TI | Developer Conference
March 7-9, 2007 • Dallas, TX

Minds in Motion

DLP® Technology-Driven, Optical Neural Network Results and Future Design

Emmett Redd
Professor
Missouri State University

Missouri State University

Neural Network Applications

- **Stock Prediction:** Currency, Bonds, S&P 500 and Natural Gas
- **Business:** Direct mail, Credit Scoring, Appraisal and Summoning Juries
- **Medical:** Breast Cancer, Heart Attack Diagnosis and ER Test Ordering
- **Sports:** Horse and Dog Racing
- **Science:** Solar Flares, Protein Sequencing, Mosquito ID and Weather
- **Manufacturing:** Welding Quality, Plastics or Concrete Testing
- **Pattern Recognition:** Speech, Article Class. and Chem. Drawings
- **No Optical Applications—We are starting with Boolean**

- most from www.calsci.com/Applications.html

Optical Computing & Neural Networks

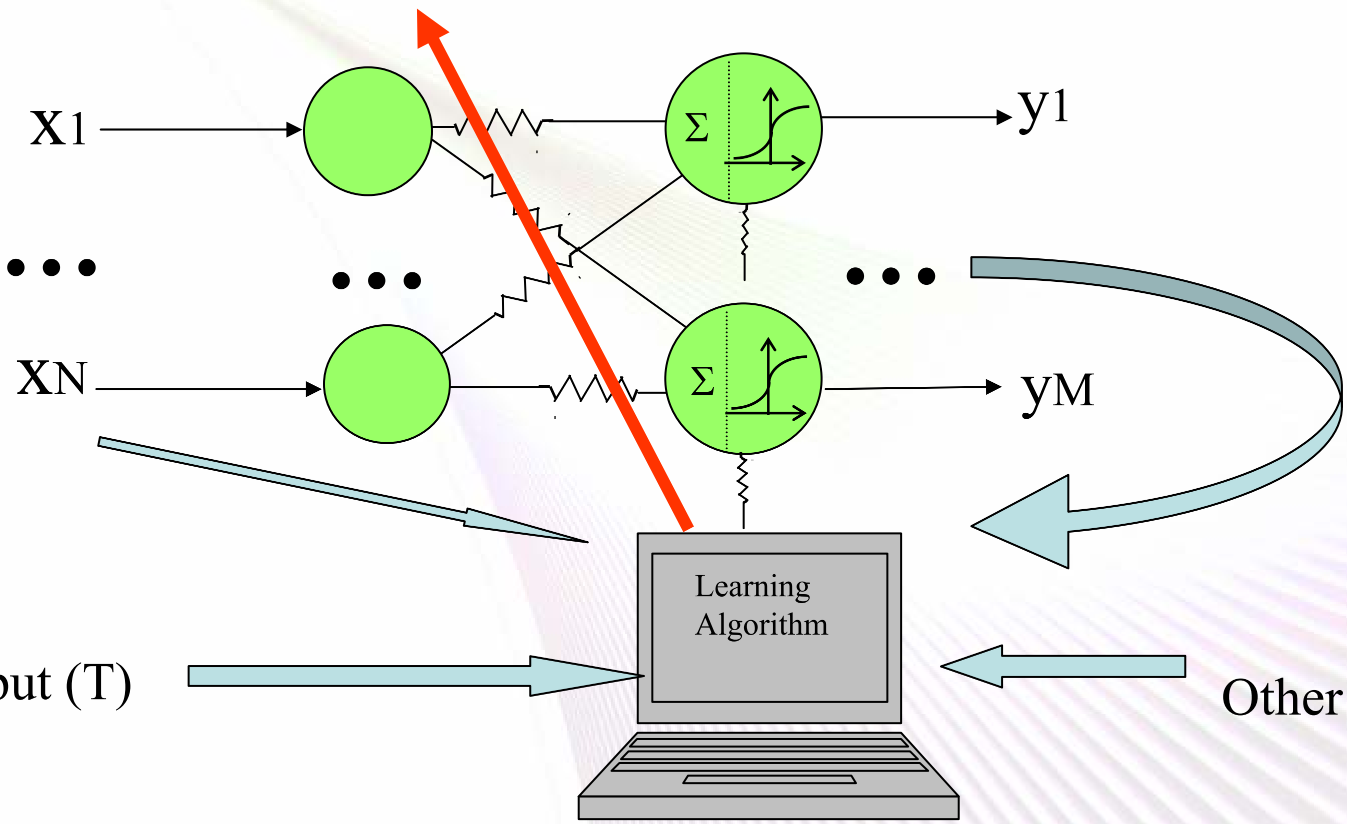
- Optical Parallel Processing Gives Speed
  - Lenslet's Enlight 256—8000 Giga Multiply and Accumulate per second
  - Order 10^{11} connections per second possible with holographic attenuators
- Neural Networks
  - Parallel versus Serial
  - Learn versus Program
  - Solutions beyond Programming
  - Deal with Ambiguous Inputs
  - Solve Non-Linear problems
  - Thinking versus Constrained Results

Optical Neural Networks

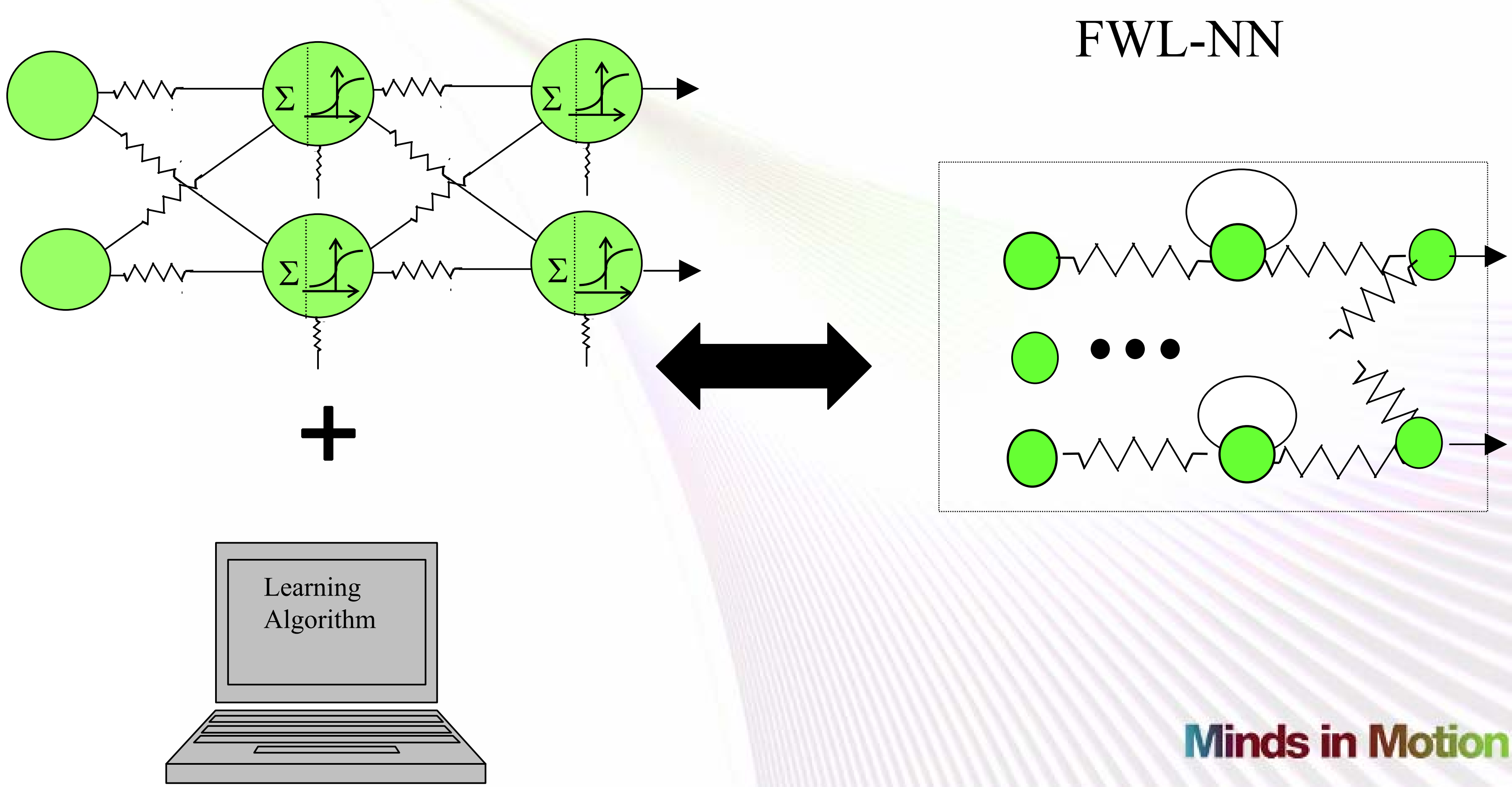
- **Sources are modulated light beams (pulse or amplitude)**
- **Synaptic Multiplications are due to attenuation of light passing through an optical medium (30 fs)**
- **Geometric or Holographic**
- **Target neurons sum signals from many source neurons.**
- **Squashing by operational-amps or nonlinear optics**

Standard Neural Net Learning

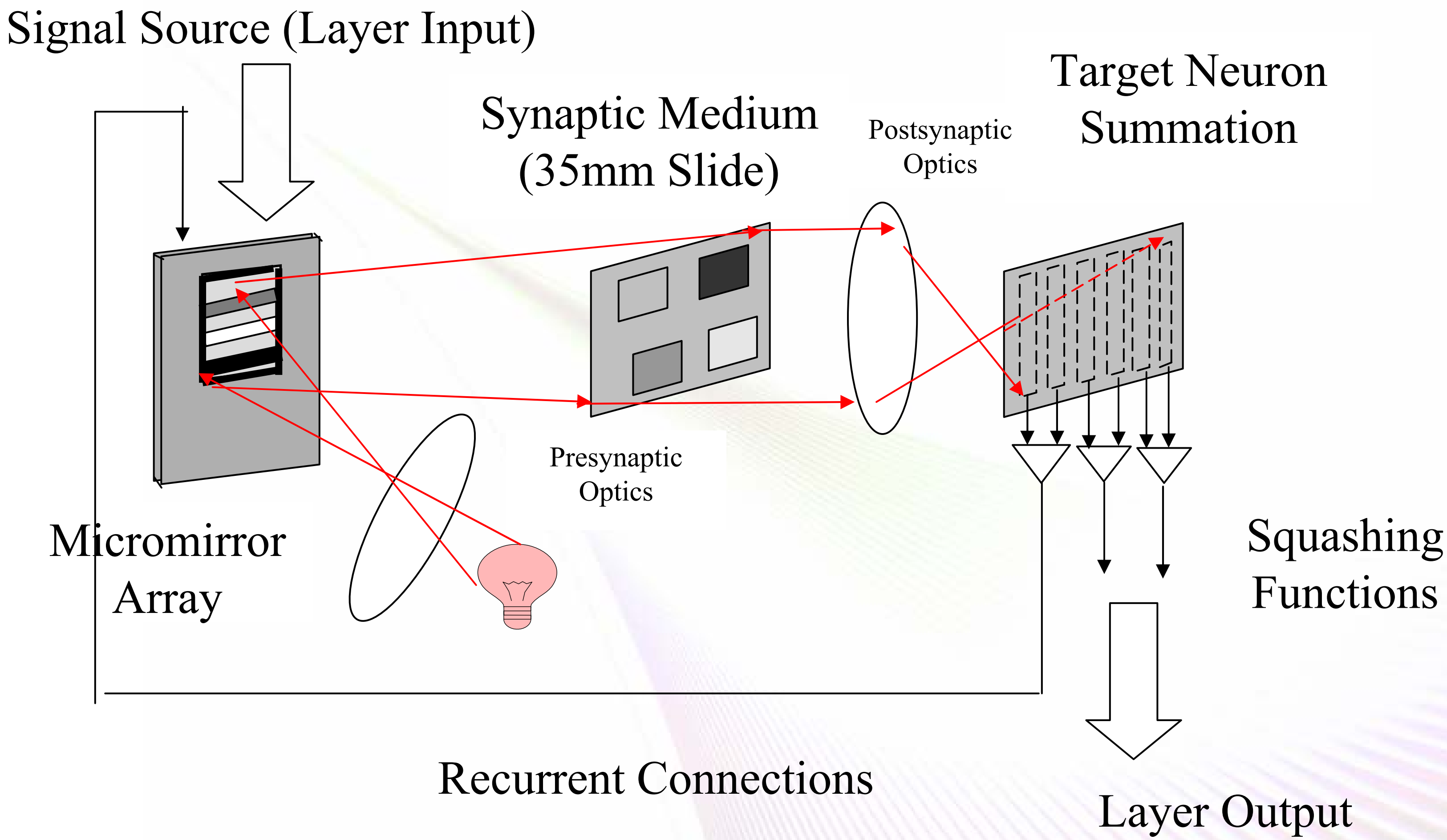
- We use a Training or Learning algorithm to adjust the weights, usually in an iterative manner.



