Deep Learning for Optical Imaging

Lecture 3b

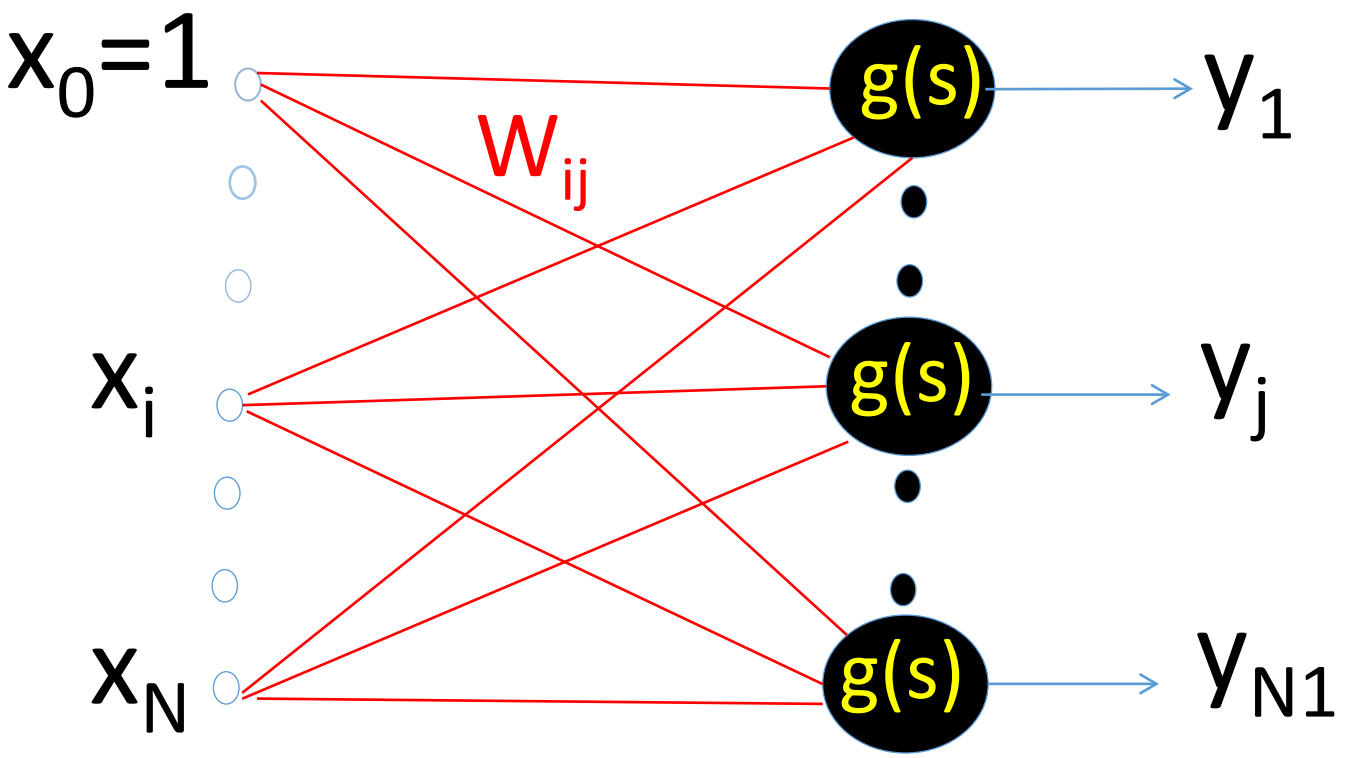
Pseudoinverse and Regression

Multliple classes

