NEURAL NETWORKS AND DISTRIBUTED INFORMATION PROCESSING

MOTIVATION: HOW INFORMATION IS PROCESSED IN THE BRAIN?

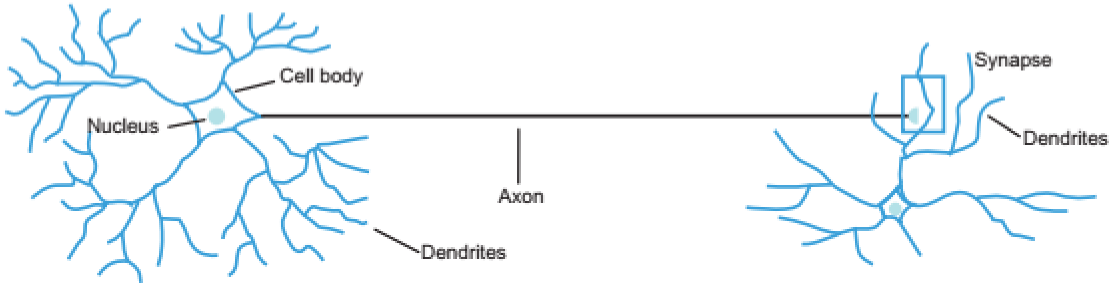
1. Single unit recording: too fine grained approach
2. PET, fMRI: too coarse grained approach
   - Identification of activated brain region for a certain task cannot tell us about how information is processed

MOTIVATION: HOW INFORMATION IS PROCESSED IN THE BRAIN?

1. Fundamental feature of the brain is its *connectivity* and the crucial question in understanding the brain is how distributed patterns of activation across populations of neurons can give rise to perception, memory, sensori-motor control, and high-level cognition.
2. Indirect way of studying populations of neurons: neural network model
   - Modeling biological neurons and populations of neurons

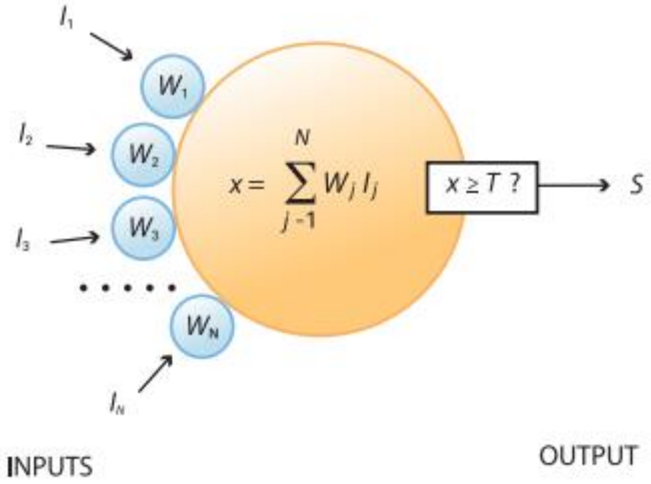
NEURONS AND ARTIFICIAL NEURONS

Neurons



A typical neuron receives inputs from 10000 neurons

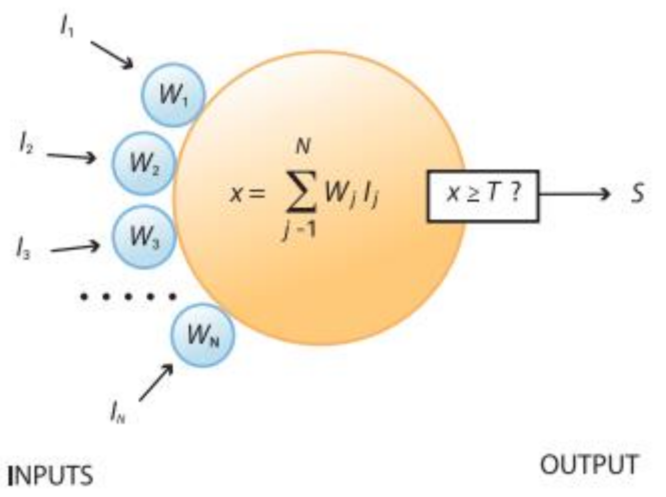
Artificial neurons



I_i	Input $_i$
W_i	The weight attached to input $_i$
T	The threshold of the neuron
X	The total input to the neuron
S	The output signal