FWL-NN is equivalent to a standard Neural Network + Learning Algorithm



Optical Recurrent Neural Network

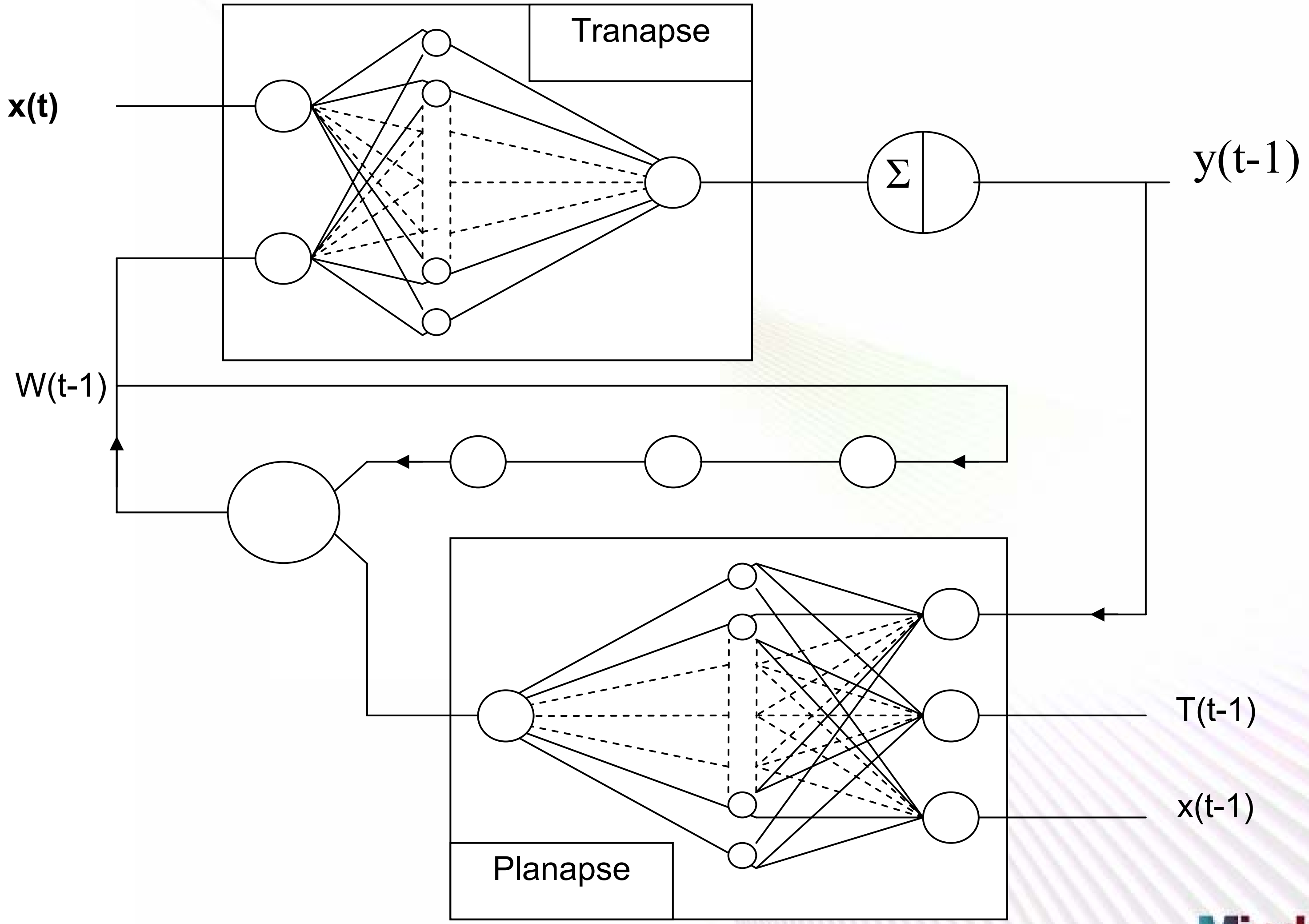


A Single Layer of an Optical Recurrent Neural Network. Only four synapses are shown. Actual networks will have a large number of synapses. A multi-layer network has several consecutive layers.

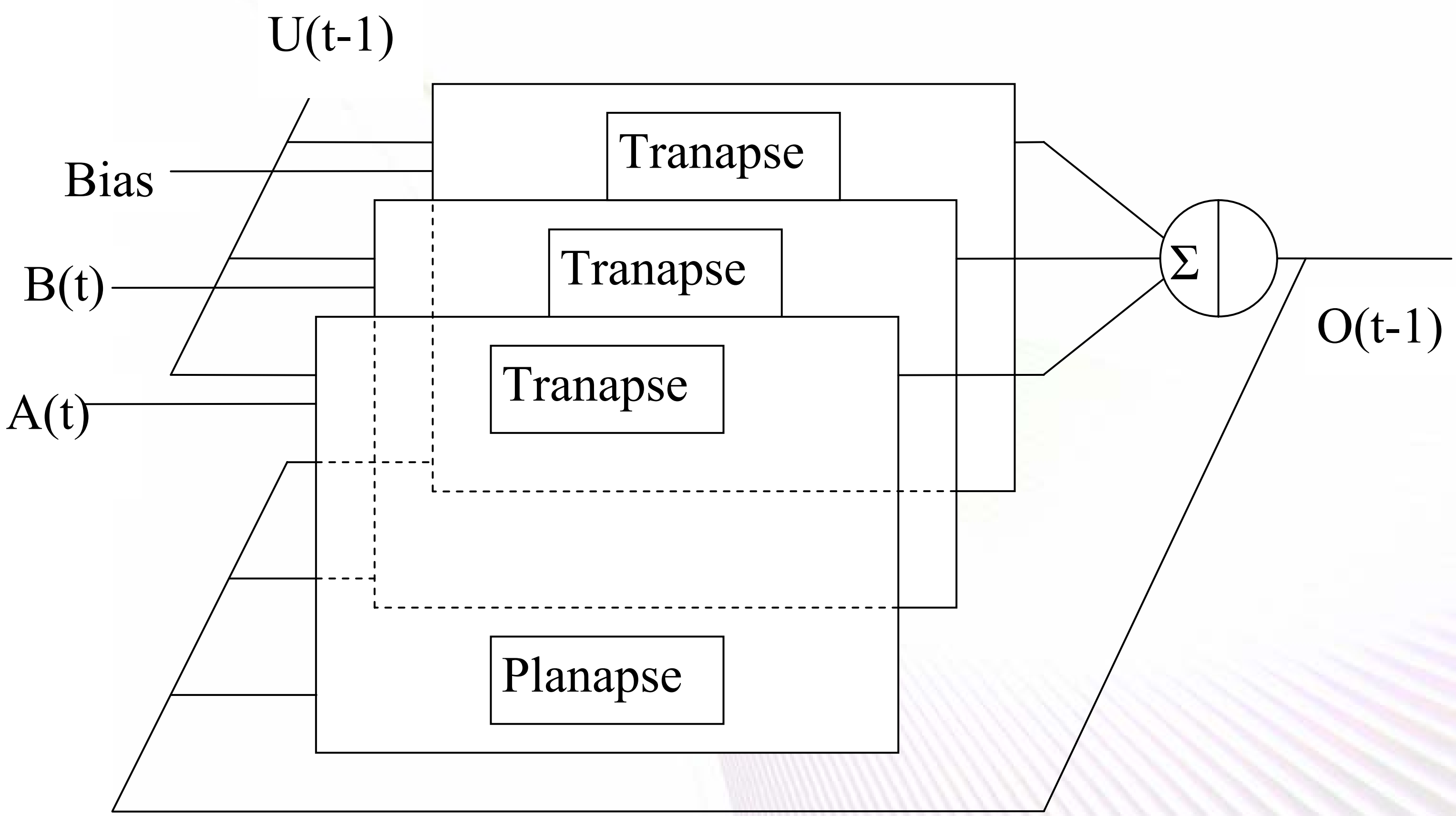
Definitions

- **Fixed-Weight Learning Neural Network (FWL-NN) – A recurrent network that learns without changing synaptic weights**
- **Potency – A weight signal**
- **Tranapse – A Potency modulated synapse**
- **Planapse – Supplies Potency error signal**
- **Zenapse – Non-Participatory synapse**
- **Recurron – A recurrent neuron**
- **Recurral Network – A network of Recurrons**

Optical Fixed-Weight Learning Synapse



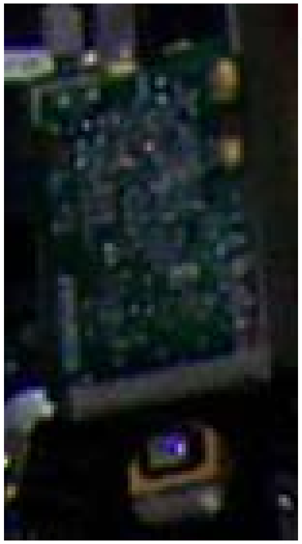
Page Representation of a Recurron

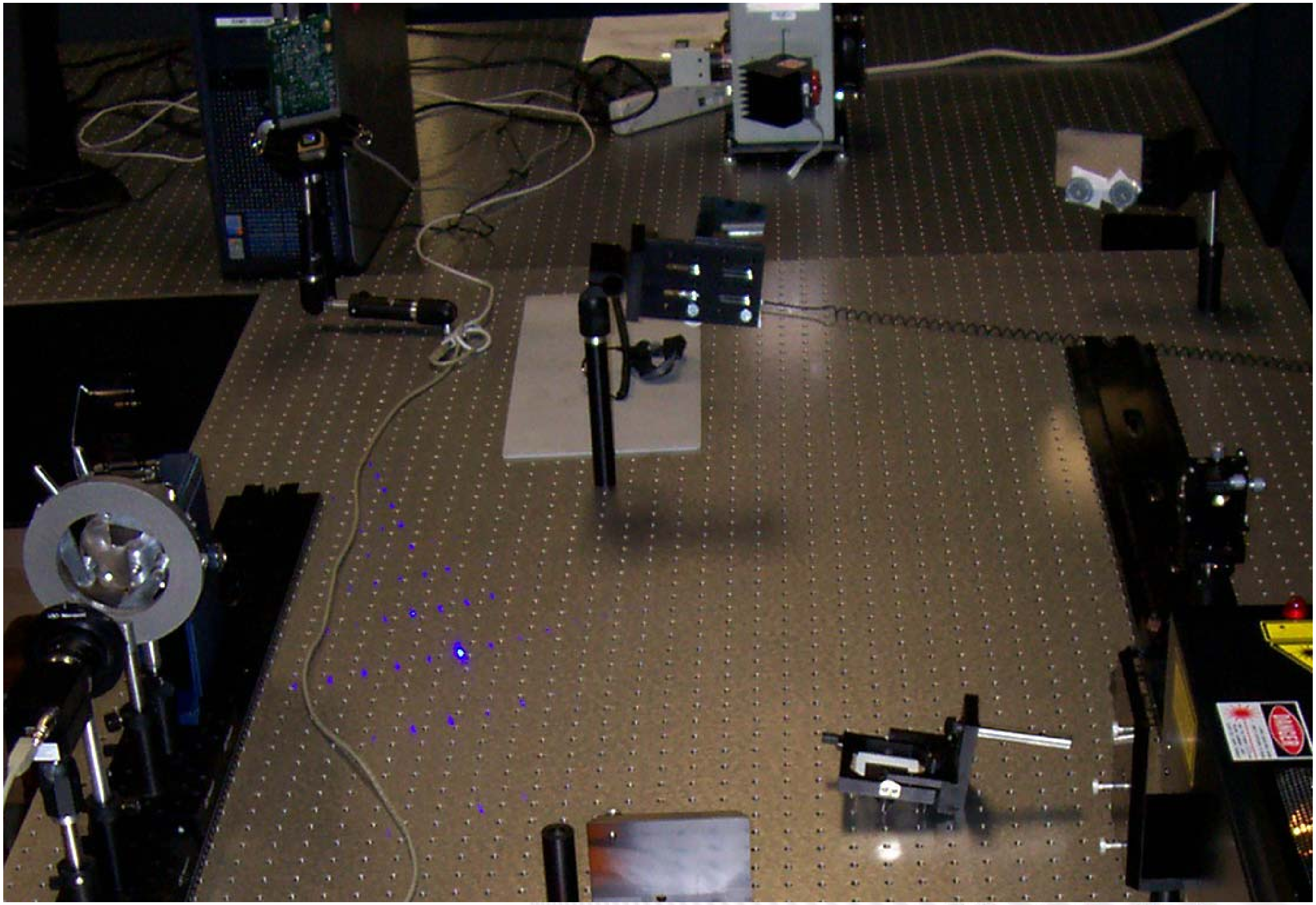


Optical Neural Network Constraints

- Finite Range Unipolar Signals [0,+1]
- Finite Range Bipolar Attenuation[-1,+1]
- Excitatory/Inhibitory handled separately
- Limited Resolution Signal
- Limited Resolution Synaptic Weights
- Alignment and Calibration Issues