Outline

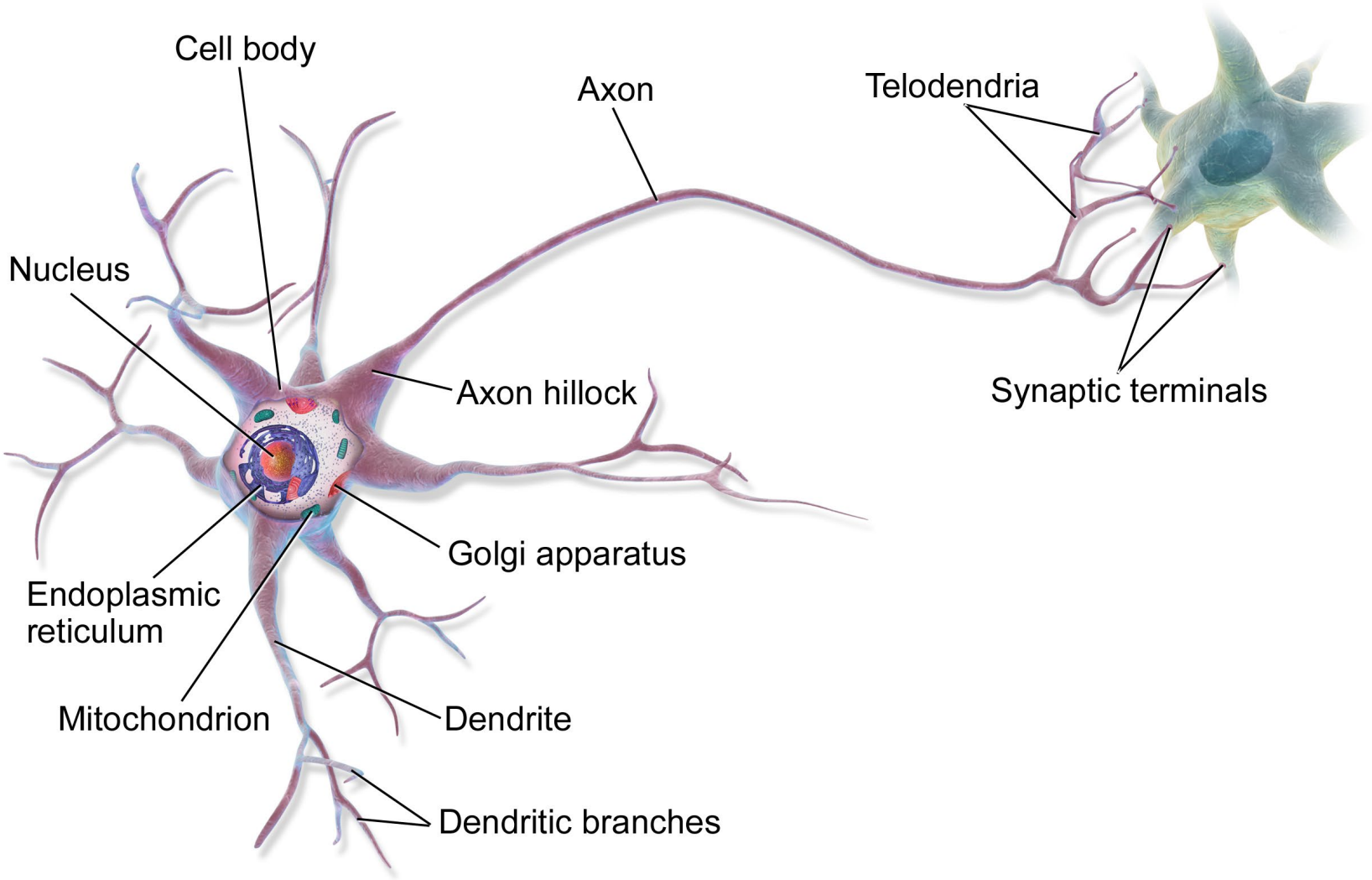
- Hebbian learning; sum of outer products
- Associative memories
- Hopfield network

