

Exercises

<https://github.com/ericpostma/ep>

VIVAT1.pdf

VIVAT2.pdf

VIVAT3.pdf

eric.postma@gmail.com

The rise of AI

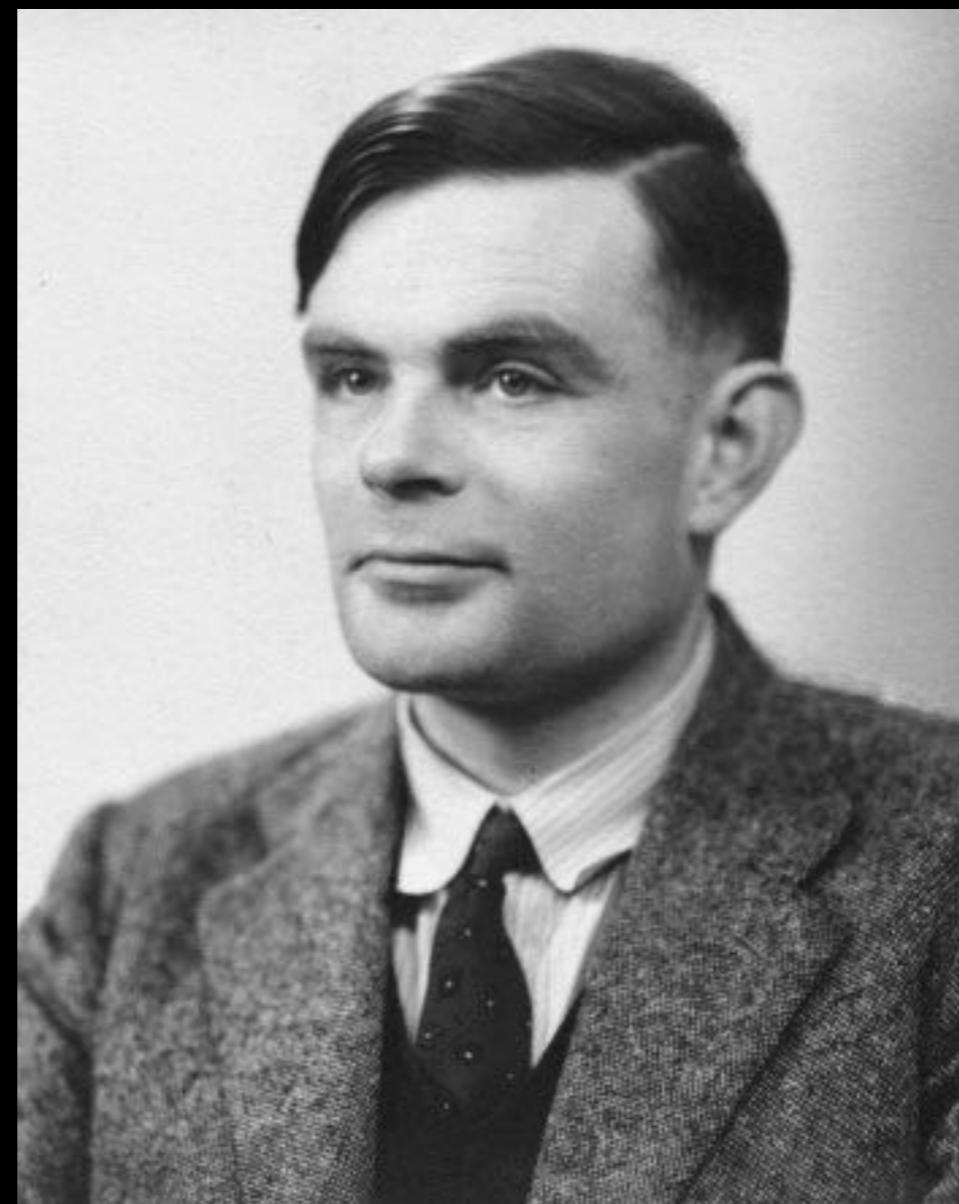
Eric Postma
CS&AI
Tilburg University

Cognitive Science & AI

- Department at Tilburg School of Humanities
- Responsible for Cognitive Science & AI program
- Research focusses on computational methods for text analysis, signal analysis, image analysis, and so forth



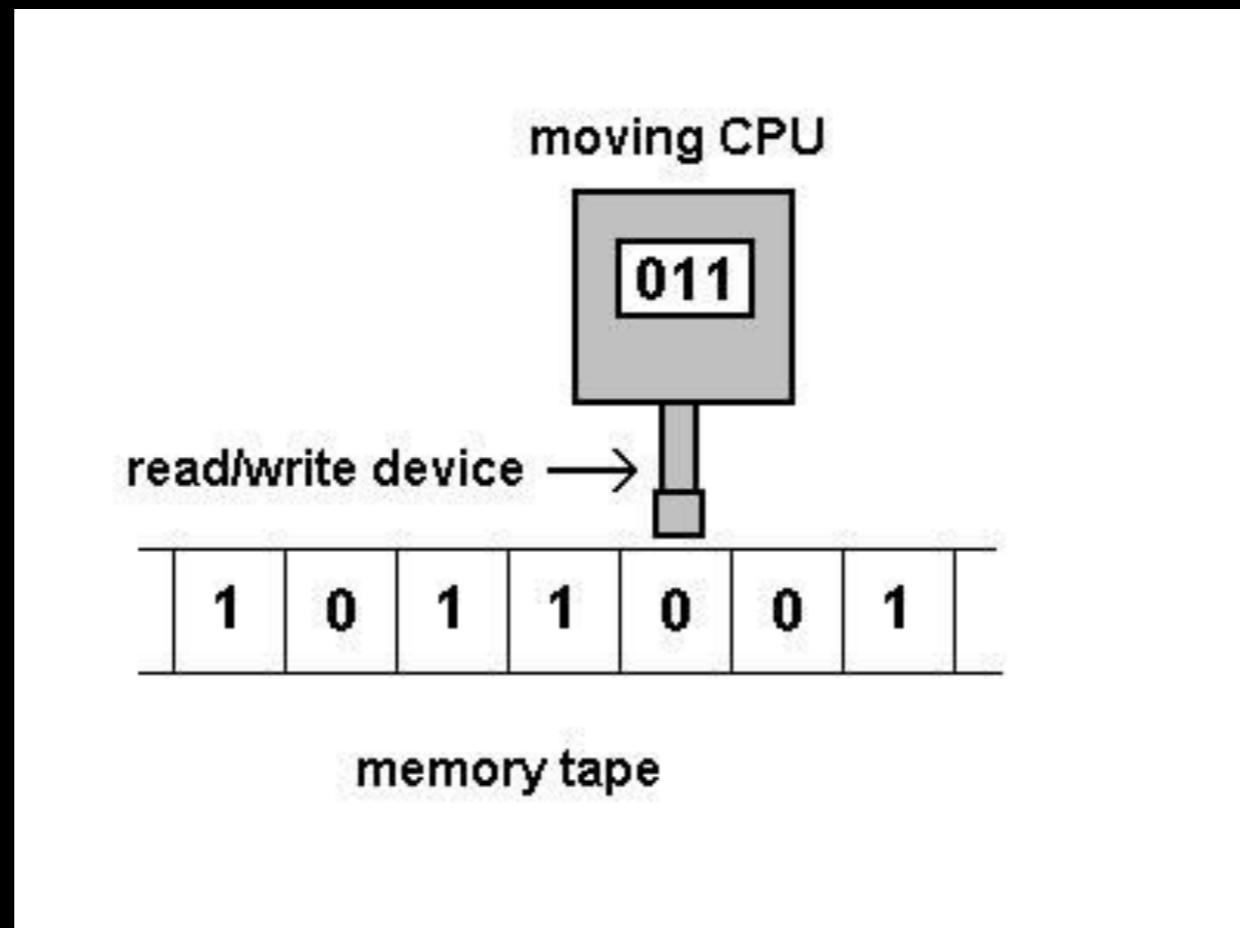
A brief history of Artificial Intelligence



Alan Turing



Turing Machine Imitation Game

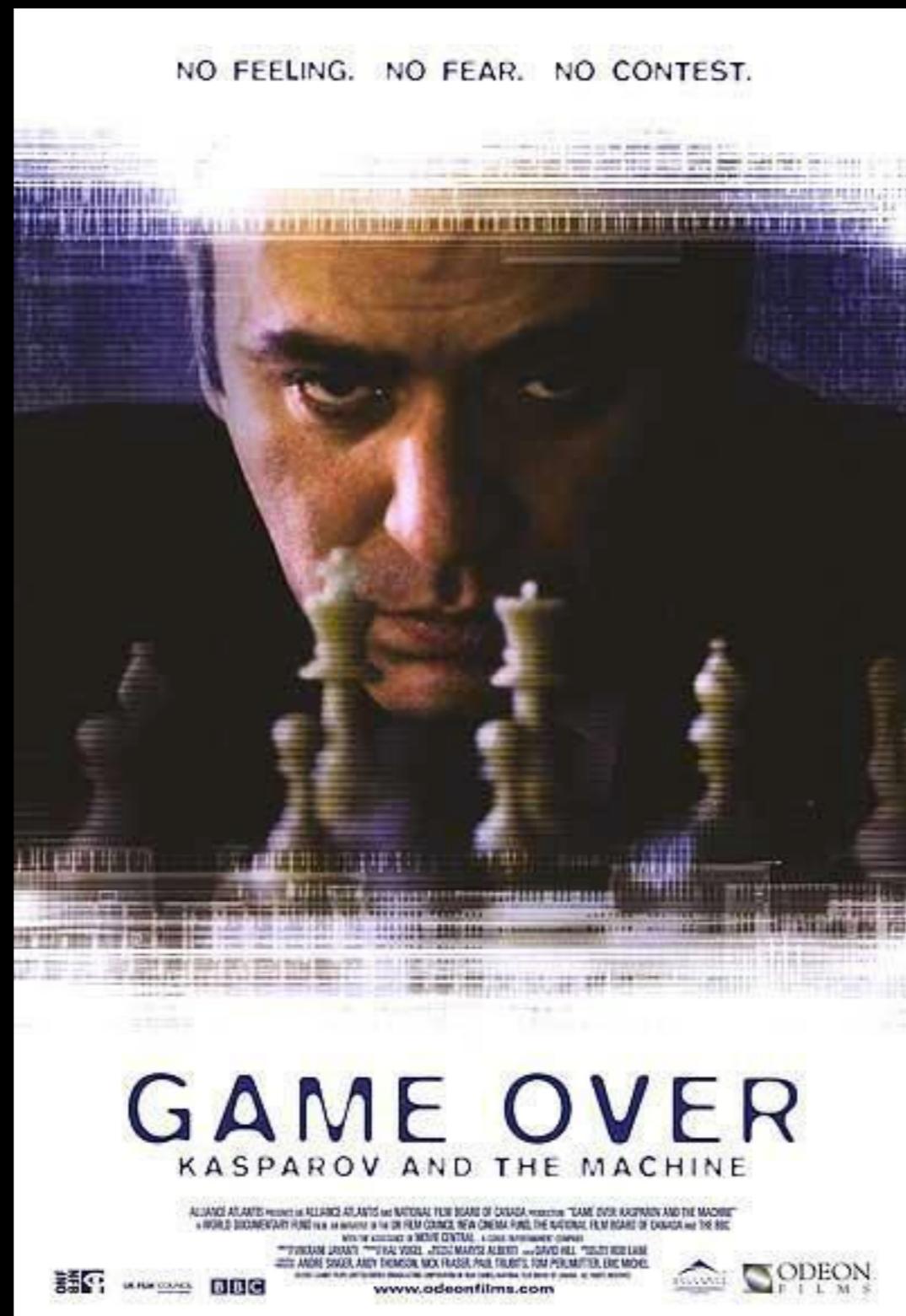


Symbolic AI (1957-2000)

- Emphasis on formal logic and symbolic representations
- Neuroscience is irrelevant
- Focus on high-level cognition (reasoning, problem-solving, ...)



Deep Blue (1997)



The “new AI”

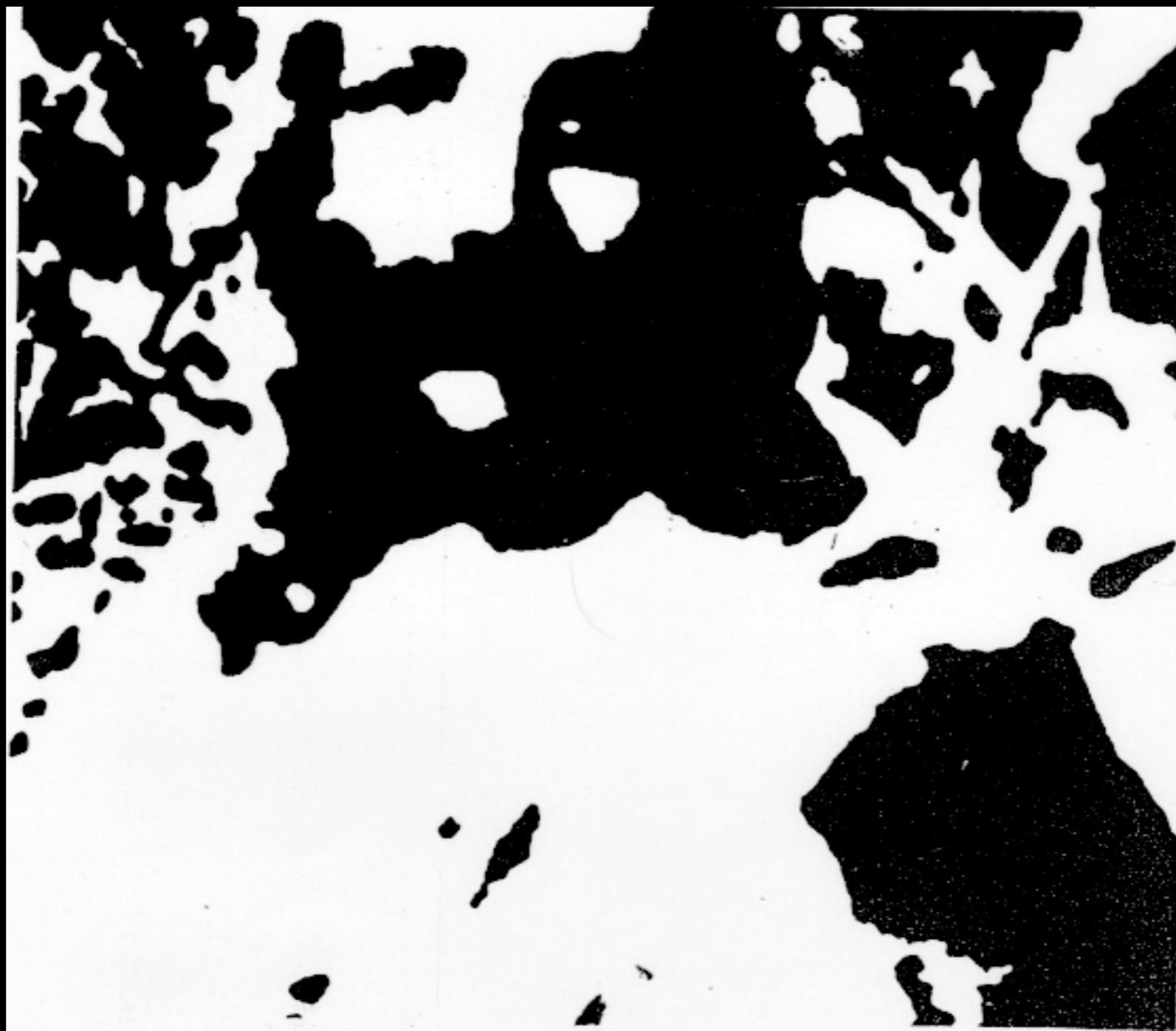


The Sojourner Rover (1997)

“Sub-symbolic” AI (1988-2016)

- Emphasis on machine learning (neural networks)
- Neuroscience is relevant
- Emphasis on low-level cognition
(e.g., perception)

Recognising Patterns



How to recognise Popov?



Deep learning algorithm does as well as dermatologists in identifying skin cancer

Date: January 25, 2017

Source: Stanford University

Summary: In hopes of creating better access to medical care, researchers have trained an algorithm to diagnose skin cancer.

Share:



RELATED TOPICS

Health & Medicine

- > [Skin Care](#)
- > [Skin Cancer](#)
- > [Psoriasis](#)

Computers & Math

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- > [Artificial Intelligence](#)

FULL STORY



A dermatologist using a dermatoscope, a type of handheld microscope, to look at skin. Computer scientists at Stanford have created an artificially intelligent diagnosis algorithm for skin cancer that matched the performance of board-certified

RELATED TERMS

- > [Stem cell treatments](#)

Fears for AI



ELON MUSK'S BILLION-DOLLAR CRUSADE TO STOP THE A.I. APOCALYPSE

Stephen Hawking warns artificial intelligence could end mankind



Deep Learning

Literature

- <http://www.deeplearningbook.org/>
- arXiv server (<https://arxiv.org/>)



arXiv:1509.09308v2 [cs.NE] 10 Nov 2015

Fast Algorithms for Convolutional Neural Networks

Andrew Lavin
alevin@eecs.berkeley.edu

Scott Gray
Nervana Systems
sggray@nervanasys.com

Abstract

Deep convolutional neural networks take GPU days of compute time to train on large data sets. Pedestrian detection for self driving cars requires very low latency. Image recognition for mobile phones is constrained by limited processing resources. The success of convolutional neural networks in these situations is limited by how fast we can compute them. Conventional FFT based convolution is fast for large filters, but state of the art convolutional neural networks use small, 3×3 filters. We introduce a new class of fast algorithms for convolutional neural networks using Winograd's minimal filtering algorithms. The algorithms compute minimal complexity convolution over small tiles, which scales them fast with small filters and small batch sizes. We benchmark a GPU implementation of our algorithm with the VGG network and show state of the art throughput at batch sizes from 1 to 64.

1. Introduction

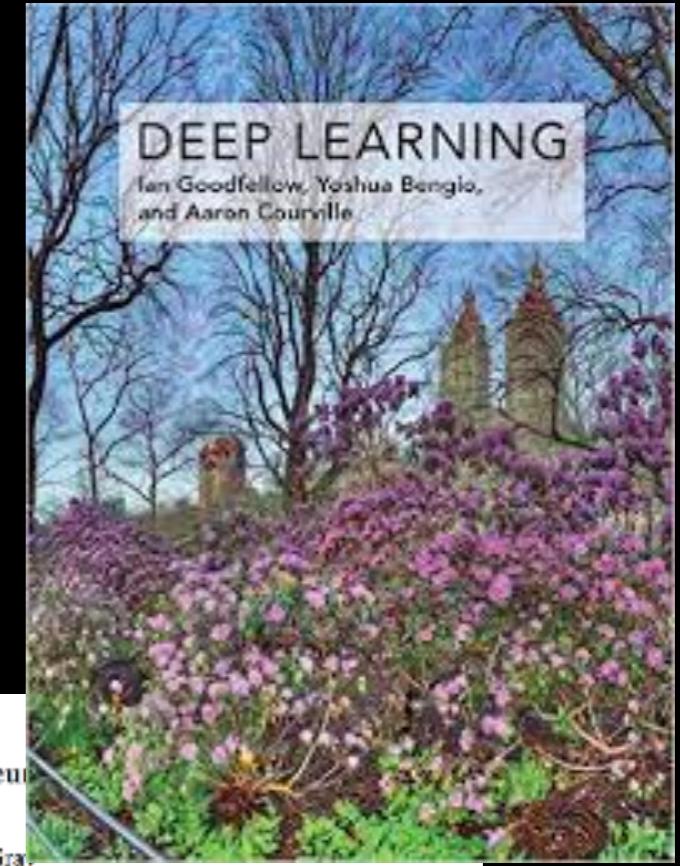
Deep convolutional neural networks (convnets) achieve state of the art results on image recognition problems [11][7]. The networks take several days of GPU time to train and require significant compute resources during classification as well. Larger data sets and models lead to better accuracy but also increase computation time. Therefore progress in deep neural networks is limited by how fast

cause they achieve better accuracy with fewer weights than shallow networks with larger filters [11, 7]. Therefore there is a strong need for fast convnet algorithms for small batch sizes and small filters. However conventional convnet libraries require large batch sizes and large filters for fast operation.

This paper introduces a new class of fast algorithms for convolutional neural networks based on the minimal filtering algorithms pioneered by Winograd [13]. The algorithms can reduce the arithmetic complexity of a convnet layer by up to a factor of 4 compared to direct convolution. Almost all of the arithmetic is performed by dense matrix multiplies of sufficient dimensions to be computed efficiently, even when the batch size is very small. The memory requirements are also light compared to the conventional FFT convolution algorithm. These factors make practical implementations possible. Our implementation for NVIDIA Maxwell GPUs achieves state of the art throughput for all batch sizes measured, from 1 to 64, while using at most 16MB of workspace memory.

2. Related Work

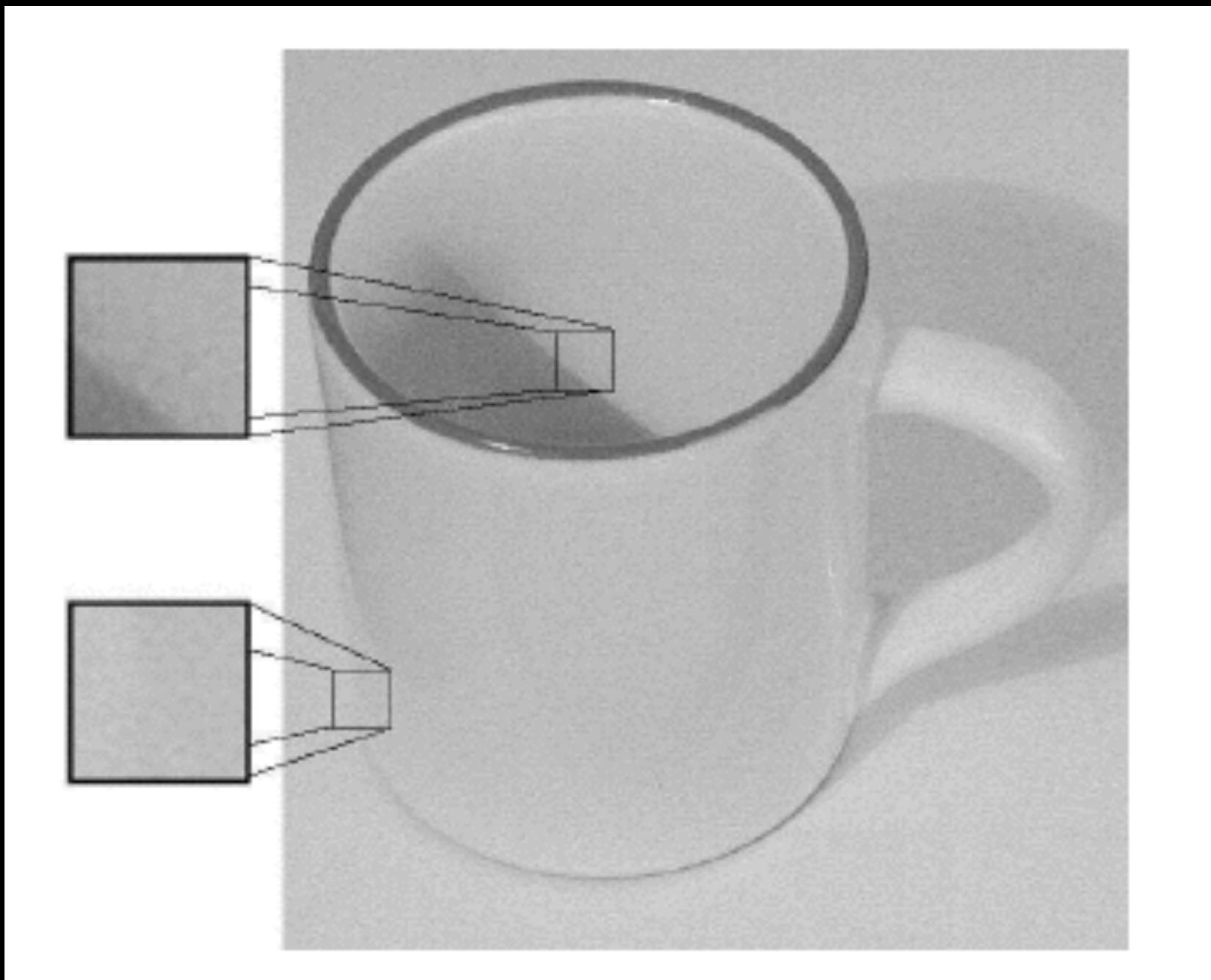
The FFT and convolution theorem have been used to reduce the arithmetic complexity of convnet layers, first by Mathieu *et al.* [10], then refined by Visalache *et al.* [12], and then implemented in the NVIDIA cuDNN library [1].



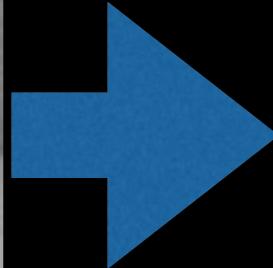
Today

- Deep Learning essentials
- Acquiring intuition about convolutional neural networks
- Exploring deep neural networks
- Exploring convolution
- Exploring convolutional neural networks

Local Processing (visual “features”)



Filters

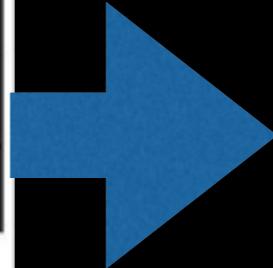


-1	0	+1
-2	0	+2
-1	0	+1

G_x

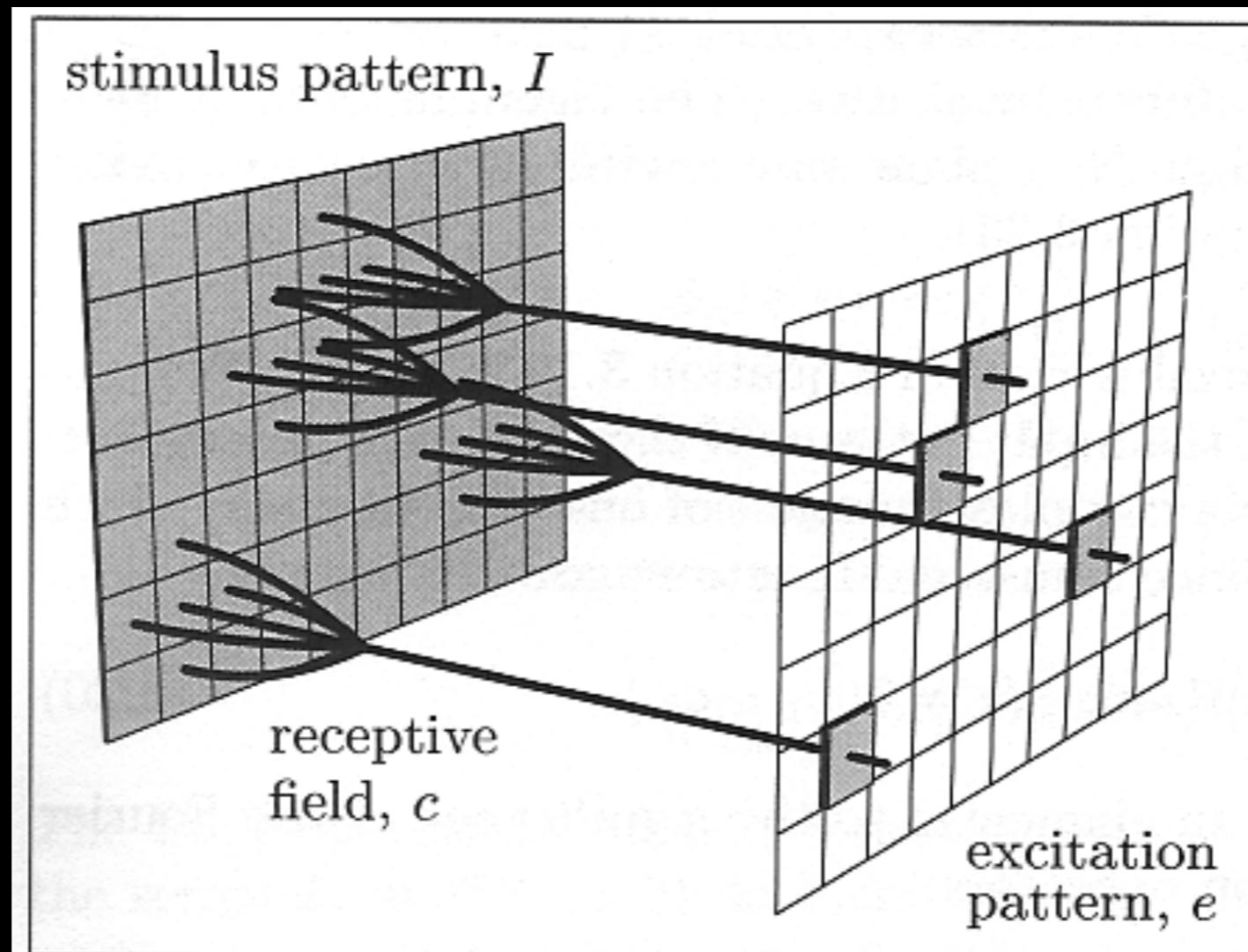
+1	+2	+1
0	0	0
-1	-2	-1

G_y

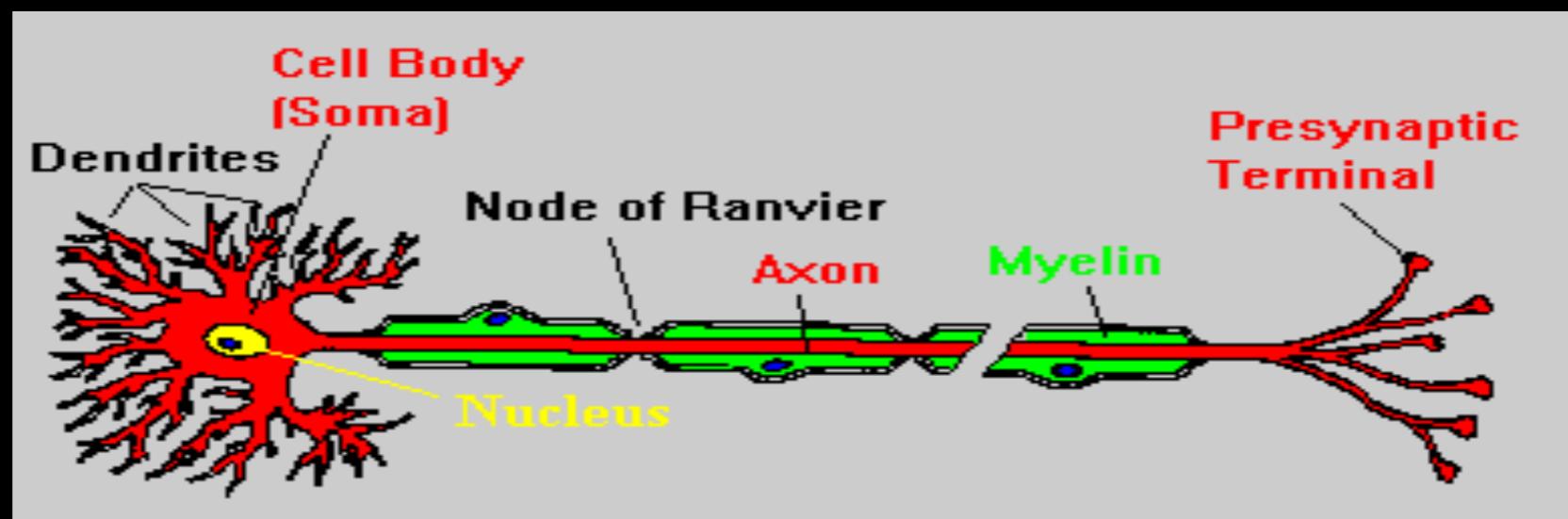
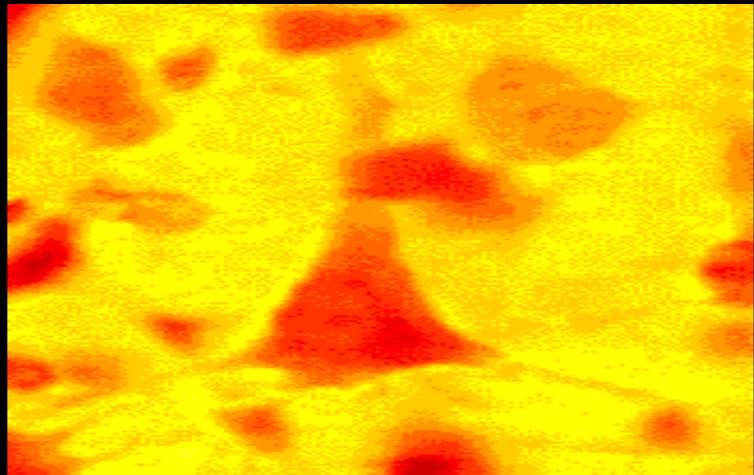


convolution

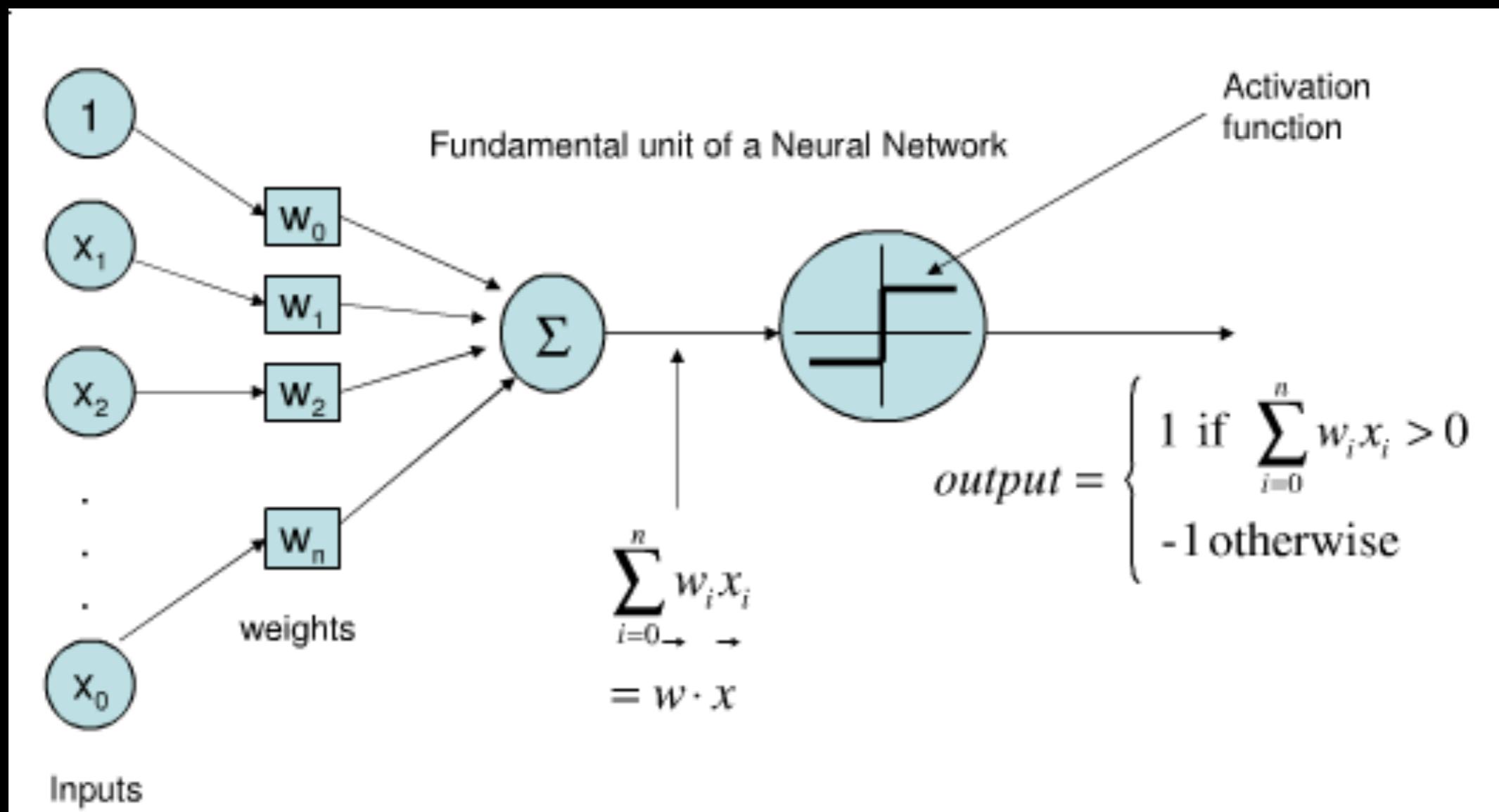
Filtering in Neural Networks



A brief history of neural networks

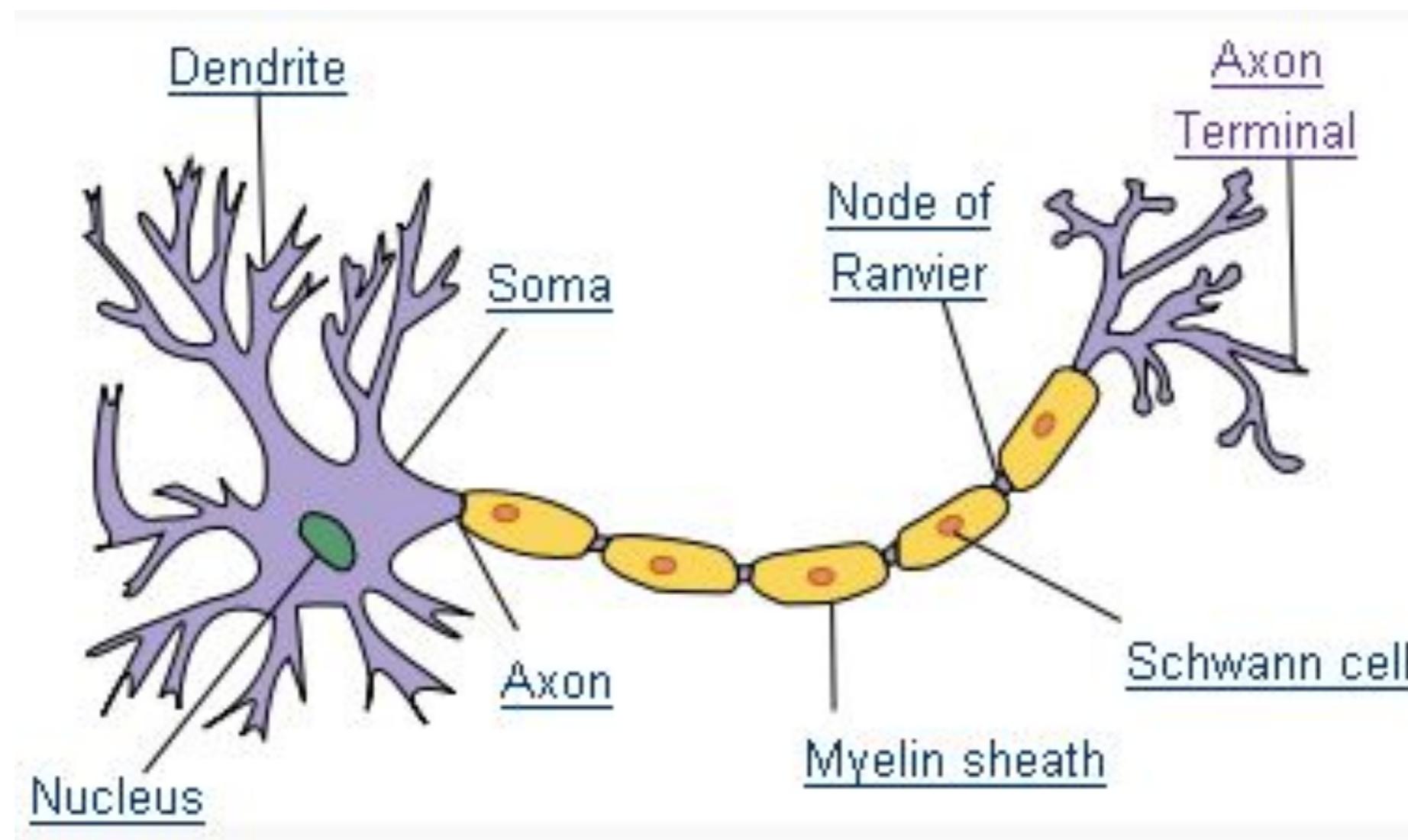


Perceptron (1957)

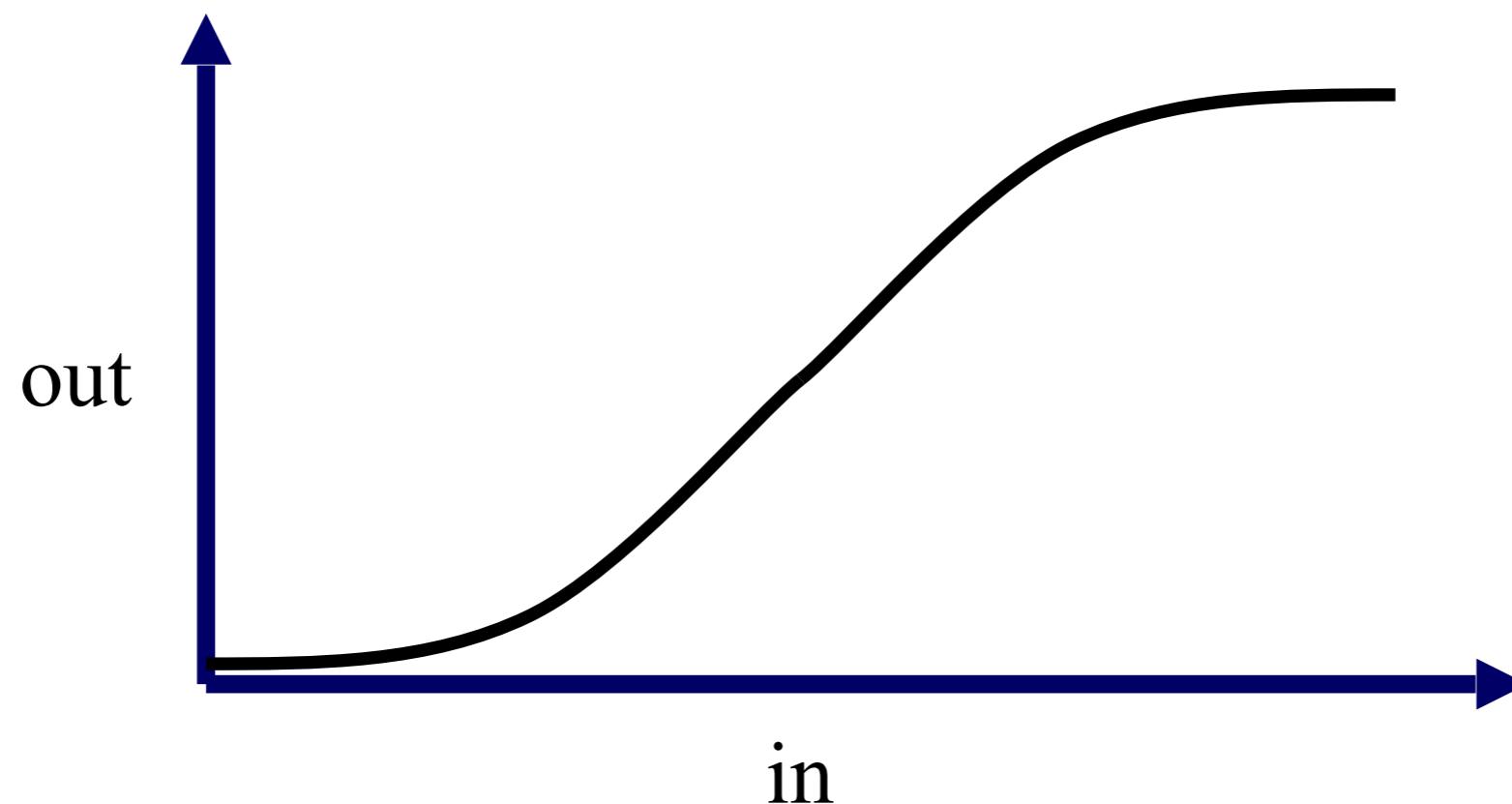


Automatically Learns Linear Mappings

Neurons, the building blocks of the brain

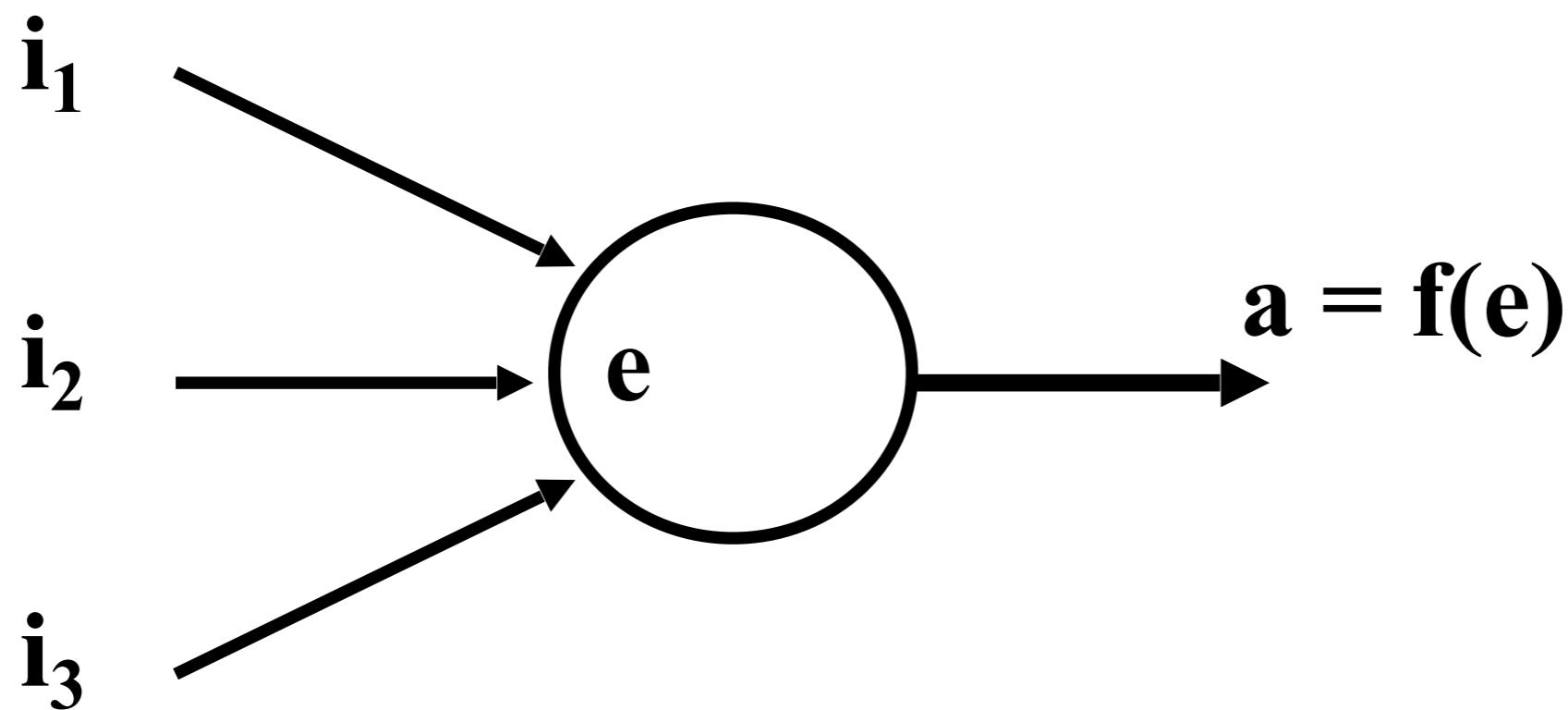


Neural activity



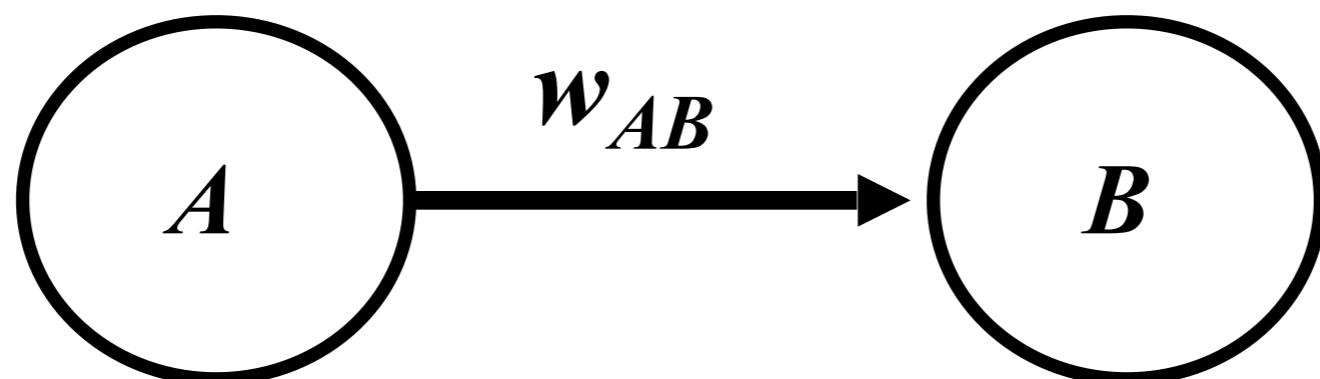
Artificial Neurons

- input (vectors)
- summation (excitation)
- output (activation)

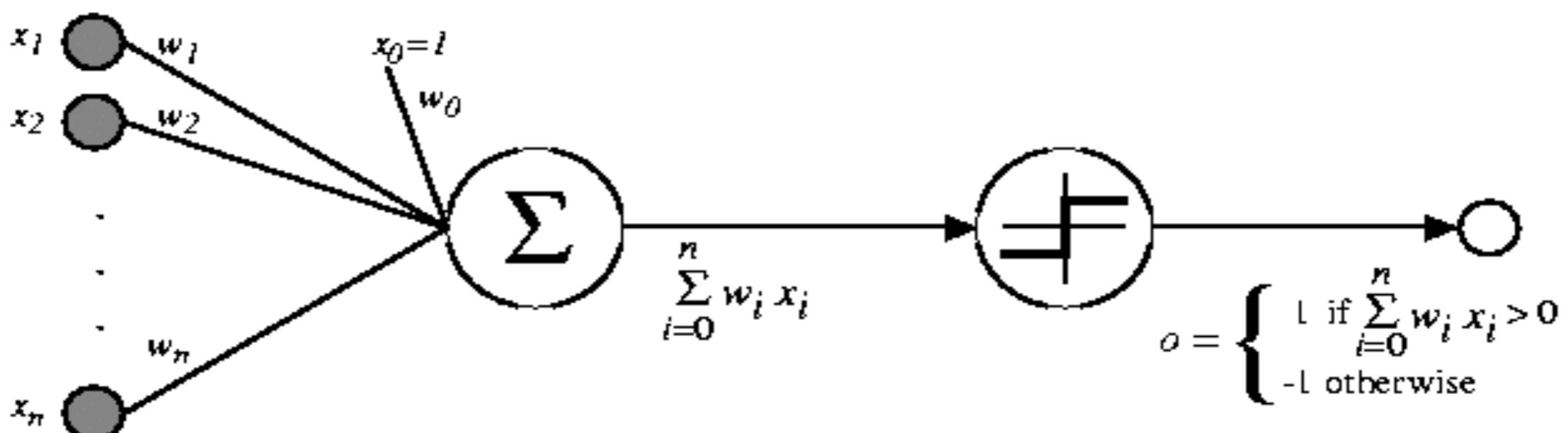


Artificial Connections (Synapses)

- w_{AB}
 - The weight of the connection from neuron A to neuron B



The Perceptron



$$o(x_1, \dots, x_n) = \begin{cases} 1 & \text{if } w_0 + w_1 x_1 + \dots + w_n x_n > 0 \\ -1 & \text{otherwise.} \end{cases}$$

