

# Automated classification of light curves of eclipsing binary stars using Fourier descriptors and artificial neural networks

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## Introduction

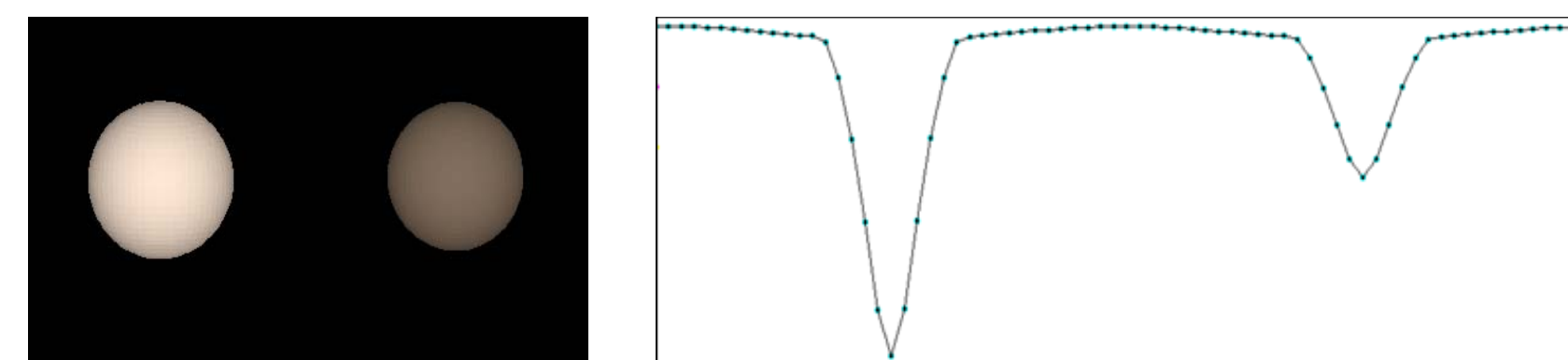
Advances in observational astronomy have given astronomers the opportunity to conduct sky surveys capable of collecting terabytes of data nightly. Photometric observation of stars has drastically increased the number of known variable stars to a point where traditional object-by-object analysis is not feasible.

One important class of variable stars is eclipsing binaries, in which a pair of stars revolves about a common center of mass. Eclipsing binaries are useful as standard candles and are an important tool for determining the mass of distant stars, which gives insight into how stars form. Automatic classification of variable stars is the only feasible way to handle the vast quantities of data.

Eclipsing binaries are classified into three types. Each type of binary star produces a characteristic light curve whose shape corresponds to the physical geometry of the star system, as shown below:

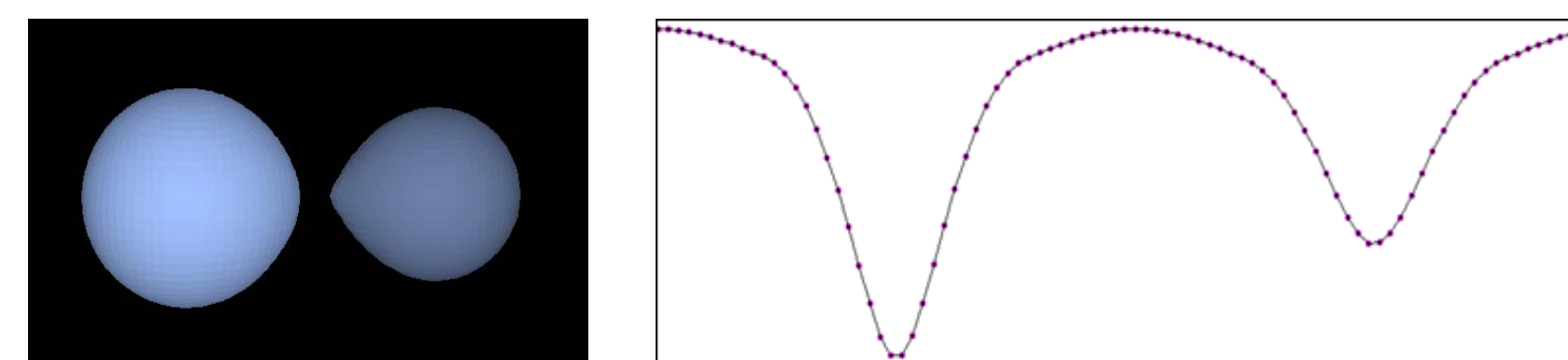
### Detached system

The two stars are separate and no mass transfer occurs. Designated Type 1.



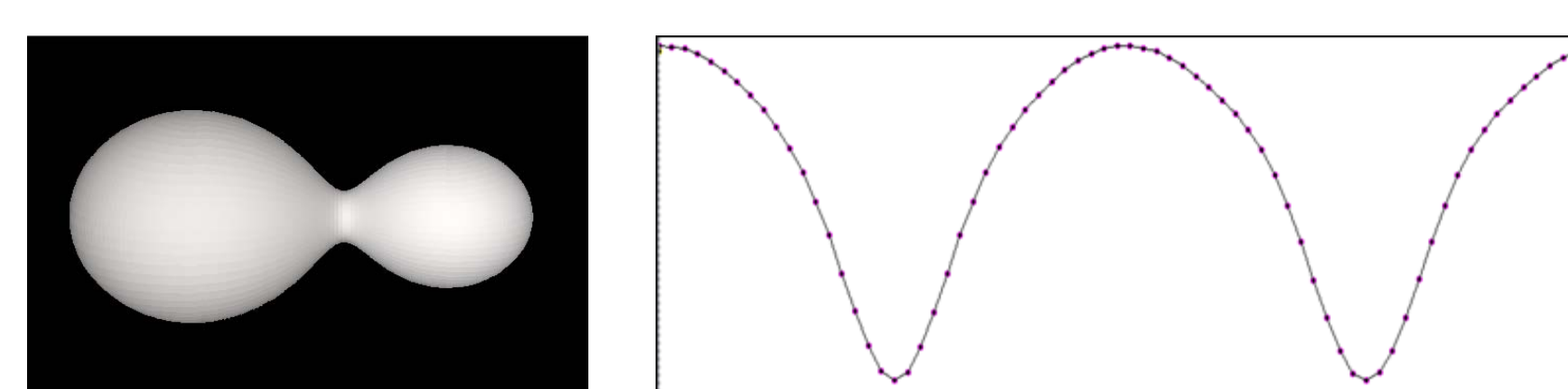
### Semi-detached system

One star loses matter to the other. Designated Type 2.



### Contact system

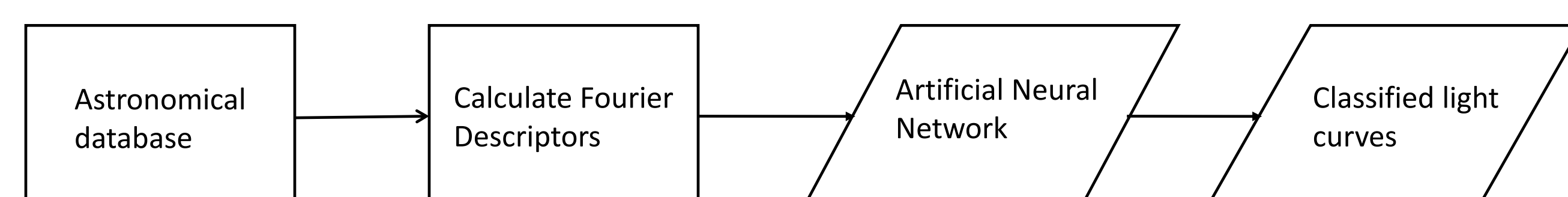
Matter is being exchanged within a stellar atmosphere surrounding both stars. Designated Type 3.



