Neural Networks Overview

Source:

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What are Neural Networks?

- Simple computational elements forming a large network
  - Emphasis on learning (pattern recognition)
  - Local computation (neurons)

- Definition of NNs is vague
  - Often | but not always | inspired by biological brain

History – 1 of 4

- Roots of work on NN are in:
- **Neurobiological studies** (more than one century ago):
  - How do nerves behave when stimulated by different magnitudes of electric current? Is there a minimal threshold needed for nerves to be activated? Given that no single nerve cel is long enough, how do different nerve cells communicate among each other?
- **Psychological studies**:
  - How do animals learn, forget, recognize and perform other types of tasks?
- **Psycho-physical** experiments helped to understand how individual neurons and groups of neurons work.
- **McCulloch and Pitts** introduced the first mathematical model of single neuron, widely applied in subsequent work.

History – 2 of 4

Prehistory:

- Golgi and Ramon y Cajal study the nervous system and discover neurons (end of 19th century)

History (brief):

- McCulloch and Pitts (1943): the first artificial neural network with binary neurons
- Hebb (1949): learning = neurons that are together wire together
- Minsky (1954): neural networks for reinforcement learning
- Taylor (1956): associative memory
- Rosenblatt (1958): perceptron, a single neuron for supervised learning

History – 3 of 4

- Widrow and Hoff (1960): Adaline
- Minsky and Papert (1969): limitations of single-layer perceptrons (and they erroneously claimed that the limitations hold for multi-layer perceptrons)

Stagnation in the 70's:

- Individual researchers continue laying foundations
- von der Marlsburg (1973): competitive learning and self-organization

Big neural-nets boom in the 80's

- Grossberg: adaptive resonance theory (ART)
- Hopfield: Hopfield network
- Kohonen: self-organising map (SOM)

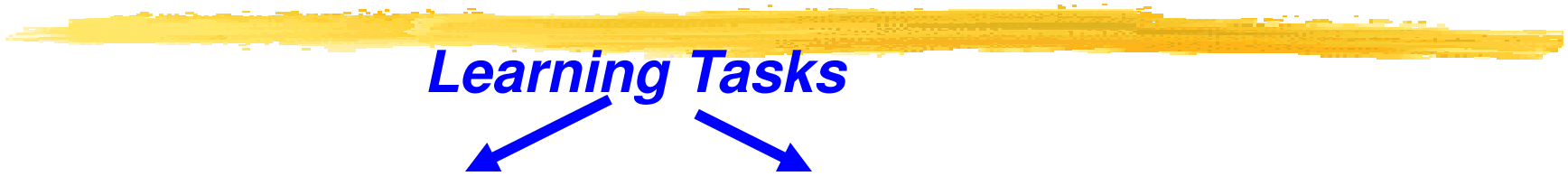
History – 4 of 4

- Oja: neural principal component analysis (PCA)
- Ackley, Hinton and Sejnowski: Boltzmann machine
- Rumelhart, Hinton and Williams: backpropagation

Diversification during the 90's:

- Machine learning: mathematical rigor, Bayesian methods, infomation theory, support vector machines, ...
- Computational neurosciences: workings of most subsystems of the brain are understood at some level; research ranges from low-level compartmental models of individual neurons to large-scale brain models

Supervised vs Unsupervised Learning



Supervised

Data:
Labeled examples
(input , desired output)

Tasks:
classification
pattern recognition
regression
NN models:
perceptron
adaline
feed-forward NN
radial basis function
support vector machines

Unsupervised

Data:
Unlabeled examples
(different realizations of the input)

Tasks:
clustering
content addressable memory

NN models:
self-organizing maps (SOM)
Hopfield networks

NNs: goal and design

- Knowledge about the learning task is given in the form of examples called training examples.
- A NN is specified by:
- an architecture: a set of neurons and links connecting neurons. Each link has a weight,
- a neuron model: the information processing unit of the NN,
- a learning algorithm: used for training the NN by modifying the weights in order to solve the particular learning task correctly on the training examples.