NEURONS AND ARTIFICIAL NEURONS

Artificial neurons



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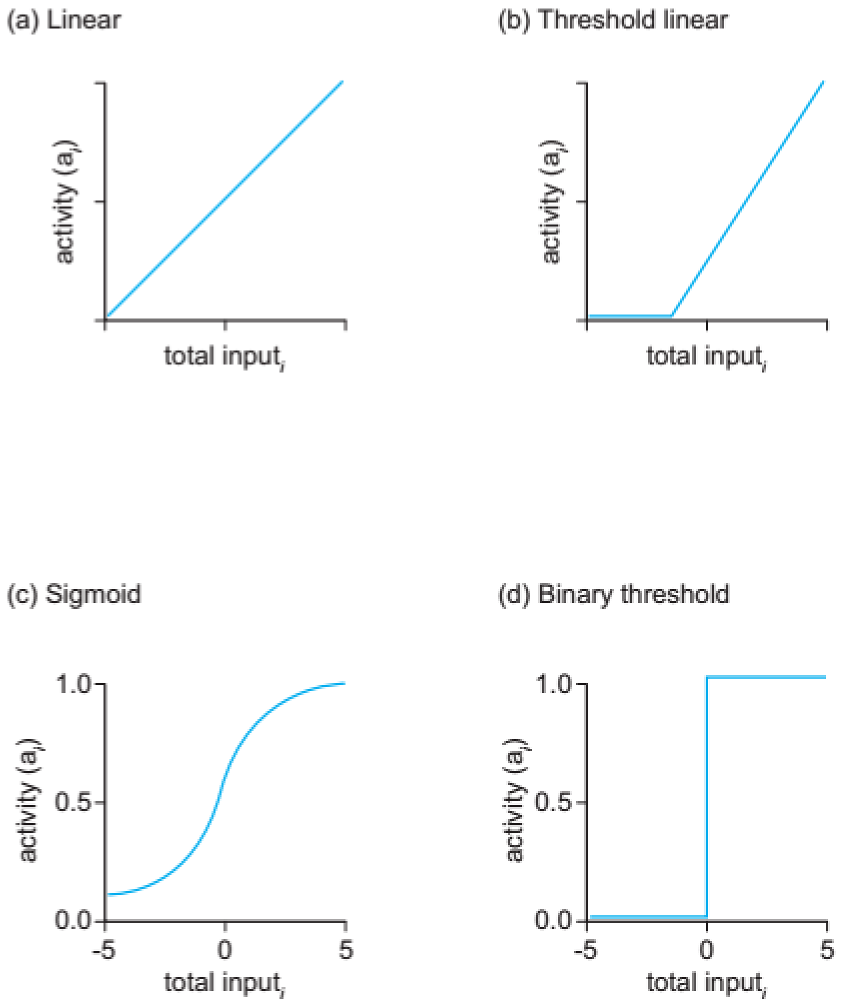
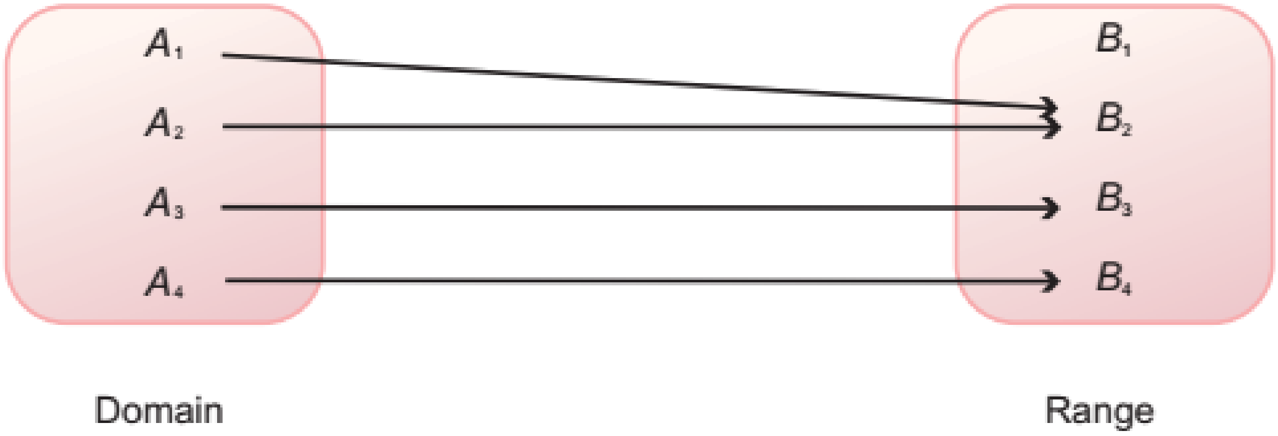
Activation functions



