Thesis Presentation

Signal Classification through Multifractal Analysis and Neural Networks

Group 13

Kevin Cannons

Vincent Cheung

Electrical & Computer Engineering

University of Manitoba

Winnipeg, Manitoba, Canada

Advisor: Dr. W. Kinsner

Outline

- Introduction [Kevin]
- Project Overview [Kevin]
- System Design [Kevin]
- Component Design [Kevin and Vincent]
- Experimental Results and Discussion [Vincent]
- Conclusions and Recommendations [Vincent]

Project Overview

- Classification of stochastic, self-similar, non-stationary signals from non-linear systems
- Many real world signals are of this type
- Cannot use traditional analysis techniques such as Fourier transform
- Complex, unique techniques were utilized for the classification system

Signal Classification

- Signal classification means identifying a signal as belonging to a class based on a certain set of features
  - Reveals information about the physical process
- A wide range of applications:
  - Speech signals
  - Power line transients
  - Internet traffic

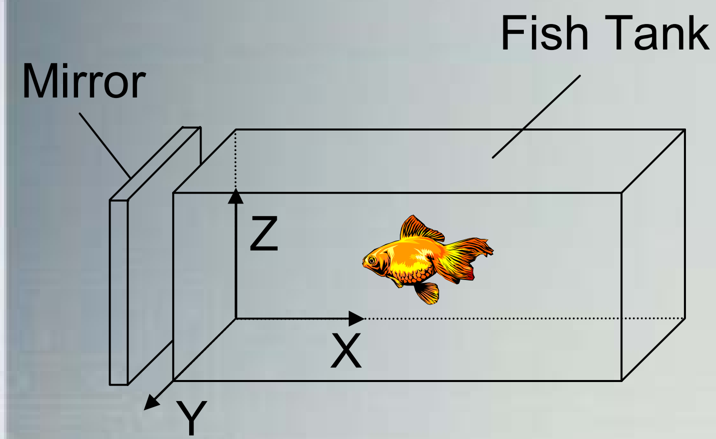
Signal Classification

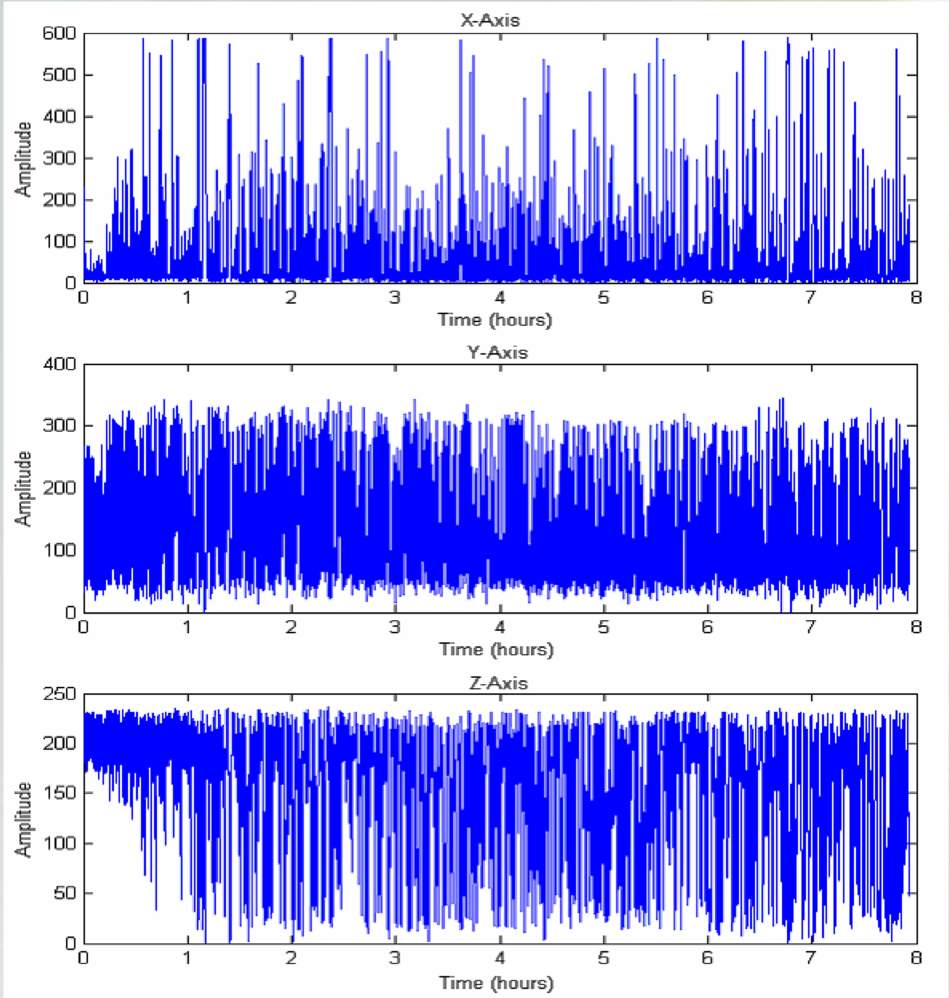
- Classification systems typically involve two main stages
  - Extraction of features
    - Mean
    - Fourier coefficients
    - Wavelet coefficients [Mall98]
  - Classification based on the selected features
    - Expert systems
    - Neural networks