Multiple neurons

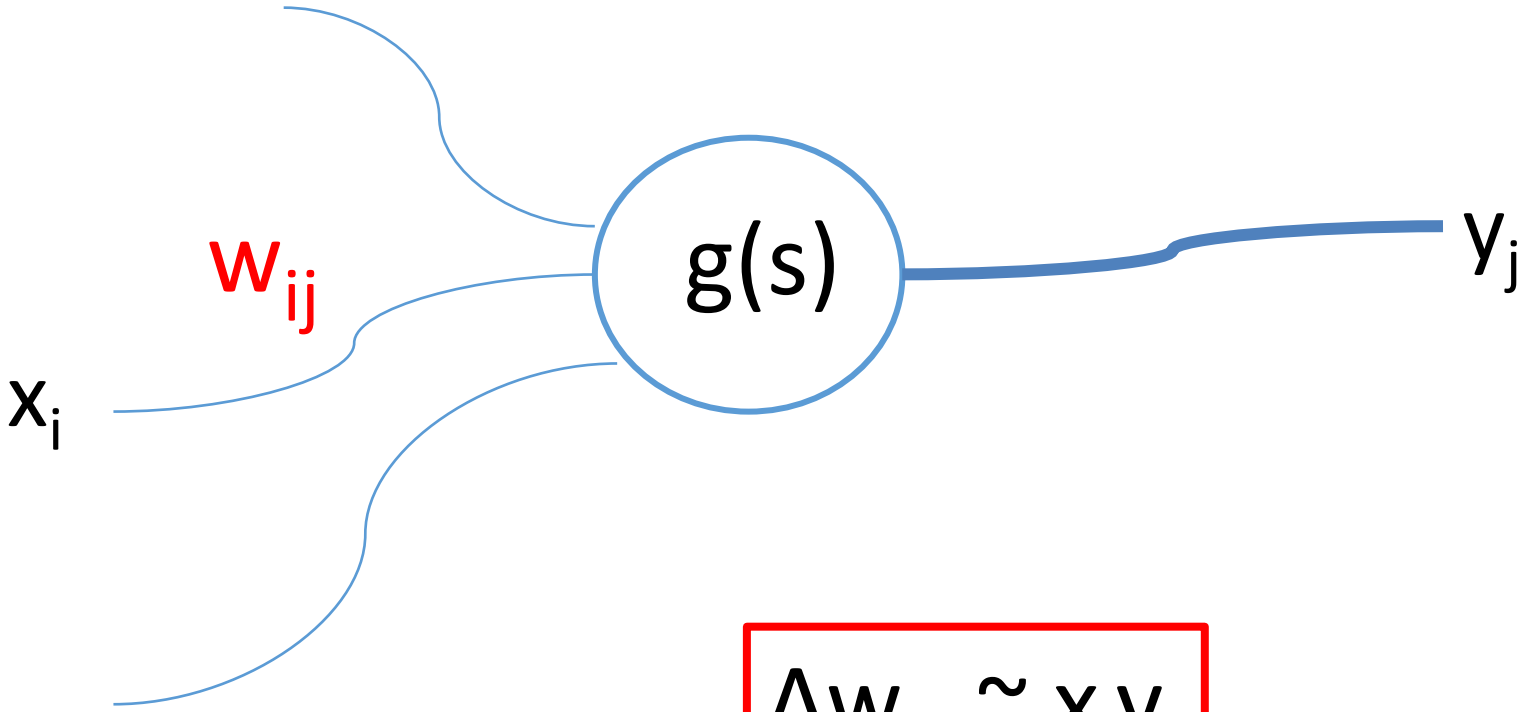


$$Y_j = g(\Sigma w_{ij} x_i + w_{0j})$$

Neuron

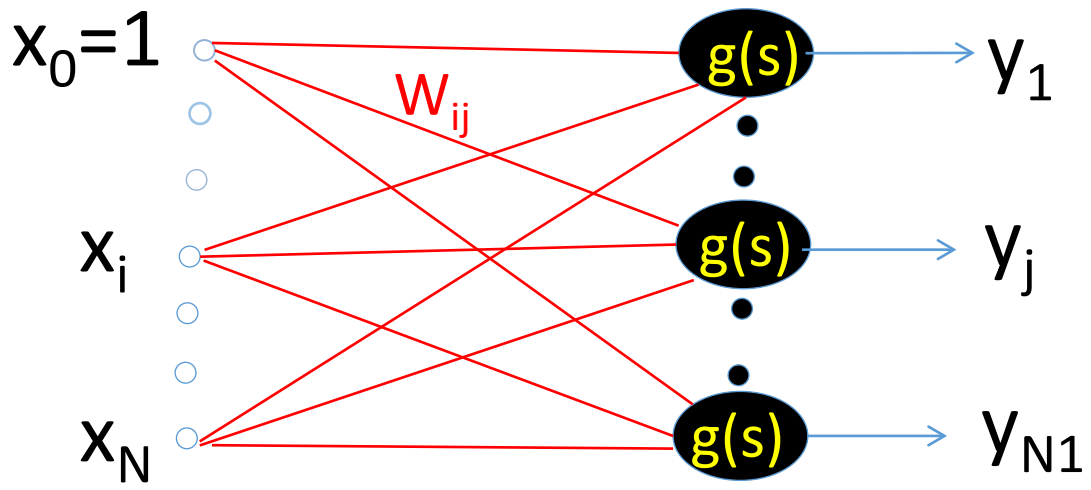

Cell body
Axon
Telodendria
Nucleus
Axon hillock
Synaptic terminals
Golgi apparatus
Endoplasmic reticulum
Mitochondrion
Dendrite
Dendritic branches

Hebbian Learning



$$\Delta w_{ij} \sim x_i y_j$$

Associative memory



Training set

$$\vec{x}^{(m)} \rightarrow \vec{y}^{(m)},\ m = 1\ to\ M$$

$$\Delta w_{ij} = x_i^{(m)} y_j^{(m)} \quad \rightarrow \quad w_{ij} = \sum_{m=1}^{M} x_i^{(m)} y_j^{(m)}$$

Associative memory

$$y_j = g\left(\sum_{i=1}^{N} w_{ij} x_i + w_{oj}\right) = g\left(\sum_{m=1}^{M} \left\{\sum_{i=1}^{N} x_i^{(m)} x_j\right\} y_j^{(m)} + w_{oj}\right)$$

$$w_{ij} = \sum_{m=1}^{M} x_i^{(m)} y_j^{(m)} \qquad if\ \vec{x} = \vec{x}^{(m_0)}$$

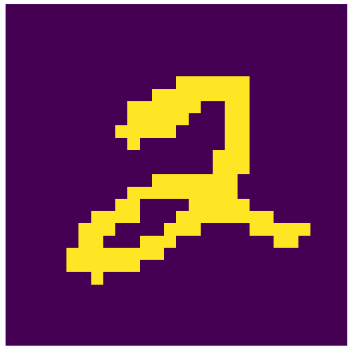
$$y_j = \sum_{i=1}^{N} \underbrace{x_i^{(m_0)} x_i^{(m_0)}}_{\square\, N} \right\} y_j^{m_0)} + \sum_{m \neq m_0}^{M} \left\{\sum_{i=1}^{N} \underbrace{x_i^{(m)} x_i^{(m_0)}}_{\square\, \sqrt{N}}\right\} y_j^{(m)} + w_{oj}$$