Images courtesy of Starlight Pro

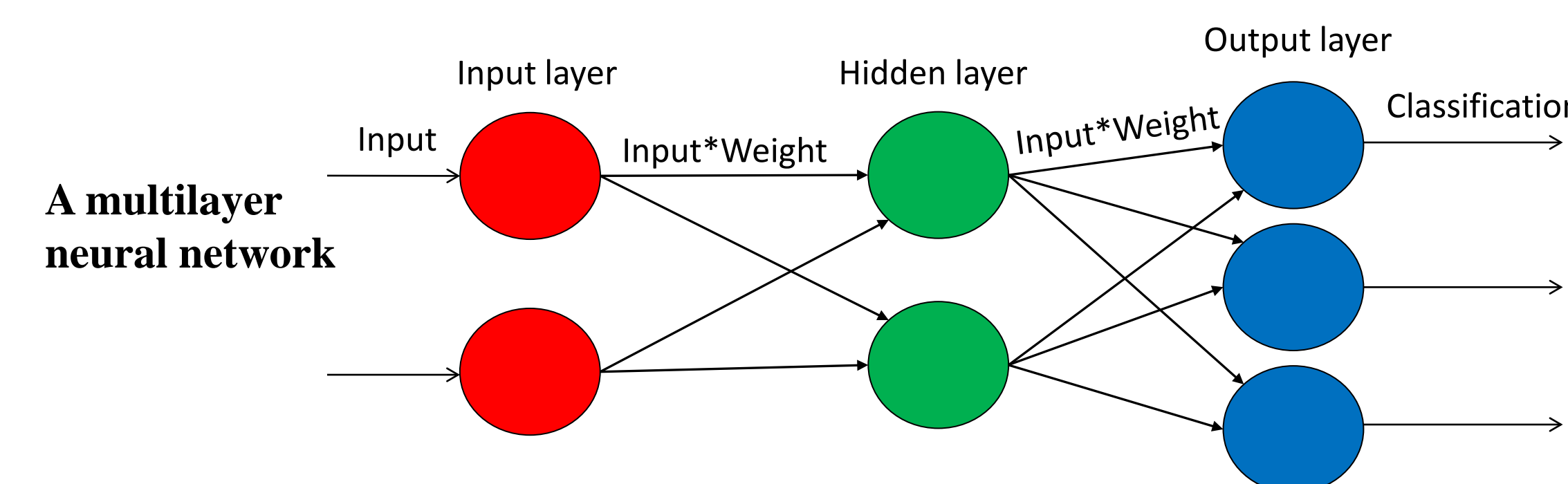
## Methods

Data is gathered from astronomical databases. The phase and intensity measurements are fed to a FORTRAN program that calculates the desired number of Fourier shape descriptors. The Fourier descriptors are then sent to a neural network for training and classifying.



## Supervised Artificial Neural Networks

Neural networks are a type of artificial intelligence which imitate the behavior and function of our brains. Neural nets are powerful because the network as a whole has greater abilities than the elements (nodes) that make up the net. In supervised networks, the net is trained with known data, which determines the weights assigned to the connections. Each link between layers has an associated weight that multiplies the input transmitted across. The types of connections are determined by the network's architecture, while the weights on those connections are determined by the network's training. Training can be accomplished with a wide variety of techniques; backpropagation has been thus far used here.