Classification Terminology

- Non-stationary
  - Statistical properties of the signal change over time
- Self-similar
  - “Zooming in” yields a signal with similar statistical properties
  - Fractals
- Stochastic
  - Events in the signal occur at random
- Non-linear systems
  - Do not obey superposition

Fish Trajectory Signals

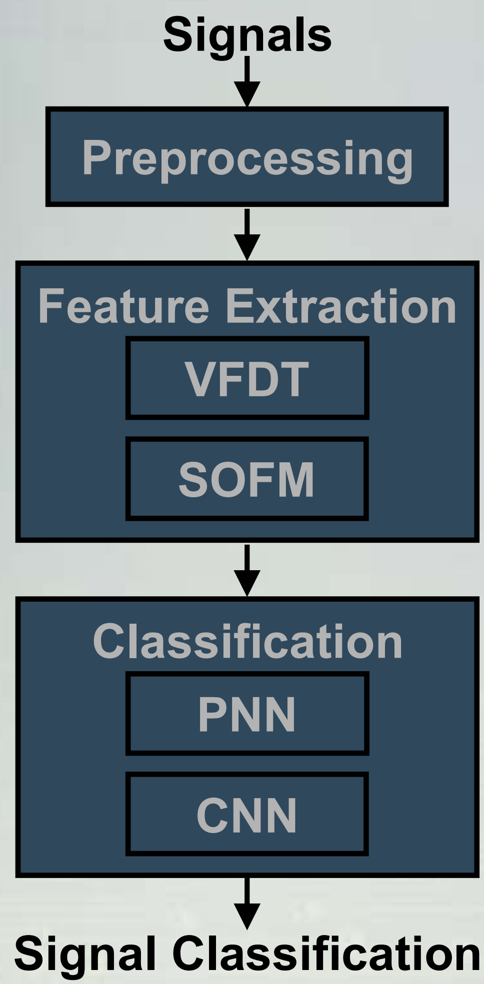




System Design

- Three design constraints
  - Correct classification rate greater than 90%
  - Training time less than one day
  - Execution time less than the duration of the input signal