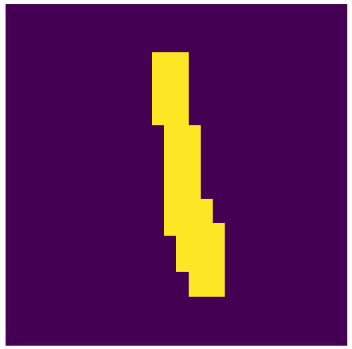
Hebbian learning : heteroassociative memory

2 image training:

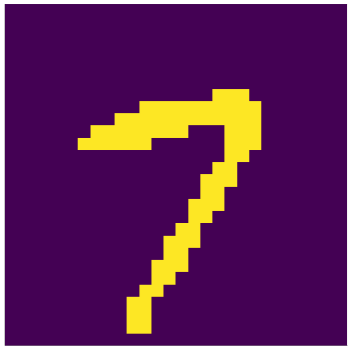
Training

Input



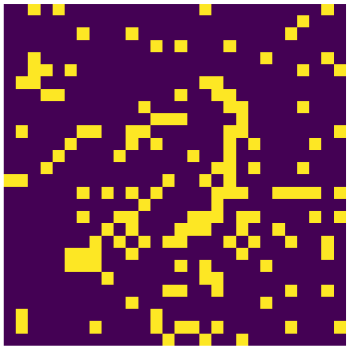


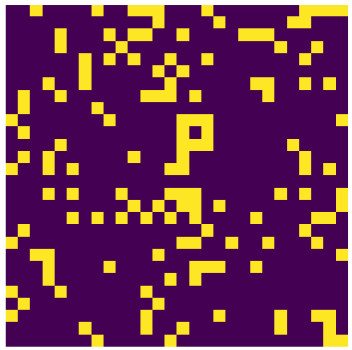
Output



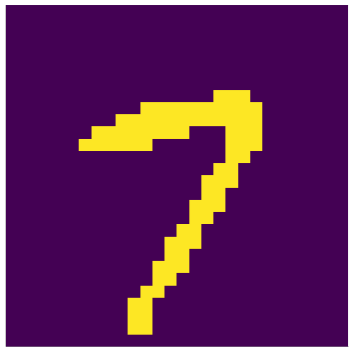
Test

Input

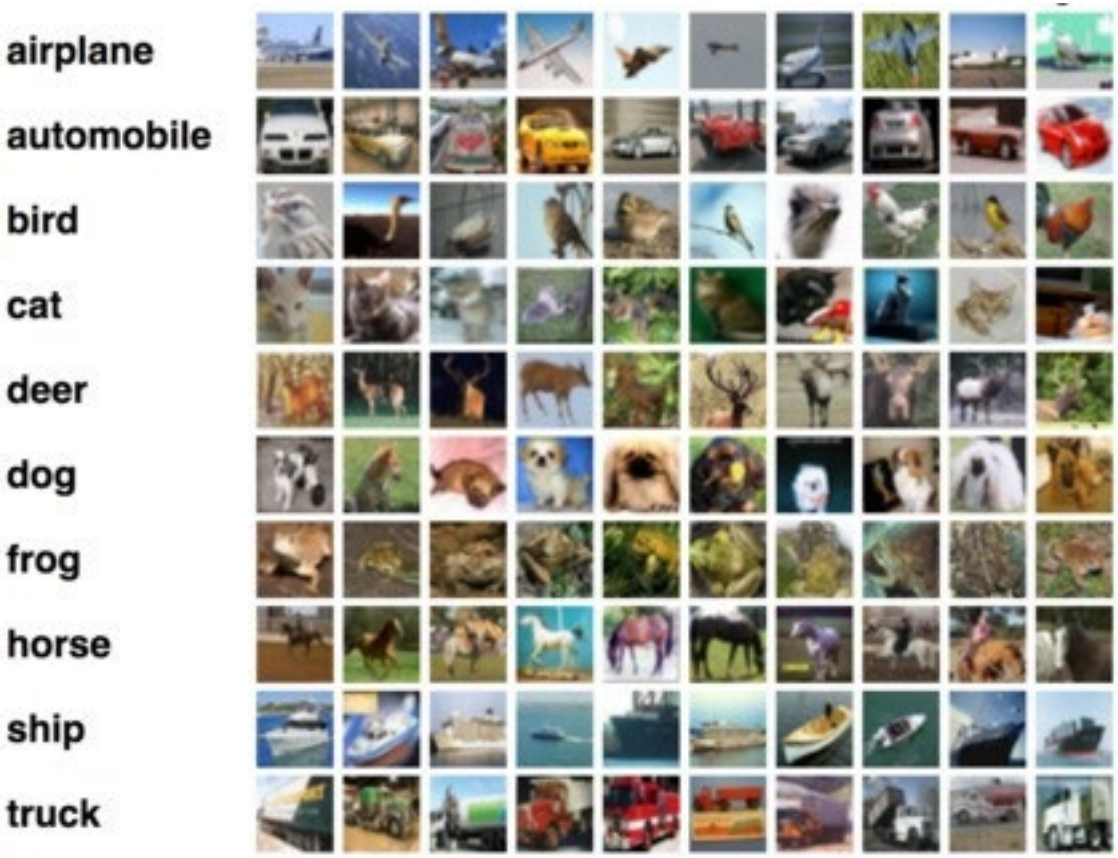