The aim is to obtain a NN that generalizes well, that is, that behaves correctly on new instances of the learning task.

Dimensions of a Neural Network

- network architectures
- types of neurons
- learning algorithms
- applications

Network architectures

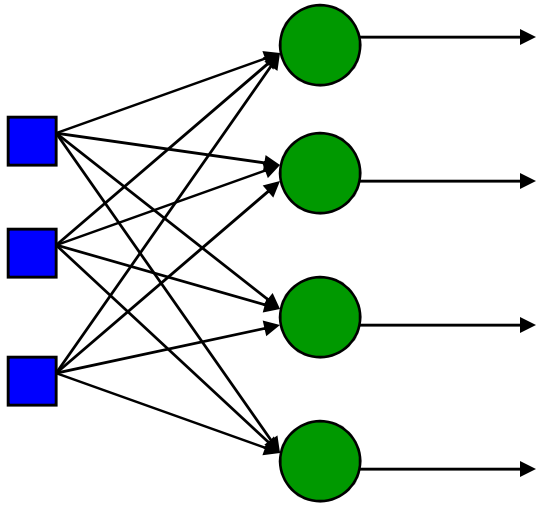
- Three different classes of network architectures
  - single-layer feed-forward
  - multi-layer feed-forward

  } neurons are organized in acyclic layers
  - recurrent

- The architecture of a neural network is linked with the learning algorithm used to train

