Characterizing Fluidization from movies *using Artificial Intelligence and Clustering Techniques*

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Introduction

✓Complex processes

✓Need to know the 'process state'

✓Improve control and monitoring; Predict possible problems

✓Measurements

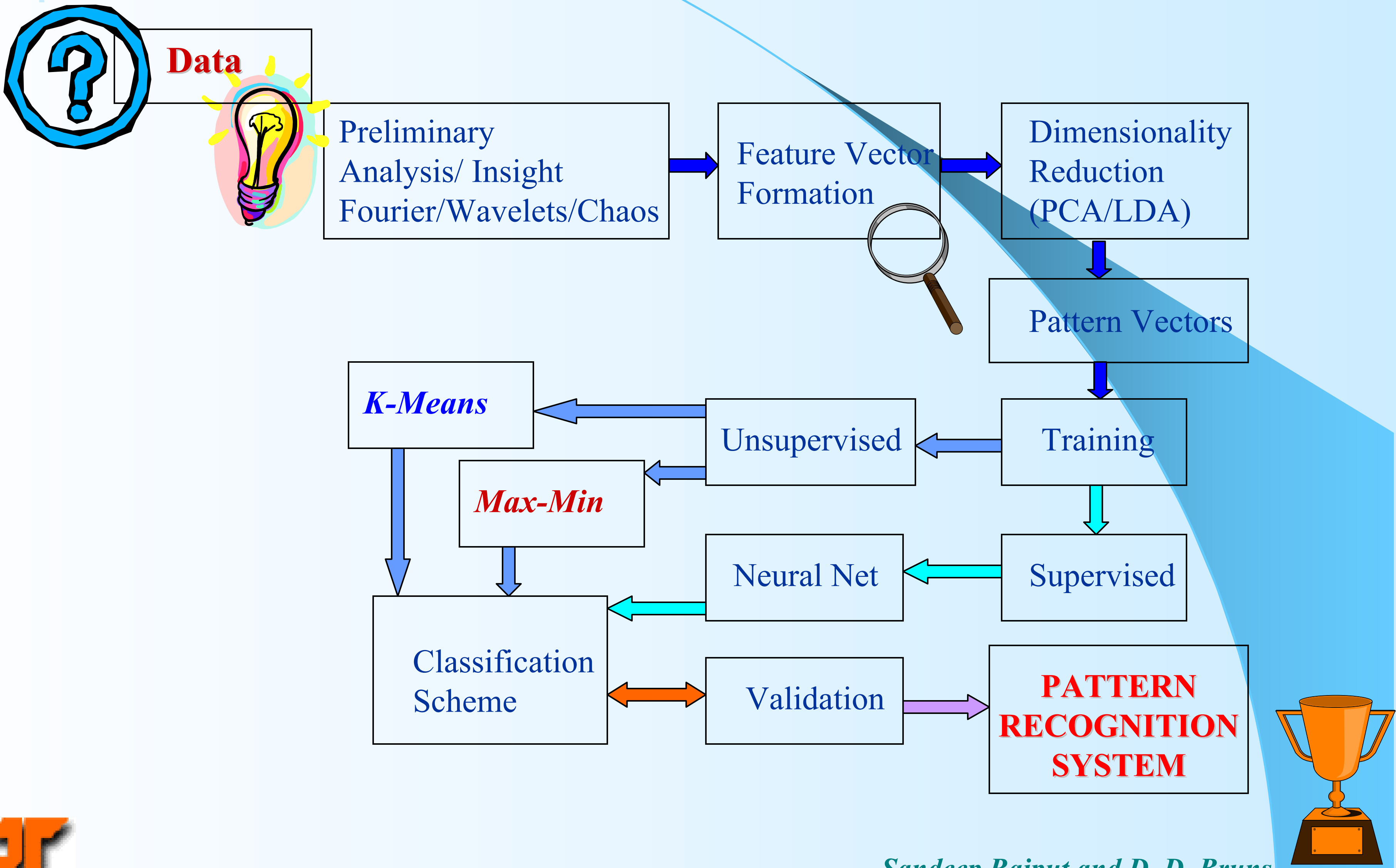
- Temperature, Pressure, composition, etc.
- Audio-Visual Information