Output



Hebbian learning : heteroassociative memory cifar10 database

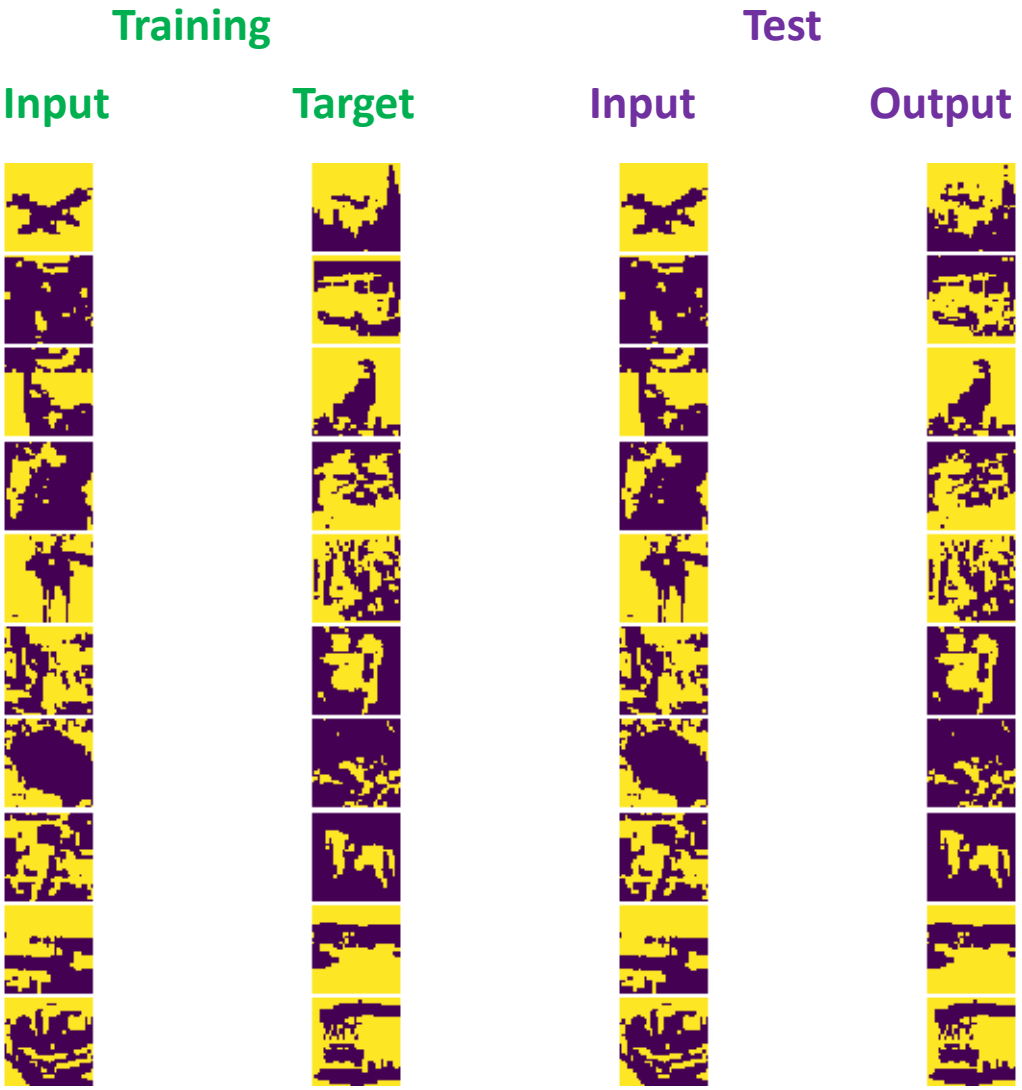


60000 images
10 classes
32x32 pixels images

Using Hebbian learning, image of each category is mapped to another image in the same category.

Images are converted to grayscale. Bipolar representation of each image is used in the network.