SINGLE-LAYER NETWORKS AND BOOLEAN FUNCTIONS

1. Mapping functions: Addition is a function, multiplication is a function, but taking square root is not a function (why?)
2. Domain, Range: A mapping function maps each item from the domain onto exactly one item from the range
   - Functions are single-valued



BINARY BOOLEAN FUNCTION: AND GATE

Truth table for binary Boolean function

DOMAIN	RANGE
FALSE, FALSE	
FALSE, TRUE	FALSE
TRUE, FALSE	TRUE
TRUE, TRUE	

Truth table for the Boolean function AND

A	B	A AND B
FALSE	FALSE	FALSE
FALSE	TRUE	FALSE
TRUE	FALSE	FALSE
TRUE	TRUE	TRUE

BINARY BOOLEAN FUNCTION: AND GATE

Truth table for the Boolean function AND

A	B	A AND B
FALSE	FALSE	FALSE
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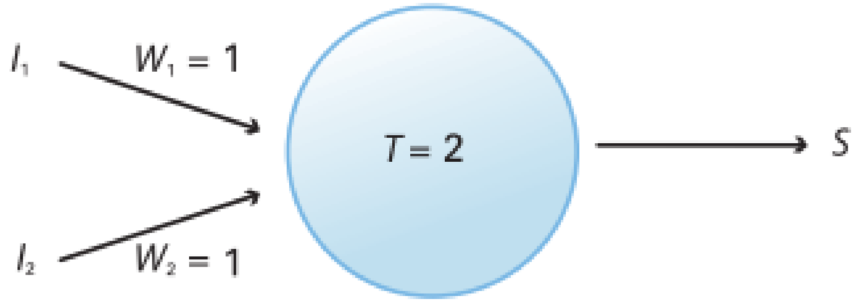
Single-layer network representing AND

