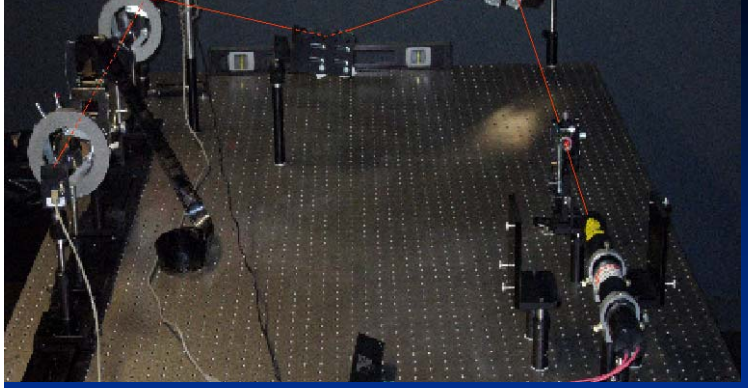


Optical Neural Network

By:

Roghayeh Saeidi

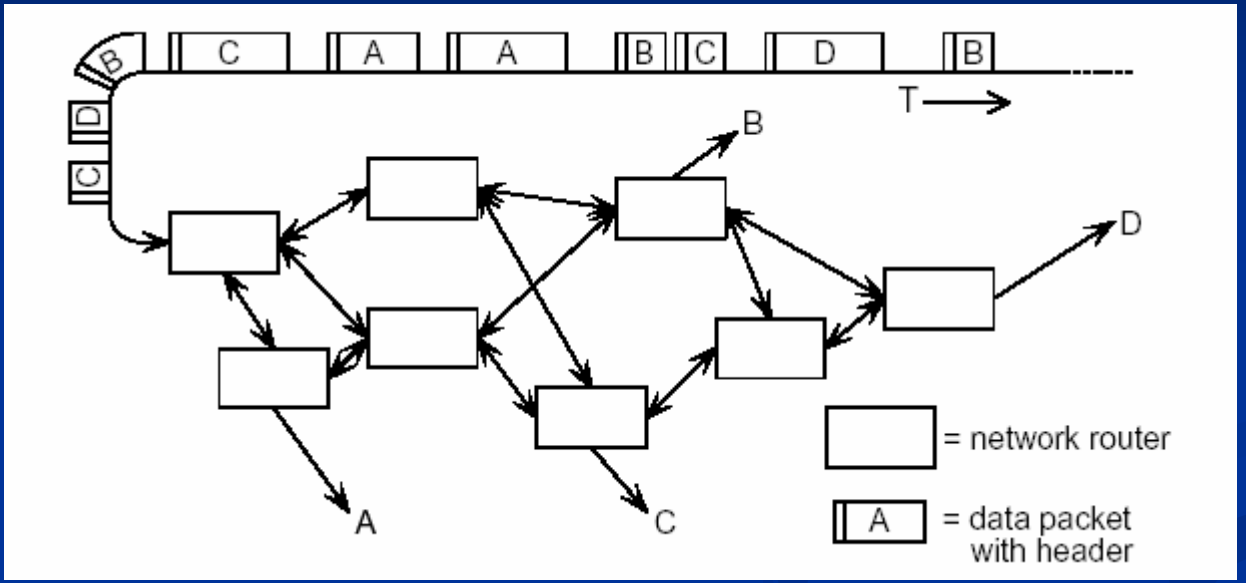
Motivation

ONN Features:

- Massive interconnections
- Parallel processing operation
- Inherent additive properties

✓ Fast optical computing
✓ Power efficient manner

All Optic Systems



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 detect sequence and classify the packets by their destination address.

Outline

- Introduction
- Optical Medium
- ONN Examples
  - BP Traning of an ONN
  - A Multilayer ONN
- References

Optical Neural Network

Introduction

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.

History

- 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 Elements of ONN

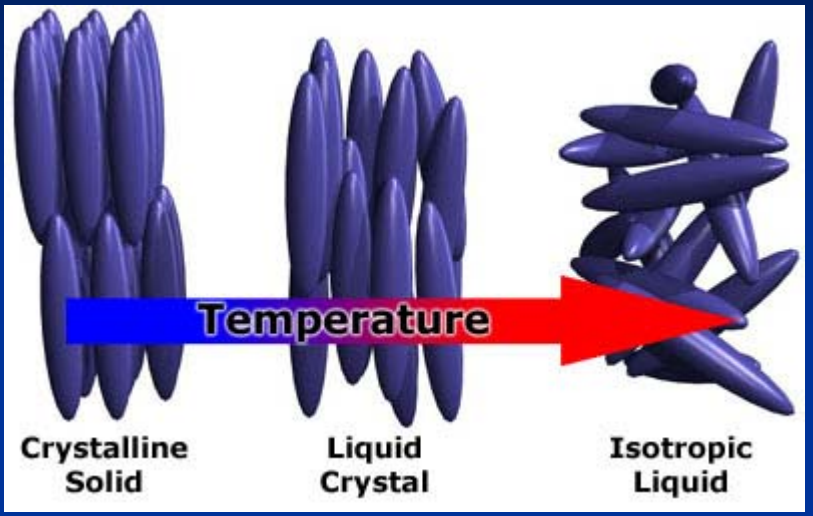
Optical Elements of ONN

- Laser (1960)
- Lenses
- Liquid Crystals (1888)

Laser

- 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.

Liquid Crystal



- The study of liquid crystals began in 1888 when an Austrian botanist observed that a material had two distinct melting point.