Hebbian learning : heteroassociative memory cifar10 database

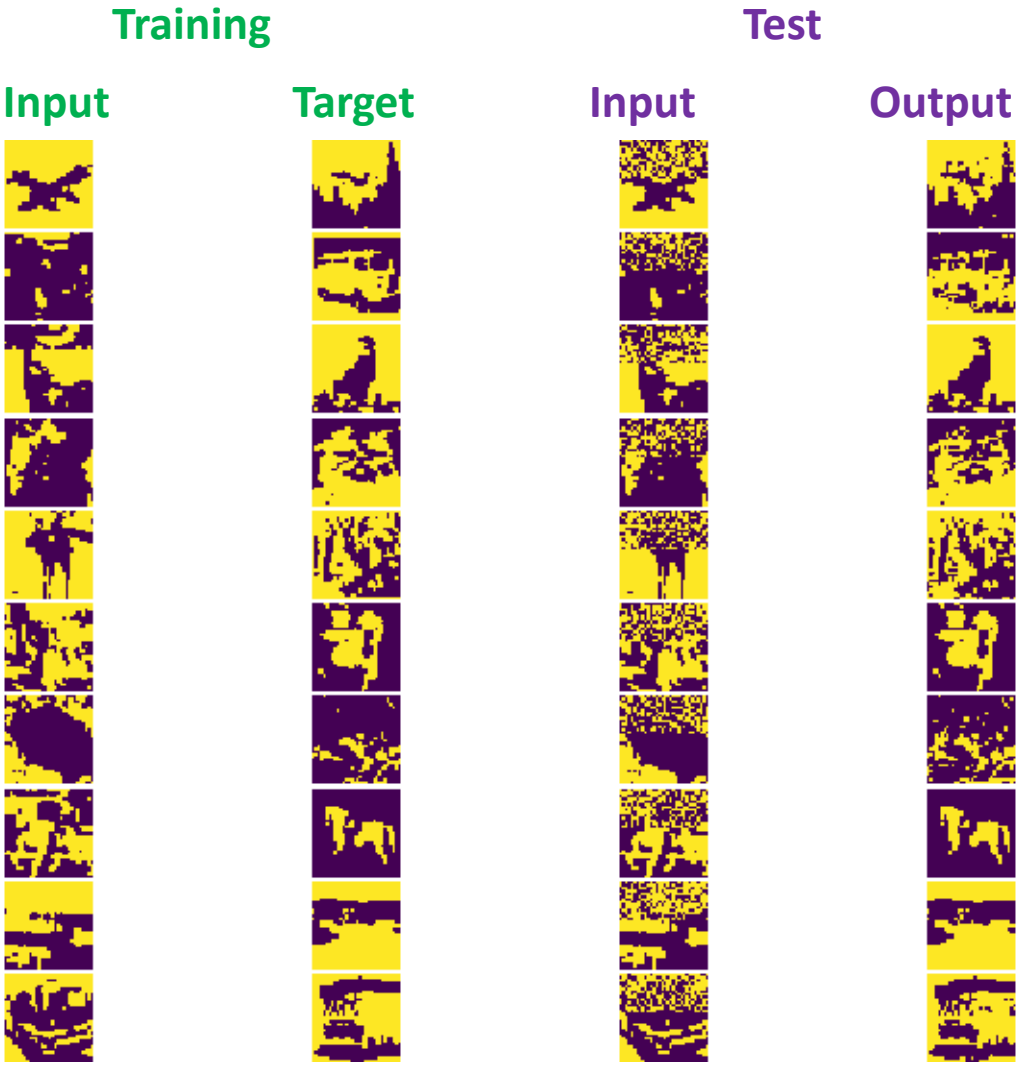


10 images are mapped to 10 other different images.

Reconstruction accuracy : 97.52%

1024 neurons

Hebbian learning : heteroassociative memory cifar10 database – noisy test images

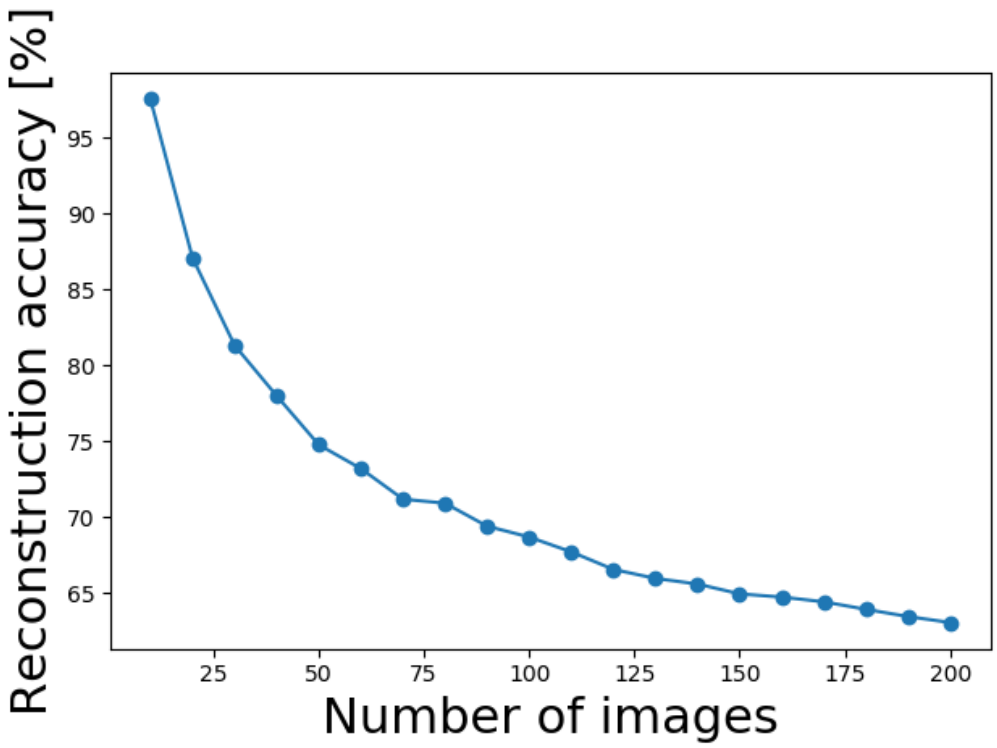


Noise is applied to the top part of the test input images.