Single Layer Feed-forward

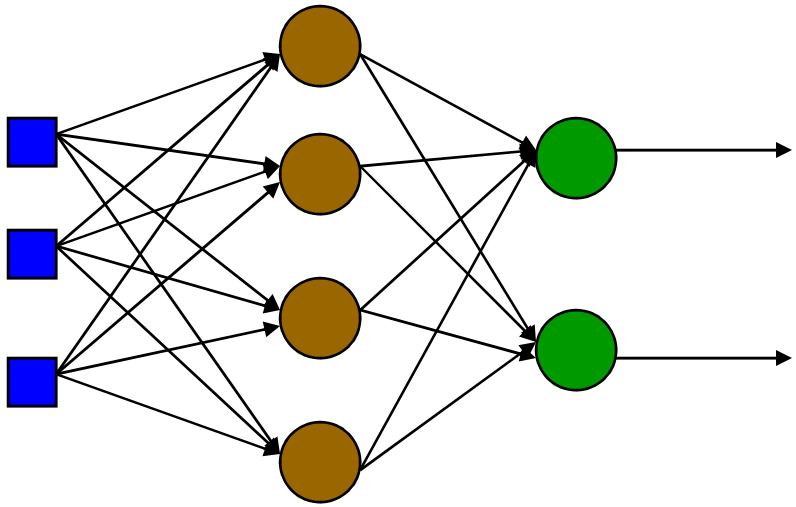
Input layer of source nodes



Output layer of neurons

Multi layer feed-forward

3-4-2 Network



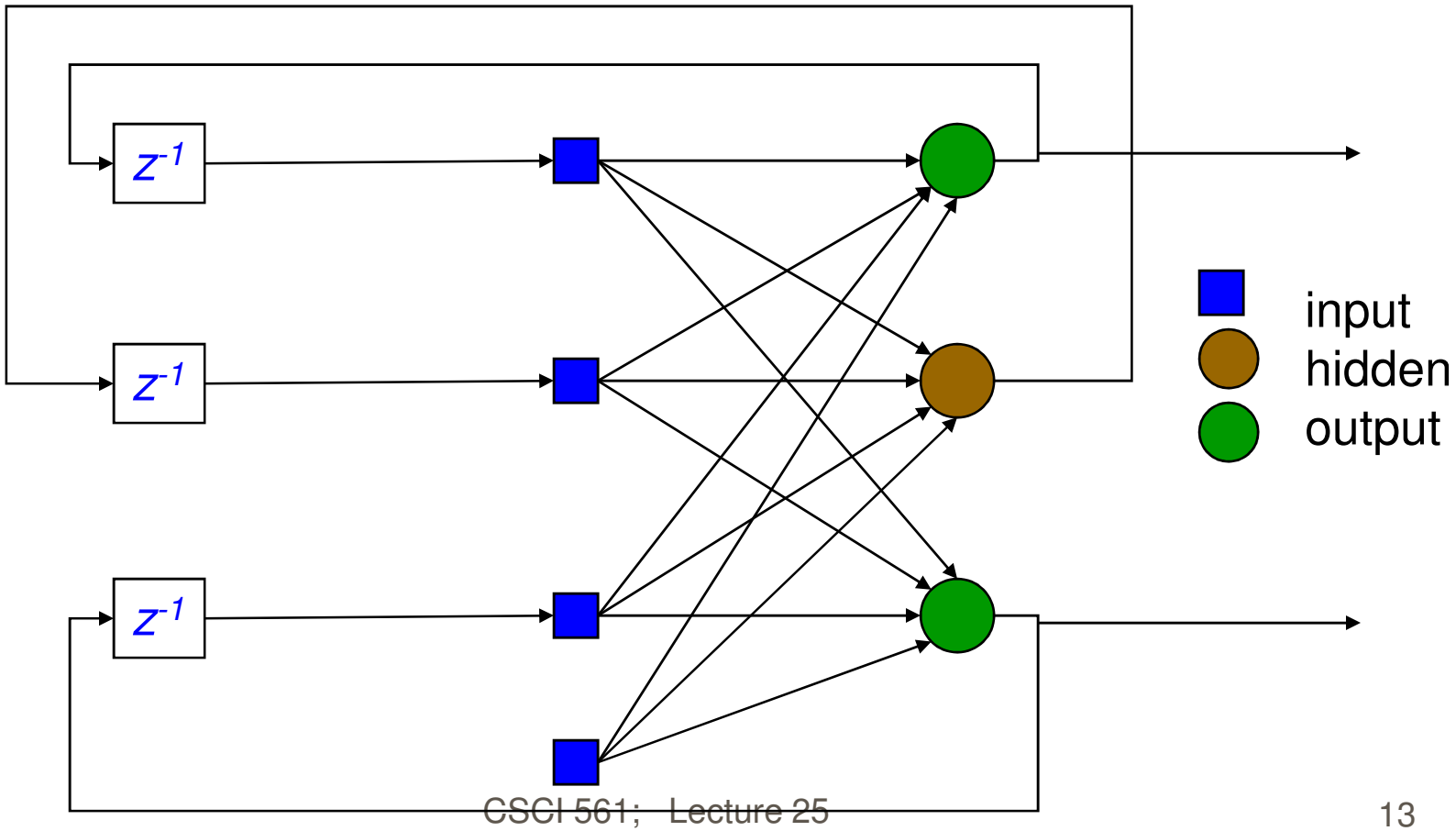
Input layer

Output layer

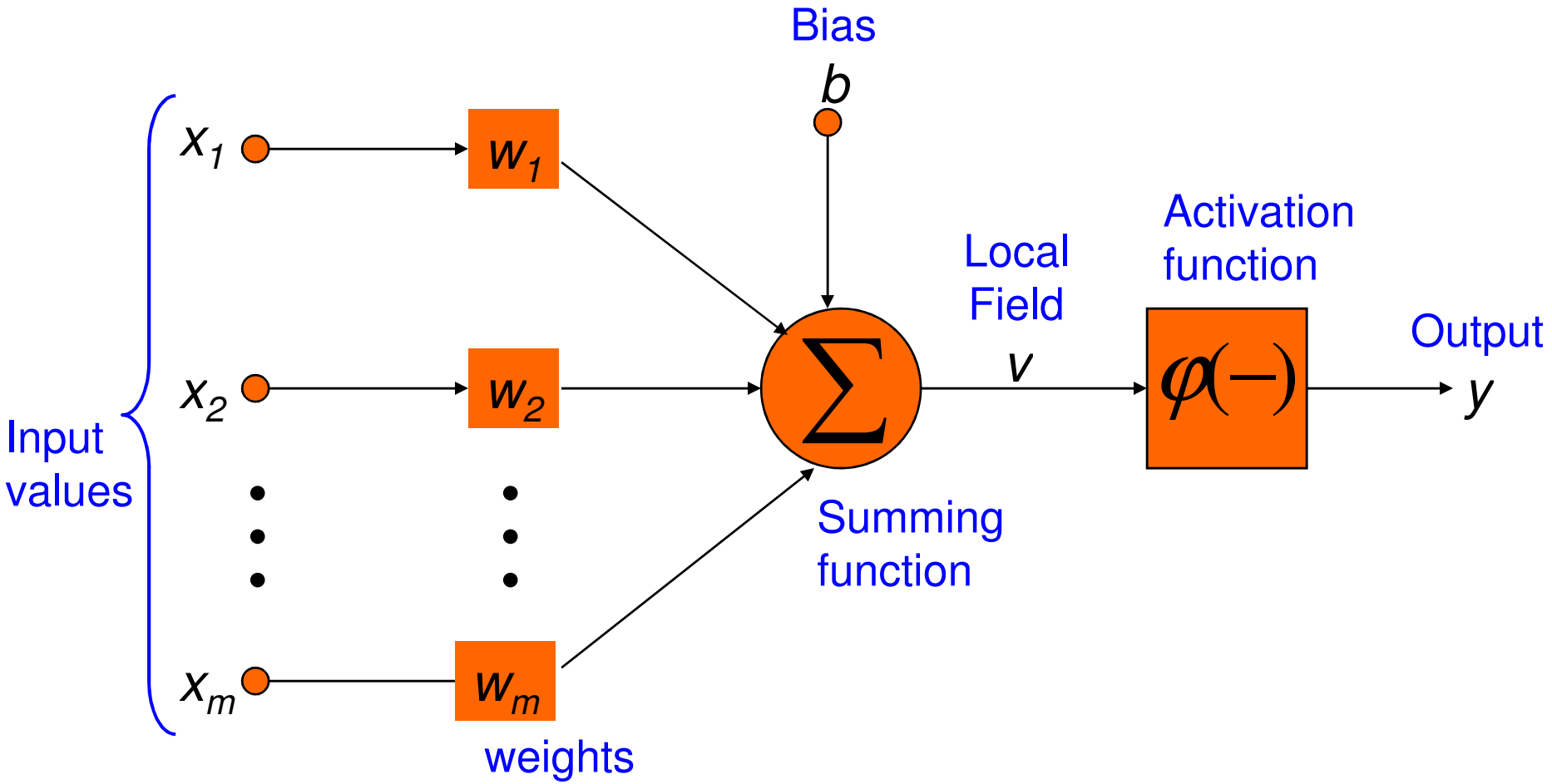
Hidden Layer

Recurrent network

Recurrent Network with ***hidden neuron***: unit delay operator z^{-1} is used to model a dynamic system



The Neuron


Bias
b
x_1
w_1
x_2
w_2
x_m
w_m
Input values
weights
Local Field
v
Activation function
$\varphi(-)$
Output
y
Summing function