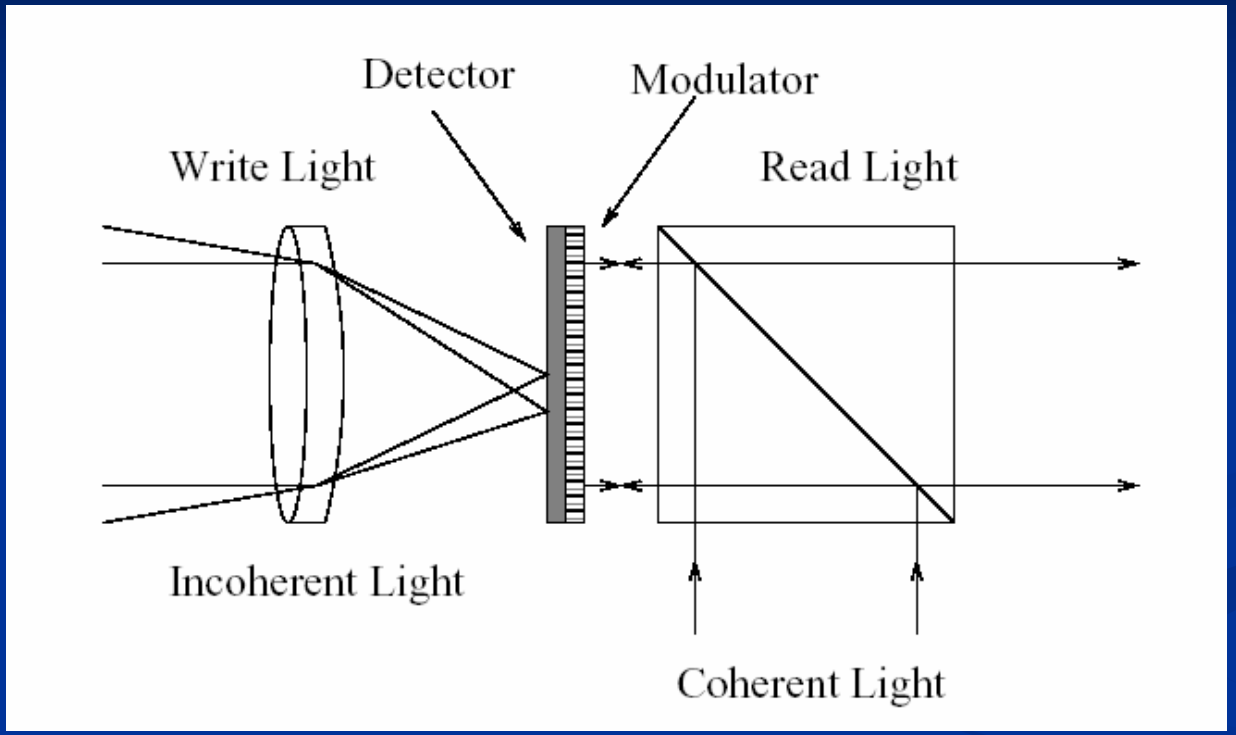
-Liquid crystals are a phase of matter whose order is intermediate between that of a liquid and that of a crystal.

-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)

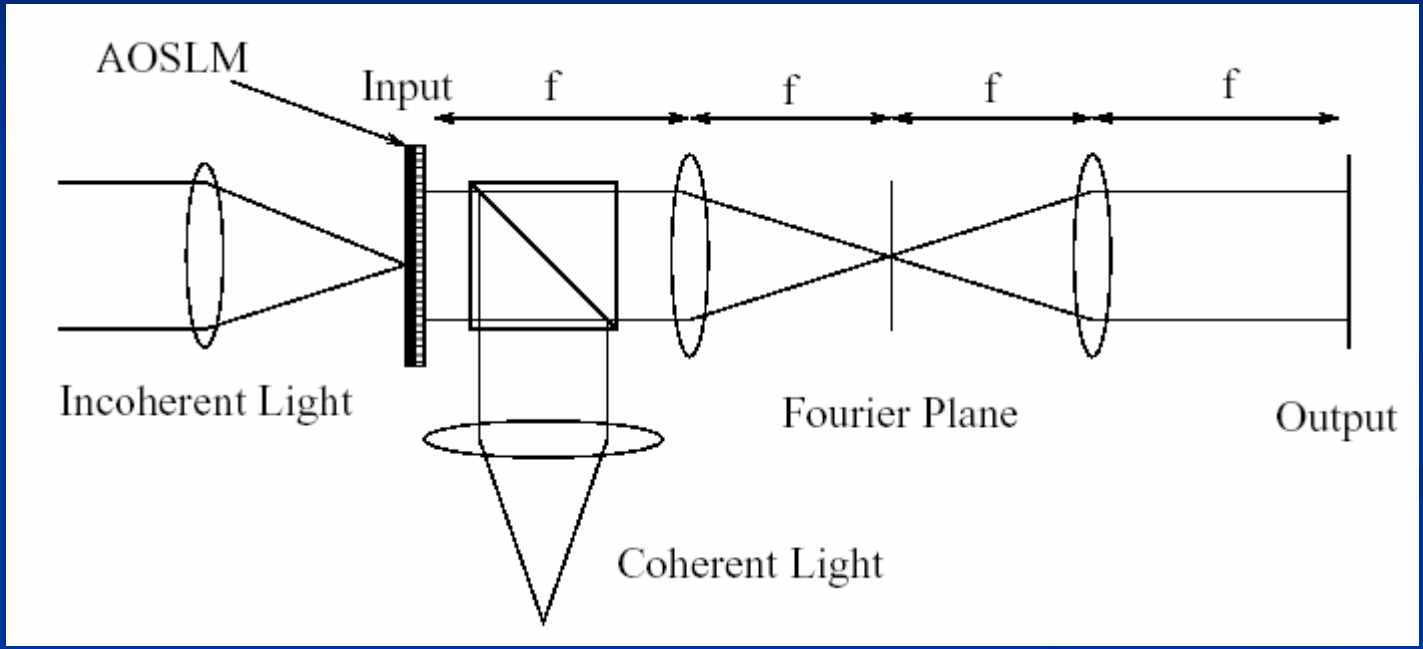
Optically Addressed SLM



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.

