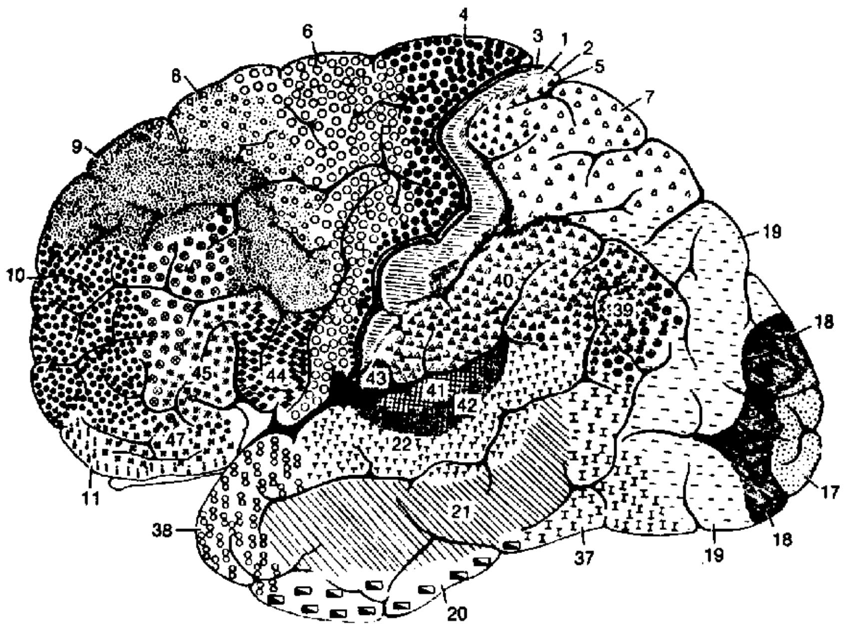
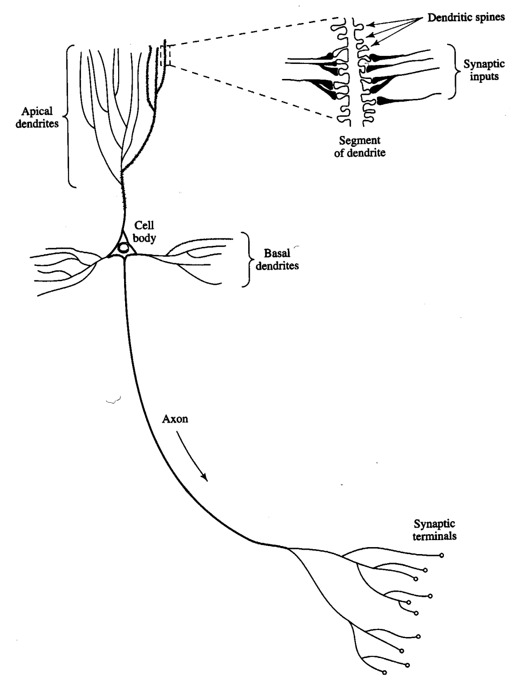
Neural Networks and Gas Turbine Diagnostics