## Fourier Shape Descriptors

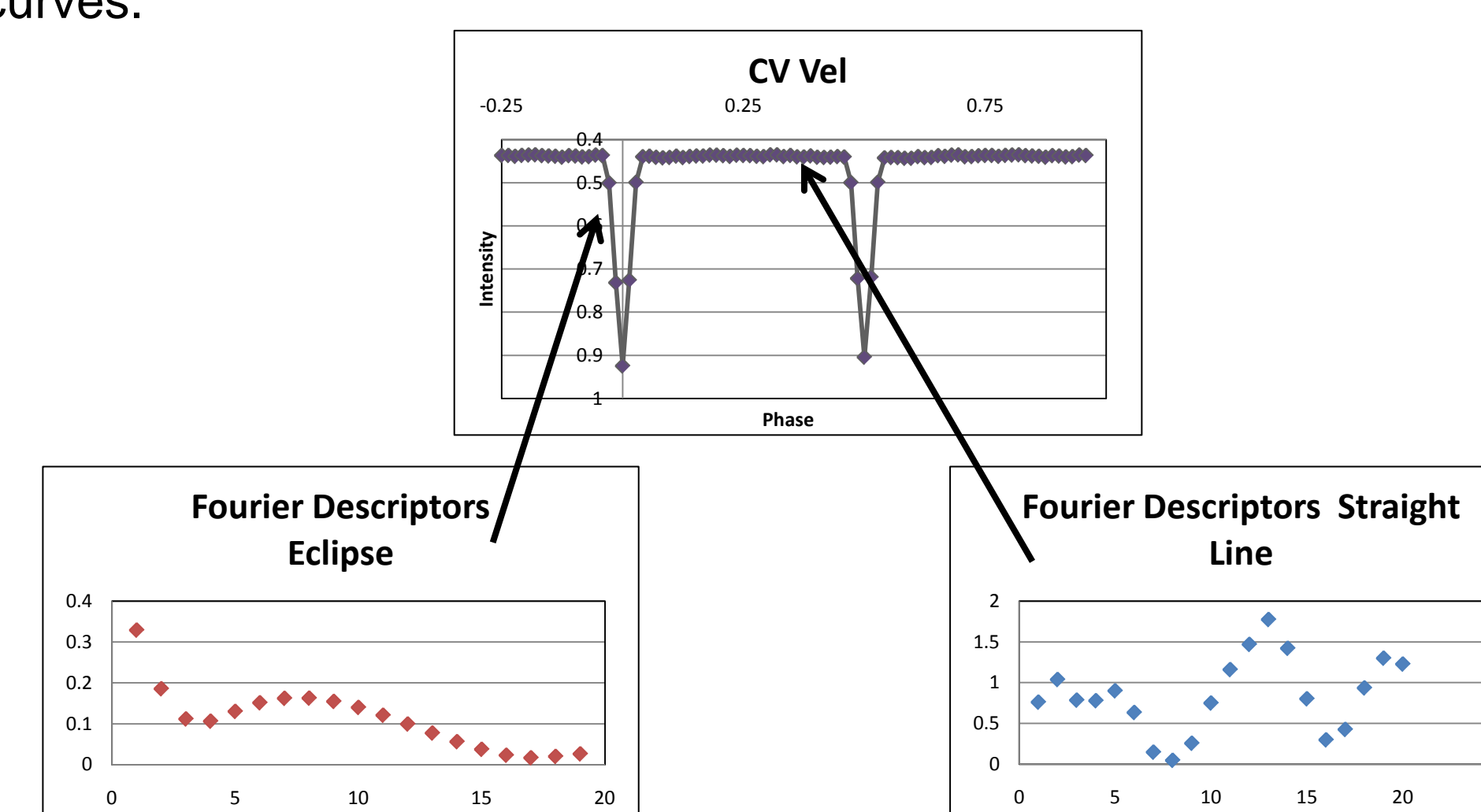
A light curve can be represented by a Fourier series whose coefficients are obtained the following relation:

$$Z_k = \sum_{n=0}^{N-1} z_n e^{-2\pi i k n / N} \text{ where } k = 0, 1, \dots, N-1$$

