

Enhancing Online Learning Performance: An Application of Data Mining Methods¹

Behrouz Minaei-Bidgoli¹, Gerd Kortemeyer², William F. Punch¹

¹ Genetic Algorithms Research and Applications Group (GARAGe),
Department of Computer Science & Engineering, Michigan State University
2340 Engineering Building, East Lansing, MI 48824, USA
{minaeibi, punch}@cse.msu.edu
<http://garage.cse.msu.edu>

² Division of Science and Math Education, Michigan State University,
College of Natural Science, LITE lab, East Lansing, MI 48824, USA
korte@lite.msu.edu
<http://www.lon-capa.org>

Abstract. Recently web-based educational systems collect vast amounts of data on user patterns, and data mining methods can be applied to these databases to discover interesting associations based on students' features and the actions taken by students in solving homework and exam problems. The main purpose of data mining is to discover the hidden relationships among the data points within given data sets. Classification has emerged as a popular data mining task to find a model for grouping the data points based on extracted features of the training samples. This paper proposes a model for feature importance mining within a web-based educational system and represents an approach for classifying students in order to predict their final grades based on features extracted from logged data in the online educational system. A combination of multiple classifiers leads to significant improvement in classification performance. By weighing feature vectors representing feature importance using a Genetic Algorithm we can optimize the prediction accuracy and obtain significant improvement over raw classification. This approach is easily adaptable to different types of online courses, different population sizes, and allows for different features to be analyzed. This work represents a rigorous application of known classifiers as a means of analyzing and comparing use and performance of students who have taken a technical course that was partially/completely administered via the web.

Index Terms – Web-based Educational System, Data Mining, Classification fusion, Genetic Algorithm

1 Introduction

The ever-increasing progress of network-distributed computing and particularly the rapid expansion of the web have had a broad impact on society in a relatively short period of time. Education is on the brink of a new era based on these changes. Online delivery of educational instruction provides the opportunity to bring colleges and universities new energy, students, and revenues. Many leading educational institutions are working to establish an online teaching and learning presence. Several web-based educational systems with different capabilities and approaches have been developed to deliver online education in an academic setting. In particular, Michigan State University (MSU) has pioneered some of these systems to provide an infrastructure for online instruction. The research presented here was performed on a part of the latest online educational system

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developed at MSU, the *Learning Online Network with Computer-Assisted Personalized Approach (LON-CAPA)* [1].

This system outperforms other course management systems in three important points with respect to the learning assessment. The first is its capability to individualize problems, both algorithmic numerical exercises as well problems that are qualitative and conceptual [2]. The second is in the tools provided that allow instructor to collaborate in the creation and sharing of content in a fast and efficient manner, both within and across institutions [3]. And the third is its one-source multiple target capabilities: that is, its ability to automatically transform one educational resource, for example a numerical or conceptual homework question, into a format suitable for multiple uses [4].

LON-CAPA is involved with three kinds of large data sets: 1) educational resources such as web pages, demonstrations, simulations, and individualized problems designed for use on homework assignments, quizzes, and examinations; 2) information about users who create, modify, assess, or use these resources; and 3) activity log databases which log actions taken by students in solving homework and exam problems. In other words, we have three ever-growing pools of data.

This paper investigates methods for extracting useful and interesting patterns from these large databases using online educational resources and their recorded paths within the system. We aim to answer the following research questions: Can we find *classes* of students? In other words, do there exist groups of students who use these online resources in a *similar* way? If so, can we predict a class for any individual student? With this information, can we then *help* a student use the resources better, based on the usage of the resource by other students in their groups? We find similar patterns of use in the data gathered from LON-CAPA, and eventually make predictions as to the most-beneficial course of studies for each learner based on their past and present usage. The system could then make suggestions to the learner as to how best to proceed.

2 Datasets and Features

We selected 10 student/course data sets of LON-CAPA courses, which were held at MSU in spring semester 2003 (SS03) as shown in Table 1. For example, the second row of the table shows that BS111 03 (Biological Science: Cells and Molecules) was held in spring semester 2003 and contained 229 online homework problems, and 402 students used LON-CAPA for this course. The BS111 course had an activity log with approximately 368 MB.