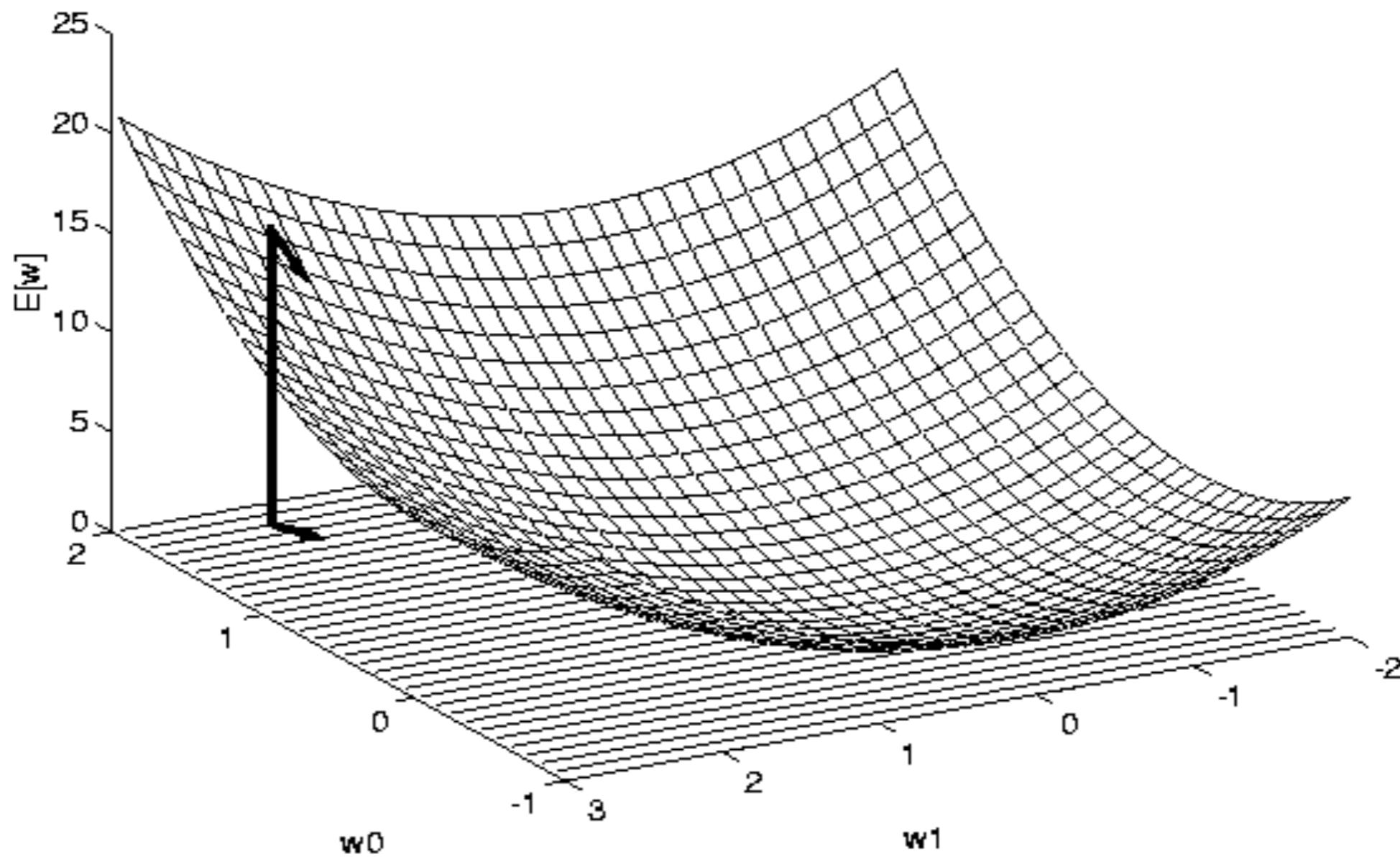
Learning in the Perceptron

- Delta learning rule
 - the difference between the desired output t and the actual output o , given input x

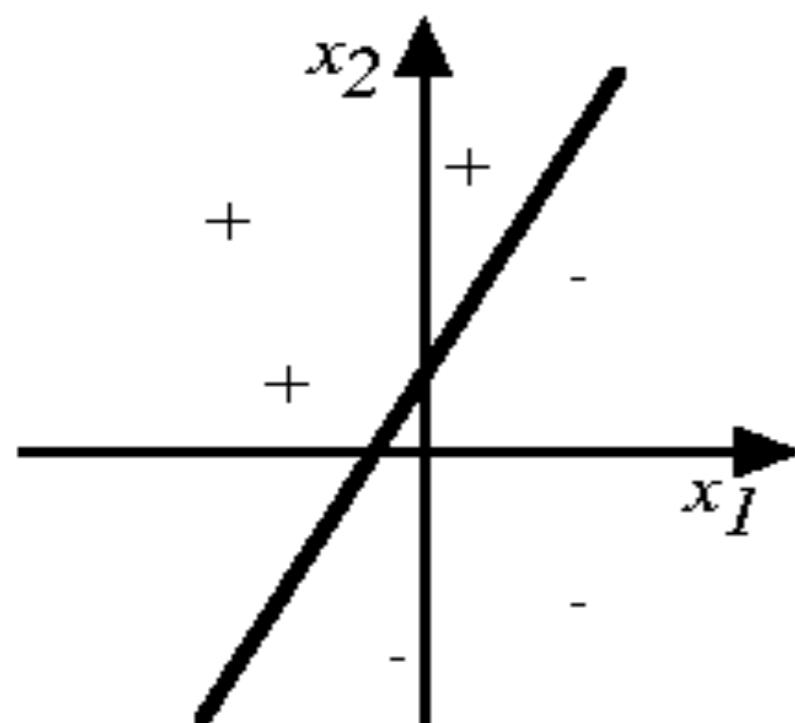
weights are adjusted to minimise the difference

- Global error E
 - is a function of the differences between the desired (t) and actual (o) outputs

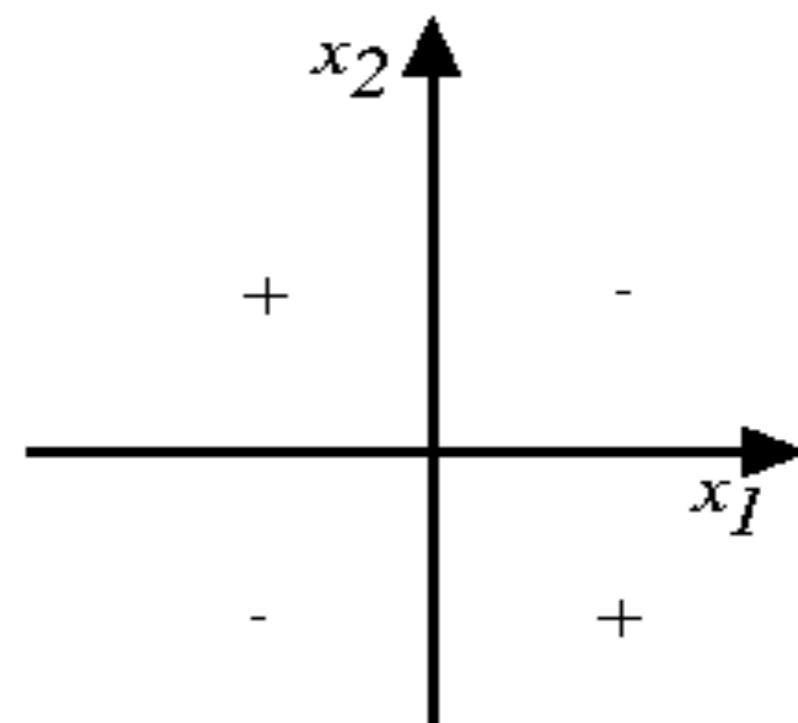
Gradient Descent



Can only learn linearly separable classification tasks



(a)



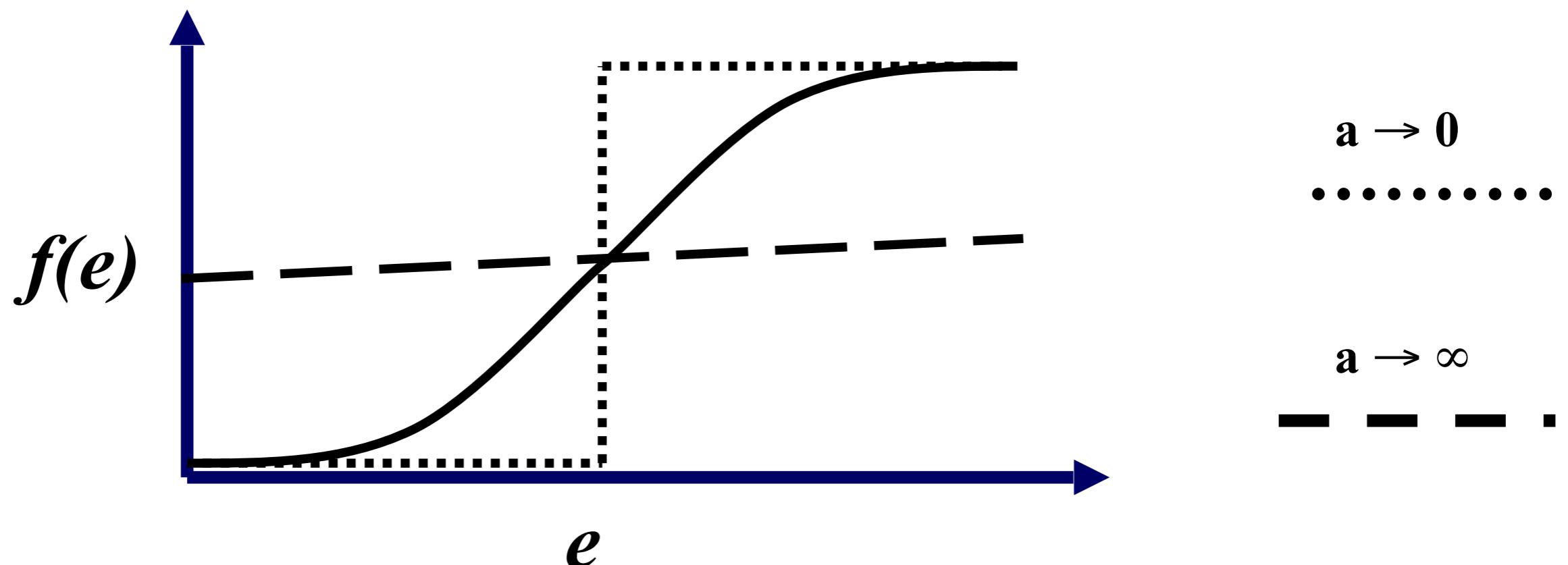
(b)

The history of the Perceptron

- Rosenblatt (1959)
- Minsky & Papert (1961)
- Rumelhart, McClelland & Hinton (1986)
- LeCun (1989), Hinton, LeCun (2016...)

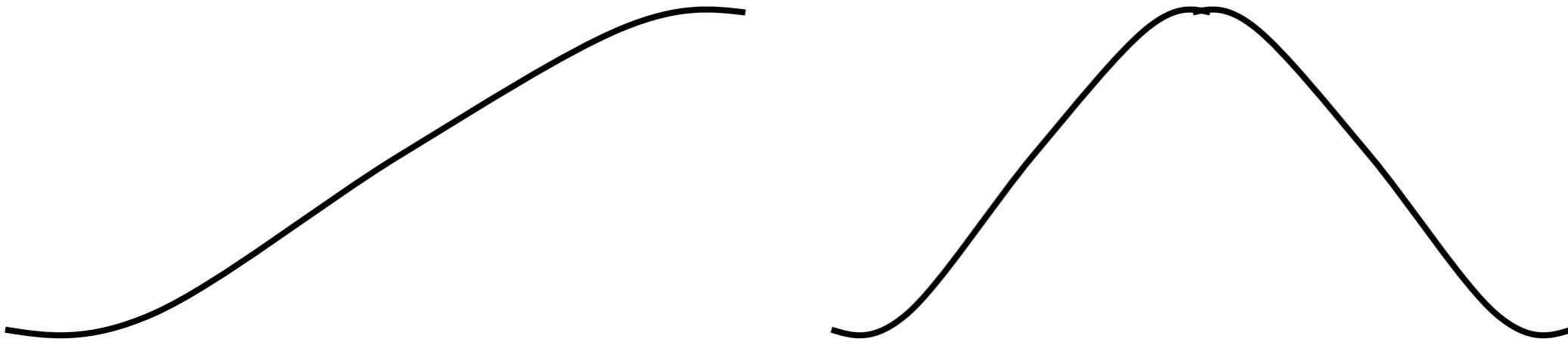
Sigmoid transfer (input-output) function

- nonlinear function: $f(x) = \frac{1}{1 + e^{-x/a}}$

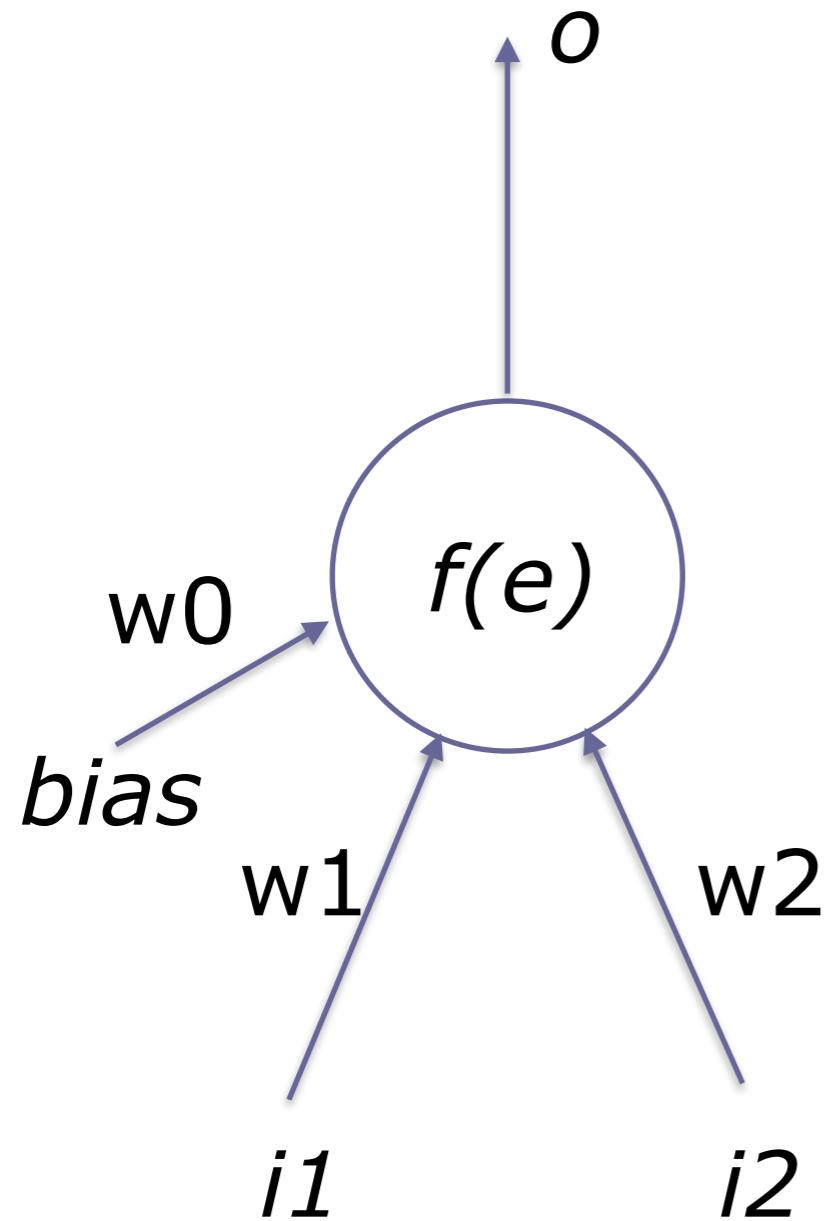


sigmoid transfer function

- May also be the **tanh** function ($<-1,+1>$ instead of $<0,1>$)
- Derivative $f'(x) = f(x) [1 - f(x)]$



Perceptron



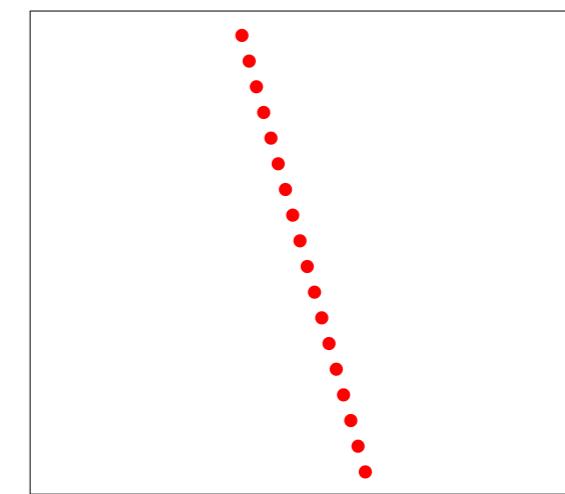
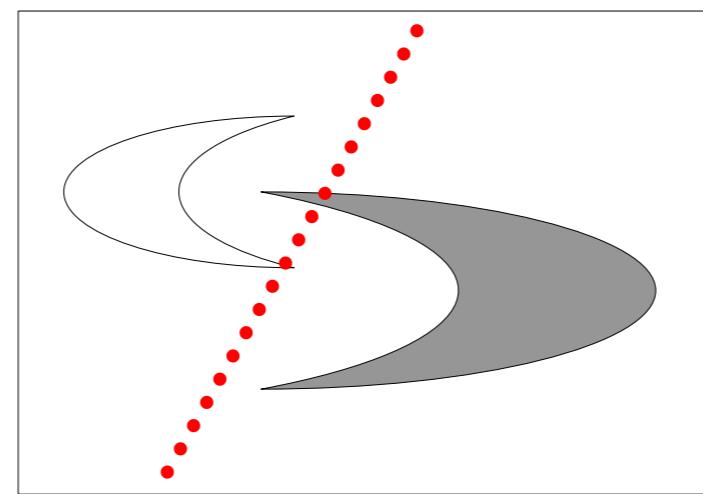
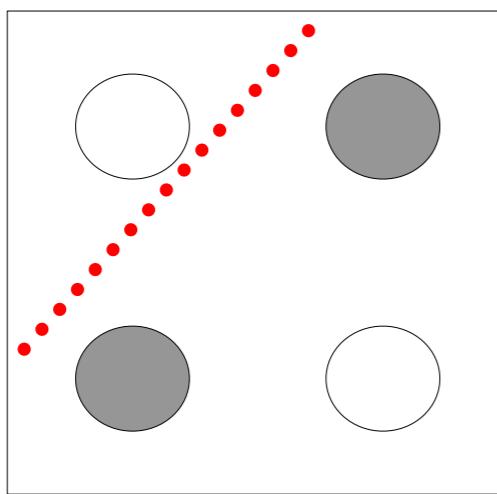
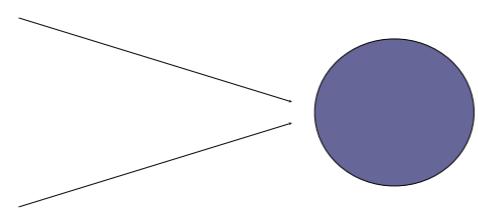
$$o = f \left(\sum_{i=0}^I w_i i_i \right) = f(e)$$

Derivation of the delta learning rule (for a sigmoid transfer function)

$$E = \sum_{p=1}^P \frac{1}{2} (t_p - o_p)^2$$

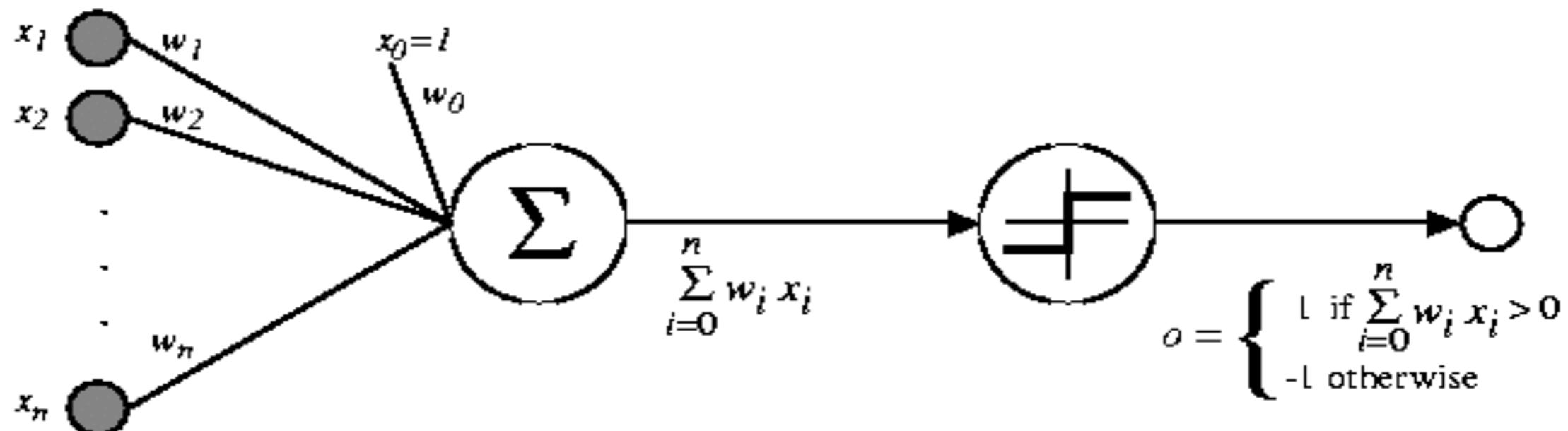
$$\Delta w_k = -\eta \frac{\partial E}{\partial w_k} = \eta \sum_{p=1}^P (t_p - o_p) f'(e_p) i_k = \eta \sum_{p=1}^P \sigma i_k$$

Decision boundaries of Perceptrons



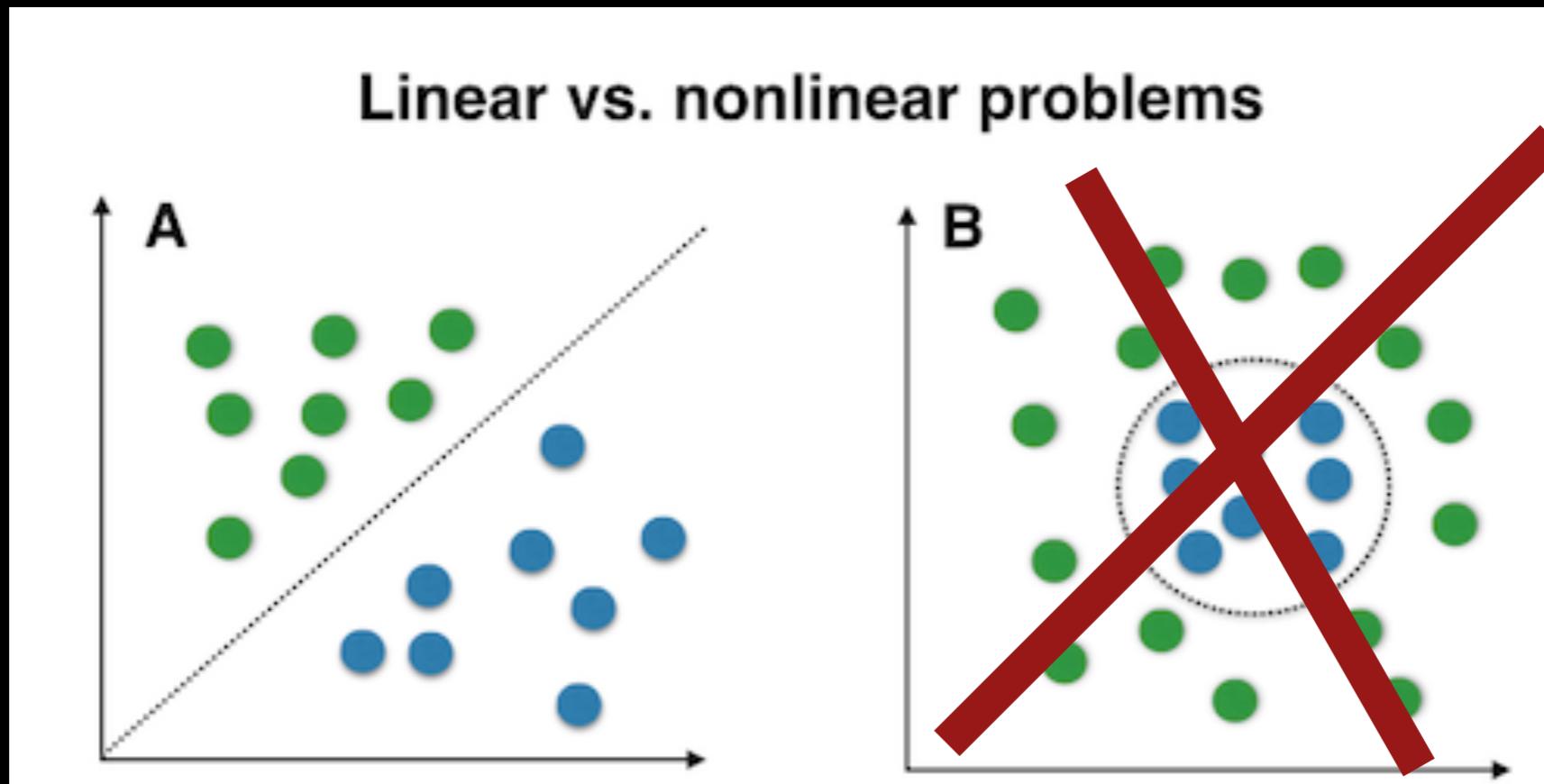
Straight lines (surfaces), linear separable

Can you derive the equation of the decision boundary for a perceptron with 2 inputs (+ 1 bias input)?



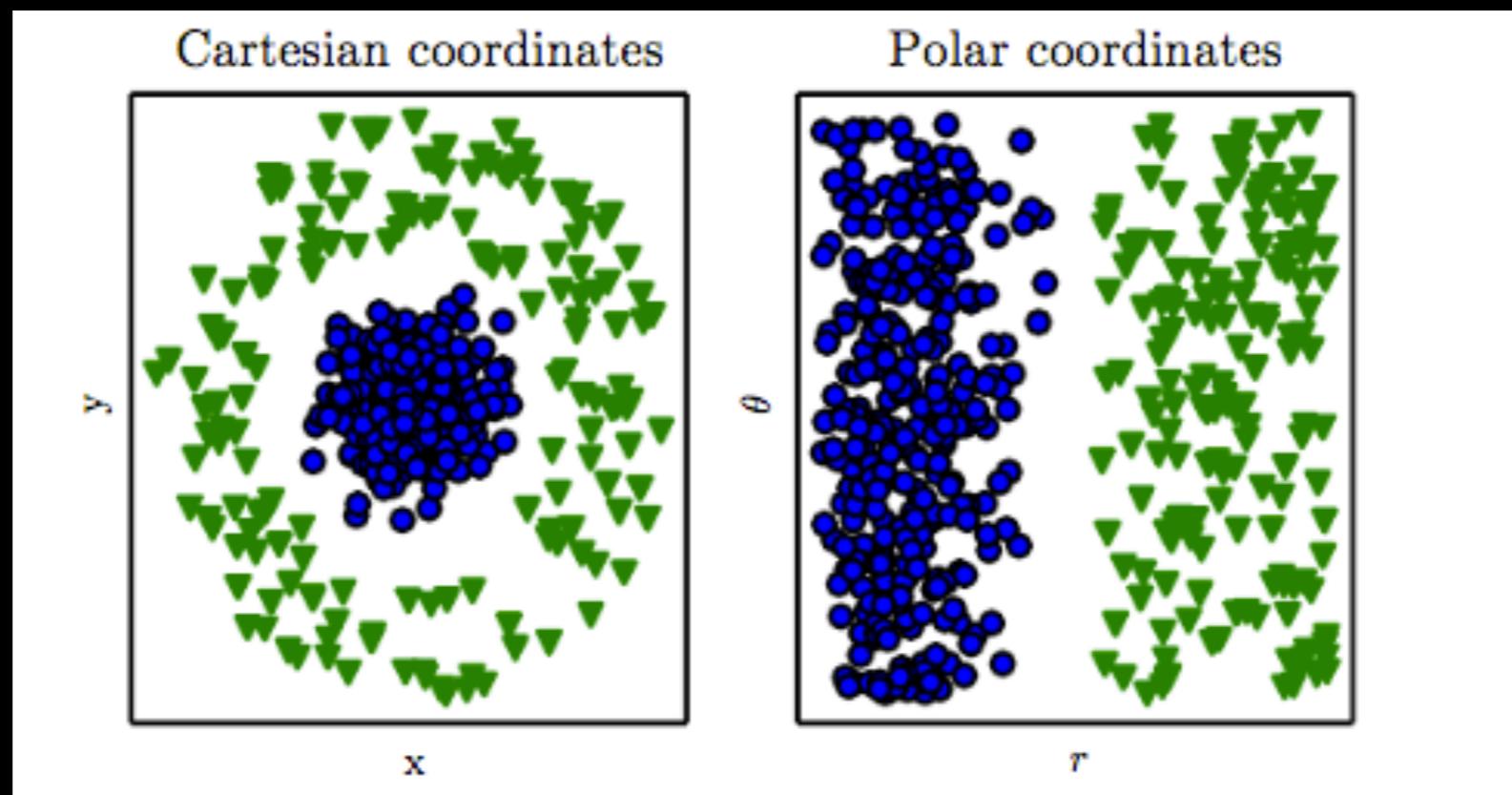
$$o(x_1, \dots, x_n) = \begin{cases} 1 & \text{if } w_0 + w_1 x_1 + \dots + w_n x_n > 0 \\ -1 & \text{otherwise.} \end{cases}$$

Linear separability



The importance of representation

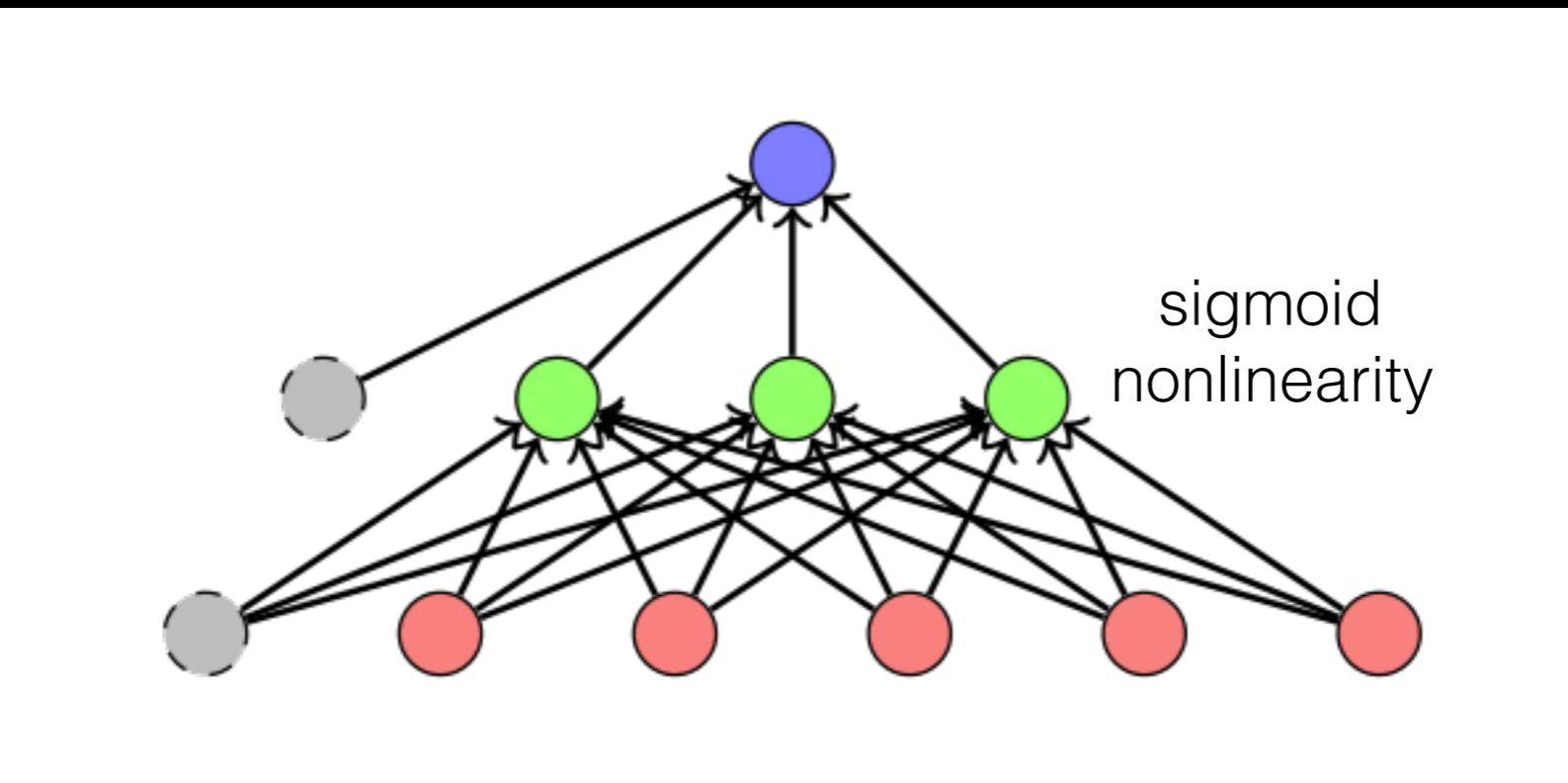
Perceptron
can't
classify this



Perceptron
can
classify this

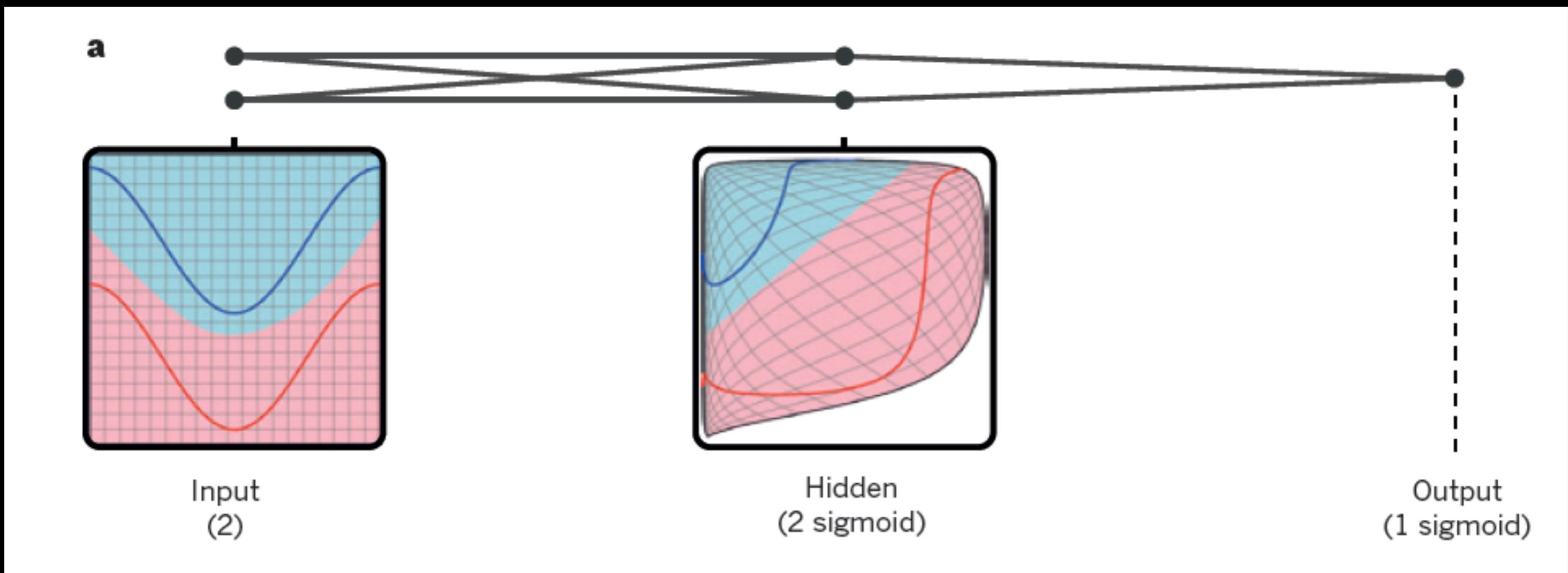
same task, different representation

Stacking Perceptrons



Main challenge (in the period 1960-1988):
How to automatically adapt the weights.

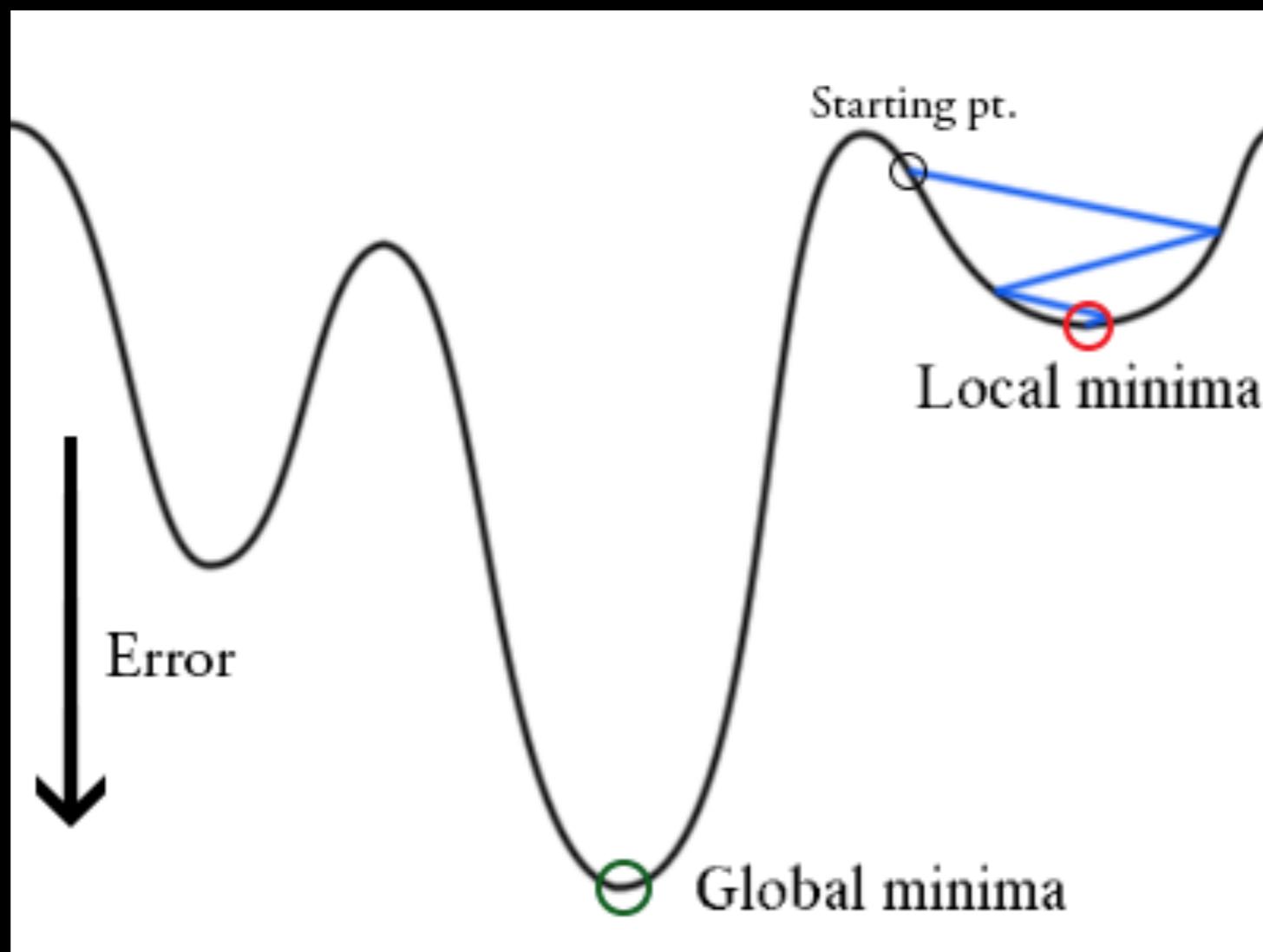
Multilayer Perceptron (1988)



Automatically Learns Non-Linear Mappings

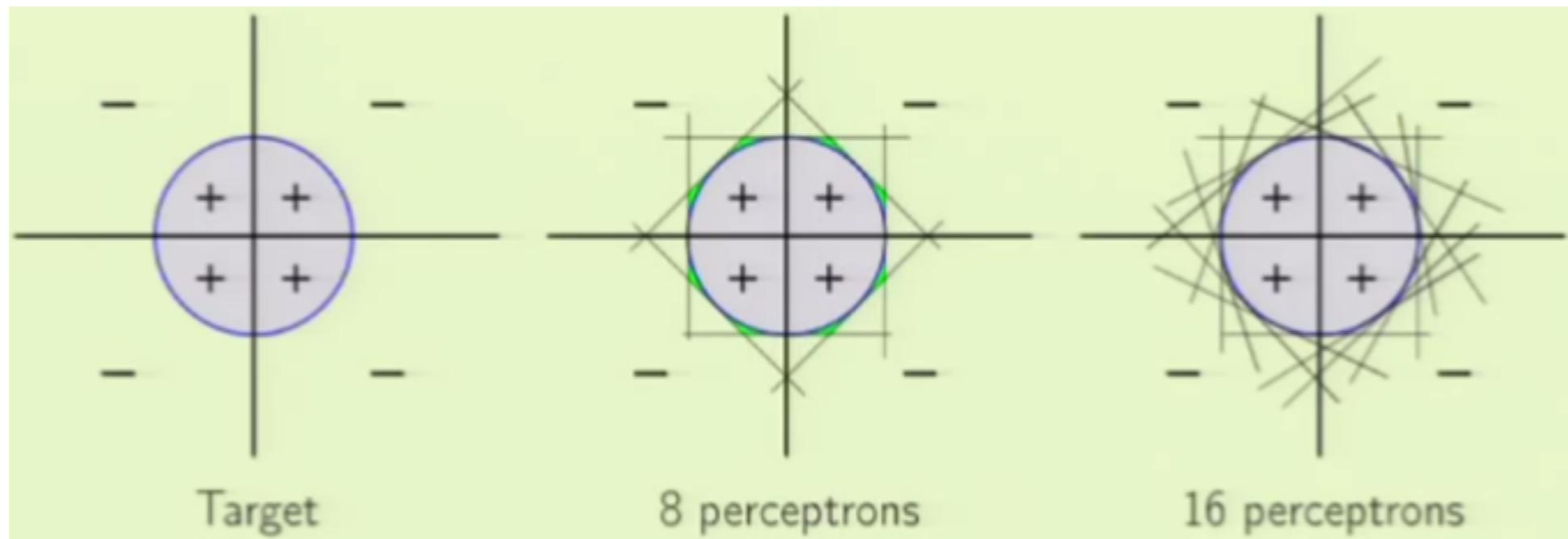
Gradient Descent

- Backpropagation (generalised delta rule)



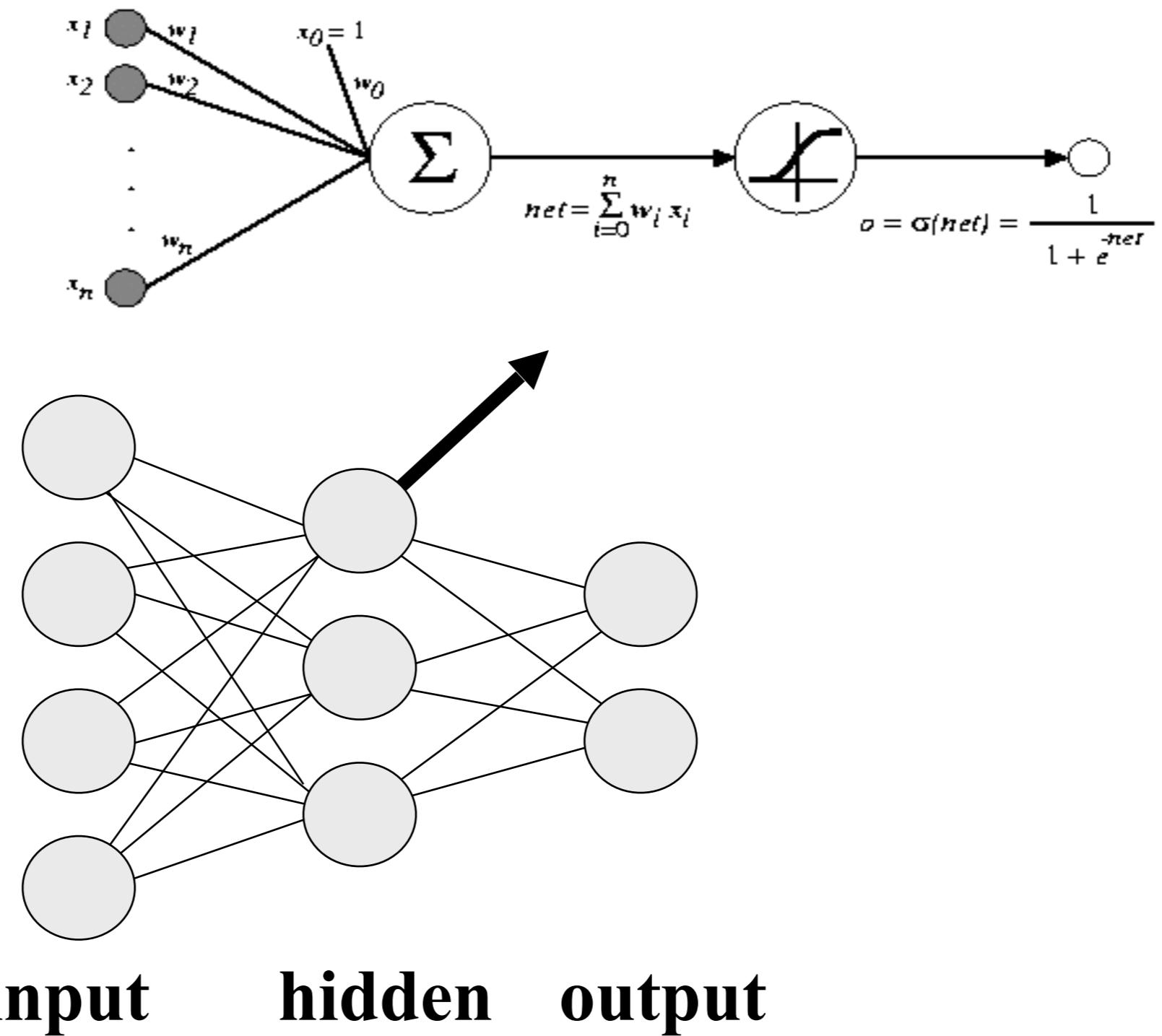
Coping with the limits of perceptrons

- Stacking perceptrons



what do these stacked
perceptrons look like?