Reconstruction accuracy : 95.42%

1024 neurons

Hebbian learning : heteroassociative memory cifar10 database – Number of samples

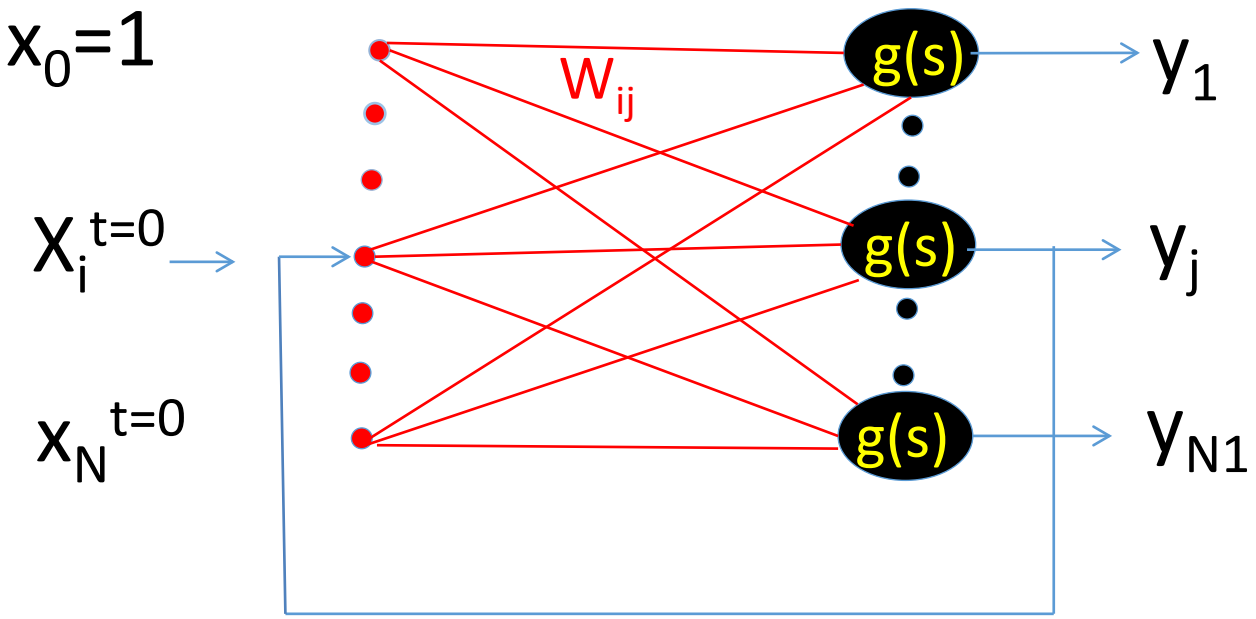


Hebbian learning can memorize more images from cifar10 than digits database. Images in digits database only use the pixels in the center of the image while in cifar10 database, all pixels are used.

Test inputs are the same as the training inputs.