System Design



Preprocessing

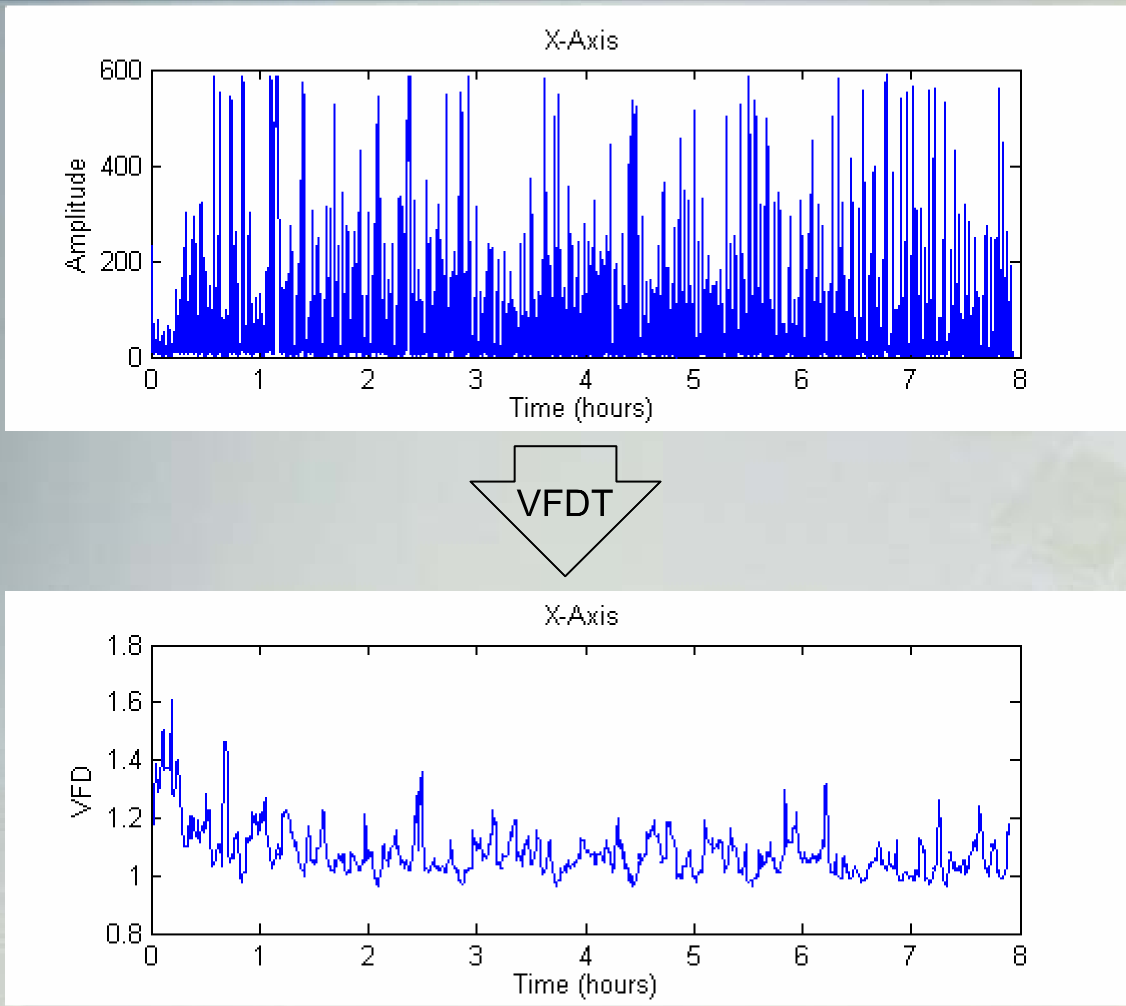
- Converts a signal to an acceptable format for the rest of the system
- Makes the system general
  - To classify a new type of signal, simply create a new unit within the preprocessor

Variance Fractal Dimension Trajectory

- First feature extraction technique utilized
- Calculates the variance fractal dimension of a small segment of the signal in a sliding-window fashion over the entire signal [Kins94]
- The variance fractal dimension provides information about that portion of the signal
- Variance fractal dimension trajectory has many advantages
  - Emphasizes the underlying complexity of the signal
  - Provides a normalizing effect

Overview
Design
Results
Conclusion

Variance Fractal Dimension



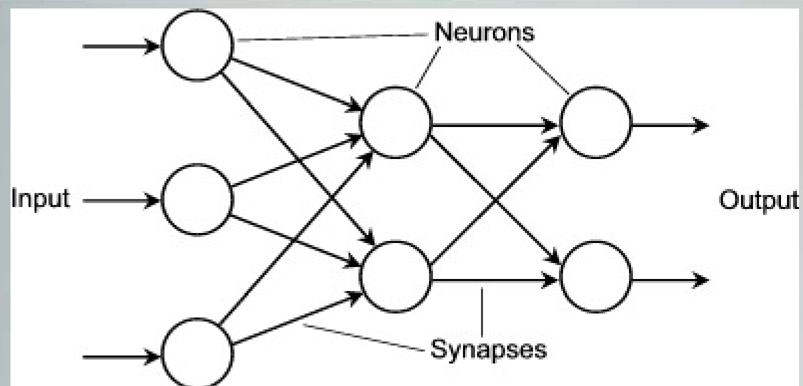
Neural Networks

- Advantages
  - Can learn almost any function
  - Great ability to generalize
  - Robust to noise
- Disadvantages
  - Complex
  - Requires training
- Ref: [Mast93]