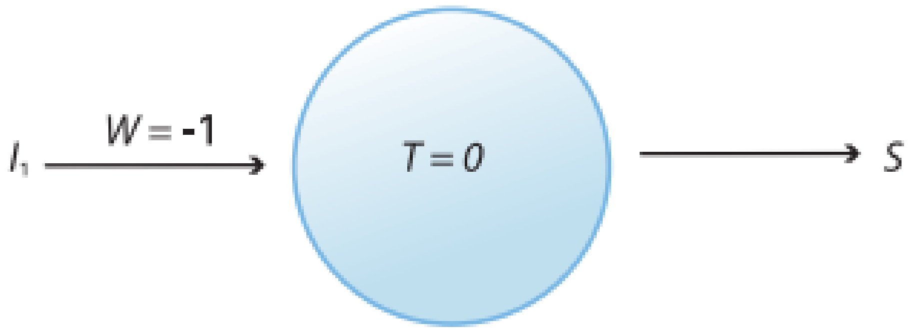


BINARY BOOLEAN FUNCTION: OR GATE

Truth table for the Boolean function OR

Single-layer network representing OR

UNARY FUNCTION: NOT GATE



LEARNING IN SINGLE-LAYER NETWORKS: THE PERCEPTRON CONVERGENCE RULE

- The key to getting single unit to represent Boolean functions such as NOT and OR lies in setting the weights and the threshold.
- How do the weights get set? How does the threshold get set?

HEBBIAN LEARNING (HEBBIAN SYNAPSE)

- "The Organization of Behavior" (1949, Donald Hebb)
- Fire together, wire together – Hebbian learning (unsupervised learning)
- Frank Rosenblatt: Modification of Hebbian learning rule
  - Perceptron!!!
  - Supervised learning – adjust weight and threshold by the error between desired output and actual output of the neural population (perceptron convergence rule)

THE PERCEPTRON CONVERGENCE RULE

$\delta =$ Intended output - Actual output

ε : learning rate ($0<\varepsilon<1$)

$\Delta T = -\varepsilon \times \delta$ (ΔT : threshold adjustment)

$\Delta W_i = \varepsilon \times \delta \times I_i$($\Delta W_i$: weight adjustment for input i)

NOT gate

THE PERCEPTRON CONVERGENCE RULE

$\delta =$ Intended output - Actual output

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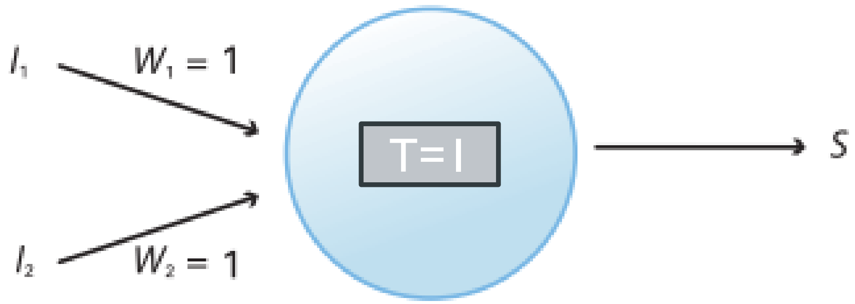
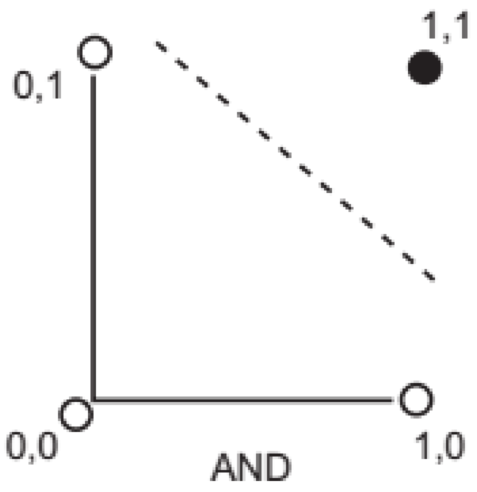
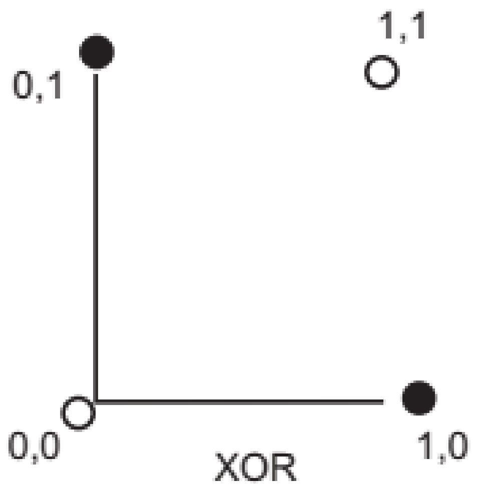
AND gate