✓Utilize operator knowledge

GOAL

Design Expert System to predict 'process state' online

Using nonlinear and chaotic time series analysis expertise



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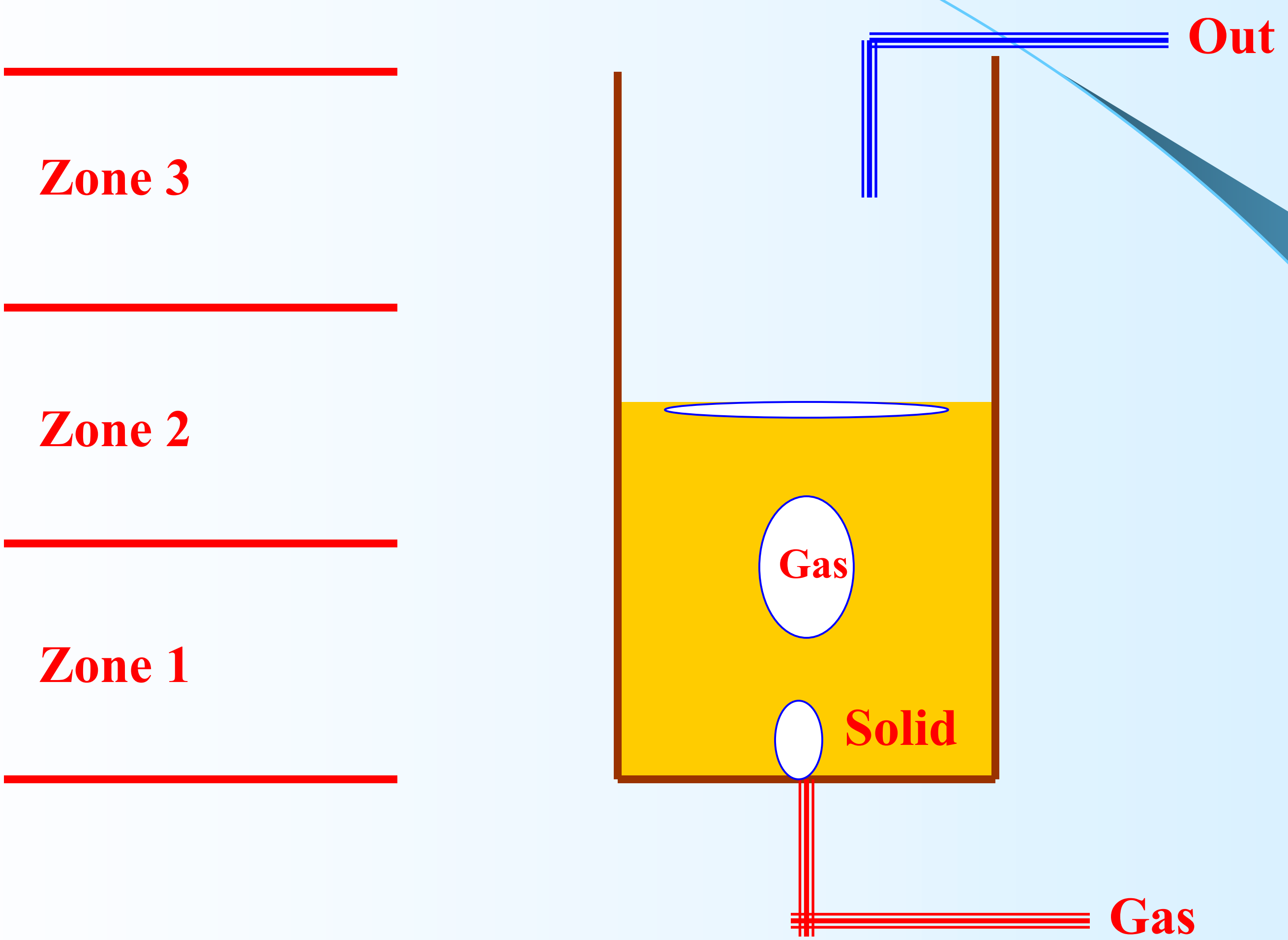
System Preview

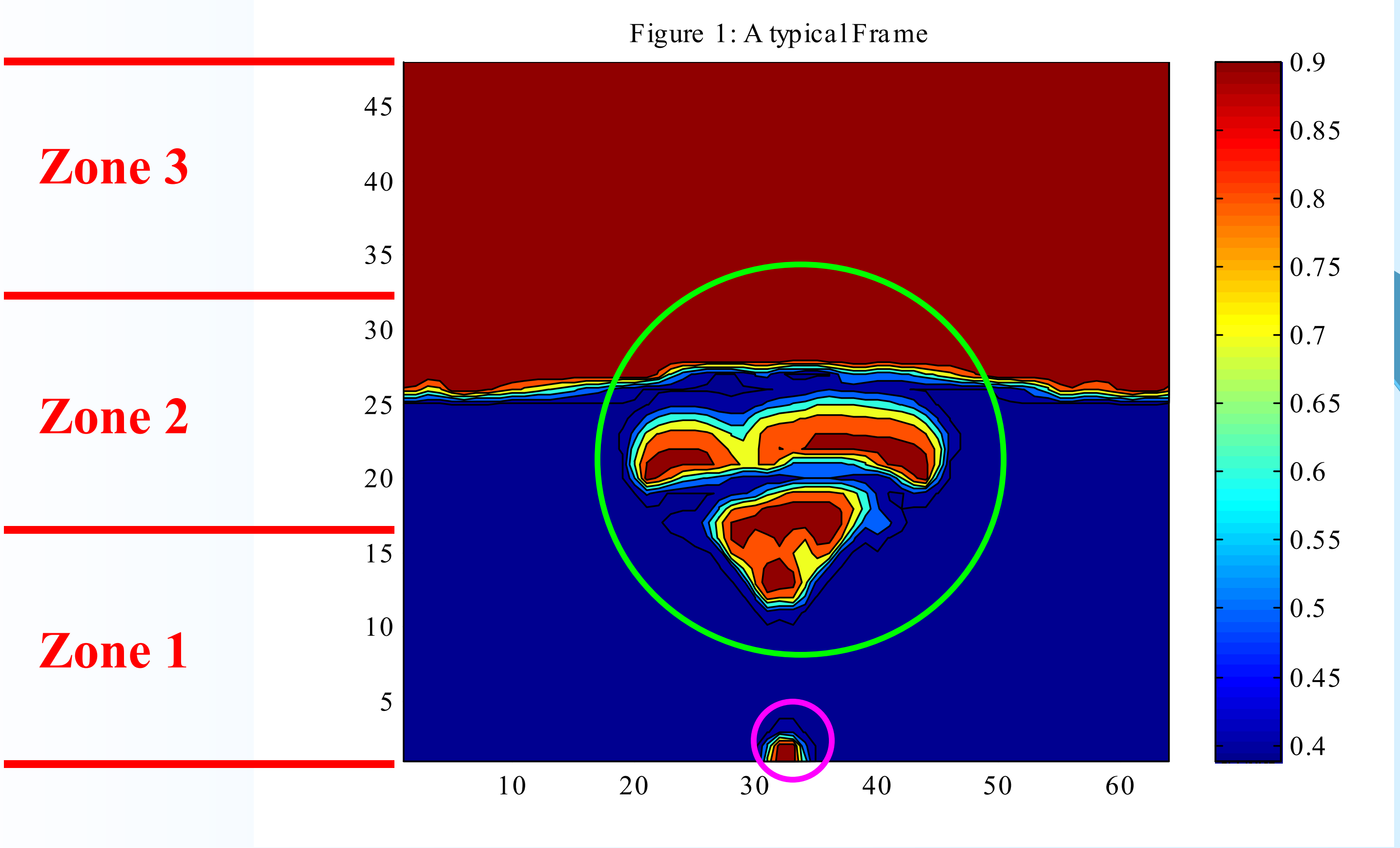
- ✓Fluidized bed as a complex non-linear process
- ✓CFD :MFIX simulation; Daw-Halow model
  - Computer code being developed by a consortium of companies
- ✓Movies or strings of frames (48 x 64) : 100 every second
- ✓Intricate information; high redundancy