The Neuron

- The neuron is the basic information processing unit of a NN. It consists of:
  1 A set of links, describing the neuron inputs, with weights $W_1, W_2, \ldots, W_m$
  2 An adder function (linear combiner) for computing the weighted sum of the inputs (real numbers):

$$u = \sum_{j=1}^{m} w_j x_j$$

  3 Activation function (squashing function) φ for limiting the amplitude of the neuron output.

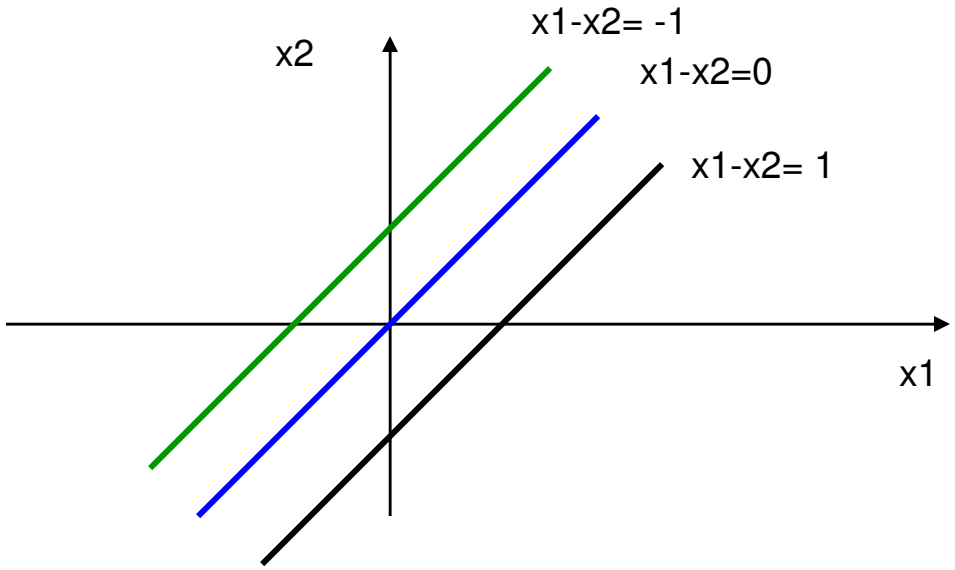
$$y = \varphi(u + b)$$

Bias of a Neuron

- The bias ***b*** has the effect of applying an affine transformation to the weighted sum ***u***