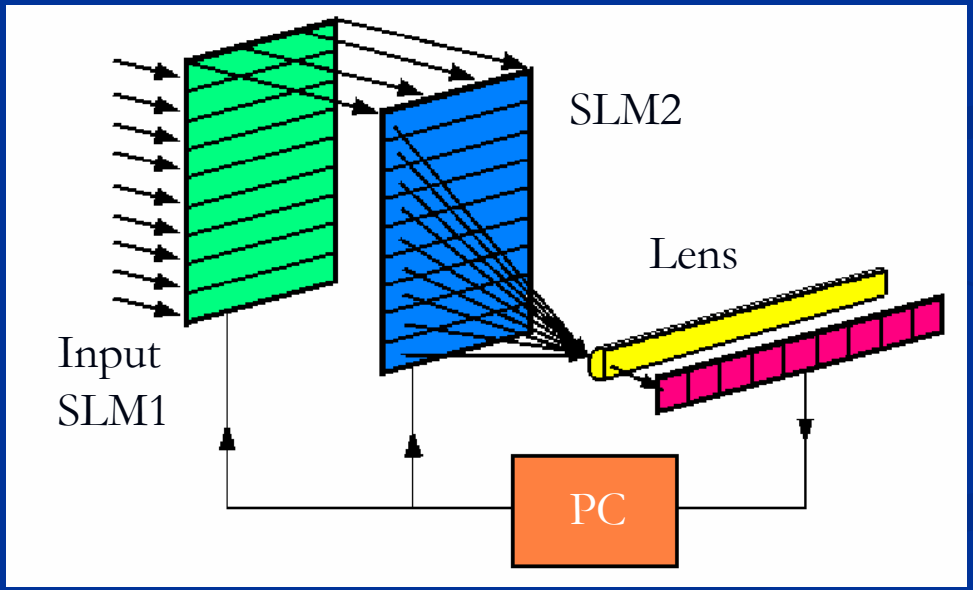
Practical Uses of AOSLMs



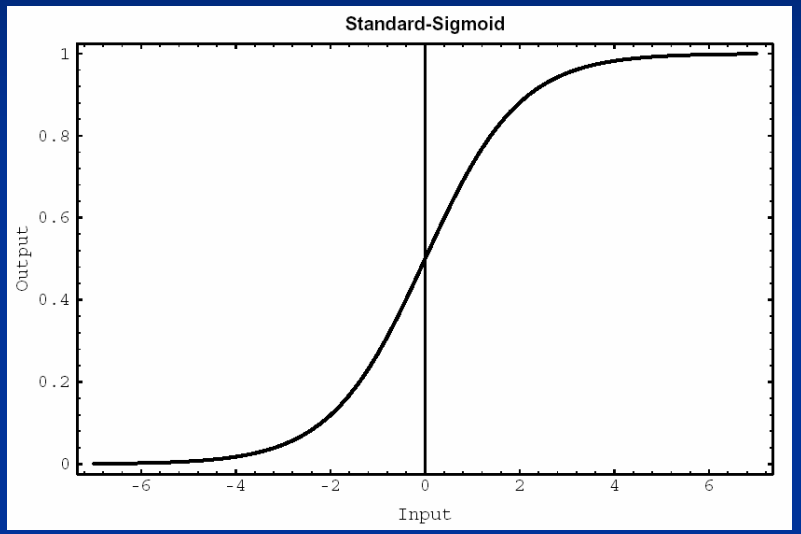
Simplest applications is for real-time input to "4-f" optical processor

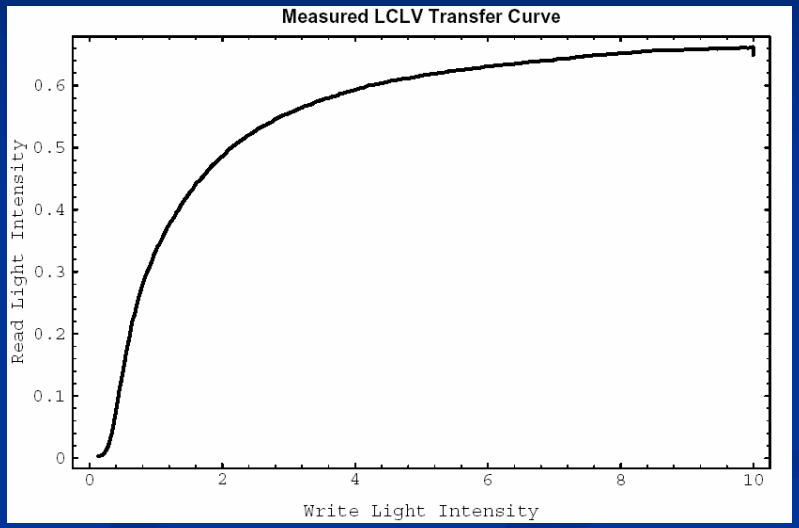
Electrically Addressed SLM

- The hologram is generated on SLM by a computer.
- EASLM is similar to LCTV.