The Multilayer Perceptron



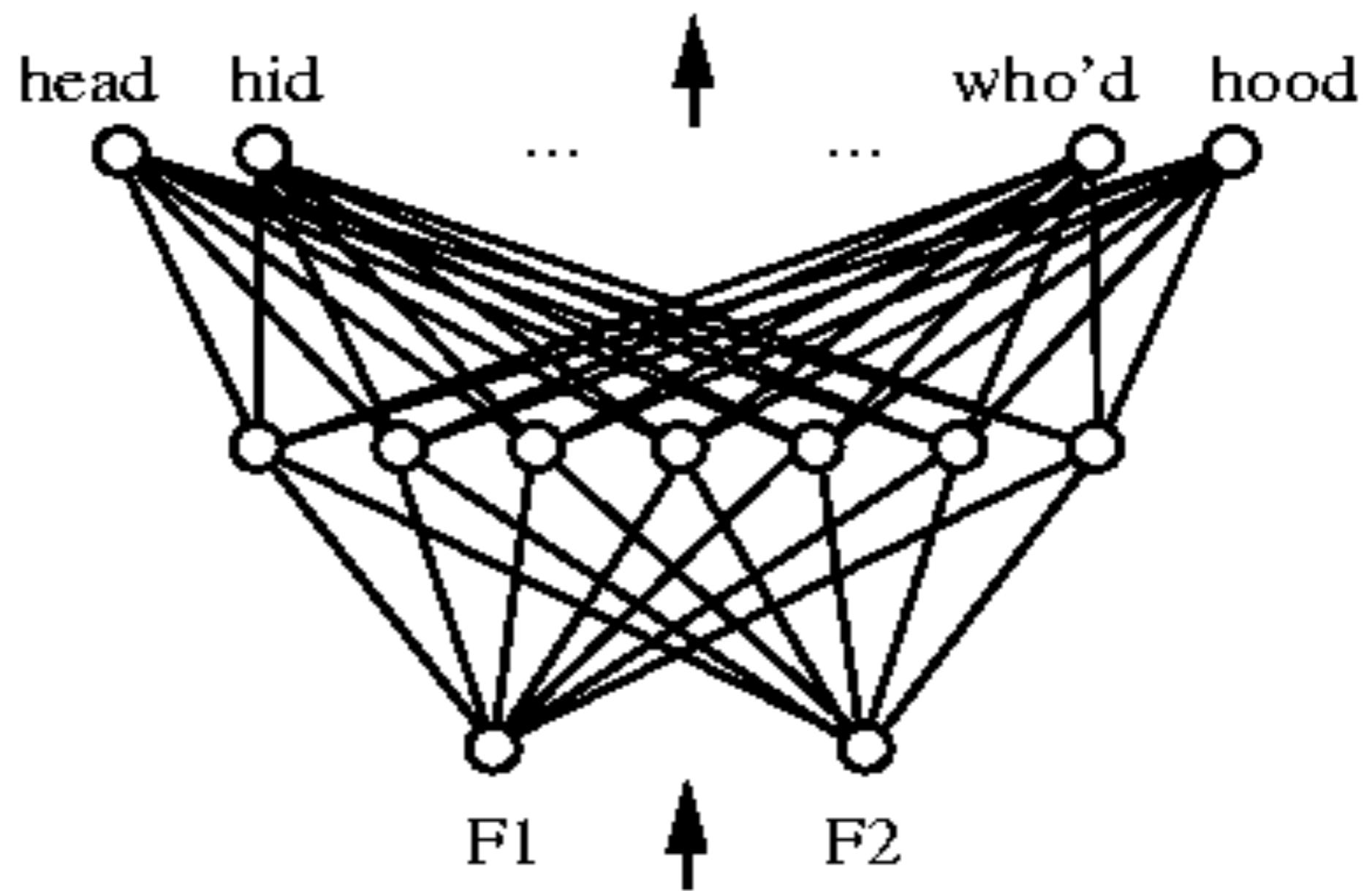
Training the MLP

- supervised learning
 - each training pattern: input I + desired output T
 - in each *epoch*: present all patterns
 - at each presentation: adapt weights
 - after many epochs convergence to a local minimum

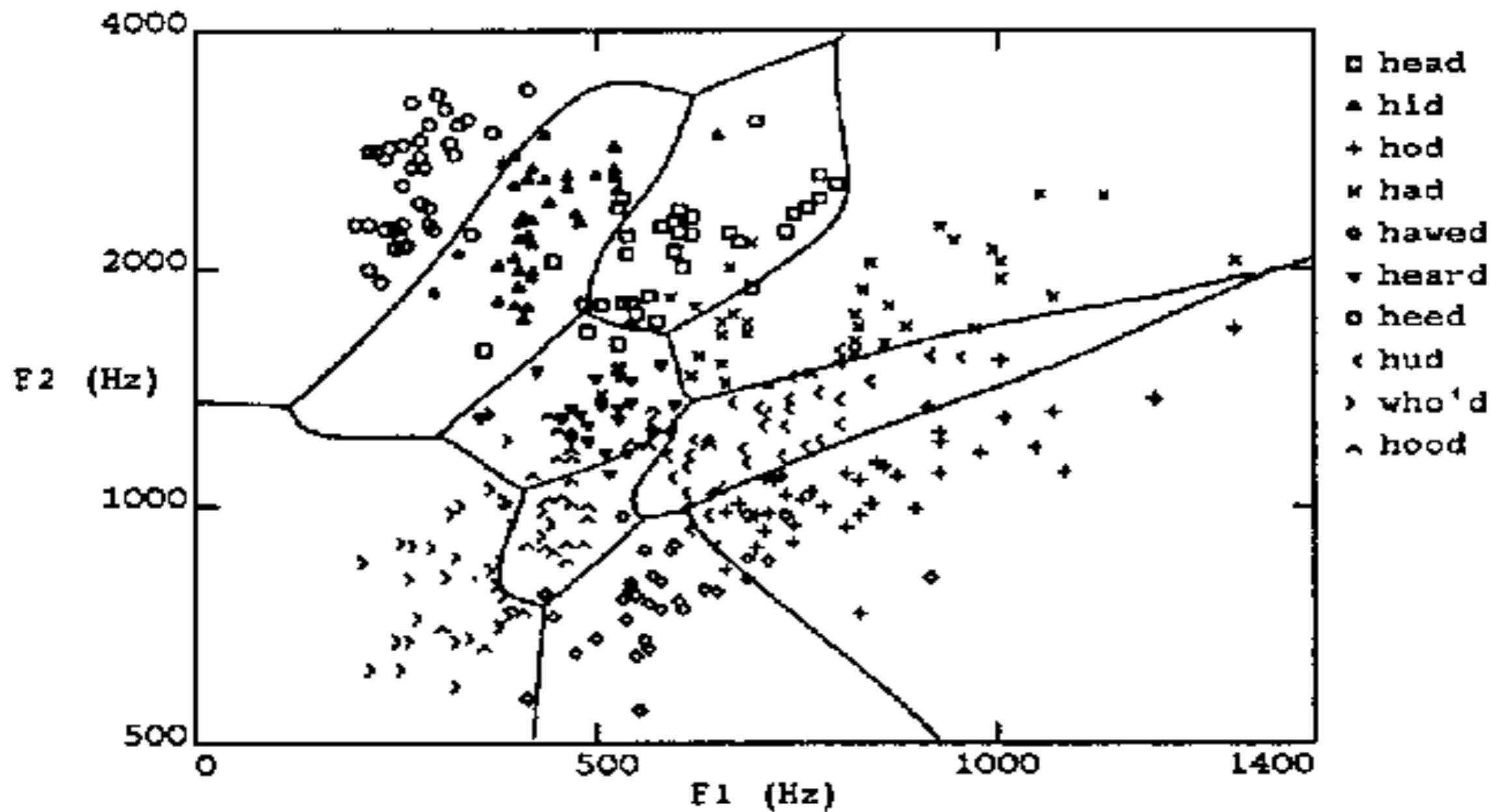
phoneme recognition with a MLP

Output:
pronunciation

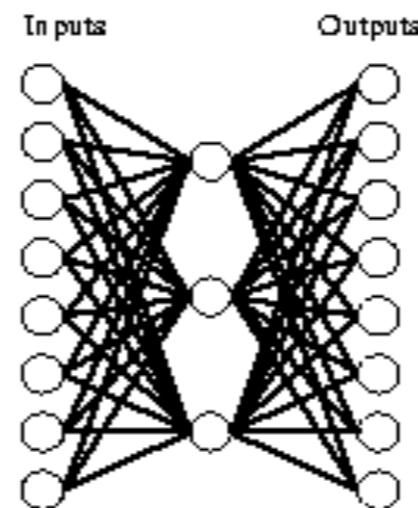
input:
frequencies



Non-linear decision boundaries



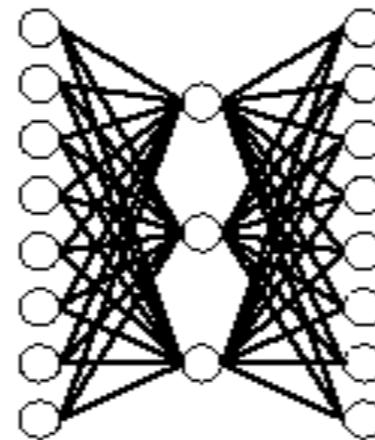
The *Autoencoder* (Compression with an MLP)



A target function:

Input	Output
10000000	\rightarrow 10000000
01000000	\rightarrow 01000000
00100000	\rightarrow 00100000
00010000	\rightarrow 00010000
00001000	\rightarrow 00001000
00000100	\rightarrow 00000100
00000010	\rightarrow 00000010
00000001	\rightarrow 00000001

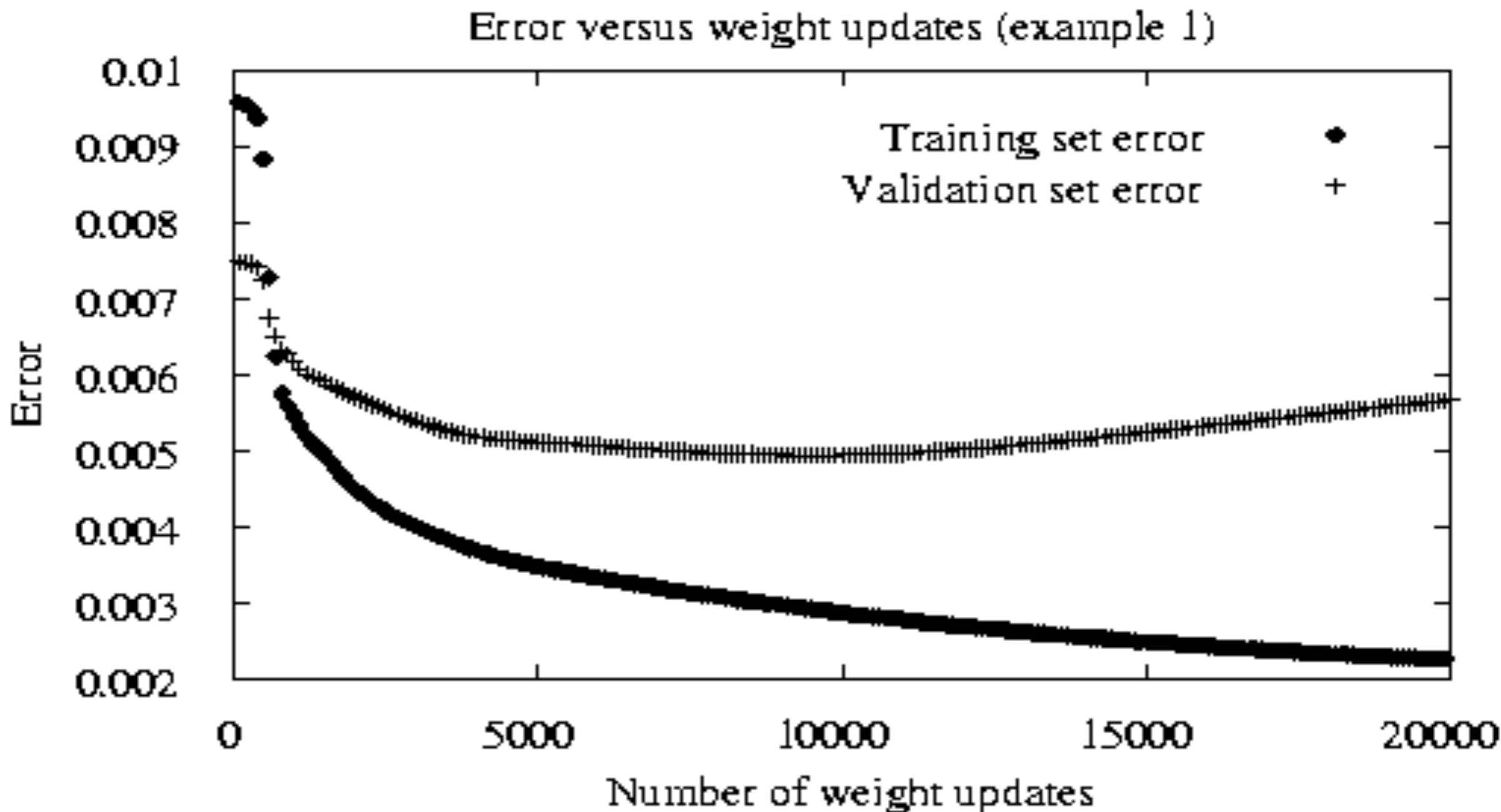
hidden representation



Learned hidden layer representation:

Input	Hidden Values	Output
10000000	→ .89 .04 .08	→ 10000000
01000000	→ .01 .11 .88	→ 01000000
00100000	→ .01 .97 .27	→ 00100000
00010000	→ .99 .97 .71	→ 00010000
00001000	→ .03 .05 .02	→ 00001000
00000100	→ .22 .99 .99	→ 00000100
00000010	→ .80 .01 .98	→ 00000010
00000001	→ .60 .94 .01	→ 00000001

Learning in the MLP



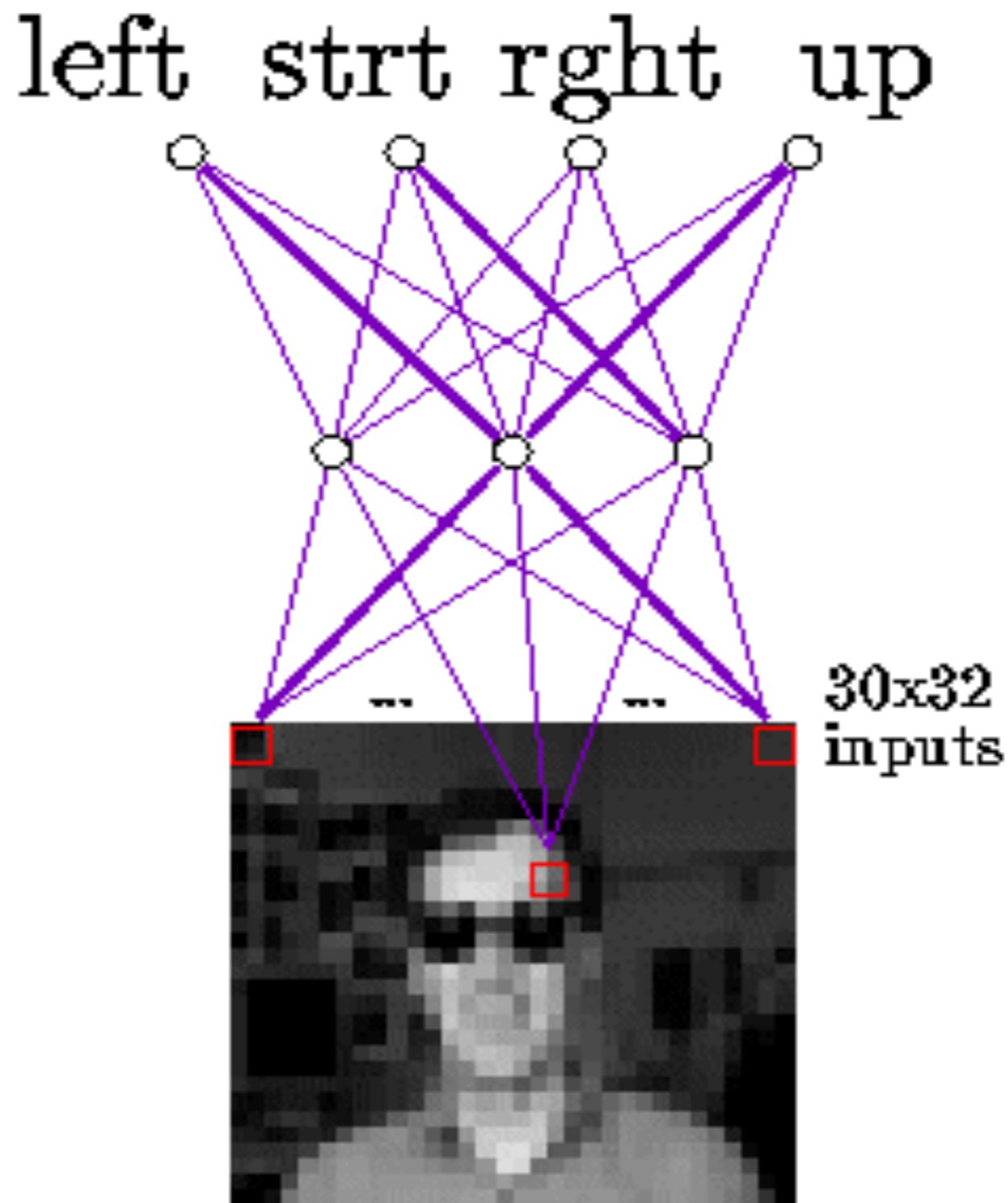
Preventing Overfitting

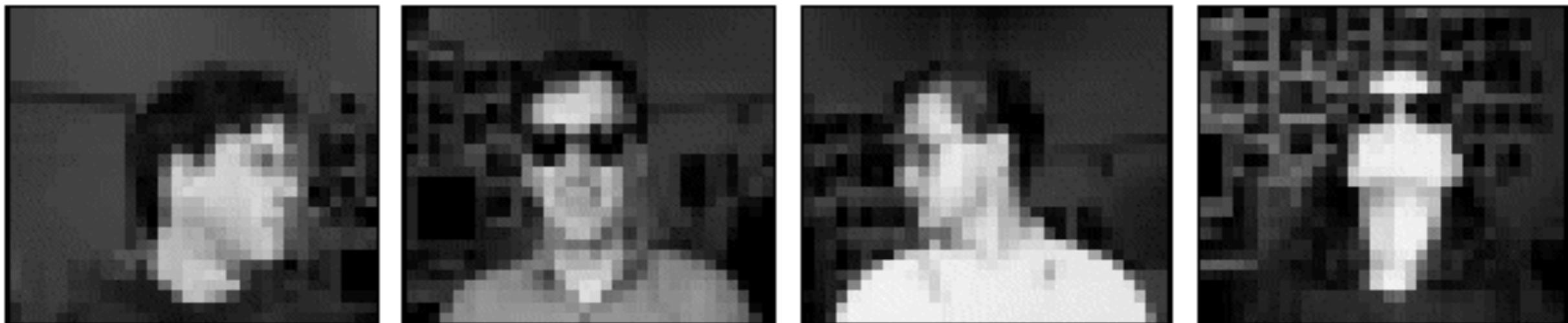
GENERALISATION

= performance on test set (unseen data)

- Early stopping
- Training, Validation and Test set
- k -fold cross validation
- Regularisation

Image Recognition with the MLP

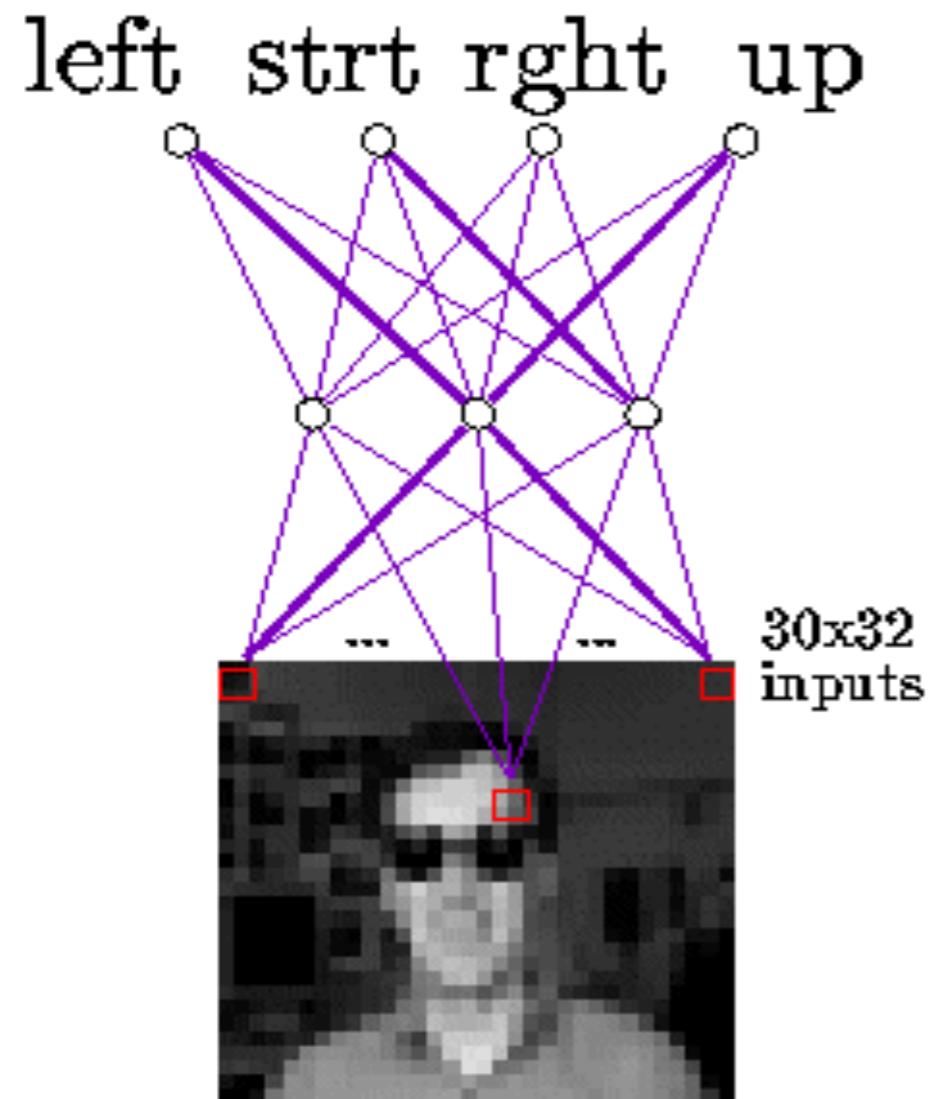




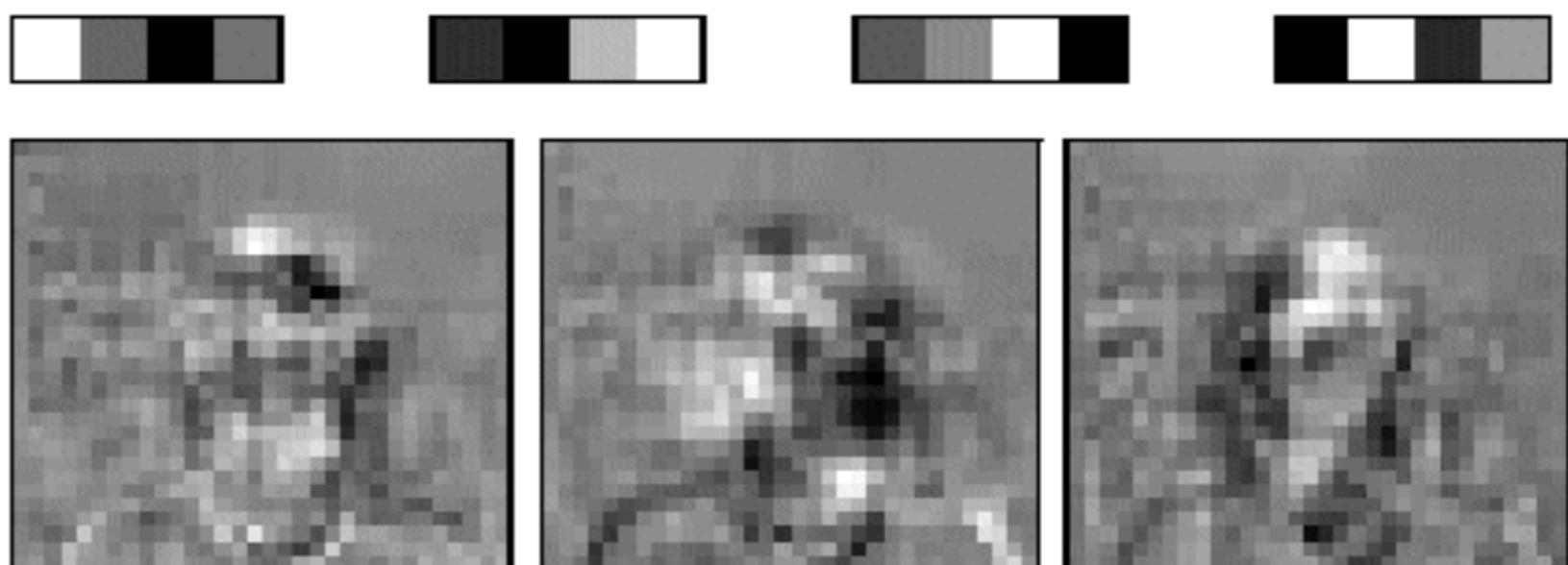
Typical input images

After training...

Hidden Representations



Learned Weights



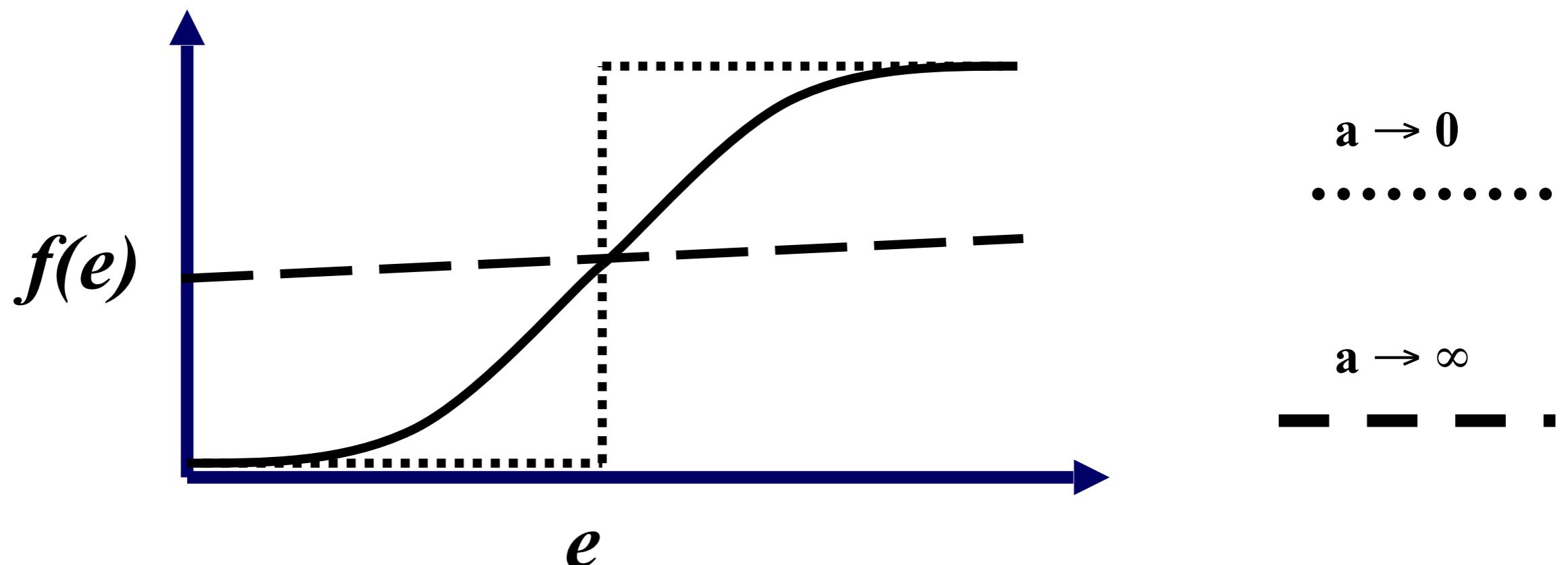
Questions

- The MLP consists of one (or more) hidden layers, i.e., hidden neurons with sigmoid transfer functions
 1. Can linear transfer functions be used? What would be the pro's and con's?
 2. Can step transfer functions be used? What would be the pro's and con's?

RECAP PERCEPTRON...

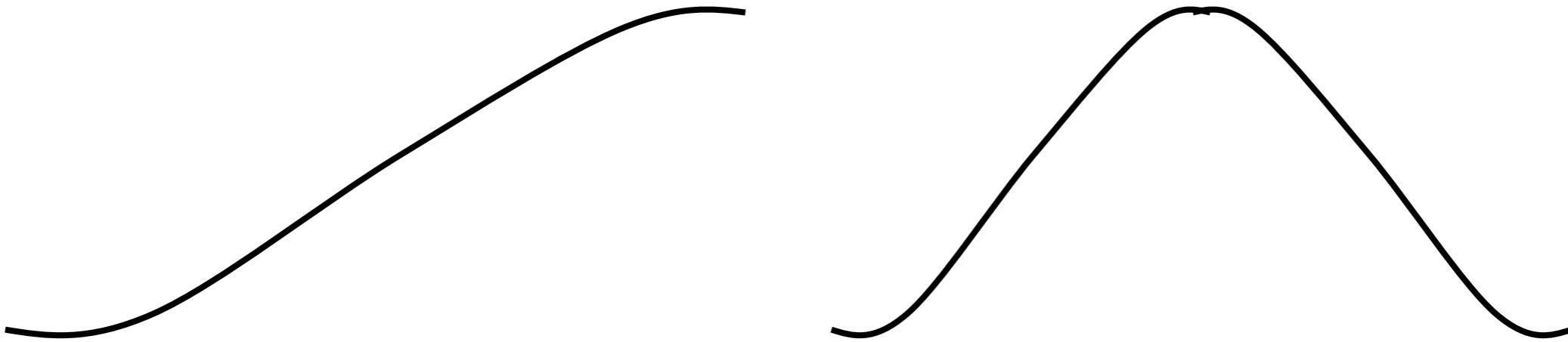
Sigmoid transfer (input-output) function

- nonlinear function: $f(x) = \frac{1}{1 + e^{-x/a}}$

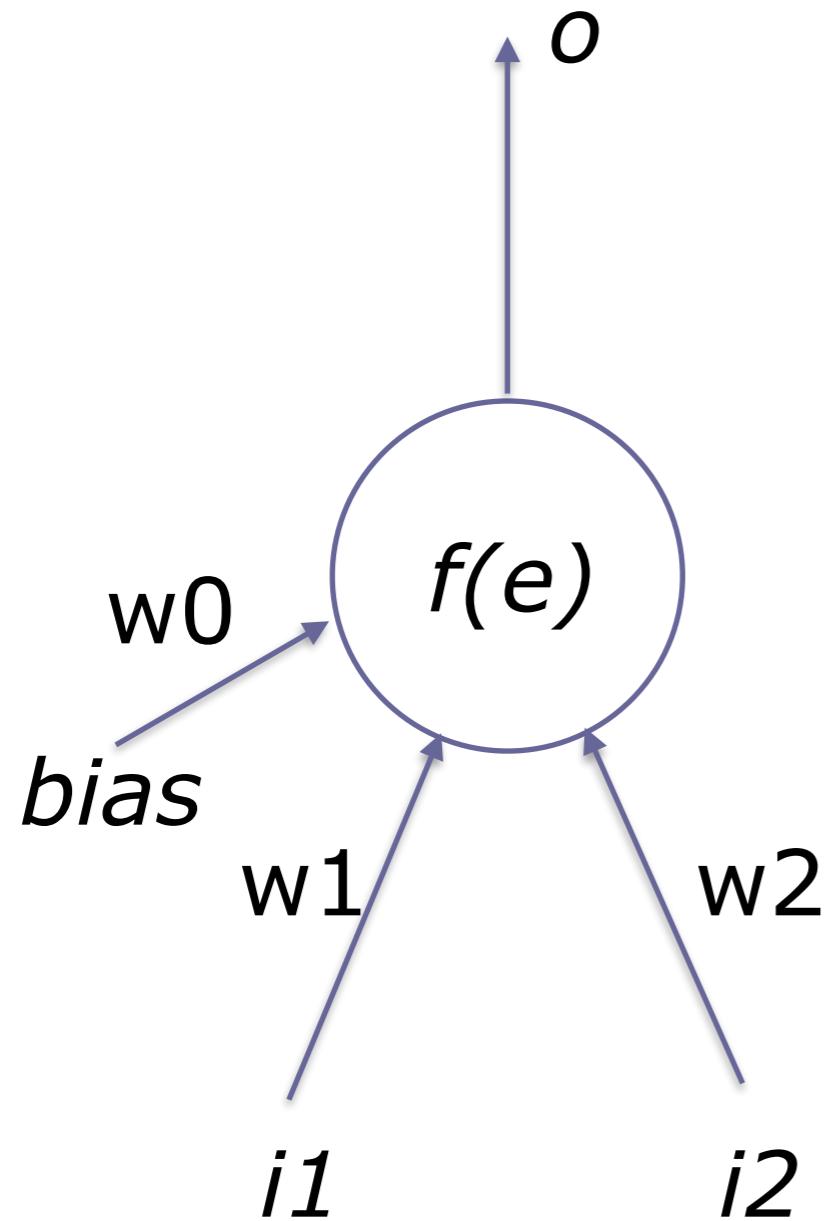


sigmoid transfer function

- May also be the **tanh** function ($<-1,+1>$ instead of $<0,1>$)
- Derivative $f'(x) = f(x) [1 - f(x)]$



Perceptron



$$o = f \left(\sum_{i=0}^I w_i i_i \right) = f(e)$$

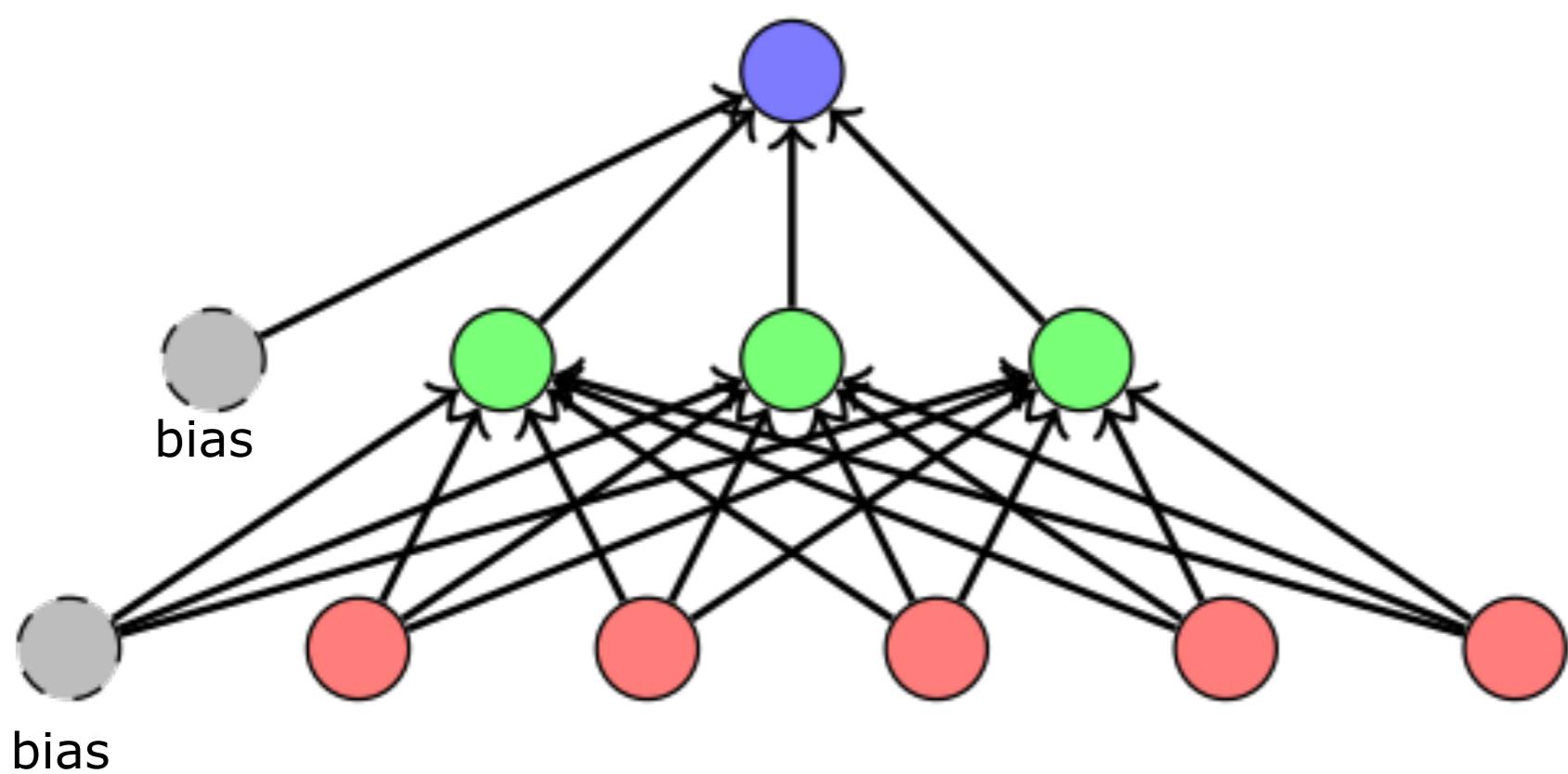
Derivation of the delta learning rule (for a sigmoid transfer function)

$$E = \sum_{p=1}^P \frac{1}{2} (t_p - o_p)^2$$

$$\Delta w_k = -\eta \frac{\partial E}{\partial w_k} = \eta \sum_{p=1}^P (t_p - o_p) f'(e_p) i_k = \eta \sum_{p=1}^P \delta_i_k$$

Question

- How does the rate of weight change depend on the activation value of the neuron?



output neuron(s)

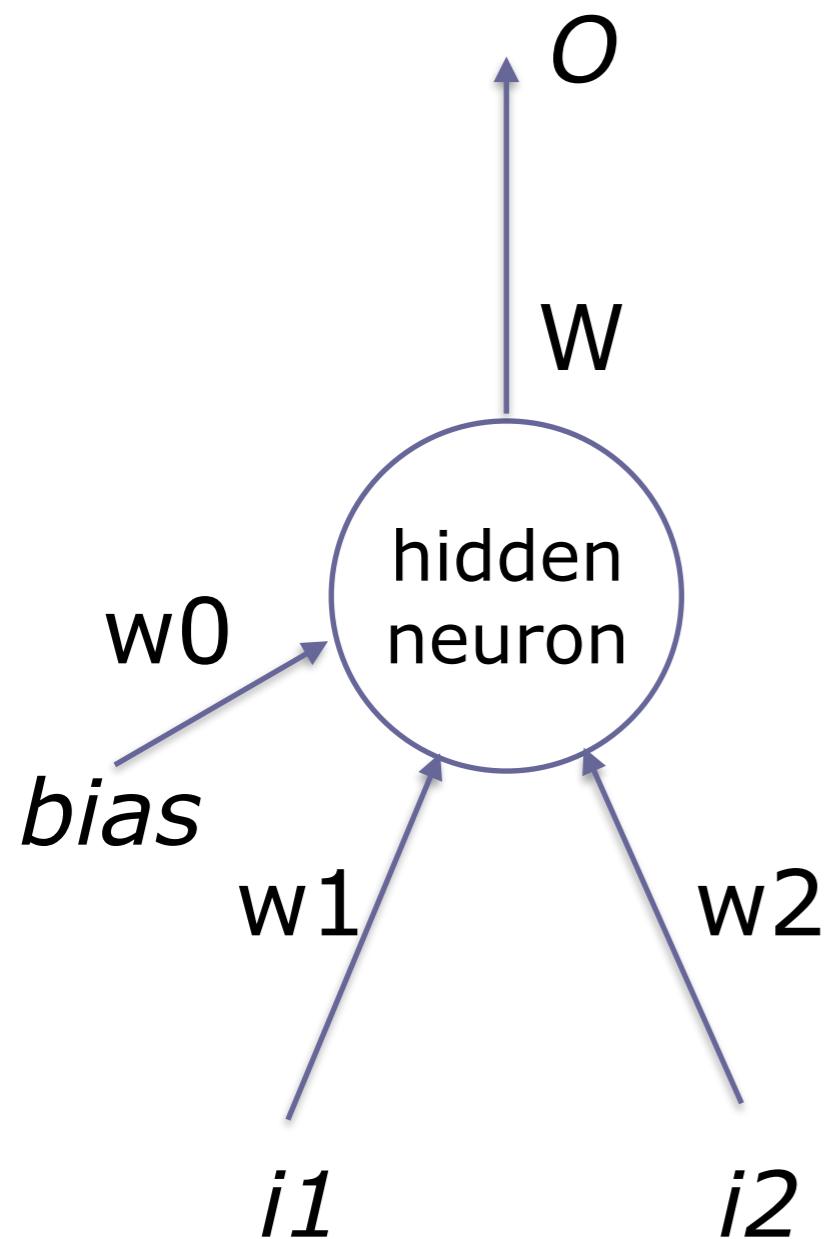
hidden neurons

inputs

bias

bias

Multilayer Perceptron



$$o_k = f \left(\sum_{j=0}^H W_{kj} h_j \right) = f(e_k)$$

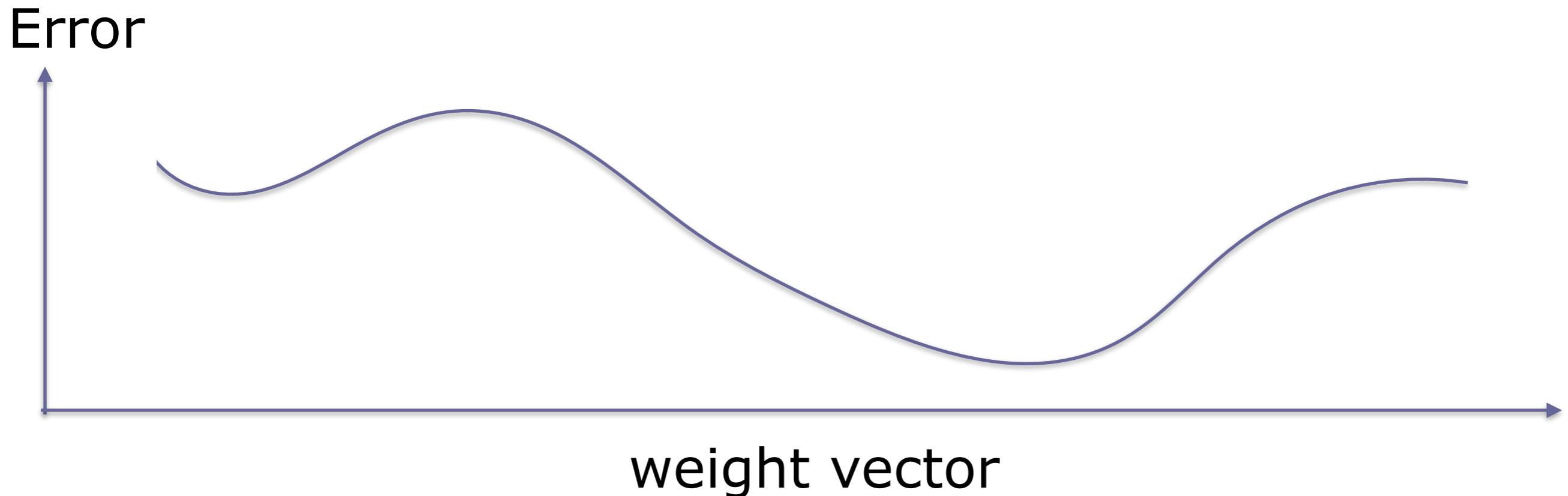
large $W \rightarrow$ hidden to output weights

$$h_j = f \left(\sum_{i=0}^I w_{ji} i_i \right) = f(e_j)$$

small $w \rightarrow$ input to hidden weights

Training the MLP

- Gradient Descent
- Error function is not convex
- Local minima



MLP with one hidden layer (mathematical equation)

O = number of output neurons

H = number of hidden neurons

I = number of inputs

$$o_k = f \left(\sum_{k=1, j=0}^{O, H} w_{kj} f \left(\sum_{j=1, i=0}^{H, I} w_{ji} i_i \right) \right)$$

output of k-th output neuron

hidden-to-output weights

input-to-hidden weights

Error function of MLP

$$E = \sum_{p=1, k=1}^{P, O} \frac{1}{2} (t_{pk} - o_{pk})^2$$

$$E_{pk} = \frac{1}{2} (t_{pk} - o_{pk})^2$$

$$E_{pk} = \frac{1}{2} \left(t_{pk} - f \left(\sum_{k=1, j=0}^{O, H} W_{kj} f \left(\sum_{j=1, i=0}^{H, I} w_{ji} i_{pi} \right) \right) \right)^2$$

Derivation of the generalised delta learning rule (MLP with one hidden layer)

$$\Delta W_{kj} = -\eta \frac{\partial E}{\partial W_{kj}} = \eta \sum_{p=1}^P (t_{pk} - o_{pk}) f'(e_{pk}) h_{pj} = \eta \sum_{p=1}^P \delta_{pk} h_{pj}$$

the adaptation of the hidden to output weights is identical to that of the perceptron weights (except for $h \leftrightarrow i$)

Adaptation of input to hidden weights

- More complicated due to non-linearity of the hidden neuron transfer function
- Makes use of the chain rule

The chain rule may be written, in Leibniz's notation, in the following way. If a variable z depends on the variable y , which itself depends on the variable x , so that y and z are therefore dependent variables, then z , via the intermediate variable of y , depends on x as well. The chain rule then states,

$$\frac{dz}{dx} = \frac{dz}{dy} \cdot \frac{dy}{dx}.$$

[https://en.wikipedia.org/wiki/
Chain_rule](https://en.wikipedia.org/wiki/Chain_rule)

$$\Delta w_{ji} = -\eta \frac{\partial E}{\partial w_{ji}} = -\eta \frac{\partial E}{\partial h_{pj}} \frac{\partial h_{pj}}{\partial w_{ji}}$$

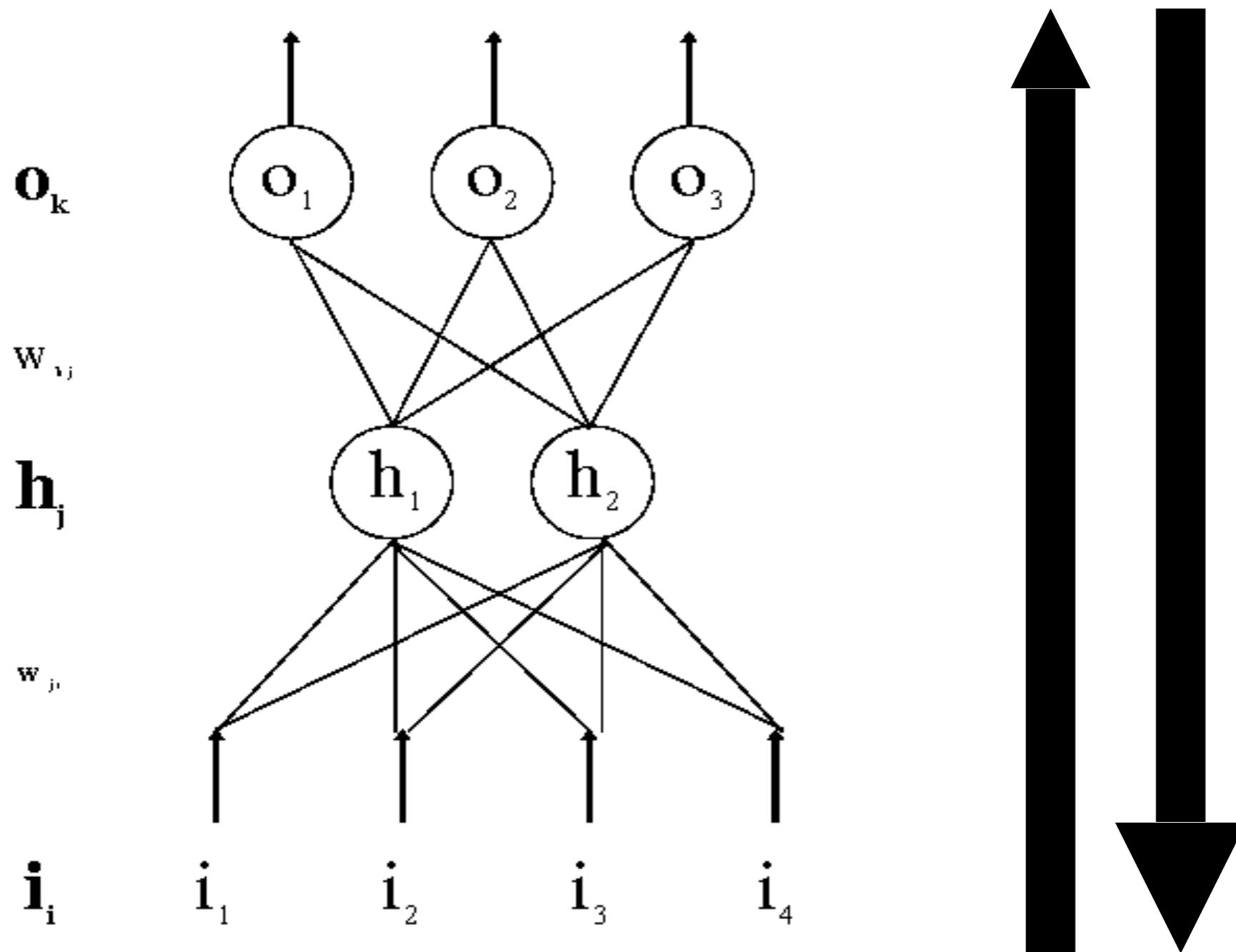
chain rule

$$= \eta \sum_{p=1, k=1}^{P, H} (t_{pk} - o_{pk}) f'(e_{pk}) W_{kj} f'(e_{pj}) i_{pi}$$

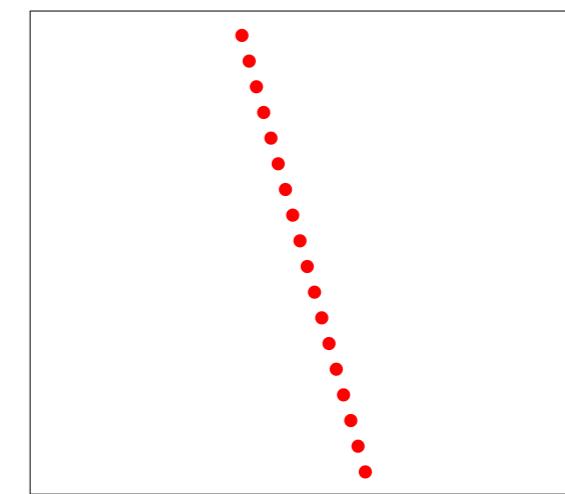
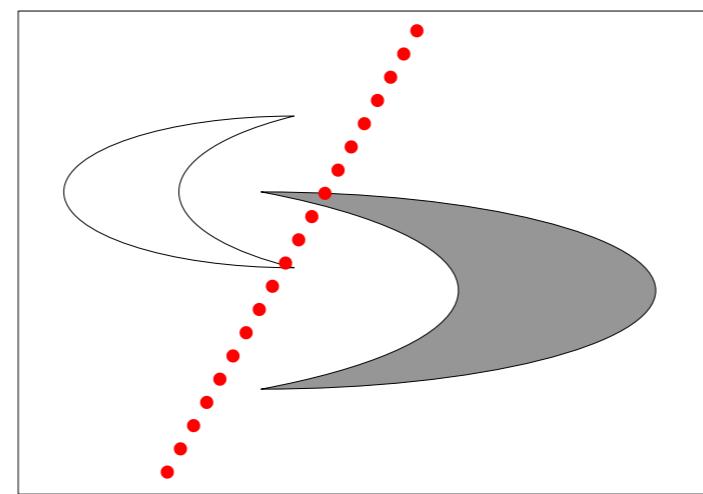
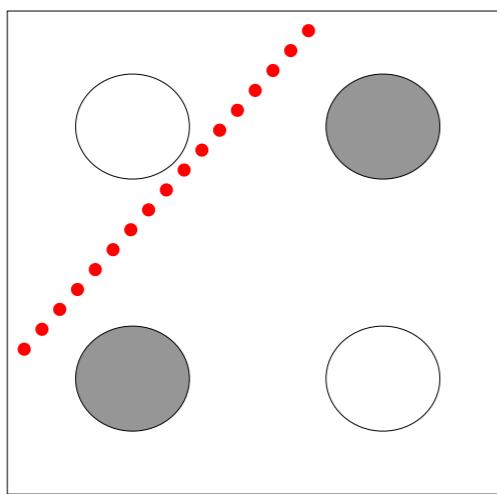
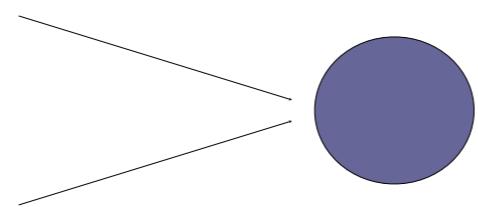
$$= \eta \sum_{p=1, k=1}^{P, H} \delta_{pk} W_{kj} f'(e_{pj}) i_{pi}$$

$$= \eta \sum_{p=1, k=1}^{P, H} \delta_{pj} i_{pi}$$

Forward and Backward Propagation

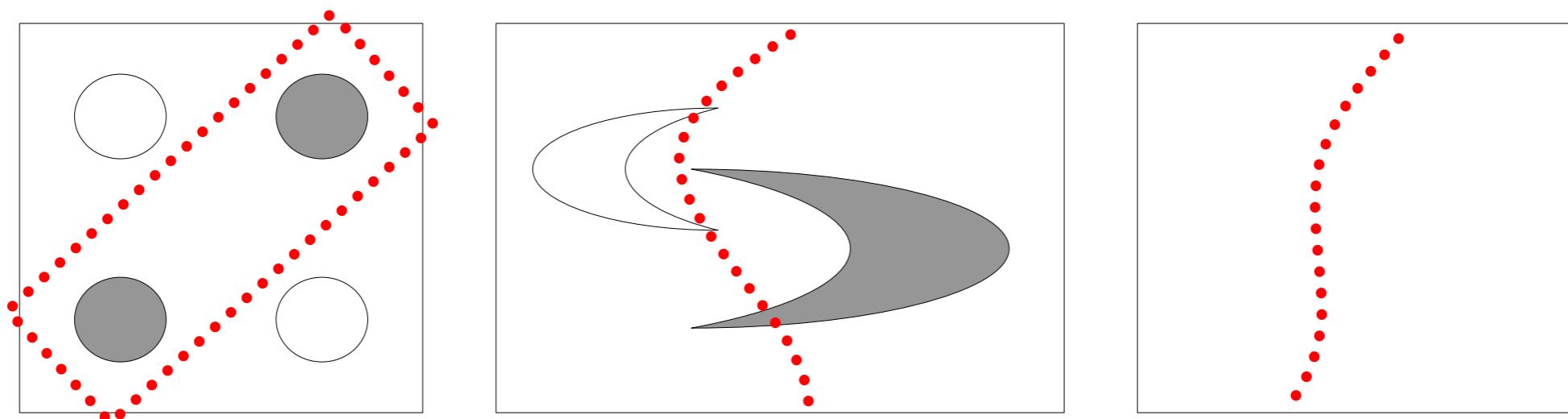
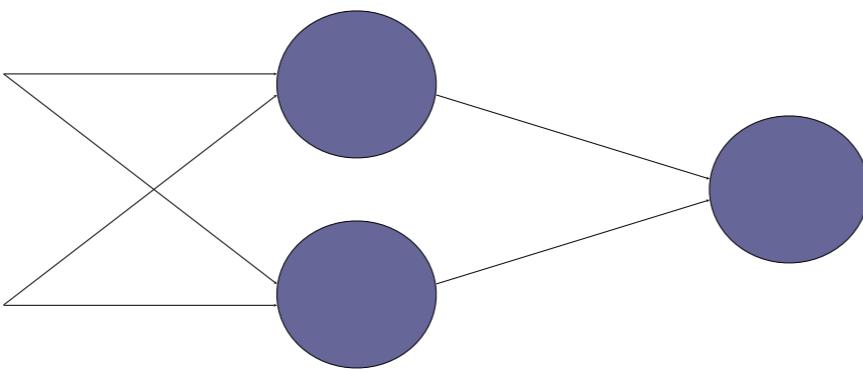


Decision boundaries of Perceptrons



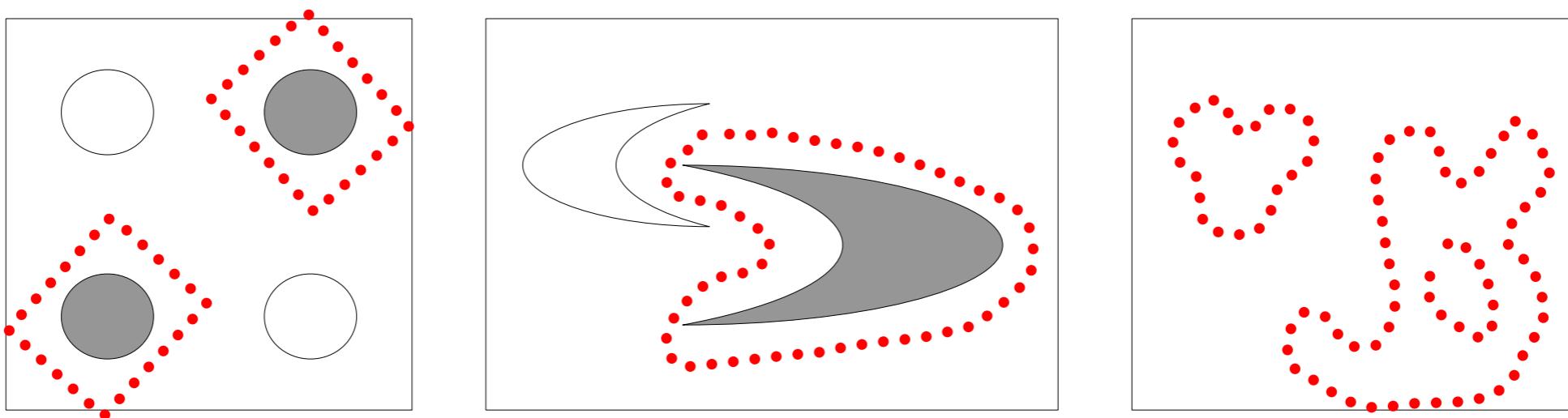
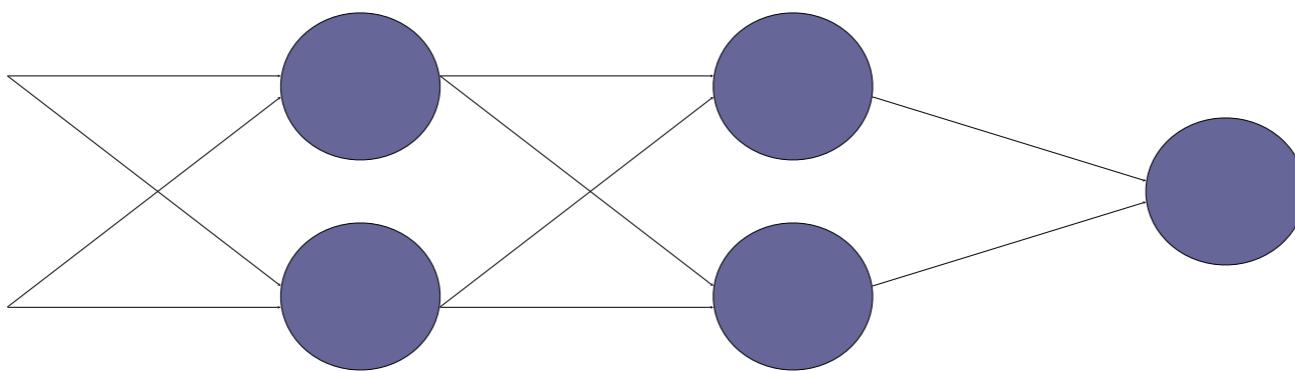
Straight lines (surfaces), linear separable