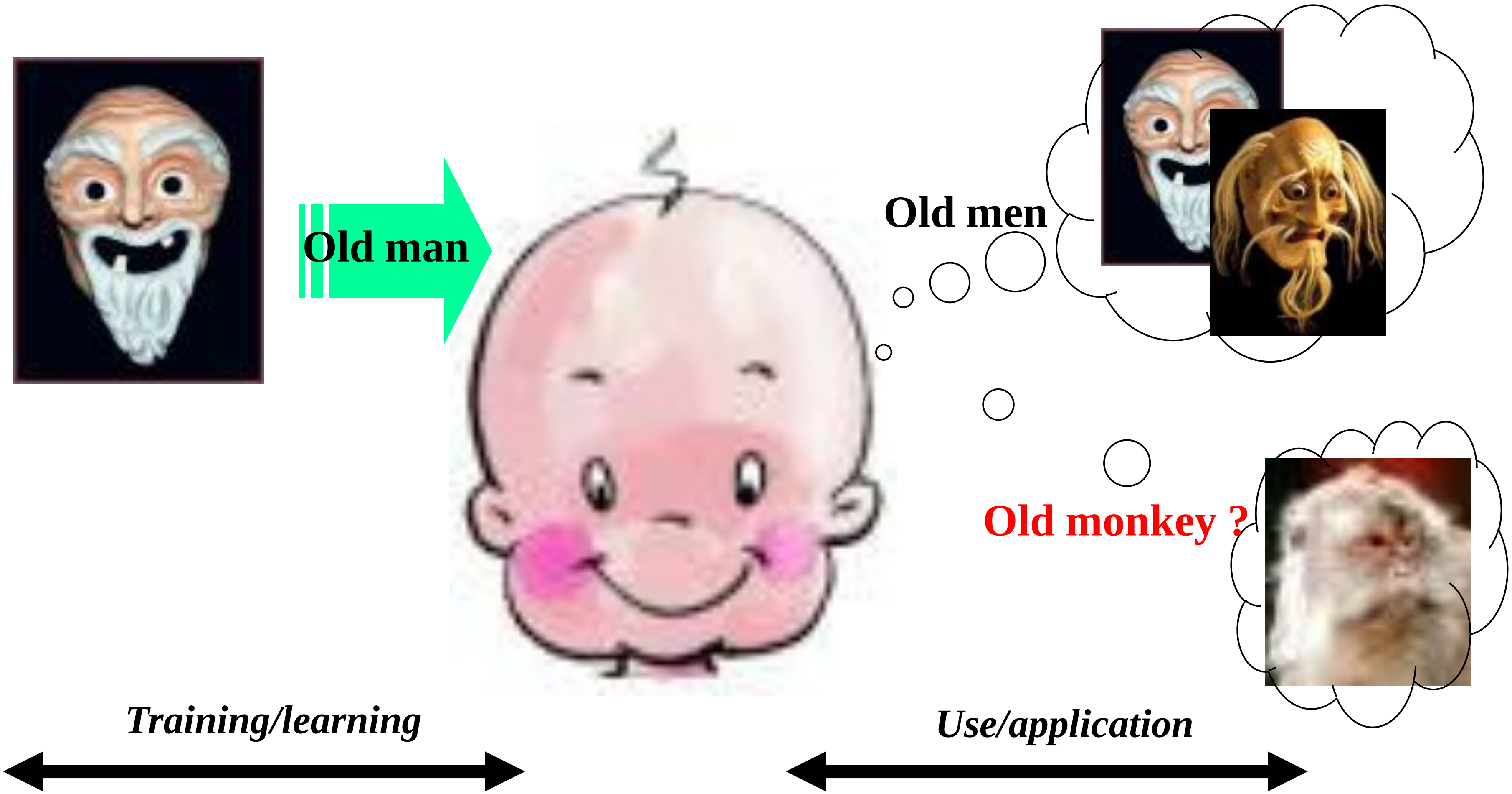
Artificial Neural Networks



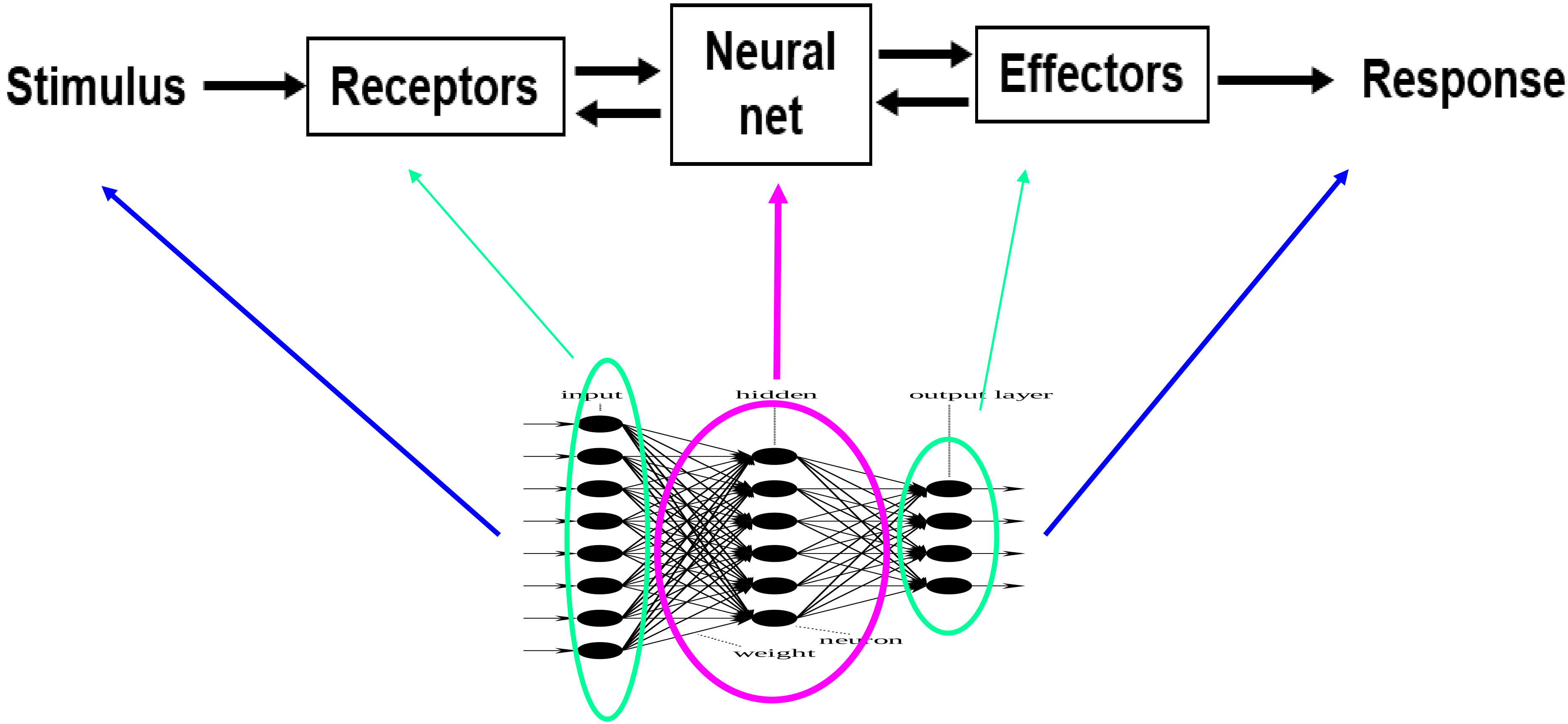


- Work on ANN has been motivated by the recognition that the human brain computes entirely differently from computers
- A brain learns from experience

Artificial Neural Networks



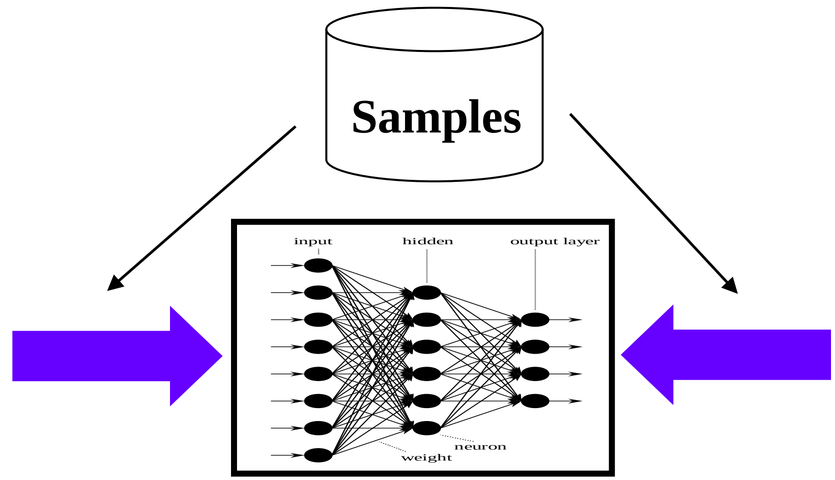
Artificial Neural Networks



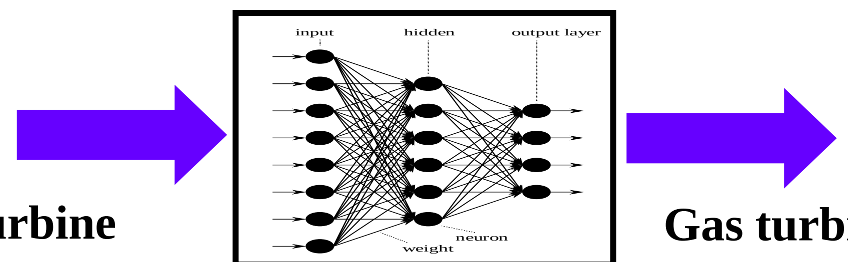
Neural network: a massively parallel distributed processor made up of simple processing units, which has a natural propensity for storing experimental knowledge and making it available for use.

Artificial Neural Networks

Training of ANN:



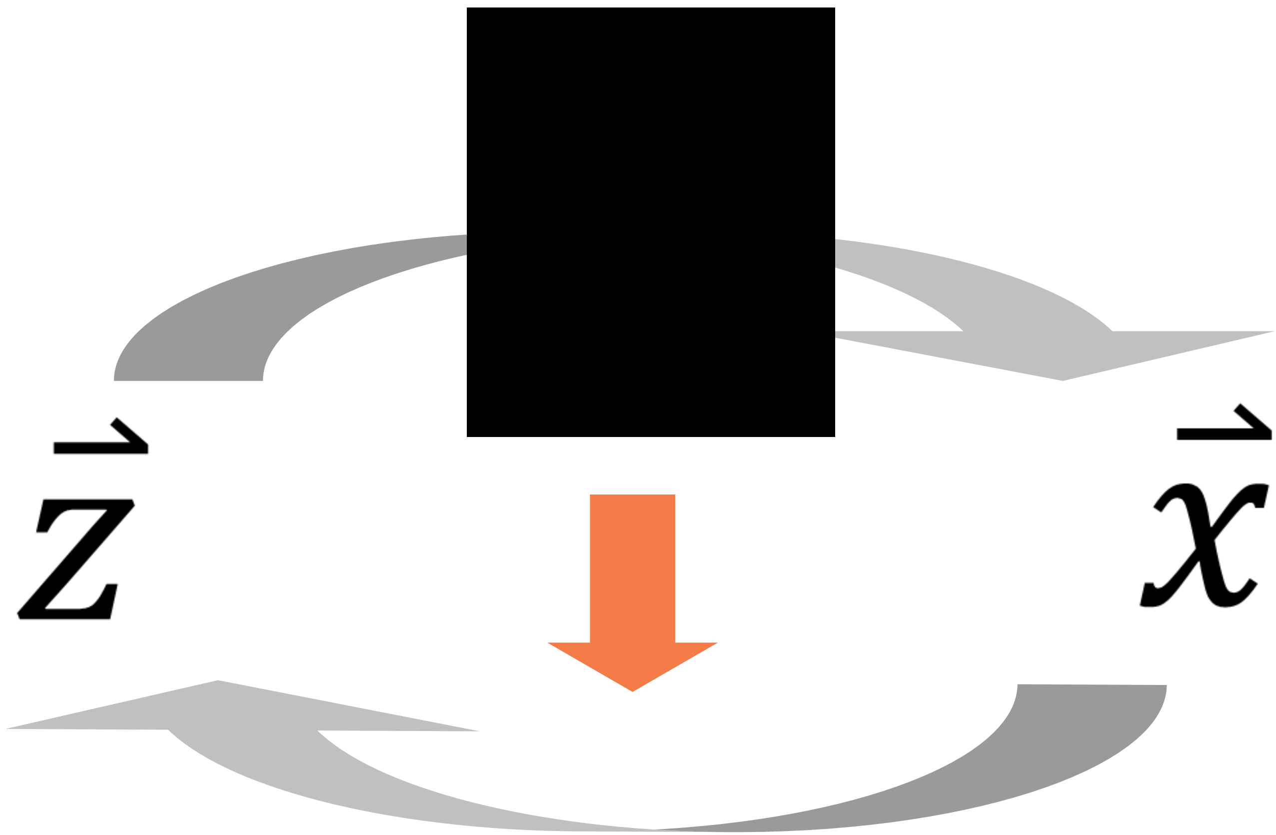
Application of ANN:



Gas turbine measurements

Gas turbine degradation

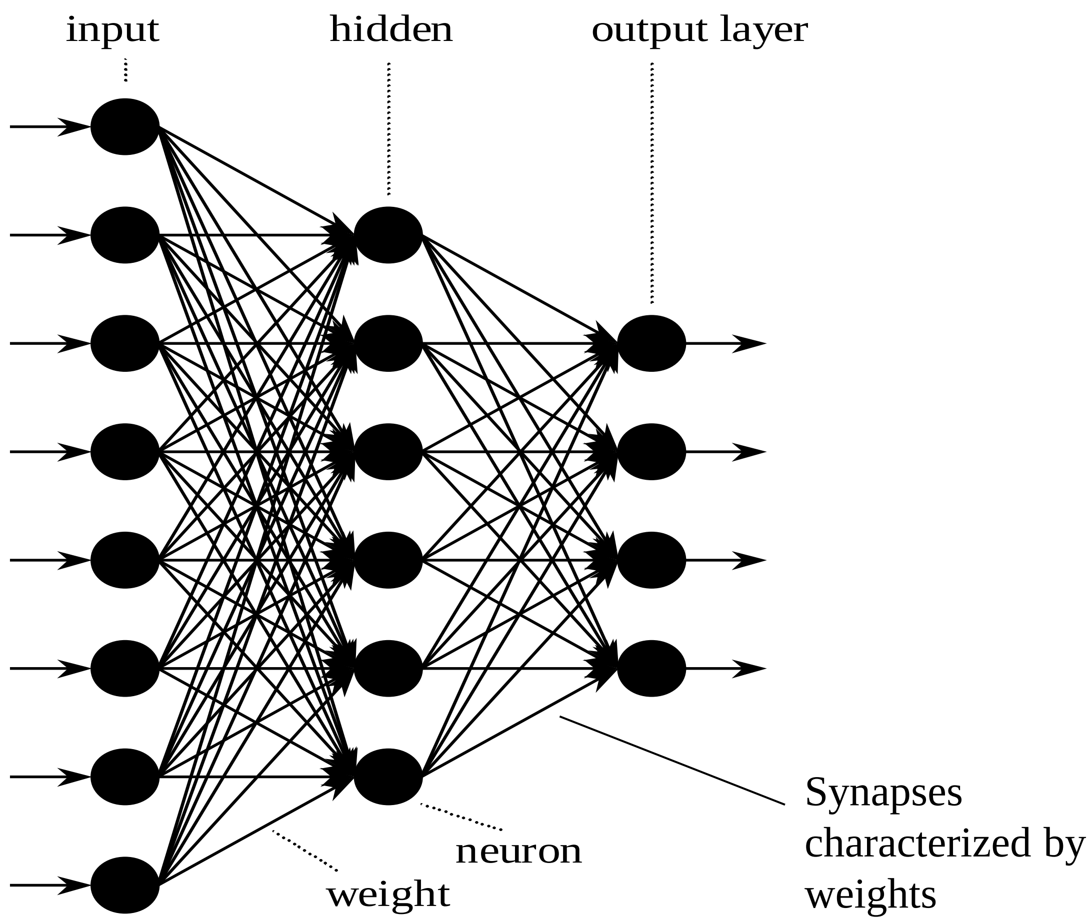
Artificial Neural Networks



$$\vec{z} = h(\vec{x})$$

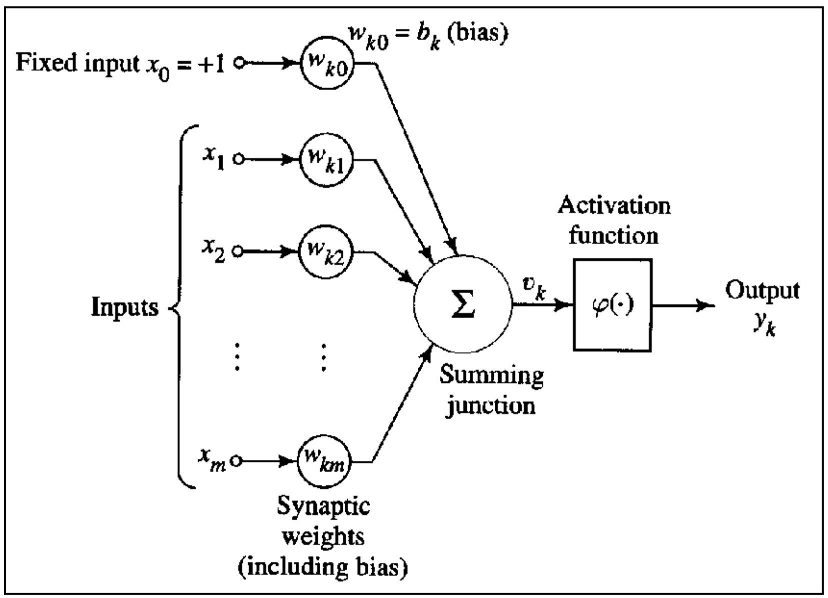
Artificial Neural Networks

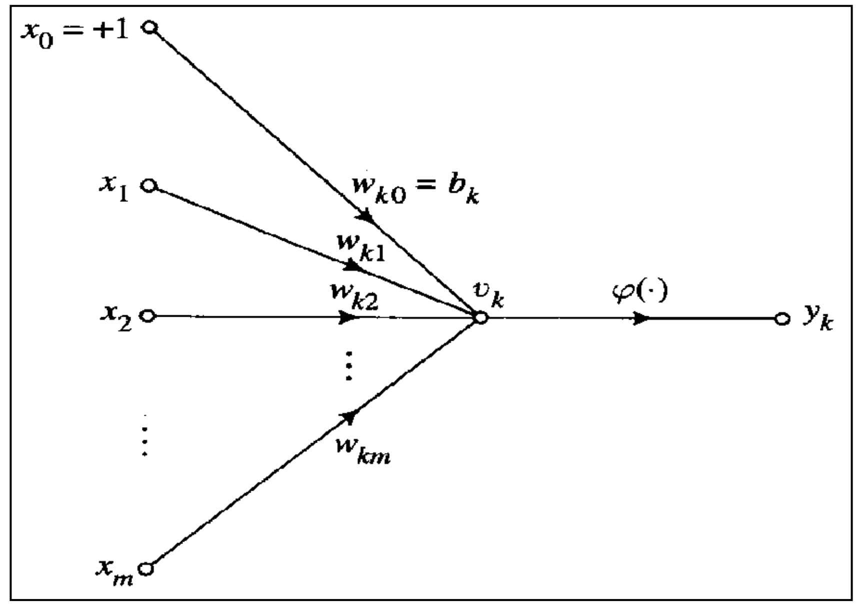
A typical Neural Network



Artificial Neural Networks

A neuron is an information-processing unit – fundamental to the operation of NN





Signal-flow graph of a neuron

THREE KEY ELEMENTS:

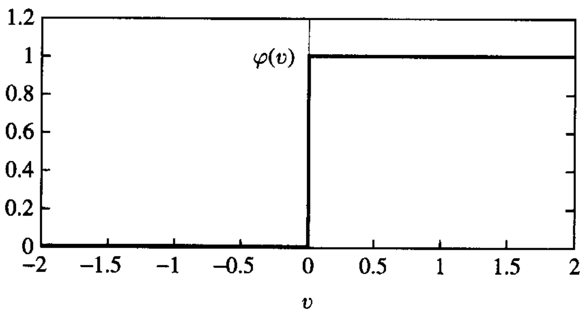
- ✓ A set of synapses
- ✓ An adder
- ✓ An activation function

$$y_k = \varphi\left(\sum_{j=1}^{m} w_{kj} x_j + b_k\right)$$

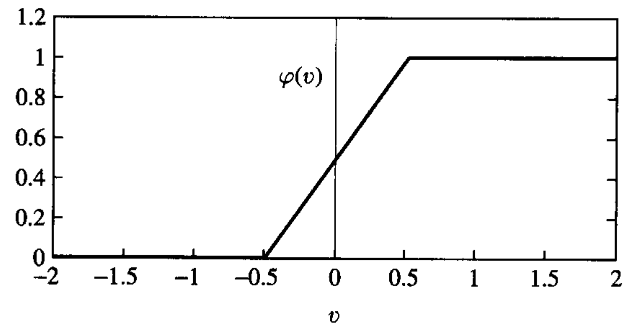
Artificial Neural Networks

Activation function to take into account non-linearity:

Threshold Function:

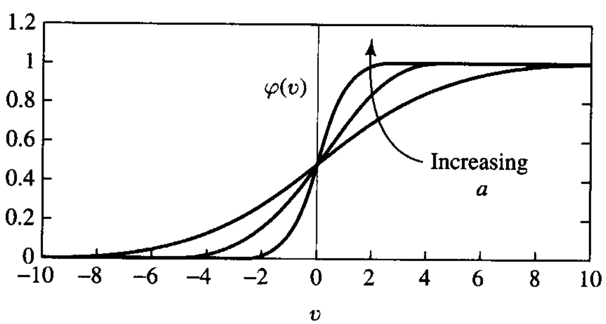


Piecewise-Linear Function:



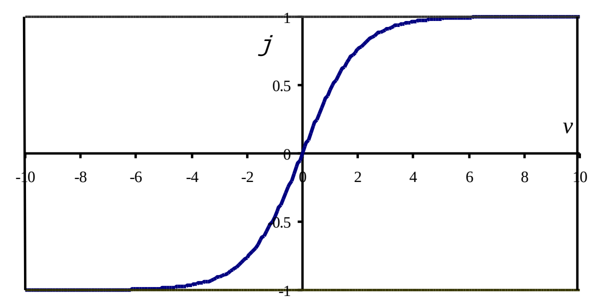
Sigmoid function
(logistic function):

$$\varphi(v) = \frac{1}{1+\exp(-av)}$$



Sigmoid function
(hyperbolic tangent function):

$$\varphi(v) = \tanh(v) = \frac{1-e^{-v}}{1+e^{-v}}$$



Artificial Neural Networks

Samples: Examples of individual cases – experience:

$$(\vec{z}_1, \vec{x}_1)$$

$$(\vec{z}_2, \vec{x}_2)$$

$$\cdots\cdots$$

$$(\vec{z}_3, \vec{x}_3)$$

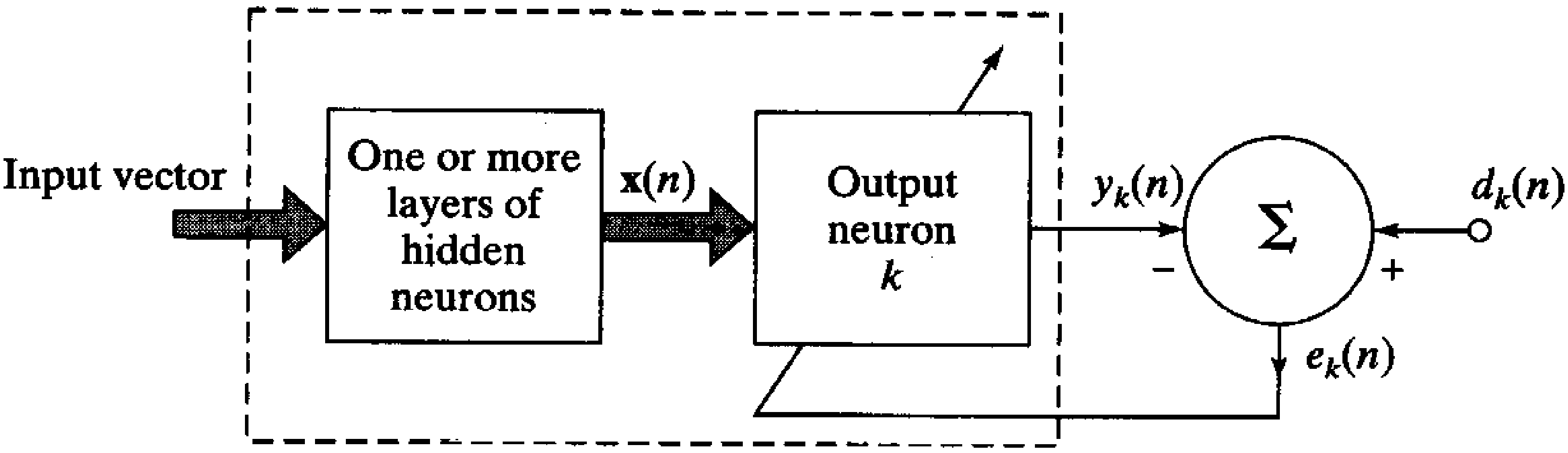
- **Training samples**
- **Validation/Test samples**

Observable information

Truth

Artificial Neural Networks

Training Algorithm: Feed-Forward Back-Propagation (FFBP)



Forward propagation of ***FUNCTION SIGNALS***

Backward propagation of ***ERROR SIGNALS***

Artificial Neural Networks

Rate of learning:

$$w_{ji}(n) = w_{ji}(n-1) + \Delta \mathrm{w}_{\mathrm{ji}}(n)$$

$$\Delta w_{ji}(n) = -\eta \frac{\partial E(n)}{\partial w_{ji}(n)} + \alpha \Delta w_{ji}(n-1)$$

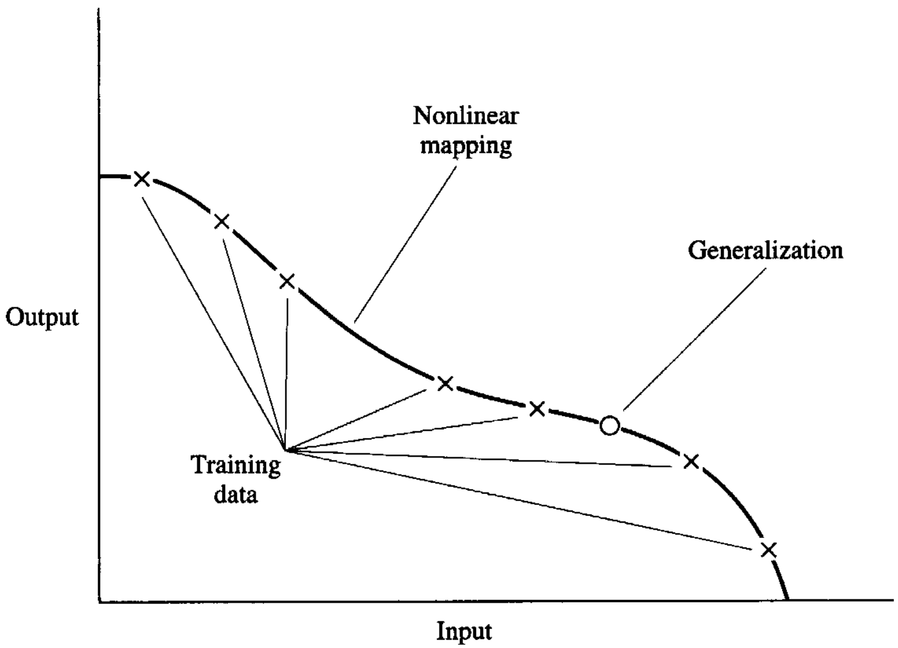
where $E(n) = \frac{1}{2}\sum_{j=1}^{p} e_j^2(n)$ $e_j(n) = d_j(n) - y_j(n)$

η -- learning rate parameter α -- constant

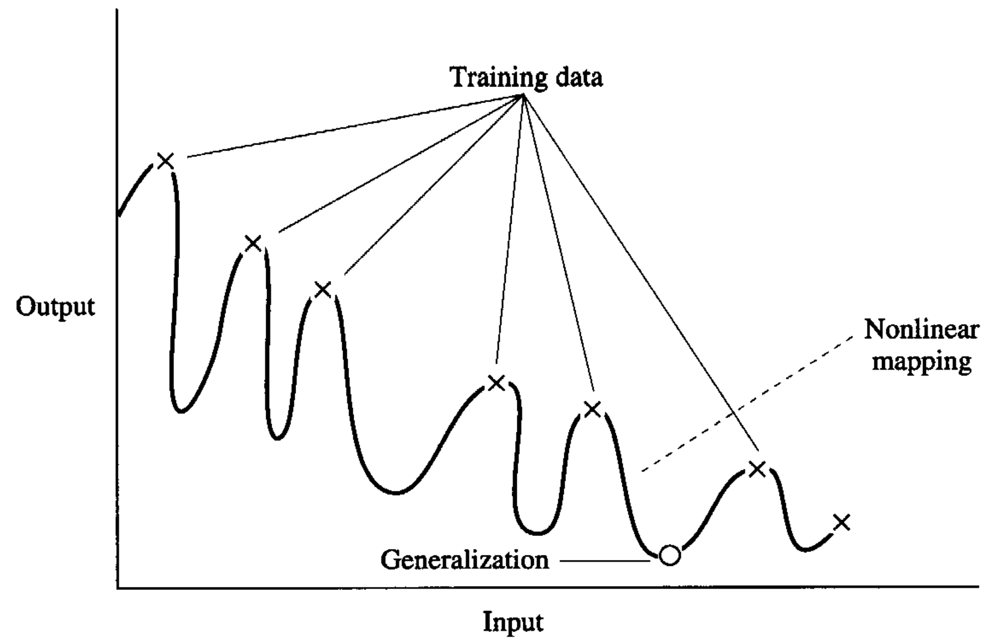
A low η produces slow training process;
A large η may introduce instability to the learning curve