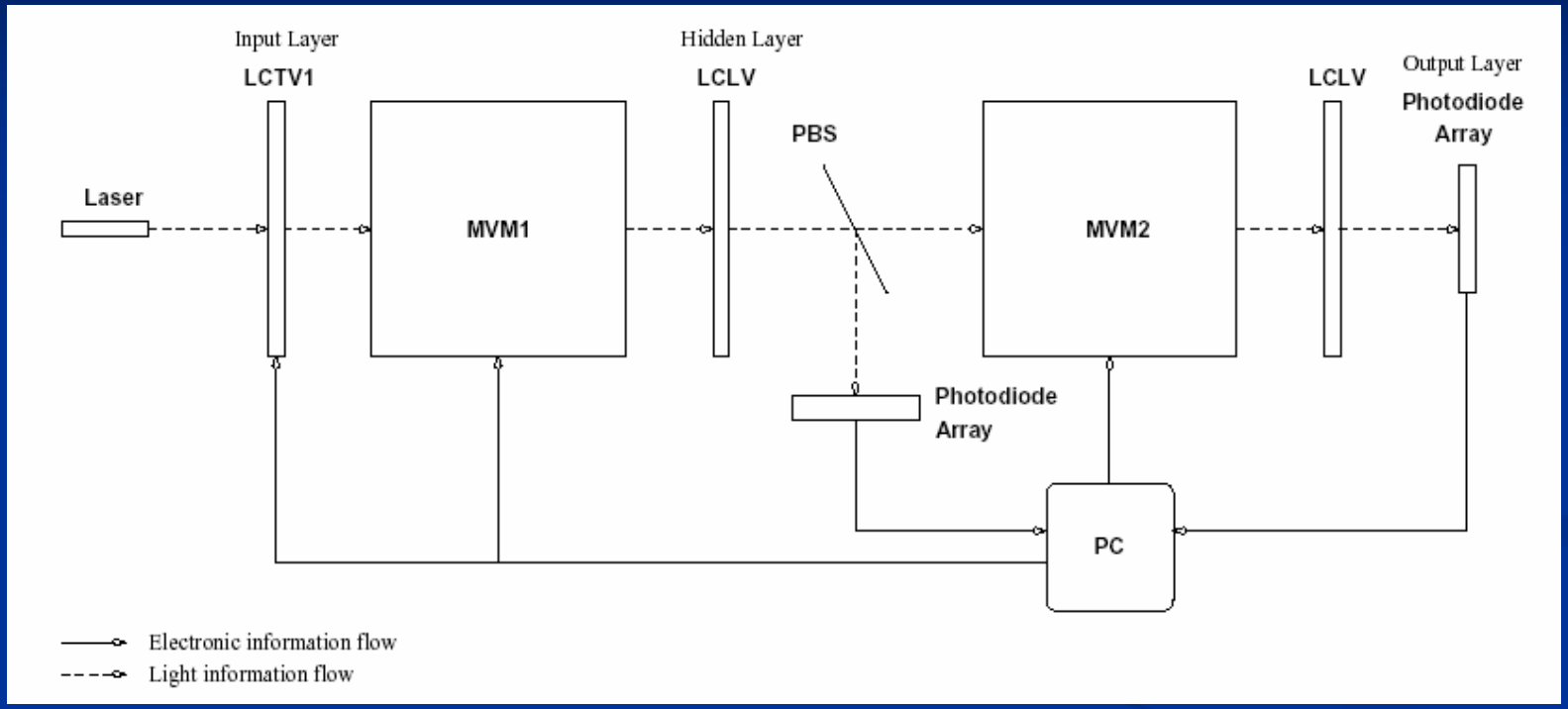
LCLV: Optical Thresholding





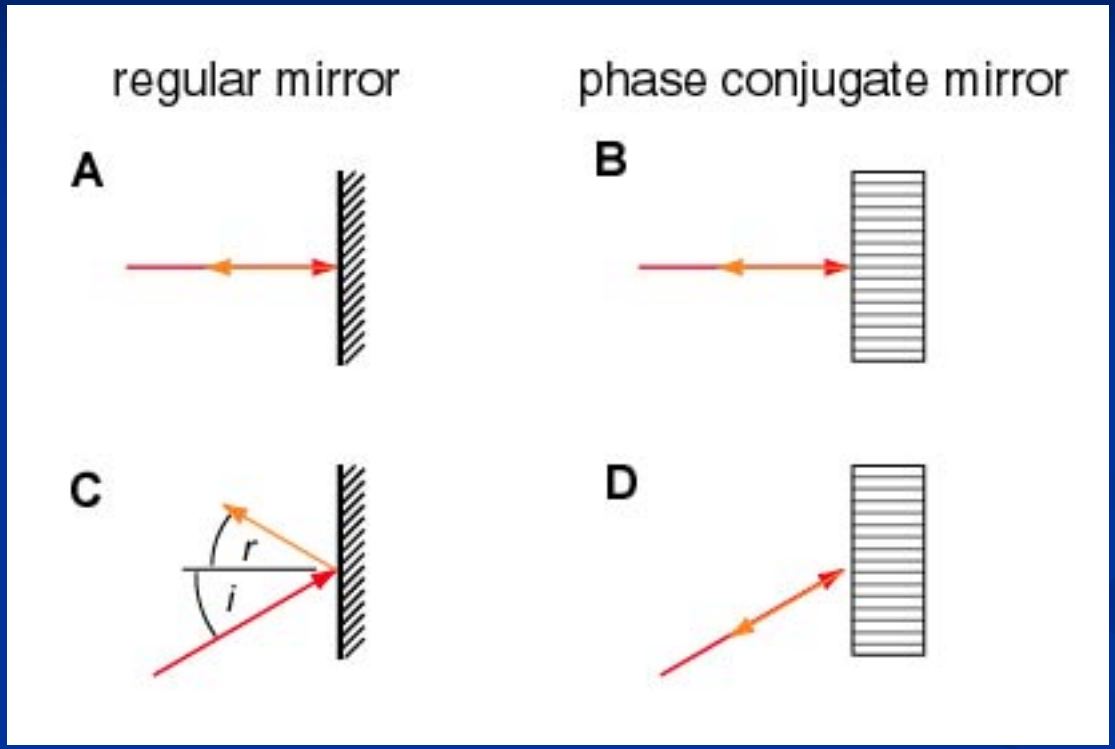
$1/(1+e^{-x})$ → $s(x) = \alpha + \frac{\gamma}{1+e^{-\beta x+\delta}}$

Sigmoid Curve fit for LCLVs



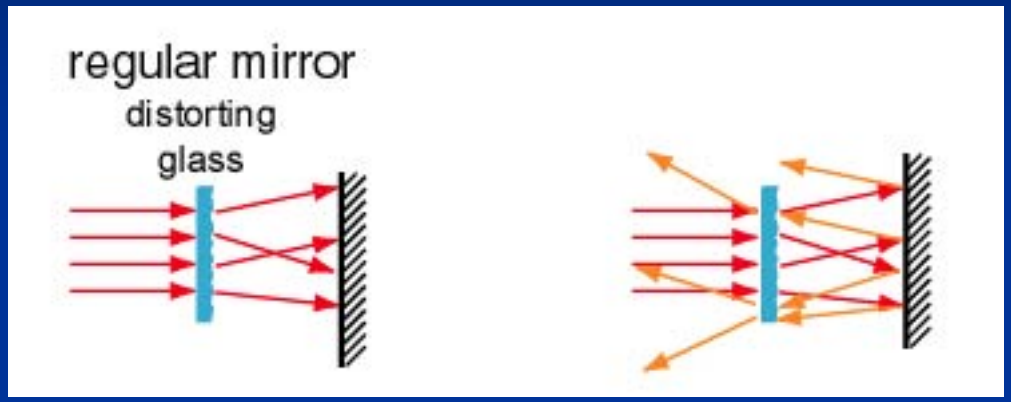
	standard sigmoid	LCLV1	LCLV2	LCLV3	LCLV4a	LCLV4b
α	0	−0.41	−2.34	0.015	−11.4	−0.019
β	1	0.087	0.0062	0.043	0.79	1.40
γ	1	1.41	3.34	1.0	12.4	1.0
δ	0	0.93	−0.82	3.20	−2.31	4.57

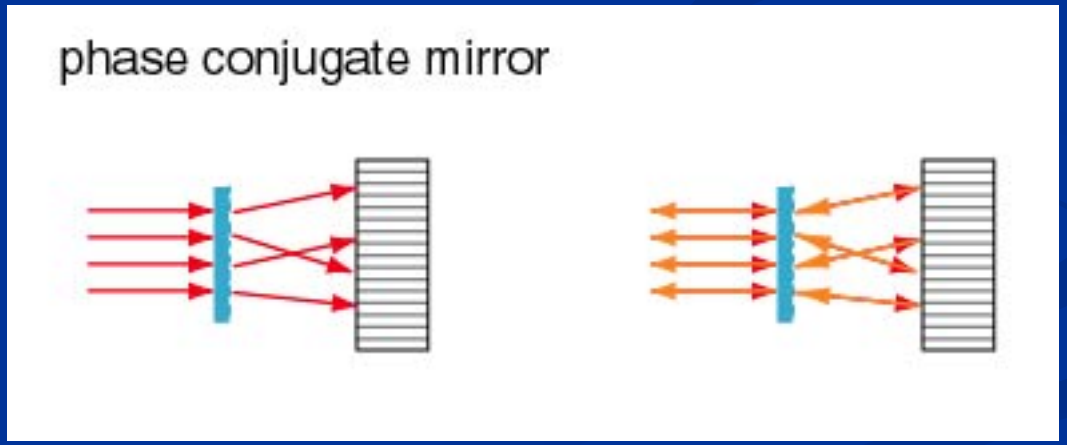
Phase Conjugate Mirror



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.