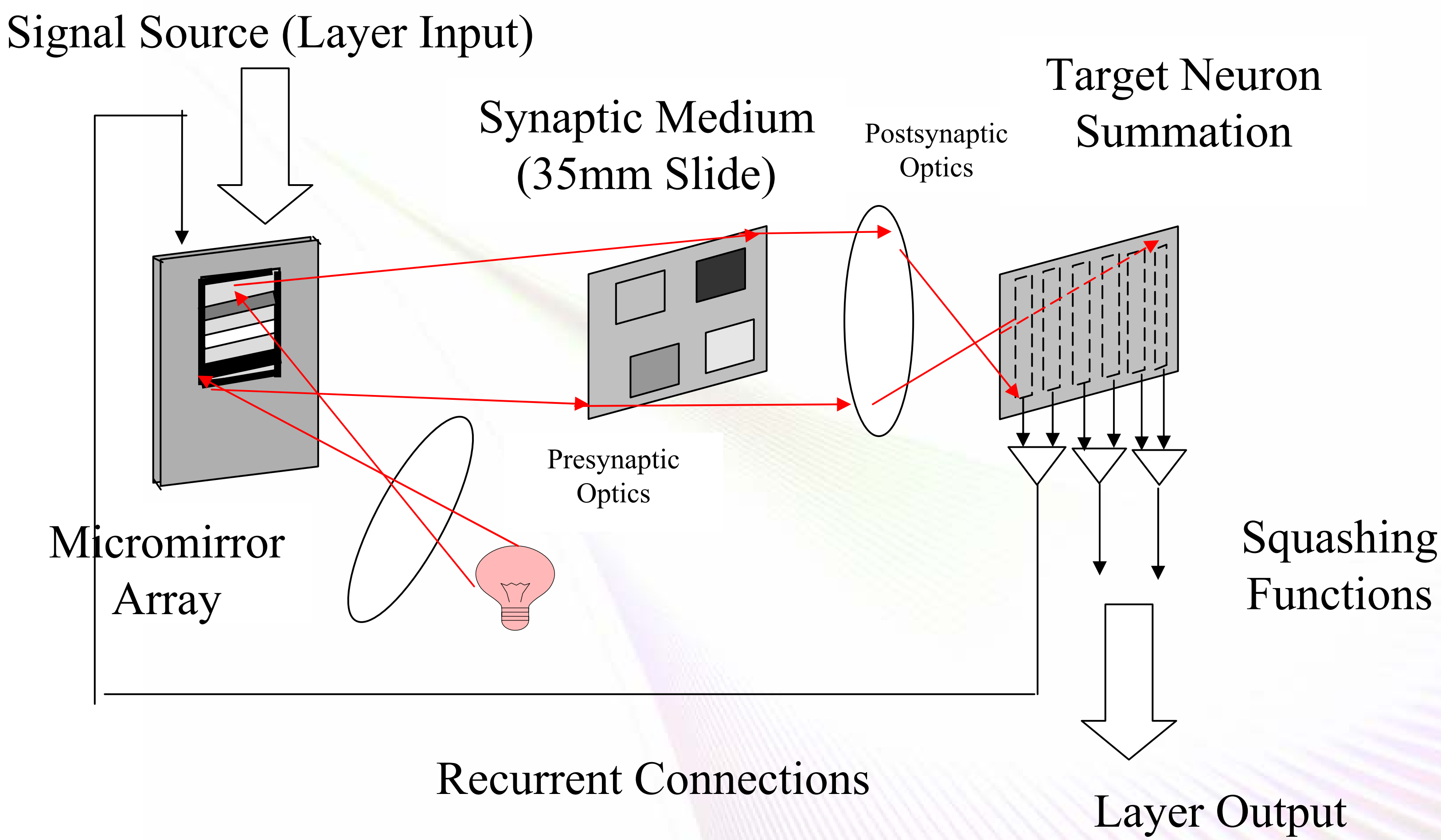
Optical System





DMD or DLP®

Optical Recurrent Neural Network



A Single Layer of an Optical Recurrent Neural Network. Only four synapses are shown. Actual networks will have a large number of synapses. A multi-layer network has several consecutive layers.

Design Details and Networks

- Digital Micromirror Device
- 35 mm slide Synaptic Media
- CCD Camera
- Synaptic Weights - Positionally Encoded
  - Digital Attenuation
- Allows flexibility for evaluation.

Recurrent AND
Unsigned Multiply
FWL Recurron

DMD/DLP®—A Versatile Tool

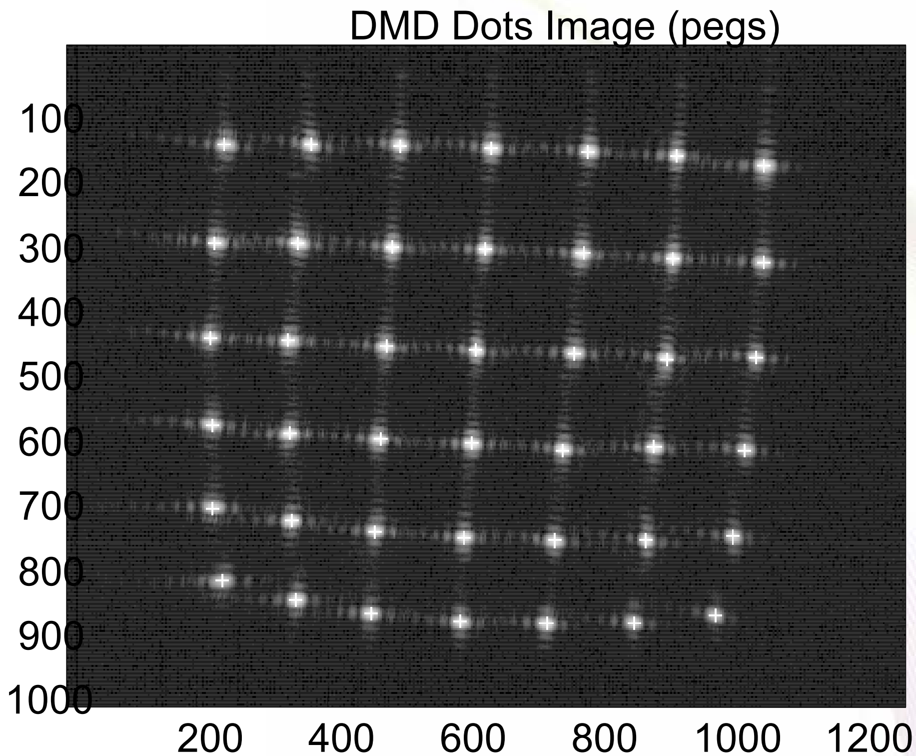
- Alignment and Distortion Correction
  - Align DMD/DLP® to CCD——PEGS
  - Align Synaptic Media to CCD——HOLES
  - Calculate DMD/DLP® to Synaptic Media Alignment——Putting PEGS in HOLES
  - Correct projected DMD/DLP® Images
- Nonlinearities

Stretch, Squash, and Rotate

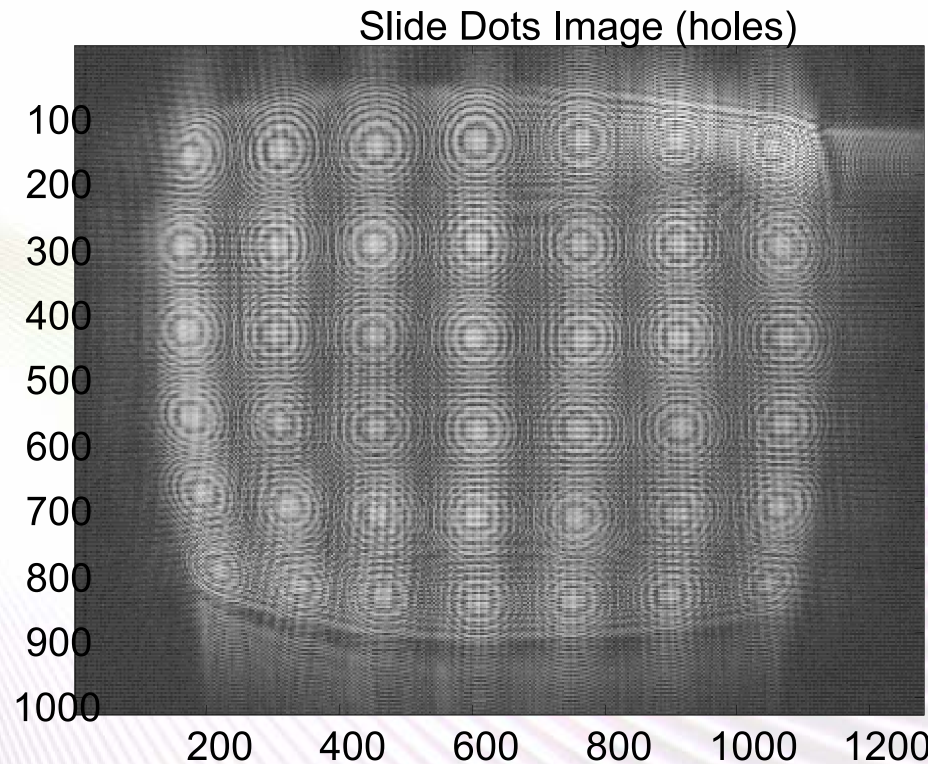
$$D = \begin{bmatrix} x_1 & \cdots & x_P \\ y_1 & \cdots & y_P \\ {x_1}^2 & \cdots & {x_P}^2 \\ x_1 y_1 & \cdots & x_P y_P \\ {y_1}^2 & \cdots & {y_P}^2 \\ 1 & \cdots & 1 \end{bmatrix}$$

1	None
x^1y^0 x^0y^1	Linear
x^2y^0 x^1y^1 x^0y^2	Quadratic
x^3y^0 x^2y^1 x^1y^2 x^0y^3	Cubic
etc.	etc.

Where We Are and Where We Want to Be

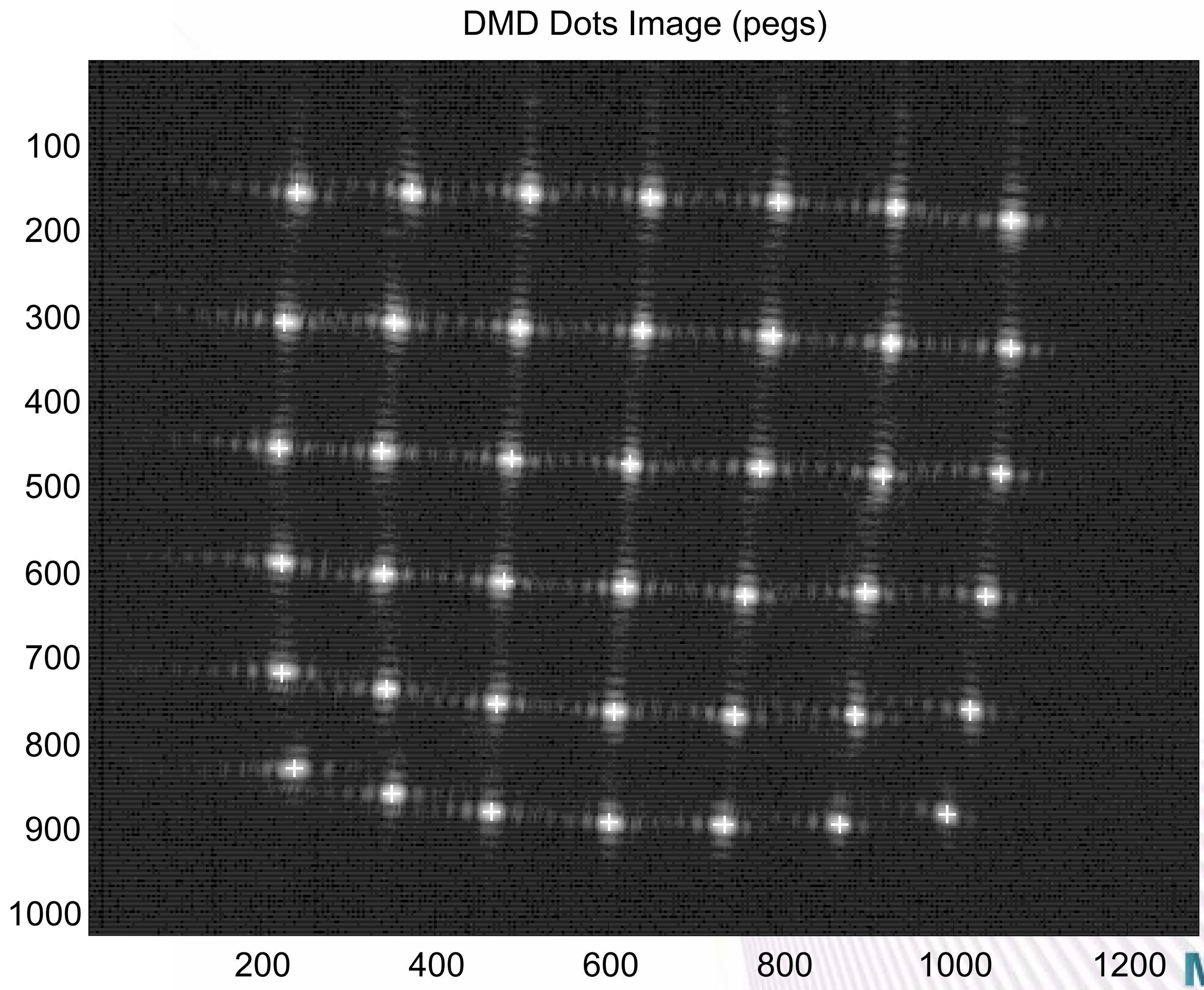


C



C'