$$v = u + b$$

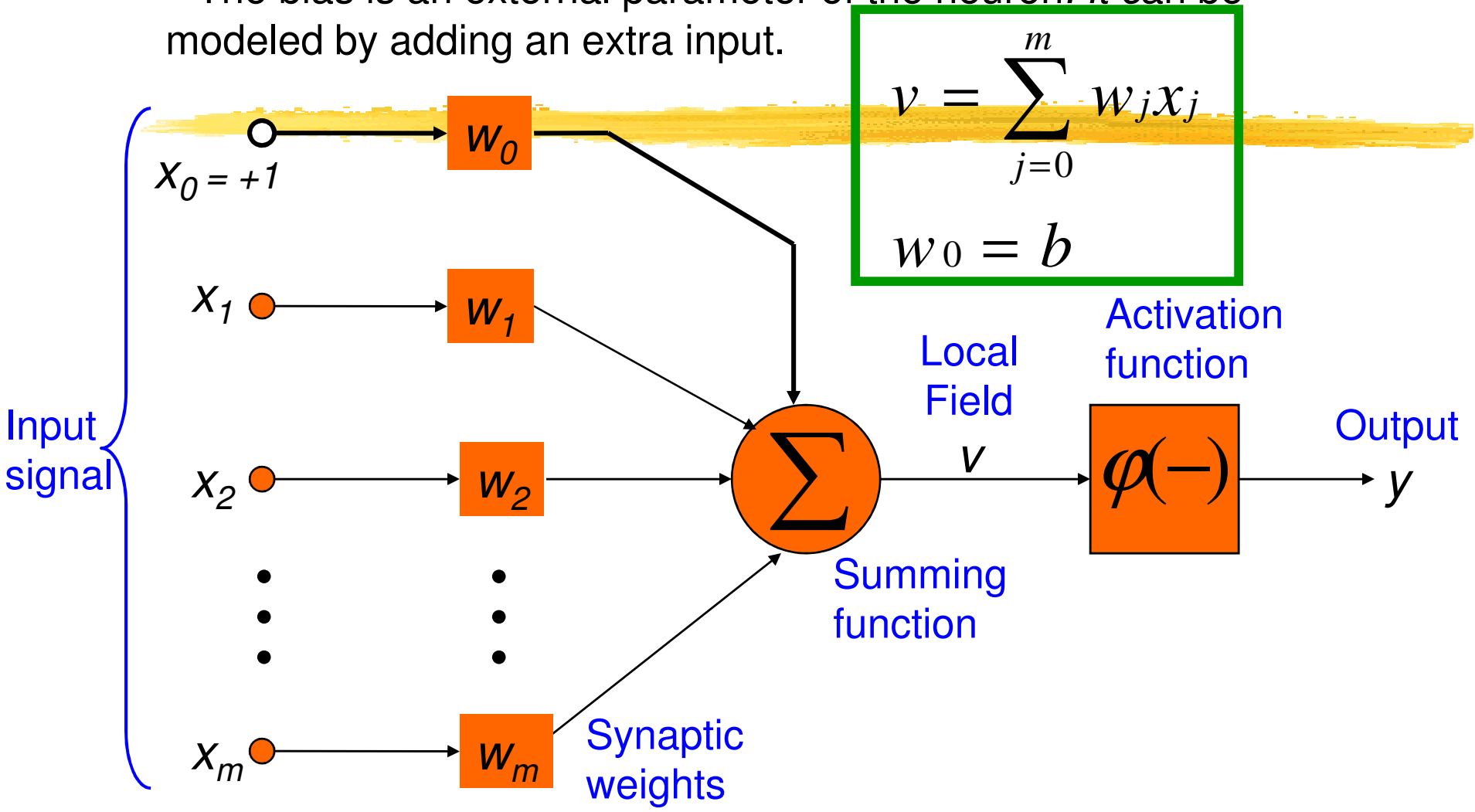
- ***v*** is called **induced field** of the neuron



$$u = x1 - x2$$

Bias as extra input

- The bias is an external parameter of the neuron. *It c*an be modeled by adding an extra input.