Phase Conjugate Mirror





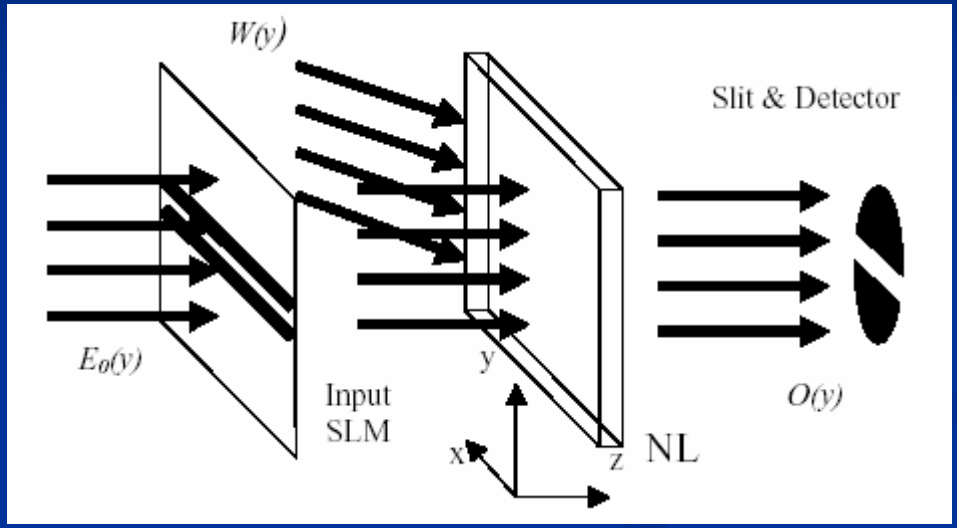
Examples

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.

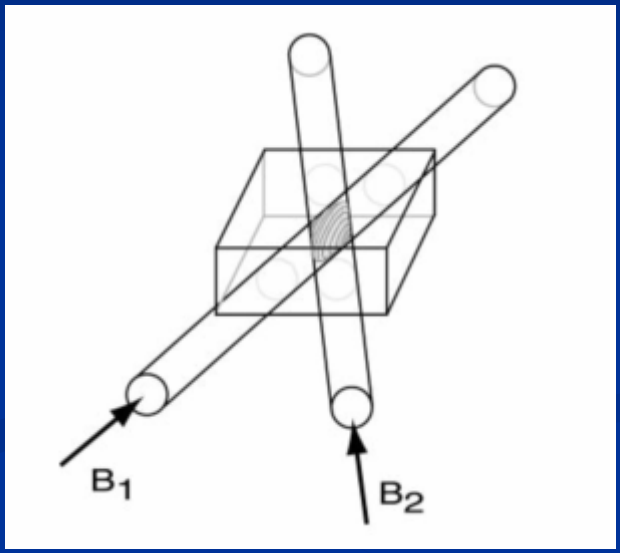
Basic Neural Network



Two-Wave Mixing

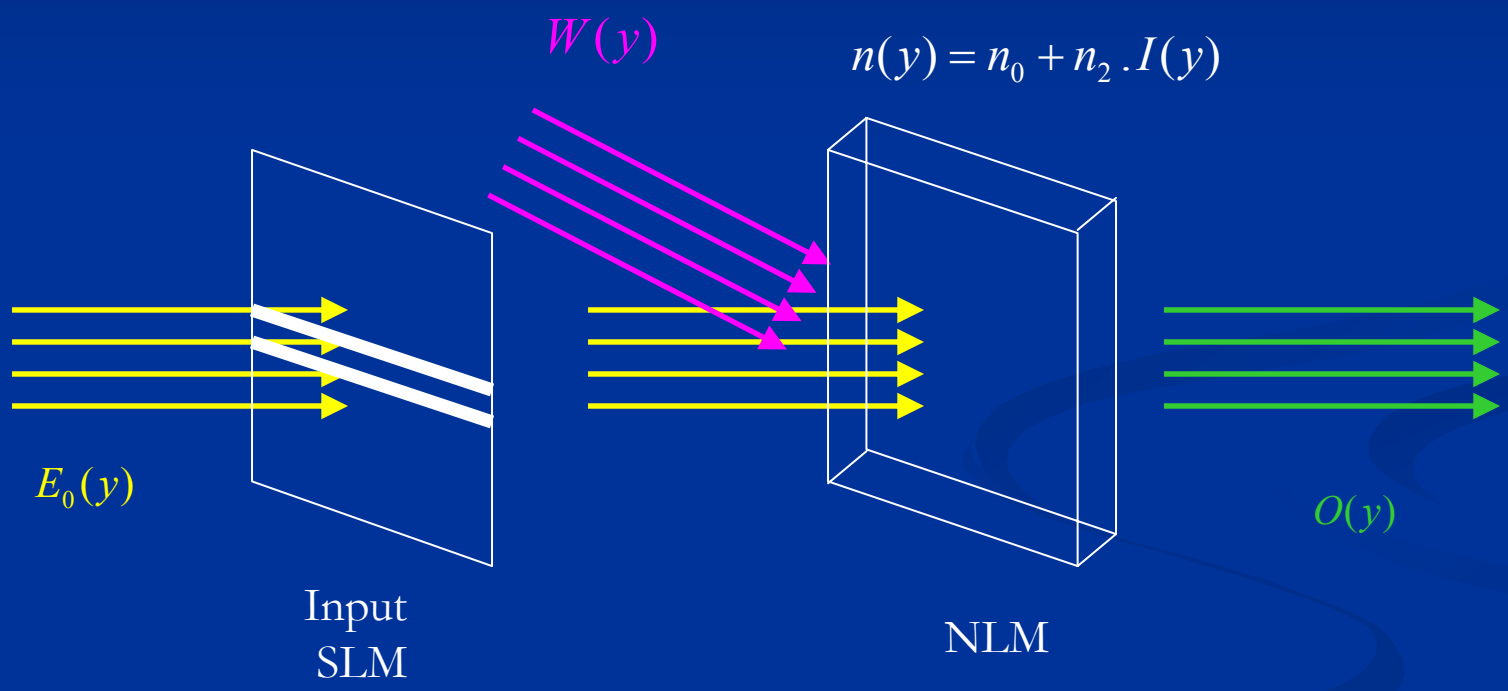
In linear optics
is a transient phenomenon that has no effect on anything else.