CCD Image of Known DLP® Positions

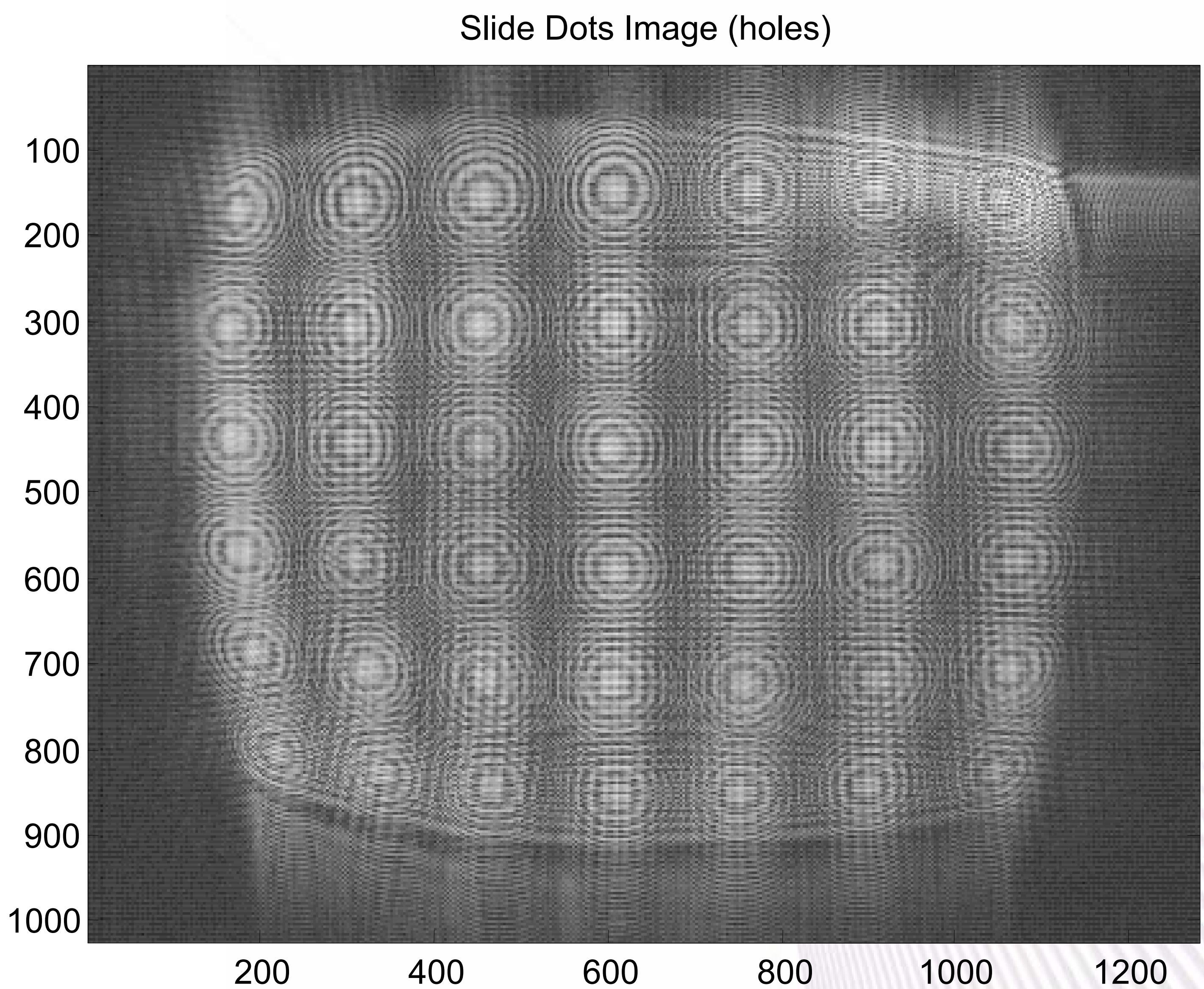


Automatically Finds Points via Projecting 42 Individual Pegs

$C = H \bullet D$

$H = C \bullet D^P$

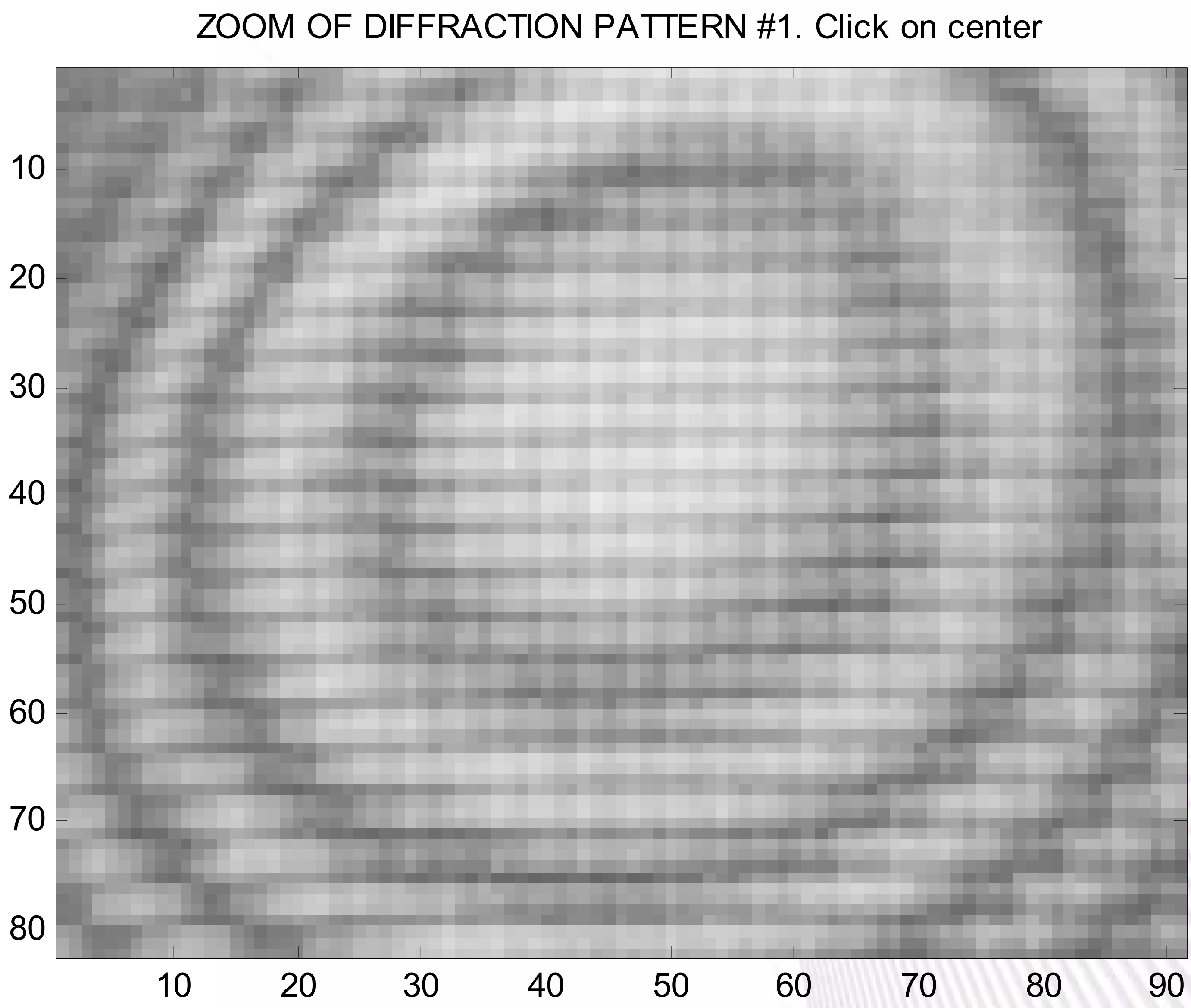
CCD Image of Holes in Slide Film



Manually Click on Interference to Zoom In

TI | Developer Conference

Mark the Center



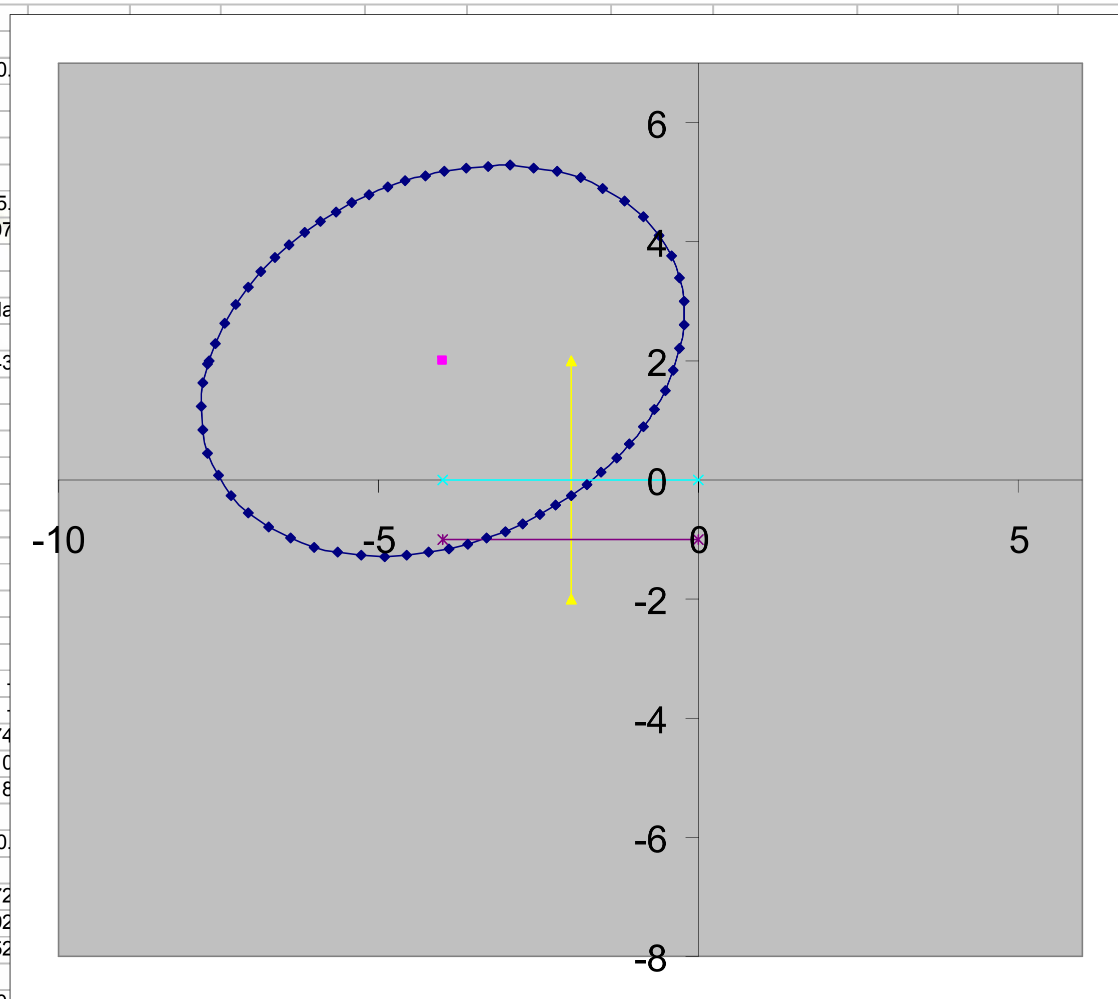
Minds in Motion

Options for Automatic Alignment

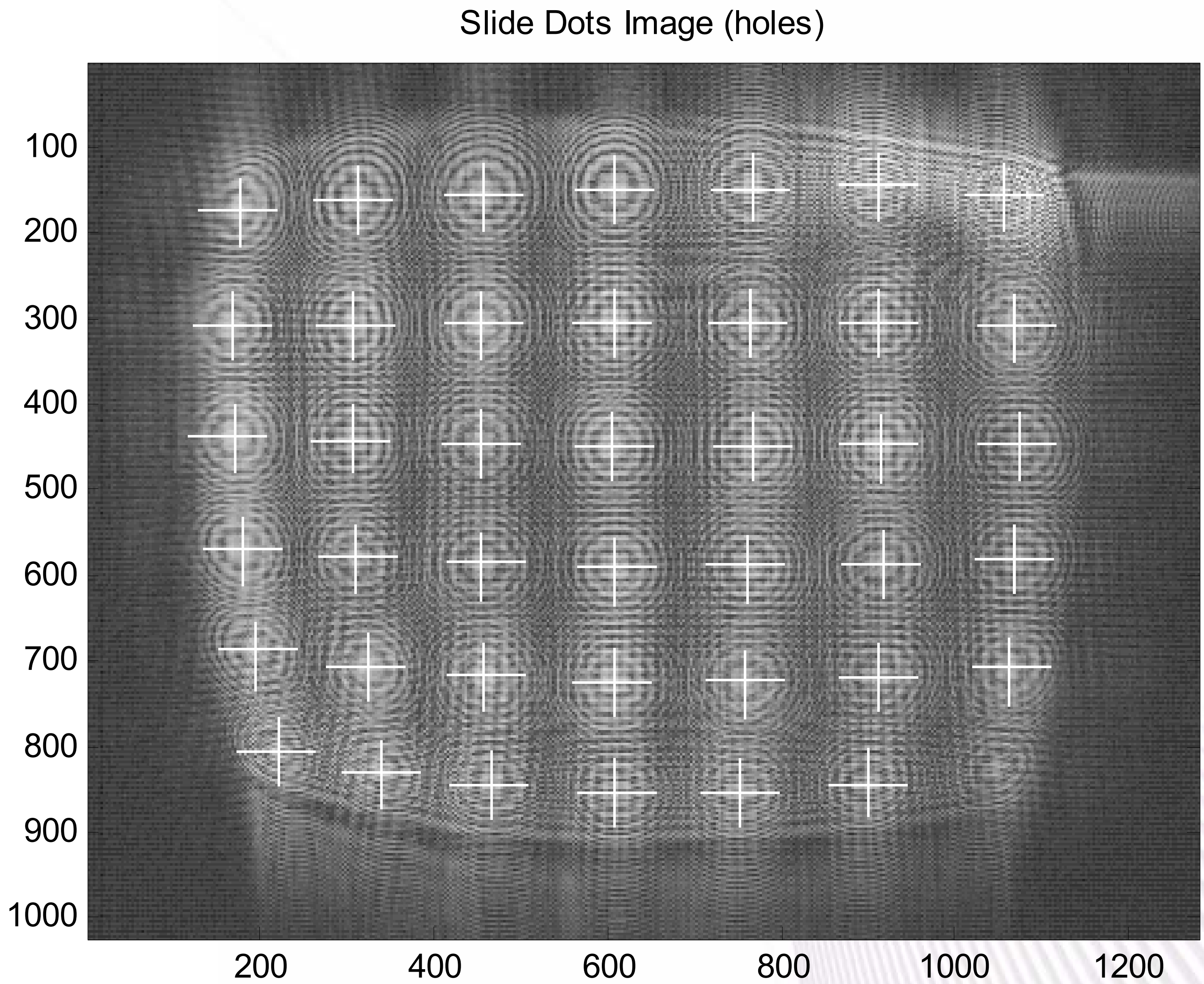
- Make holes larger so diffraction is reduced
  - A single large Peg might illuminate only one Hole at a time
  - Maximum intensity would mark Hole location
- Fit ellipse to 1st minimum— $Ax^2+Bxy+Cy^2+Dx+Ey+1 = 0$
  - Find its center— $x_c=(BE-2CD)/(4AC-B^2)$, $y_c=(BD-2AE)/(4AC-B^2)$ – Hole location

Ellipse Fitting

Changeable center and orientation parameters			
4	3	theta	
-4	2	0.523598767	0.
x	4	-4	
y	0	0	
x'	-0.535898367	-7.464101633	-5.
y'	3.999999969	3.09401E-08	4.59807
General Equation resulting from rotating and transla			
A	B	C	D
10.75	-6.062177764	14.25000005	98.1243
	0	0	
Recovered center and orientation parameters			
h	k	theta	
-4	2	0.523598767	
Gaussian Elimination Below			
4	-10.24293658	26.22943744	-
4	0.541272651	0.073244021	-
2.76805	0	0	-1.66374
55.7128	0	0	-7.46410
11.3514	3.369186883	1	-3.36918
1	-2.560734145	6.557359359	-0.
0	10.78420923	-26.15619342	
0	7.088237103	-18.15109078	-0.27972
0	142.6657023	-365.3289352	20.392
0	32.43715631	-73.43534183	2.30652
1	0	0.34651384	-0.