Decision boundaries of MLPs

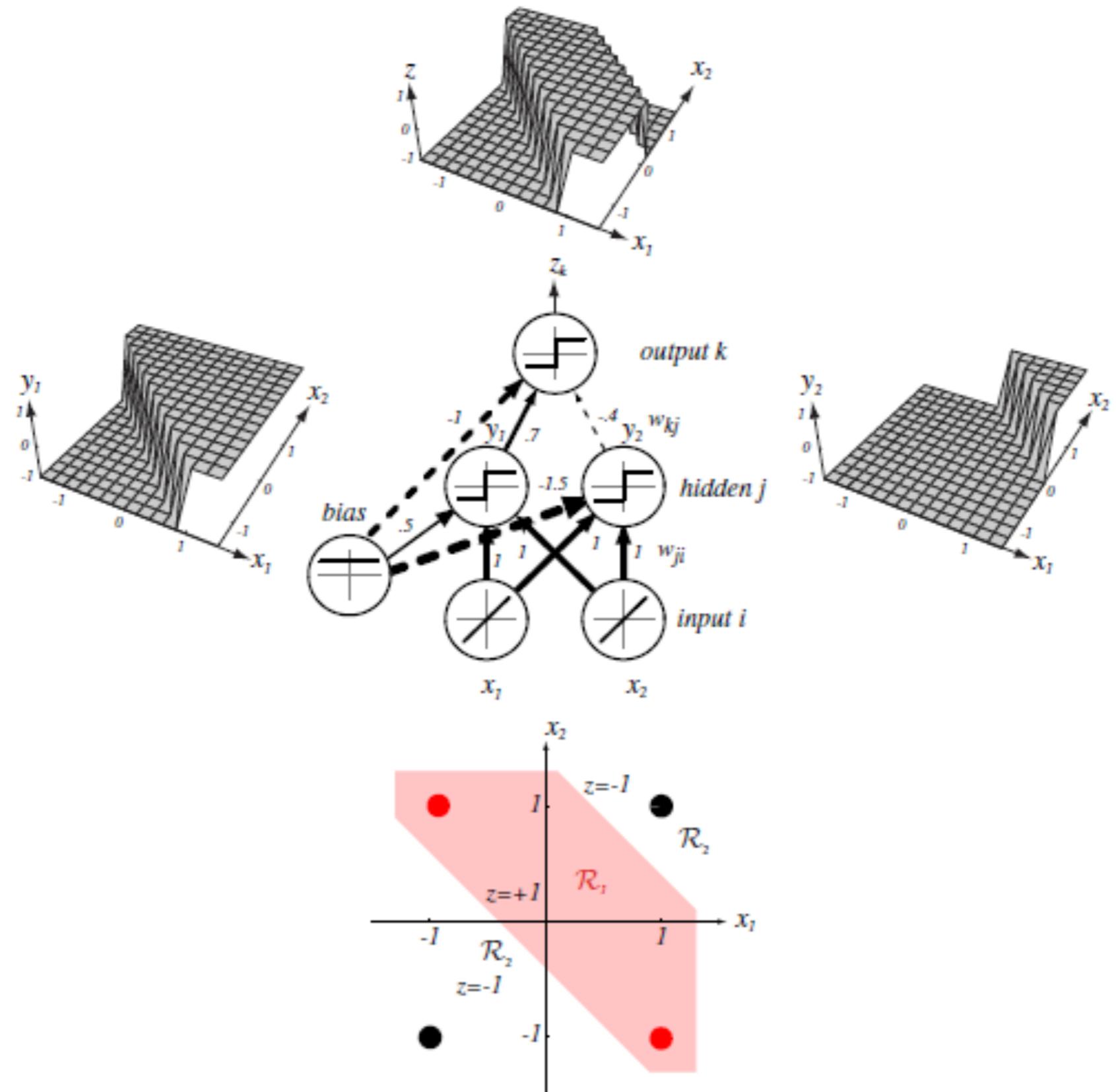


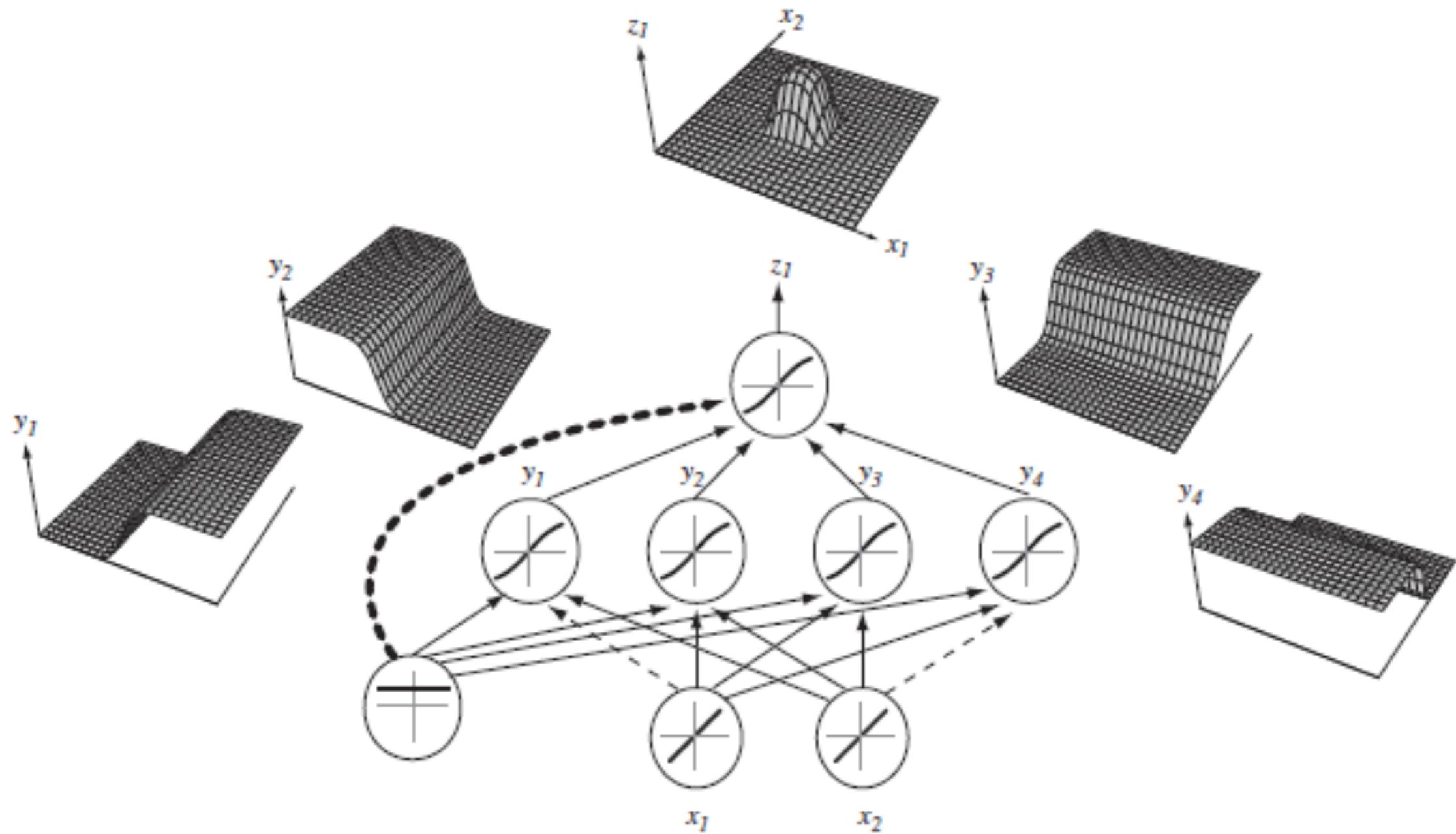
Convex areas (open or closed)

Decision boundaries of MLPs



Combinations of convex areas





Soft thresholds (sigmoid functions) allow for smoother decision boundaries

Hands-on exercise 1

Preliminaries



About numbers and bits

- Computers represent numbers in terms of bits (zeros and ones)
- Binary versus decimal numbers
- Brains are not computers but they have (kind of) binary elements

Representing images by numbers



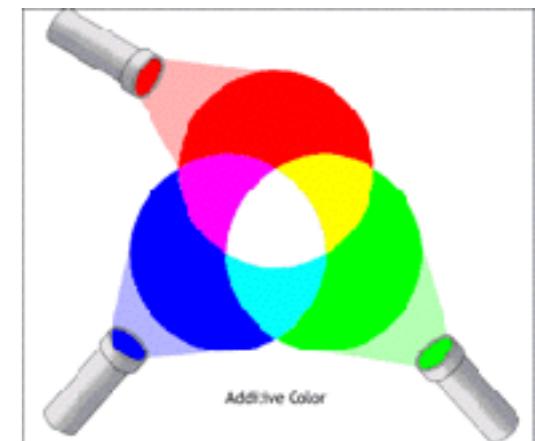
- In mathematics this is called a matrix (2D)
 - If all numbers form a row or column it is called a vector (1D)

- The number of different gray levels depends on the number of bits
- 1 bits: 2 levels
 - black and white
- 2 bits: 4 levels
 - Black, gray, white
- 3 bits: 8 levels
 - Black, 6 grays, white
- 8 bits: 256 levels
 - Black, 254 grays, white
- N bits: 2^N levels
 - Black, $2^N - 2$ grays, white

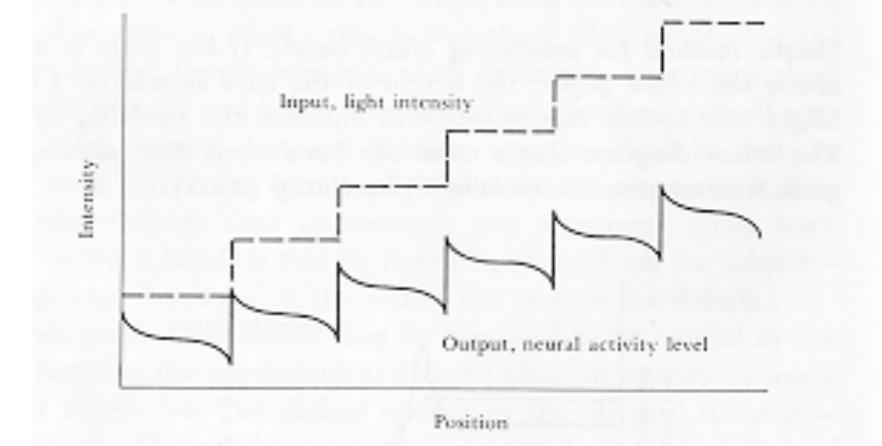
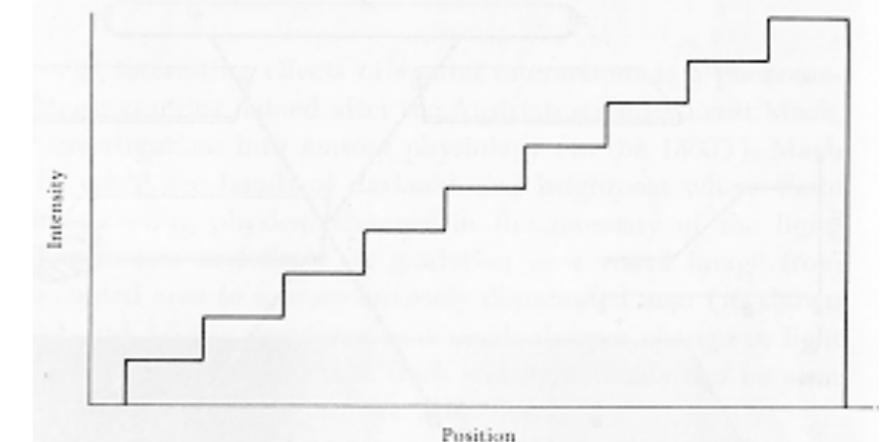
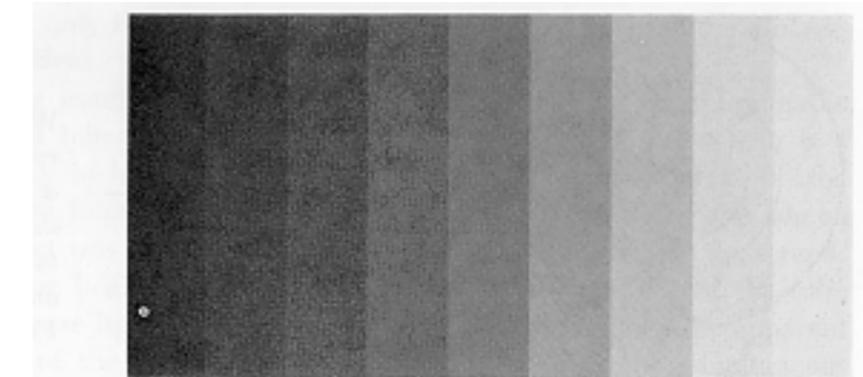
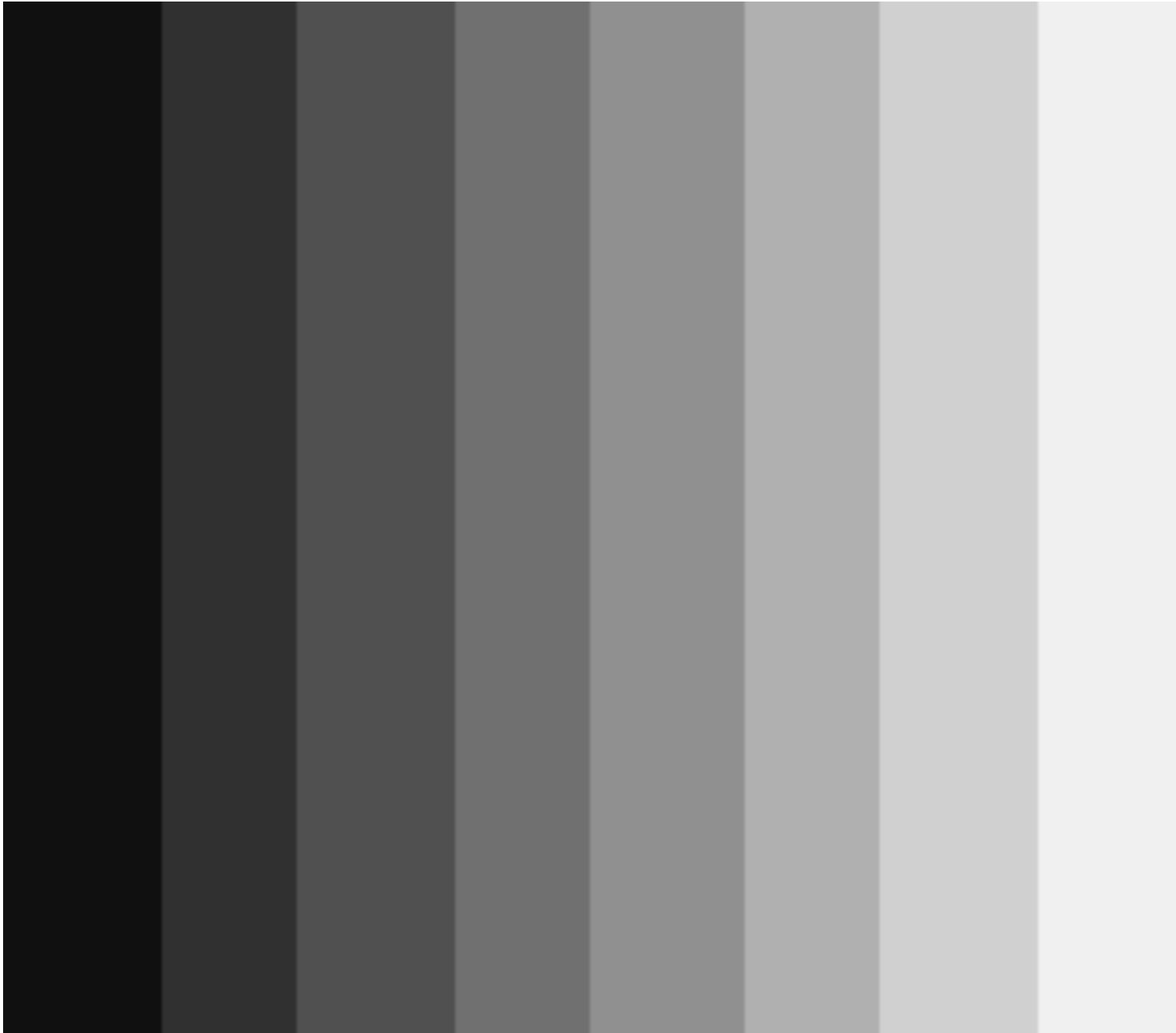


Color images

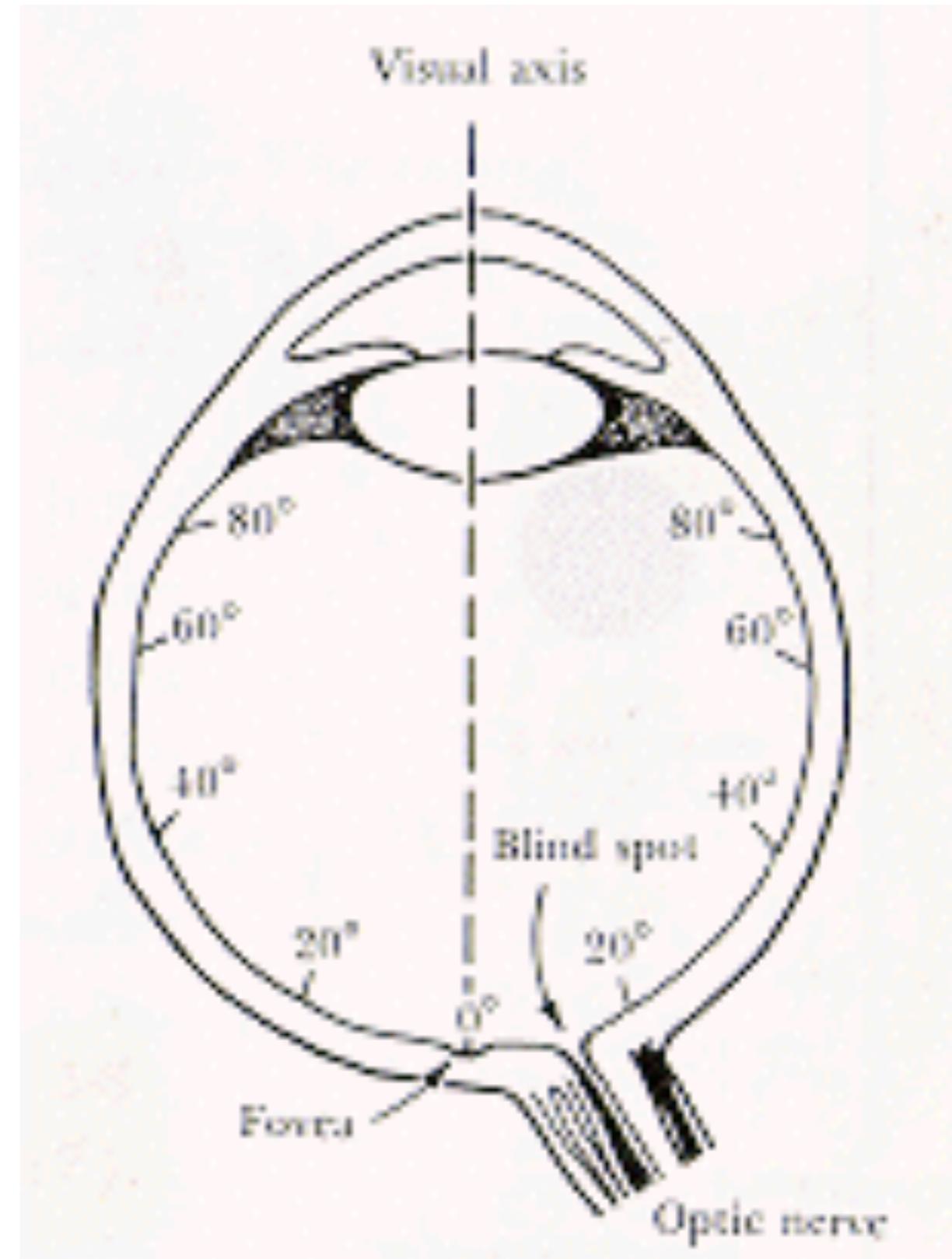
- Rows × columns × primary colors
- Number of primary colors is typically 3
- Red, Green, Blue
- Each represented by 8 bits
 - $256 \times 256 \times 256 = 16.777.216$ colours

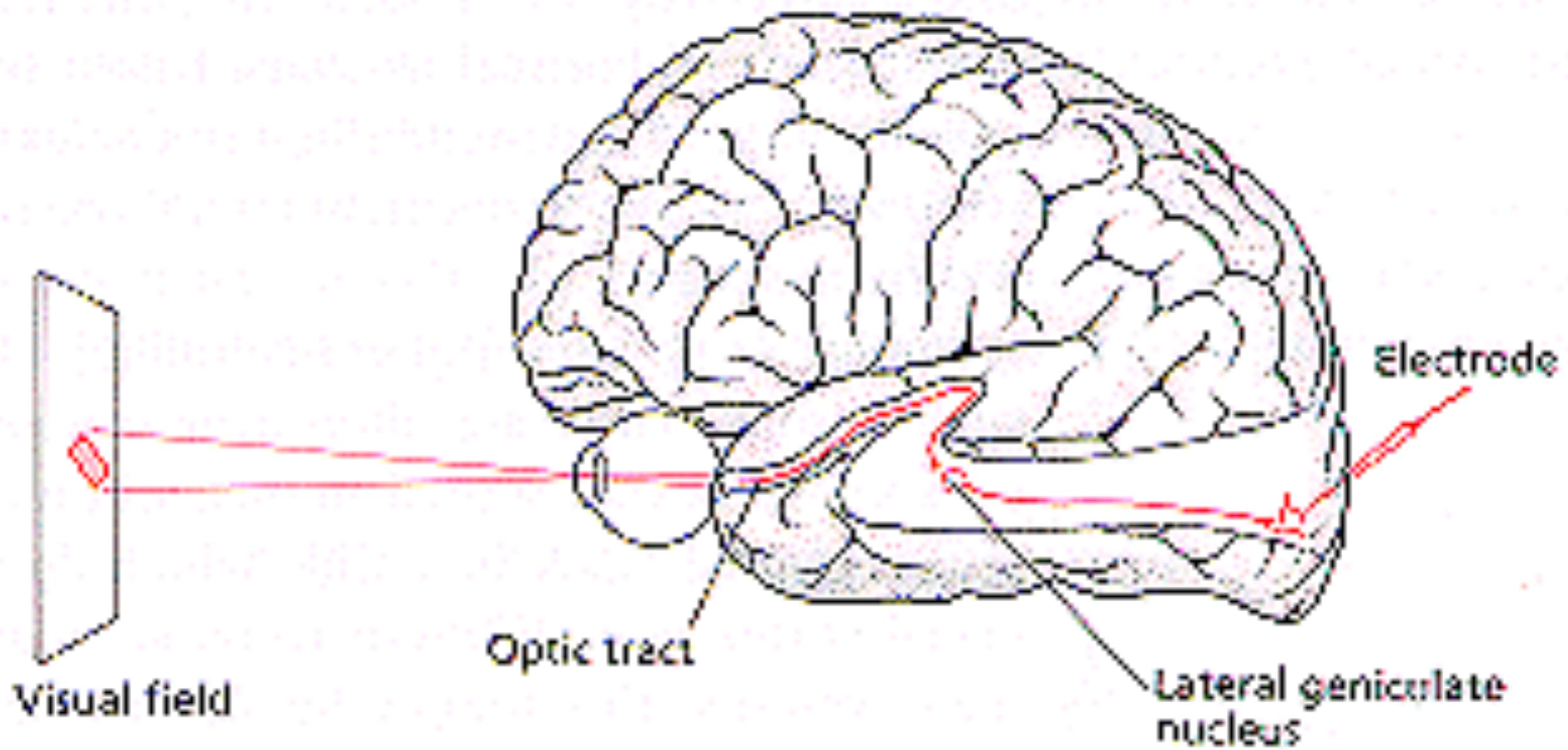


What you see is **not** what you get

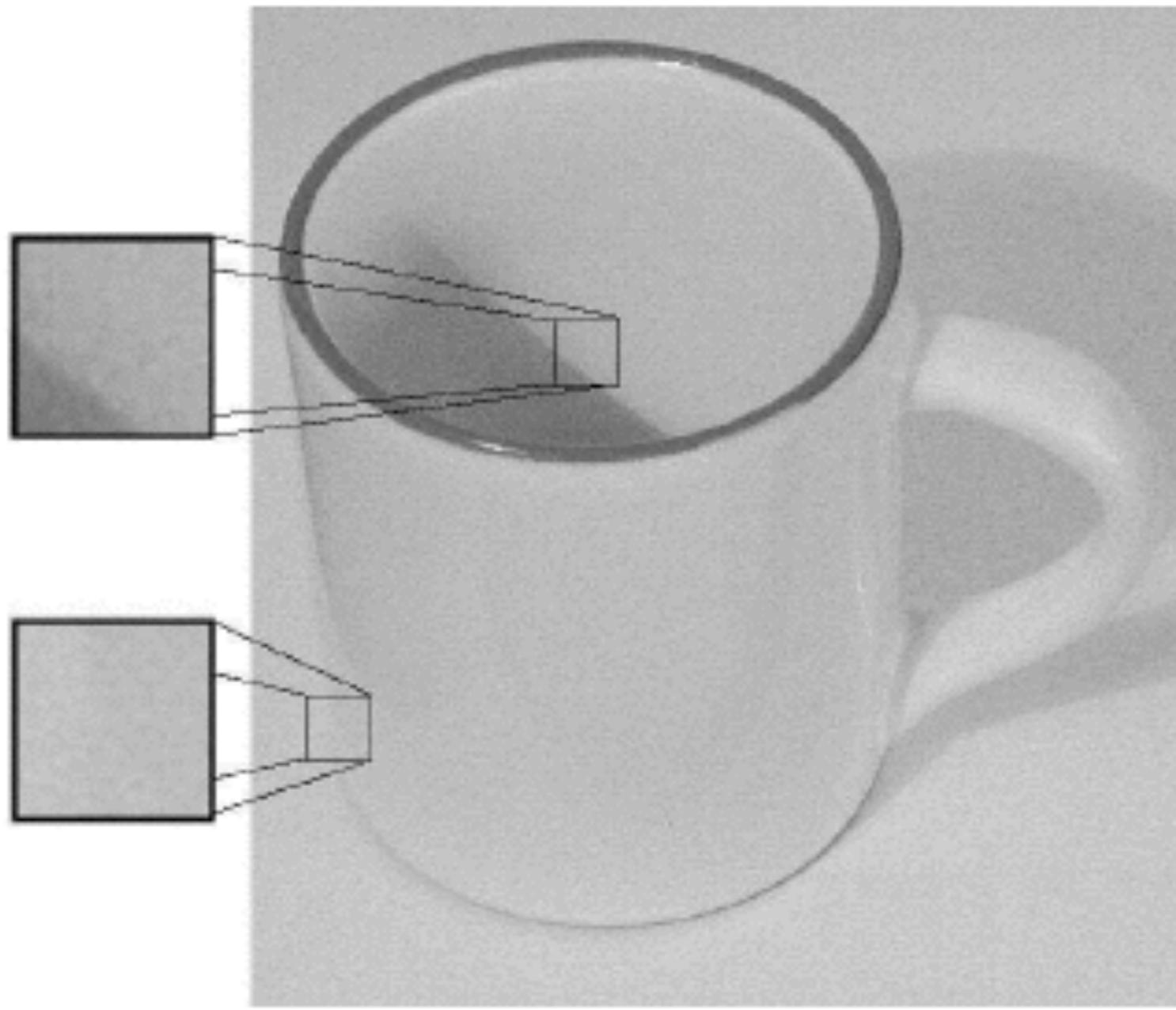


The eye and visual degrees

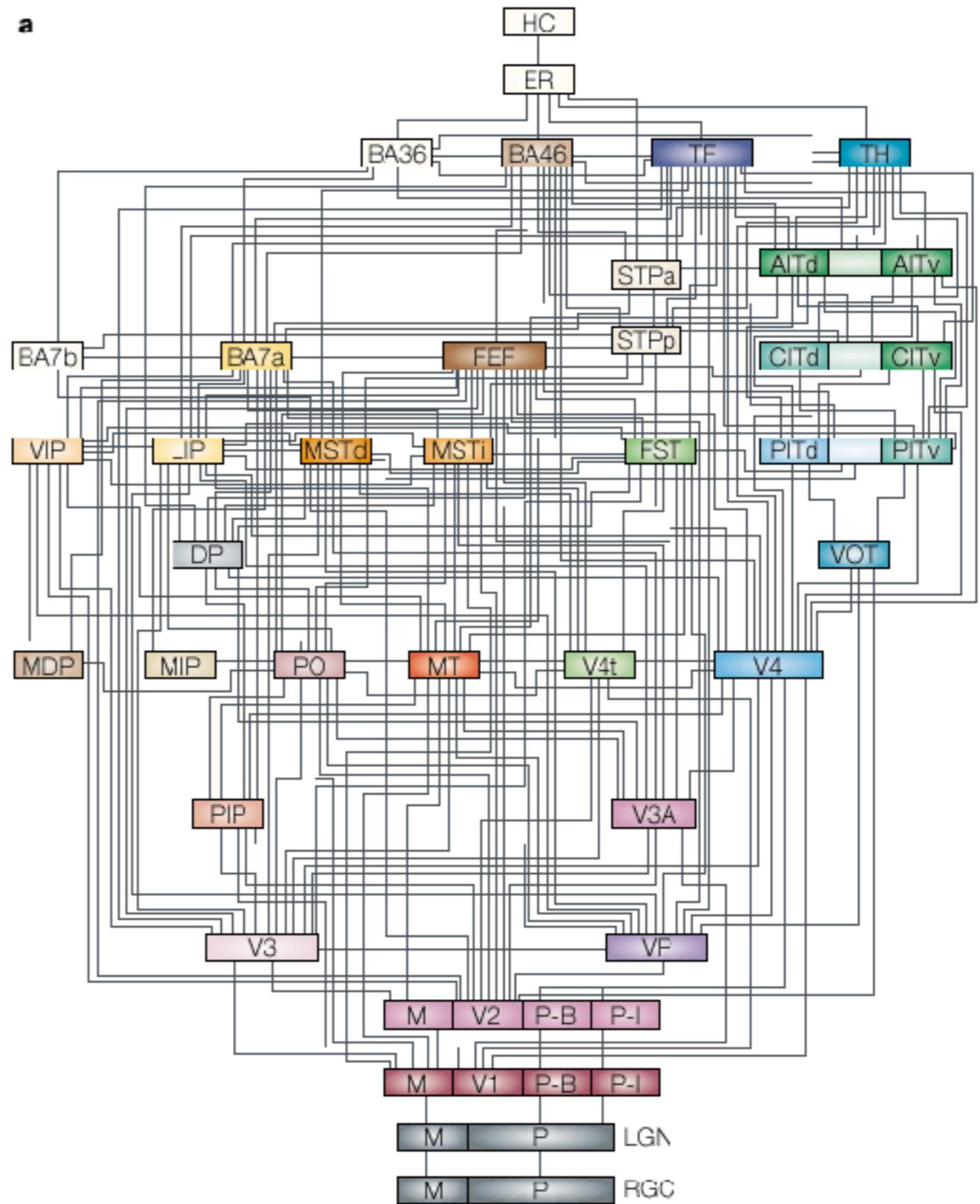




Contours (“edges”) are important



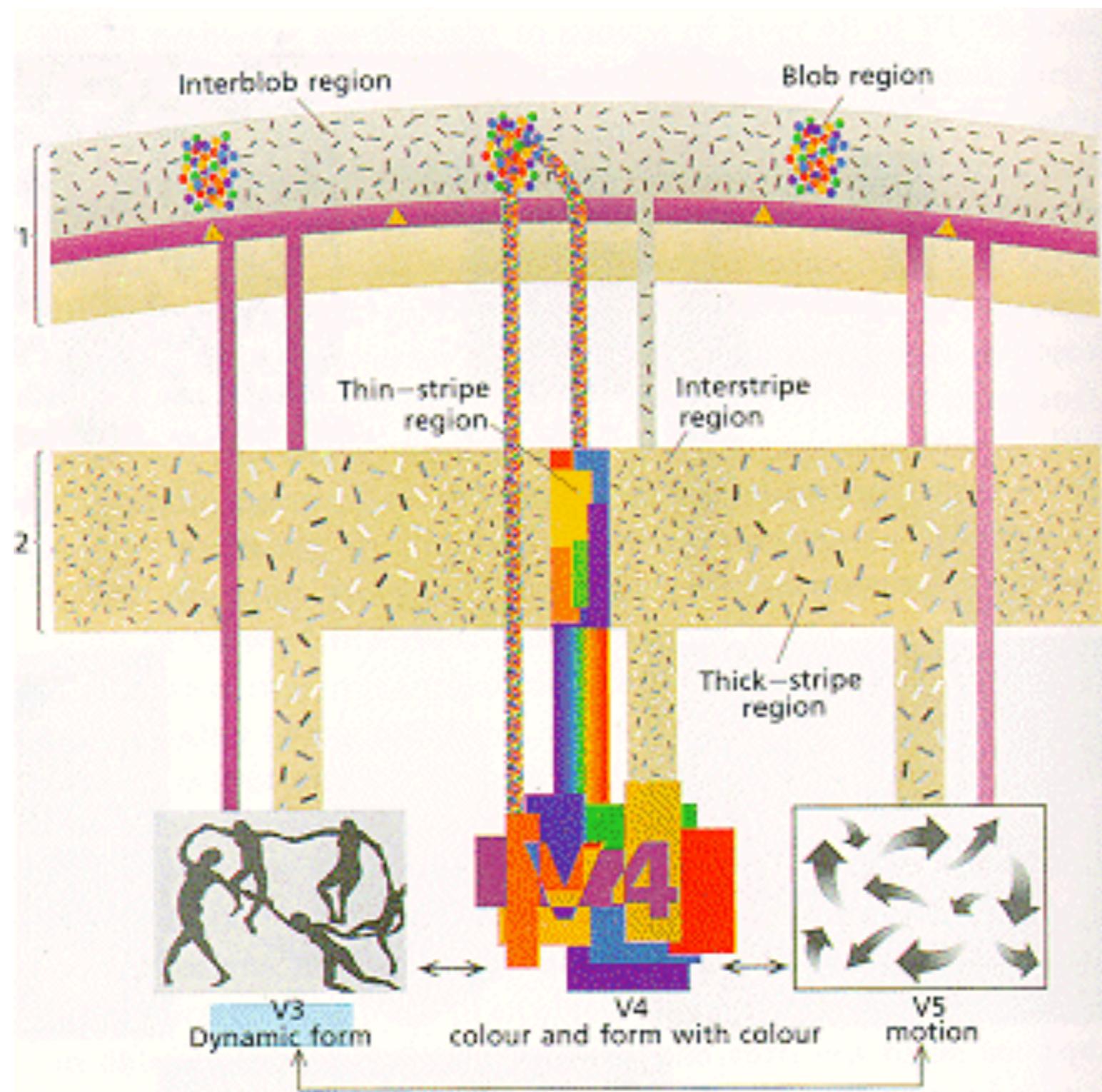
The Visual System



Multiple feature analysis

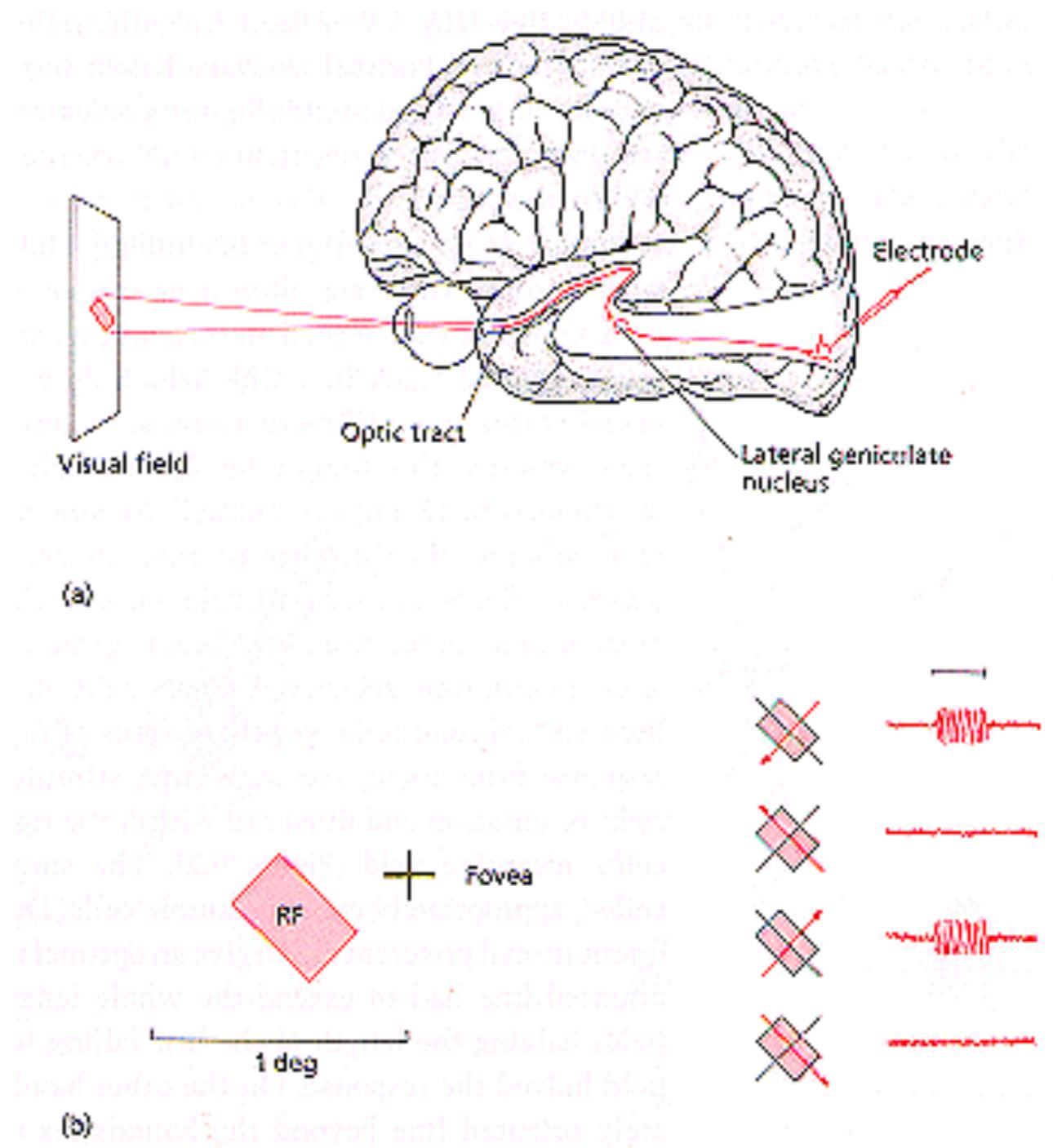
■ V1

■ V2



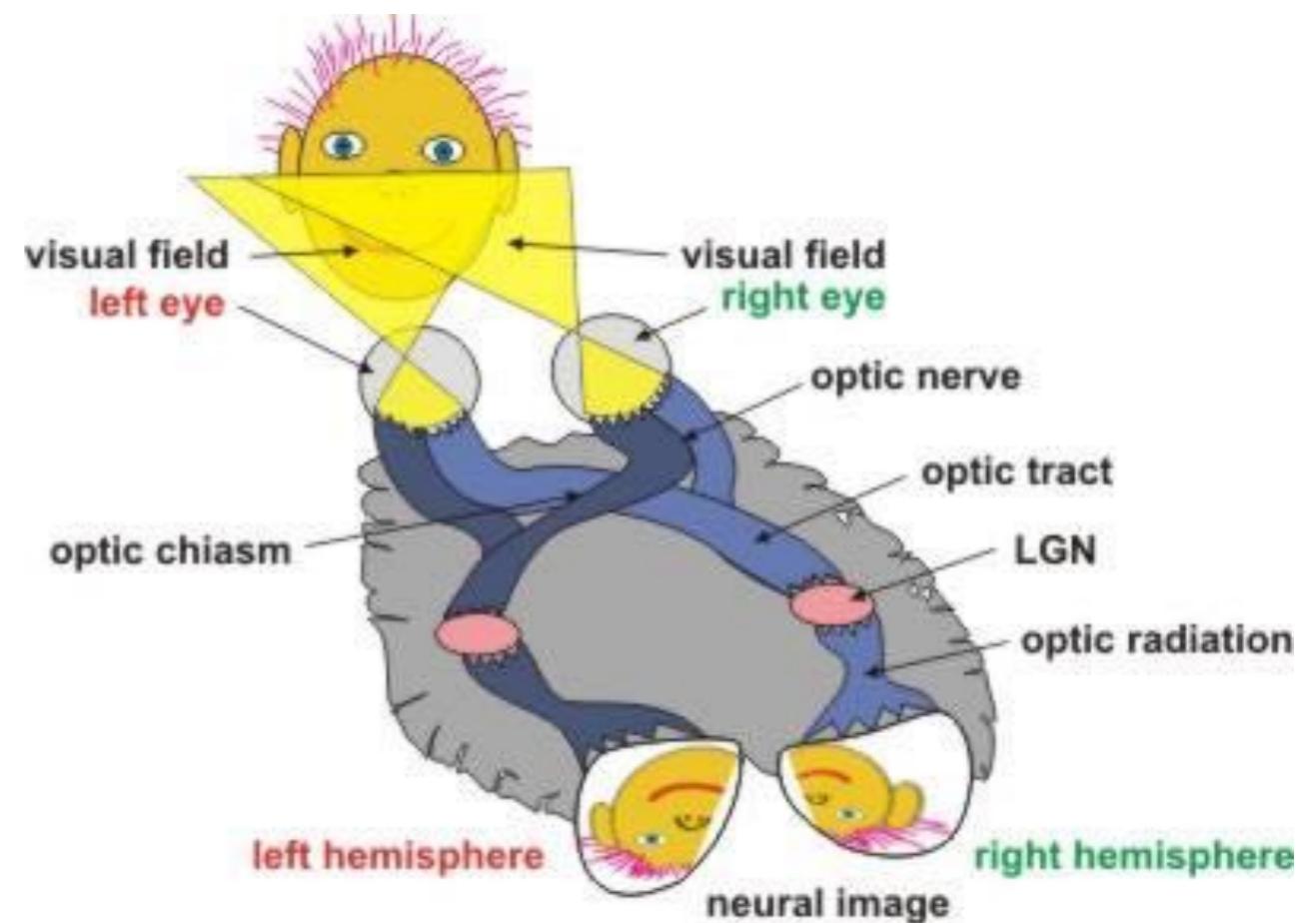
Feature analysis in V1 (and V2)

- orientation selectivity
 - Hubel & Wiesel
- color selectivity
- direction of motion selectivity
- size (spatial-frequency) selectivity
- texture selectivity



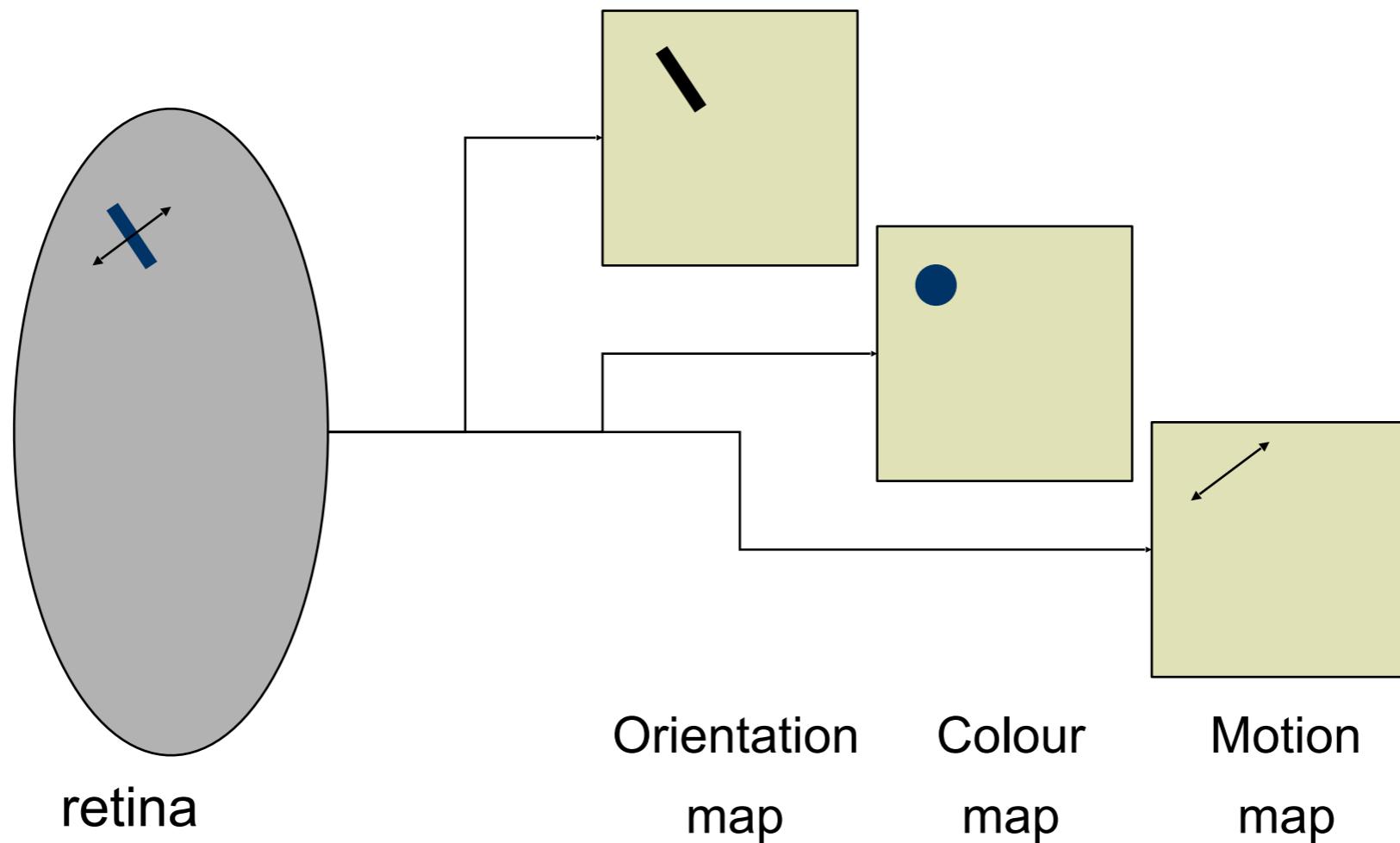
Feature maps in the visual system

- For each visual “point” (= retinal receptor)
 - “detector-cells” in all orientations
- Retinotopic organization
 - V1 neurons are spatially organized in a way that reflects the spatial organization of the retina



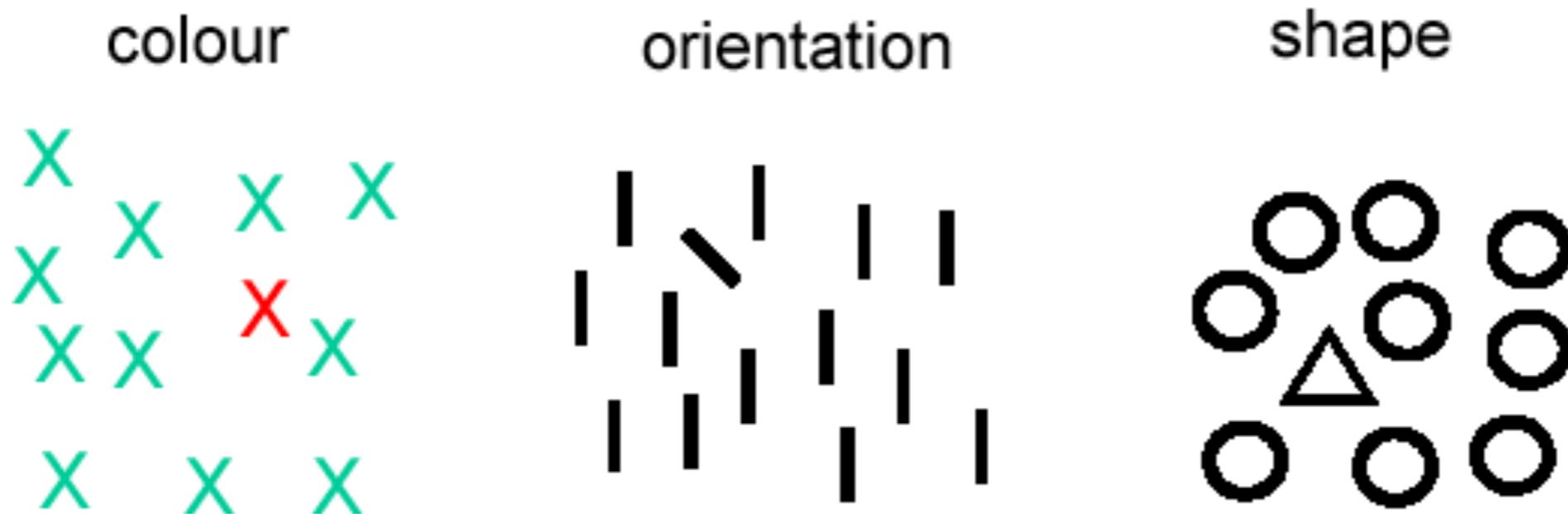
Retinotopic maps in the visual system

- The visual system has many retinotopically-organised feature maps



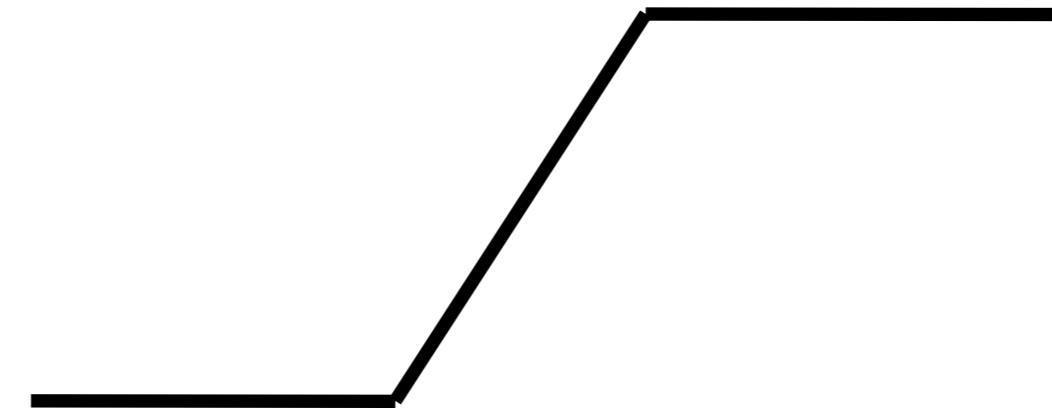
What happens in feature maps?

- Very similar to what current computer vision systems do
- Look for “features” at all locations of the retinal image
- Features: edges, oriented contours, colours, textures, ...