Table 1. Characteristics of 10 of MSU courses, which held by LON-CAPA

| Course | Title | # of Students | # of Problems | Size of Activity log | Size of useful data | # of Transactions |
|----------|---|---------------|---------------|----------------------|---------------------|-------------------|
| ADV 205 | Principles of Advertising | 609 | 773 | 82.5 MB | 12.1 MB | 424,481 |
| BS 111 | Biological Science: Cells and Molecules | 402 | 229 | 367.6 MB | 50.2 MB | 1,689,656 |
| CE 280 | Civil Engineering: Intro Environment Eng. | 178 | 19 6 | 28.9 MB | 3.5 MB | 127,779 |
| FI 414 | Advanced Business Finance | 169 | 68 | 16.8 MB | 2.2 MB | 83,715 |
| LBS 272 | Lyman Briggs School: Physics II | 102 | 166 | 73.9 MB | 15.3 MB | 585,524 |
| MT 204 | Medical Tech.: Mechanisms of Disease | 27 | 150 | 5.2 MB | 0.7 MB | 23,741 |
| MT 432 | Clinic Immun. & Immunohematology | 62 | 150 | 20.0 MB | 2.4 MB | 90,120 |
| PHY 183 | Physics Scientists & Engineers I | 306 | 255 | 210.1 MB | 26.8 MB | 889,775 |
| PHY 231c | Introductory Physics I | 99 | 247 | 67.2 MB | 14.1 MB | 536,691 |
| PHY 232 | Introductory Physics II | 220 | 259 | 138.5 MB | 19.7 MB | 981,568 |

Using some perl script modules for cleansing the data, we found 48 MB of useful data in the BS111 SS03 course. We then pulled from these logged data 1,689,656 transactions (interactions between students and homework/exam/quiz problems) from which we extracted the following nine features:

1. Total number of tries for doing homework. (Number of attempts before correct answer is derived)
2. Total number of correct answers. (Success rate)
3. Getting the problem correct on the first try vs. those with high number of tries. (Success at the first try)
4. Getting the problem correct on the second try
5. Getting the problem correct between 3 and 9 tries
6. Getting the problem correct with a high number of tries (10 or more tries).
7. Total time that passed from the first attempt, until the correct solution was demonstrated, regardless of the time spent logged in to the system
8. Total time spent on the problem regardless of whether they got the correct answer or not
9. Participating in the communication mechanisms, vs. those working alone. LON-CAPA provides online interaction both with other students and with the instructor

Based on the above extracted features in each course, we classify the students, and try to predict for every student to which class he/she belongs. We categorize the students with one of two class labels: “*Passed*” for grades higher than 2.0, and “*Failed*” for grades less than or equal to 2.0 where the MSU grading system is based on grades from 0.0 to 4.0.

3 Classification fusion

Pattern recognition has a wide variety of applications in many different fields, such that it is not possible to come up with a single classifier that can give good results in all cases. The optimal classifier in every case is highly dependent upon the problem domain. In practice, one might come across a case where no single classifier can achieve an acceptable level of accuracy. In such cases it would be better to pool the results of different classifiers to achieve the optimal accuracy. Every classifier operates well on different aspects of the training or test feature vector. As a result, assuming appropriate conditions, combining multiple classifiers may improve classification performance when compared with any single classifier.

The scope of this study is restricted to comparing some popular non-parametric pattern classifiers and a single parametric pattern classifier according to the error estimate. Four different classifiers using the LON-CAPA dataset are compared in this study. The classifiers used in this study include *Quadratic Bayesian classifier*, *1-nearest neighbor (1-NN)*, *k-nearest neighbor (k-NN)*, *Parzen-window*.² These are some of the common classifiers used in most practical classification problems. After some preprocessing

² The classifiers are coded in MATLAB™ 6.5.

operations the optimal $k=3$ is chosen for kNN algorithm. To improve classification performance, a fusion of classifiers is performed.

Normalization. Having assumed in Bayesian and Parzen-window classifiers that the features are normally distributed, it is necessary that the data for each feature be normalized. This ensures that each feature has the same weight in the decision process. Assuming that the given data is Gaussian, this normalization is performed using the mean and standard deviation of the training data. In order to normalize the training data, it is necessary first to calculate the sample mean μ , and the standard deviation σ of each feature in this dataset, and then normalize the data using the equation (1).

$$x_i = \frac{x_i - \mu}{\sigma} \quad (1)$$

This ensures that each feature of the training dataset has a normal distribution with a mean of zero and a standard deviation of unity. In addition, the kNN method requires normalization of all features into the same range.

Combination of Multiple Classifiers. In combining multiple classifiers we improve classifier performance. There are different ways one can think of combining classifiers:

- The simplest way is to find the overall error rate of the classifiers and choose the one which has the least error rate on the given dataset. This is called an *offline classification fusion*. This may appear to be a classification fusion; however, in general, it has a better performance than individual classifiers.
- The second method, which is called *online classification fusion*, uses all the classifiers followed by a vote. The class getting the *maximum votes* from the individual classifiers will be assigned to the test sample.