THE LIMITS OF PERCEPTRON CONVERGENCE

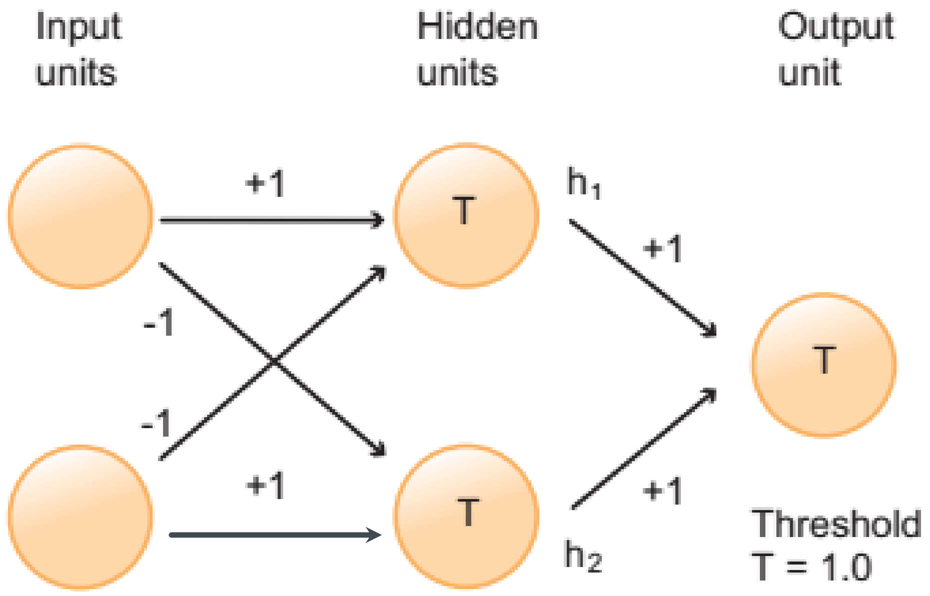
- Linear separability : XOR gate





I_1	I_2	OUTPUT
0	0	0
0	1	1
1	0	1
1	1	0

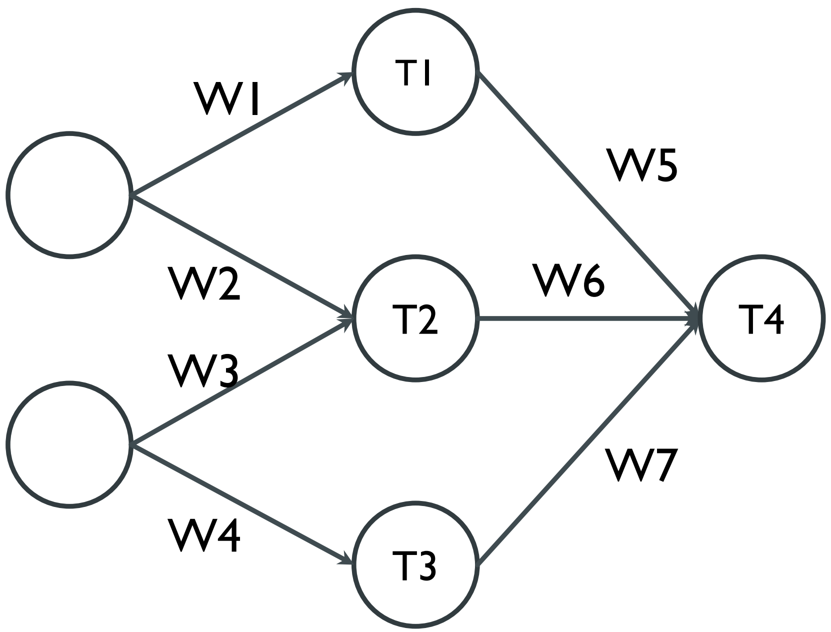
A MULTILAYER NETWORK