Receptive fields

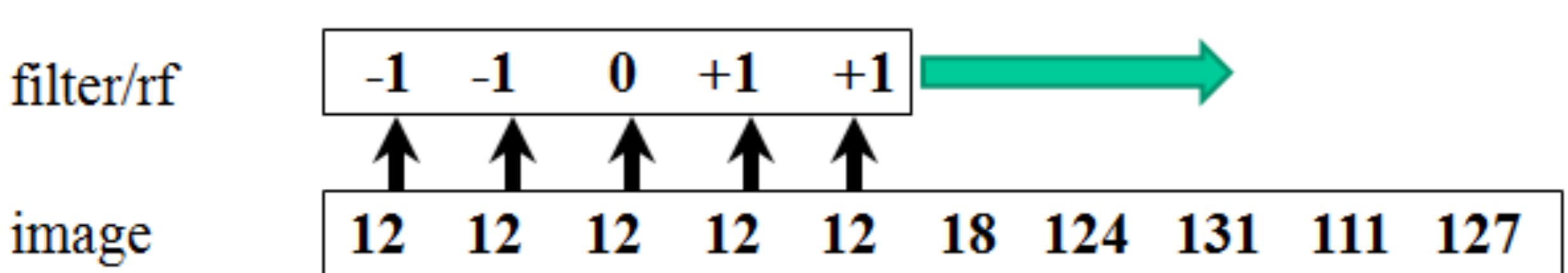
- “Edge detector” (dark to light)



-1	-1	0	+1	+1
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Filter/receptive field

- A filter contains values (coefficients) each of which is multiplied with the corresponding pixel value in the image



- Homogeneous image region: no edge detected

result

.... **0**

filter/rf

-1 -1 **0** +1 +1

image

12 12 12 12 12 18 124 131 111 127



$$(-1 \cdot -1 + 0 \cdot 1 + 1 \cdot 1 = 0)$$

- Inhomogeneous image region: edge detected

result

.... **231**



$$(-1 \cdot -1 + 0 + 1 \cdot 24 + 1 \cdot 31 = 231)$$

filter/rf

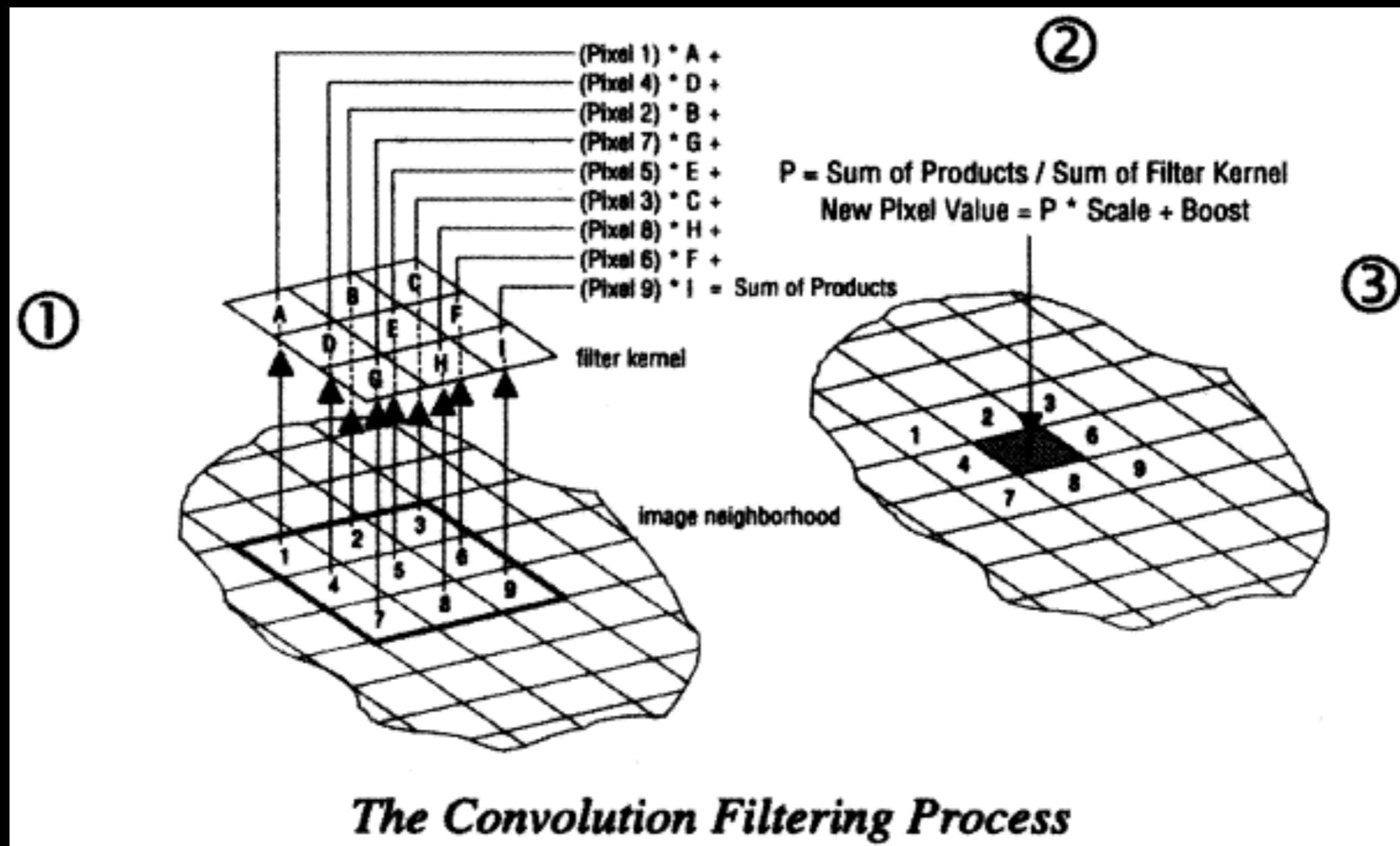
-1 -1 0 +1 +1



image

12 12 12 12 12 18 124 131 111 127

Convolution



Computer Vision: Sobel edge detector

- Applies 2 filters
(1 vertical and 1 horizontal)

-1	0	+1
-2	0	+2
-1	0	+1

Gx

+1	+2	+1
0	0	0
-1	-2	-1

Gy



Laplace edge detector

- Applies a 5×5 filter to each image location

-1	-1	-1	-1	-1
-1	-1	-1	-1	-1
-1	-1	24	-1	-1
-1	-1	-1	-1	-1
-1	-1	-1	-1	-1



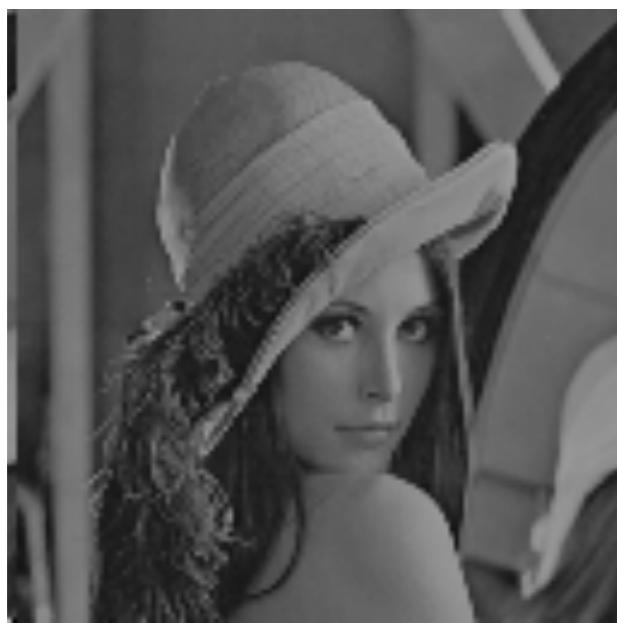
Canny edge detector

1. Gaussian blurring
2. Sobel edge detector

$$\frac{1}{115} \begin{array}{|c|c|c|c|c|}\hline 2 & 4 & 5 & 4 & 2 \\ \hline 4 & 9 & 12 & 9 & 4 \\ \hline 5 & 12 & 15 & 12 & 5 \\ \hline 4 & 9 & 12 & 9 & 4 \\ \hline 2 & 4 & 5 & 4 & 2 \\ \hline \end{array}$$

Steps 3-6: tracing edges

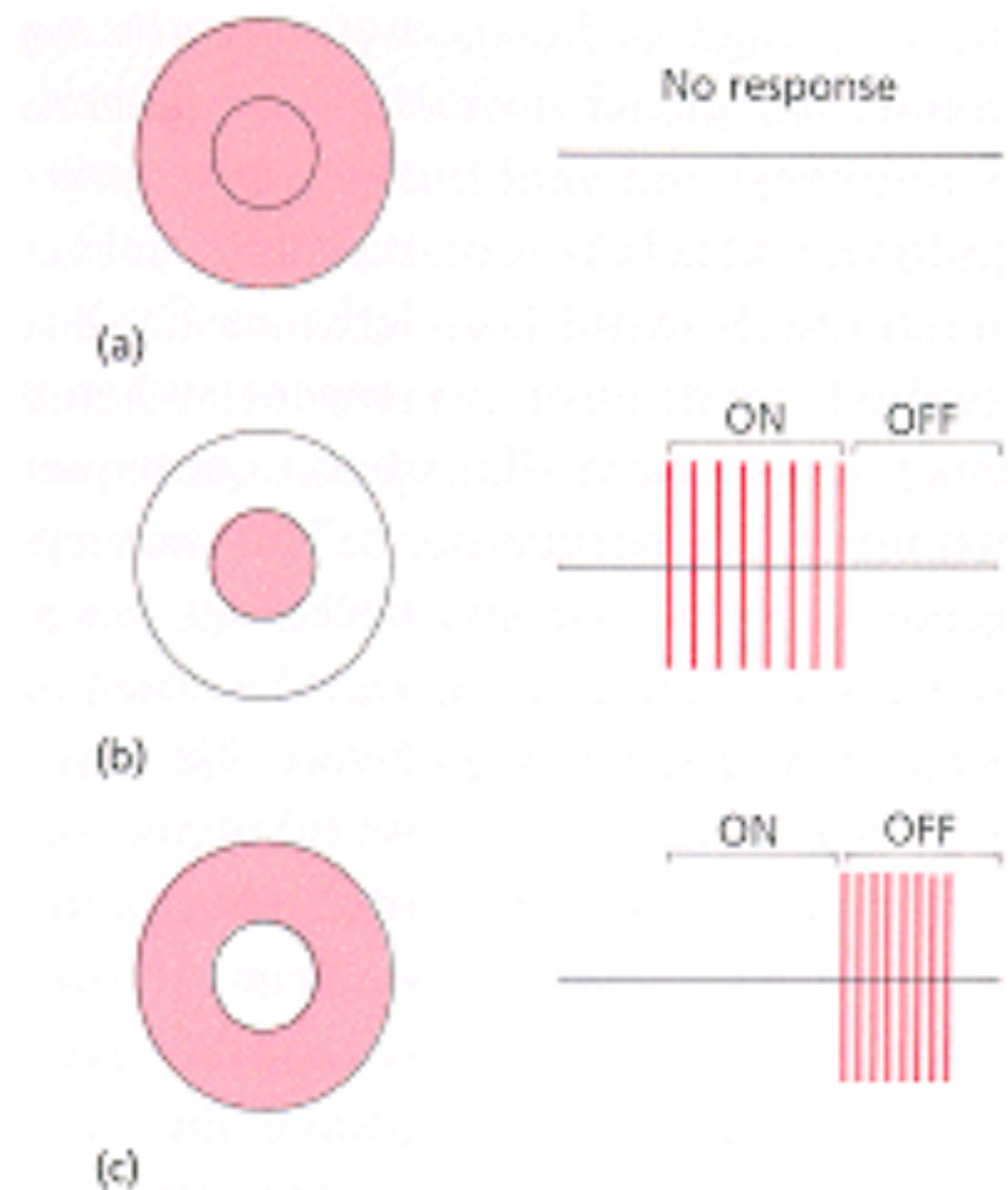
Figure 3 Discrete approximation to Gaussian function with $\sigma=1.4$

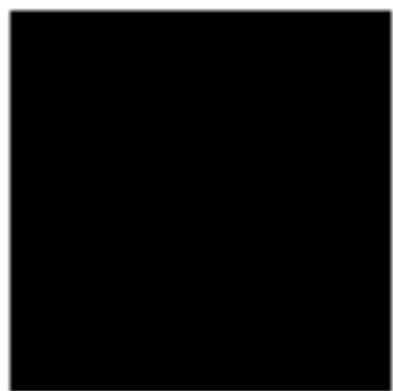
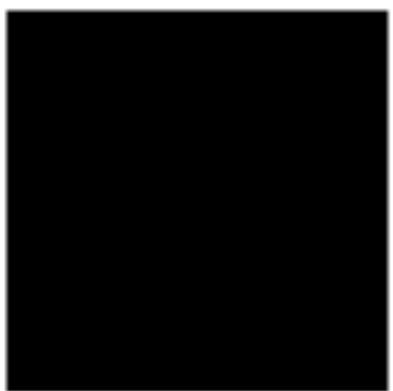
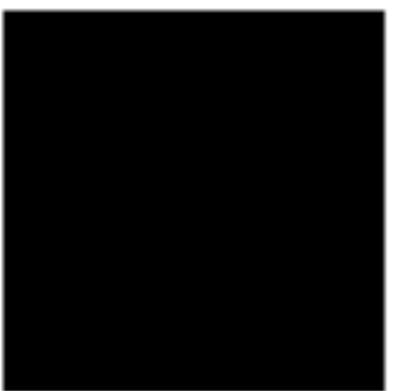
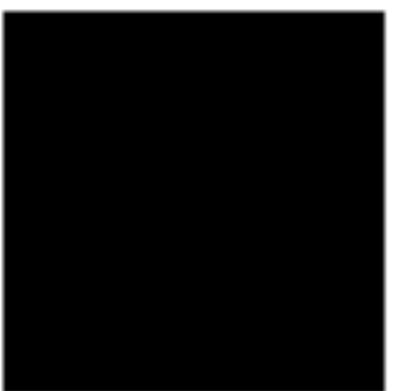


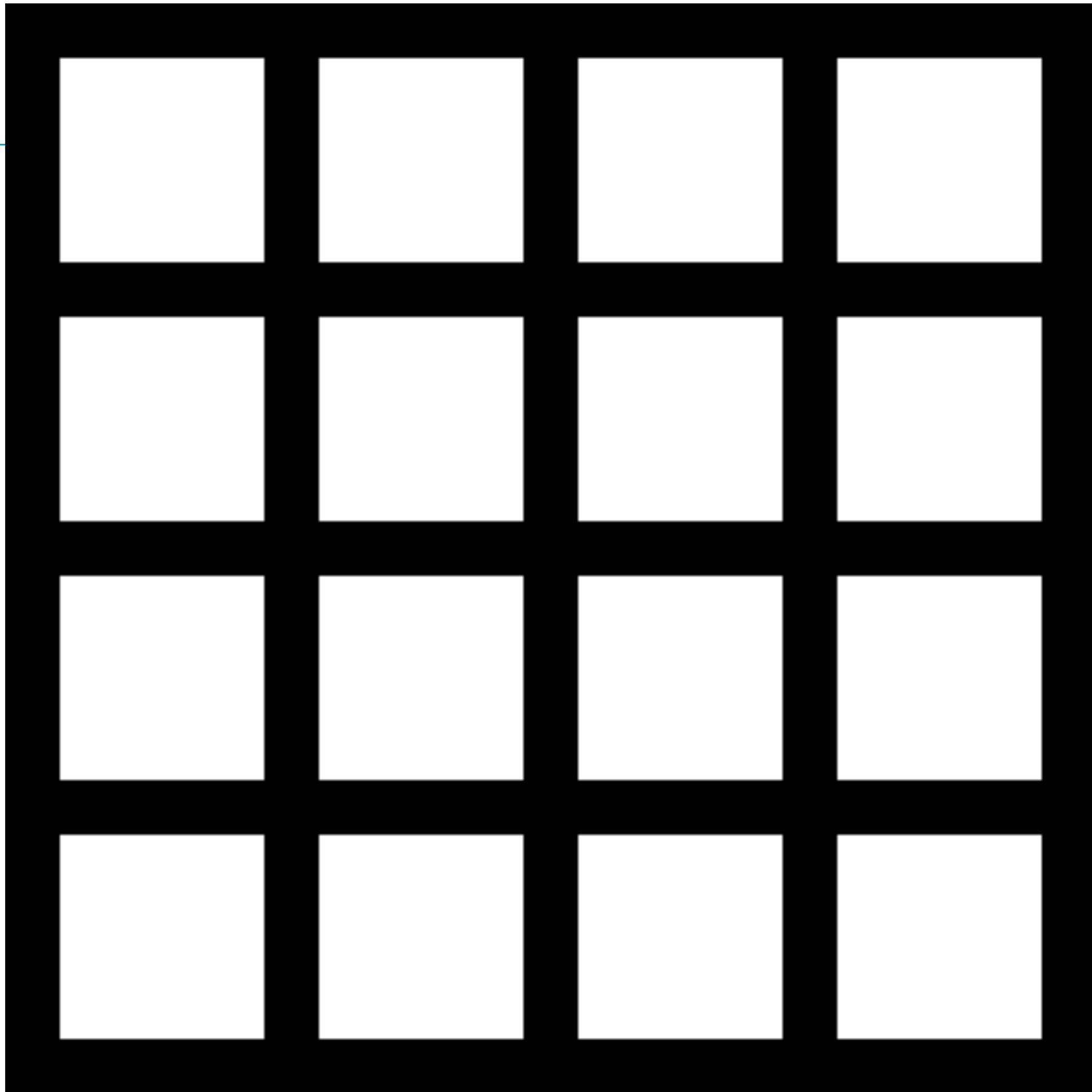
Hands-on exercise 2

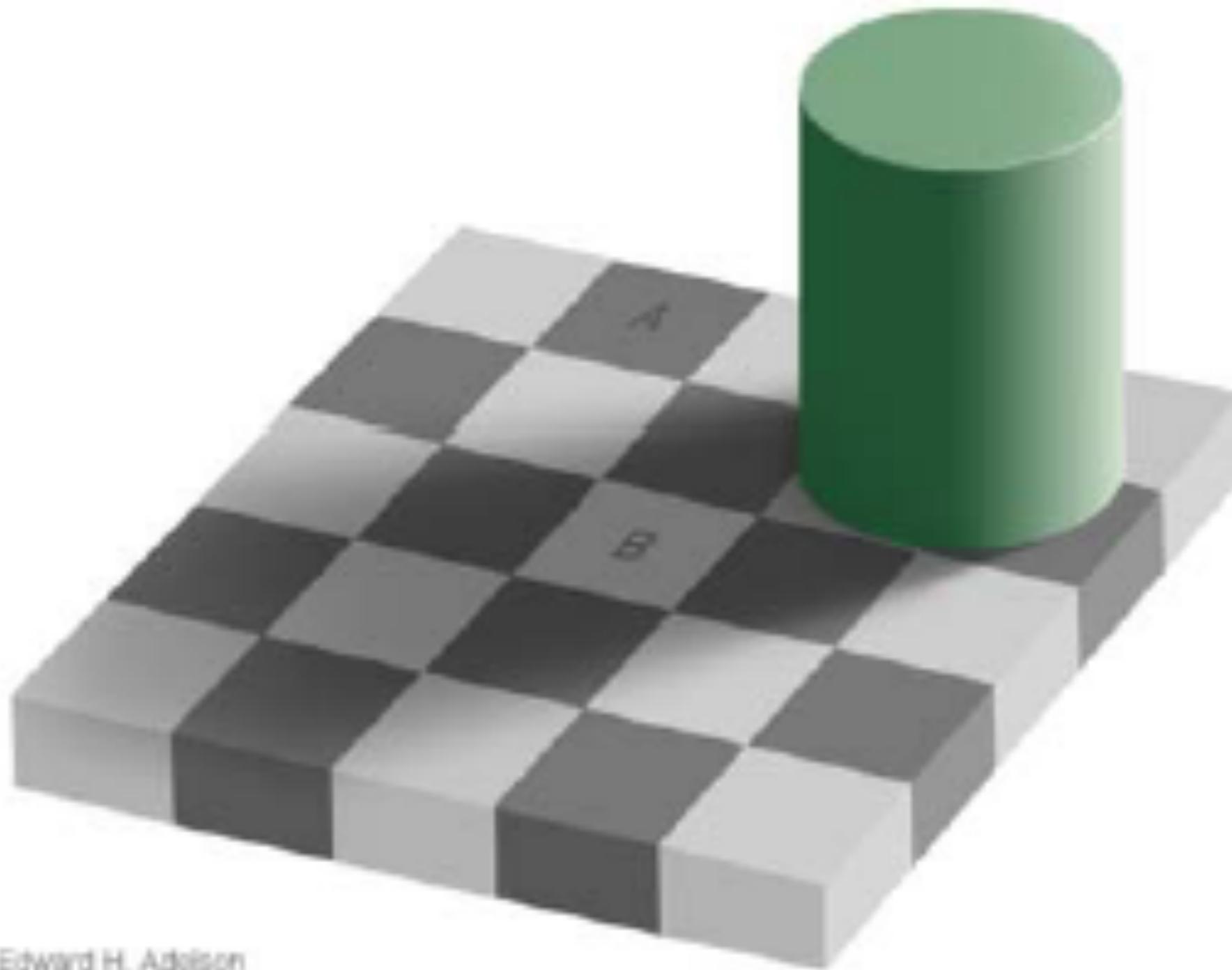
On-center off-surround cell

- a Diffuse light does not activate the cell
- b Light focused on the centre does activate the cell
- b Light focused on the surround generates an “off” response







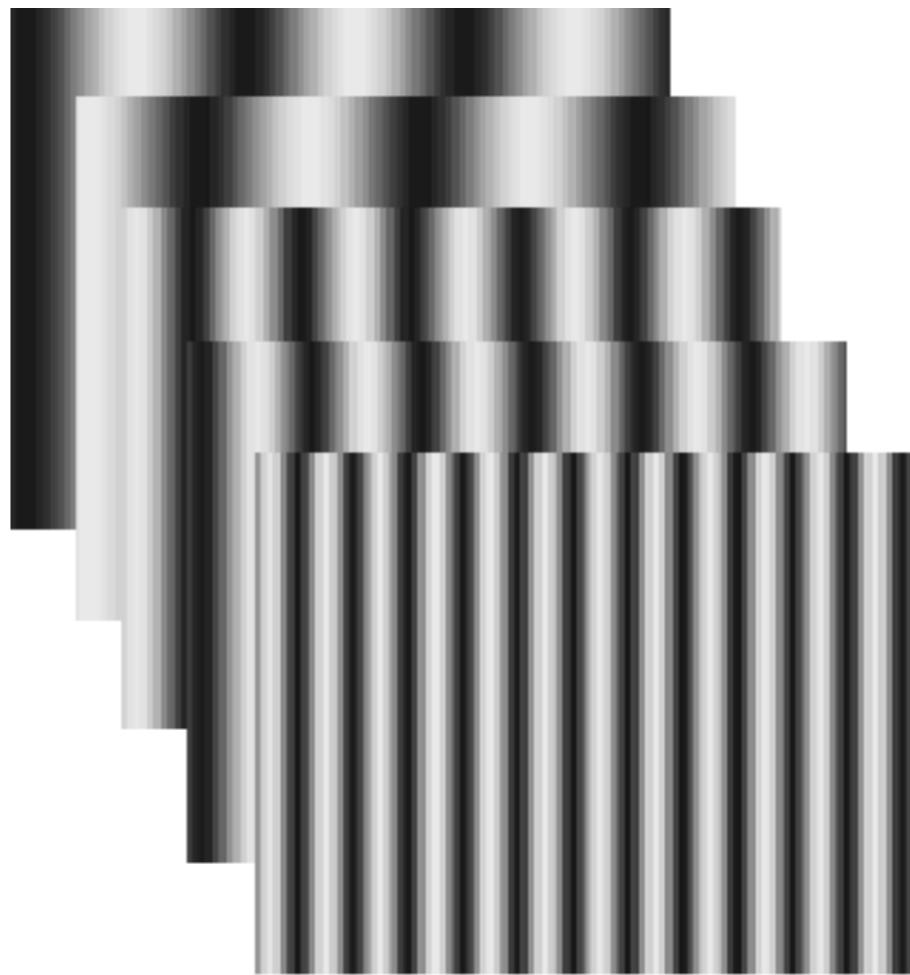


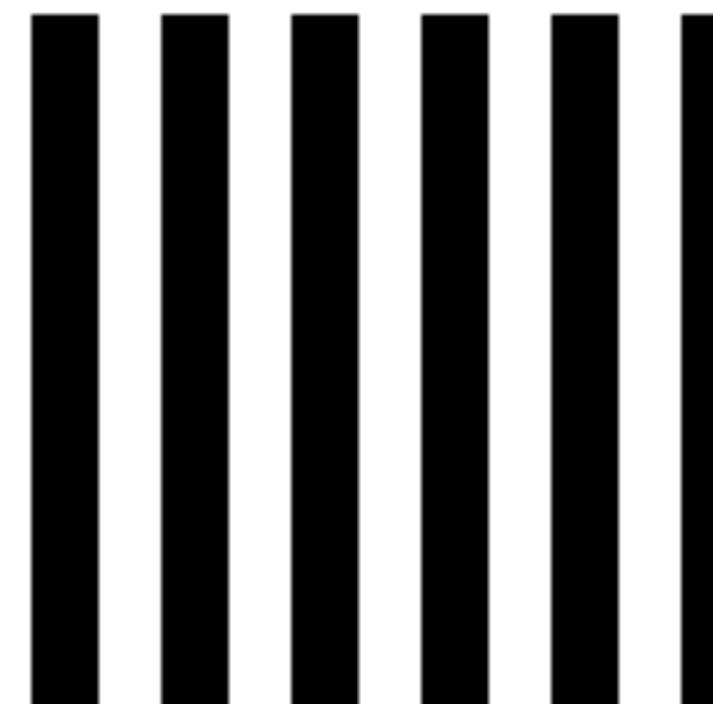
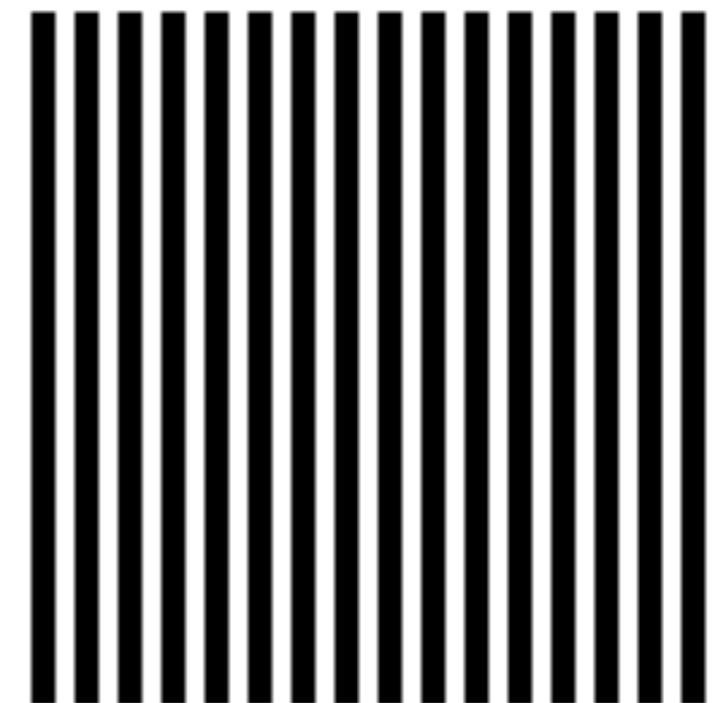
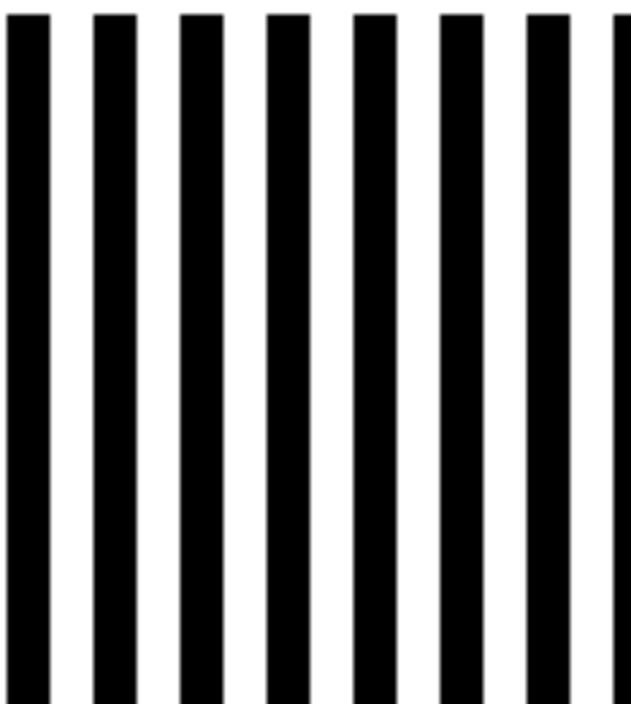
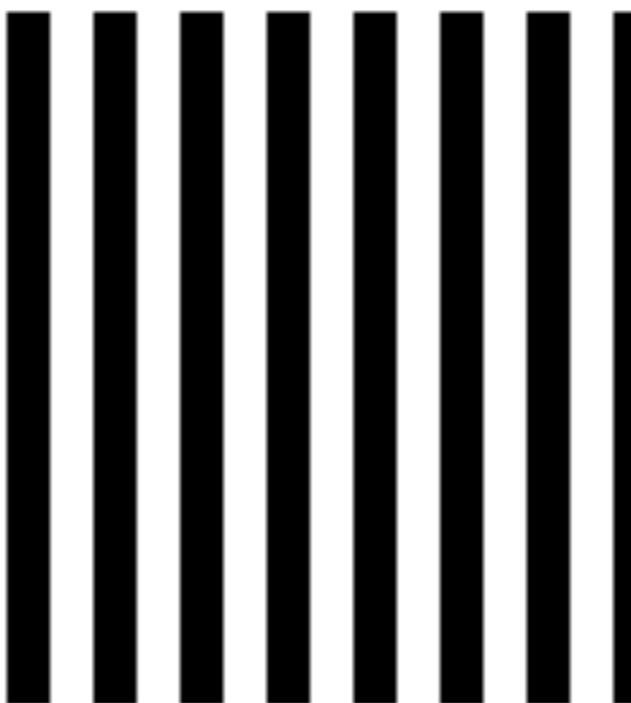
Edward H. Adelson

Convolution, Fourier and Gabor

- Fourier transform operates globally on images
 - extracts the global spatial frequencies and orientations of visual images
 - e.g., details of the face + face + other faces + bodies + background
- Gabor transform operates locally on images
 - extracts the local spatial frequencies and orientations of visual images
 - e.g., details of the face
- Convolution
 - comparing a template (or filter) with the local contents of an image at each image position
 - i.e., local comparison/filtering, but global operation
- Convolution can be performed in the spatial domain or in the Fourier domain

Feature extraction: example in vision





Jean Baptiste Joseph Fourier

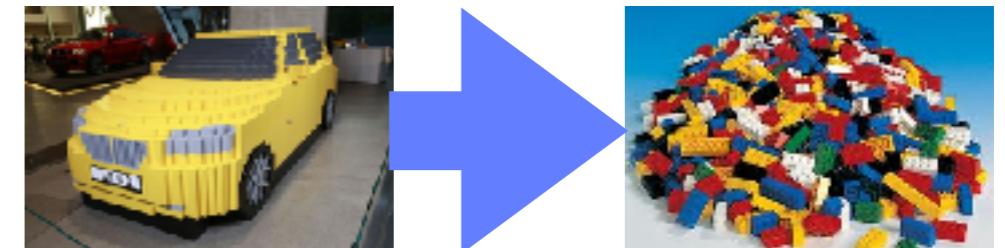


March 21, 1768 - May 16, 1830
Born Auxerre, France.
Died Paris, France.

Analysis & synthesis

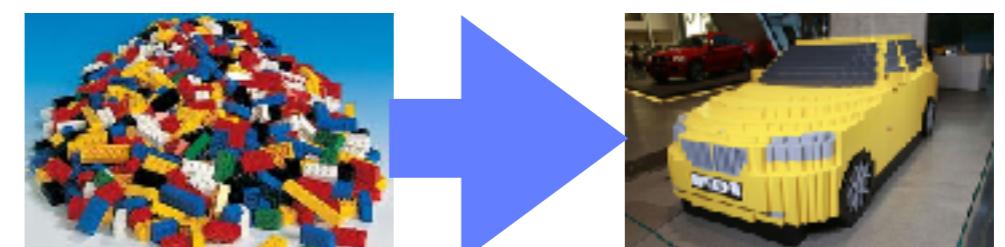
■ FOURIER ANALYSIS

- The representation of a periodic sound or waveform as a sum of Fourier components (i.e. pure sinusoidal waves).



■ FOURIER SYNTHESIS

- The construction of a periodic signal on the basis of Fourier coefficients which give the amplitude and phase of each component sine wave.



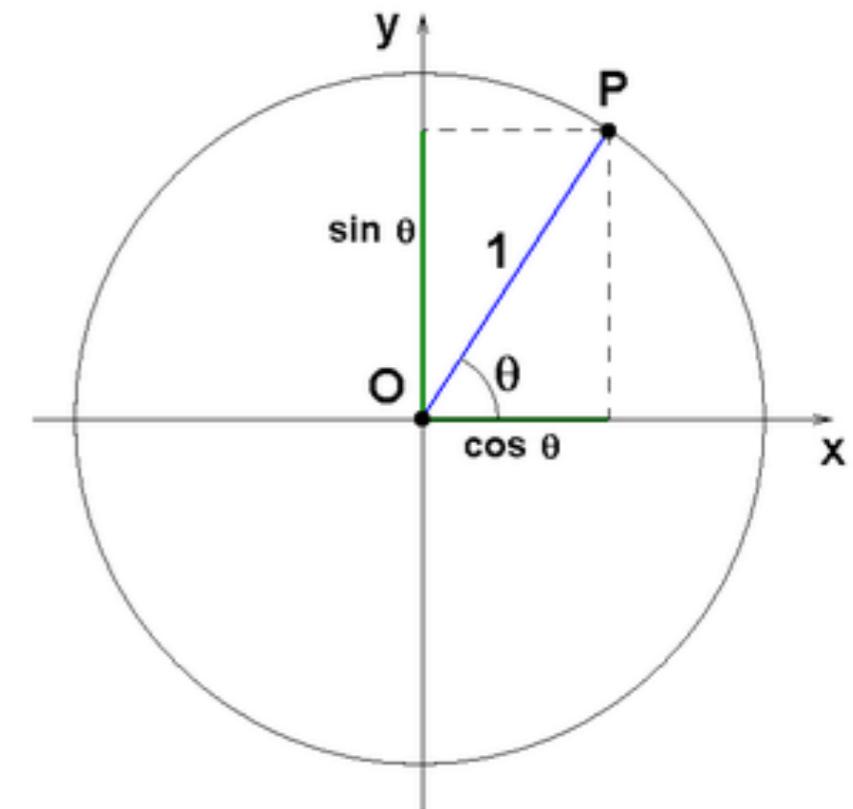
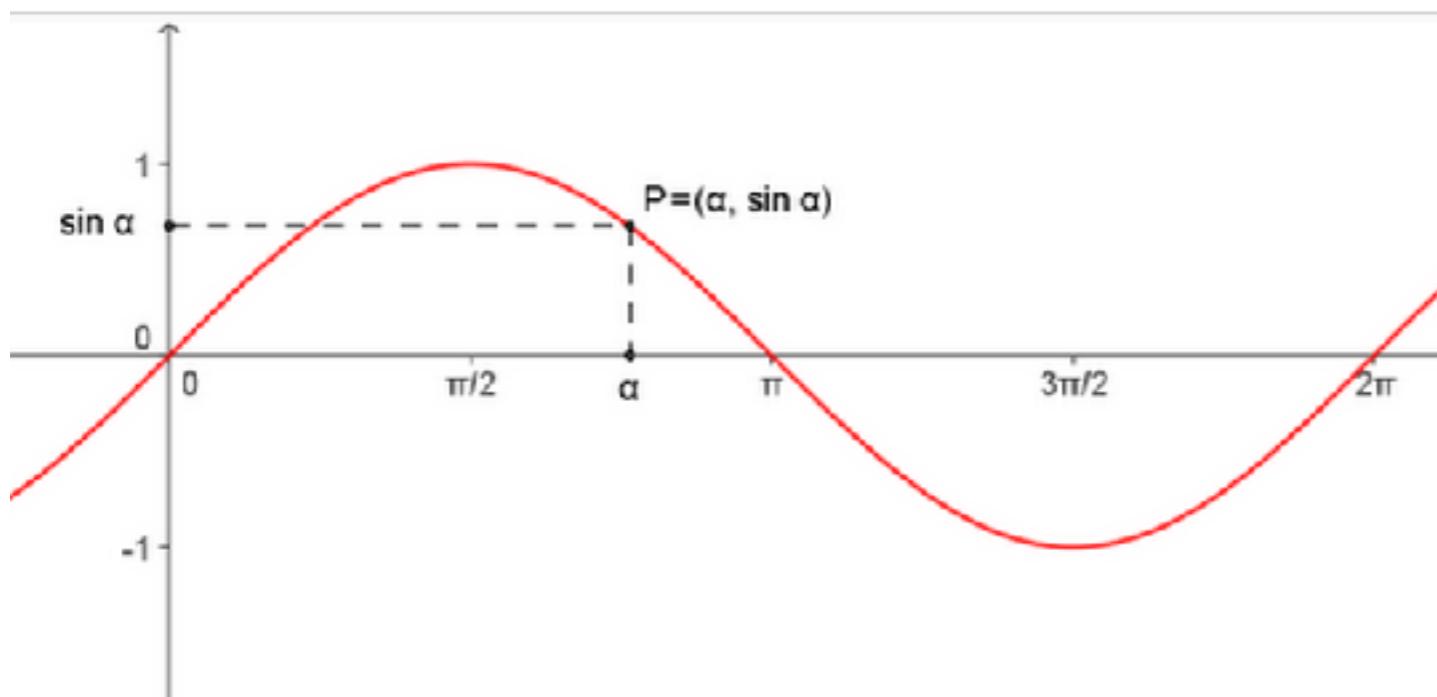
Frequency

- 1-dimensional (e.g., speech)
 - For instance, auditory signals
 - High frequency: high pitch
 - Low frequency: low pitch

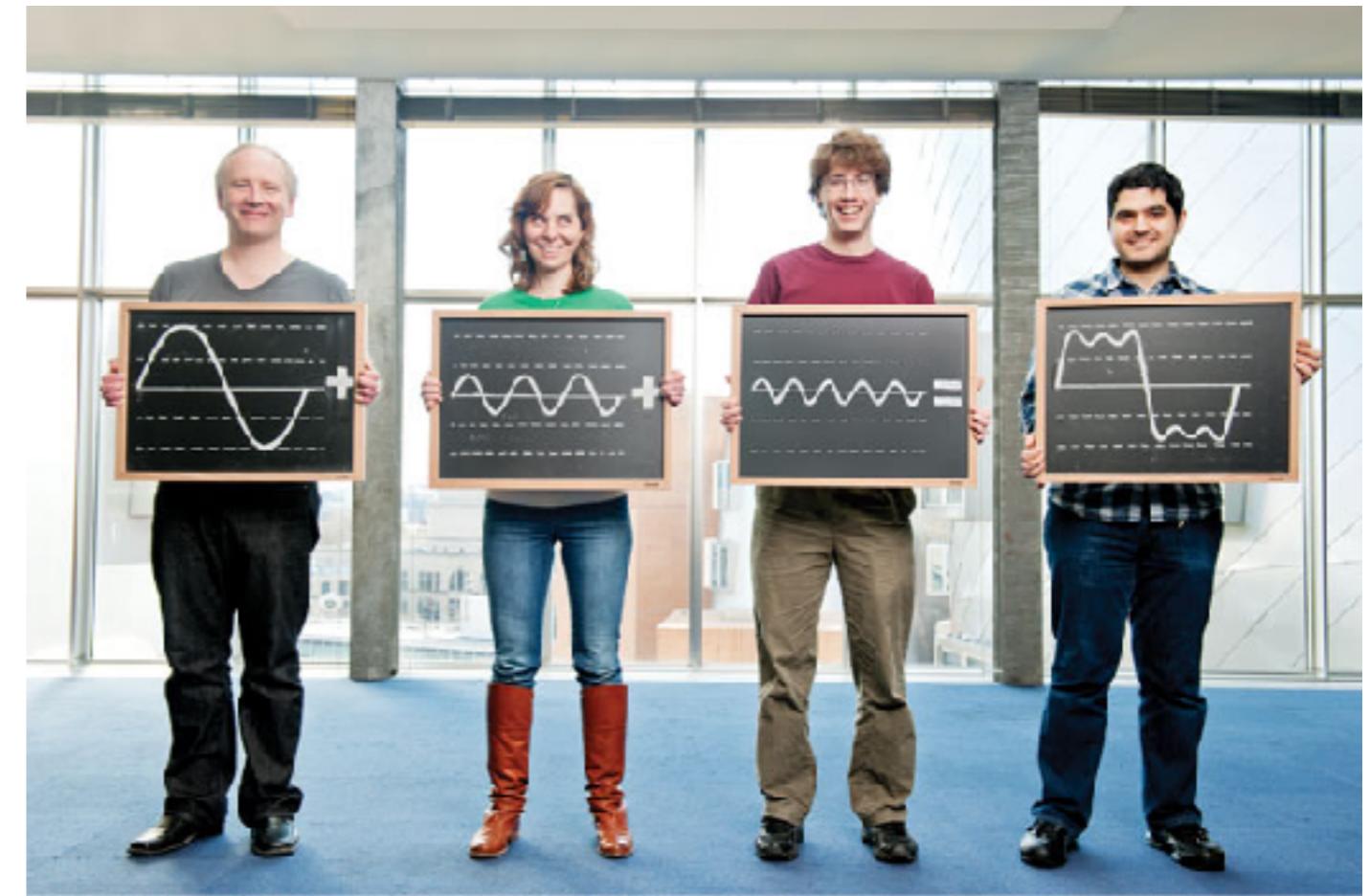
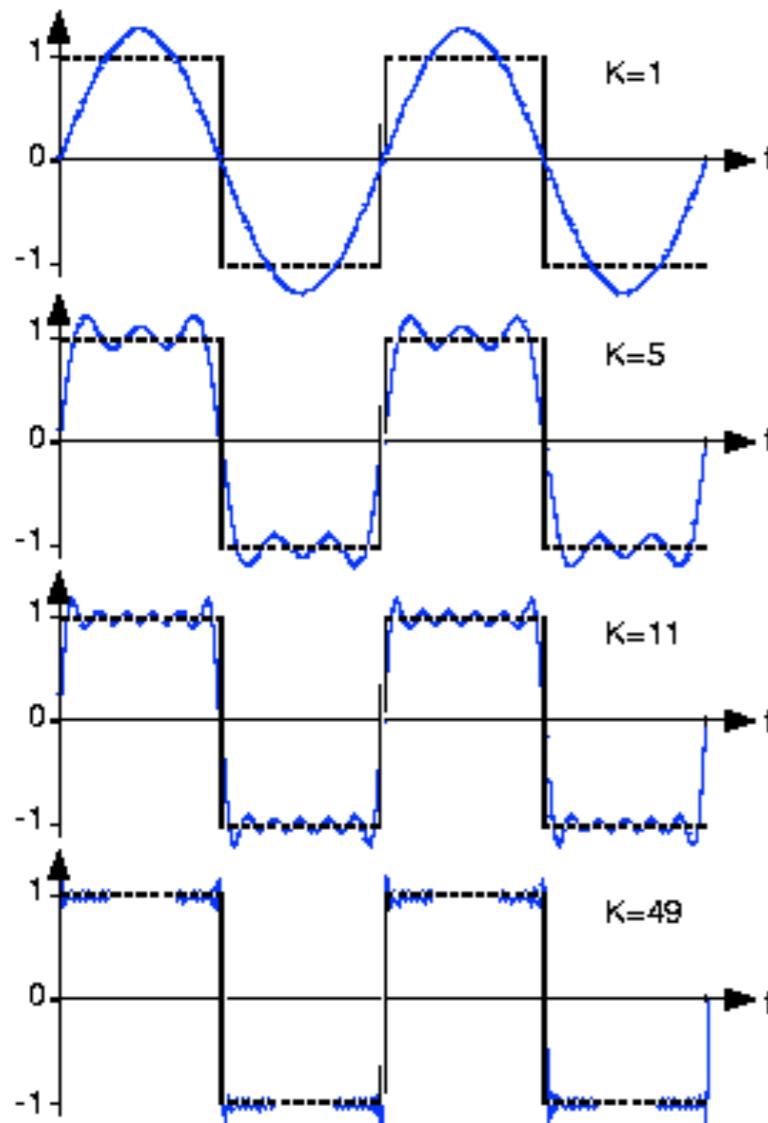
- 2-dimensional (e.g., vision)
 - Visual images
 - High spatial frequency: small objects (details)
 - Low spatial frequency: large objects

Basic building blocks

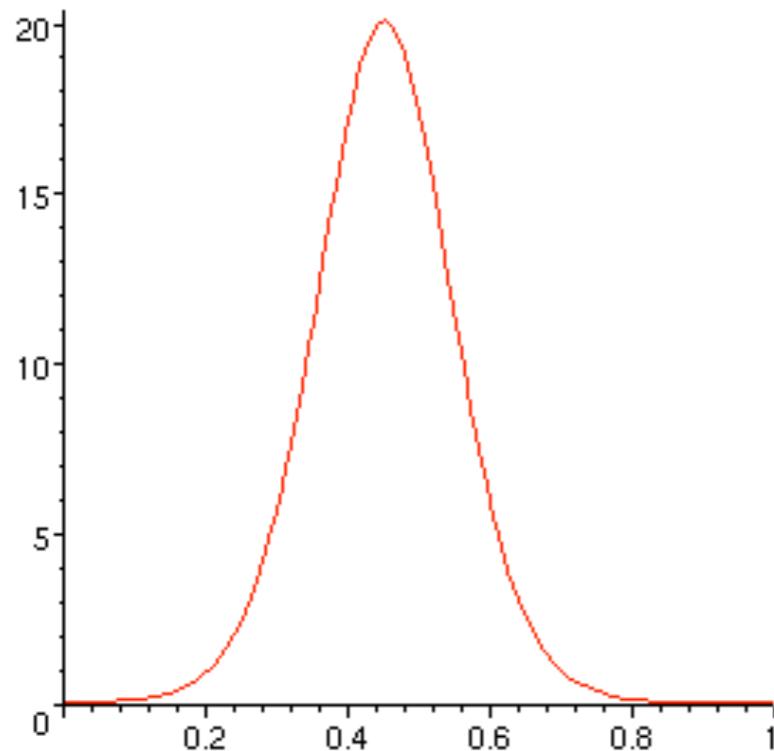
- SIN and COS
- COS is just a shifted SIN



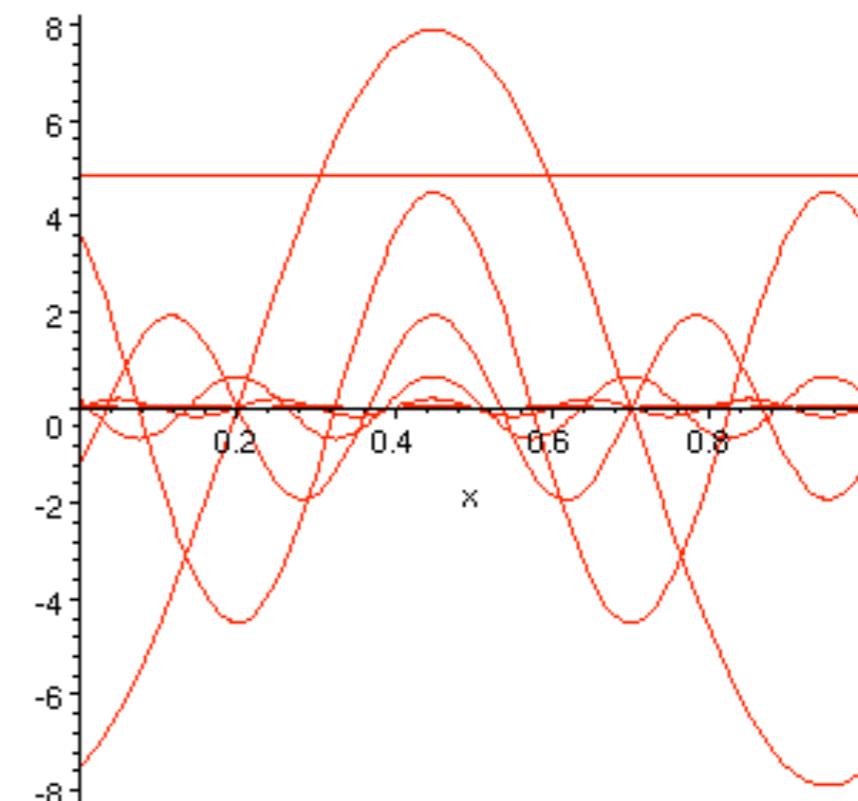
Approximating a square wave by adding many sine waves



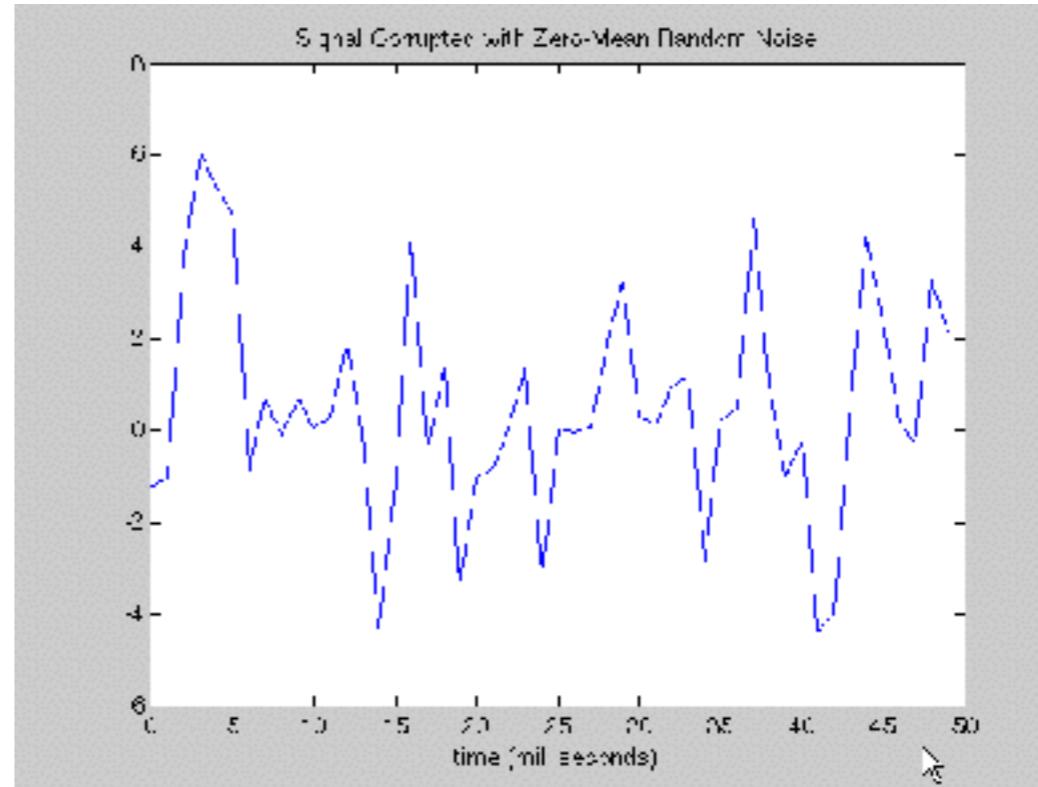
the function we want to represent



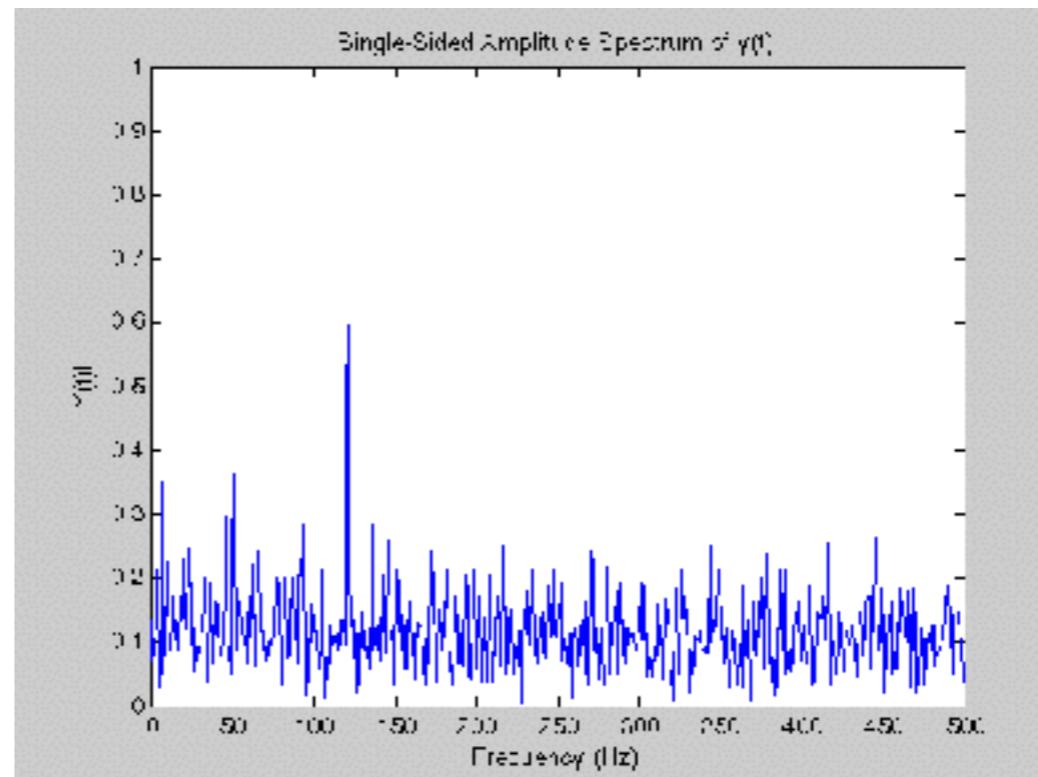
the fourier components:



- temporal signal
 - E.g. a sound



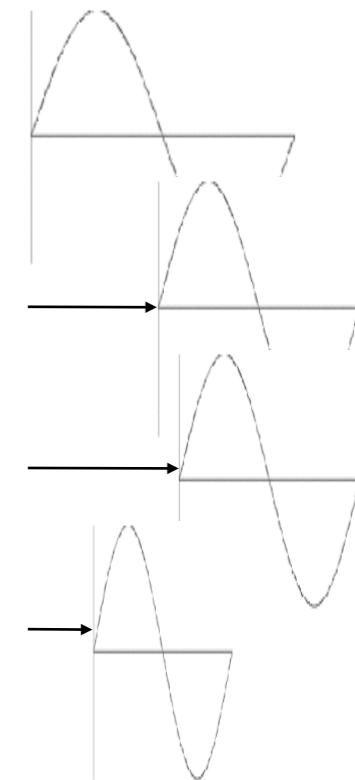
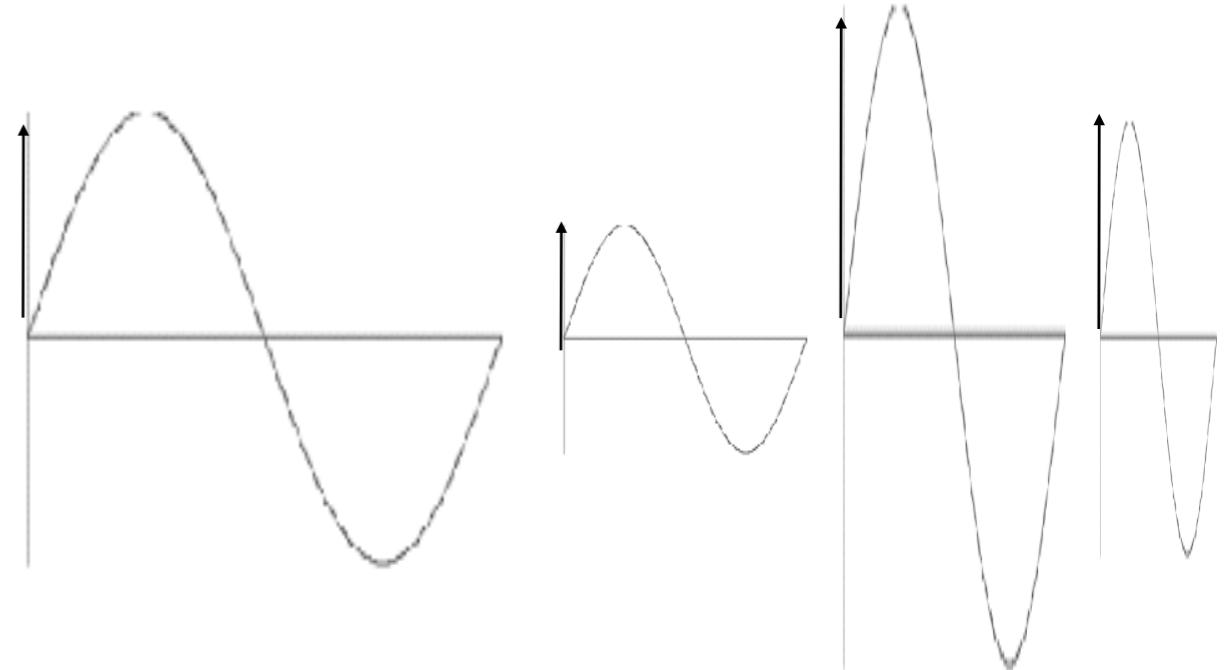
- spectral signal
 - Showing the strength of the constituent frequencies

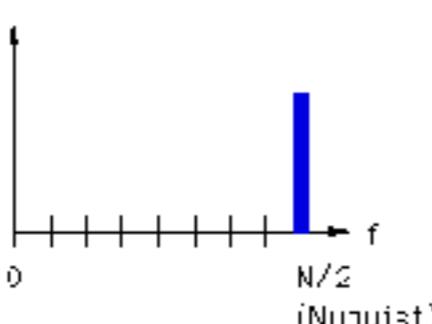
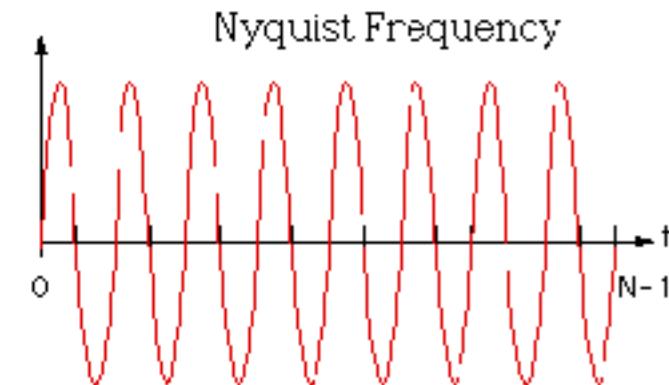
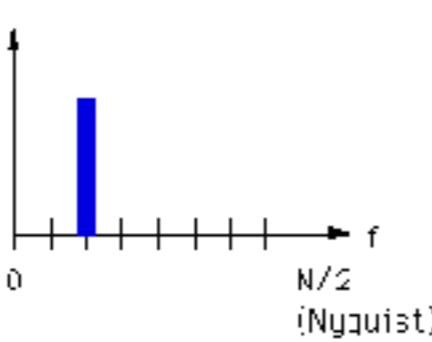
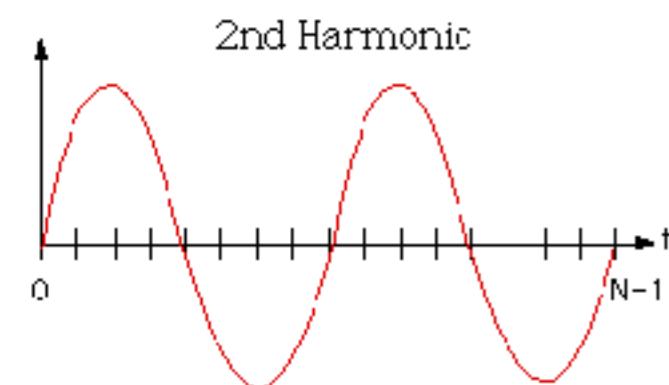
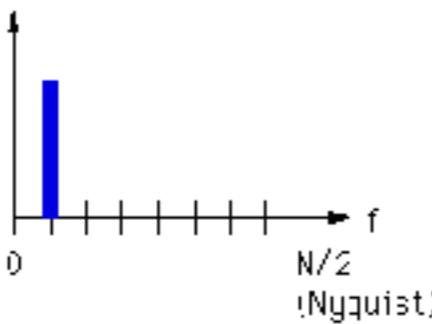
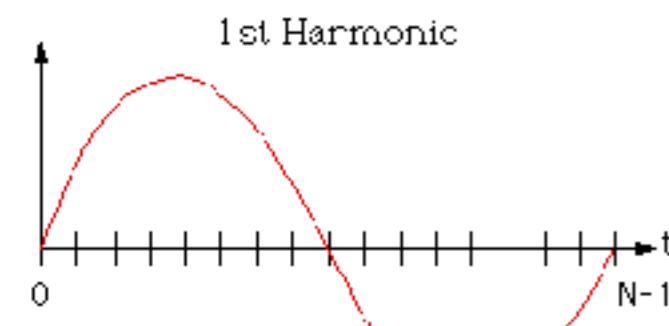
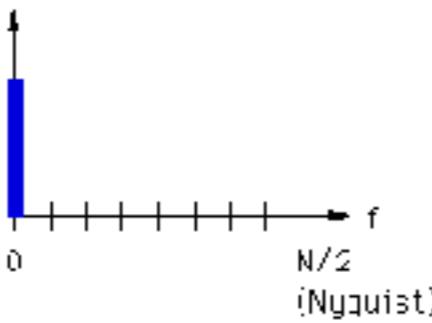
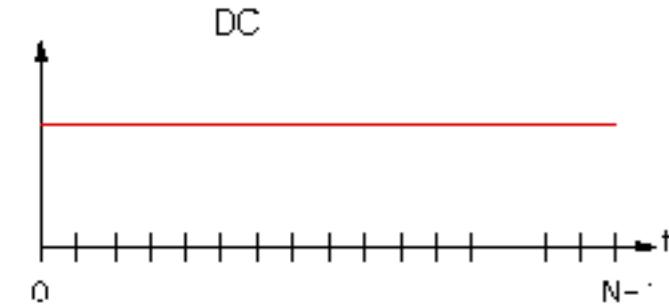


Magnitude and phase

- Magnitude
 - The strength of the individual frequencies (vertical enlargements)

- Phase
 - The position of the individual frequencies (horizontal shifts)

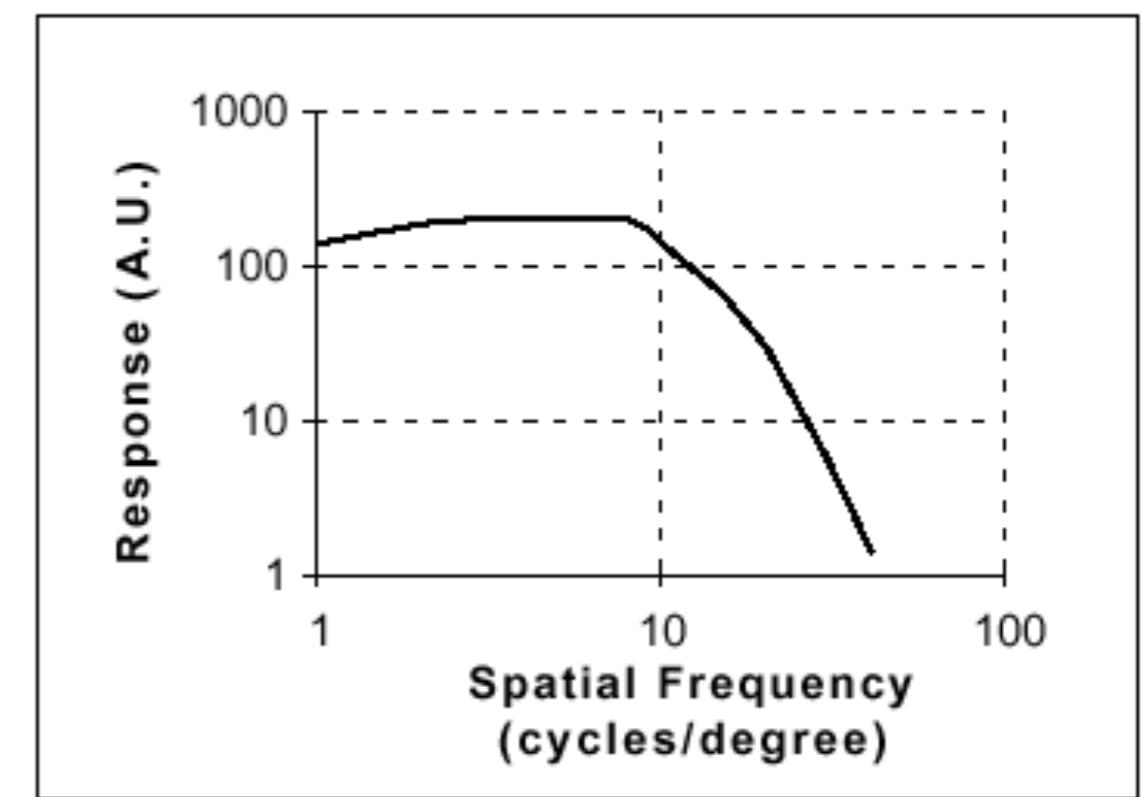
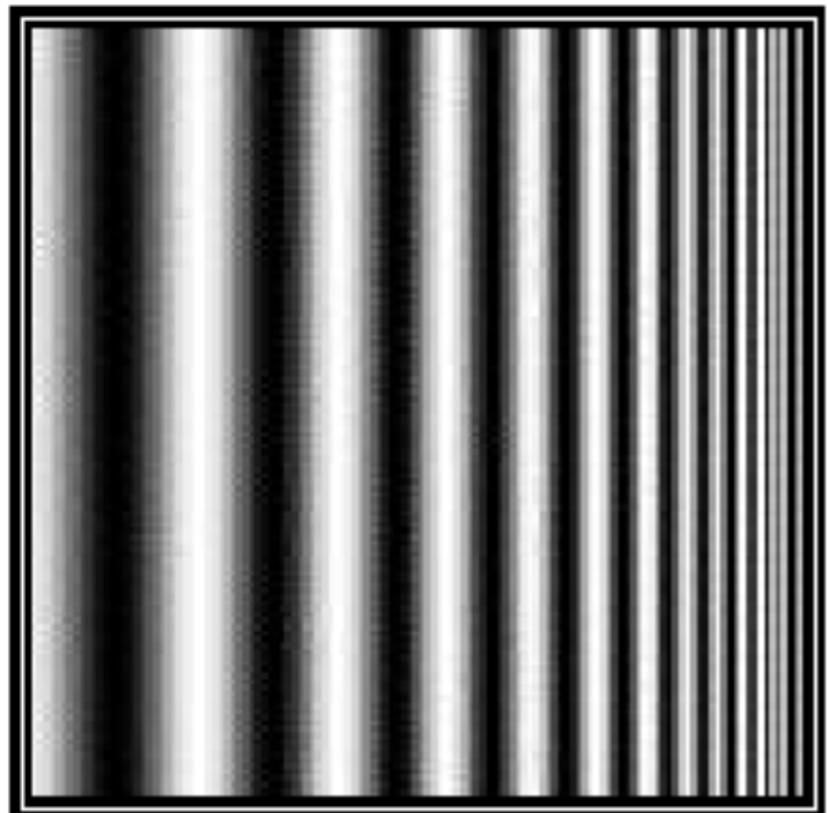




- The smallest frequency that can be represented

- The largest frequency that can be represented

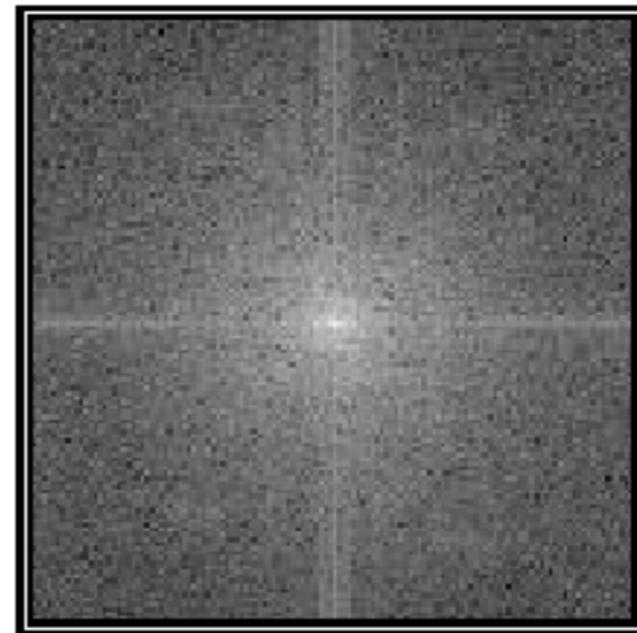
Spatial frequencies



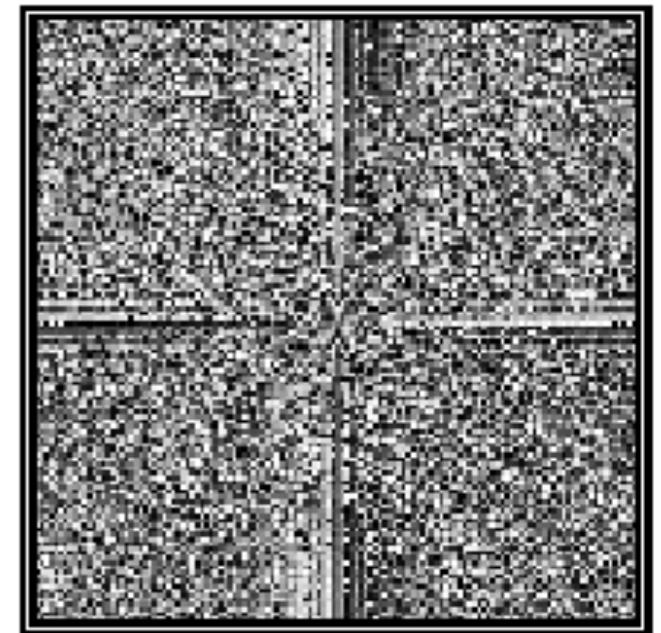
Fourier



image

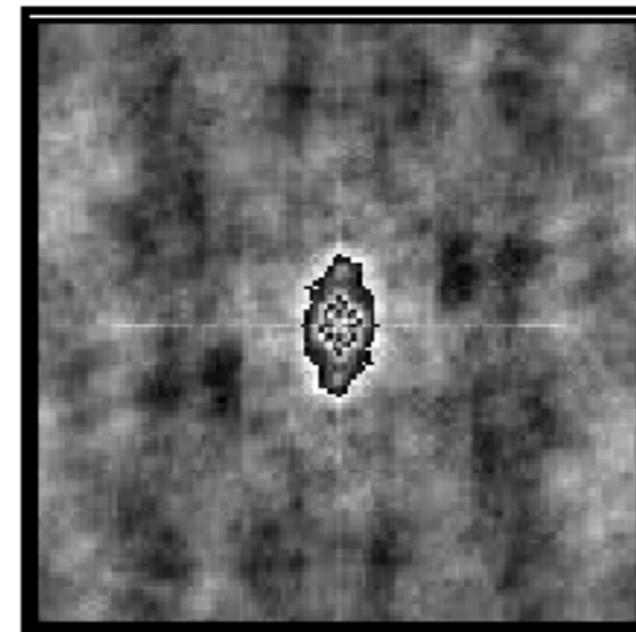


magnitude



phase

Inverse
Fourier

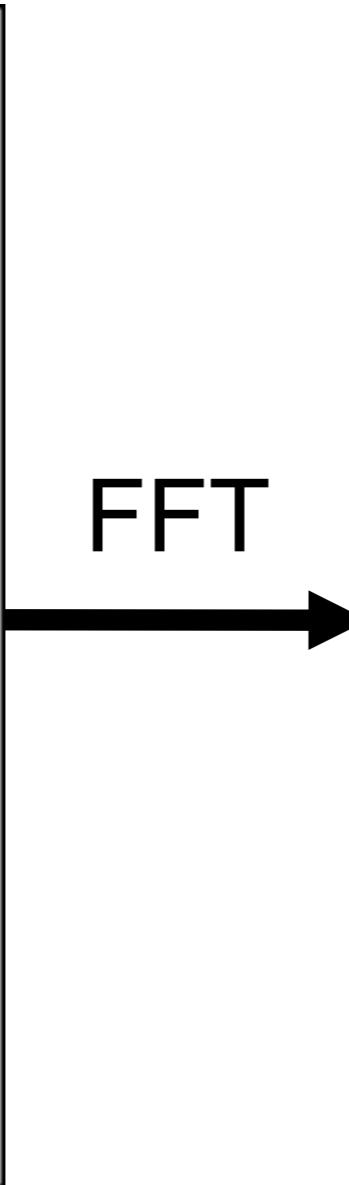
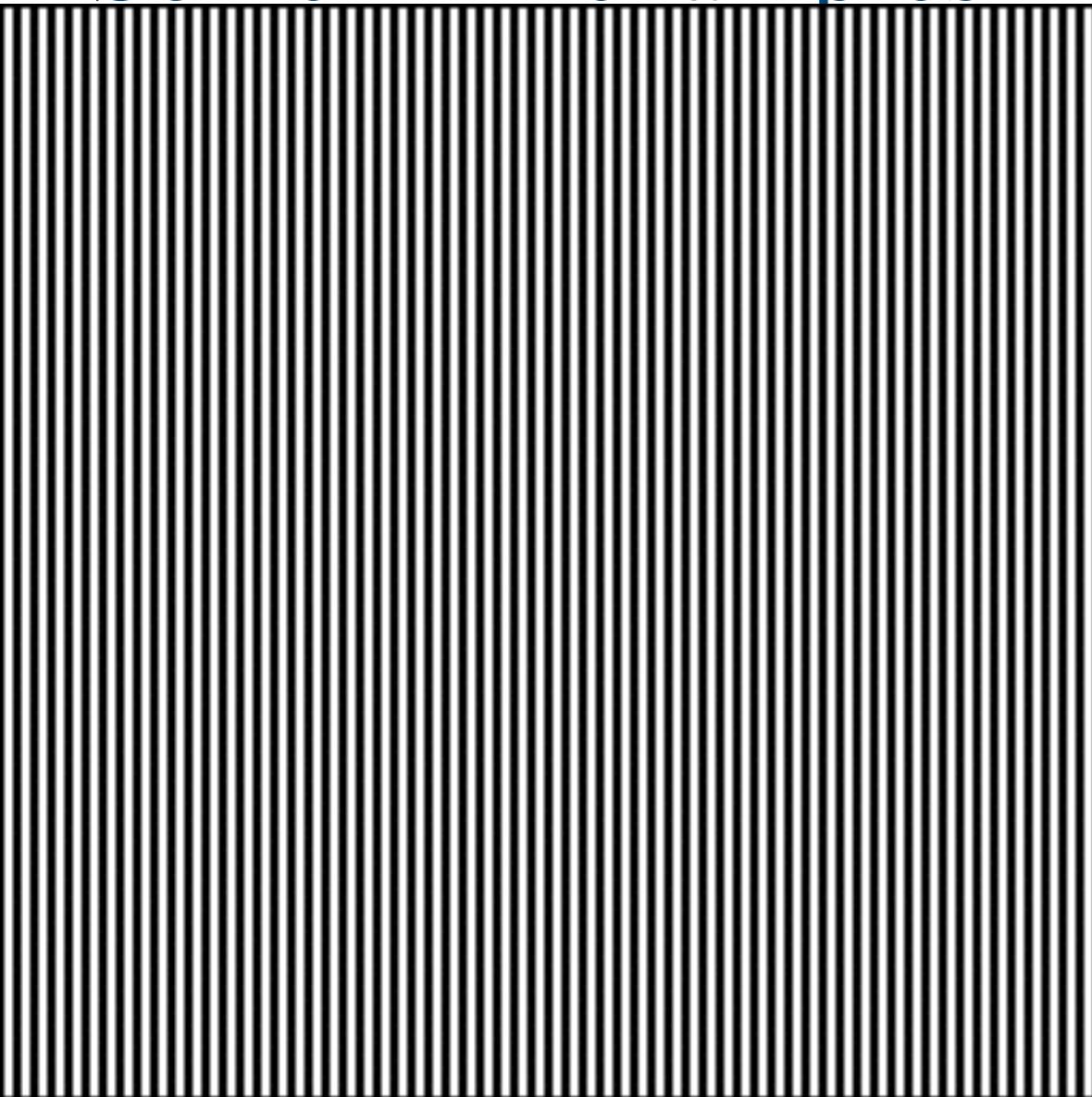


magnitude only

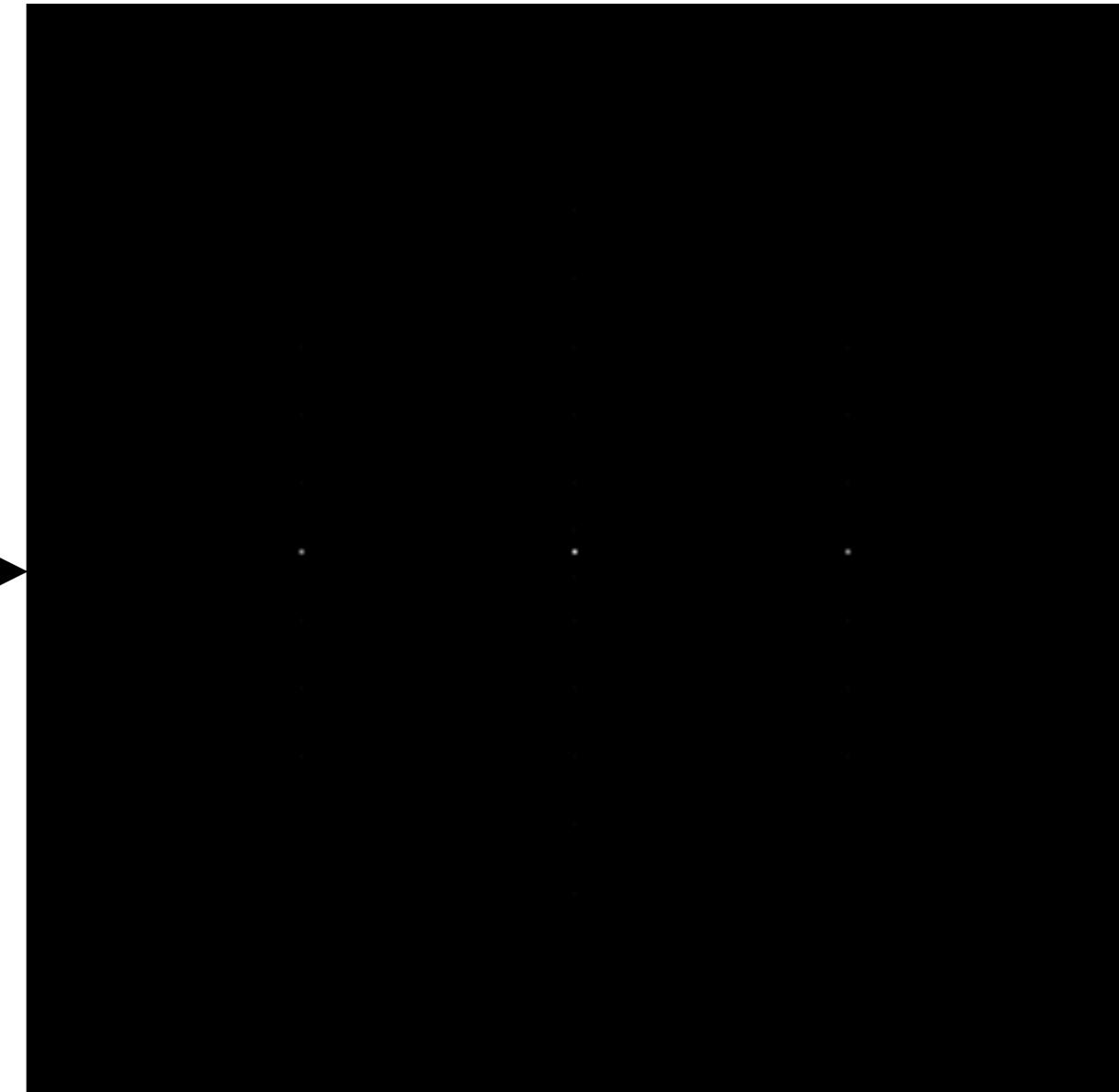


phase only

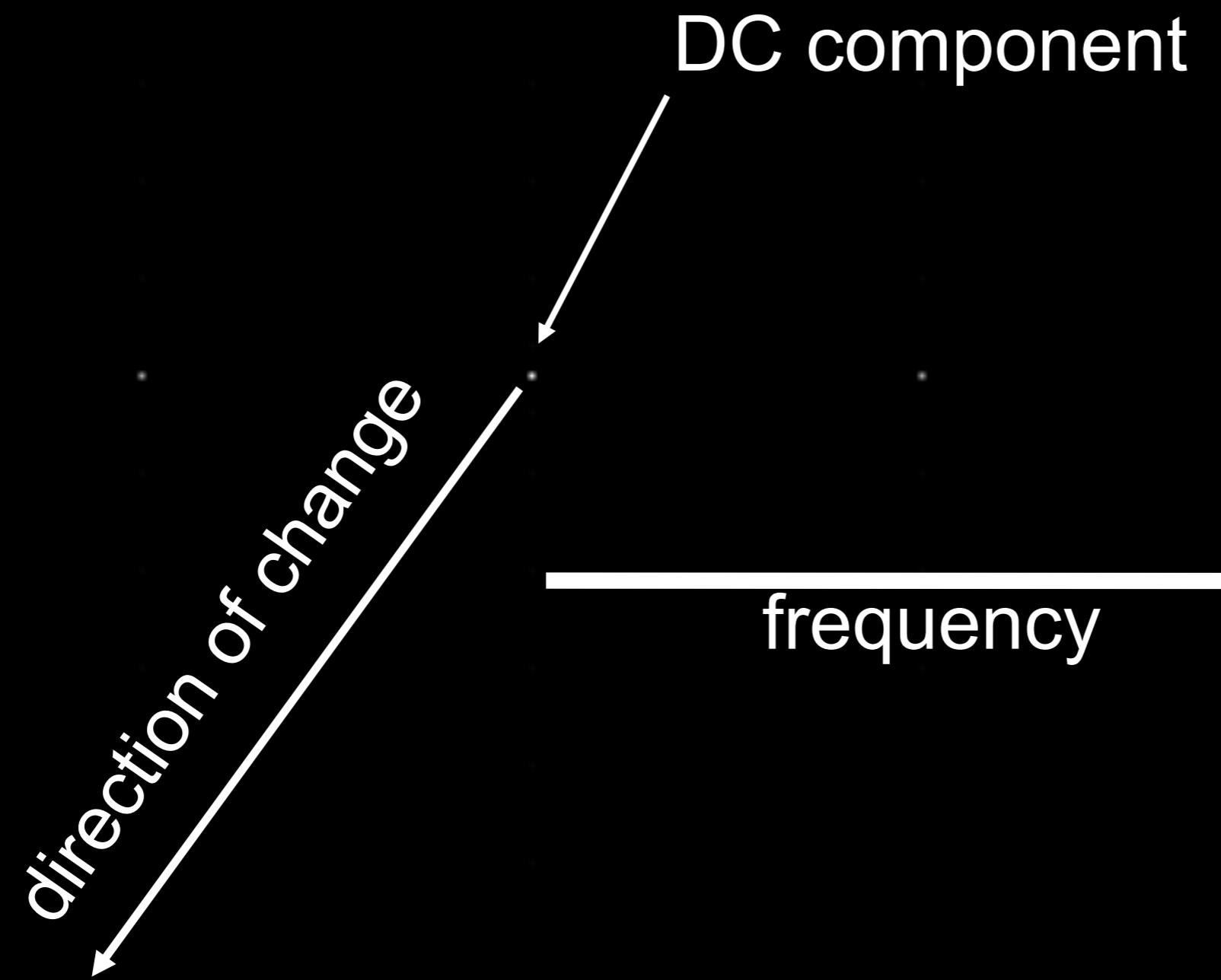
Some FFT examples



Individual lines are 2 pixels wide

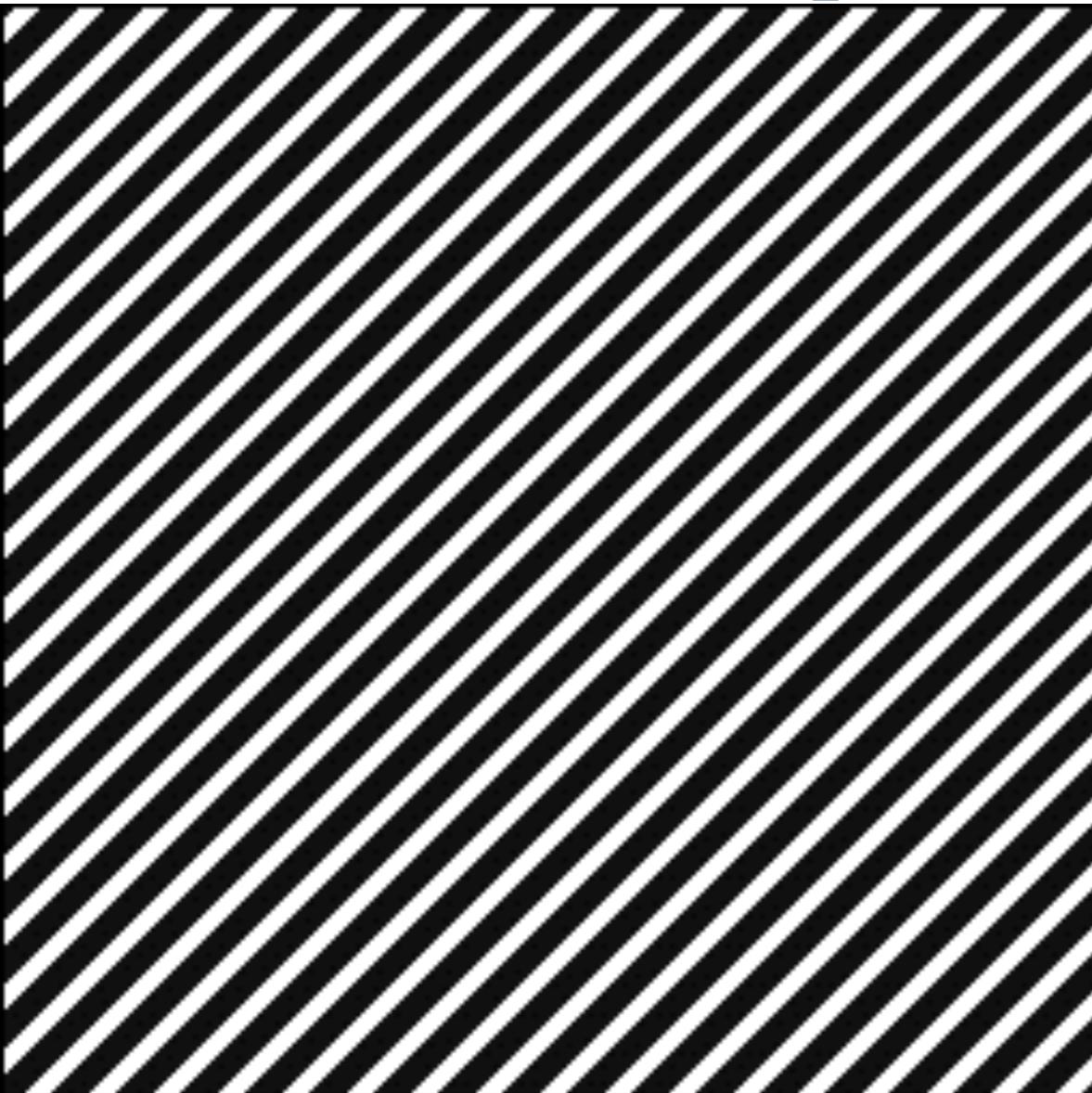


magnitude



Max frequency
1-pixel wide line

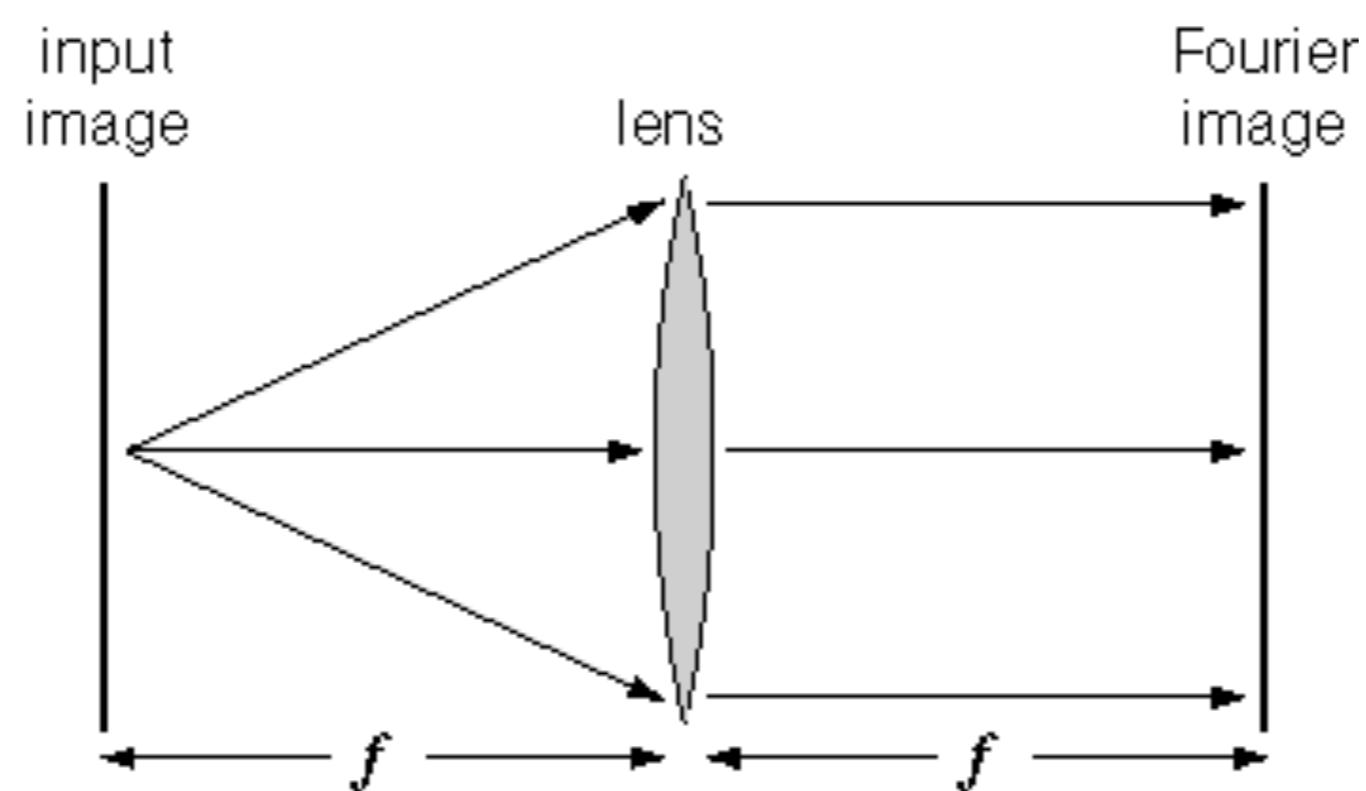
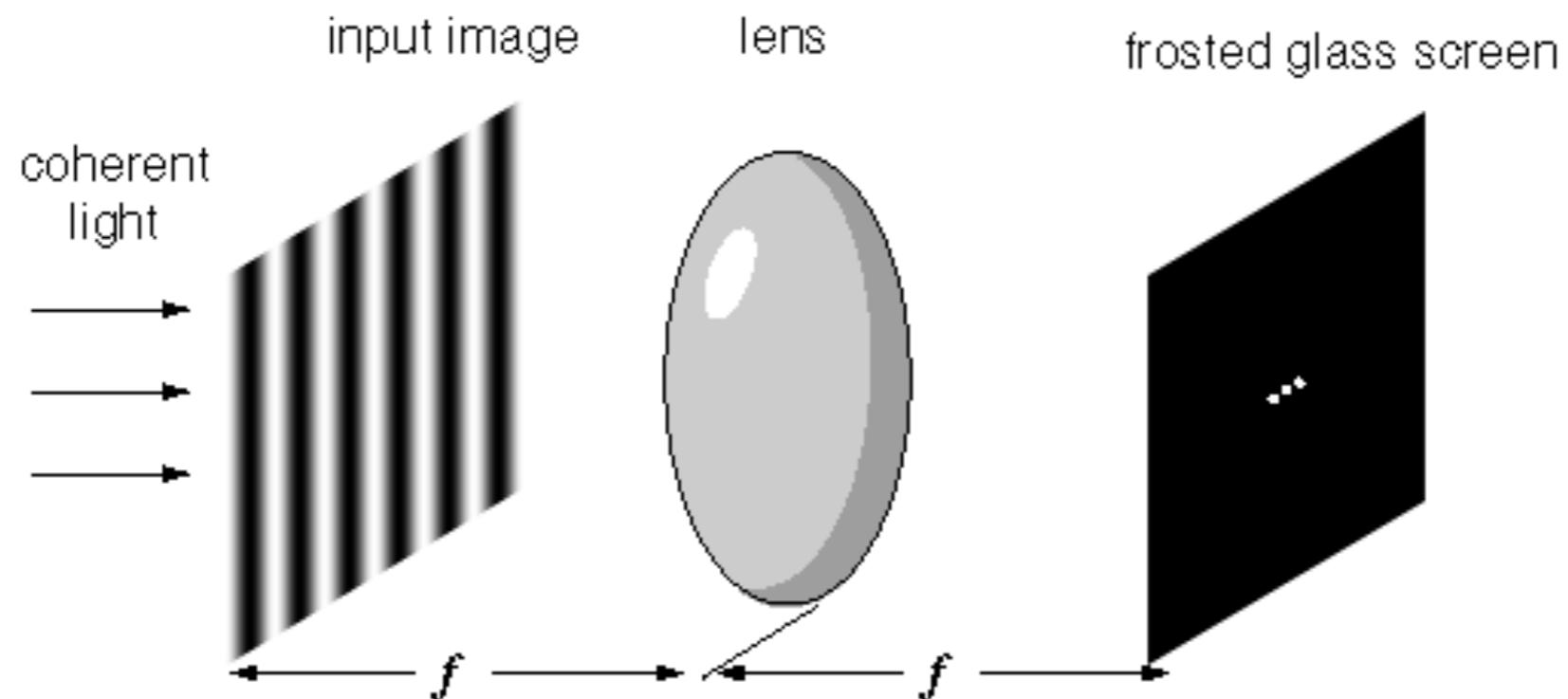
Some FFT examples



FFT

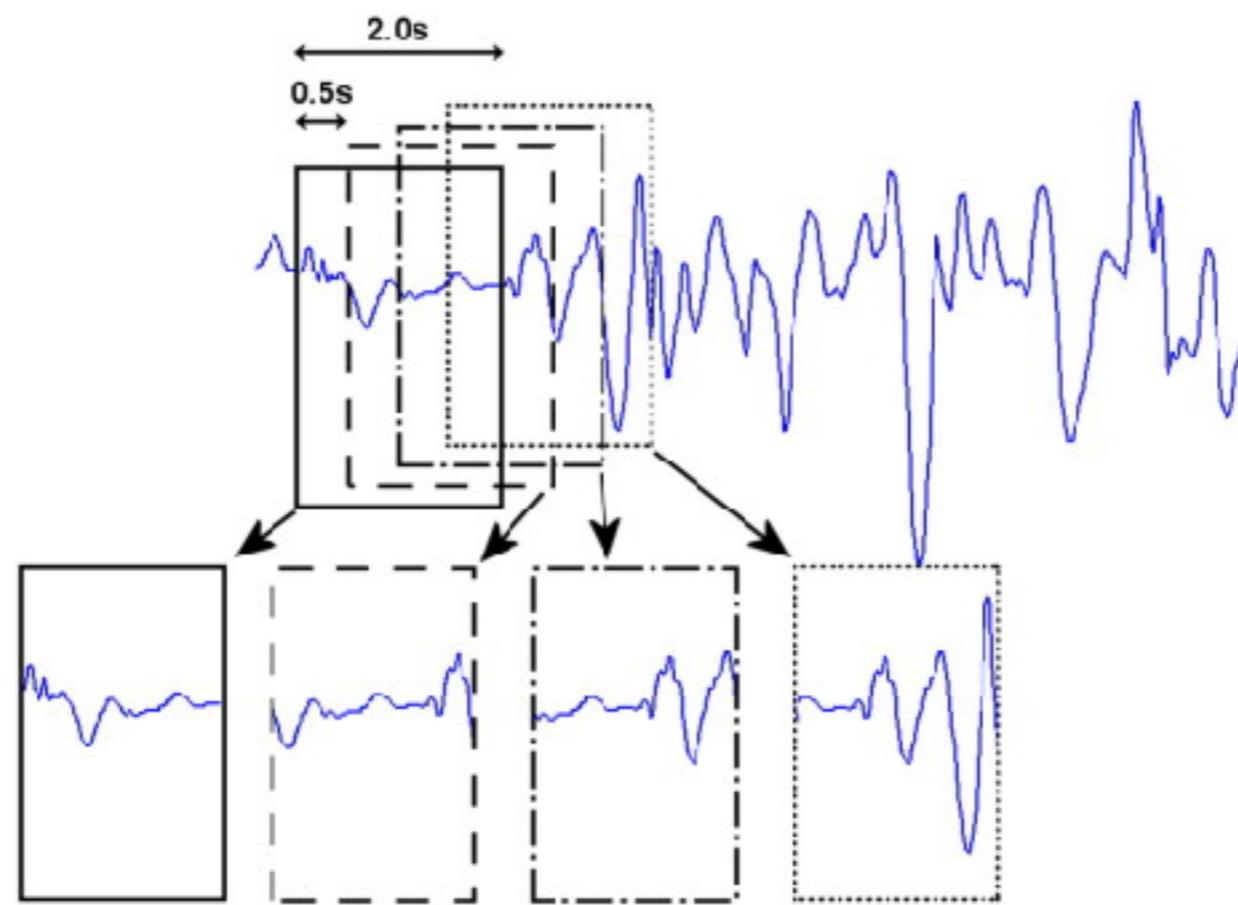


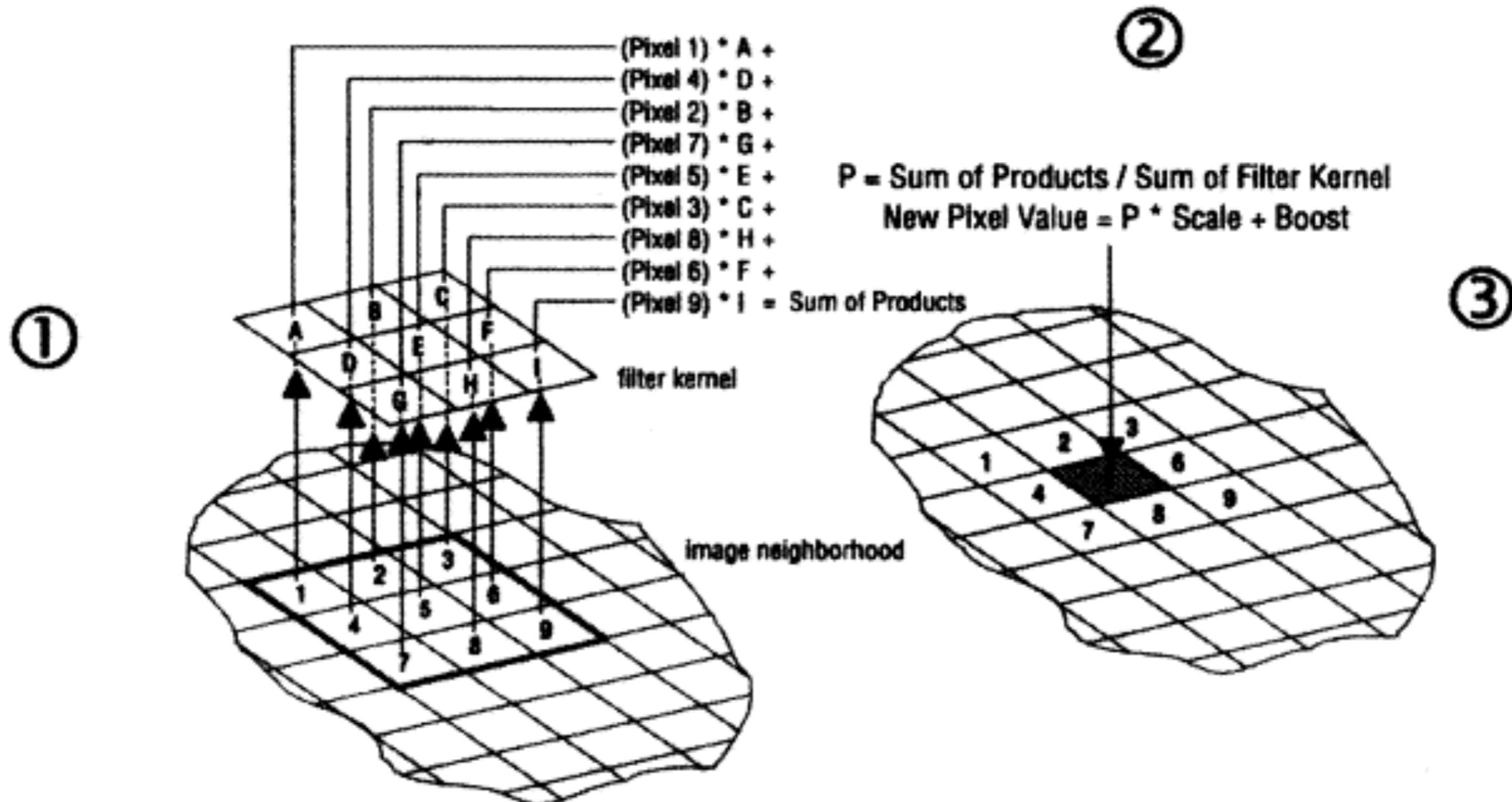
magnitude



Filtering in the temporal or spatial (image) domain

- Filtering can be done directly in the image domain by applying a filter (matrix of weights) to regions of the image
- This is the so-called “sliding window” method



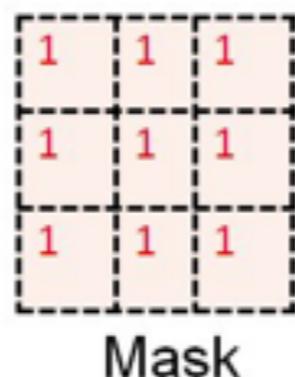


The Convolution Filtering Process

1	1	2	5	6	3	6	7	3
2	3	4	6	7	5	1	8	4
8	7	6	5	7	6	3	3	4
2	3	5	6	7	8	2	7	3
4	5	3	2	1	6	8	7	2
1	4	5	3	2	6	7	8	1
2	3	4	5	6	8	9	2	1

Input image

$$* \frac{1}{9}$$



Mask



Convolution operation

1	1	1	1	5	6	3	6	7	3
1	2	1	3	1	4	6	7	5	1
1	8	1	7	1	6	5	7	6	3
2	3	5	6	7	8	2	7	3	
4	5	3	2	1	6	1	8	1	2
1	4	5	3	2	6	1	7	1	8
2	3	4	5	6	8	1	9	1	2

1	2	3	4	4	4	4	4	3
3	4	5	6	6	5	5	5	4
3	5	5	6	7	6	5	4	4
4	5	5	5	6	6	6	5	3
3	4	4	4	5	6	7	5	3
3	4	4	4	5	6	7	5	3
2	3	3	3	4	5	5	4	2