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.

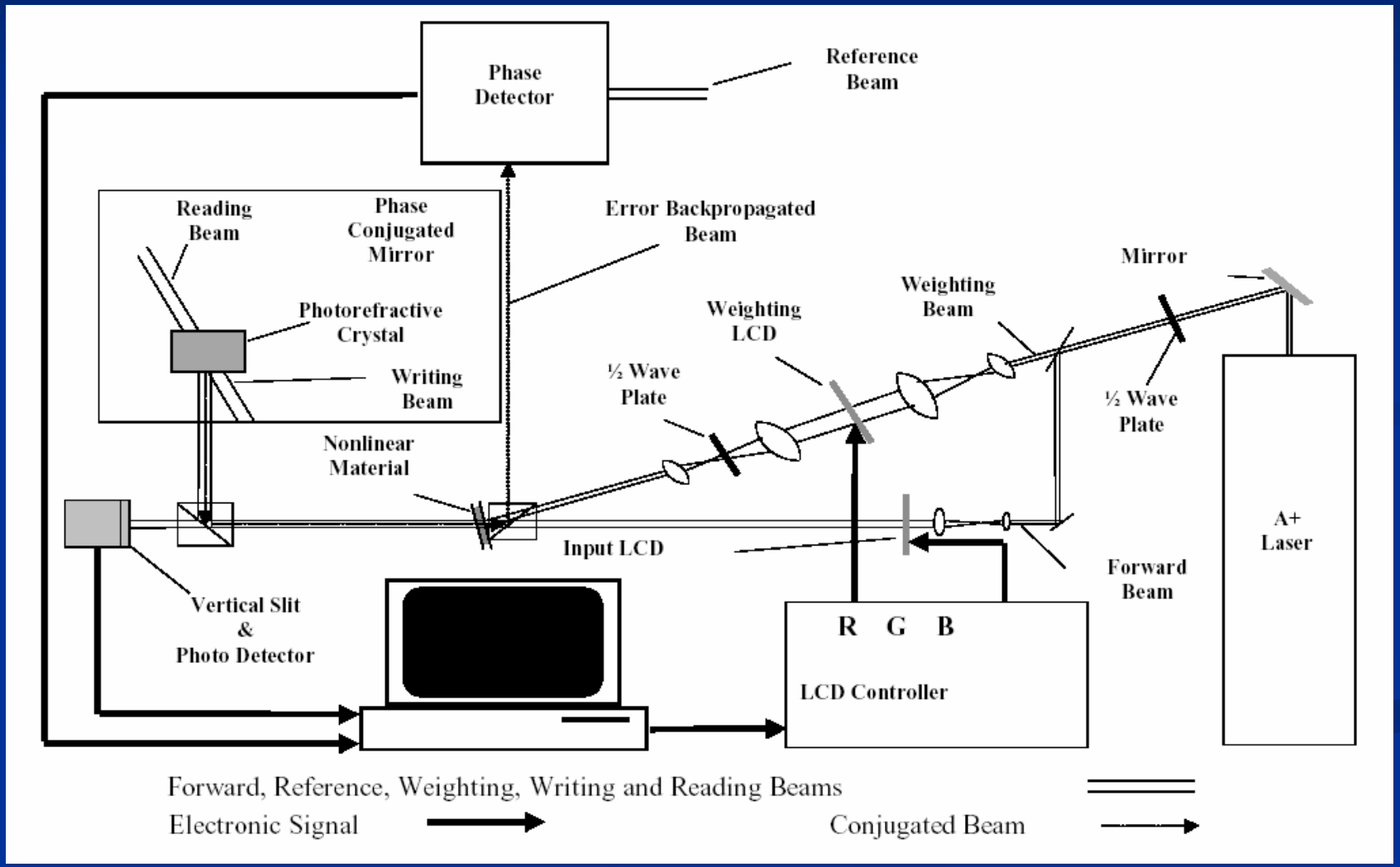


$$n(y) = n_0 + n_2 . I(y)$$

Network Description



Experimental Set up



BP Training Results

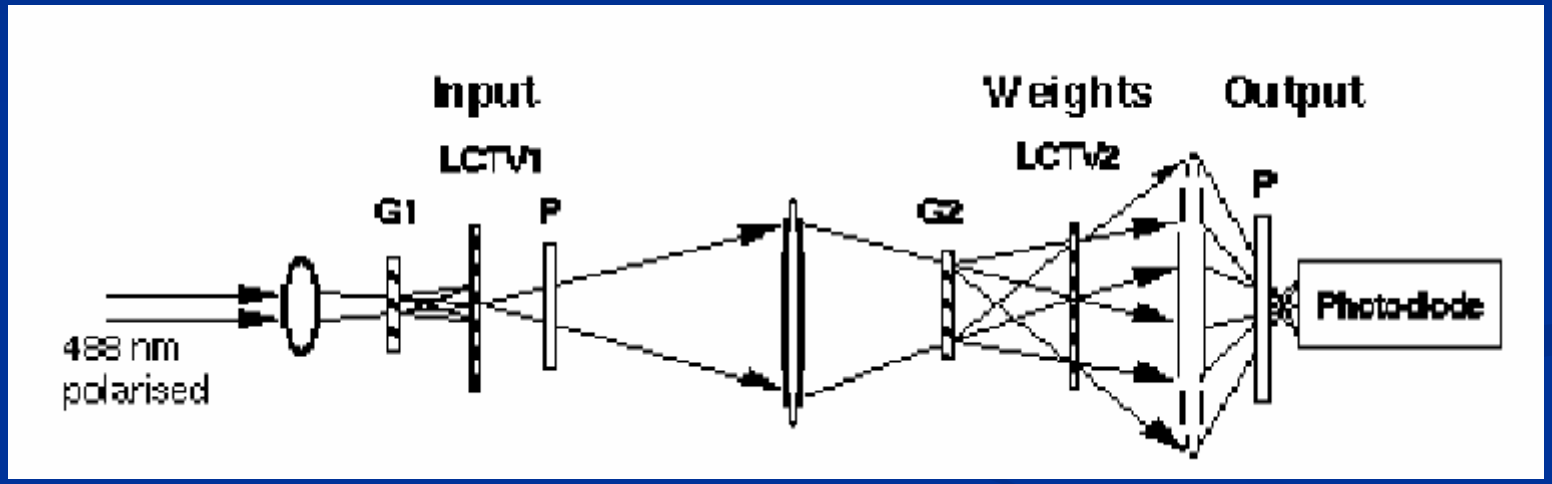
Mean Square Error (MSE)