These coefficients are used to construct the Fourier descriptors:

$$C_k - 2 = \frac{|Z_k|}{|Z_1|} \text{ where } k = 2, 3, \dots, N-1$$

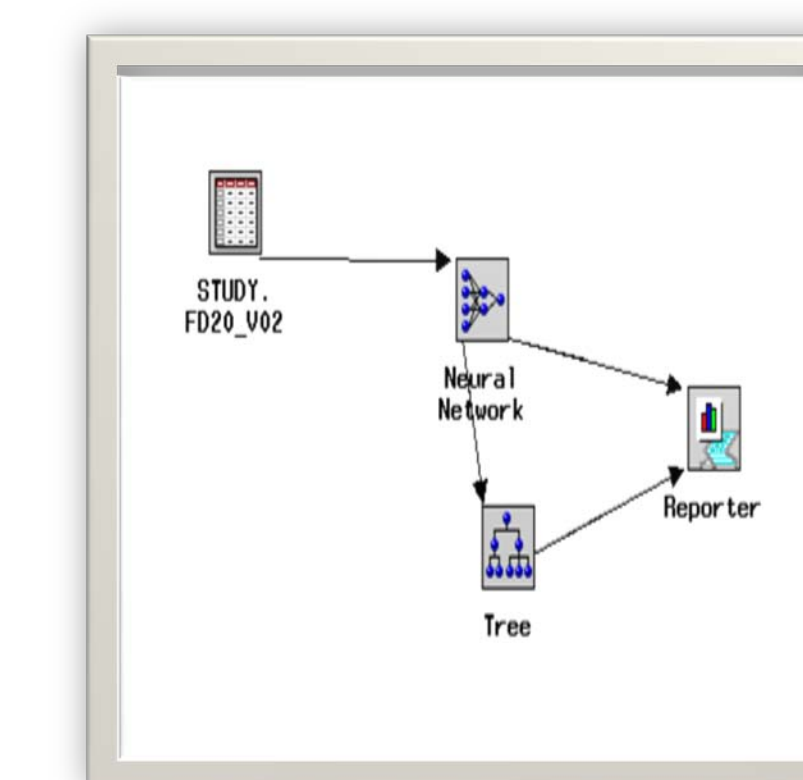
The advantage of using Fourier descriptors is that the light curve is invariant to rotation, translation, or scaling. Further, large variation in the shape of the curve can easily be seen in the numerical content of the Fourier descriptors. It is these characteristics of Fourier descriptors that are useful in classifying different types of light curves.



## First Results

As a proof of concept, a small sample data set was prepared for neural network analysis. Using 10 Fourier descriptors, the network achieved >95% accuracy in classifying the light curves. Increasing the number of Fourier descriptors will also be tested to improve the efficiency of the network. The network used for proof of concept is shown below. It employs decision tree algorithm to select the best Fourier descriptors for each light curve class. The results are presented in the confusion matrix.

SAS Enterprise Miner network diagram used in the analysis.



Confusion Matrix - Table of target by output

Frequency Percent Row Pct Col Pct	Type 1	Type 2	Type 3	Total
Type 1	163 50.94 100.00	0 0.00 0.00	0 0.00 0.00	163 50.94
Type 2	0 0.00 0.00	81 25.31 100.00	0 0.00 95.29	81 25.31
Type 3	0 0.00 0.00	4 1.25 5.26	72 22.50 94.74	76 23.75
Total	163 50.94	85 26.56	72 22.50	320 100.00

## Ongoing Research

The next step is to identify the Fourier Descriptors that uniquely describe the characteristic shape of each type of light curve. The neural network will then be trained to recognize those descriptors that identify each specific light curve. The network's output will be used to initiate a detailed study of judiciously selected contact binaries.

## Conclusion

Application of NNs to the classification of eclipsing binaries stars is new and novel. This successful pilot test of a neural network with a small sample confirms a feasible model to classify binary stars using data mining on databases of tens of thousands of stars to isolate previously unknown contact binaries for further observation. Classification of eclipsing binaries provides for the study of contact systems in particular, which is a critical contribution to the study of the theory of stellar evolution and structure.

## Acknowledgements

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