, min, centroid defuzzification) were emphasized. The module on rule based systems first required an introduction to expert systems, modus ponens logic, backward or forward chaining, and other fundamental aspects. Then the advantages of fuzzy logic were presented, and students were required to construct their own simple rule bases, without and with fuzzy logic. The clustering module proved to be novel to all students. First, an introduction to the field of clustering and classification was given, culminating in the standard c-means algorithm. Then, fuzzy c-means was introduced along with various measures of cluster appropriateness. A C code of the classic and fuzzy versions of c-means was given to the students to use for homework and projects. Some classic pattern classification tasks studied included the two class, 15 data points butterfly shown as Figure 1. Fuzzy edge detection algorithms for machine vision and medical image processing were also introduced.

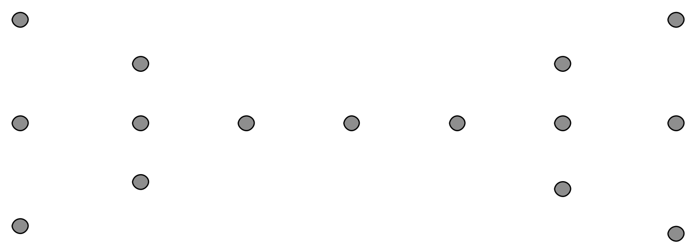

Figure 1: Classic butterfly problem for pattern classification.

The control systems module was problematic in that the electrical engineering students (the majority of the class) were well versed in control theory, while the other students knew little or nothing. The two lecture review of classic control theory was tedious for the electrical engineers and somewhat overwhelming to the others. However, once the subject of fuzzy control was tackled, the class quickly equalized. Mamdani and Assilian's original motor controller [21] was studied in depth.

Student projects consisted of a variety of topics, reflecting their diverse backgrounds and research interests. These included chemical plant control, clustering of MRI brain tissue images, an expert system to diagnose bar coding equipment faults, robotic motor control, dynamic valve control for respiratory devices, and classification of locomotives by sound waves. Many of the students were part time Masters students who applied fuzzy logic to problems from their jobs. The student reviews were positive, although improvements need to be made to ease the differences in backgrounds and interests of the electrical and industrial engineers.

ACKNOWLEDGMENT

The author gratefully acknowledges support of the National Science Foundation CAREER grant DMI 95-02134.

REFERENCES

[1] Baeck, Thomas, *Evolutionary Algorithms in Theory and Practice*, Oxford University Press, New York, NY, 1996.

[2] *Brainmaker User's Guide* and software, California Scientific Software, Nevada City, CA, various years.

[3] Carnahan, Brian and Alice E. Smith, *User's Guide to Pittnet Neural Network Educational Software*, University of Pittsburgh, Department of Industrial Engineering Technical Report, 1996. Also available at http://www.pitt.edu/~aesmith/.

[4] Fausett, Laurene, *Fundamentals of Neural Networks*, Prentice Hall, Englewood Cliffs, NJ, 1994.

[5] Fogel, David B., *Evolutionary Computing*, IEEE Press, New York, NY, 1995.

[6] Fowler, Eddie R. and William B. Hudson, "Distance education from the faculty perspective," *Proceedings of the 1994 24th Annual Conference on Frontiers in Education*, San Jose, CA, 1994, 583-585.