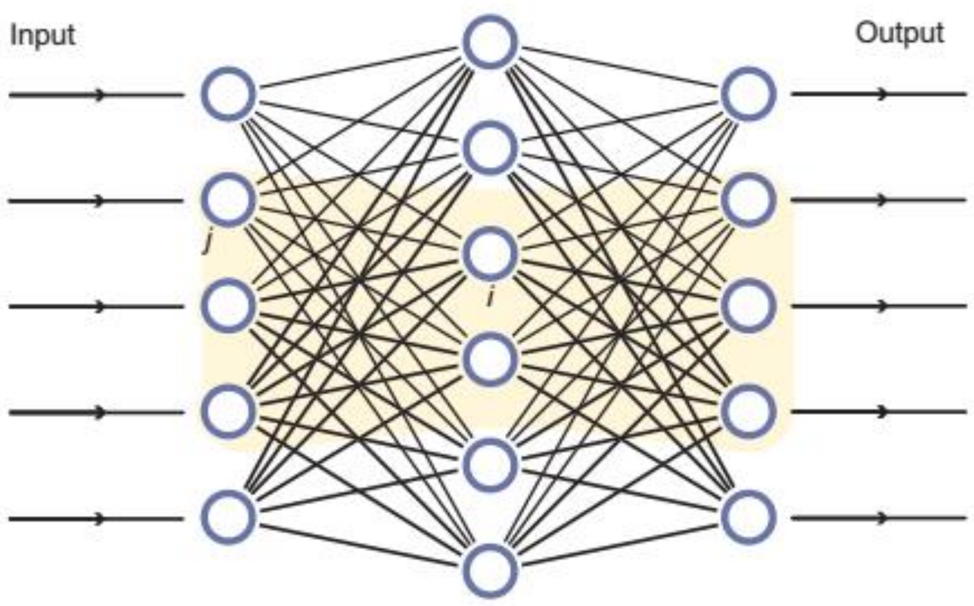
Training rule? What is the required output of the hidden units?

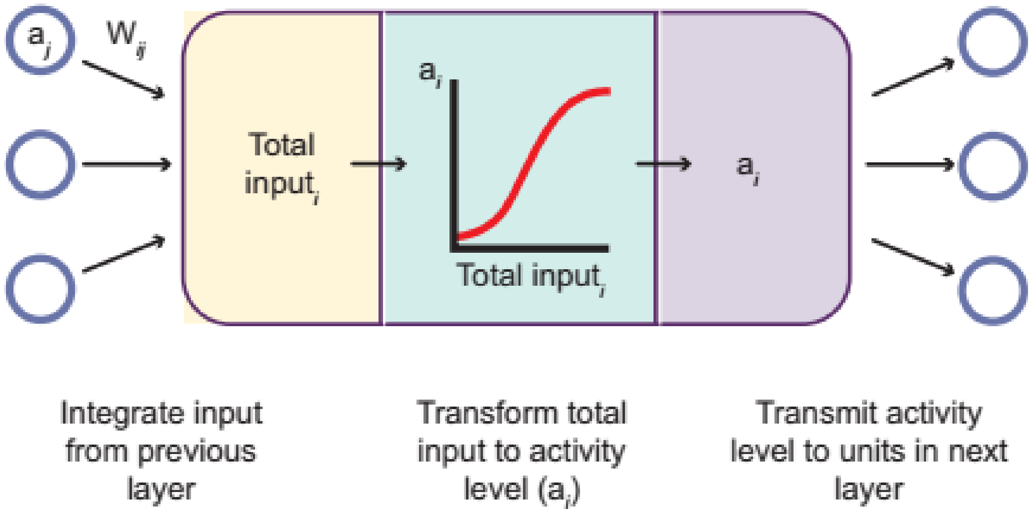
A MULTILAYER NETWORK

Other solution for XOR gate?