Artificial Neural Networks

Training Quality:



(a)



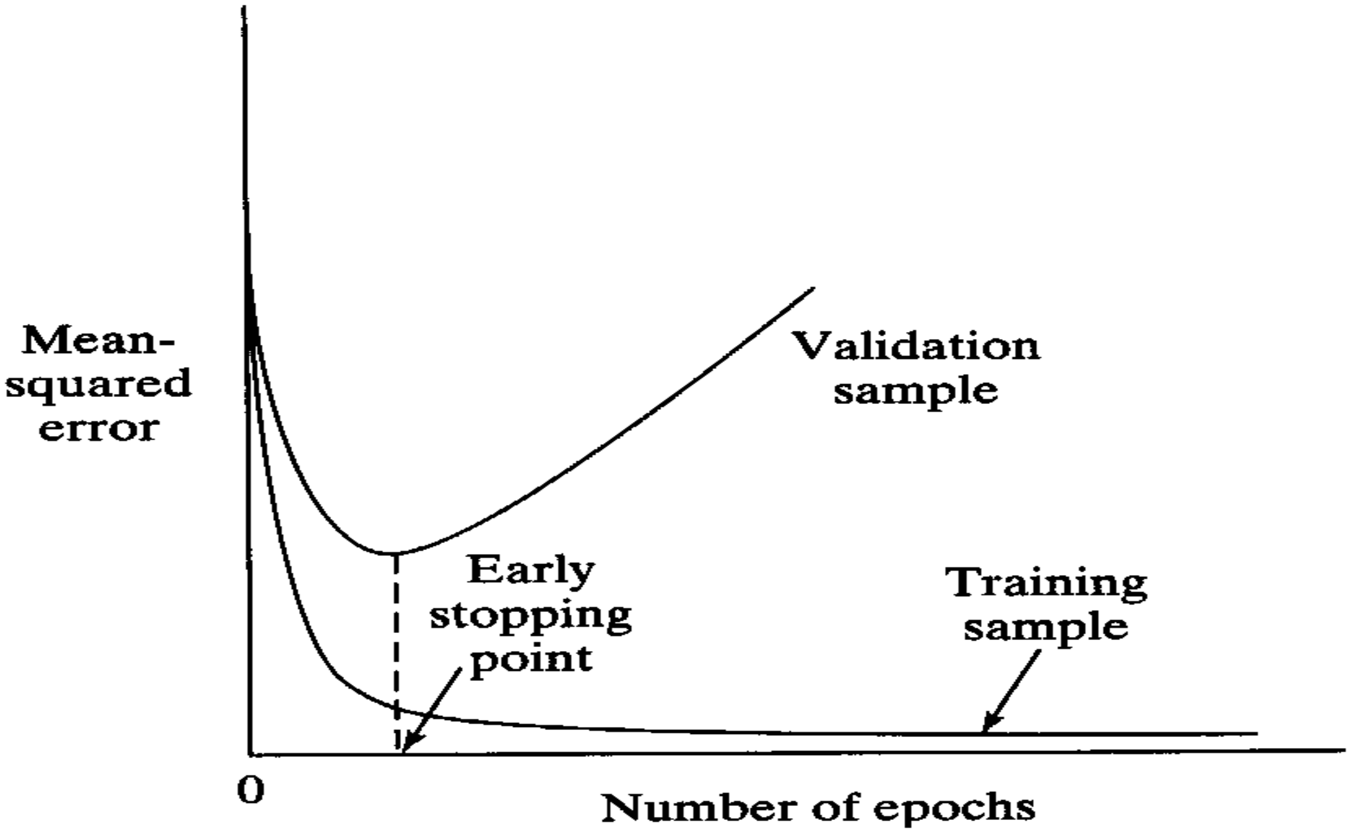
(b)

Properly fitted data
(good generation)

Overfitted data
(poor generation)

Artificial Neural Networks

Cross-Validation:



Artificial Neural Networks

NN Validation:

$$\text{Success Rate} = \frac{\text{Successfully identified samples}}{\text{Total validation samples}}$$

Actual Faults ===➔

Confusion matrix:

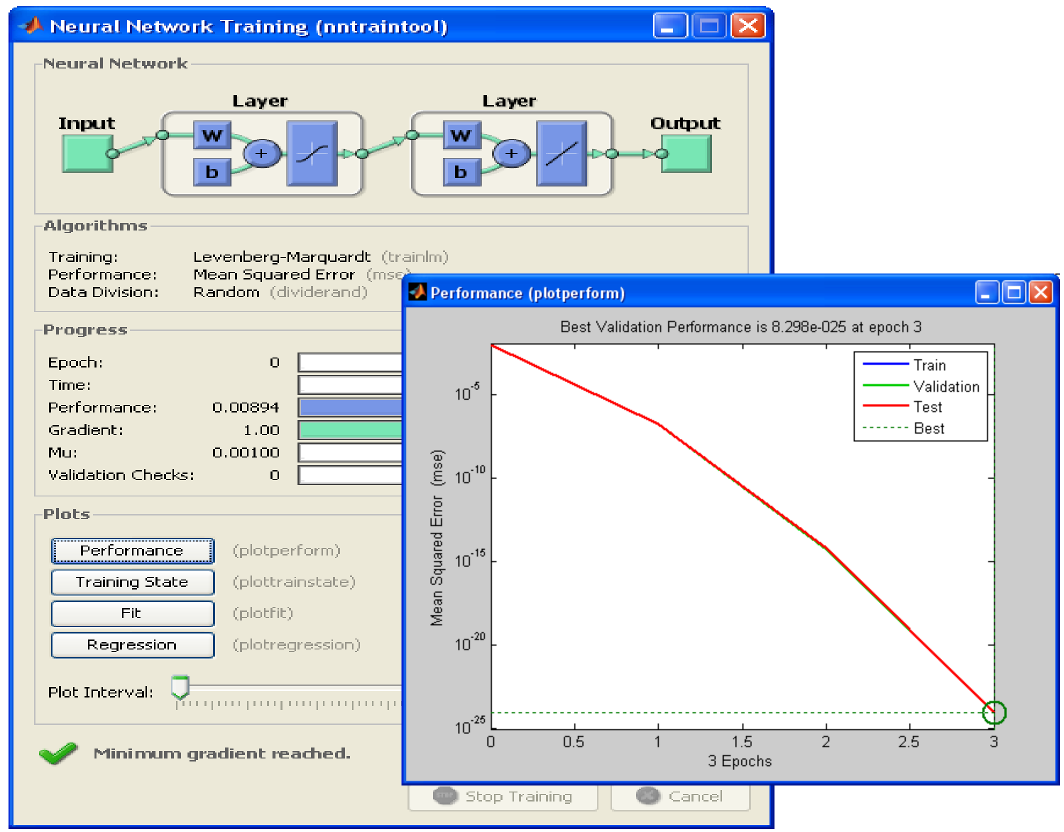
<===Predicted Faults

	Fault 1	**Fault 2**	**Fault 3**
Fault 1	100%	0	0
Fault 2	2%	98%	0
Fault 3	0	0	100%

Matlab Neural Network Toolbox

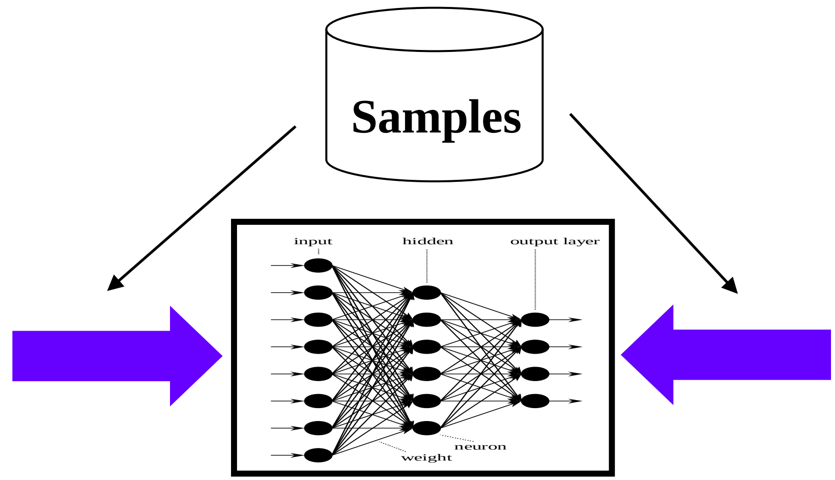
- Design and simulate Neural Networks

Neural Network Toolbox™ provides tools for designing, implementing, visualizing, and simulating neural networks.