- ✓Density information on the matrix of frame
- ✓3 gas flow rates : 50, 90 and 100 cc/min
- ✓Neural network or clustering methods to divine the ‘state’

Fluidized Bed



A typical frame in the ‘movie’



The color (scale on right) relates to void fraction, or fraction of gas

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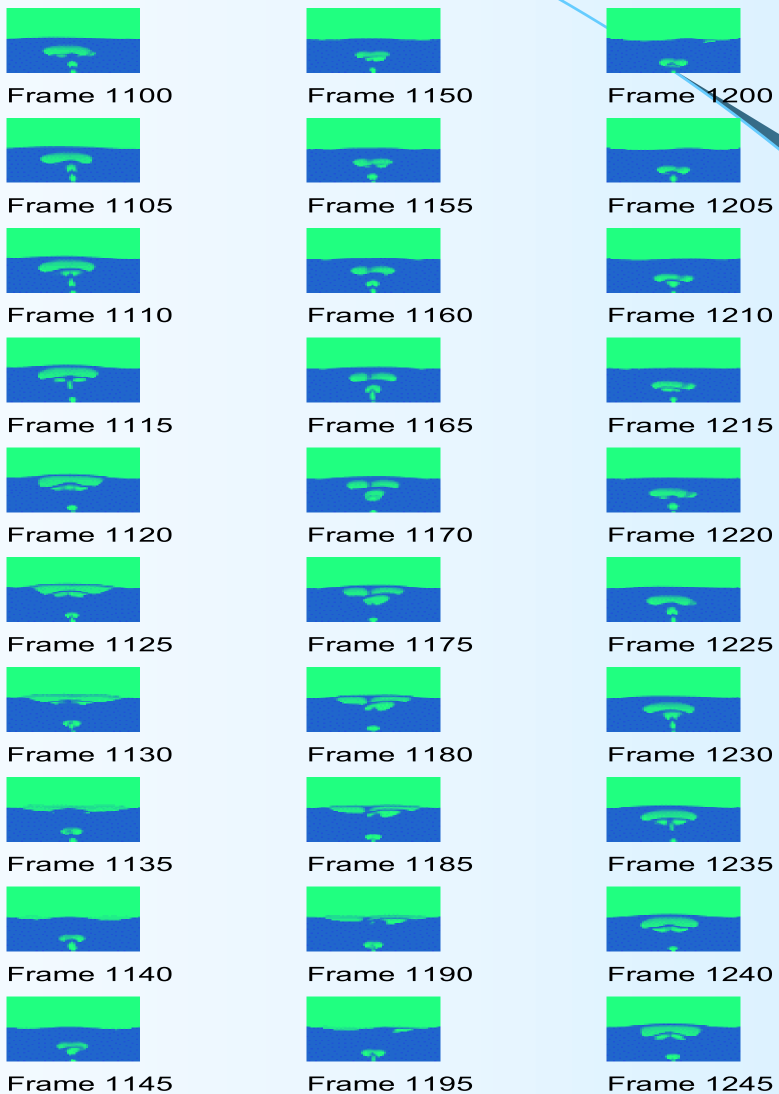
Stills from the 'movie'