Neural Networks Basics

- Essentially a function approximator
  - Transforms inputs into outputs to the best of its ability
- Training is the method used by a neural networks to "learn" the function that it is approximating
  - Present the network with sample inputs and modifying parameters throughout the network to better approximate the desired function
- There are two main types of training
  - Supervised Training
    - Supplies the neural network with inputs and the desired outputs
  - Unsupervised Training
    - Supplies only inputs

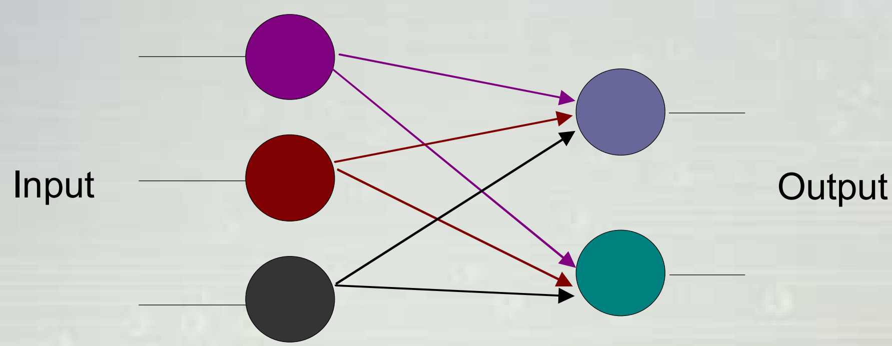
Neural Network Architecture



- Basic multilayer feedforward network consists of two components
  - Neurons
  - Synapses
- Neurons perform calculations
- Synapses connect neurons
  - Are often associated with weights

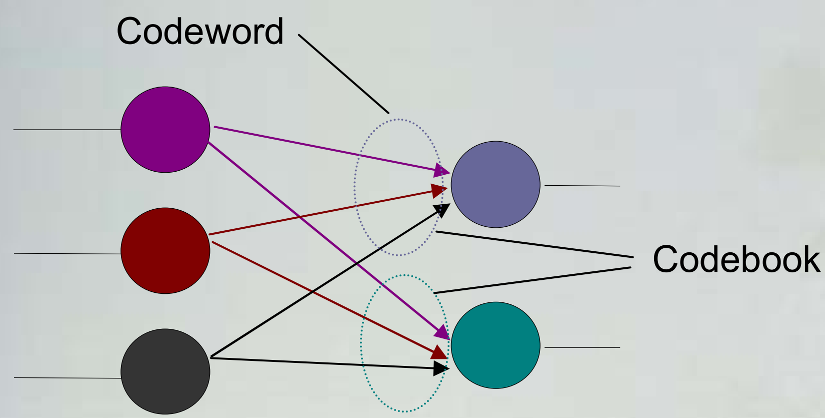
Self-Organizing Feature Maps (SOFM)

- Have a variety of applications including feature extraction and clustering [Koho84]
- Utilize unsupervised training
  - The “winning” neuron is the neuron whose weights most closely resemble the input to the network
  - The weights of the “winning” neuron and those surrounding it are updated
    - Encourages grouping and clustering



Self-Organizing Feature Maps (SOFM)

