Optical Neural Network

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Motivation

ONN Features:

- Massive interconnections
- Parallel processing operation
- Inherent additive properties

✓ Fast optical computing
✓ Power efficient manner
A packet switched telecommunication network.
- In each network router data packets are routed according to their destination address.
- The routers should perform a pattern detection task on the header sequence and classify the packets by their destination address.
Outline

- Introduction
- Optical Medium
- ONN Examples
  - BP Training of an ONN
  - A Multilayer ONN
- References
Optical Neural Network

Introduction
In an Optical NN:

- Sources are modulated light beams
- Synaptic Multiplications are due to attenuation of light passing through an optical medium: Geometric or Holographic.
- Target neurons sum signals from many source neurons.
ONN was suggested by Farhat ad Pissaltis in 1987.

Many of the early ONNs had electro-optical components

- Computers were slow
- With converters between optical beams and electrical current
- The full theoretical advantages of fully-optical NN couldn’t be displayed.

With the advent of all-optical components it became possible to create complete all-optical ONN.

- They are not as accurate as their electronic equivalents,
- That it is not easy to integrate a large number of optical units on a chip

A common misconception: Optical NNs work much faster than Electronic NNs.

The future of ONN is yet uncertain.
Optical Neural Network

Optical Elements of ONN
Optical Elements of ONN

- Laser (1960)
- Lenses
- Liquid Crystals (1888)
A **laser** is a device that emits light through a process called stimulated emission.

The term "laser" is an acronym for *Light Amplification by Stimulated Emission of Radiation*.

Laser light is usually spatially coherent, which means that the light either is emitted in a narrow, low divergence beam, or can be converted into one with the help of optical components such as lenses.
- The study of liquid crystals began in 1888 when an Austrian botanist observed that a material had two distinct melting points.
- Liquid crystals are a phase of matter whose order is intermediate between that of a liquid and that of a crystal.
- The molecules are typically rod-shaped organic moieties about 25 Angstroms in length and their ordering is a function of temperature.
Liquid Crystals in ONN

- SLM (Spatial Light Modulation)
  - OA-SLM
  - EA-SLM
- LCVT (Liquid Crystal Television)
- LCLV (Liquid Crystal Light Valve)
- PCM (Phase Conjugate Mirror)
The “incoherent” light is detected (as intensity), by a photo-detector (as an electrical change distribution). This charge distribution affects the modulator, and so changes the Amplitude or Phase of the reflected coherent light.
Practical Uses of AOSLMs

Simplest applications is for real-time input to “4-f” optical processor
Electrically Addressed SLM

- The hologram is generated on SLM by a computer.
- EASLM is similar to LCTV.
LCLV: Optical Thresholding

\[ s(x) = \alpha + \frac{\gamma}{1 + e^{-\beta x + \delta}} \]

\[ \frac{1}{1 + e^{-x}} \]
Optical Elements:
LCLV2

Sigmoid Curve fit for LCLVs

<table>
<thead>
<tr>
<th>Standard sigmoid</th>
<th>LCLV1</th>
<th>LCLV2</th>
<th>LCLV3</th>
<th>LCLV4a</th>
<th>LCLV4b</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>0</td>
<td>-0.41</td>
<td>-2.34</td>
<td>0.015</td>
<td>-11.4</td>
</tr>
<tr>
<td>$\beta$</td>
<td>1</td>
<td>0.087</td>
<td>0.0062</td>
<td>0.043</td>
<td>0.79</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1</td>
<td>1.41</td>
<td>3.34</td>
<td>1.0</td>
<td>12.4</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0</td>
<td>0.93</td>
<td>-0.82</td>
<td>3.20</td>
<td>-2.31</td>
</tr>
</tbody>
</table>
A phase conjugate mirror is like a mirror, in that it reflects incident light back towards where it came from, but it does so in a different way than a regular mirror.
Optical Elements:
PCM2

Phase Conjugate Mirror

regular mirror
distorting
glass

phase conjugate mirror
Optical Neural Network

Examples

1- BP Training of an ONN
2- A Multilayer ONN for Digit Recognition
BP Training of an ONN

- Use optical BP in a feed-forward ONN
- Is the first report of BP training in an optical system.
- Uses a thermal nonlinear material as a neural processing layer and a photorefractive crystal as a phase conjugate mirror to backpropagate the optical error.
- The nonlinear material modulates the phase front of a forward propagating information beam by dynamically altering the index of the refraction profile of the material via a stronger weighting beam.
**Basic Neural Network**

![Diagram of Basic Neural Network](image)

- **$W(y)$**: Weight matrix
- **$E_0(y)$**: Input
- **Input SLM**: Input SLM (Spatial Light Modulator)
- **$O(y)$**: Output
- **Slit & Detector**: Slit and detector

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**Optical Neural Network**

22
In linear optics
is a transient phenomenon that has no
effect on anything else.

In the transparent volume of a
nonlinear optical medium
the interference pattern will cause a
change in the refractive index of the
nonlinear medium in the shape of
those same parallel planes.

\[ n(y) = n_0 + n_2 \cdot I(y) \]
Network Description

Example Description

\[ n(y) = n_0 + n_2 \cdot I(y) \]

\[ W(y) \]

\[ E_0(y) \]

Input SLM

NLM

\[ O(y) \]
Experimental Set up

Diagram showing the experimental set up of an Optical Neural Network.
## BP Training Results

Mean Square Error (MSE)

<table>
<thead>
<tr>
<th>INPUT (A B)</th>
<th>(0-0)</th>
<th>(0-1)</th>
<th>(1-0)</th>
<th>(1 1)</th>
<th>RME</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AND</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>1.22</td>
<td>0.87</td>
<td>0.92</td>
<td>0.82</td>
<td>0.29</td>
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<tr>
<td>End</td>
<td>0.82</td>
<td>0.90</td>
<td>0.84</td>
<td>1.18</td>
<td>0.06</td>
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<tr>
<td>Desired</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td><strong>NAND</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>1.35</td>
<td>0.87</td>
<td>0.93</td>
<td>0.86</td>
<td>0.22</td>
</tr>
<tr>
<td>End</td>
<td>1.70</td>
<td>1.23</td>
<td>1.32</td>
<td>0.86</td>
<td>0.03</td>
</tr>
<tr>
<td>Desired</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td><strong>NOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>1.28</td>
<td>0.87</td>
<td>0.91</td>
<td>0.85</td>
<td>0.07</td>
</tr>
<tr>
<td>End</td>
<td>1.13</td>
<td>0.78</td>
<td>0.85</td>
<td>0.78</td>
<td>0.04</td>
</tr>
<tr>
<td>Desired</td>
<td>1.2</td>
<td>0.8</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>
A Multilayer ONN for Digit Recognition

- An optical perceptron with a soft optical threshold is implemented, that is trained with an adapted BP algorithm.

- An optical thresholding perceptron is composed of two parts:
  - Matrix-vector-Multiplier (MVM),
  - A thresholding device.
Matrix Vector Multiplier (MVM)

P: Polariser; Gn: Gratings
Weight Mappings

Behaviour of optical weights under different weight mappings: x-axis has calculated weights, and y-axis has corresponding optical weights or LCTV2 transmittances.
Test inputs

A set of handwritten digits

0123456789
LCLV output images without and with write light
Digit Recognition

Recognition of a 0, 2, 3, 4, 5, 6, 7, and 9
Optical Neural Network

References
References


[9] Google Search for so many optic concepts in Optical Neural Networks!