[7] Freeman, James A. and David M. Skapura, *Neural Networks: Algorithms, Applications, and Programming Techniques*, Addison-Wesley, Reading, MA, 1992.
[8] Gen, Mitsuo and Runwei Cheng, *Genetic Algorithms and Engineering Design*, John Wiley, New York, NY, 1997.
[9] Goldberg, David E., *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison-Wesley, Reading, MA, 1989.
[10] Hagan, Martin T., Howard B. Demuth and Mark Beale, *Neural Network Design*, PWS Publishing, Boston, MA, 1996.
[11] Hassoun, Mohamad H., *Fundamentals of Artificial Neural Networks*, The MIT Press, Cambridge, MA, 1995.
[12] Haykin, Simon, *Neural Networks: A Comprehensive Foundation*, Macmillan College Publishing, New York, NY, 1994.
[13] Jamshidi, Mohammad, Nader Vadiee and Timothy J. Ross, editors, *Fuzzy Logic and Control*, Prentice Hall, Englewood Cliffs, NJ, 1993.
[14] Kartam, Nabil, Ian Flood and James H. Garrett, Jr., editors, *Artificial Neural Networks for Civil Engineers: Fundamentals and Applications*, ASCE Press, New York, NY, 1997.
[15] Klir, George J. and Tina A. Folger, *Fuzzy Sets, Uncertainty, and Information*, Prentice Hall, Englewood Cliffs, NJ, 1988.
[16] Klir, George J. and Bo Yuan, *Fuzzy Sets and Fuzzy Logic*, Prentice Hall, Upper Saddle River, NJ, 1995.
[17] Klir, George J., Ute H. St.Clair and Bo Yuan, *Fuzzy Set Theory*, Prentice Hall, Upper Saddle River, NJ, 1997.
[18] Kosko, Bart, *Fuzzy Engineering*, Prentice Hall, Upper Saddle River, NJ, 1997.
[19] Lee, Kwang Y., "Curriculum for development of power plant intelligent distributed control," *Proceedings of the 1995 Annual ASEE Conference*, Anaheim, CA, 1995, 1065-1071.
[20] Looney, Carl G., *Pattern Recognition Using Neural Networks*, Oxford University Press, New York, NY, 1997.
[21] Mamdani, E. H. and S. Assilian, "An experiment in linguistic synthesis with a fuzzy logic controller," *International Journal of Man-Machine Studies* **7**, 1975, 1-13.
[22] Mehrotra, Kishan, Chilukuri K. Mohan and Sanjay Ranka, *Elements of Artificial Neural Networks*, The MIT Press, Cambridge, MA, 1997.
[23] *NeuralWorks Reference Guide* and Explorer software, NeuralWare, Pittsburgh, PA, various years.
[24] Nugent, C. E., T. E. Vollmann and J. Ruml, "An experimental comparison of techniques for the assignment of facilities to locations," *Operations Research* **16**, 1968, 150-173.
[25] Reeves, Colin R., editor, *Modern Heuristic Techniques for Combinatorial Problems*, John Wiley & Sons, New York, 1993.
[26] Ribeiro, Paulo F. and David A. Rogers, "Power electronics, power quality and modern analytical tools: the impact on electrical engineering education," *Proceedings of the 1994 24th Annual Conference on Frontiers in Education*, San Jose, CA, 1994, 448-451.
[27] Ross, Timothy J., *Fuzzy Logic with Engineering Applications*, McGraw-Hill, New York, NY, 1995.
[28] Schalkoff, Robert J., *Artificial Neural Networks*, McGraw-Hill, New York, NY, 1997.
[29] Schwefel, Hans-Paul, *Evolution and Optimum Seeking*, John Wiley & Sons, New York 1995.
[30] *TilShell User's Manual* and software, Togai Infralogic, Inc., Irvine, CA, various years.
[31] Wang, Li-Xin, *A Course in Fuzzy Systems and Control*, Prentice Hall, Upper Saddle River, NJ, 1997.
[32] Winston, Arthur W., "Use of neural networks in engineering applications and the education of engineering leaders," *Proceedings of the 1995 Annual ASEE Conference*, Anaheim, CA, 1995, 2828-2834.
[33] Zimmermann, H.-J., *Fuzzy Set Theory and Its Applications, Second Edition*, Kluwer Academic Publishers, Boston, MA, 1991.
[34] Zurada, Jacek M., *Introduction to Artificial Neural Systems*, West Publishing Group, St. Paul, MN, 1992.