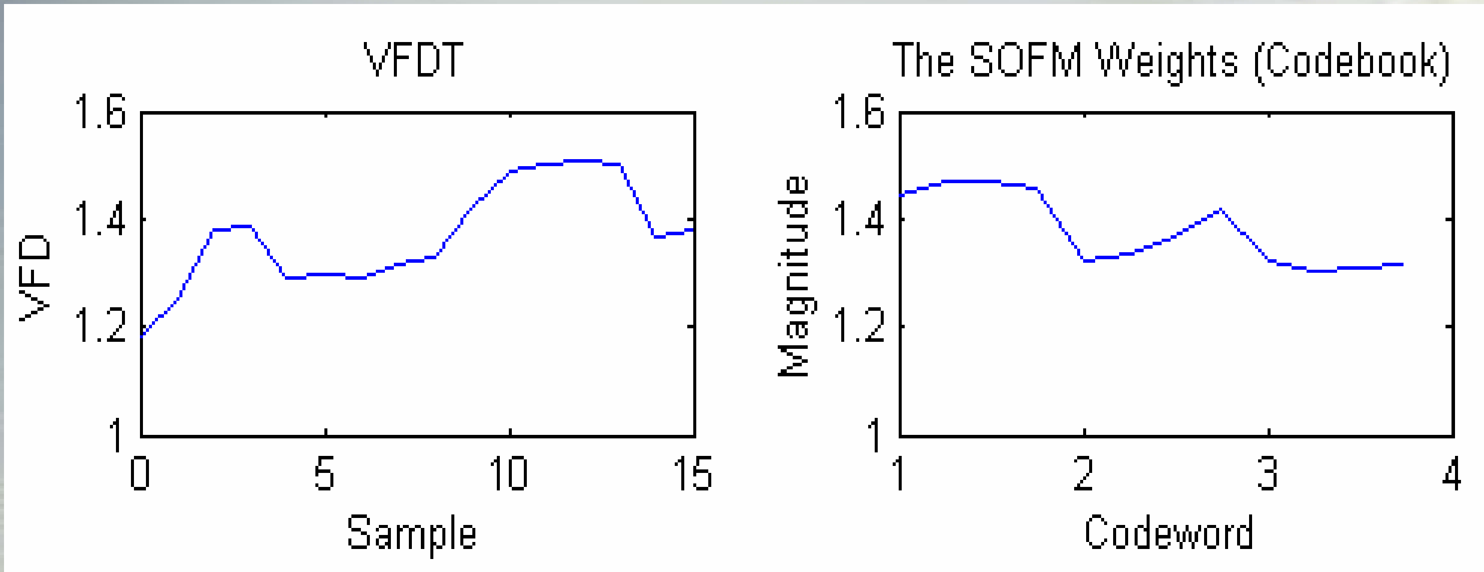
- For feature extraction, the self-organizing feature map creates a codebook of the most prominent features, or codewords, that are present within a signal



- Two main advantages of self-organizing feature maps for feature extraction
  - The codebook compresses the features into fewer points
  - The codebook is robust to translational shifting

Self-Organizing Feature Maps (SOFM)

- Without self-organizing feature maps, segments of the variance fractal dimension trajectory are the input for the classifiers
- When including self-organizing feature maps in the system it is the codebook that is used as input to the classifier



Probabilistic Neural Networks

- Neural network implementation of a Bayes classifier [Spec88]
  - eg. Spam filters
- Advantages
  - Asympotically Bayes optimal
    - Good classifiers
  - Trains orders of magnitude faster than other NNs
- Disadvantages
  - Slower execution than other NNs
  - Require large amounts of memory