Figure 3 : Frames for flow rate of 90 cm/s

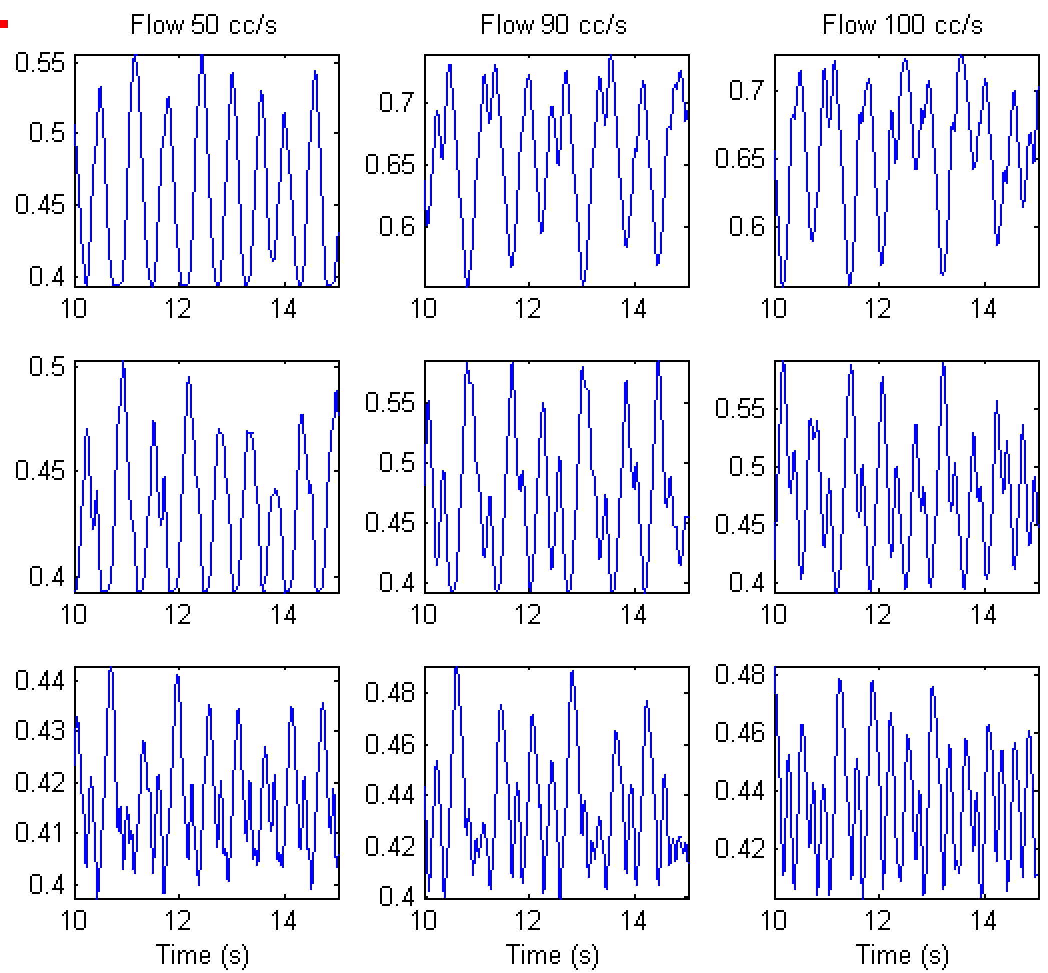


Void fraction time series

Zone 3

Zone 2

Zone 1



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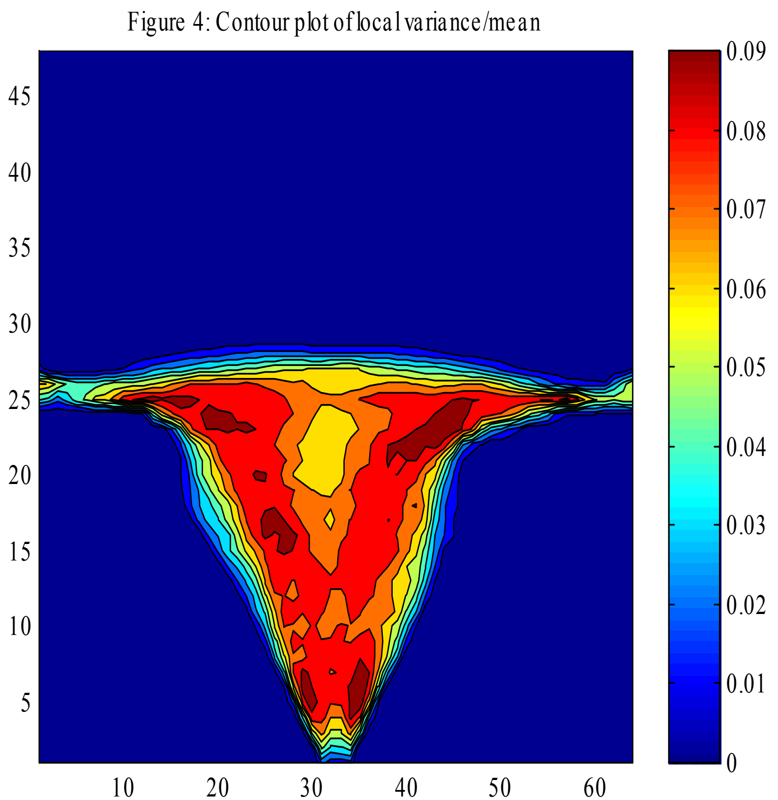
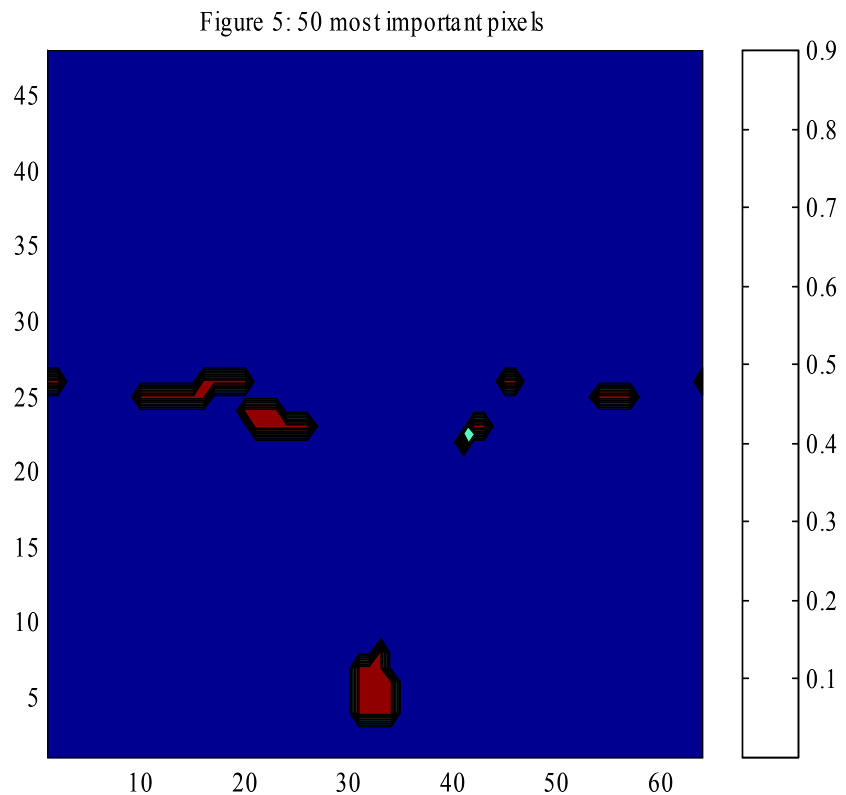
Dimension reduction using engineering sense

- ✓Dimension too high. 64 x 48
- ✓Redundancy of information
- ✓Identify the points where most variation occurs

- ✓Identify 50 pixels with highest variance
- ✓Identify a zone with highest variance
- ✓Zone 2 or middle zone : gas-solid interface
- ✓Check for preservation of information

Dimension reduction using engineering sense





Ratios of variances to means

High (maroon) Low (Blue)

50 pixels with most variation (brown)