Output Image

Alternative way of filtering: spectral filtering

- Image → convolve with filter/receptive field
→ filtered image

-1	0	+1
-2	0	+2
-1	0	+1

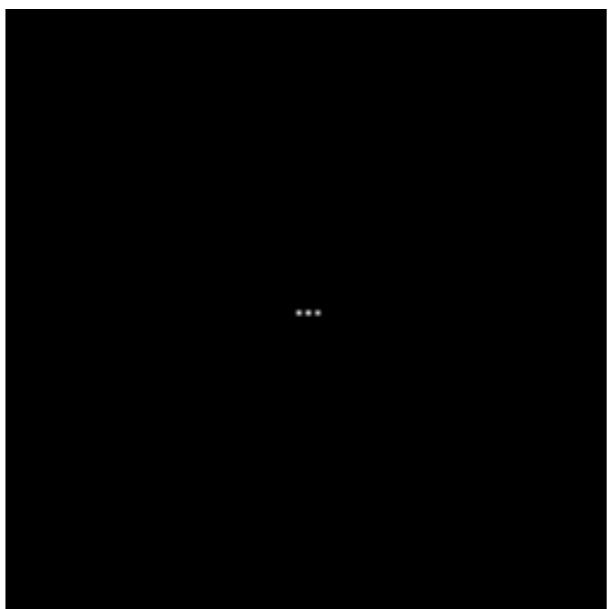
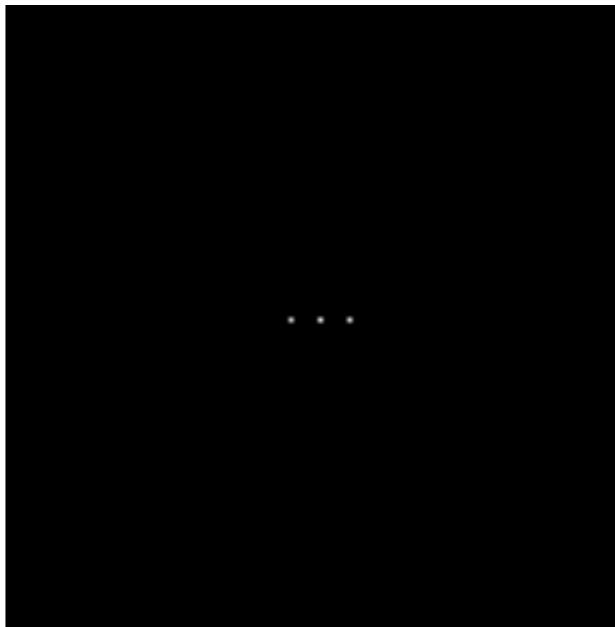
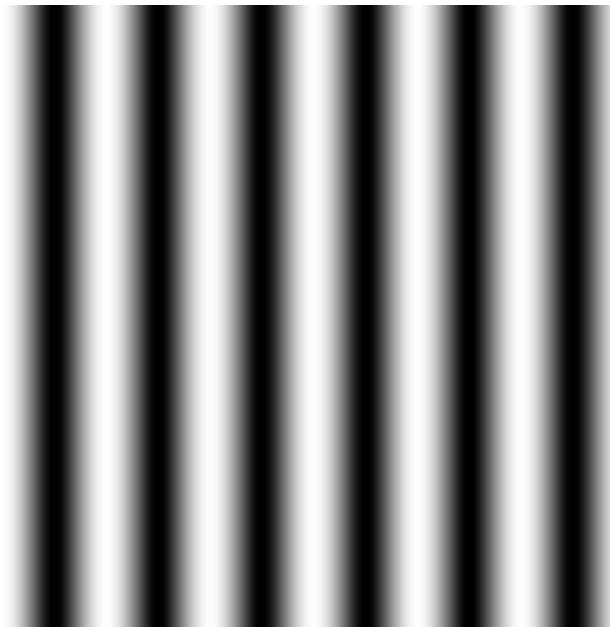
Gx

+1	+2	+1
0	0	0
-1	-2	-1

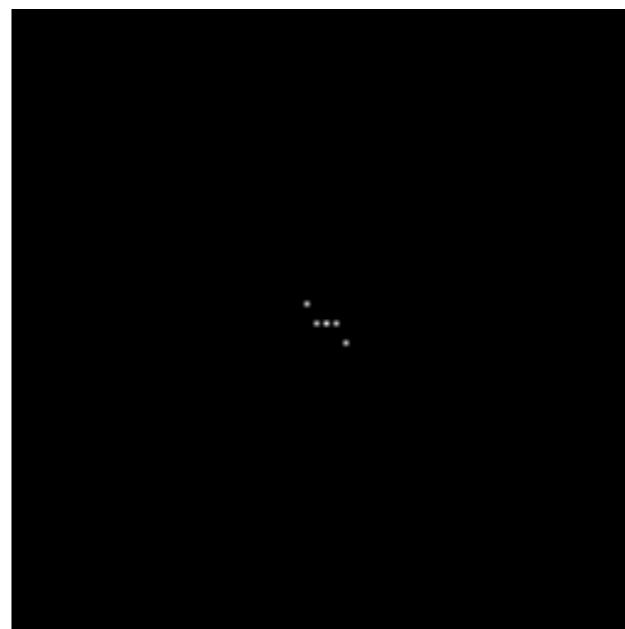
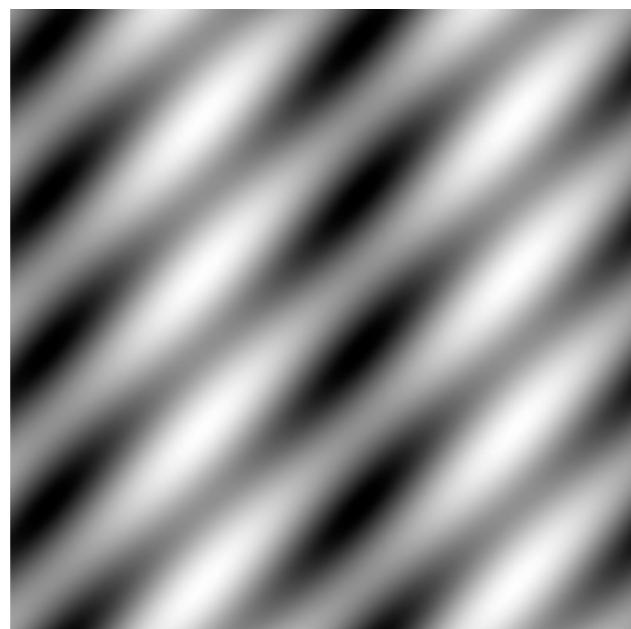
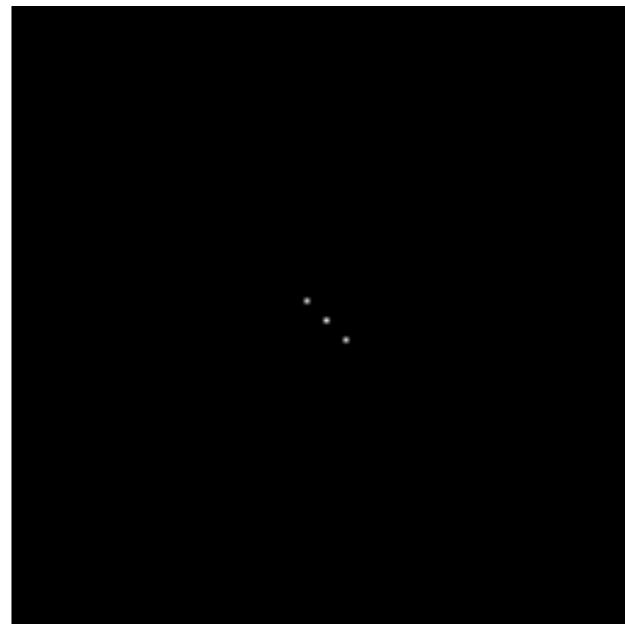
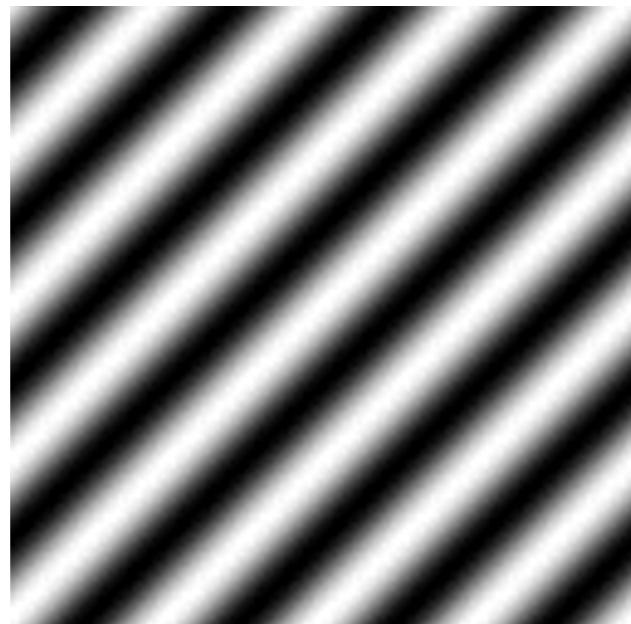
Gy

- Image → Image to Spectrum → apply filter → Spectrum to Image = filtered image
 - “Image to Spectrum”: Fast Fourier Transform
 - “Spectrum to Image”: Inverse Fast Fourier Transform

Brightness image – Fourier transform

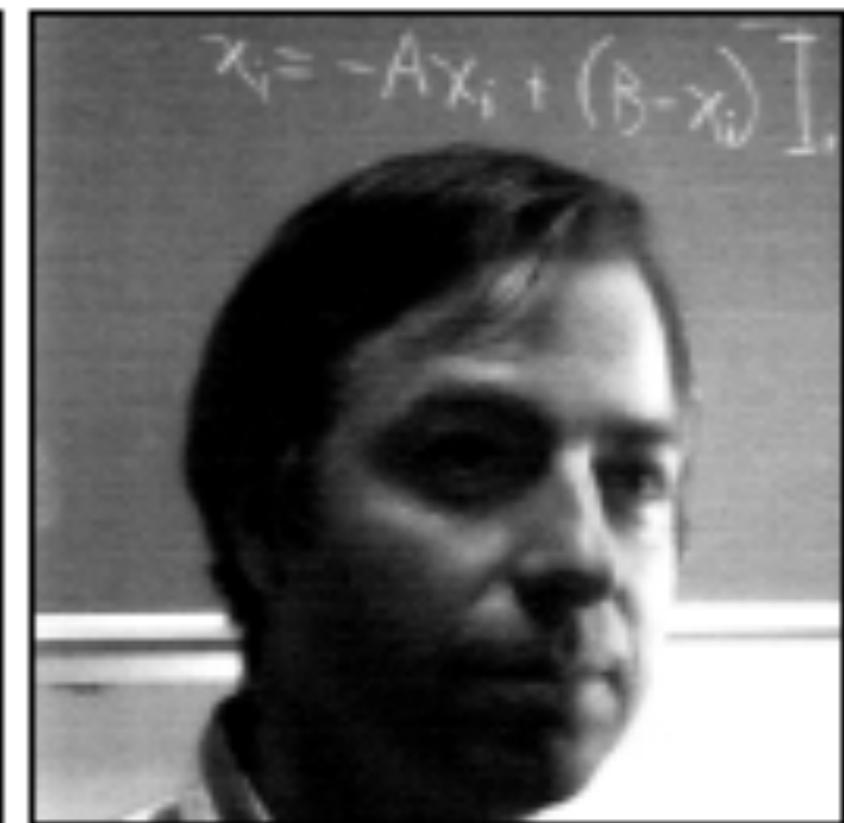
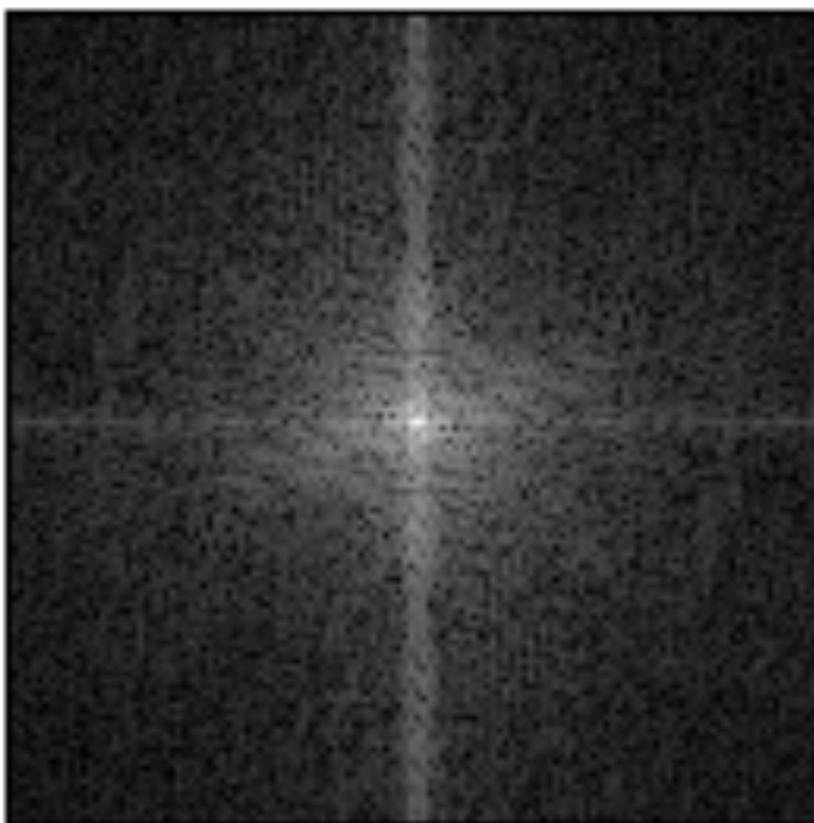
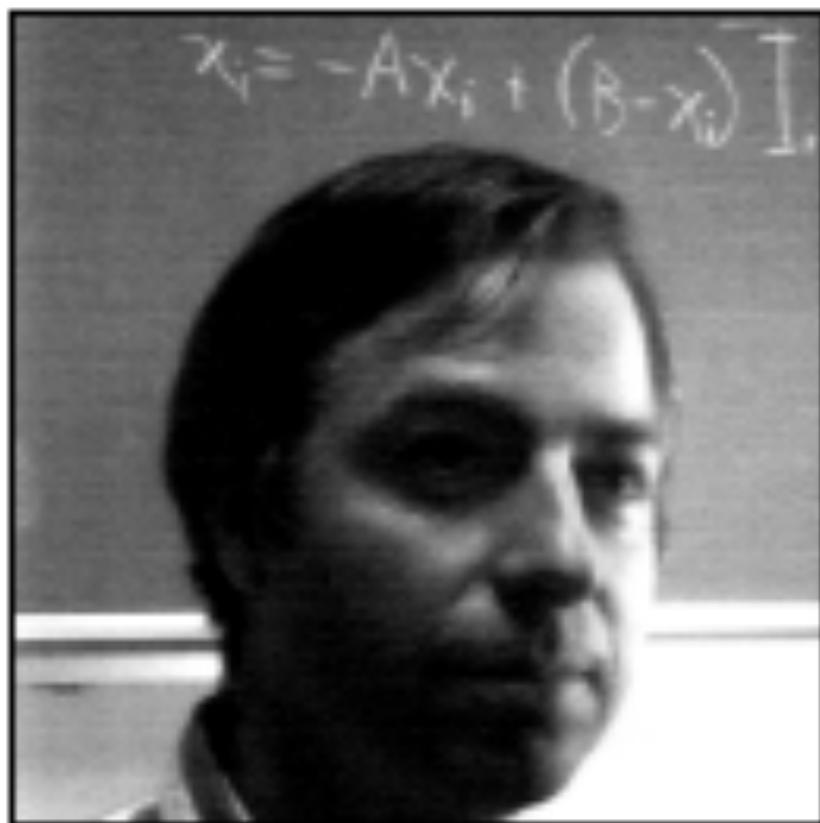


Brightness image – Fourier transform



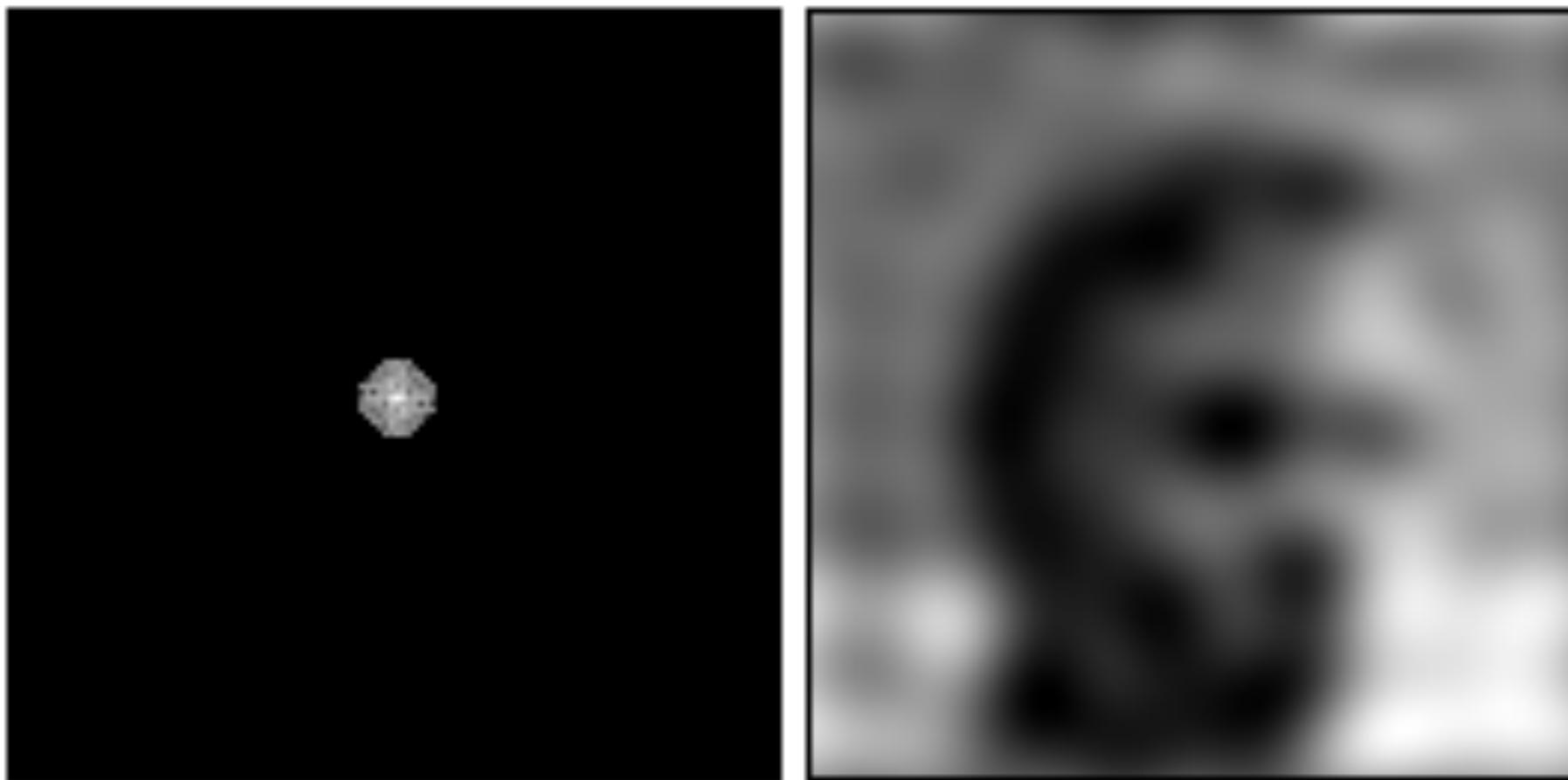
Brightness image – Fourier transform – Brightness image

Brightness Image Fourier Transform Inverse Transformed



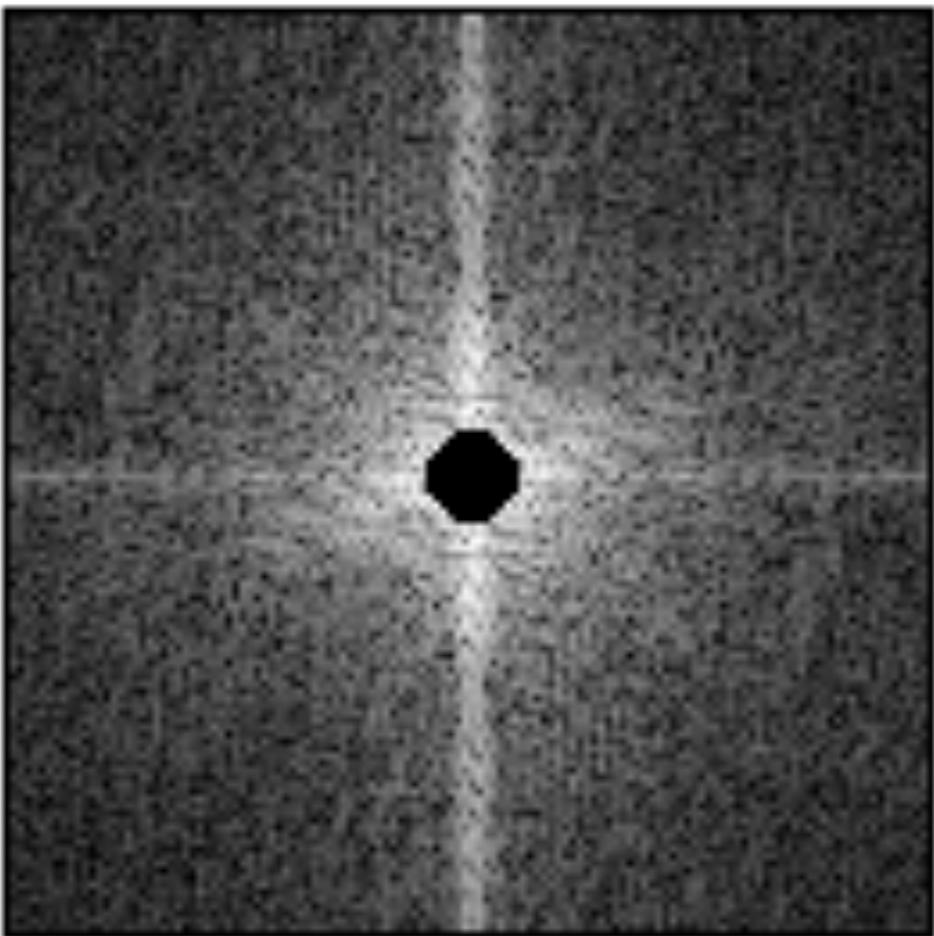
Filtering in the Fourier domain: keeping the low spatial frequencies only

Low-Pass Filtered Inverse Transformed

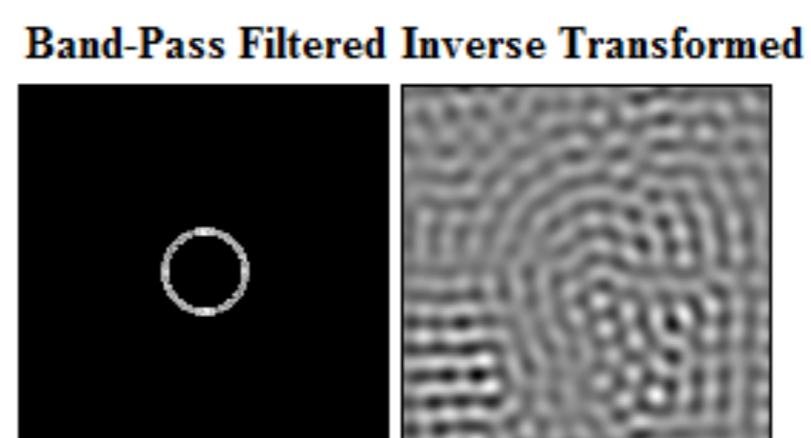
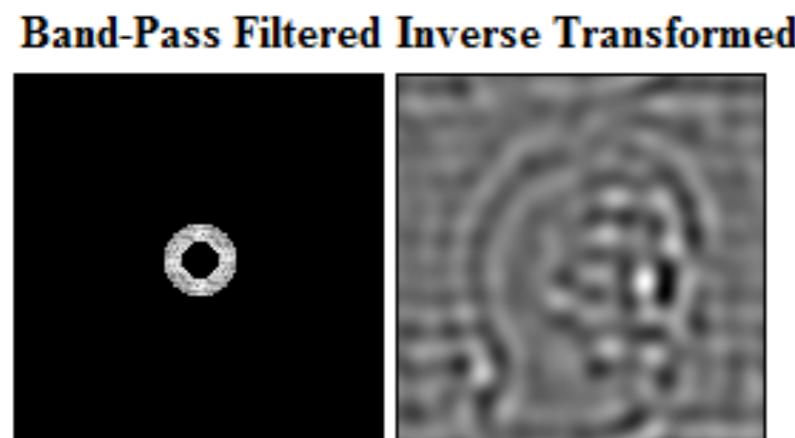
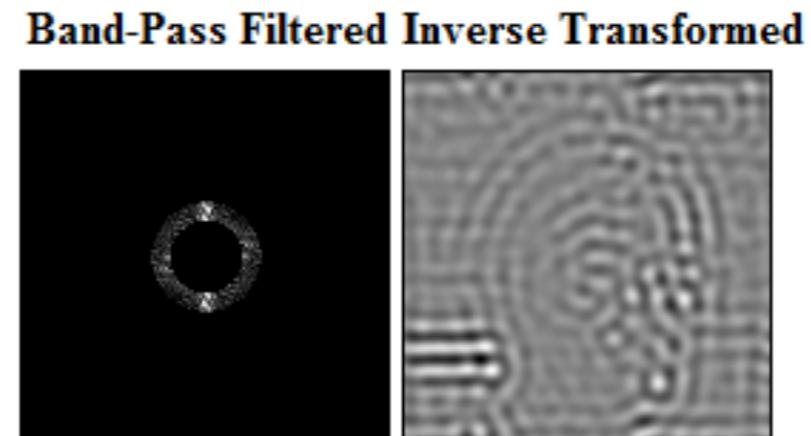
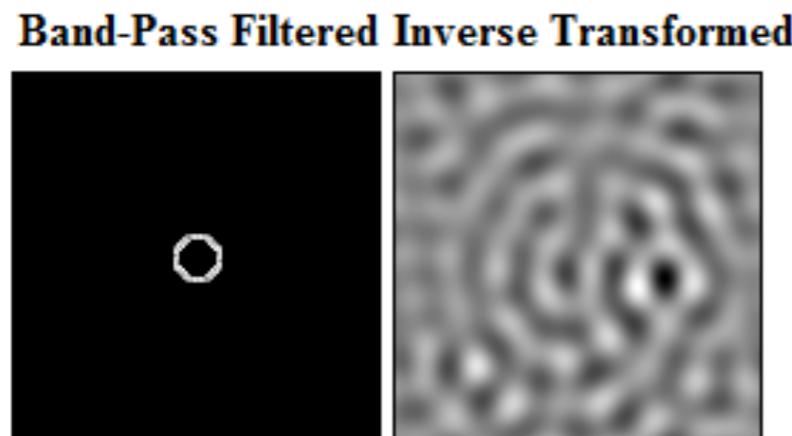


Filtering in the Fourier domain: keeping the high spatial frequencies only

High-Pass Filtered Inverse Transformed

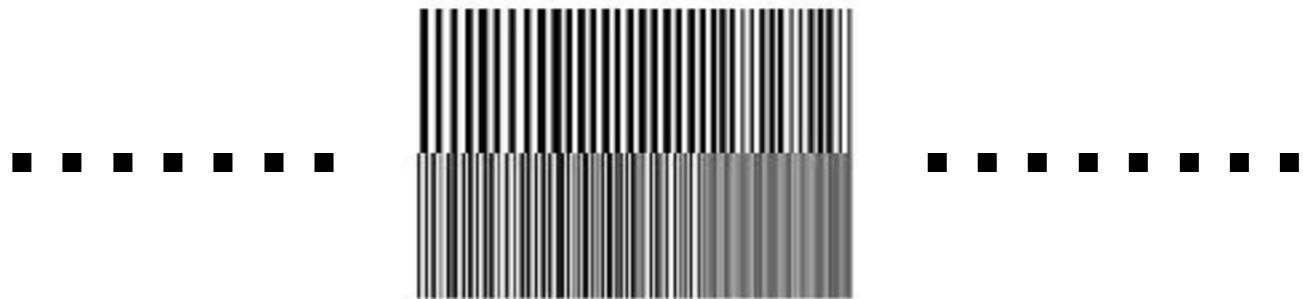


Filtering in the Fourier domain: keeping the intermediate spatial frequencies only

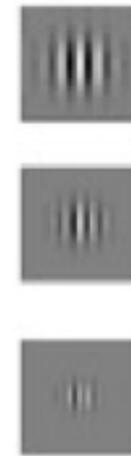


Fourier transform versus Gabor transform

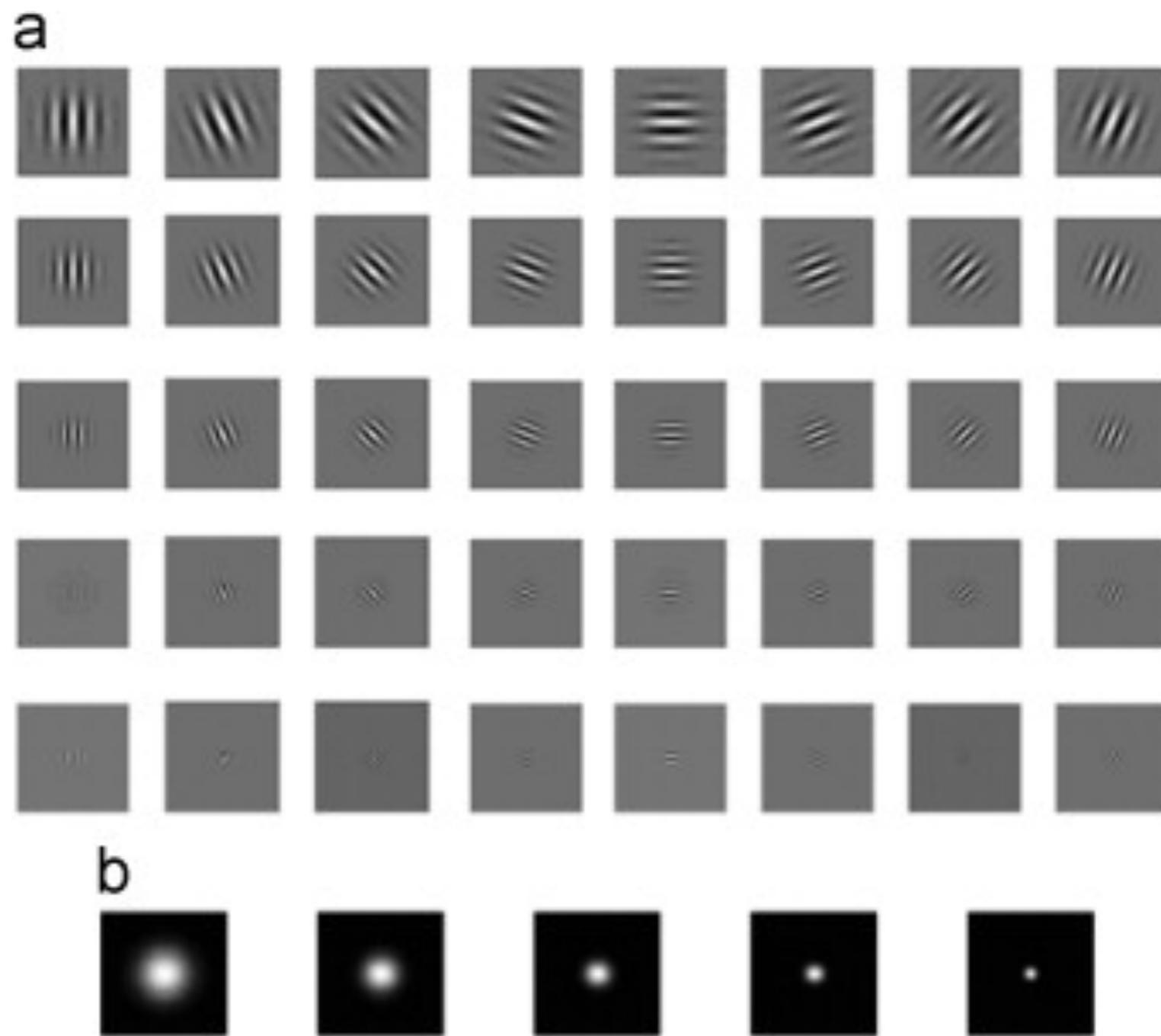
- Fourier analysis decomposes images in terms of global spatial frequencies (they continue forever)



- Gabor analysis decomposes image in terms of LOCAL spatial frequencies (they do not continue forever)



Convolution with Gabor filters (see this week's paper)



Facial expression coding with local Fourier analysis

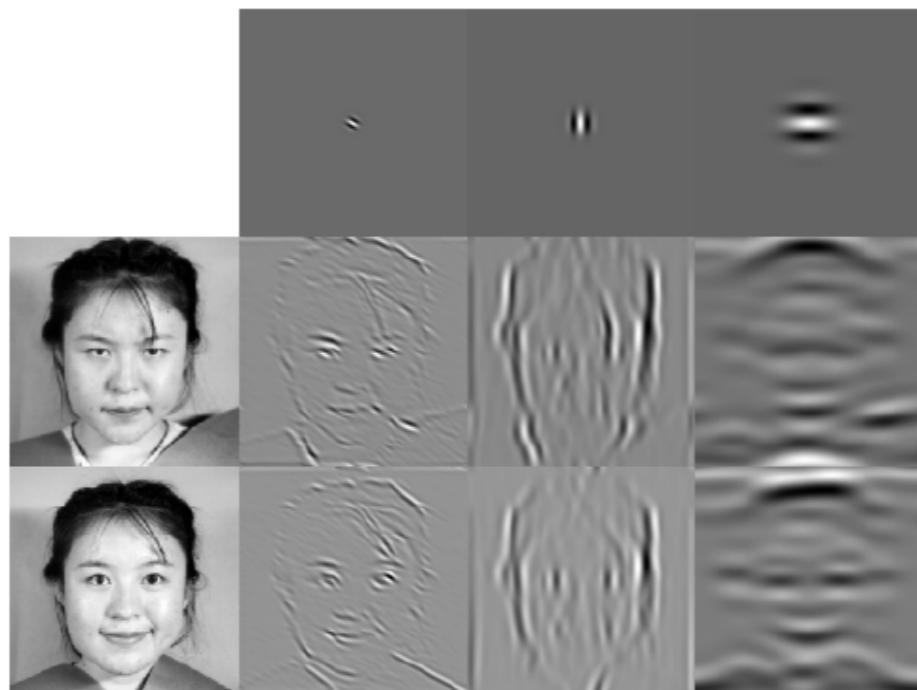


Figure 1. Examples of Gabor filter responses to two facial expression images for three of the filters used.

Correspondence with human ratings

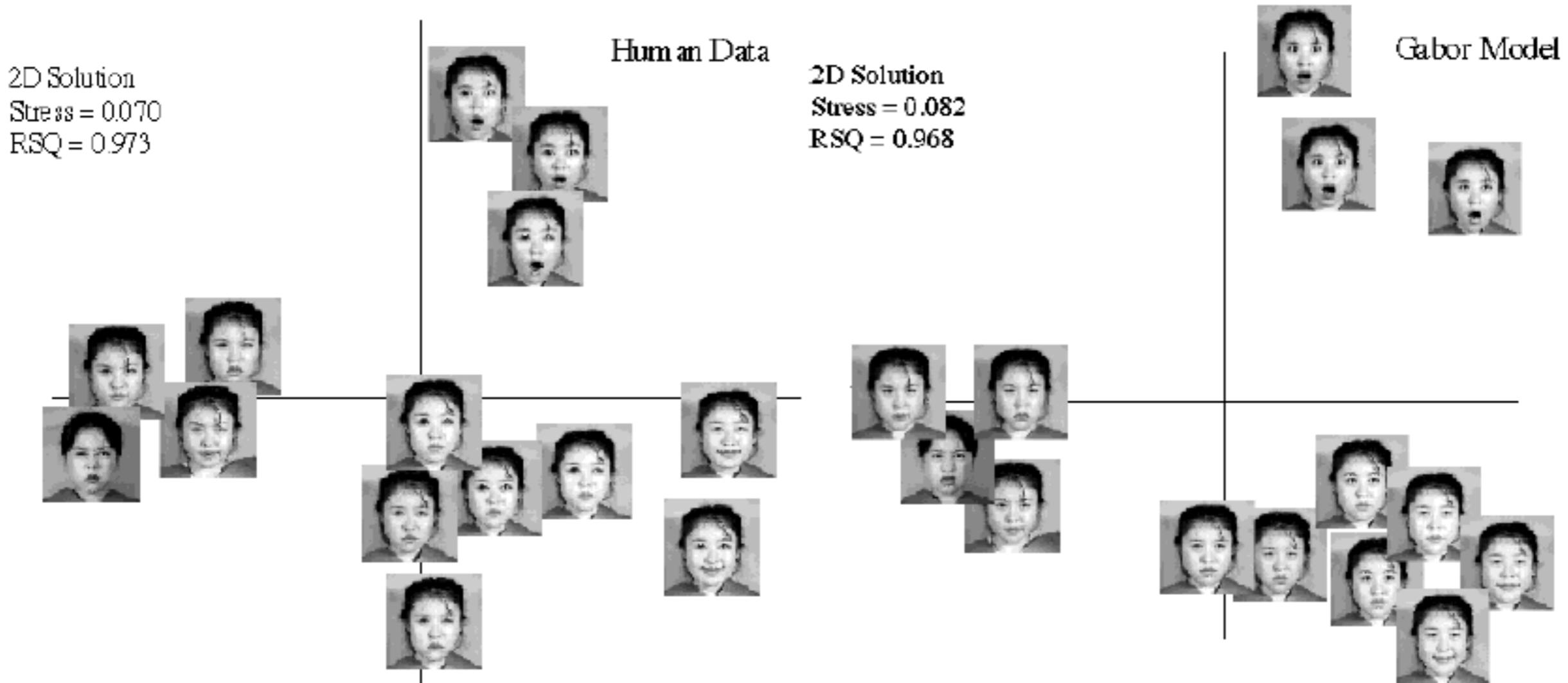
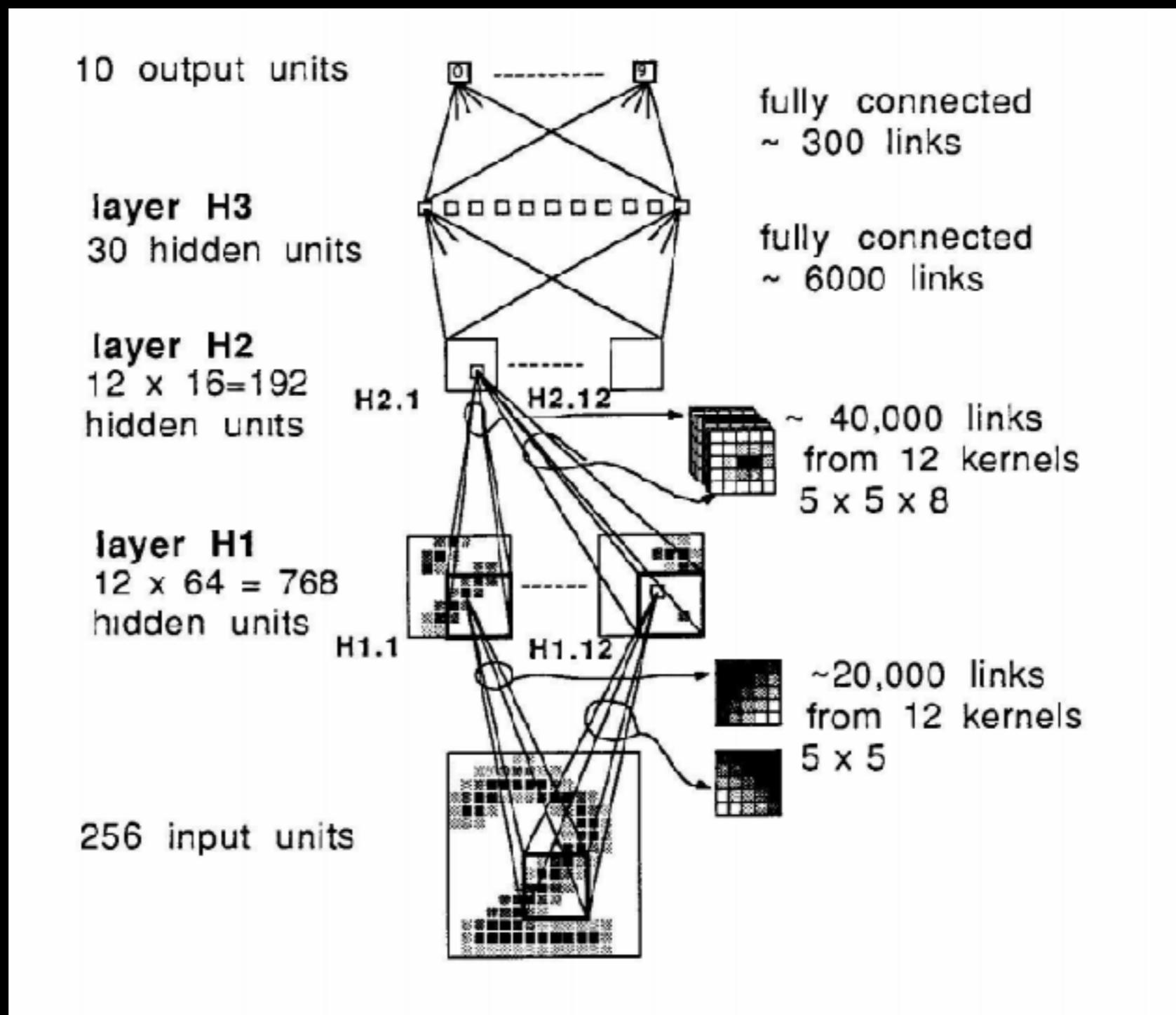


Figure 5. nMDS solutions for Gabor and semantic rating similarities (data from pilot study).

Exercise with convolution

LeCun et al. (1989)



opinions 1990-2012

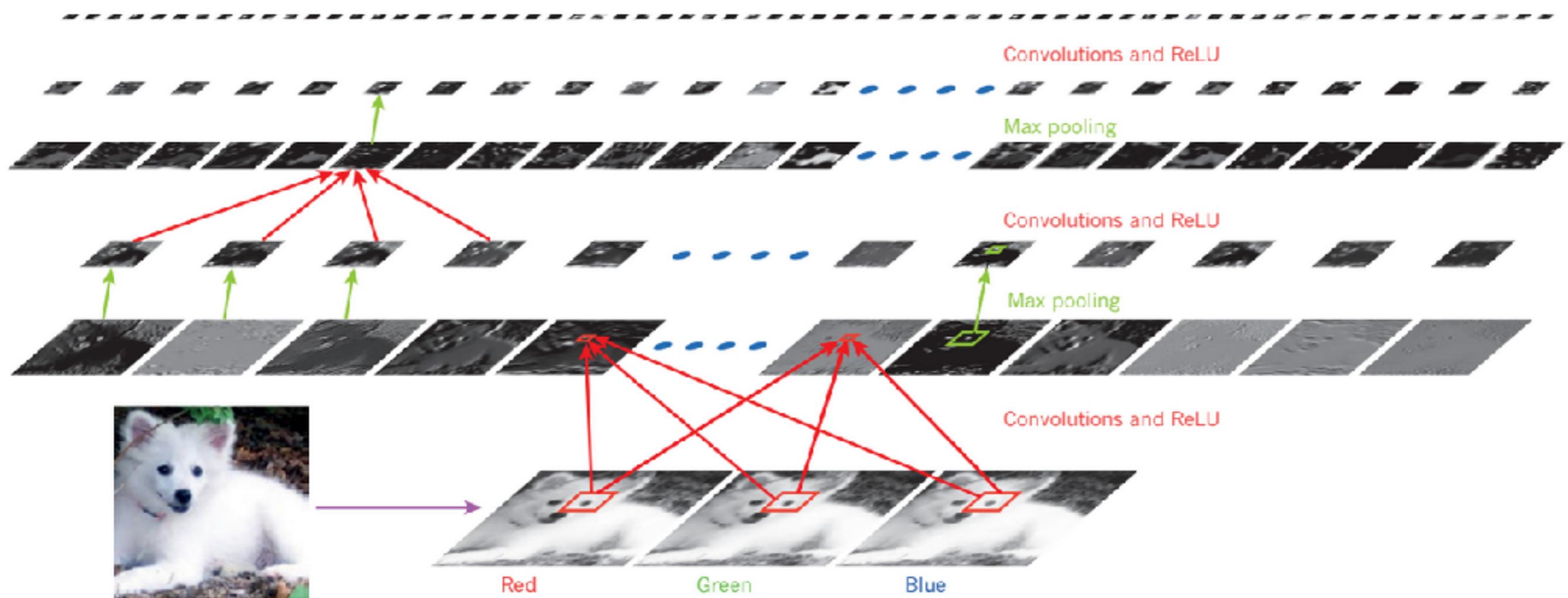
- “It is very hard to train multilayer networks with more than 1 hidden layer”
- “This is a fundamental limit of multilayer perceptrons and (stochastic) gradient descent learning”

Shift towards other machine learning methods
(SVM, graphical models, ...)

Deep Learning (2015)

Convolutional Neural Network (LeCun)

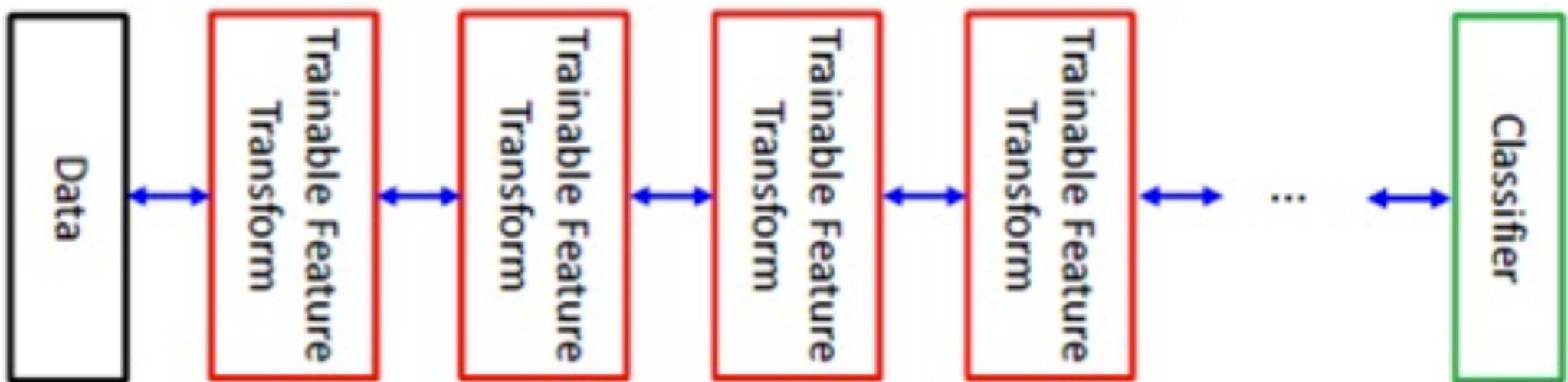
Samoyed (16); Papillon (5.7); Pomeranian (2.7); Arctic fox (1.0); Eskimo dog (0.6); white wolf (0.4); Siberian husky (0.4)



Automatically Learns Complex Non-Linear Mappings

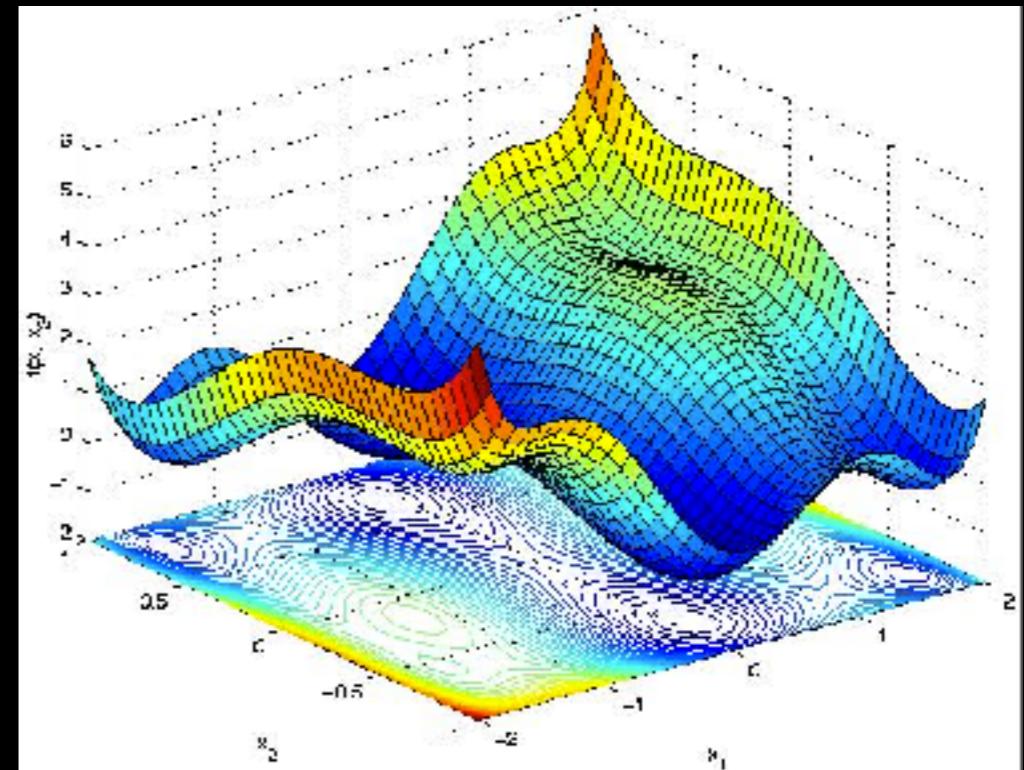
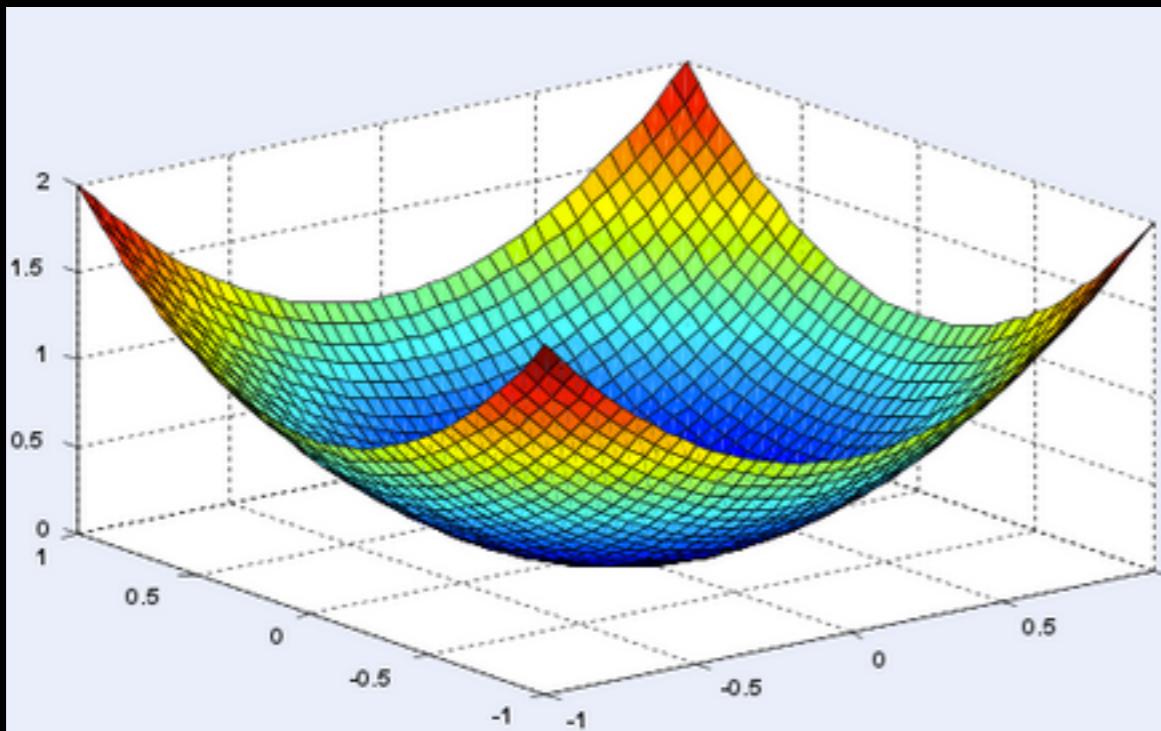
Stochastic Gradient Descent