1024 neurons

Hopfield Model



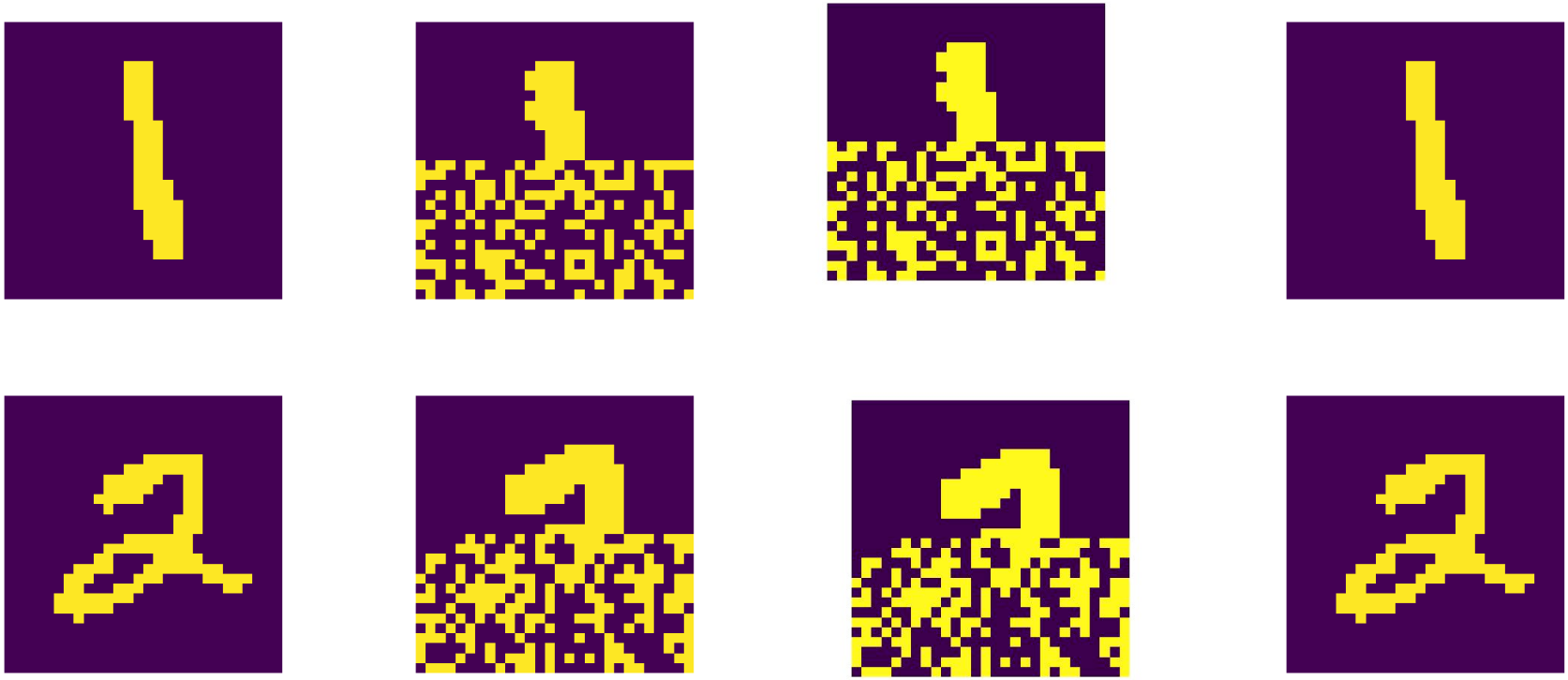
$$x_j^{t+1} = g\left(\sum_{i=1}^{N} w_{ij} x_i^t\right) \qquad g(s) = \mathrm{sgn}(s)$$

$$w_{ij} = \sum_{m=1}^{M} x_i^{(m)} x_j^{(m)}), \qquad w_{ii} = 0, \quad w_{0j} = 0$$

Hopfield network: image reconstruction

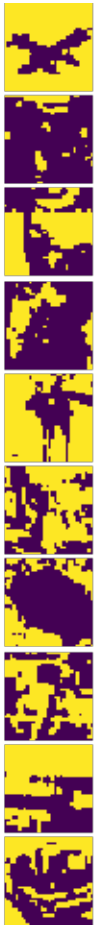
784 Neurons
2 Samples

Training samples | Test input | Reconstruction movie | Network output



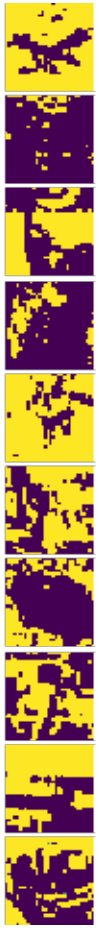
Hebbian learning : autoassociative memory

Training Input



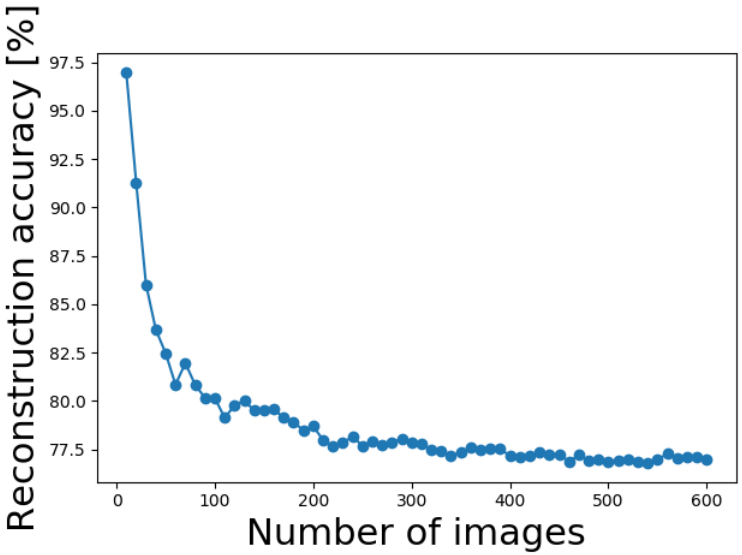
Test Input

Network Output



Top part of test inputs is different than the training input.

Reconstruction accuracy for different number of images



1024 neurons

Exercise/Homework

- Hopfield network with images; iterations
- Heteroassocative memory with feddback; oscillations
- Change the feedback gain and interconnection patterns and explore behavior