CS344: Introduction to Artificial Intelligence
(associated lab: CS386)

Pushpak Bhattacharyya
CSE Dept.,
IIT Bombay

Lecture 20: Neural Networks
28th Feb, 2011
A perspective of AI
Artificial Intelligence - Knowledge based computing
Disciplines which form the core of AI - inner circle
Fields which draw from these disciplines - outer circle.
Symbolic AI

Connectionist AI is contrasted with Symbolic AI
Symbolic AI - Physical Symbol System Hypothesis
  Every intelligent system can be constructed by storing and processing symbols and nothing more is necessary.

Symbolic AI has a bearing on models of computation such as
  Turing Machine
  Von Neumann Machine
  Lambda calculus
Turing Machine & Von Neumann Machine

Turing machine

Von Neumann Machine
Challenges to Symbolic AI

Motivation for challenging Symbolic AI
A large number of computations and information process tasks that living beings are comfortable with, are not performed well by computers!

The Differences

<table>
<thead>
<tr>
<th>Brain computation in living beings</th>
<th>TM computation in computers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern Recognition</td>
<td>Numerical Processing</td>
</tr>
<tr>
<td>Learning oriented</td>
<td>Programming oriented</td>
</tr>
<tr>
<td>Distributed &amp; parallel processing</td>
<td>Centralized &amp; serial</td>
</tr>
<tr>
<td>Content addressable</td>
<td>Location addressable</td>
</tr>
</tbody>
</table>
The human brain

Seat of consciousness and cognition

Perhaps the most complex information processing machine in nature
Beginner’s Brain Map

Forebrain (Cerebral Cortex):
Language, maths, sensation, movement, cognition, emotion

Midbrain: Information Routing; involuntary controls

Cerebellum: Motor Control

Hindbrain: Control of breathing, heartbeat, blood circulation

Spinal cord: Reflexes, information highways between body & brain
Brain: a computational machine?

Information processing: brains vs computers
- brains better at perception / cognition
- slower at numerical calculations
- parallel and distributed Processing
- associative memory
Brain: a computational machine? (contd.)

- Evolutionarily, brain has developed algorithms most suitable for survival
- Algorithms unknown: the search is on
- Brain astonishing in the amount of information it processes
  - Typical computers: $10^9$ operations/sec
  - Housefly brain: $10^{11}$ operations/sec
Brain facts & figures

- Basic building block of nervous system: nerve cell (neuron)
- $\sim 10^{12}$ neurons in brain
- $\sim 10^{15}$ connections between them
- Connections made at “synapses”
- The speed: events on millisecond scale in neurons, nanosecond scale in silicon chips
3-Layers: Cerebrum
       Cerebellum
       Higher brain
Higher brain (responsible for higher needs)

3- Layers: Cerebrum
          Cerebellum
          Higher brain

Cerebrum (crucial for survival)
Mapping of Brain

- Back of brain (vision)
- Lot of resilience:
  Visual and auditory areas can do each other’s job
- Side areas
  For auditory information processing
Left Brain and Right Brain

Dichotomy

Right Brain

Left Brain
Left Brain – Logic, Reasoning, Verbal ability
Right Brain – Emotion, Creativity

Words – left Brain
Music
Tune – Right Brain

Maps in the brain. Limbs are mapped to brain
Neuron - “classical”

- **Dendrites**
  - Receiving stations of neurons
  - Don't generate action potentials

- **Cell body**
  - Site at which information received is integrated

- **Axon**
  - Generate and relay action potential
  - Terminal
    - Relays information to next neuron in the pathway

Computation in Biological Neuron

- Incoming signals from synapses are summed up at the soma \( \sum \), the biological “inner product”
- On crossing a threshold, the cell “fires” generating an action potential in the axon hillock region

Synaptic inputs: Artist’s conception
The biological neuron

Pyramidal neuron, from the amygdala (Rupshi et al. 2005)

A CA1 pyramidal neuron (Mel et al. 2004)
Perceptron
The Perceptron Model

A perceptron is a computing element with input lines having associated weights and the cell having a threshold value. The perceptron model is motivated by the biological neuron.

Output = y

Threshold = Θ

\[ W_n \quad W_{n-1} \quad X_{n-1} \quad W_1 \quad X_1 \]
Step function / Threshold function

\[ y = \begin{cases} 
1 & \text{for } \sum w_i x_i \geq \theta \\
0 & \text{otherwise} 
\end{cases} \]
Features of Perceptron

- Input output behavior is discontinuous and the derivative does not exist at $\sum w_i x_i = \theta$

- $\sum w_i x_i - \theta$ is the net input denoted as net

- Referred to as a linear threshold element - linearity because of $x$ appearing with power 1

- $y = f(\text{net})$: Relation between $y$ and net is non-linear
Computation of Boolean functions

**AND of 2 inputs**

<table>
<thead>
<tr>
<th>X1</th>
<th>x2</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The parameter values (weights & thresholds) need to be found.
Computing parameter values

\[ w_1 \times 0 + w_2 \times 0 \leq \theta \Rightarrow \theta \geq 0; \text{ since } y=0 \]

\[ w_1 \times 0 + w_2 \times 1 \leq \theta \Rightarrow w_2 \leq \theta; \text{ since } y=0 \]

\[ w_1 \times 1 + w_2 \times 0 \leq \theta \Rightarrow w_1 \leq \theta; \text{ since } y=0 \]

\[ w_1 \times 1 + w_2 \times 1 > \theta \Rightarrow w_1 + w_2 > \theta; \text{ since } y=1 \]
\[ w_1 = w_2 = = 0.5 \]

satisfy these inequalities and find parameters to be used for computing AND function.
Other Boolean functions

• OR can be computed using values of \( w_1 = w_2 = 1 \) and \( \theta = 0.5 \)

• XOR function gives rise to the following inequalities:

\[
\begin{align*}
& w_1 \cdot 0 + w_2 \cdot 0 \leq \theta \Rightarrow \theta \geq 0 \\
& w_1 \cdot 0 + w_2 \cdot 1 > \theta \Rightarrow w_2 > \theta \\
& w_1 \cdot 1 + w_2 \cdot 0 > \theta \Rightarrow w_1 > \theta \\
& w_1 \cdot 1 + w_2 \cdot 1 \leq \theta \Rightarrow w_1 + w_2 \leq \theta
\end{align*}
\]

No set of parameter values satisfy these inequalities.
Threshold functions

<table>
<thead>
<tr>
<th>n</th>
<th># Boolean functions ((2^{2^n}))</th>
<th>#Threshold Functions ((2^{n^2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>256</td>
<td>128</td>
</tr>
<tr>
<td>4</td>
<td>64K</td>
<td>1008</td>
</tr>
</tbody>
</table>

- Functions computable by perceptrons - threshold functions
- \#TF becomes negligibly small for larger values of \#BF.
- For \(n=2\), all functions except XOR and XNOR are computable.