

COMP4302/COMP5322, Lecture 1
NEURAL NETWORKS

**Introduction to Neural Networks
and Machine Learning**

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Outline

- **What is this course about?**
- **Administrative matters**
- **What is an artificial neural network?**
- **Structure and operation of biological neural systems**
- **Simple neuron model**
- **Introduction to machine learning**
- **Artificial neural networks - historical sketch**

What is this course about?

- **We are using a complex biological NN - a highly interconnected set of 10^{10} neurons to facilitate our reading, breathing, motion, thinking...And it's highly parallel!**
- **Each neuron**
 - is a rich assembly of tissue and chemistry
 - has the complexity (if not the speed) of a microprocessor
- **We were born with some of our neural structures; other parts have been established by experience**
- **Scientists have only just began to understand how biological NNs operate**
 - **neural functions are stored in the neurons and their connections**
 - **learning: establishment of new and modification of existing connections**

What is this course about? - 2

- **Question:** Although we have only a rudimentary understanding of biological NNs, is it possible to construct a simple artificial “neurons” and perhaps train them to serve a useful function?
- **Answer:** Yes!
- **This course is about artificial neural networks**
 - **artificial neurons**
 - (extremely) simple abstractions of biological neurons
 - realized as a computer program or specialized hardware
 - **networks of artificial neurons**
 - do not have a fraction of the power of the human brain but can be trained to perform useful functions

Semester overview

- **Classes:** 2 hours lecture and 1 hours laboratory (prac)
 - **Lectures:** Monday, 2-4pm, Main Quad History, S223
 - **Labs:** Monday, 4-5pm, Carslaw 202B and 202C (Matlab and Matlab’s Neural Networks toolbox)
- **Consultation time:** Monday 1-2pm in Madsen g90a
- **Topics overview**

1	Artificial neural networks and their biological motivation. Introduction to machine learning.
2	Neural models and neural architectures. Perceptron.
3	ADALINE. Evaluating what has been learnt.
4	Feedforward multilayer NNs. Backpropagation algorithm
5	Advanced learning algorithms for multiplayer perceptrons.
6	Hebbian learning. Clustering. Competitive neural networks. Self-organizing feature maps.
7	More competitive NNs. Vector quantization.
8	Genetic algorithms and neural networks.
9	Radial-basis function neural networks.
10	Public holiday – Labour day
11	Hopfield networks.
12	Presentation 1
13	Presentation 2

Assessment overview

- **2 programming assignments in Matlab, presentation of a neural network application paper and written exam (closed book)**
- **Assignments can be done in pairs**

Task	%	Out	Due	Topic
Ass 1	20	W4	W7	Perceptron, adaline, backpropagation
Ass 2	15	W7	W9	Competitive learning
Presentation	15	w12-13	w12-13	Application of neural networks
Exam	50			All

- **To pass the course:** at least 50% overall (semester assessment + exam) AND at least 40% on the exam (i.e. 20 marks)
- **Late submission of assignments policy**
 - a penalty of 1 mark per each day after the deadline will apply
 - assignments will not be accepted if the delay is more than 7 days

Academic Dishonesty

- Do not confuse legitimate co-operation and cheating!
- Plagiarism or any other form of dishonesty will be dealt with by standard University procedures. Please see the policies published at:
<http://policy.rms.usyd.edu.au/000003f.pdf>
- Plagiarism is:
 - Copying all or part of another student's work (with or without their knowledge)
 - Using another person's ideas without acknowledgement
 - Obtaining material (code or other) from the web or a book and passing it off as your own (perhaps with minor modifications such as variable renaming)

Special Considerations Due to Illness or Misadventure

- There is a new on-line procedure
- Special consideration related to examinations
 - A student who finds himself/herself or otherwise indisposed at the time of an examination must consider his/her position carefully. There are two possibilities:
 1. sit the examination, in which case no opportunity of a further test will be granted.
 2. miss the examination

University and School Policies

<http://www.it.usyd.edu.au/postgrad/coursework/policies.html>

- Covers
 - Academic Honesty and Plagiarism
 - Late Submission of Assignments
 - Assessment
 - Appeal Procedures
 - Perusal of Examination Scripts
 - Special Consideration Due to Illness or Misadventure

Recommended Textbooks

- **Neural Network Design, 1st Edition**
Martin T. Hagan, Howard B. Demuth, Mark H. Beale
PWS Publ. Company, 1996. ISBN: 0-534-94332-2
- **Neural Computing: An Introduction**
R. Beale, T. Jackson
publisher: Adam Hilger, 1990, ISBN: 0-85274-262-2
- **Neural Networks for Pattern Recognition**
Christopher M. Bishop
Oxford University Press, 1996, ISBN: 0198538642
- **Introduction to the Theory of Neural Computation**
John Hertz, Anders Krogh, Richard Palmer
Addison-Wesley, 1991, ISBN: 0201515601
- **Another good book (NNs from engineering point of view):**
Neural Networks: a comprehensive foundation, 2d ed.
Simon Haykin
Prentice Hall, 1999, ISBN: 0-13-273350-1



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Neural Network Journals

- Neural Networks
- IEEE Transactions on Neural Networks
- IEEE Transactions on Pattern Analysis and Machine Intelligence
- IEEE Transactions on Circuits and Systems
- IEEE Transactions on Systems, Man, and Cybernetics
- Neural Computation
- Neurocomputing
- Neural Computing and Applications
- Machine Learning
- Connection Science
- Neural Processing Letters
- Artificial Intelligence
- Artificial Intelligence in Medicine
- Pattern Recognition
- International Journal of Pattern Recognition and Artificial Intelligence
- Intelligent Data Analysis ...