A MULTILAYER NETWORK

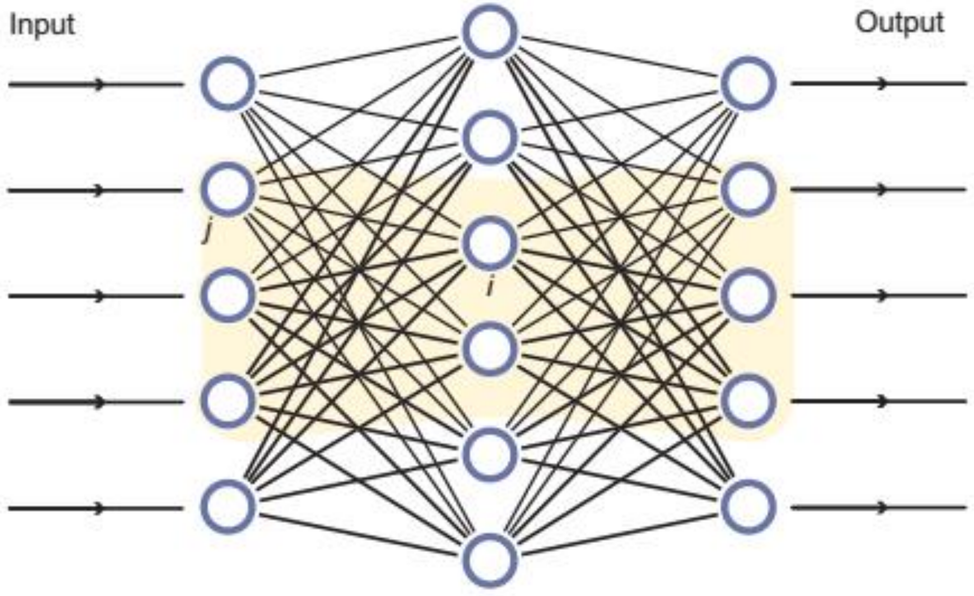




$$\text{Total input} = \sum_{j=1}^{N} w_{ij} a_i$$

A MULTILAYER NETWORK

Training rule? What is the required output of the hidden units?

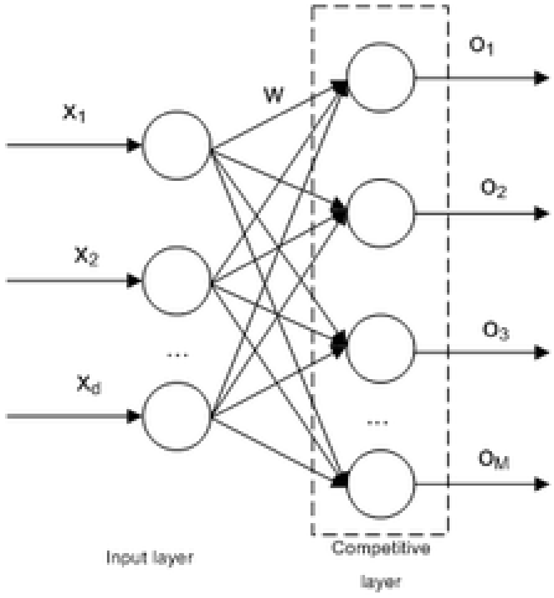


The Backpropagation algorithm

THE BACKPROPAGATION ALGORITHM

HOW BIOLOGICALLY PLAUSIBLE ARE NEURAL NETWORKS?

- A single cortical column: 200000 neurons, vs. complicated artificial neural network: 5000 units
- Random assignments of weights vs. well organized structure
- Backpropagation algorithm is not biologically plausible
- Supervised learning vs. diffuse, relatively unfocused feedback
- Alternative learning algorithm – *local algorithms*
  - *Competitive networks*



INFORMATION PROCESSING IN NEURAL NETWORKS: KEY FEATURES

1. Distributed representations

2. No clear distinction between information storage and information processing

3. The ability to learn from "experience"