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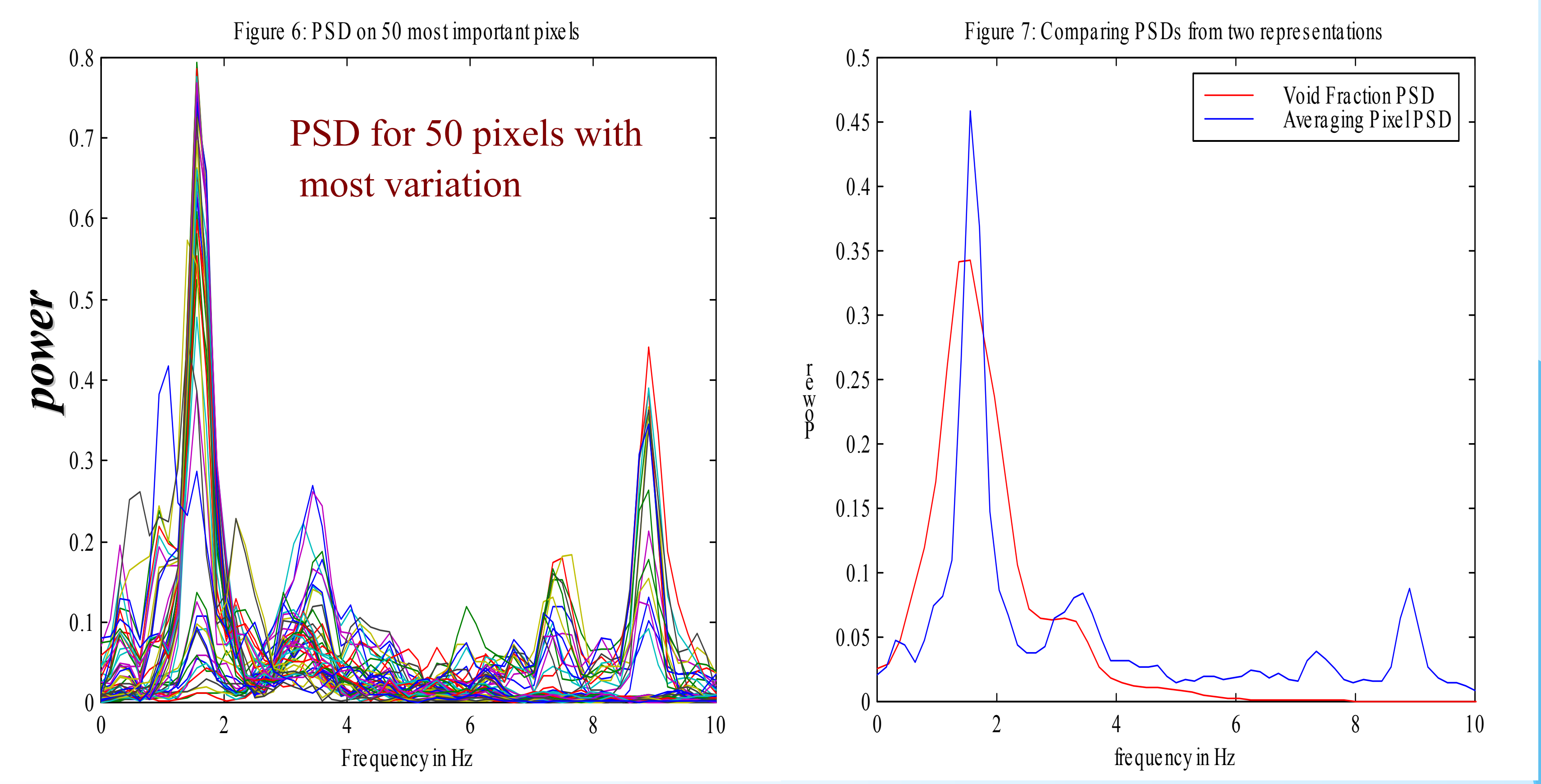
Spectral Power for select pixels and void fraction



Spectral power vector as the raw feature vector

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Further dimension reduction using multivariate techniques

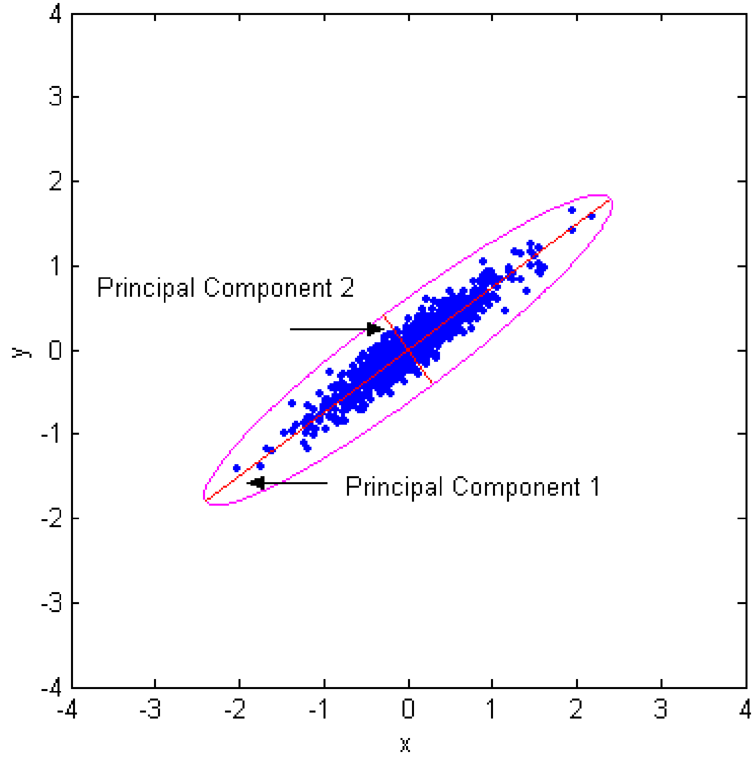
Principal Component Analysis (PCA) or K-L Transform

C = covariance matrix (symmetric), then

$C=USU^T$

U= Orthonormal

rotation matrix



Project vectors on principal components

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Further dimension reduction using multivariate techniques