INPUT (A B)		(0-0)	(0-1)	(1-0)	(1 1)	RME
AND	Start	1.22	0.87	0.92	0.82	0.29
	End	0.82	0.90	0.84	1.18	0.06
	Desired	0.8	0.8	0.8	1.2	
NAND	Start	1.35	0.87	0.93	0.86	0.22
	End	1.70	1.23	1.32	0.86	0.03
	Desired	1.2	1.2	1.2	0.8	
NOR	Start	1.28	0.87	0.91	0.85	0.07
	End	1.13	0.78	0.85	0.78	0.04
	Desired	1.2	0.8	0.8	1.2	

A Multilayer ONN for Digit Recognition

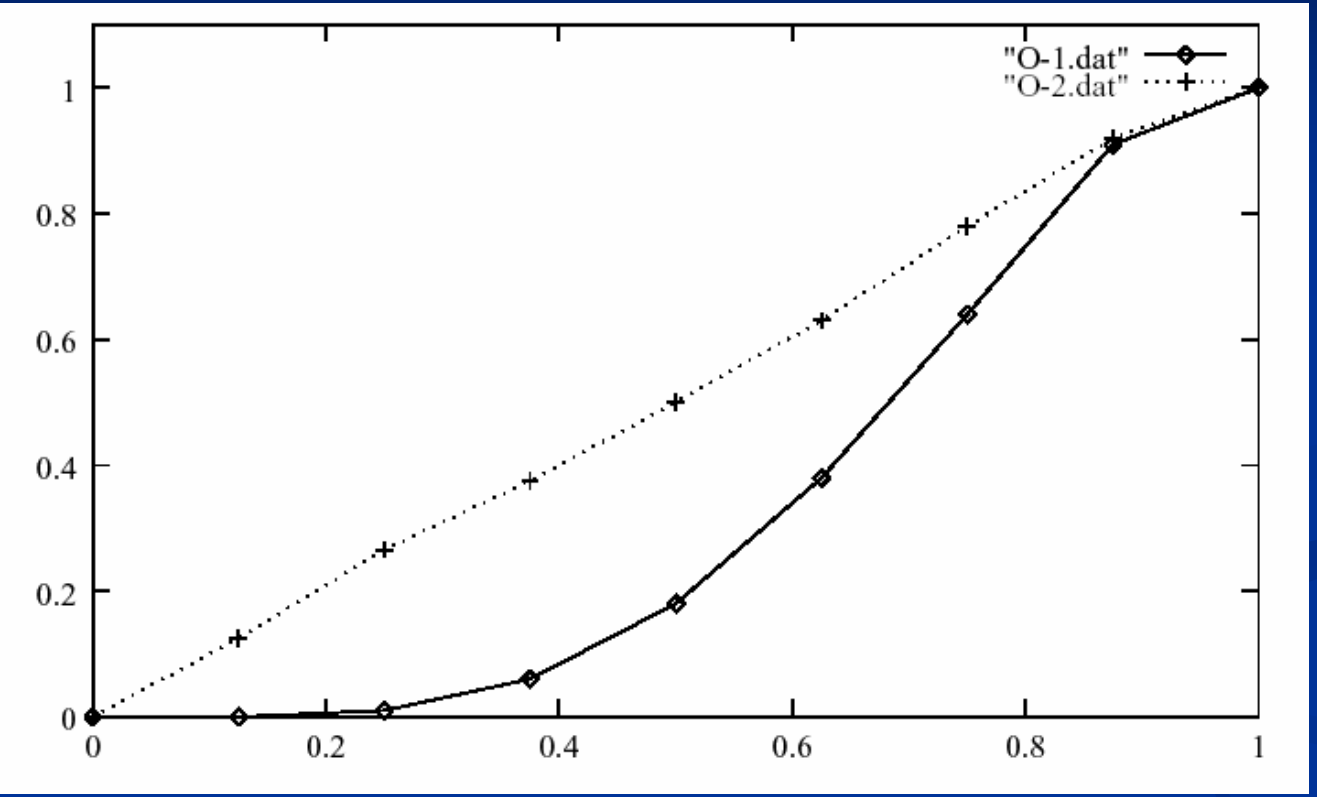
- An optical perceptron with a soft optical threshold is implemented, that is trained with an adapted BP algorithm.
- An optical thresholding perceptron is composed of two parts:
  - Matrix-vector-Multiplier (MVM),
  - A thresholding device.

Matrix Vector Multiplier (MVM)