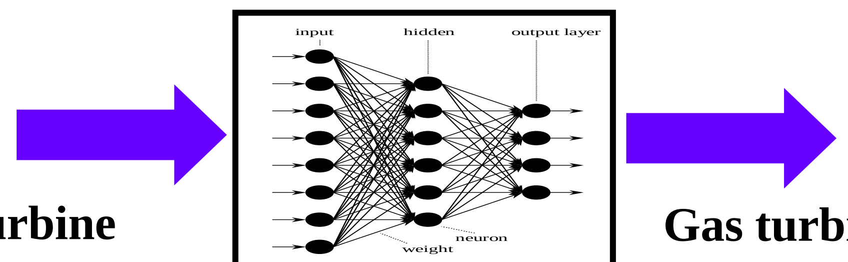
Artificial Neural Networks

Training of ANN:



Application of ANN:

Gas turbine measurements



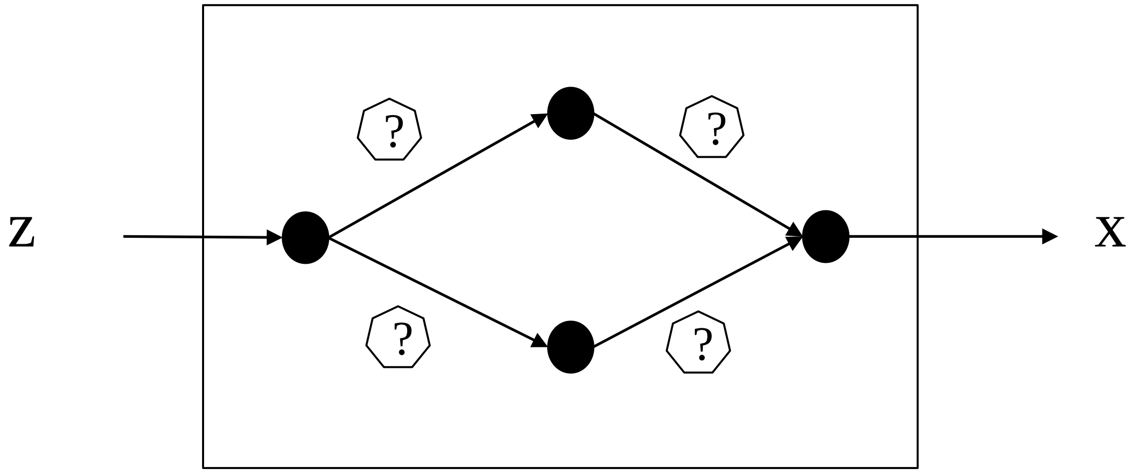
Gas turbine degradation

Artificial Neural Networks

Procedure of using a neural network:

- **Choose a neural network configuration**
- **Generate samples (experiments or simulations)**
- **Split samples into training and testing/validation samples**
- **Training of neural network (training samples)**
- **Validation of neural network (validation samples)**
- **Application of neural network (re-call mode)**

Simple Example



Two events (samples)

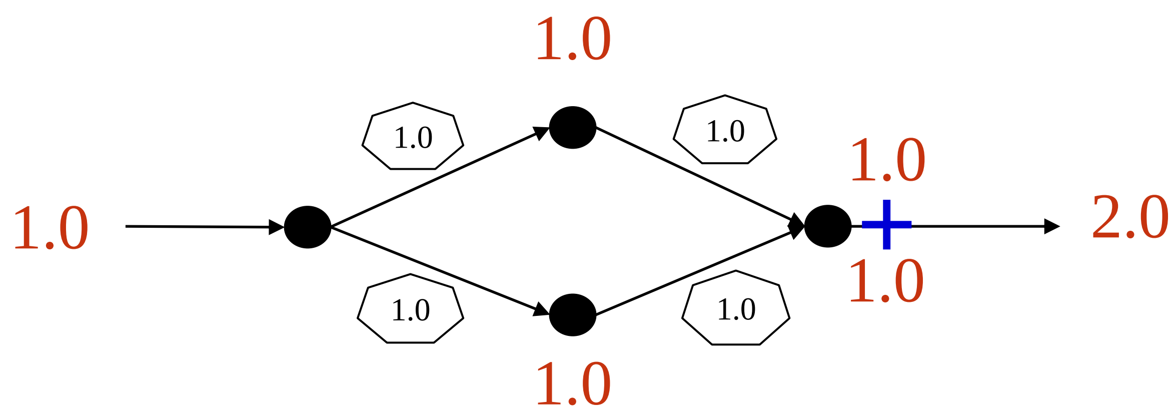
No.	(z, x)
1	(1.0, -1.0)
2	(-2.5, 2.5)

Simple Example

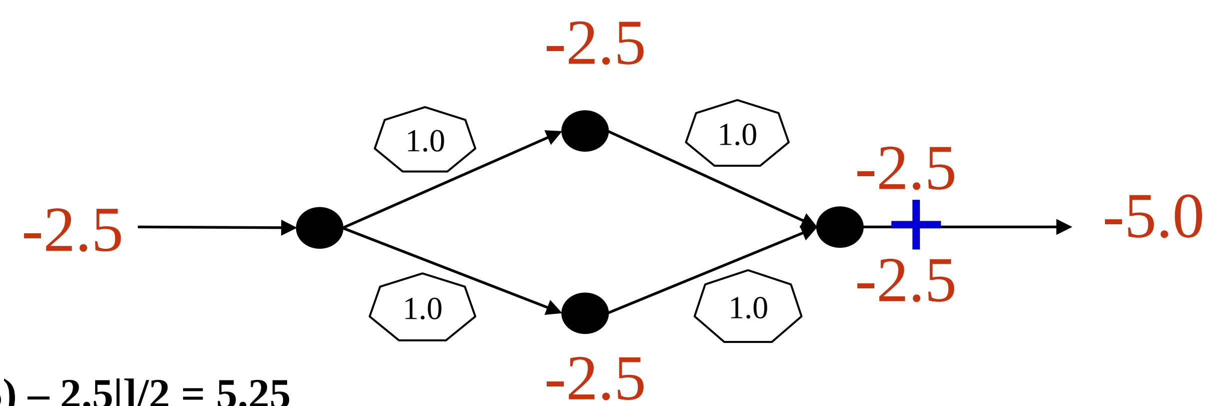
Assume all weights = 1 initially.

1st epoch:

1st sample (1.0, -1.0)



2nd sample (-2.5, 2.5)

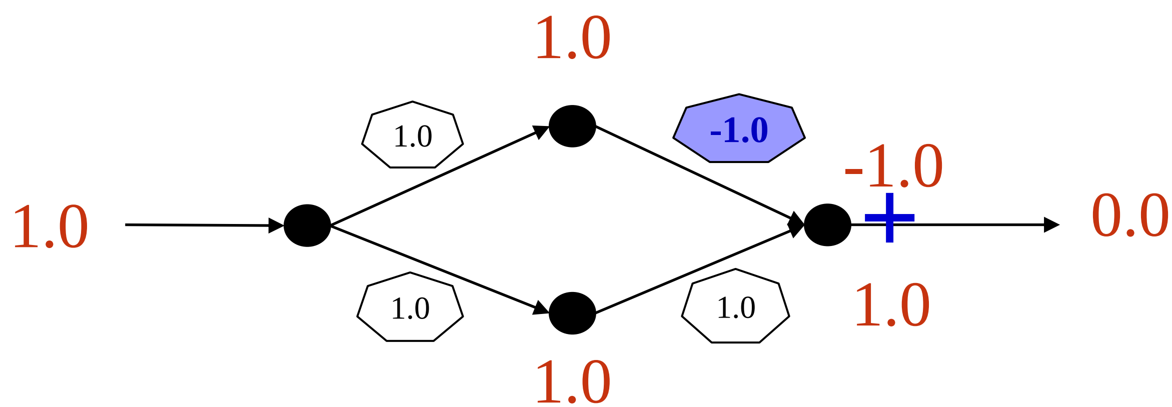


Error = [|(2) – (-1)| + |(-5) – 2.5|]/2 = 5.25

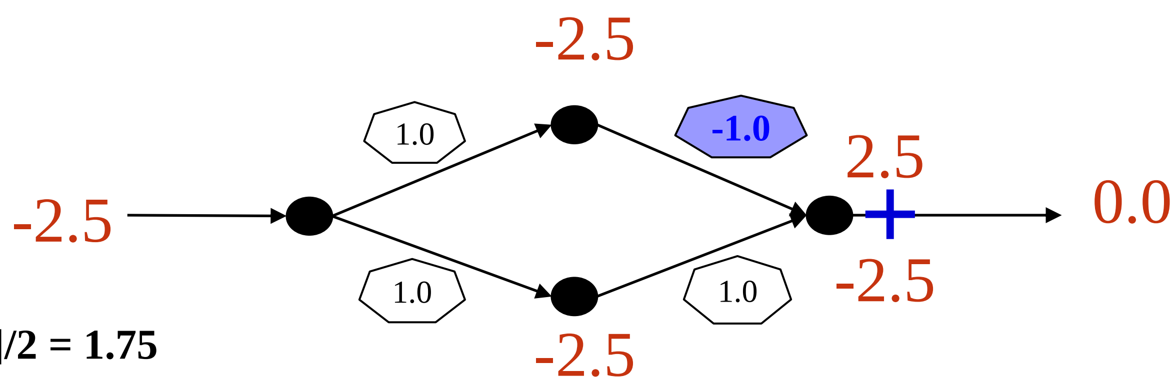
Simple Example

2nd epoch:

1st sample (1.0, -1.0)



2nd sample (-2.5, 2.5):

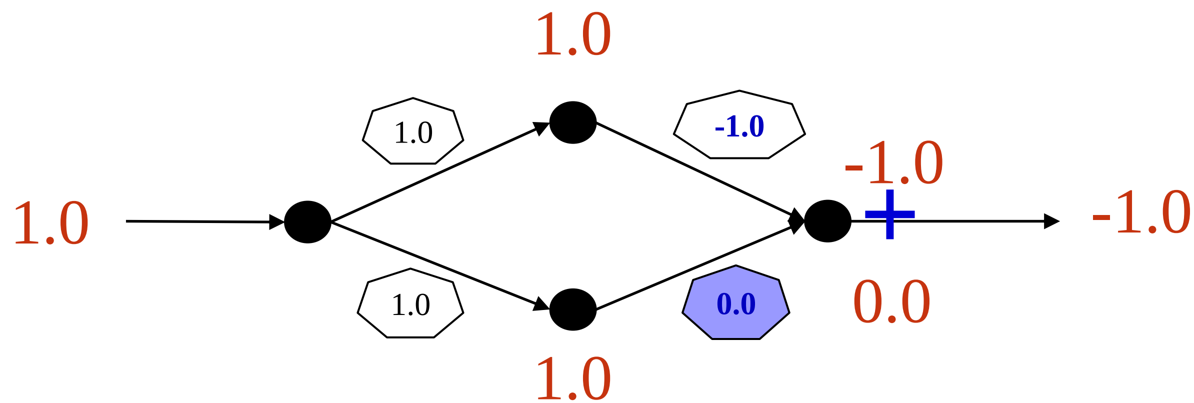


Error = [|(0.0) – (-1.0)| + |0.0 – 2.5|]/2 = 1.75

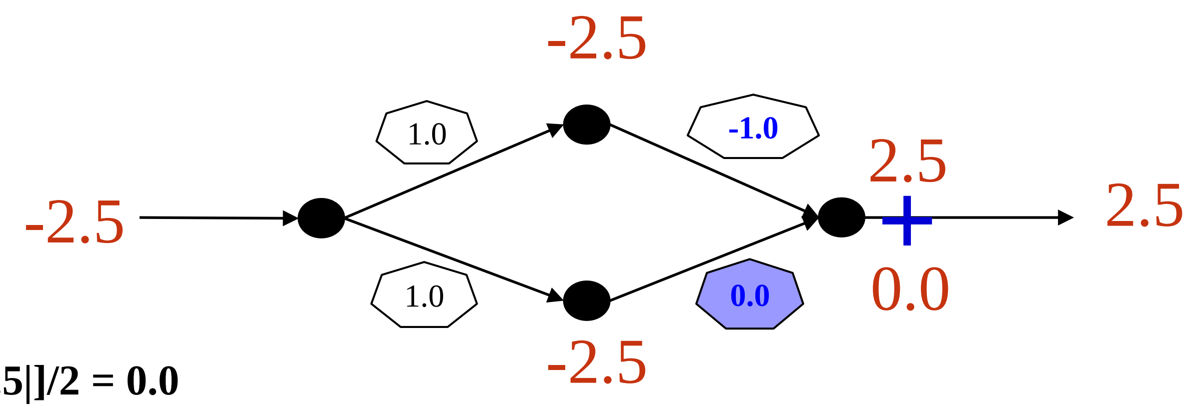
Simple Example

3rd epoch:

1st sample (1.0, -1.0)

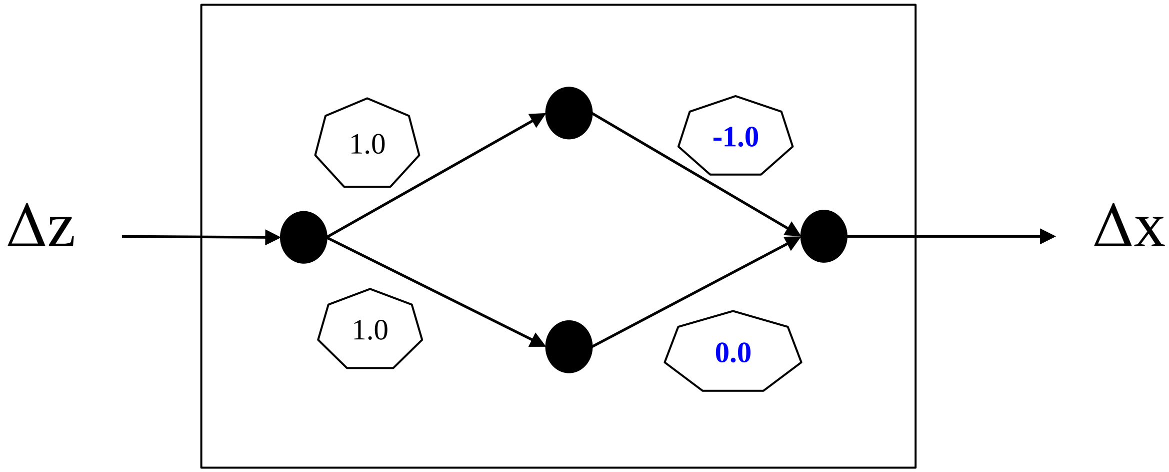


2nd sample (-2.5, 2.5):



Error = [|(-1) – (-1)| + |2.5 – 2.5|]/2 = 0.0

Simple Example

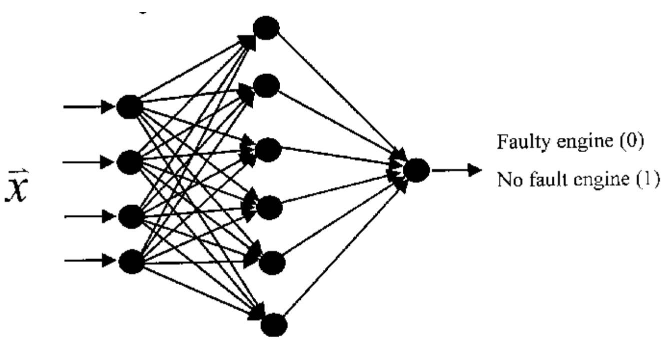


Two samples

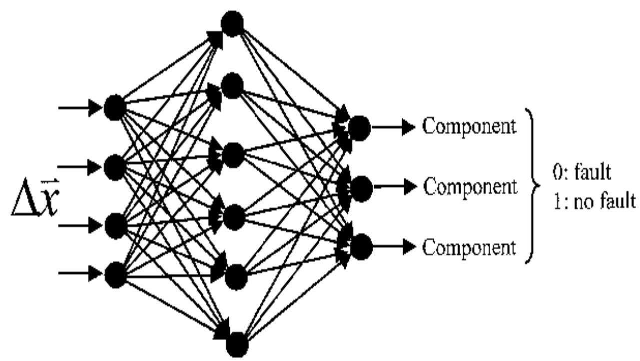
No.	(Δz, Δx)
1	(1.0, -1.0)
2	(-2.5, 2.5)