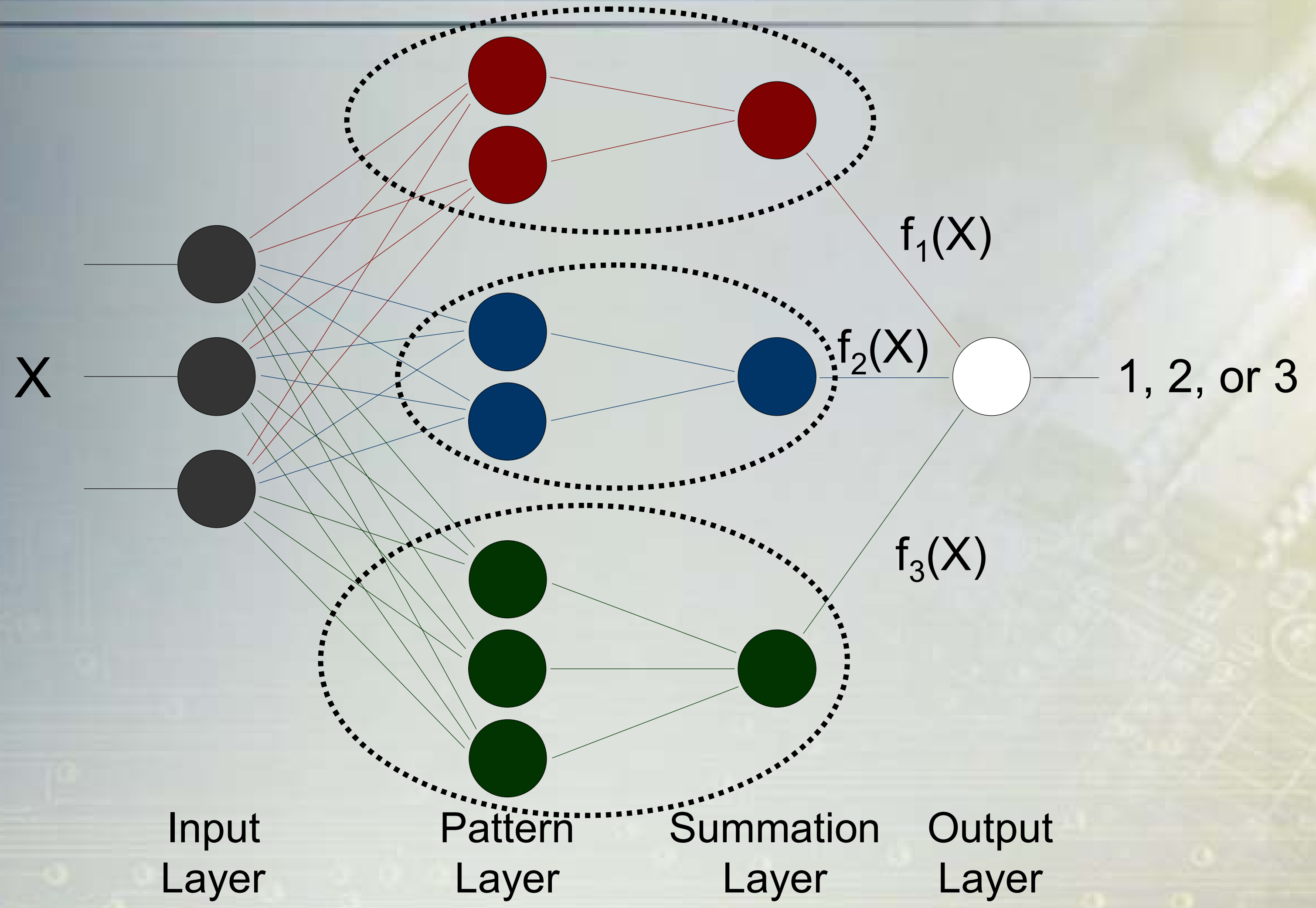
PNN Mathematics

- X belongs to class “i” if:

  $f_i(X) > f_k(X) \ \forall \ k \neq i$ (f_n is the PDF for class n)

- Don’t know PDFs
  - Estimate them based on some examples from each of the classes (training set)

PNN Architecture



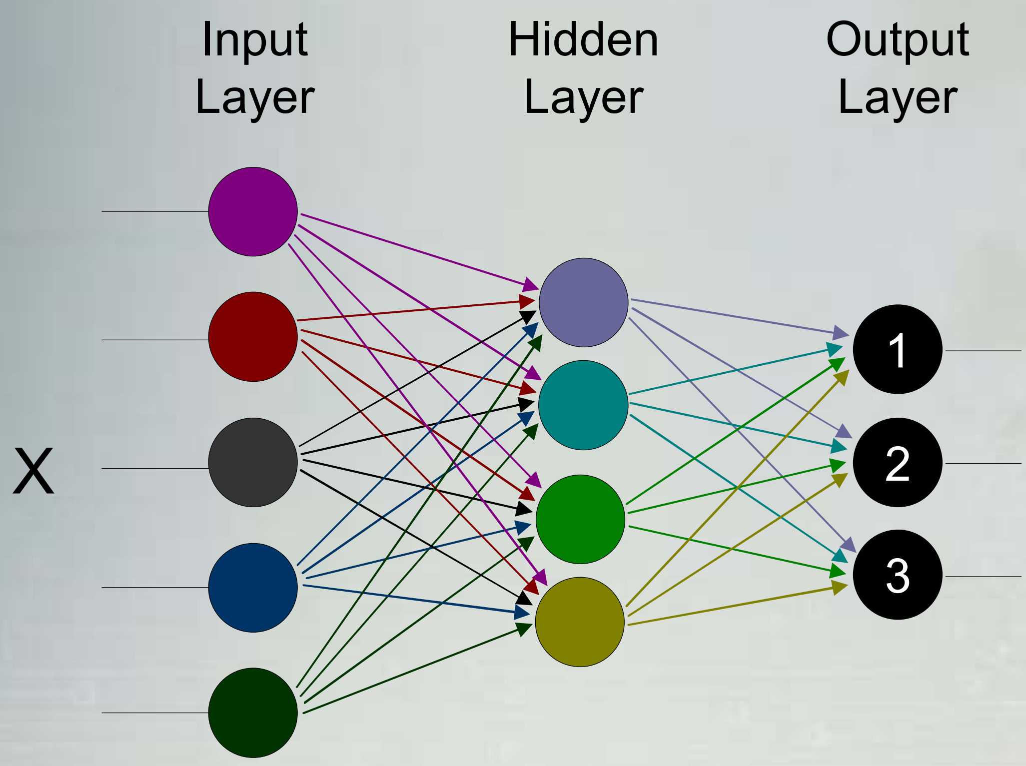
Complex Domain Neural Networks (CNN)