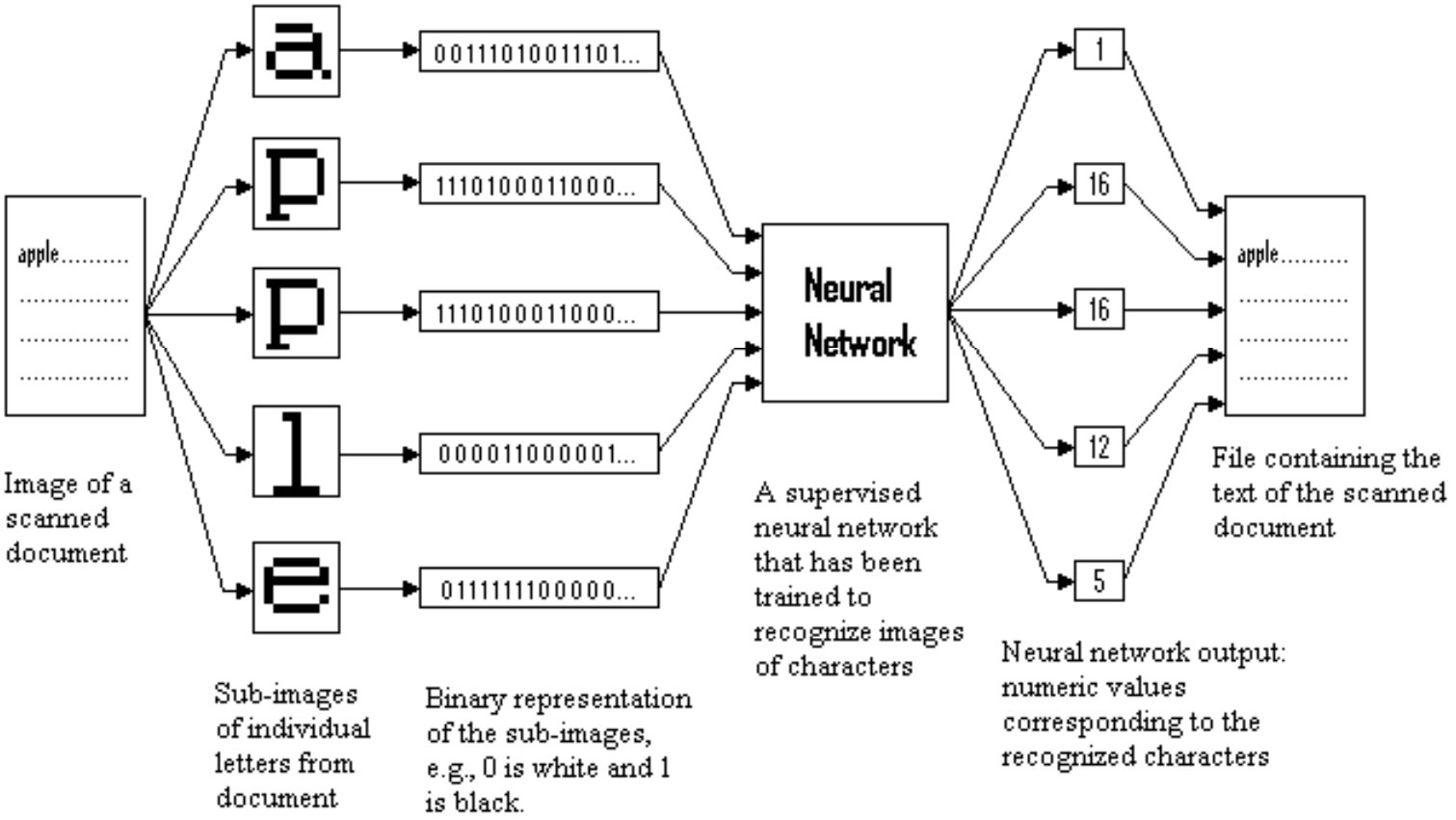
Neuron Models

- The choice of φ determines the neuron model. Examples:
- step function: $$\varphi(v) = \begin{cases} a & \text{if } v < c \\ b & \text{if } v > c \end{cases}$$
- ramp function: $$\varphi(v) = \begin{cases} a & \text{if } v < c \\ b & \text{if } v > d \\ a + ((v-c)(b-a)/(d-c)) & \text{otherwise} \end{cases}$$
- sigmoid function: with z,x,y parameters $$\varphi(v) = z + \frac{1}{1+\exp(-xv+y)}$$
- Gaussian function: $$\varphi(v) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{1}{2}\left(\frac{v-\mu}{\sigma}\right)^2\right)$$

Learning Algorithms

Depend on the network architecture:

- Error correcting learning (perceptron)
- Delta rule (AdaLine, Backprop)
- Competitive Learning (Self Organizing Maps)


apple.....
.....
.....
.....
Image of a scanned document
00111010011101...
1110100011000...
1110100011000...
0000110000001...
0111111100000...
Sub-images of individual letters from document
Binary representation of the sub-images, e.g., 0 is white and 1 is black.
Neural Network
A supervised neural network that has been trained to recognize images of characters
1
16
16
12
5
Neural network output: numeric values corresponding to the recognized characters
apple.....
.....
.....
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File containing the text of the scanned document

Areas of Neural Network "Learning" Success

- Process Modeling and Control
- Machine Diagnostics
- Portfolio Management
- Target Recognition
- Medical Diagnosis
- Credit Rating
- Targeted Marketing
- Voice Recognition
- Financial models and forecasts
- Quality control
- Intelligent search
- Fraud Detection