Artificial Neural Networks

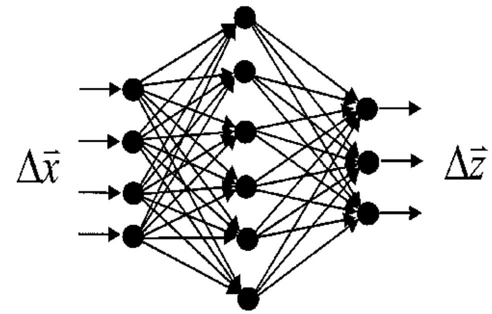
Fault Detection



Fault Isolation

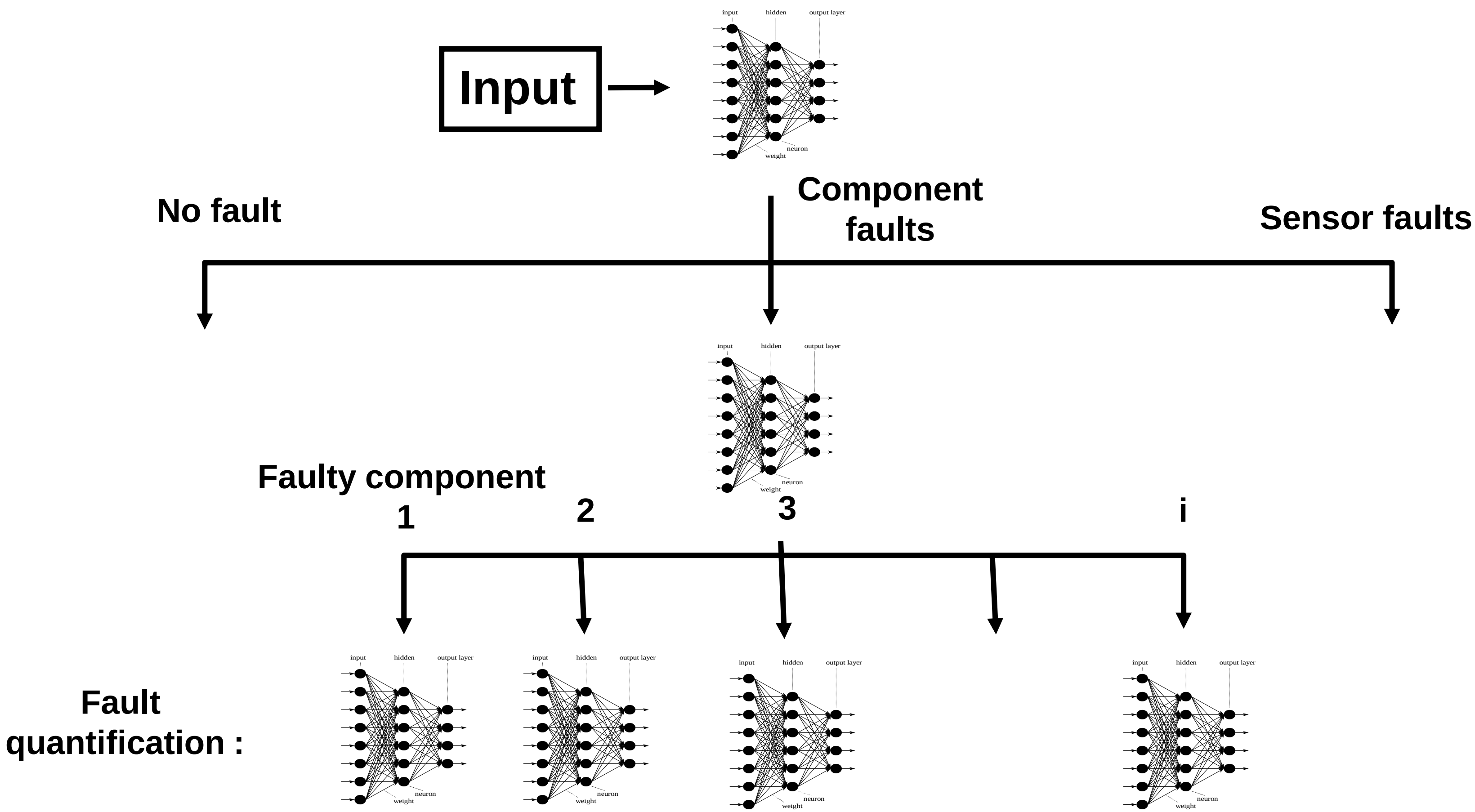


Fault Quantification

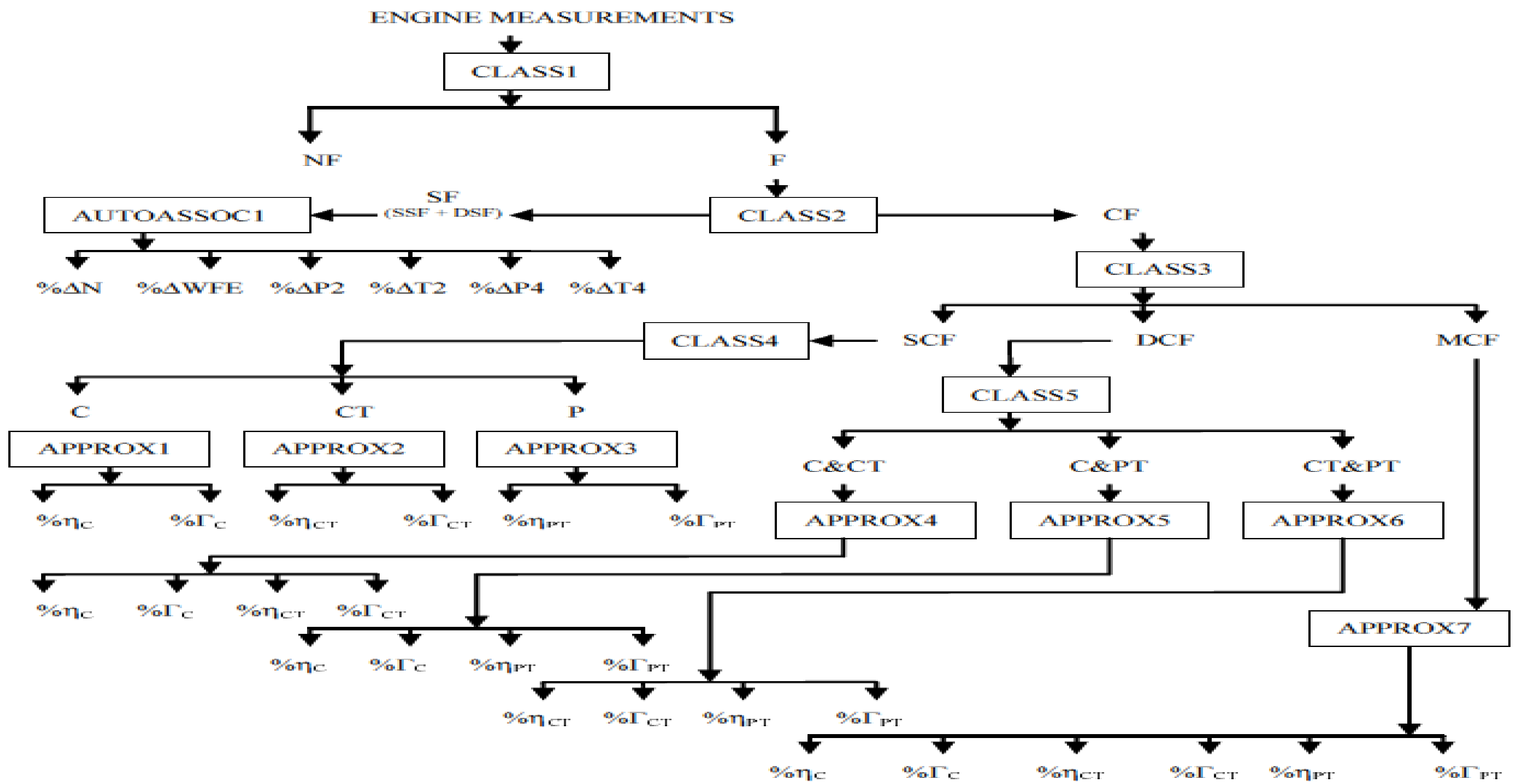


Artificial Neural Networks

A Neural Network Based Diagnostic system :



Artificial Neural Networks



Gas turbine diagnostic framework for a single spool industrial gas turbine

Artificial Neural Networks

Features :

- Non-model based
- Very quick for application once trained – suitable for online or real time applications
- Accuracy can be very high

- Long time for training
- Large number of training & validation samples required
- Can only be used in training domain
- If the physical system is modified, the NNs should be trained again