Using the second method we show that classification fusion can achieve a significant accuracy improvement in all given data sets. A Genetic Algorithm (GA) is employed to determine whether classification fusion performance can be maximized.

4 Optimizing classification fusion with GAs

GAs has been shown to be an effective tool to use in data analysis and pattern recognition [5-7]. An important aspect of GAs in a learning context is their use in pattern recognition. There are two different approaches to applying GA in pattern recognition:

1. Apply a GA directly as a classifier. Bandyopadhyay and Murthy in [8] applied GA to find the decision boundary in N dimensional feature space.
2. Use a GA as an optimization tool for resetting the parameters in other classifiers. Most applications of GAs in pattern recognition optimize some parameters in the classification process. Many researchers have used GAs in feature selection [9-12]. GAs has been applied to find an optimal set of feature weights that improve classification accuracy. First, a traditional feature extraction method such as Principal Component Analysis (PCA) is applied, and then a classifier such as k-NN is used to calculate the fitness function for GA [13-14]. Combination of classifiers is another area

that GAs have been used to optimize. Kuncheva and Jain in [15] used a GA for selecting the features as well as selecting the types of individual classifiers in their design of a Classifier Fusion System. GA is also used in selecting the prototypes in the case-based classification [16].

In this paper we focus on the second approach and use a GA to optimize a combination of classifiers. Our objective is to *predict* the students' final grades based on their web-use features, which are extracted from the homework data. We design, implement, and evaluate a series of pattern classifiers with various parameters in order to compare their performance on a dataset from LON-CAPA. Error rates for the individual classifiers, their combination and the GA optimized combination are presented.

Two approaches are proposed for the problem of feature extraction and selection. The *filter model* chooses features by heuristically determined “goodness/relevant” or knowledge, while the *wrapper model* does this by the feedback of classifier evaluation, or experiment. Research has shown the wrapper model outperforms the filter model comparing the predictive power on unseen data [17]. We propose a wrapper model for feature extraction through setting different weights for features and getting feedback from ensembles of classifiers.

Our goal is to find a population of best weights for every feature vector, which minimize the classification error rate. The feature vector for our predictors are the set of nine variables for every student: Number of attempts before correct answer is derived, Success rate, Success at the first try, Success at the second try, Success with number of tries between three and nine, Success with high number of tries, the time at which the student got the problem correct relative to the due date, and total time spent on the problem. We randomly initialized a population of nine dimensional weight vectors with values between 0 and 1, corresponding to the feature vector and experimented with different number of population sizes. We found good results using a population with 200 individuals. Real-valued populations may be initialized using the GA MATLAB Toolbox function *crtrp*. For example, to create a random population of nine individuals with 200 variables each: we define boundaries on the variables in *FieldD* which is a matrix containing the boundaries of each variable of an individual.

```
FieldD = [ 0 0 0 0 0 0 0 0 0; % lower bound
          1 1 1 1 1 1 1 1 1]; % upper bound
```

We create an initial population with `Chrom = crtrp(200, FieldD)`, So we have for example:

```
Chrom = 0.21 0.29 0.89 0.48 0.63 0.81 0.05 0.12 0.71
        0.50 0.10 0.09 0.65 0.68 0.46 0.29 0.67 0.13
        0.35 0.09 0.43 0.64 0.20 0.54 0.43 0.90 0.32
        0.23 0.17 0.95 0.38 0.06 0.26 0.31 0.52 0.65
        .....
```

We used the simple genetic algorithm (SGA), which is described by Goldberg in [18]. The SGA uses common GA operators to find a population of solutions which optimize the fitness values. During the reproduction phase, each individual is assigned a *fitness value* derived from its raw performance measure given by the objective function. This value is used in the selection to bias towards more fit individuals. Highly fit individuals, relative to the whole population, have a high probability of being selected for mating whereas less fit individuals have a correspondingly low probability of being selected. The error rate is measured in each round of cross validation by dividing “the total number of misclassified examples” into “total number of test examples”. Therefore, our *fitness function* measures the accuracy rate achieved by classification fusion and our objective would be to maximize this performance (minimize the error rate).

5 Experiments

Without using GA, the overall results of classification performance on our datasets for four classifiers and classification fusion are shown in the Table 2. Regarding individual classifiers, mostly, 1NN and k NN have the best performance. However, the classification fusion improved the classification accuracy significantly in all data sets. That is, it achieved in average 79% accuracy over the given data sets.