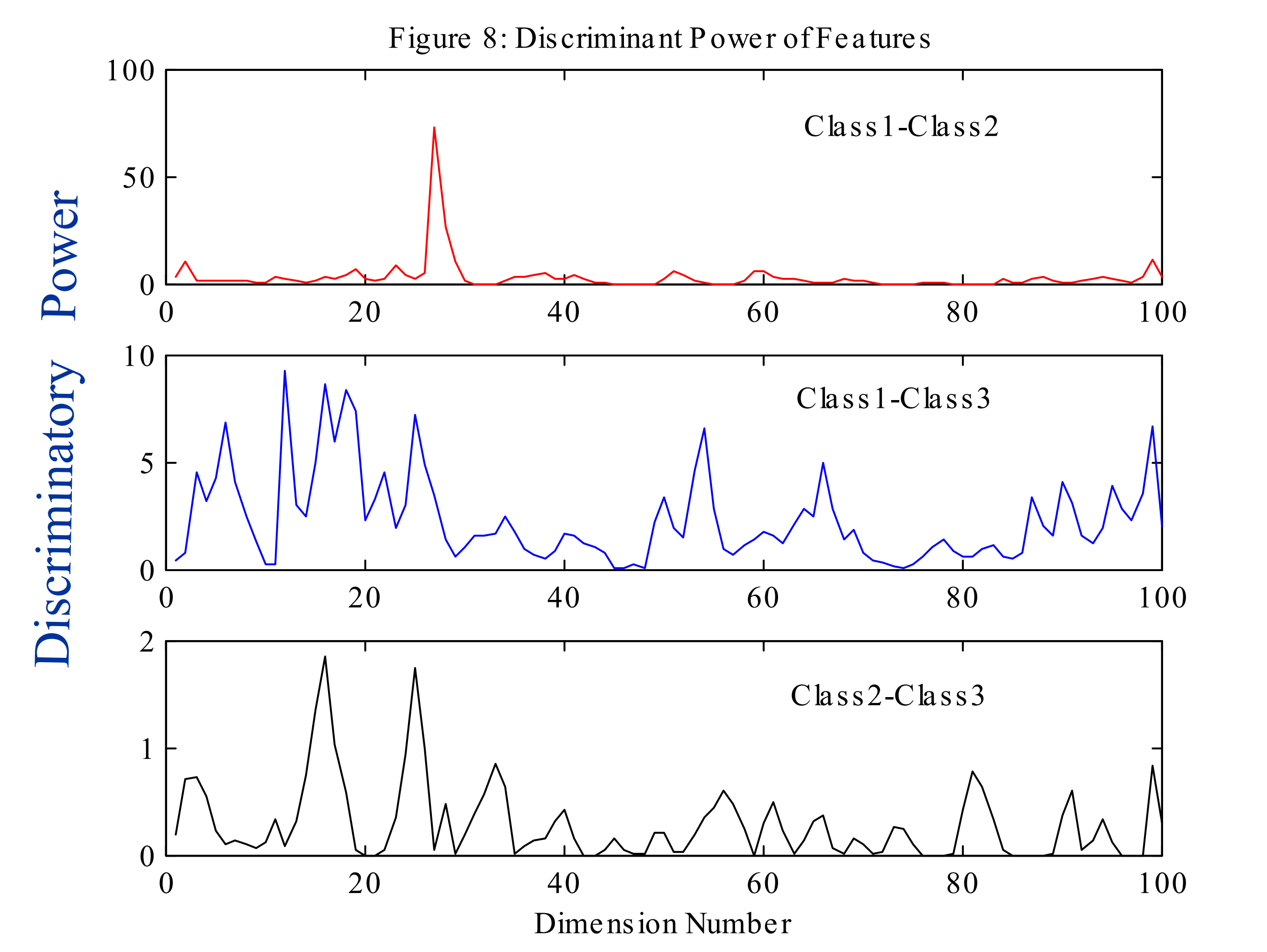
Fisher's information criterion

Discriminatory Power of each feature

$$J_{f_k}(i,j) = J_{f_k}(j,i) = \frac{\| \mu_{i,f_k} - \mu_{j,f_k} \|^2}{{\sigma_{i,f_k}}^2 + {\sigma_{j,f_k}}^2} \quad for\ k = 1,2,..L$$