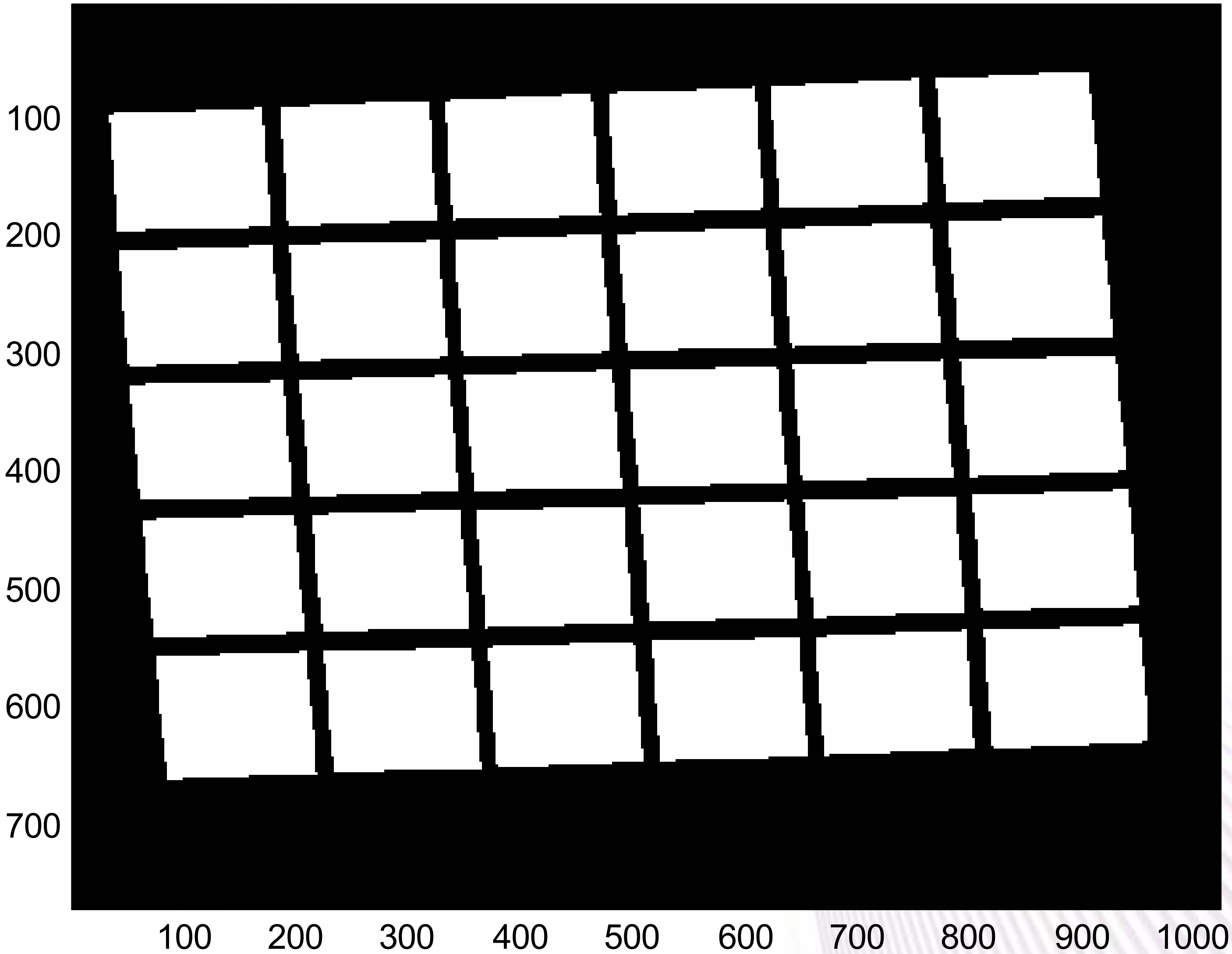
Eighty-four Clicks Later



C' = M • C

M = C' • C^P

DLP® Projected Regions of Interest

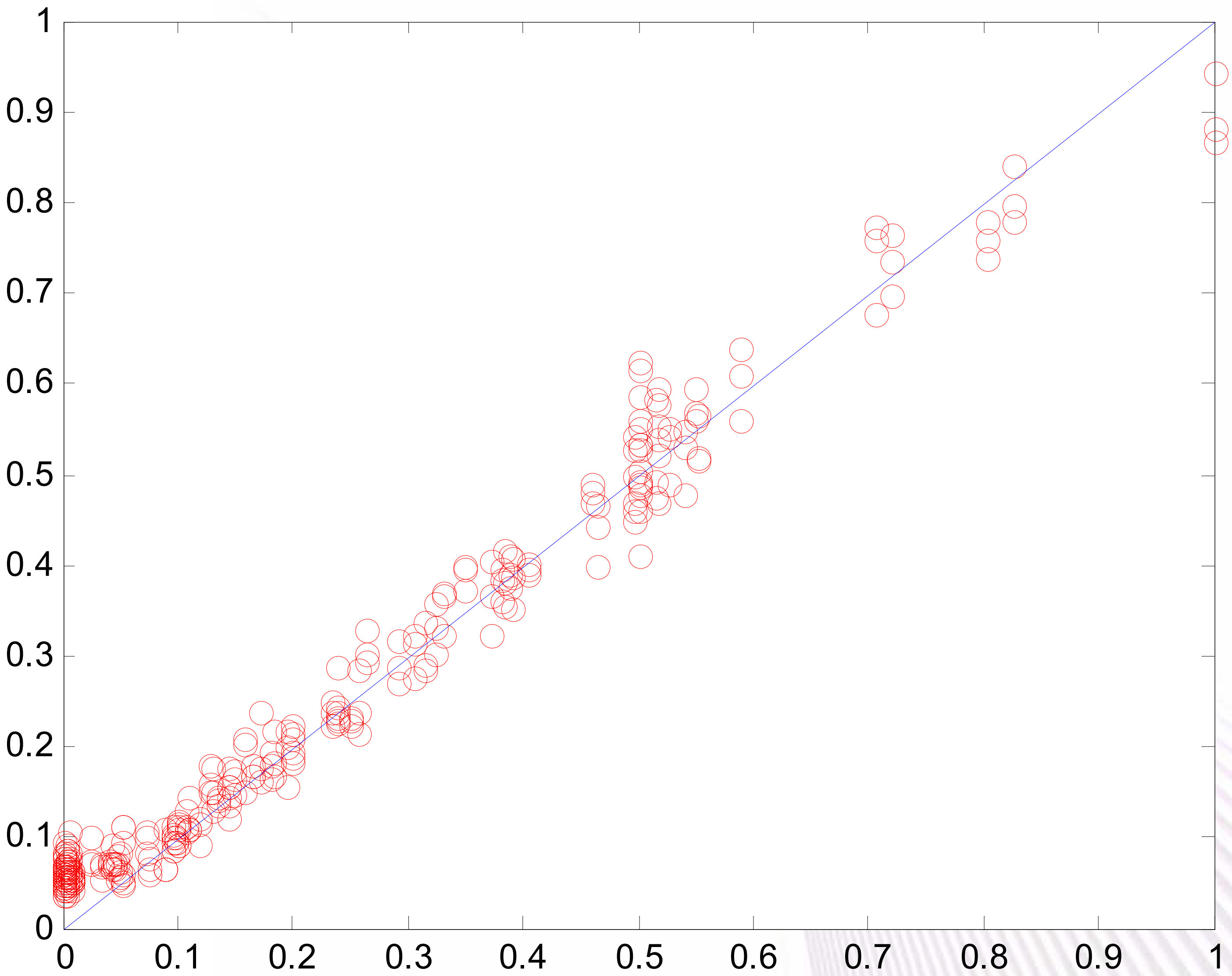


$$D' = H^{-1} \bullet M^{-1} \bullet H \bullet D$$

and

$$C' = H \bullet D'$$

Nonlinearities



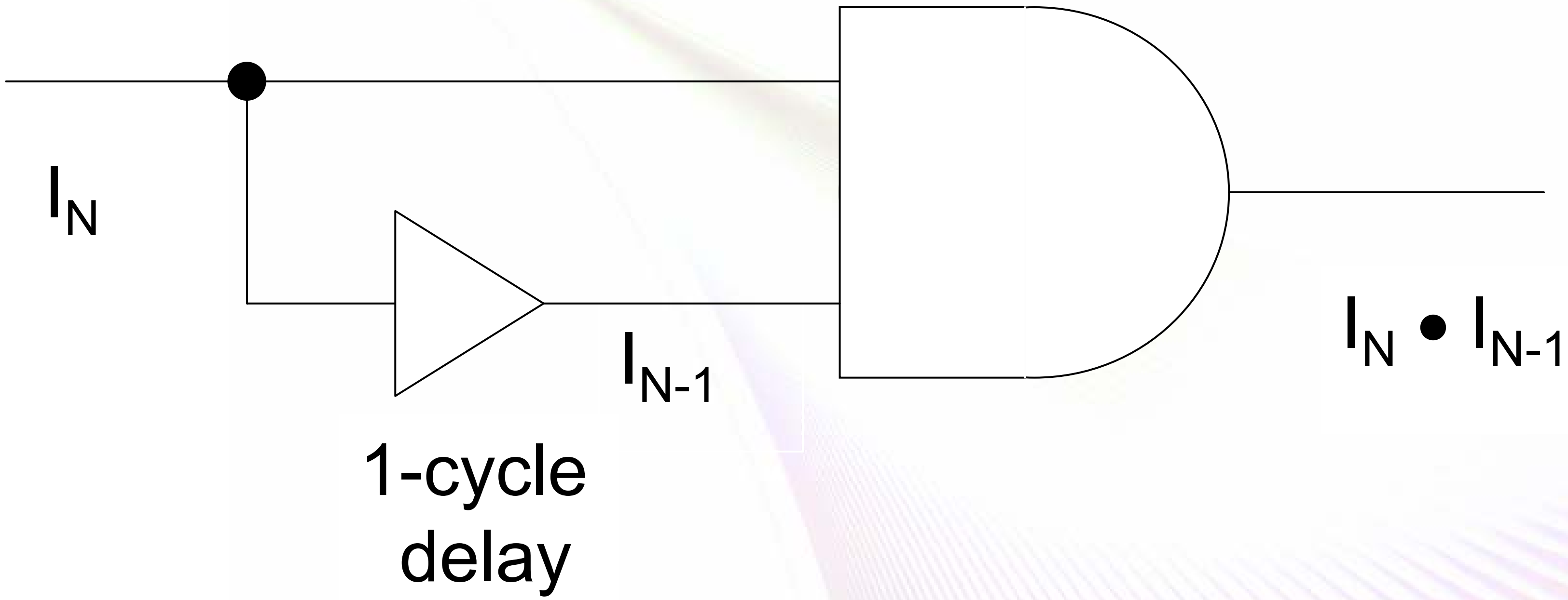
Measured light signals vs. Weights for FWL Recurron

Opaque slides aren't, ~6% leakage.