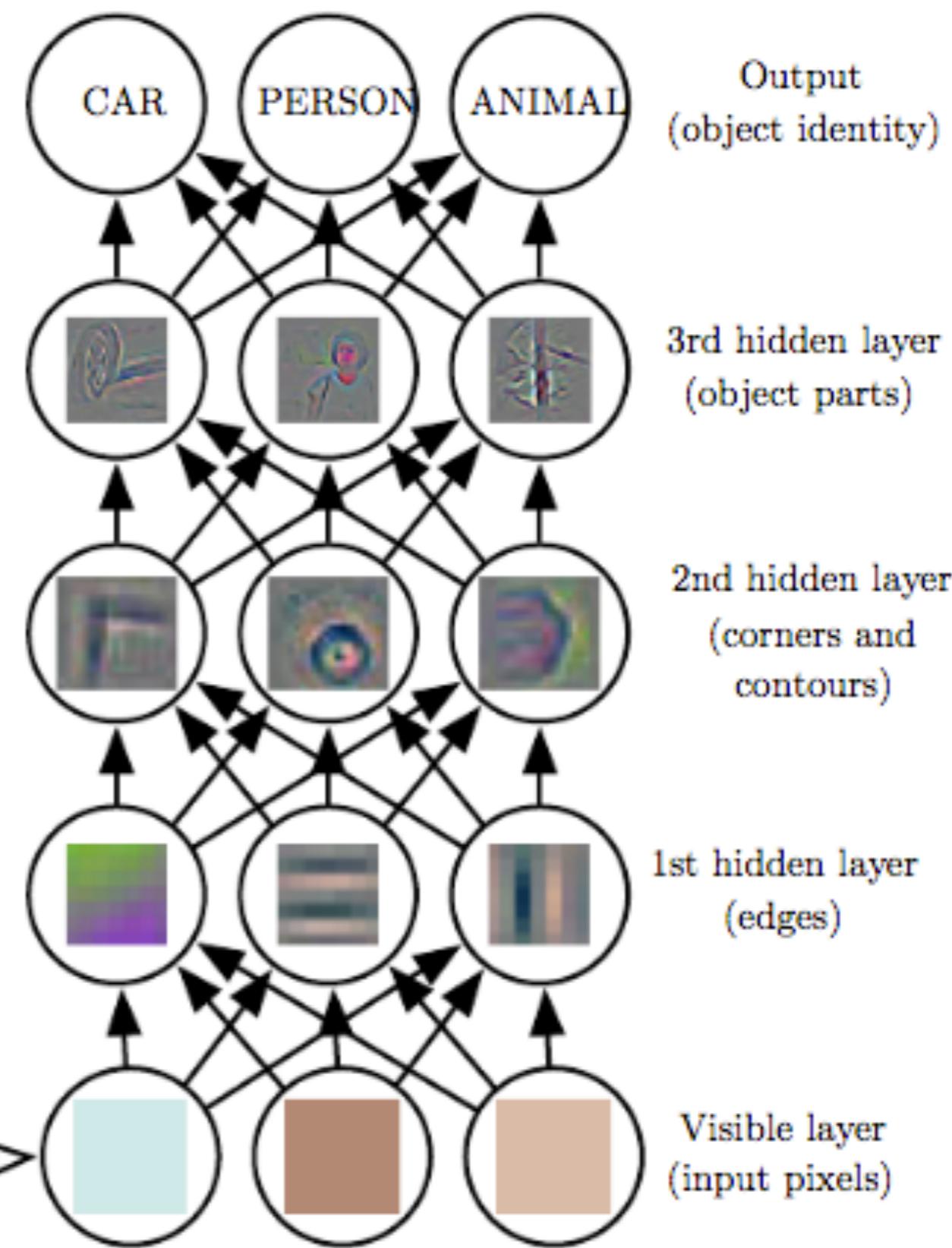
$$\mathbf{y} = F(\mathbf{W}^k \cdot F(\mathbf{W}^{k-1} \cdot F(\dots F(\mathbf{W}^0 \cdot \mathbf{x})))$$



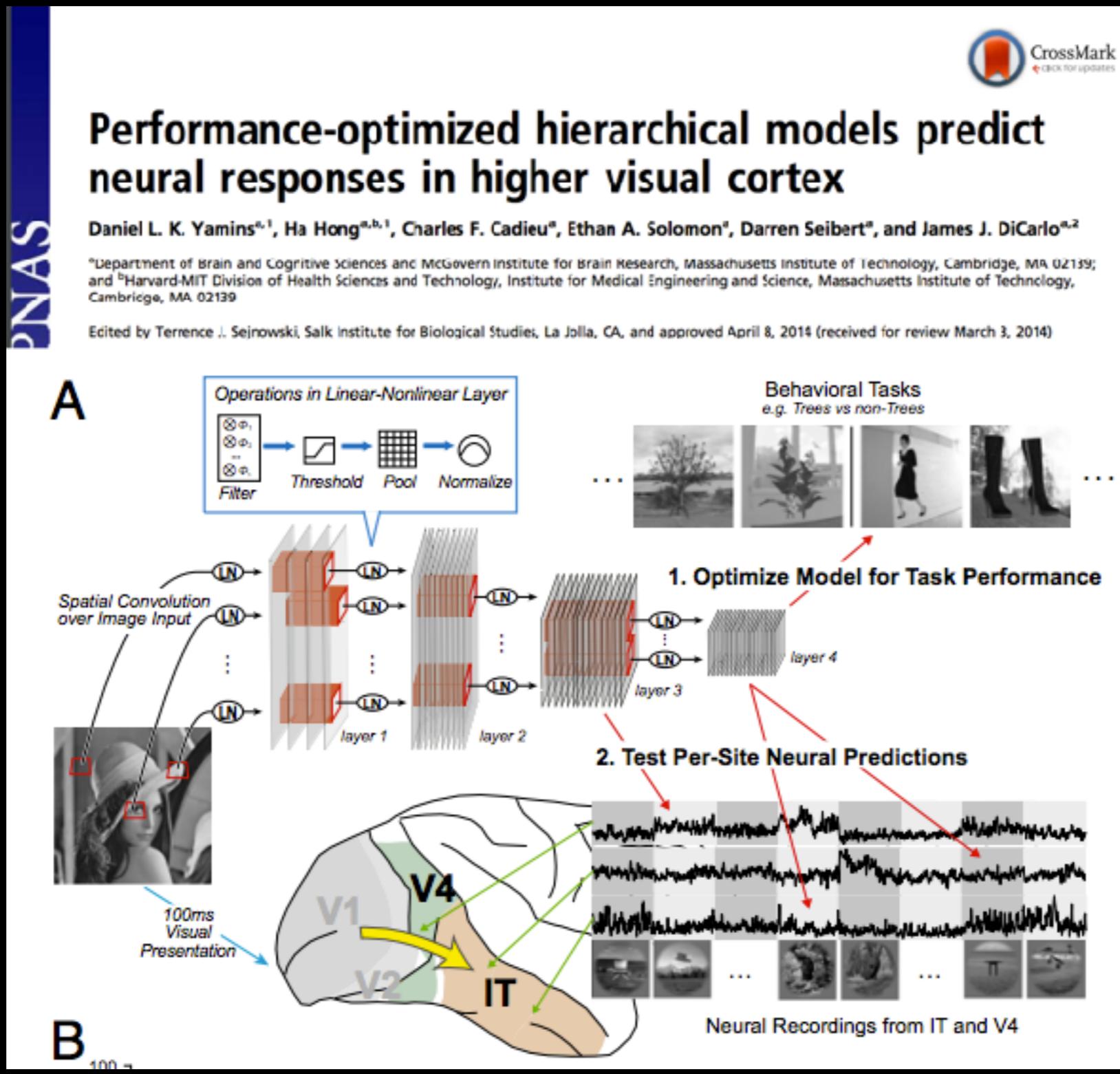
Training

- Training a Deep Convolutional Neural Network
- Non-convex optimisation problem
- Convex versus non-convex optimisation

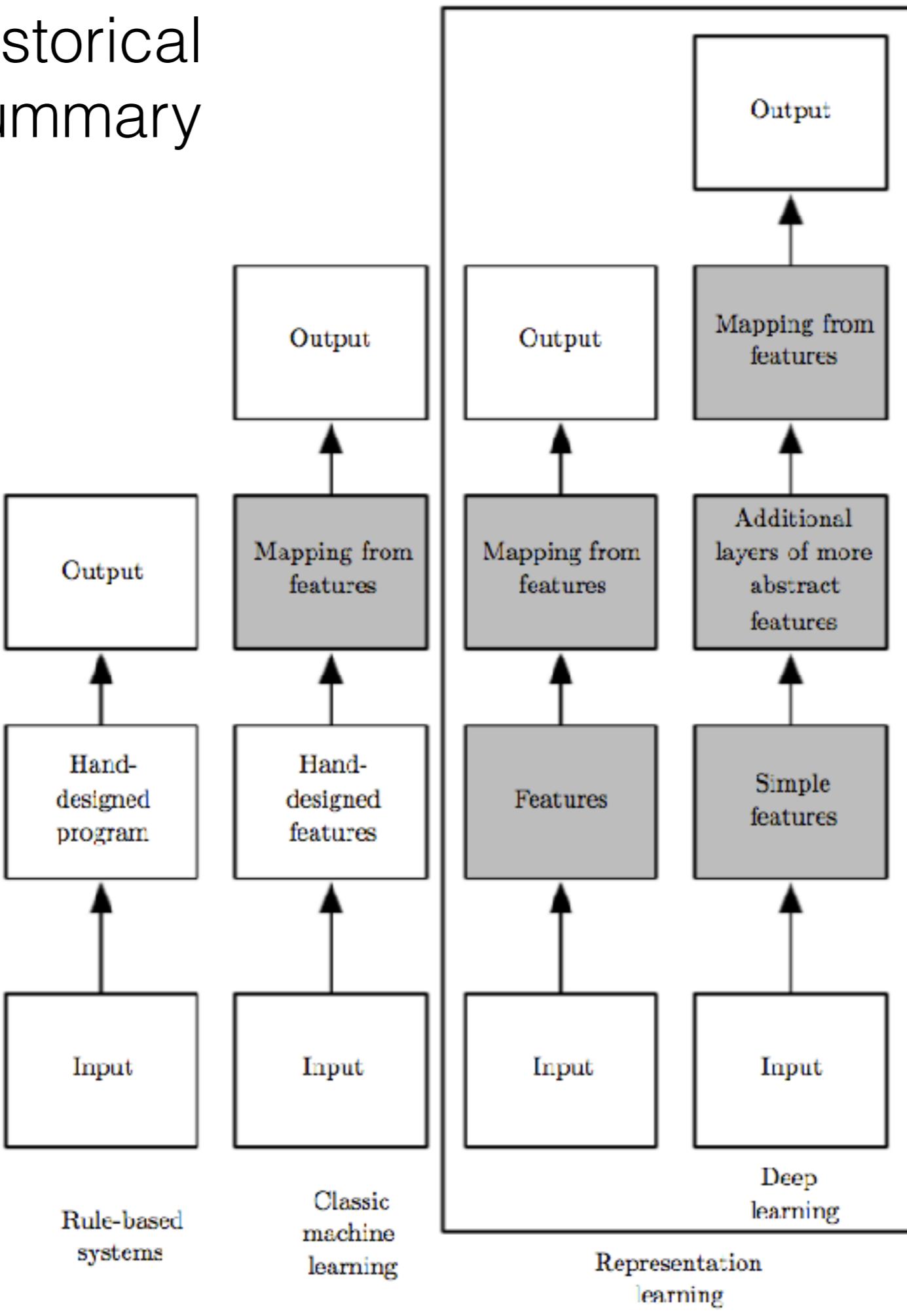




Biological Plausibility

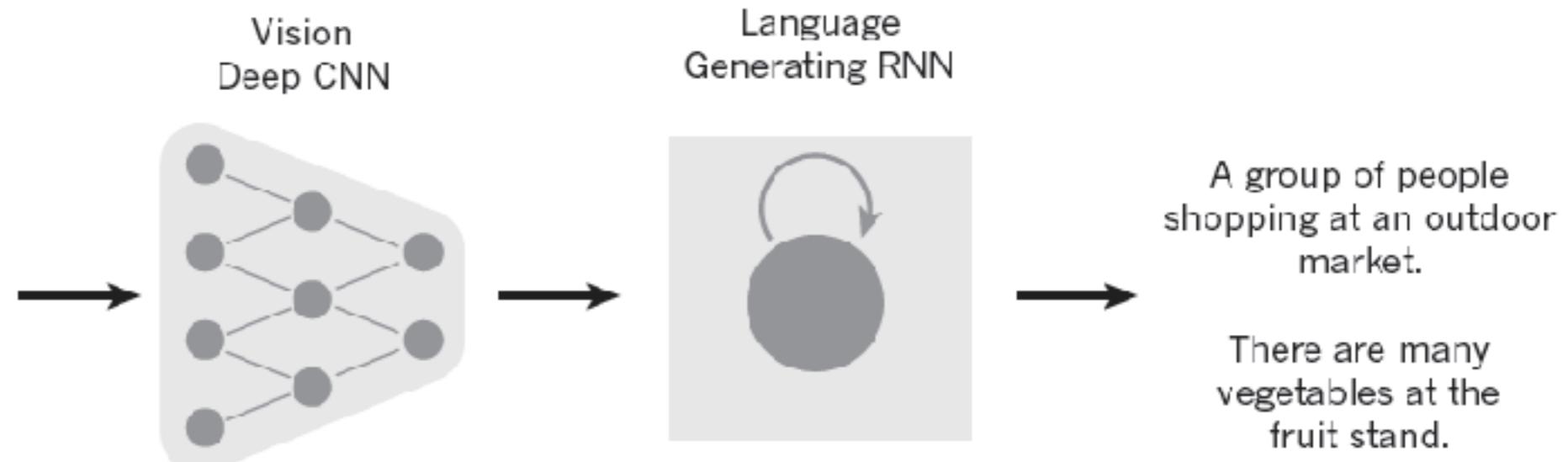


Historical summary



<http://www.deeplearningbook.org/>

Reading Images (FaceBook)

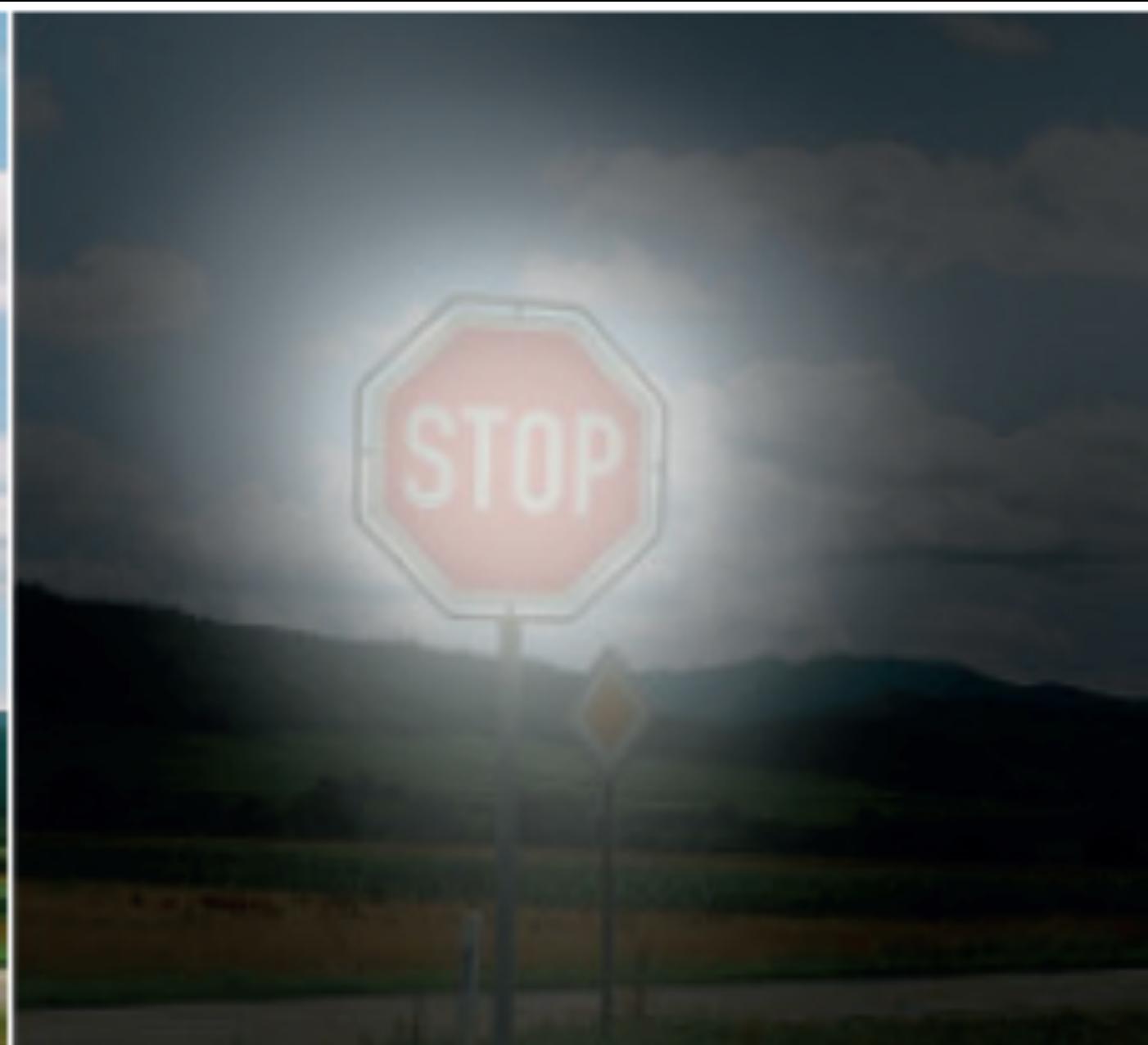




A woman is throwing a frisbee in a park.



A dog is standing on a hardwood floor.



A stop sign is on a road with a mountain in the background



A group of **people** sitting on a boat in the water.

Applications of Deep Learning

(Feedforward networks, recurrent networks,
reinforcement learning, ...)

- Speech recognition/translation
- Image and object recognition
- Control tasks (playing video games)
- Language generation

Deep Learning Catches On in New Industries, from Fashion to Finance

The machine-learning technique known as deep learning, which has shown impressive results in voice and image recognition, is finding new applications.

By Will Knight on May 31, 2015





NEWS

≡ Sections

Technology

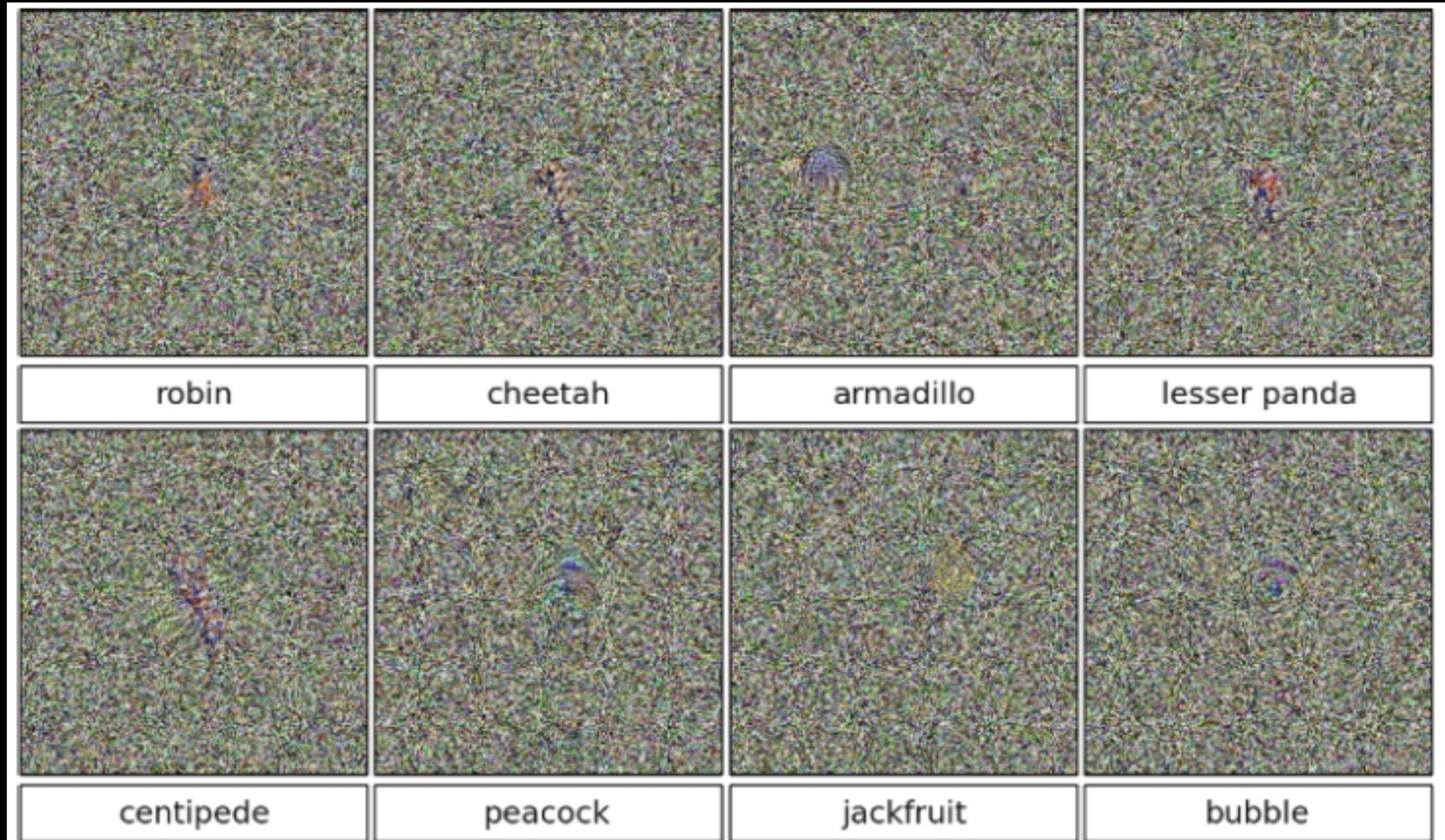
Google's AI beats world Go champion in first of five matches

🕒 9 March 2016 | Technology



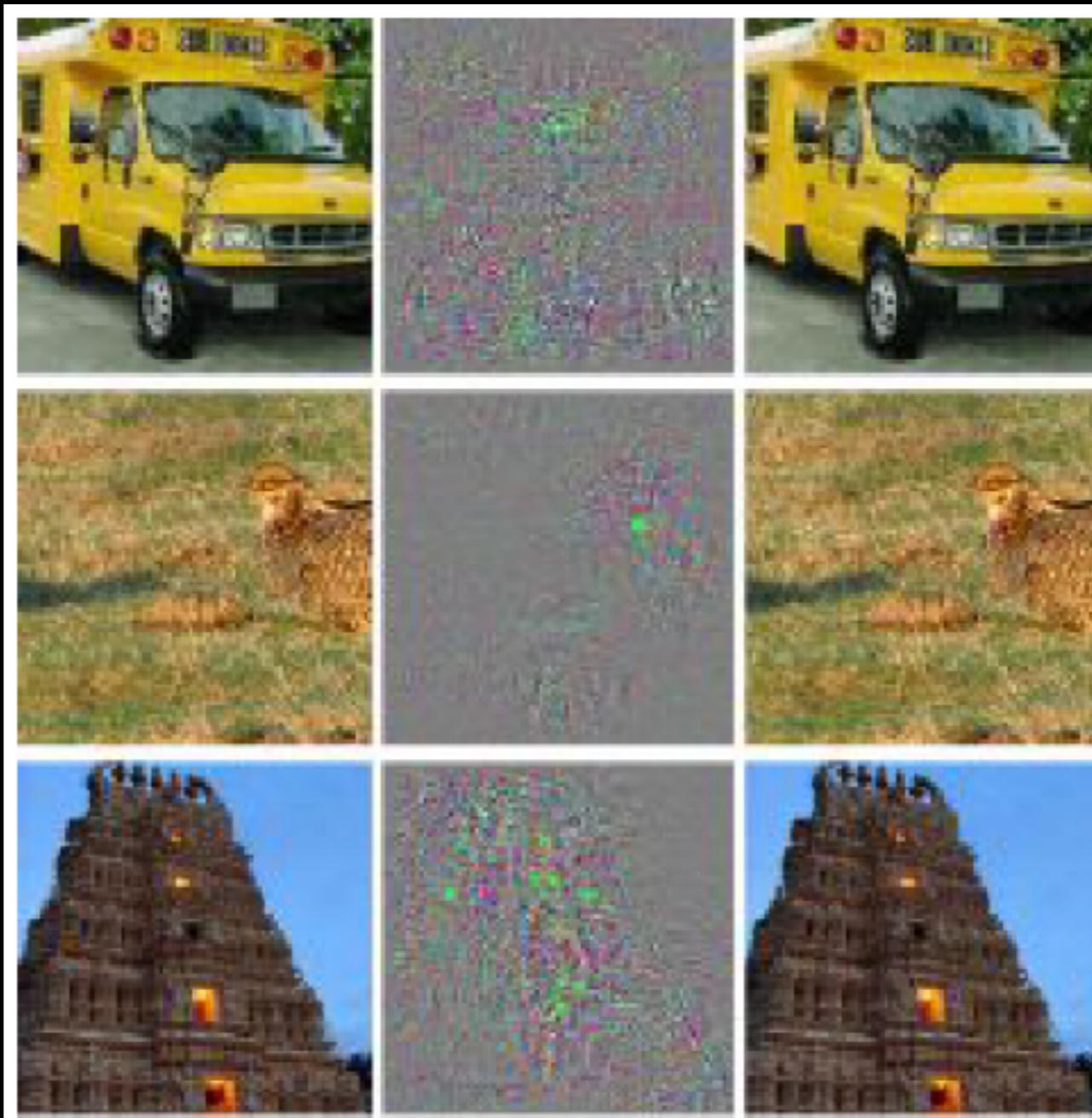
Hands-on exercise 3

Deep Learning Flaws



Nguyen, Yosinski & Clune (1994)

Deep Learning Flaws



correctly
classified

incorrectly
classified

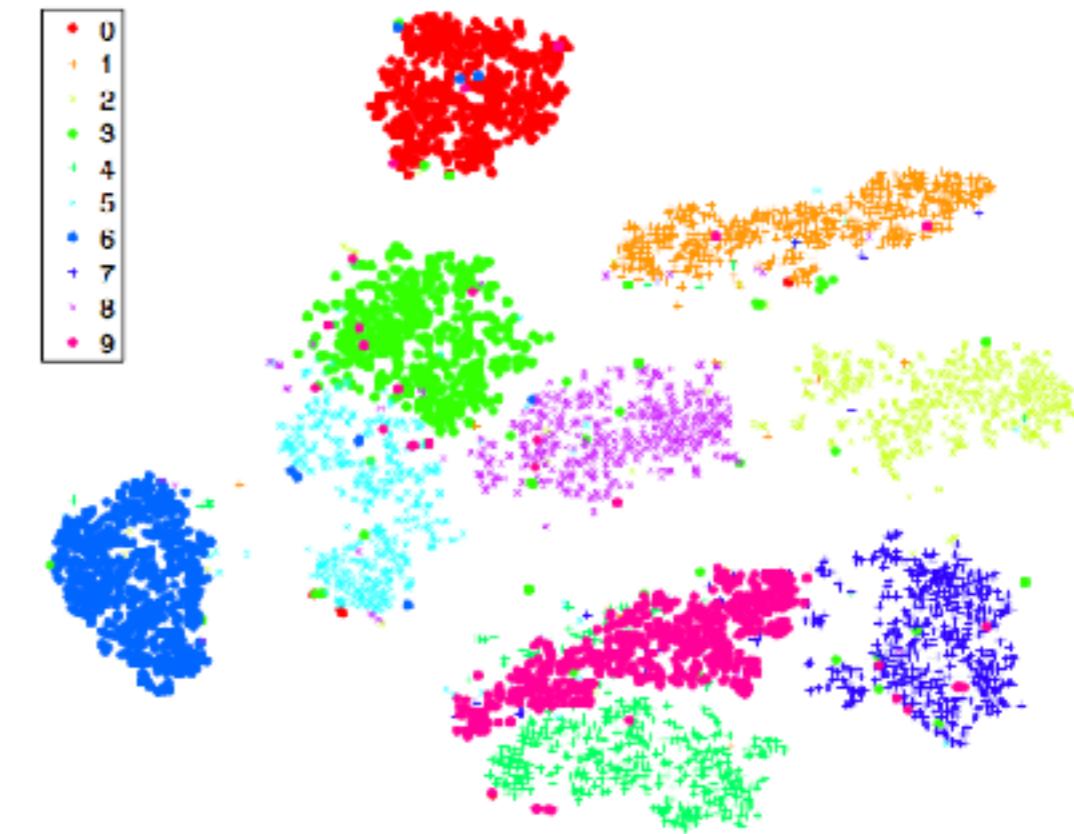
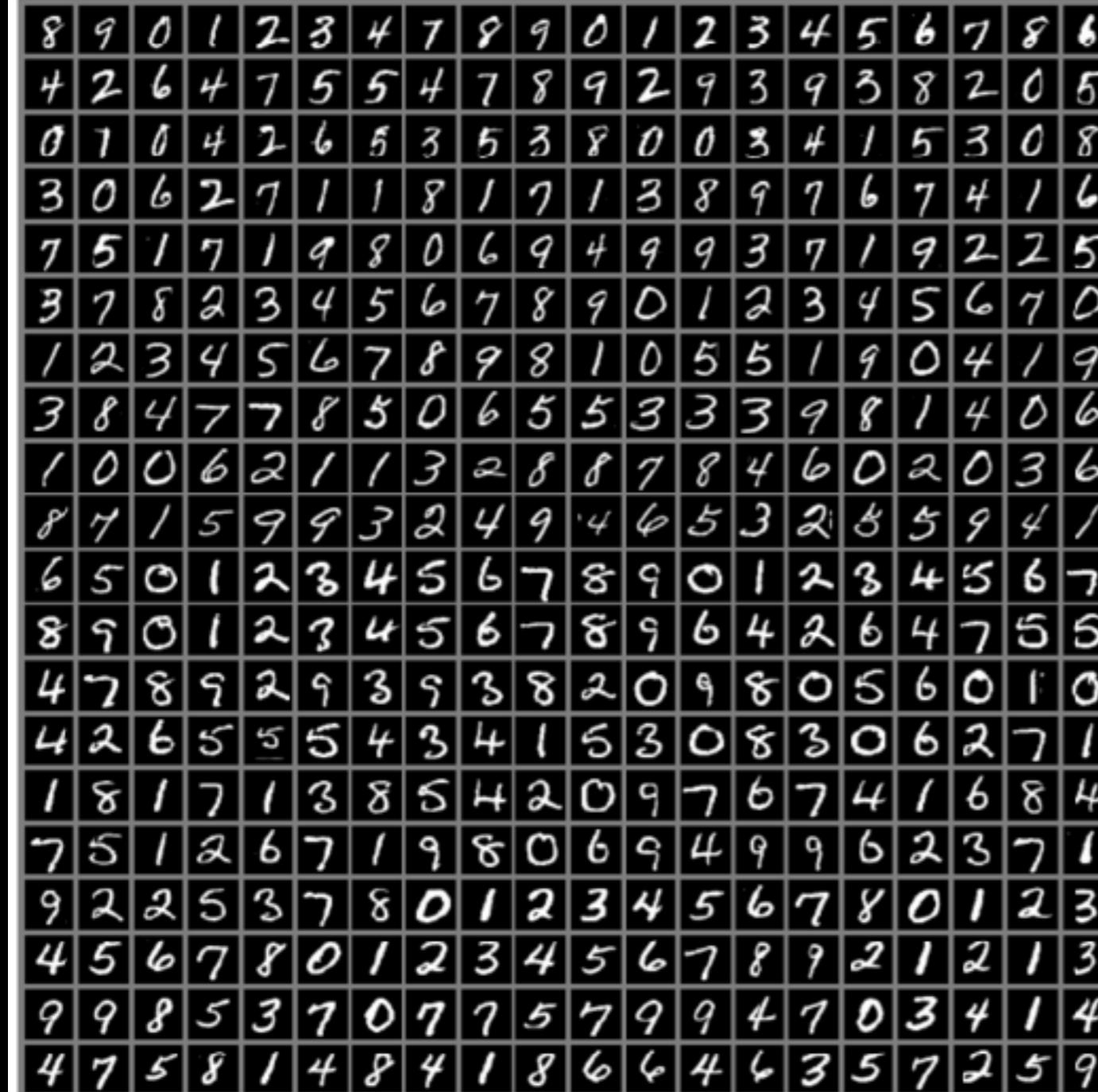
Szegedy et al. (2014)

Deep Learning versus Statistics

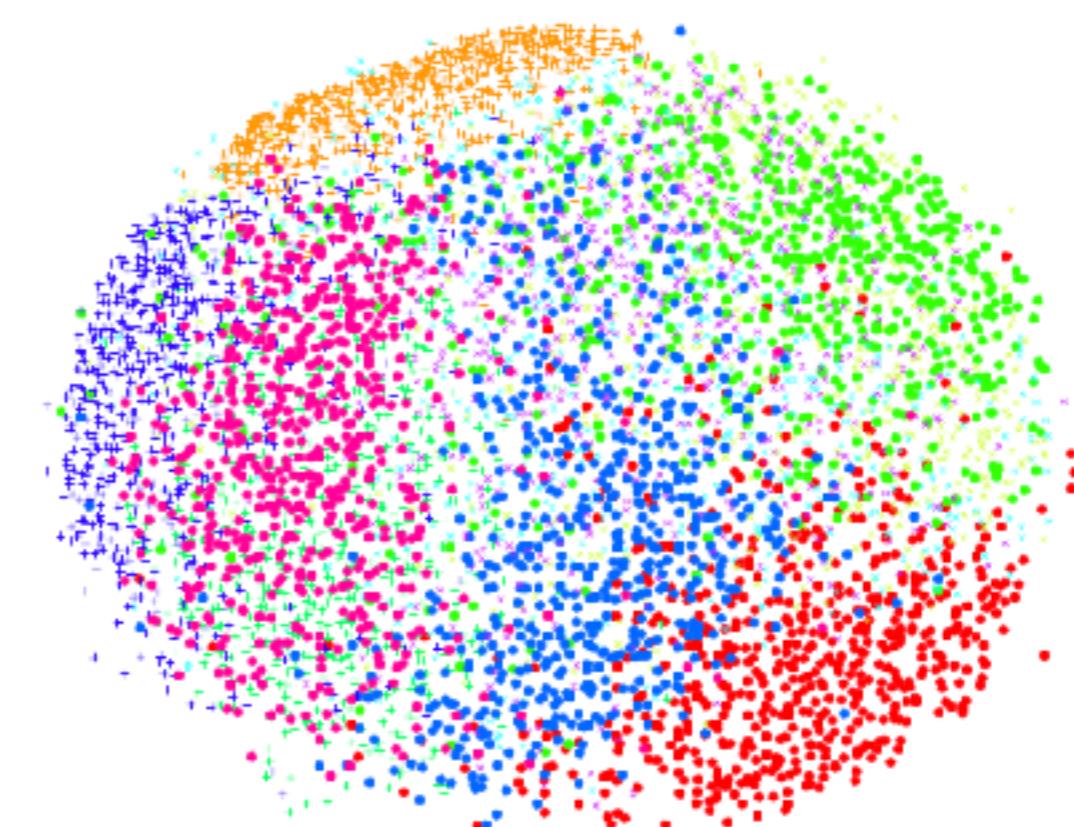
- Deep Learning:
prediction - opaque representations are like latent factors
- Statistics:
inference - transparent

CNNs representations offer some transparency



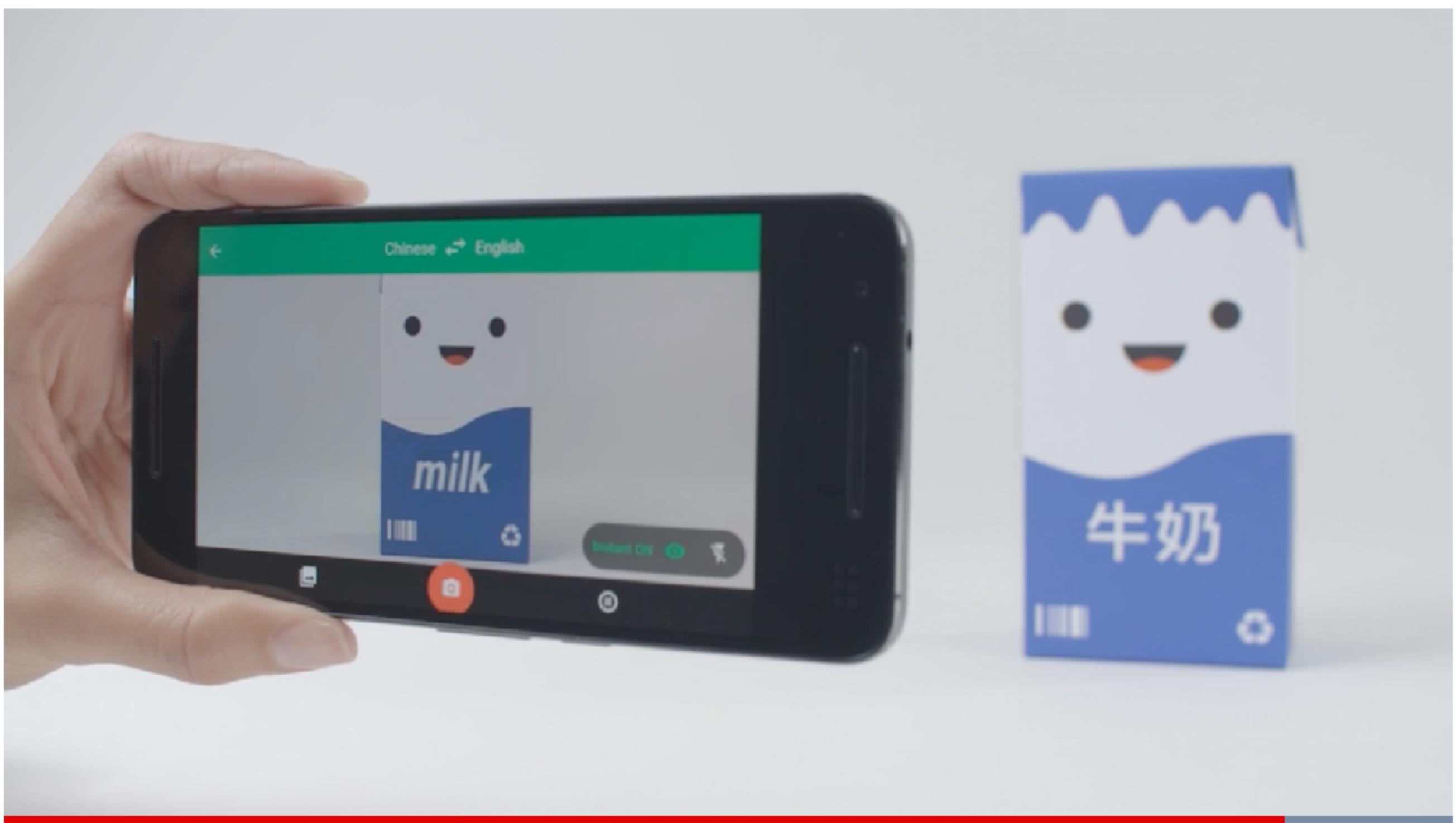


(a) Visualization by t-SNE.



(b) Visualization by Sammon mapping.

Figure 2: Visualizations of 6,000 handwritten digits from the MNIST data set.



Google's new translation software is powered by brainlike artificial intelligence

By Catherine Matacic | Sep. 27, 2016, 2:45 PM



Machines are finally getting the best of humans at poker.

dolgachov/iStockphoto

Artificial intelligence goes deep to beat humans at poker

By **Tonya Riley** | Mar. 3, 2017 , 2:15 PM

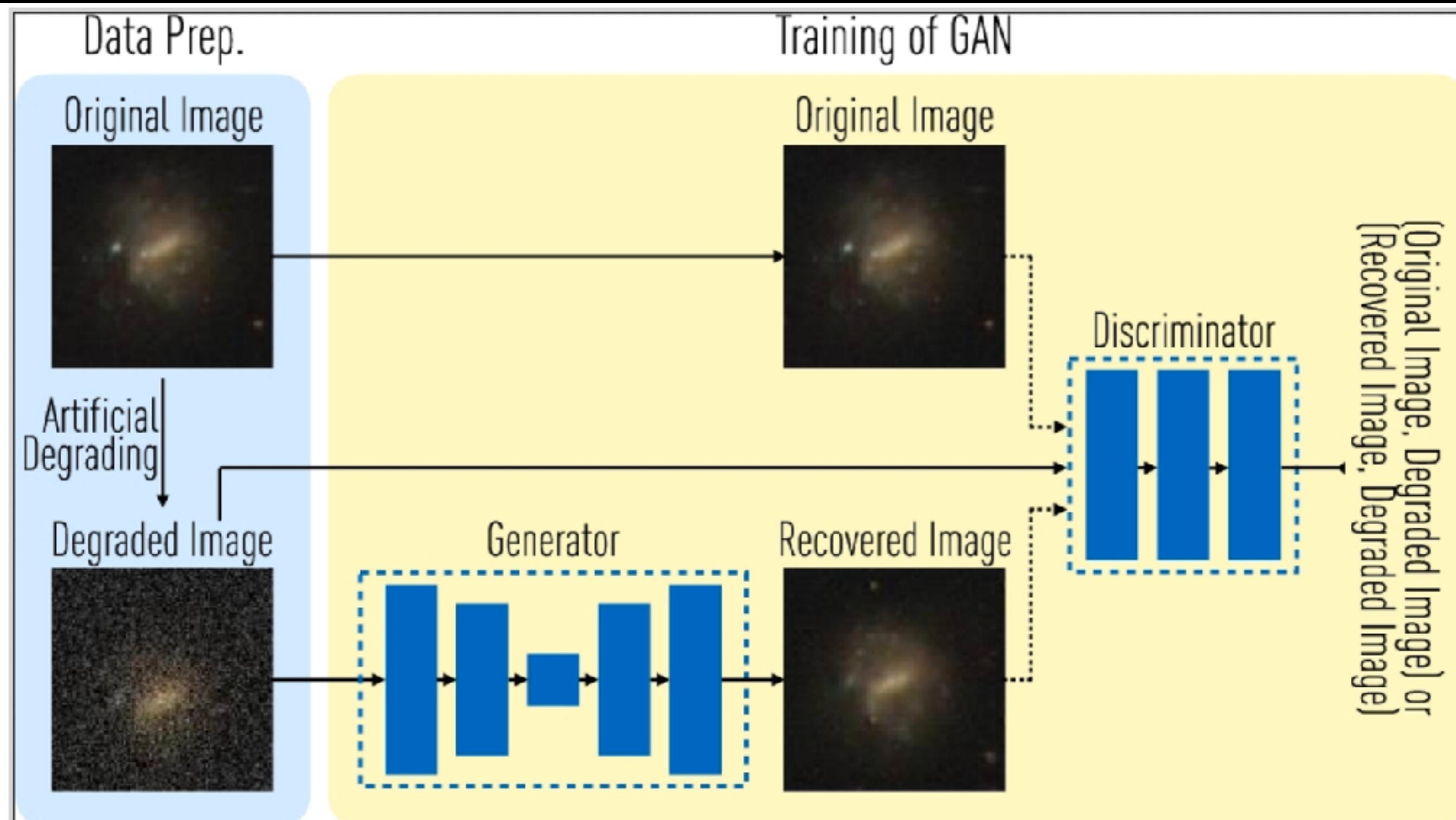
A deep learning algorithm outperforms some board-certified dermatologists in diagnosis of skin cancer

January 25, 2017



A dermatologist uses a dermatoscope, a type of handheld microscope, to look at skin. Stanford AI scientists have created a deep convolutional neural network algorithm for skin cancer that matched the performance of board-certified dermatologists. (credit: Matt Young)

Generative Adversarial Networks



Schematic illustration of the neural-network training process. The input is a set of original images. From these, the researchers automatically generate degraded images, and train a GAN. In the testing phase, only the generator will be used to recover images. (credit: K. Schawinski / C. Zhang / ETH Zurich)

Automatic Author Attribution

Nanne van Noord, Eric Postma & Ella Hendriks (2015).
Towards Discovery of the Artist's Style. *IEEE Signal Processing Magazine*.

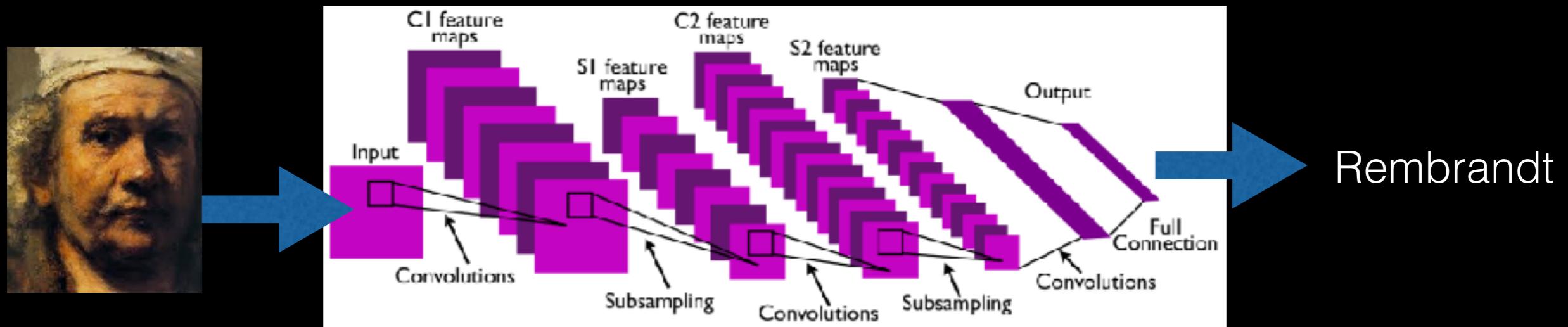


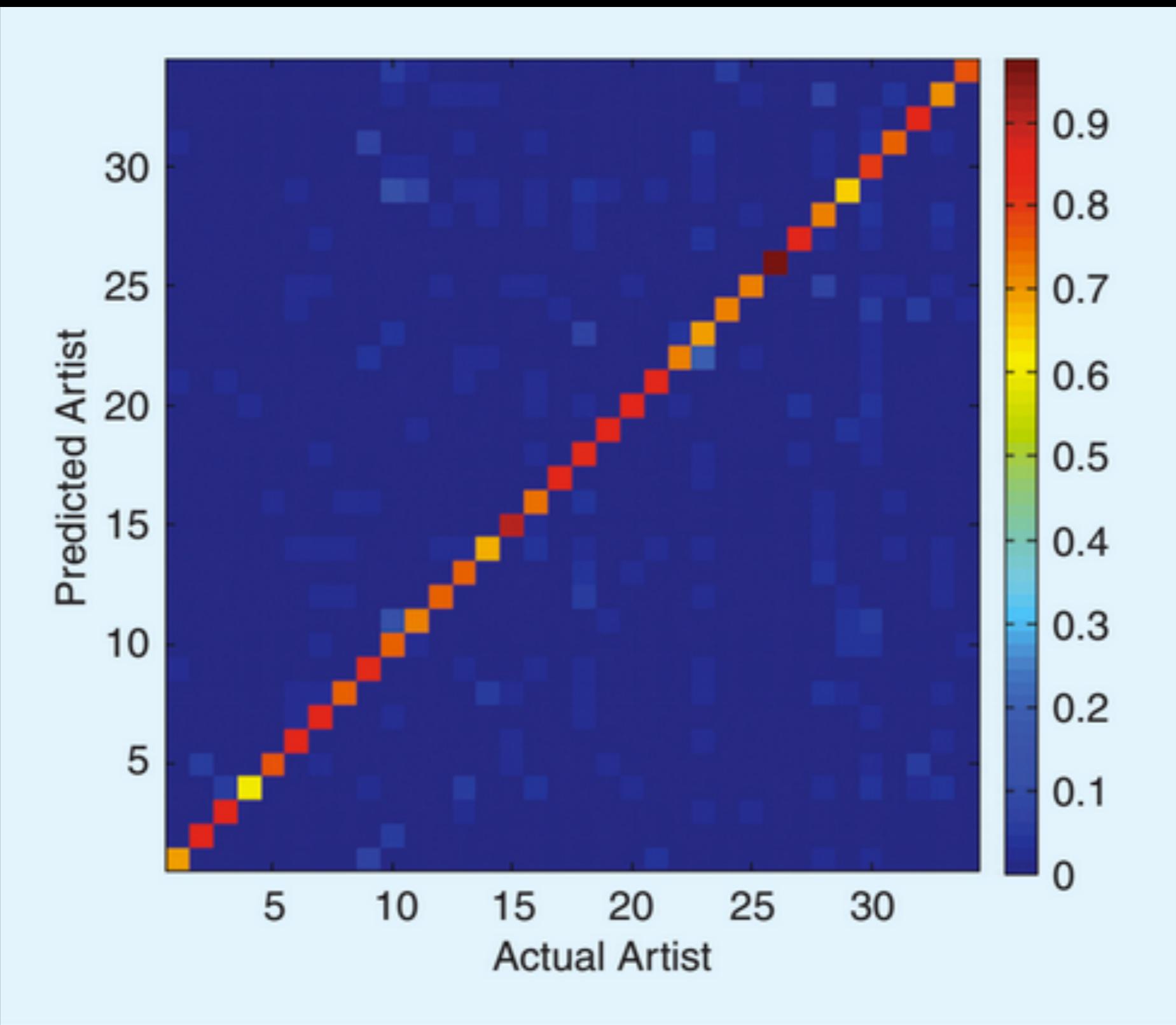
Jan Brueghel and Peter Paul Rubens (1615).
The garden of Eden with the fall of man.
The Hague, Royal Picture Gallery Mauritshuis

RIJKS MUSEUM

Database

- 112.039 digital reproductions of artworks
- 6.629 artists
- Automatic author attribution with Deep Learning



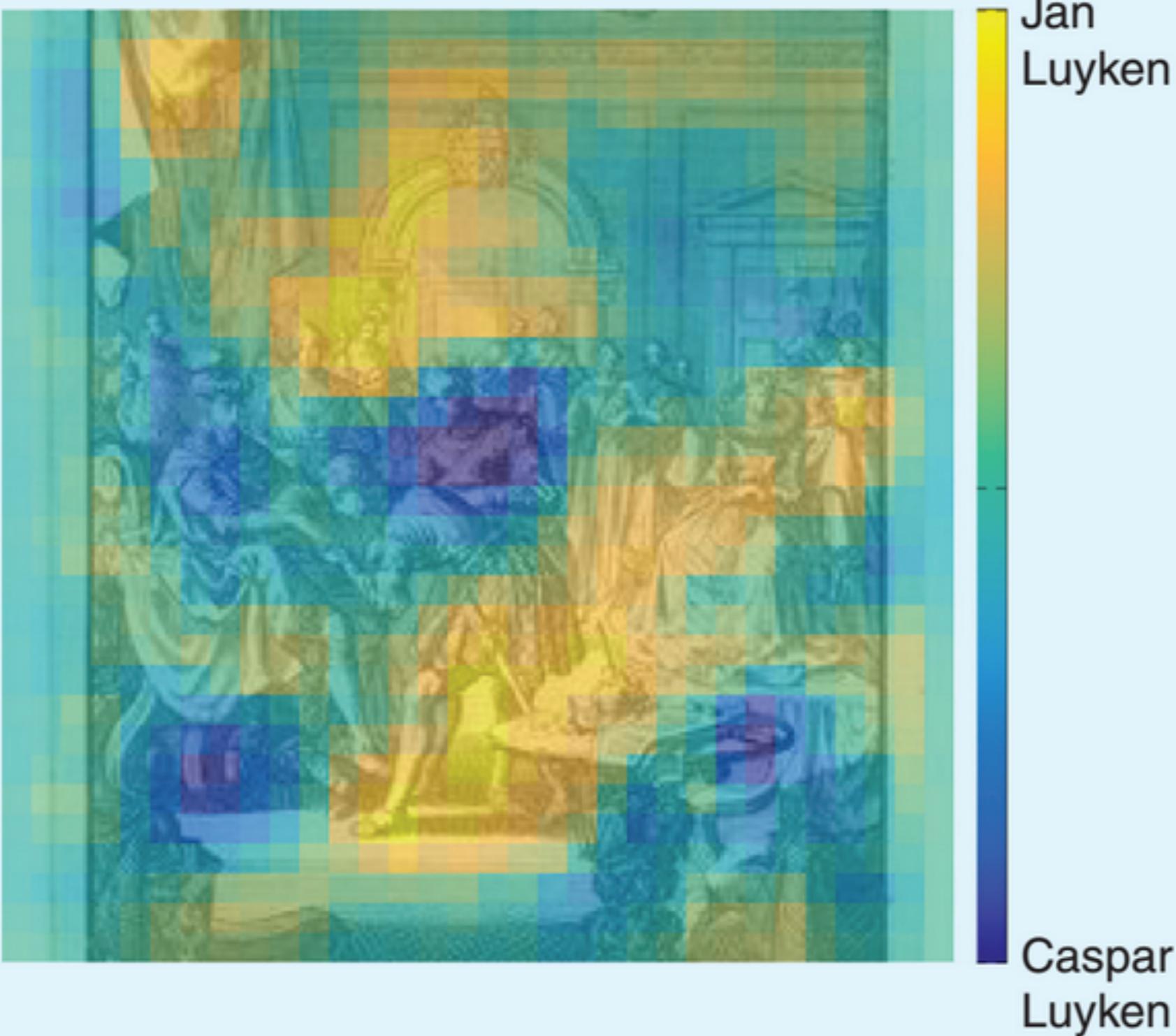


MCA > 80% (more data, better performance)

Jan &
Caspar
Luyken



[FIG5] An image of the *Overdracht der Nederlande, aan de Infante Isabella* (1697–1699) by Jan Luyken.



[FIG6] Visualization of how characteristic each image region is for the artists Jan and Caspar Luyken. The yellow regions are characteristic of Jan Luyken, whereas the blue regions are characteristic of Caspar Luyken.

Concluding remarks

- Deep Learning is an extremely powerful machine learning method
- It is not entirely clear why it works
- Future developments: more data, more principled approach (cf. MLPs vs. SVMs)
- Collaboration of statistics and AI is required to move the field forward