Choose features with highest discriminatory power

Fischer's information criterion to reduce dimensionality



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Expert systems

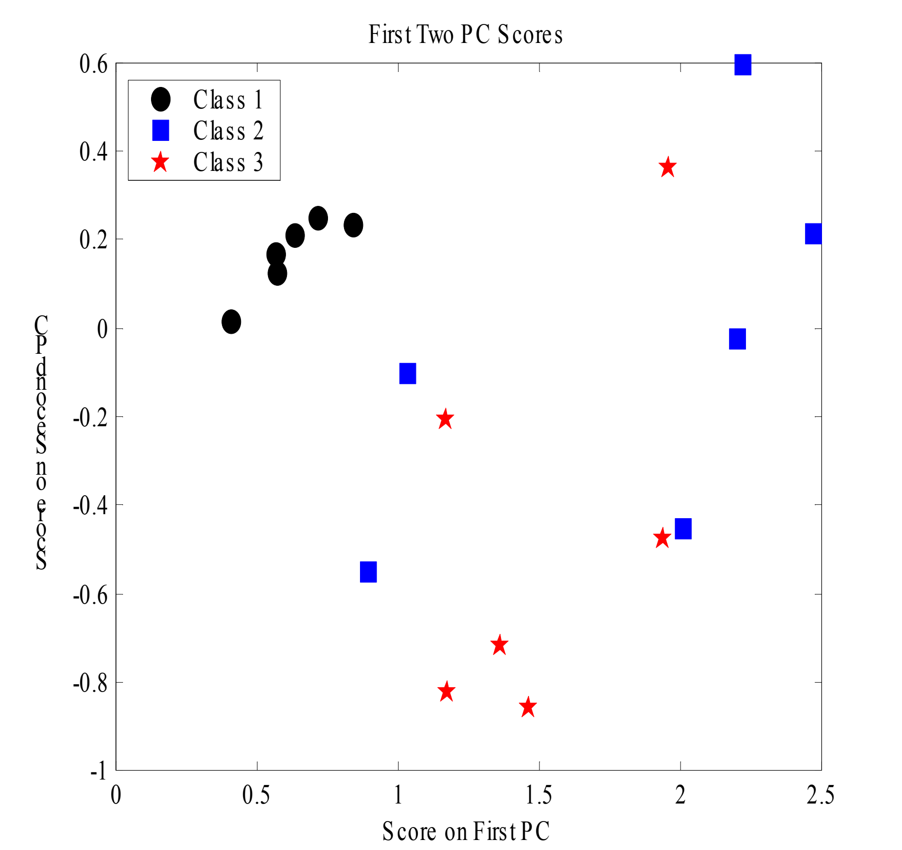
Neural Networks

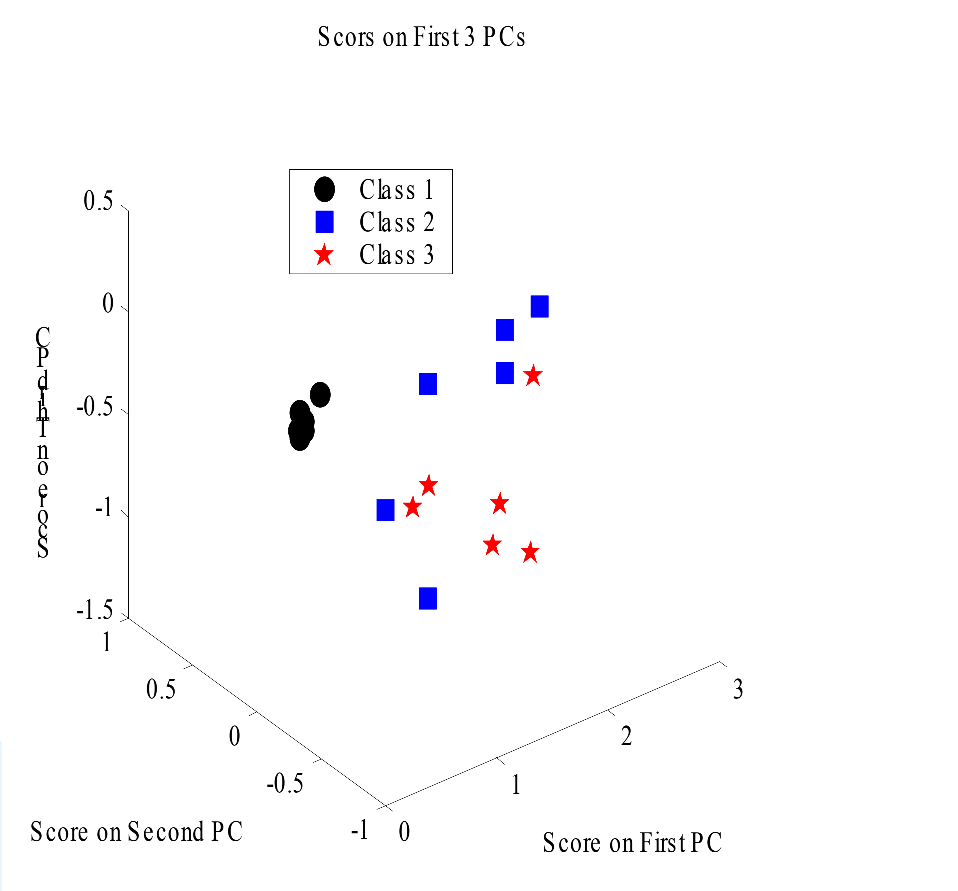
- ✓Mimic connections between human neurons in the brain
- ✓Learn by back propagating the error
- ✓Can learn non-linear or curved separation boundary
- ✓*A priori* information is required
- ✓Two ways to separate more than 2 classes

Clustering Methods

- ✓Utilizing the ‘similarity’ between two vectors to group them
- ✓Supervised or Unsupervised training
- ✓Can learn non-linear or curved separation boundary
- ✓Clustering can be arbitrary
- ✓*A priori* information not necessary

Principal score space





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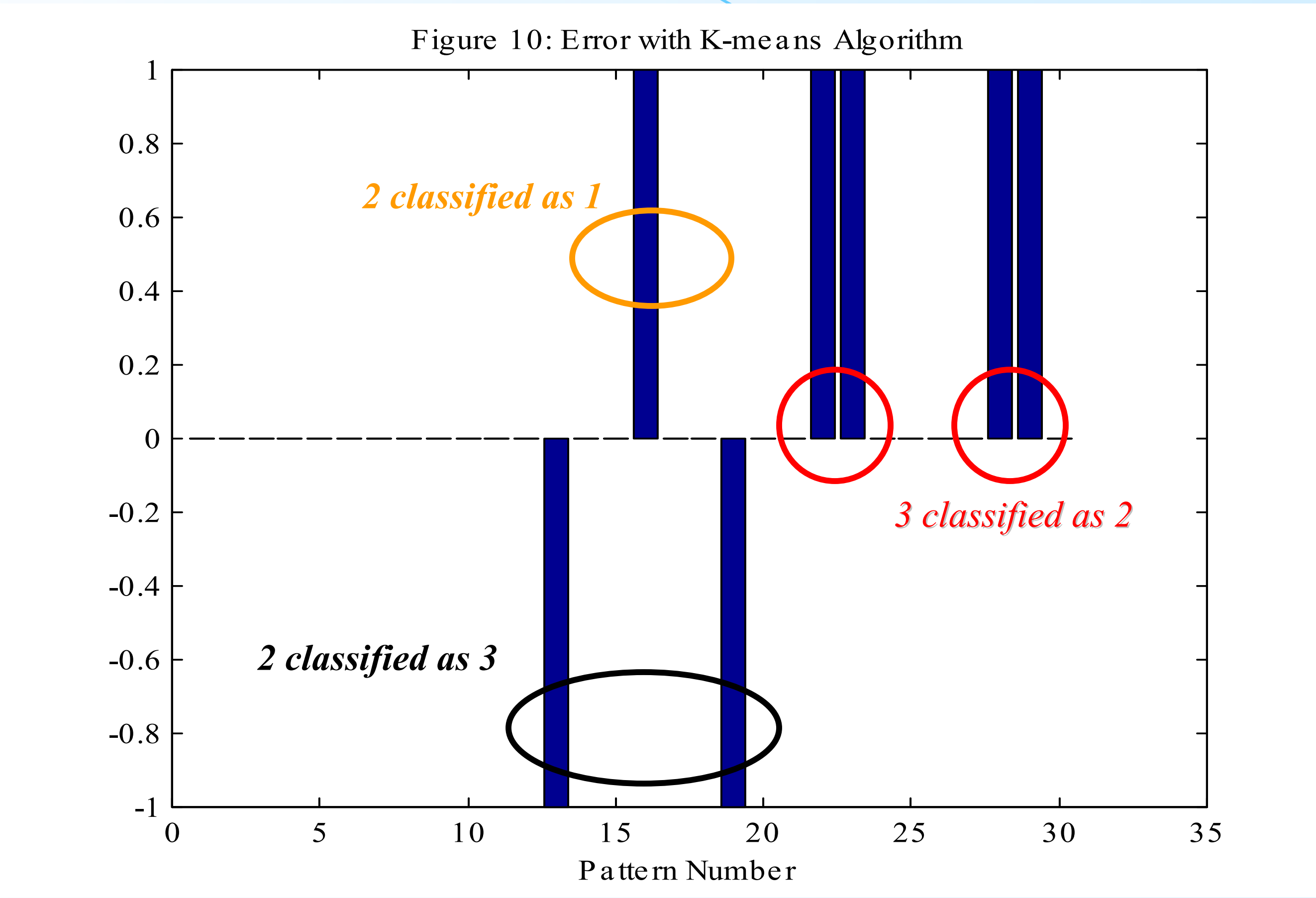
Results with clustering methods (K-means)