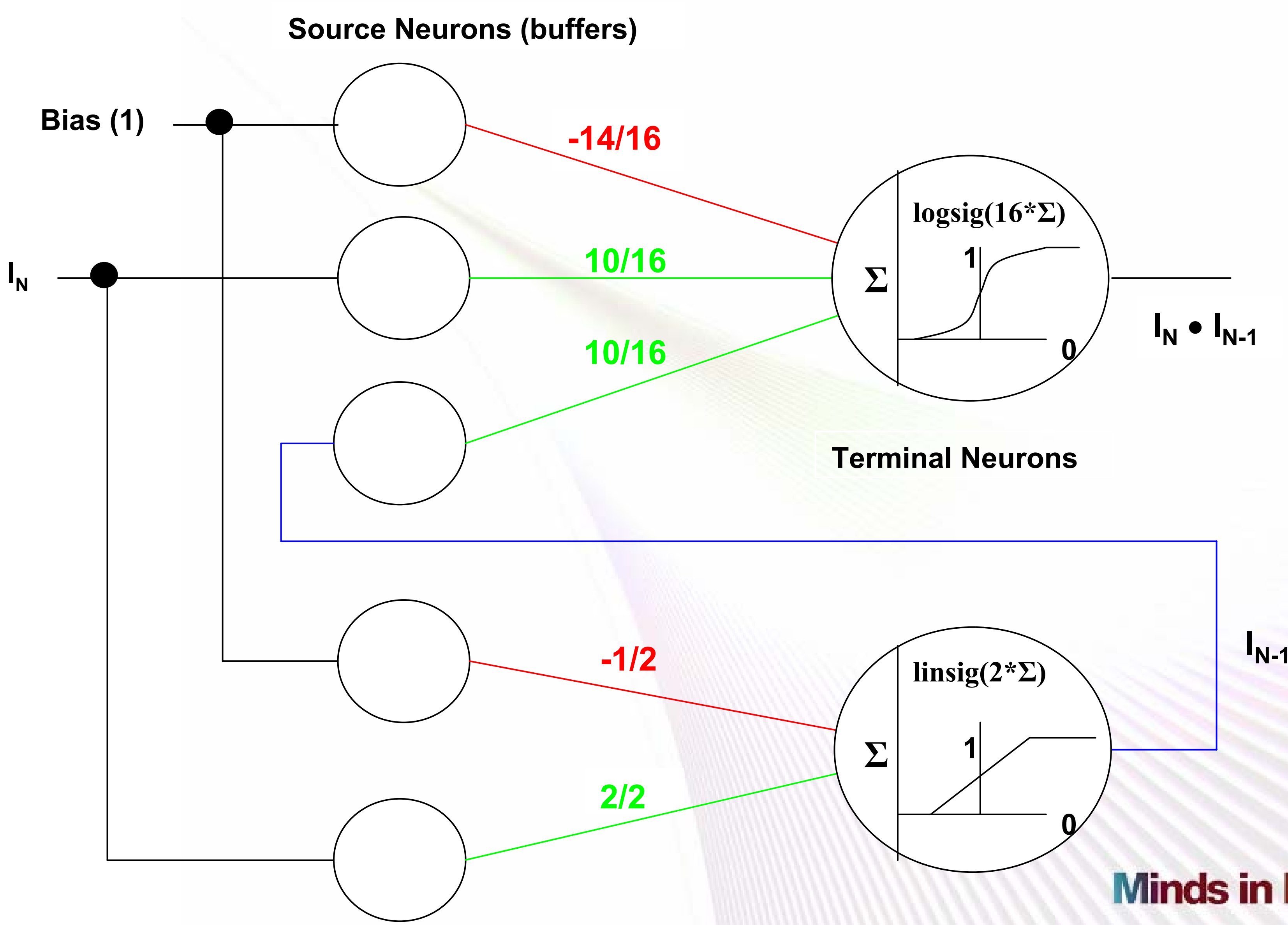
Neural Networks and Results

- Recurrent AND
- Unsigned Multiply
- Fixed Weight Learning Recurron

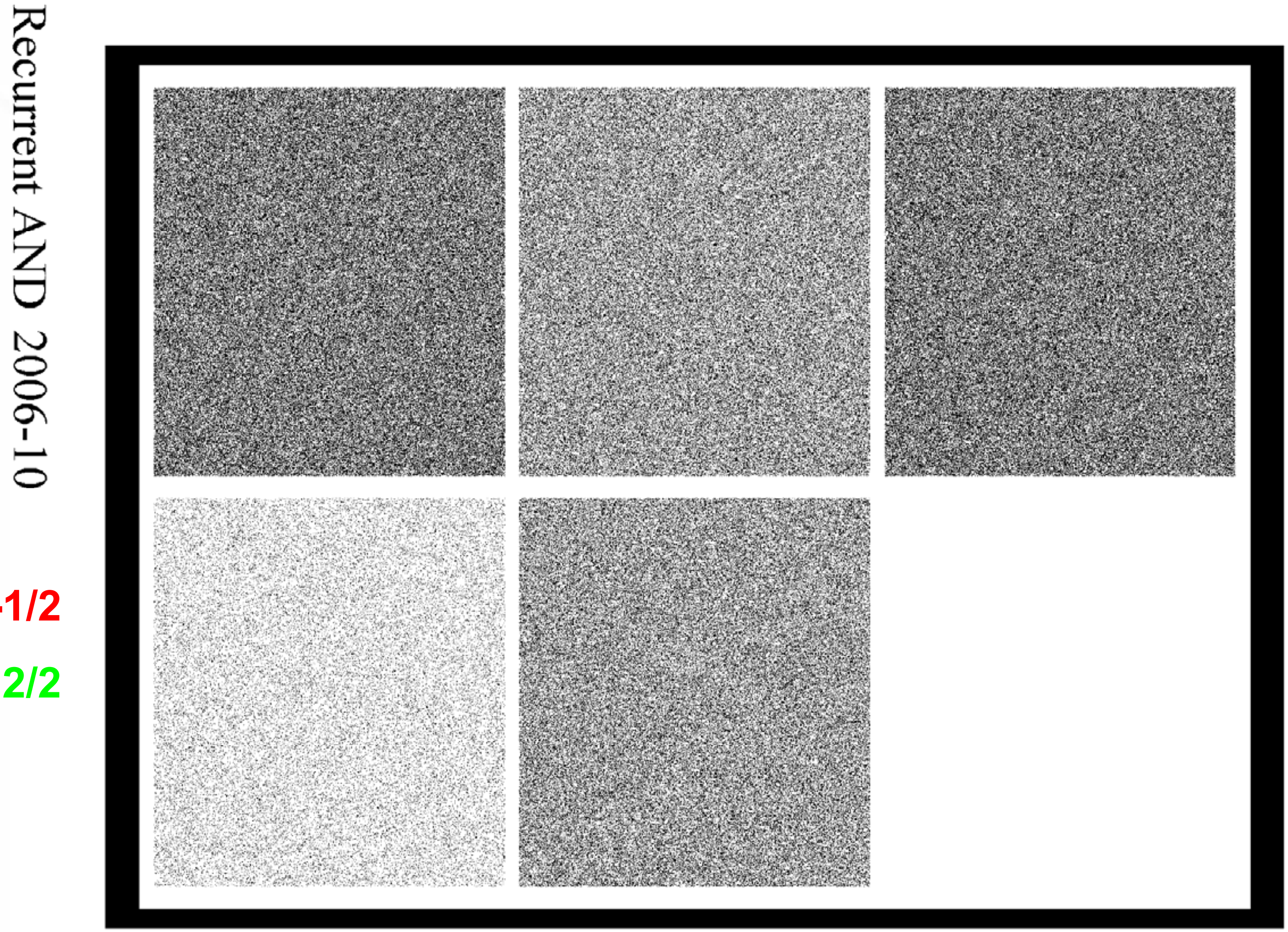
Recurrent AND



Recurrent AND Neural Network



Synaptic Weight Slide



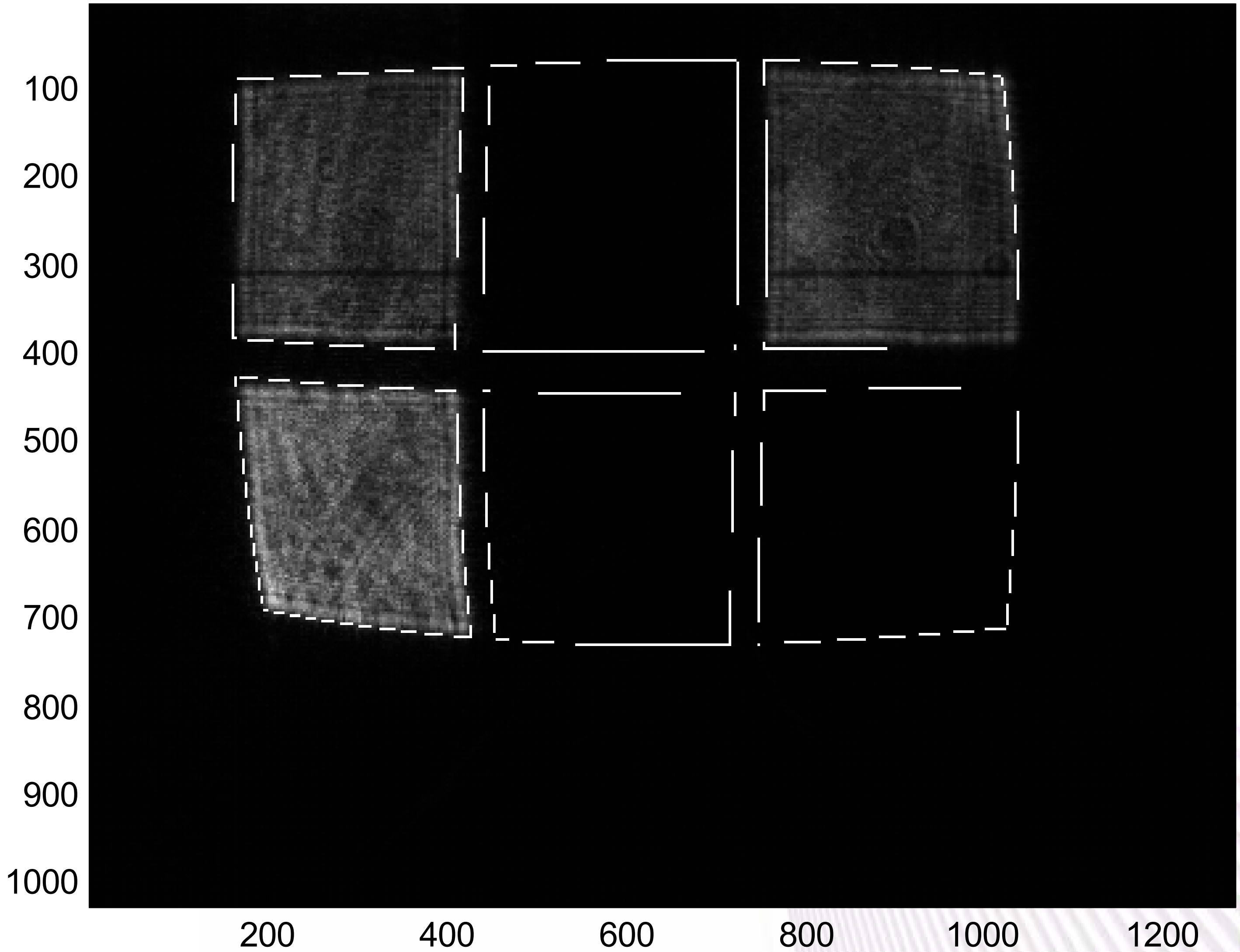
Weights

0.5	10/16	-1/2
-14/16	10/16	2/2

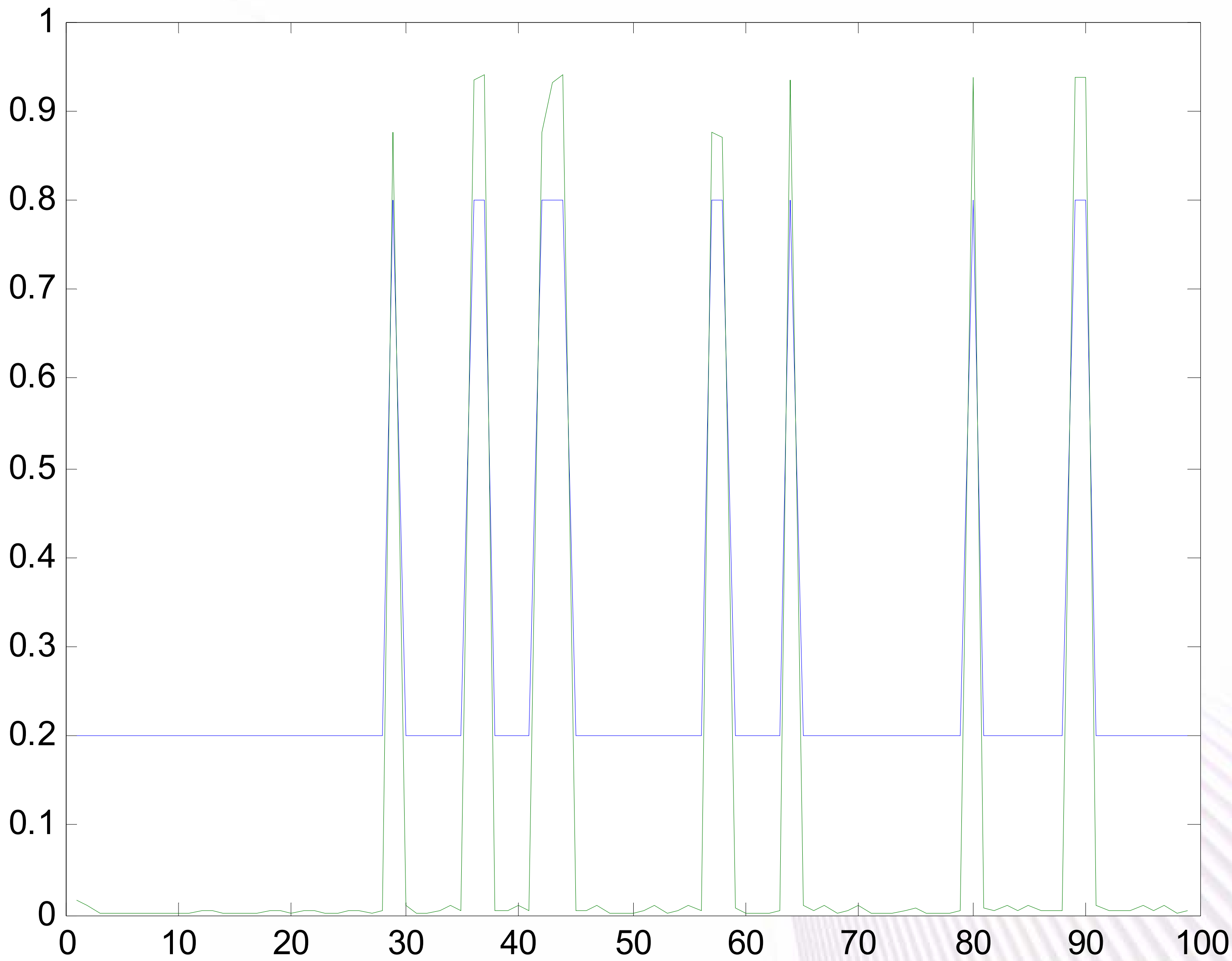
Recurrent AND Demo

- MATLAB

Pulse Image (Regions of Interest)