- **Advantages**
  - Works with inputs in their natural complex valued form
  - Faster training
  - Better generalization

- **Disadvantages**
  - More complexity
    - Convoluted partial derivatives involving complex analysis

- Ref: [Mast94]

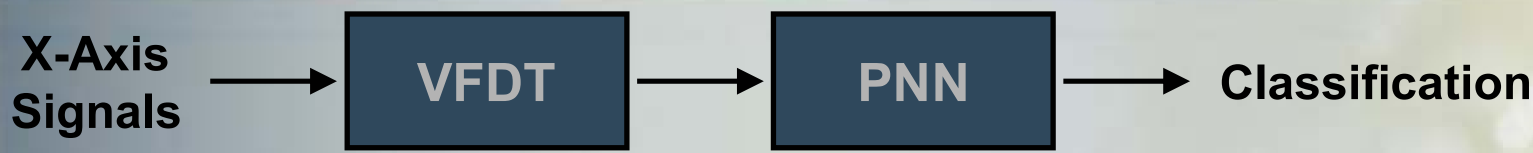
CNN Architecture



Experiment Set-Up

- Use fish trajectory signals to test the system
  - Only use the X and Z axes
  - 2 different fish, 17 recordings in total
  - Objectively defined the classes using clustering algorithms
    - 4 Classes
  - Segments from 9 recordings designated for training, the rest for testing
  - No filtering performed
- Use the training and testing sets with different configurations of the system

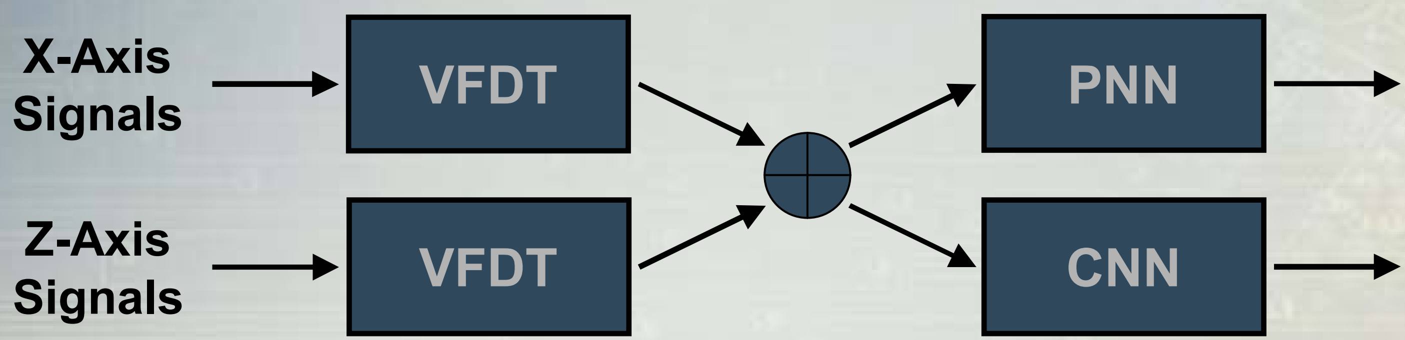
Experiment #1



		Experimental				Correct Class. Rate
		1	**2**	**3**	**4**	
Expected	**1**	**24**	0	0	0	100.00%
	2	3	**135**	4	4	92.47%
	3	0	12	**111**	65	59.04%
	4	0	23	70	**93**	50.00%
Average Correct Classification Rate: 66.73%						
95% Confidence Interval: [62.77%, 70.69%]						