P: Polariser; Gn: Gratings

Weight Mappings

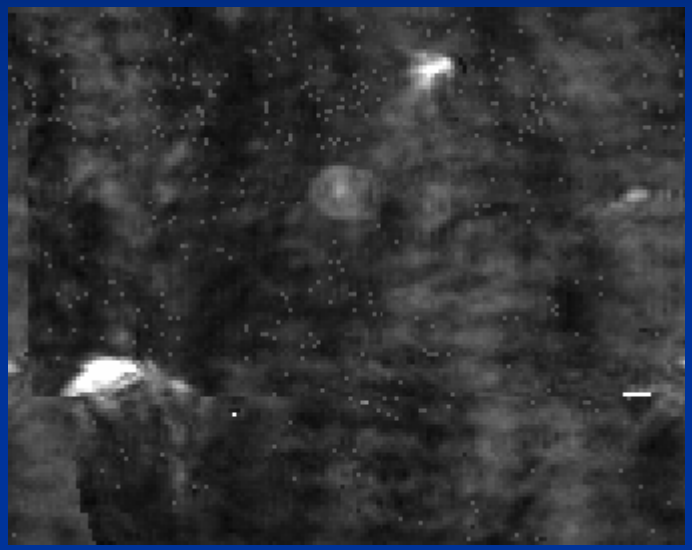


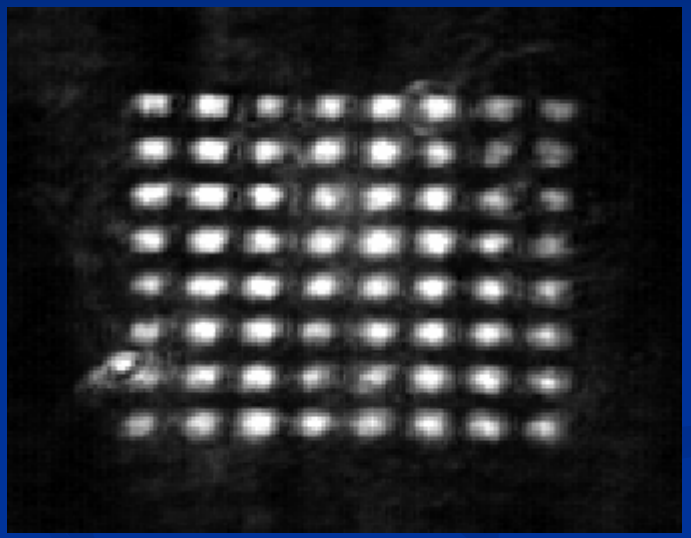
Behaviour of optical weights under different weight mappings: x-axis has calculated weights, and y-axis has corresponding optical weights or LCTV2 transmittances

Test inputs

A set of handwritten digits

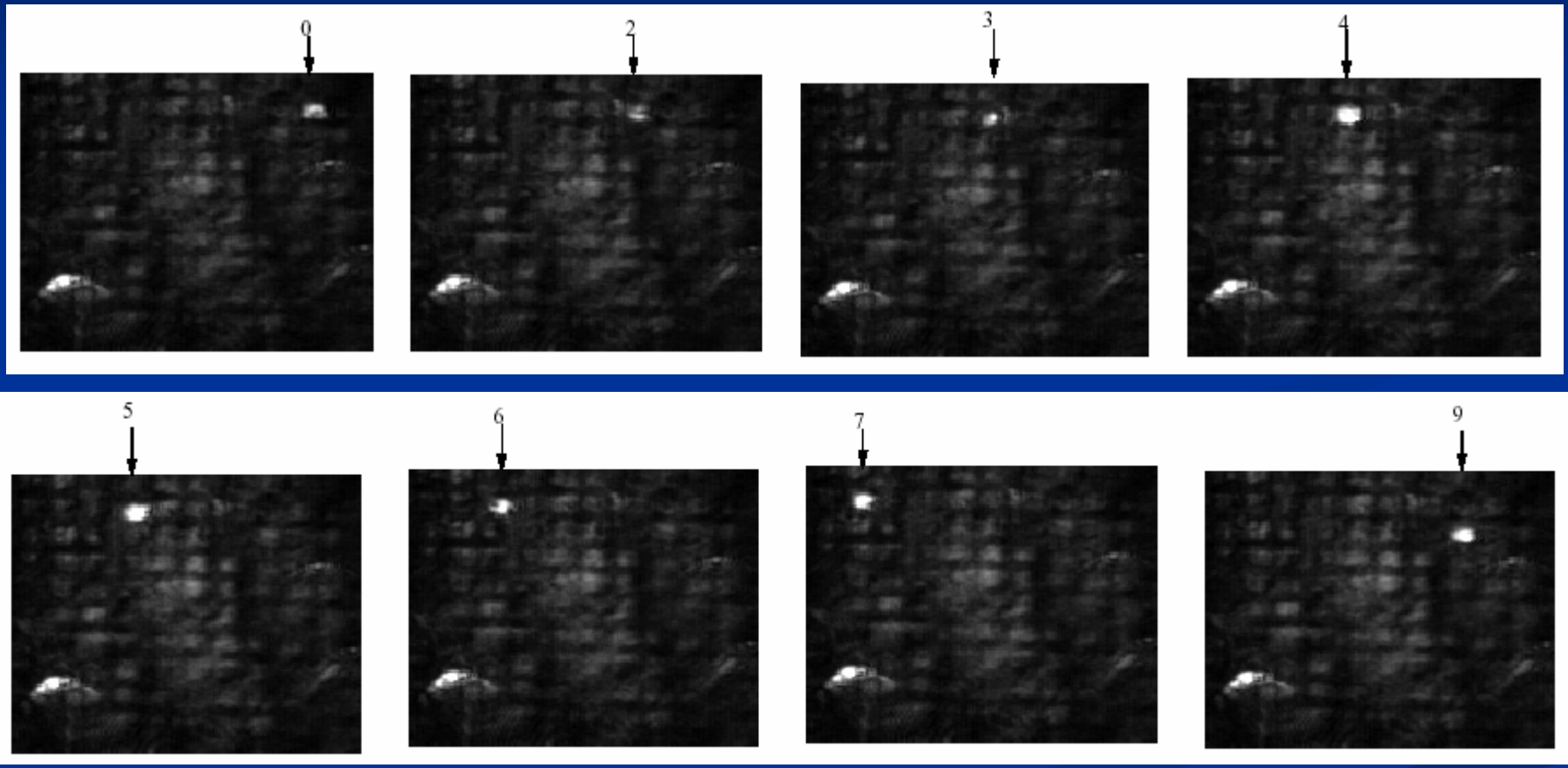
Output Screen





LCLV output images without and with write light

Digit Recognition



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

References

References

[1] J. E. Steck1, S. R. Skinner2, A. A. Cruz-Cabrera2, M. Yang, and E. C. Behrman3, "Backpropagation Training of an Optical Neural Network," IEEE, 2000.

[2] I. Saxena, P. Moerland, E. Fiesler, A. R. Pourzand, and N. Collings, "An Optical Thresholding Perceptron with Soft Optical Threshold." 1997.

[3] I. Saxena and P. Moerland, "An Adaptive Multilayer Optical Neural Network Design," 1996.

[4] I. Saxena and P. Moerland, "Adaptive Multilayer Optical Neural Network with Optical Thresholding," 1994.

[5] P. Moerland, E. Fiesler and I. Saxena, "Incorporating LCLV Non_Linearities in Optical Neural Network,"1995.

[6] T. Yatagai and M. Itoh, "Development of an Optical Neural Network," 1995.

[6] PCM: http://cns-alumni.bu.edu/~slehar/Spatial/Spatial.htm

[7] Liquid Crystal: http://plc.cwru.edu/tutorial/enhanced/files/lc/Intro.htm

[8] http://www.exo.net/~pauld/activities/liquidcrystal/liquidcrystal.html#how

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

Thanks!