Table 2. Comparing the average performance% of ten runs of classifiers on the given datasets using 10-fold cross validation, **without GA**

| Data sets | Bayes | 1NN | k NN | Parzen Window | Classification Fusion |
|--------------|-------------|-------------|-------------|---------------|-----------------------|
| ADV 205, 03 | 55.7 | 69.9 | 70.7 | 55.8 | 78.2 |
| BS 111, 03 | 52.6 | 62.1 | 55.0 | 59.7 | 71.2 |
| CE 280, 03 | 66.6 | 73.6 | 74.9 | 65.2 | 81.4 |
| FI 414, 03 | 65.0 | 76.4 | 72.3 | 70.3 | 82.2 |
| LBS 272, 03 | 72.3 | 70.4 | 69.6 | 65.3 | 77.6 |
| MT 204, 03 | 63.4 | 71.5 | 68.4 | 56.4 | 82.2 |
| MT 432, 03 | 67.6 | 77.6 | 79.1 | 59.8 | 84.0 |
| PHY 183, 03 | 59.6 | 66.5 | 70.4 | 54.4 | 76.6 |
| PHY 231c, 03 | 56.7 | 74.5 | 72.6 | 60.9 | 80.7 |
| PHY 232, 03 | 59.9 | 73.5 | 71.4 | 56.3 | 79.8 |

For GA optimization, we used 200 individuals (weight vectors) in our population, running the GA over 500 generations. We ran the program 10 times and got the averages, which are shown, in Table 3.

Table 3. Comparing the classification fusion performance on given datasets, without-GA, using-GA (Mean individual) and improvement, 95% confidence interval

| Data sets | Without GA | GA optimized | Improvement |
|----------------------|----------------------------------|------------------------------------|----------------------------------|
| ADV 205, 03 | 78.19 \pm 1.34 | 89.11 \pm 1.23 | 10.92 \pm 0.94 |
| BS 111, 03 | 71.19 \pm 1.34 | 81.09 \pm 2.42 | 9.82 \pm 1.33 |
| CE 280, 03 | 81.43 \pm 2.13 | 92.61 \pm 2.07 | 11.36 \pm 1.41 |
| FI 414, 03 | 82.24 \pm 1.54 | 91.73 \pm 1.21 | 9.50 \pm 1.76 |
| LBS 272, 03 | 77.56 \pm 0.87 | 87.61 \pm 1.03 | 10.11 \pm 0.62 |
| MT 204, 03 | 82.24 \pm 1.65 | 91.93 \pm 2.23 | 9.96 \pm 1.32 |
| MT 432, 03 | 84.03 \pm 2.13 | 95.21 \pm 1.22 | 11.16 \pm 1.28 |
| PHY 183, 03 | 76.56 \pm 1.37 | 87.14 \pm 1.69 | 9.36 \pm 1.14 |
| PHY 231c, 03 | 80.67 \pm 1.32 | 91.41 \pm 2.27 | 10.74 \pm 1.34 |
| PHY 232, 03 | 79.77 \pm 1.64 | 88.61 \pm 2.45 | 9.13 \pm 2.23 |
| Total Average | 78.98 \pm 12 | 90.03 \pm 1.30 | 10.53 \pm 56 |

The results in Table 3 represent the mean performance with a two-tailed t-test with a 95% confidence interval for every data set. For the improvement of GA over non-GA result, a P-value indicating the probability of the Null-Hypothesis (There is no improvement) is also given, showing the significance of the GA optimization. All have $p < 0.000$, indicating significant improvement. Therefore, using GA, in all the cases, we got

approximately more than a 10% mean individual performance improvement and about 10 to 17% best individual performance improvement. Fig. 2 shows the results of one of the ten runs in the case of 2-Classes (passed and failed). The dotted line represents the population mean, and the solid line shows the best individual at each generation and the best value yielded by the run (Due to the space limitation, only a graph for BS 111 2003 GA-optimization is shown).