Zero error means correct classification

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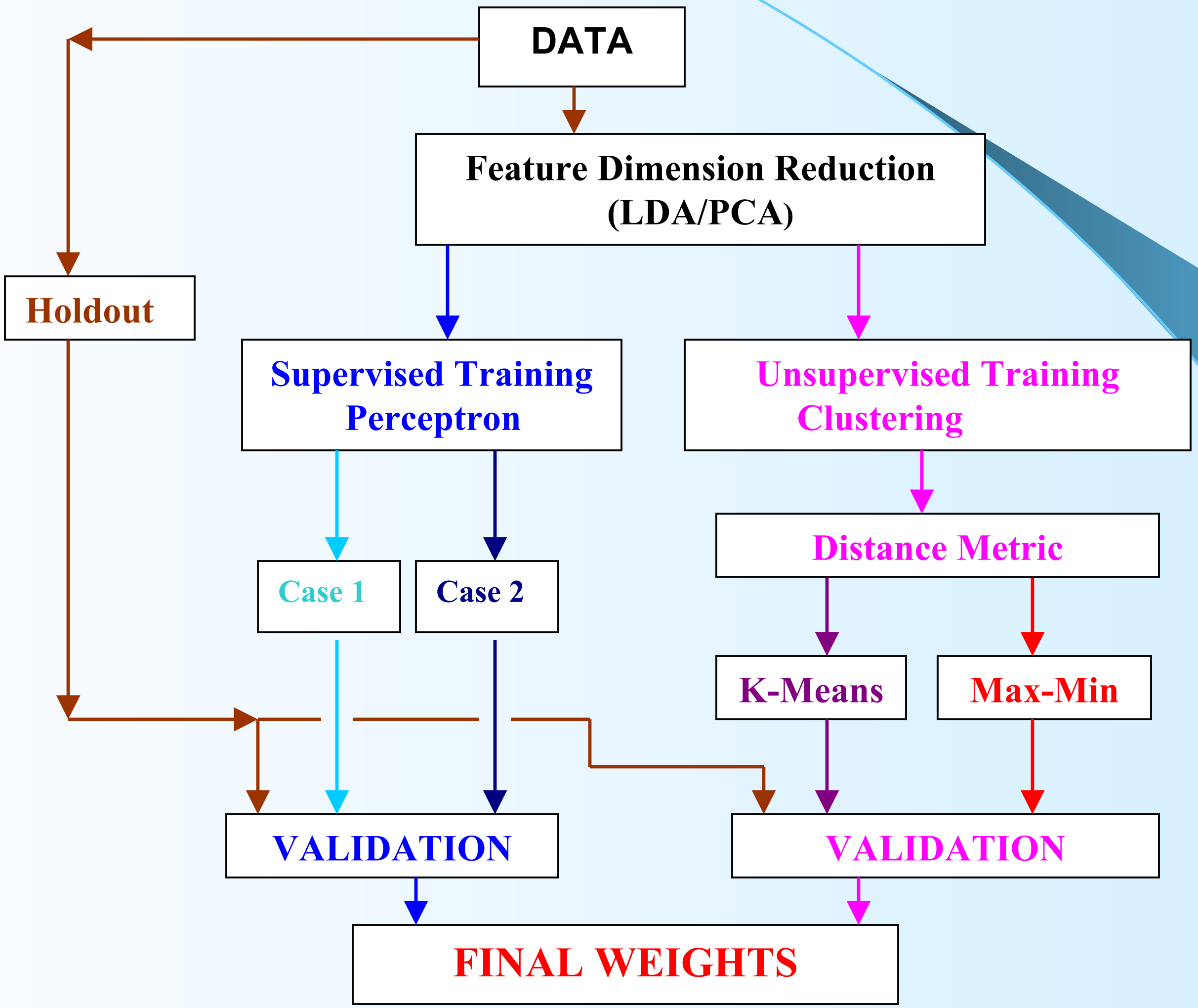
Flow Diagram



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Discussion

- ✓ PCA could separate different classes
- ✓ Fisher's Information Criterion is more efficient
- ✓ Easy to separate dynamically far states
- ✓ Hard to separate dynamically similar states
- ✓ Neural network more effective than clustering methods

Future Directions

- ✓ Nonlinear measures instead of power spectrum
- ✓ Wavelets
- ✓ 'Fuzzy' clustering
- ✓ Using multivariate measurements

Potential fields of application

- ✓ Track change in global dynamics
- ✓ Event Detection

Thank you!