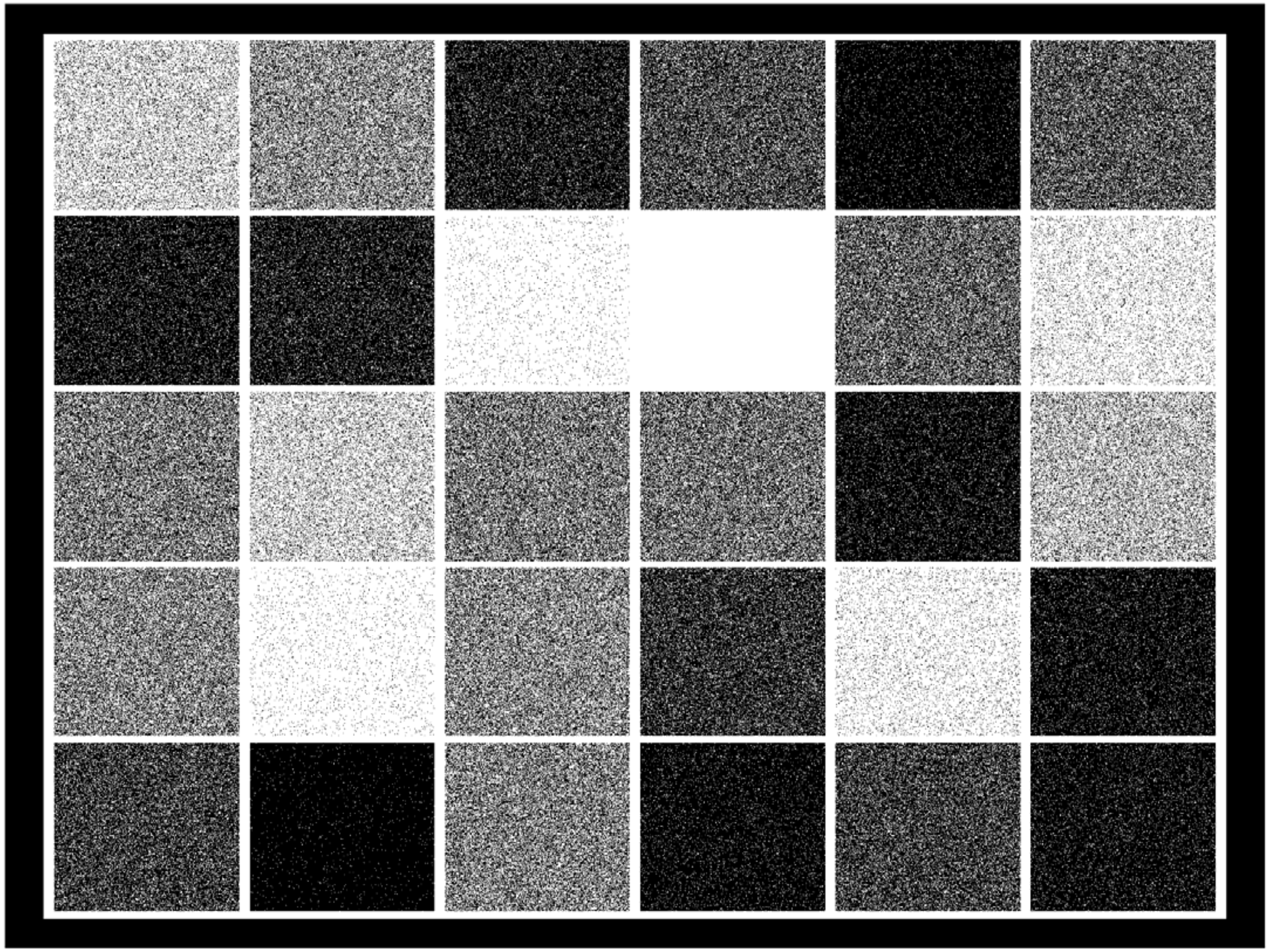


Output Swings Larger than Input

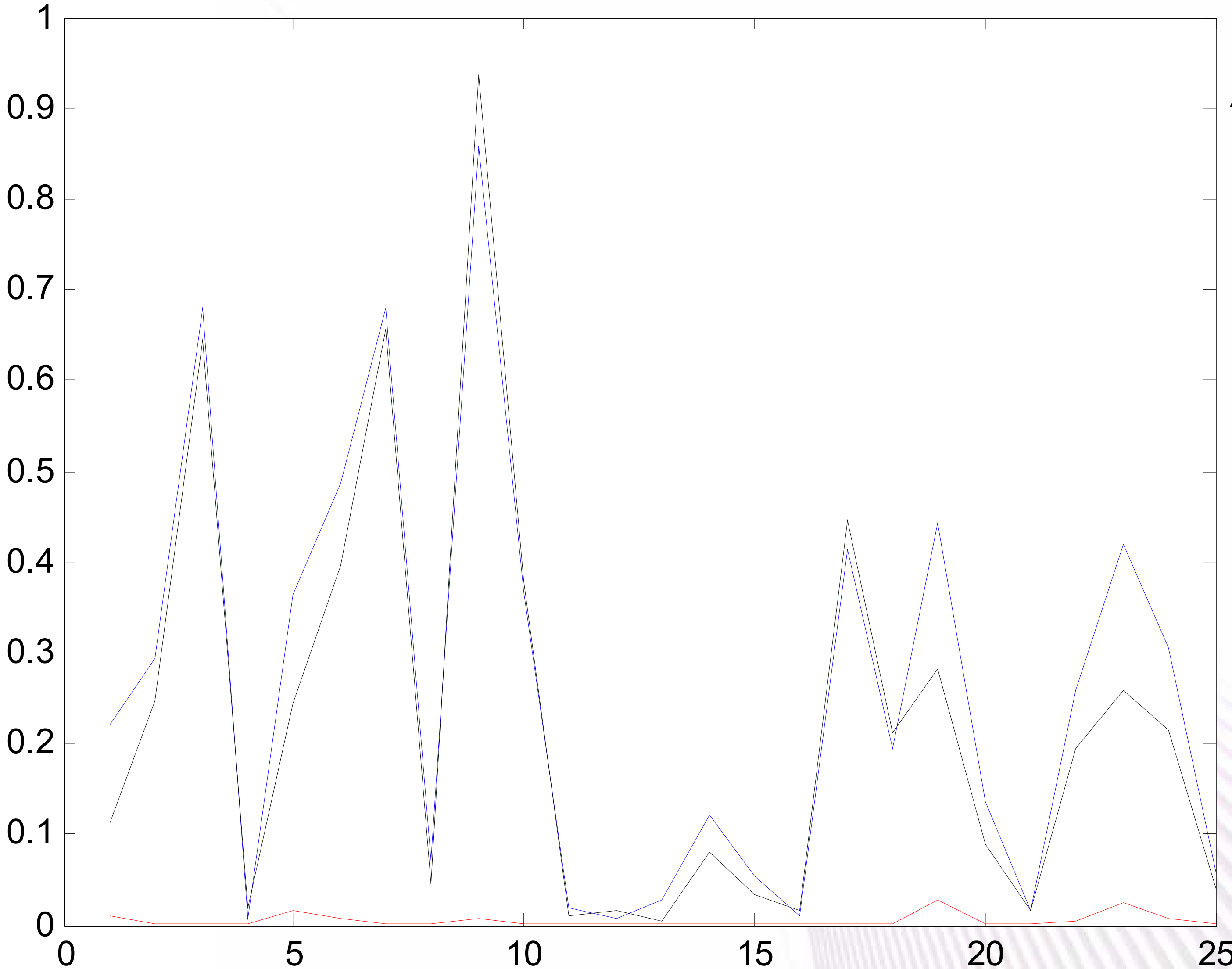


Synaptic Weight Slide

Unsigned Multiply 2006-10



Unsigned Multiply Results



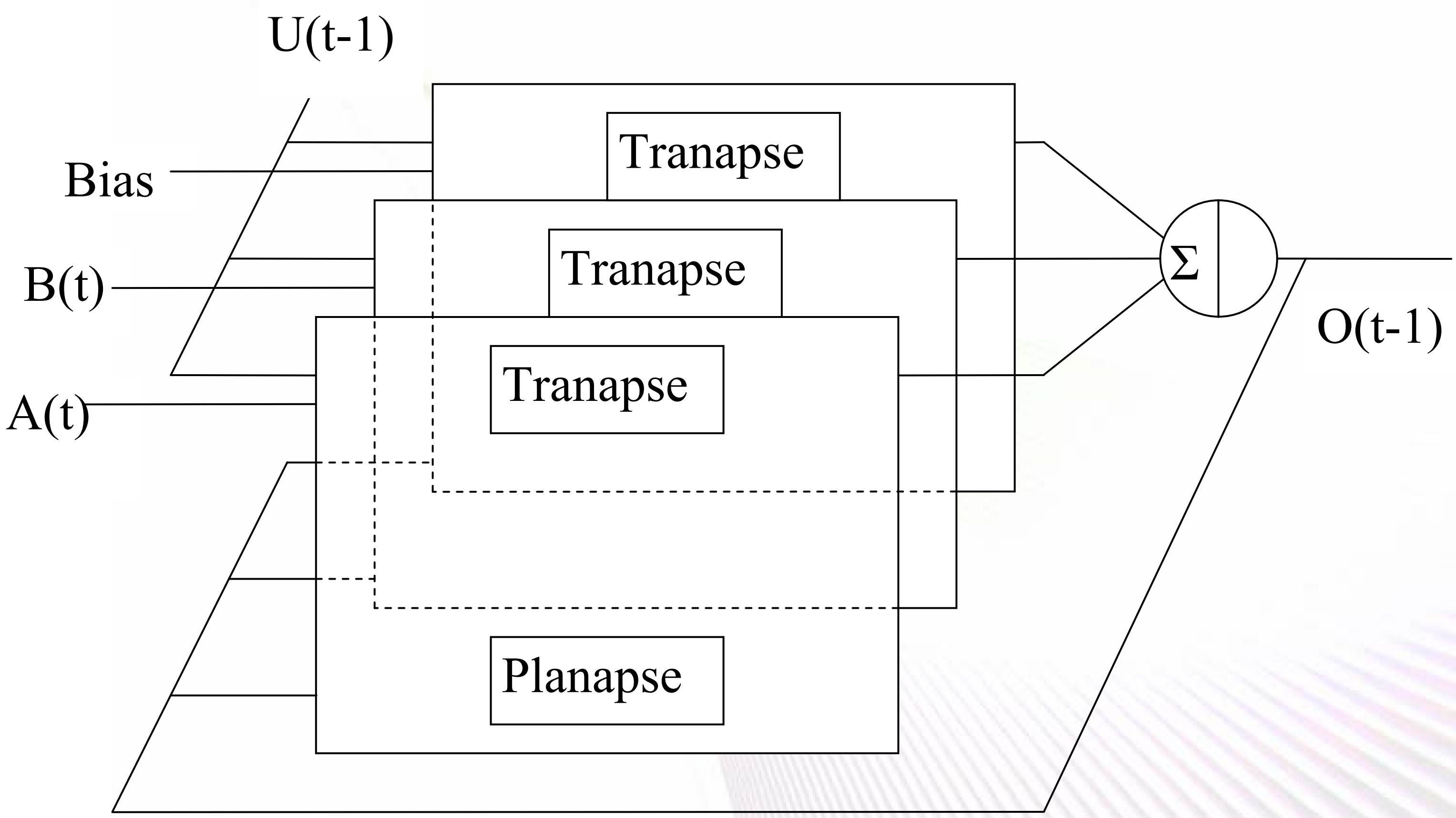
About 4 bits

Blue-expected

Black-obtained

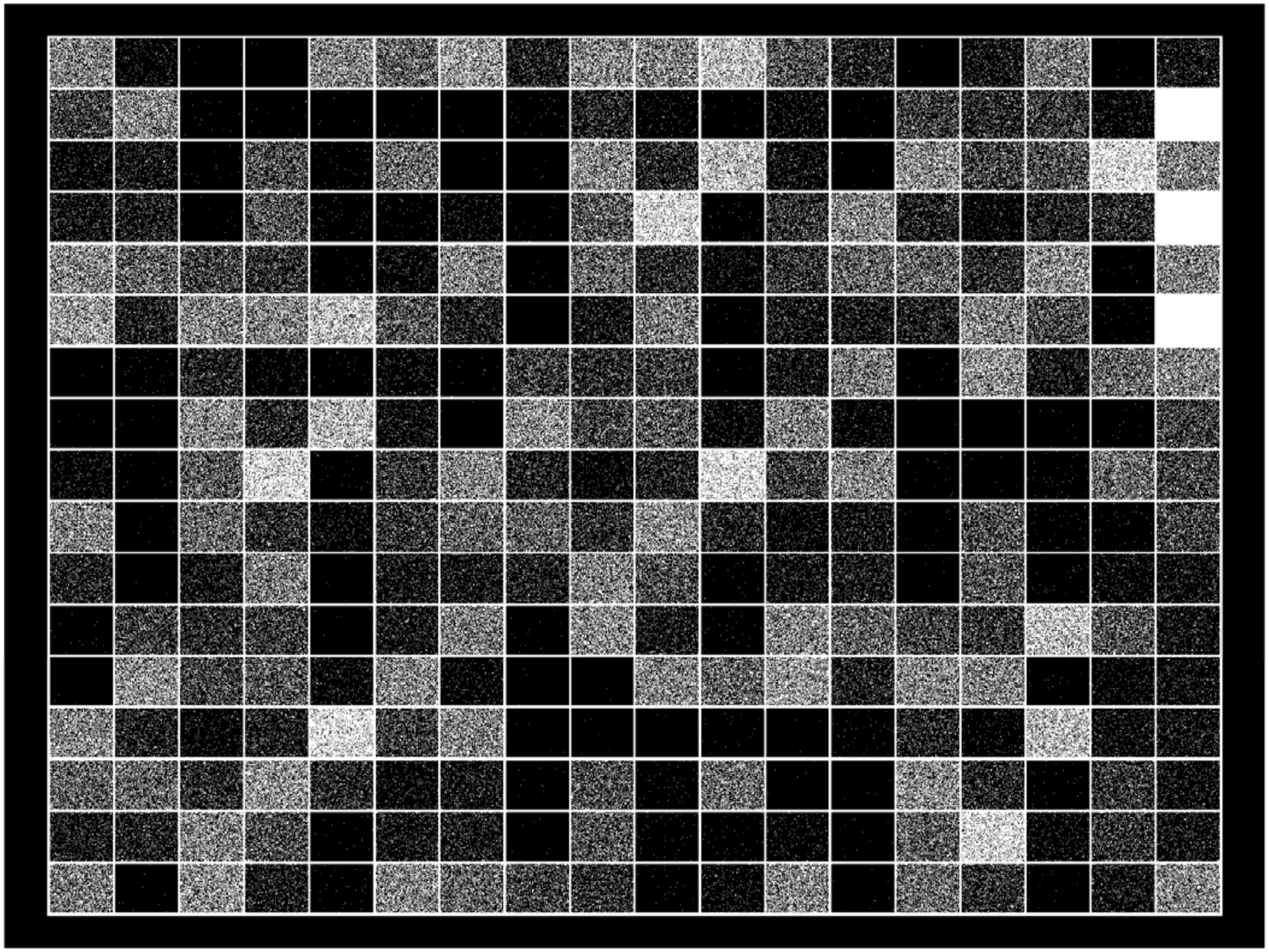
Red-squared error

Page Representation of a Recurron

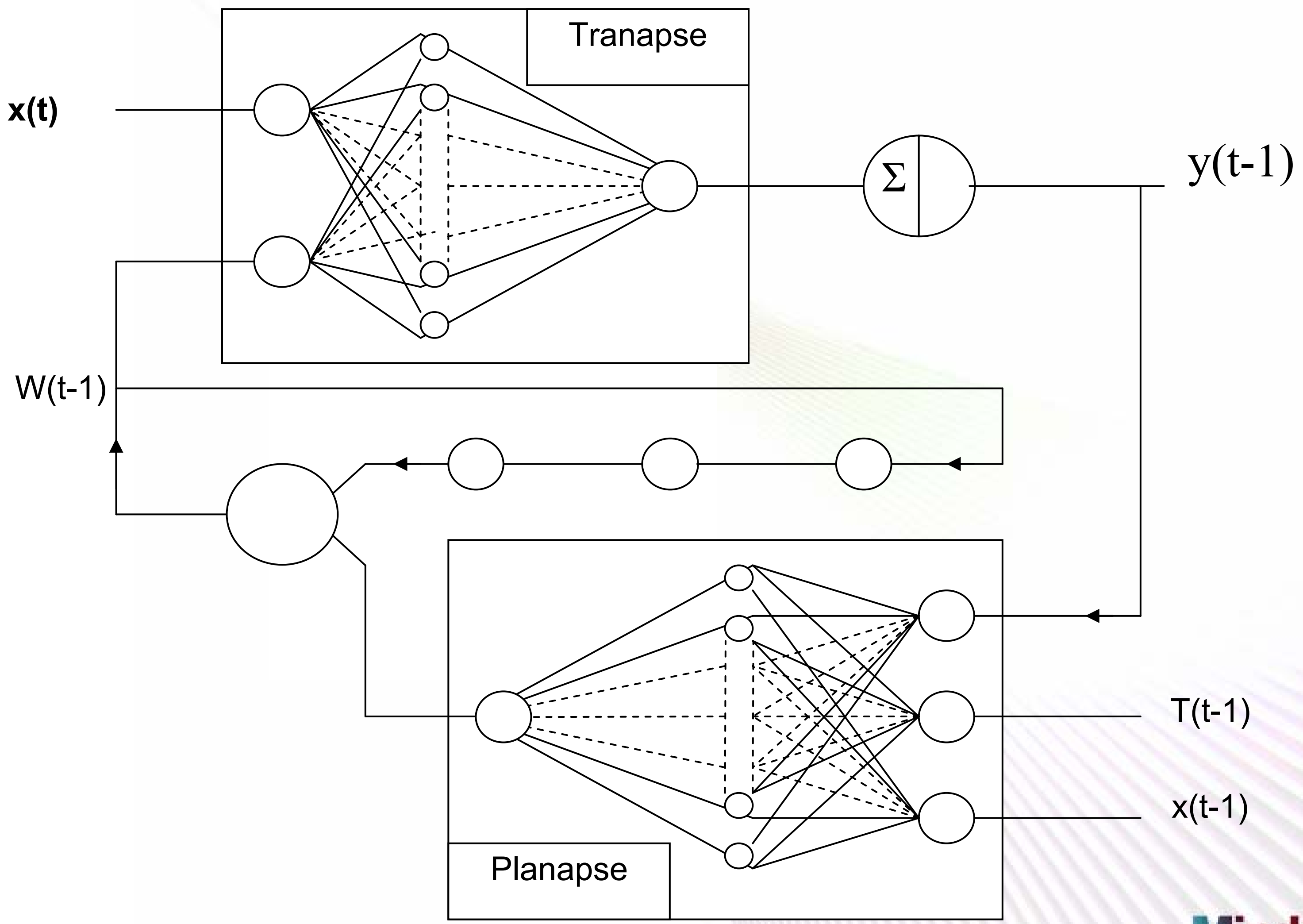


FWL Recurron Synaptic Weight Slide

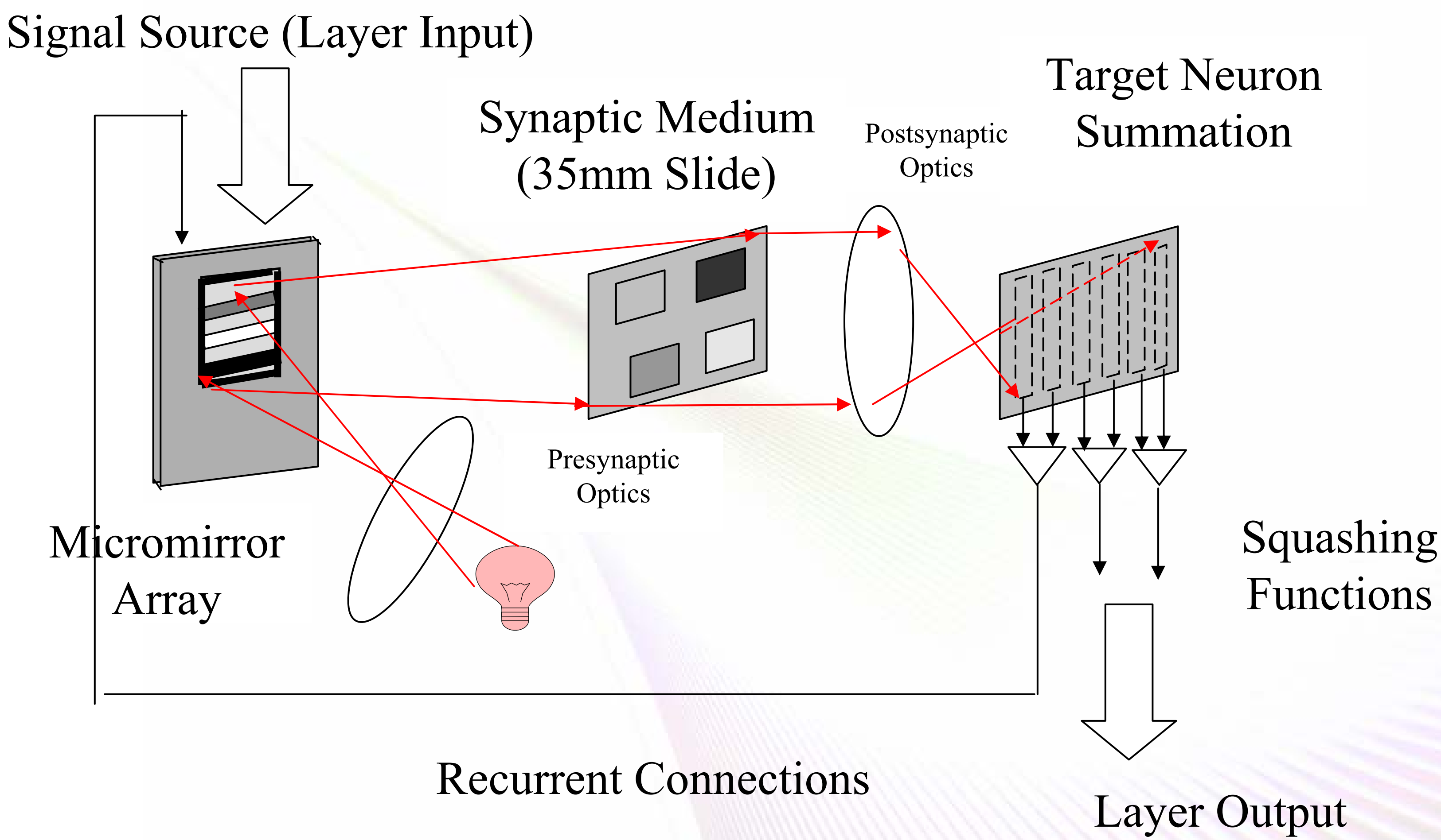
Recurron 2006-10



Optical Fixed-Weight Learning Synapse



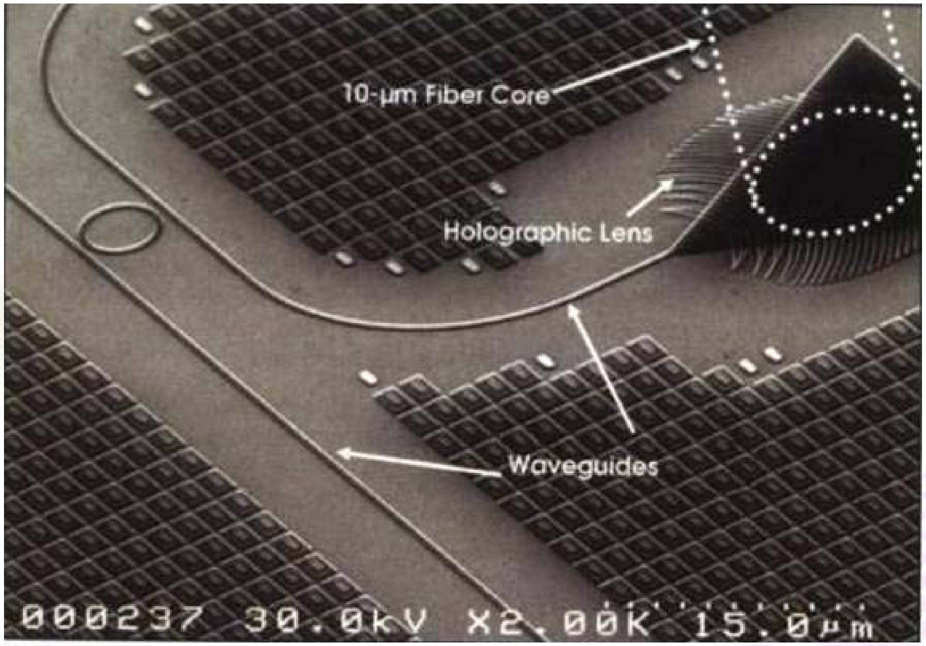
Optical Recurrent Neural Network



A Single Layer of an Optical Recurrent Neural Network. Only four synapses are shown. Actual networks will have a large number of synapses. A multi-layer network has several consecutive layers.

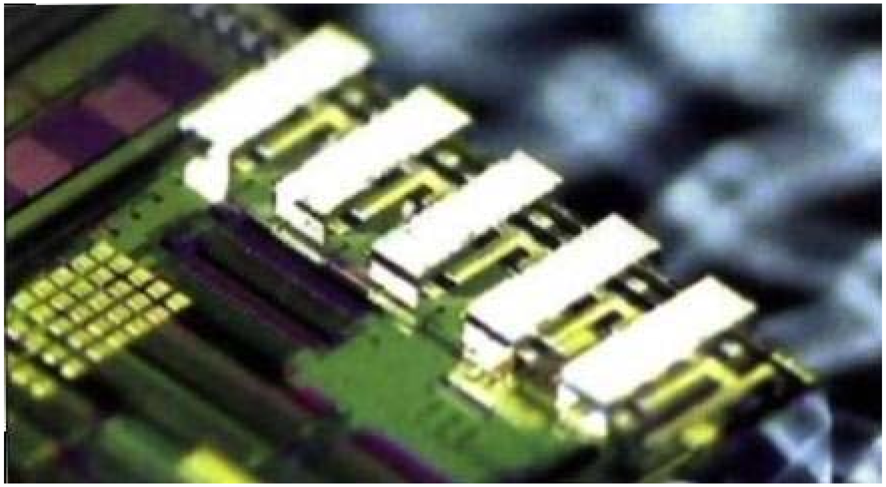
Future: Integrated Photonics

- Photonic (analog)
- i. Concept
- α. Neuron
- β. Weights
- γ. Synapses



Photonics Spectra and Luxtera

Continued



Photonics Spectra and Luxtera

- ii. Needs
- α. Laser
- β. Amplifier (detectors and control)
- γ. Splitters
- δ. Waveguides on Two Layers
- ε. Attenuators
- ζ. Combiners
- η. Constructive Interference
- θ. Destructive Interference
- ι. Phase

Interest Generated?

- We wish to implement Optical Neural Networks in Silicon—Including Fixed Weight Learning.
- To do so, we need Collaborators.
- Much research remains, but an earlier start means an earlier finish.
- Please contact me if interested.

TI | Developer Conference
March 7-9, 2007 • Dallas, TX

DLP®-Driven, Optical Neural Network Results and Future Design

Emmett Redd & A. Steven Younger
Missouri State University
EmmettRedd@MissouriState.edu

Minds in Motion

Technology for Innovators™ Texas Instruments

Source Pulse