Experimental Results Summary

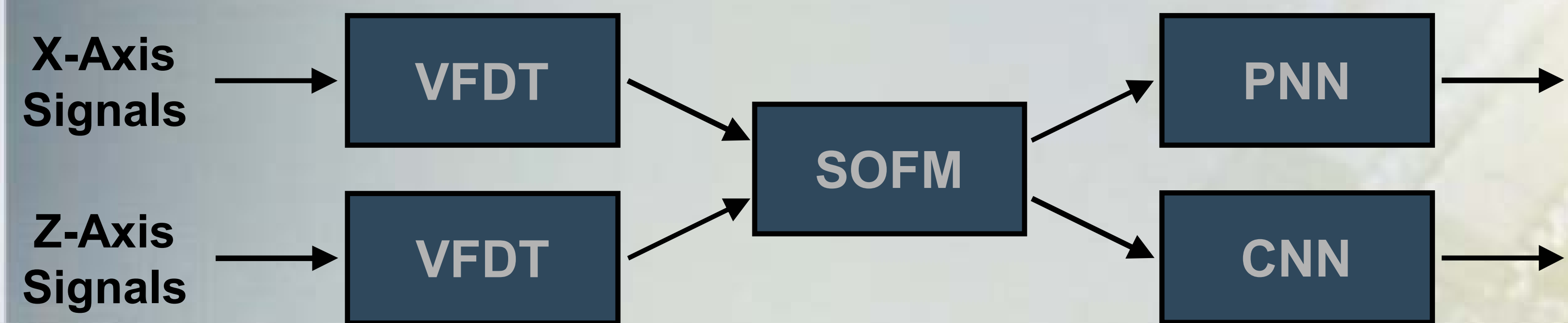
Signal	Classifier	Classification Rate (%)				Average Rate (%)
		1	2	3	4	
X	PNN	100	92	59	50	67
Z	PNN	63	29	47	91	58
X & Z	PNN	100	95	84	95	91
X & Z	CNN	96	87	80	91	87



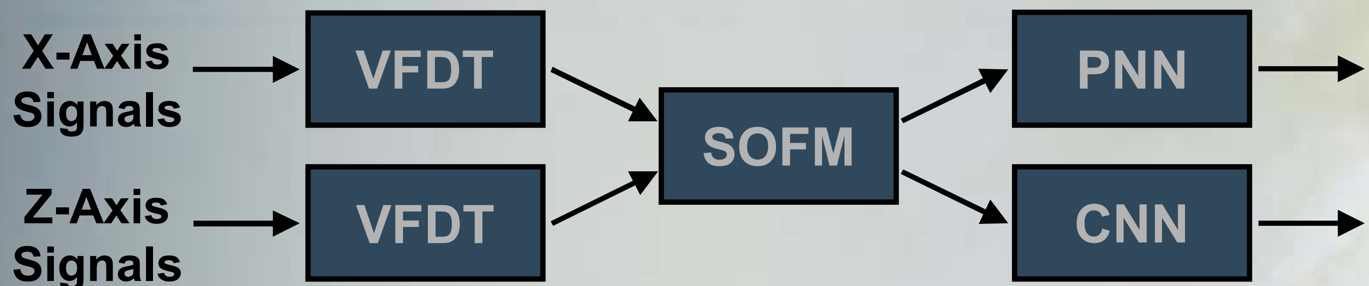
Experimental Results Summary

- Information from both axes important for classification
- Both the PNN and CNN were able to perform classification at rates at high confidence
- The multifractal characterization (fractal dimensions) seemed to provide good features for classification
- Time constraints met in all configurations
  - PNN trains faster, CNN executes faster

SOFM Feature Extraction



SOFM Feature Extraction



Signal	Classifier	Average Rate (%)	
		VFDT	+ SOFM
X	PNN	67	66
Z	PNN	58	61
X & Z	PNN	91	88
X & Z	CNN	87	85

SOFM Experimental Results Summary

- Correct classification rate about the same
- Less features
  - 12, instead of 16
  - Faster training and execution times
- Compaction of features was successful
  - Removed redundant/irrelevant information

Conclusions

- A system capable of classifying self-similar, stochastic, non-stationary signals originating from non-linear processes was developed
- Met all design constraints
- Feature extraction involving variance fractal dimensions and self-organizing feature maps shown to be effective
- Probabilistic neural networks and complex domain neural networks shown to be capable of performing the desired classification

Recommendations

- Compare with results by psychologists
- Larger training and testing sets
- Add simulated noise to the signals
- Test with other signals
- More advanced PNN (multi-sigma PNN)
- Extension to hypercomplex-valued signals
  - Signals consisting of three or more components

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- University of Manitoba

References

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