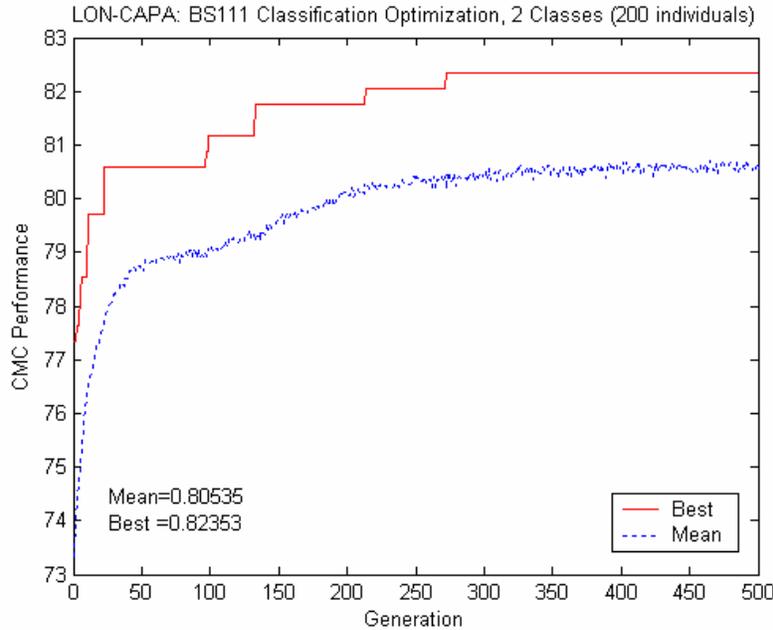


Fig. 2. GA-Optimized Combination of Multiple Classifiers’ (CMC) performance in the case of 2-Class labels (Passed and Failed) for BS111 2003, 200 weight vectors individuals, 500 Generations

Finally, we can examine the individuals (weights) for features by which we obtained the improved results. This feature weighting indicates the *importance* of each feature for making the required classification. In most cases the results are similar to Multiple Linear Regressions or some tree-based software (like CART) that use statistical methods to measure feature importance. The GA feature weighting results, as shown in Table 4, state that the “Success with high number of tries” is the most important feature. The “Total number of correct answers” feature is also the most important in some cases.

Table 4. Relative Feature Importance%, Using GA weighting for BS111 2003 course

| Feature | Importance % |
|---------------------------------------|--------------|
| Average Number of Tries | 18.9 |
| Total number of Correct Answers | 84.7 |
| # of Success at the First Try | 24.4 |
| # of Success at the Second Try | 26.5 |
| Got Correct with 3-9 Tries | 21.2 |
| Got Correct with # of Tries ≥ 10 | 91.7 |
| Time Spent to Solve the Problems | 32.1 |
| Total Time Spent on the Problems | 36.5 |
| # of communication | 3.6 |

Table 4 shows the importance of the nine features in the BS 111 SS03 course, applying the Gini splitting criterion. Based on Gini, a statistical property called *information gain* measures how well a given feature separates the training examples in relation to their target classes. Gini characterizes *impurity* of an arbitrary collection of examples S at a specific node N. In [19] the impurity of a node N is denoted by $i(N)$ such that:

$$\text{Gini}(S) = i(N) = \sum_{j \neq i} P(\omega_j)P(\omega_i) = 1 - \sum_j P^2(\omega_j) \quad (2)$$

where $P(\omega_j)$ is the fraction of examples at node N that go to category ω_j . Gini attempts to separate classes by focusing on one class at a time. It will always favor working on the largest or, if you use costs or weights, the most important class in a node.

Table 5. Feature Importance for BS111 2003, using decision-tree software CART, applying Gini Criterion

| Variable | | |
|---------------------------------------|--------|--|
| Total number of Correct Answers | 100.00 | |
| Got Correct with # of Tries ≥ 10 | 93.34 | |
| Average number of tries | 58.61 | |
| # of Success at the First Try | 37.70 | |
| Got Correct with 3-9 Tries | 30.31 | |
| # of Success at the Second Try | 23.17 | |
| Time Spent to Solve the Problems | 16.60 | |
| Total Time Spent on the Problems | 14.47 | |
| # of communication | 2.21 | |

Comparing results in Table 4 (GA-weighting) and Table 5 (Gini index criterion) shows a similar output, which demonstrates merits of the proposed method for detecting the feature importance.

6 Summary, Conclusions, and future work

We proposed a new approach to classifying student usage of web-based instruction. Four classifiers are used in grouping the students. A combination of multiple classifiers leads to a significant accuracy improvement in the given data sets. Weighing the features and using a genetic algorithm to minimize the error rate improves the prediction accuracy by at least 10% in the all three test cases.

The successful optimization of student classification in all three cases demonstrates the merits of using the LON-CAPA data to predict the students' final grades based on their features, which are extracted from the homework data. The data mining tools help instructors, problem authors, and course coordinators better design online materials. These tools identify sequences of strategies that students use in solving homework problems, help to detect anomalies in designed problems, and assist instructors in developing their homework more effectively and efficiently. The tools can identify those students who are at risk, especially in very large classes. This help the instructor provide appropriate advising in a timely manner.

For future work, we will develop a recommender system that applies student information in helping individuals to use resources more efficiently. As an example, the following suggestion might be made by the system: "You are about to start a test. Other students similar to you, who succeeded in this test, have also accessed Section 2 of

Chapter 5. You did not. Would you like to access it now before attempting the test?" This recommender system will greatly enhance the learning performance within a web-based educational system.

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