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What is an Artificial Neural Network (NN)?

- No universally accepted definition of an NN
- Most people in the field agree that an NN is a network of many simple processors (*units, neurons*)
 - The units are connected by *connections*
 - Each connection has a numeric *weight* associated with it
 - The units operate only locally - on their weights and the inputs they receive via the connections
- NNs *learn from examples* and exhibit some capability for generalization beyond the training data
 - They have some sort of *training (learning) rule* - a procedure for modifying the weights of connections in order to perform a certain task

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What is an Artificial Neural Network (NN)? - 2

According to Haykin, *NNs: A Comprehensive Foundation, 1999*

- A NN is a massively parallel distributed processor made up of simple processing units, which has a natural propensity for storing experimental knowledge and making it available for use. It resembles the brain in two respects:
 - knowledge is acquired by the network from its environment via a learning process
 - inter-neuron connections strengths known as synaptic weights are used to store knowledge

What is an Artificial Neural Network (NN)? - 3

- Some NNs are models of biological NNs and some are not
- The inspiration for the field of NNs came from the desire to produce artificial systems capable of sophisticated, perhaps "intelligent", computations similar to those that the human brain routinely performs, and thereby *also to enhance our understanding of the brain*

Characteristics of Computers and Human Brain

- Computers are good at:
 - fast arithmetic
 - doing precisely what they are programmed to do
- Computers are not so good at:
 - interacting with noisy data or data from the environment
 - massive parallelism
 - fault tolerance
 - adapting to circumstances
- Human brain is
 - Robust and fault tolerant
 - Flexible – can adjust to new environment by learning
 - Can deal with fuzzy, probabilistic, noisy or inconsistent information
 - Is highly parallel
 - Is small, compact and requires little power (10^{-16} J/oper/sec, comparing with 10^{-6} J/oper/sec for a digital computer)

Efficiency of Biological Neural Systems - 1

- The brain is highly complex, nonlinear, and parallel information processing system
- It performs tasks like pattern recognition, perception, motor control *many times faster* than the fastest digital computers
- **efficiency of the human visual system**
 - a complex task of perceptual recognition (e.g. recognition of a familiar face in a unfamiliar scene) can be accomplished in 100-200 ms, whereas tasks of much lesser complexity may take days on a conventional computer



Efficiency of Biological Neural Systems - 2

- **efficiency of the sonar system of a bat**
 - sonar is an active echo-location system
 - a bat sonar provides information about the distance from a target, its relative velocity, size, azimuth, elevation; the size of various features of the target
 - the complex neural computations needed to extract all this information from the target echo occurs within a brain which has the size of a plum!
 - the precision and success rate of the target location achieved by the echo-locating bat is rather impossible to match by radar or sonar engineers
- How does a human brain or the brain of a bat do it?



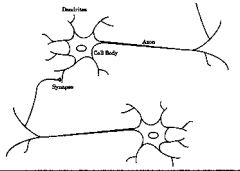
Human Nervous System

- The idea of neurons as structural components of the brain was introduced by Ramon y Cajal in 1911
- A huge number of neurons and interconnections between them:
 - 100 billion (i.e. 10^{10}) neurons in the brain
 - a full Olympic-sized swimming pool contains 10^{10} raindrops; the number of stars in the Milky Way is of the same magnitude
 - $1/20^{\text{th}}$ of a hair in diameter
 - 10^4 connections per neuron
- Neurons are slower than computers
 - Neurons operate in 10^{-3} seconds, computers in 10^{-9} seconds
 - Speed transmission in neurons 2-120 metres/second
 - The brain makes up for the slow rate of operation by the large number of neurons and connections

Biological Neurons

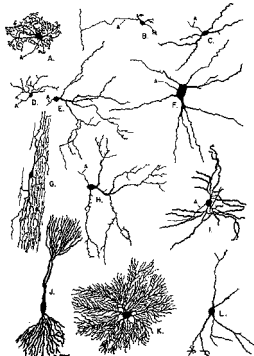
- The purpose of neurons is to transmit information
- Neuron's operation is a complicated and not fully understood process on a microscopic level, although the basic details are relatively clear:
 - it accepts many inputs, which are all added up in some way
 - if enough active inputs are received at once, the neuron will be activated and fire; if not, it will remain in its inactive state

Structure of Biological Neurons



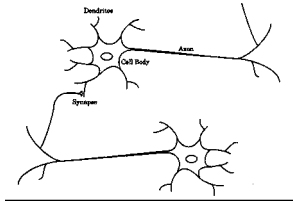
- Structure of neuron
 - body (soma) – contains nucleus containing the chromosomes
 - dendrites
 - axon
 - synapse - a narrow gap
 - couples the axon with the dendrite of another cell
 - no direct linkage across the junction, it is a chemical one
 - information is passed from one neuron to another through synapses

Different types of neurons



Operation of biological neurons

- signals are transmitted between neurons by electrical pulses (action potentials, spikes) traveling along the axon
- when the potential at the synapse is raised sufficiently by the action potential, it releases chemicals called neurotransmitters
 - it may take the arrival of more than one action potential before the synapse is triggered

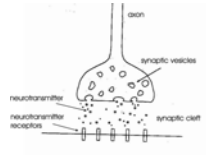


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Operation of biological neurons - 2

- the neurotransmitters diffuse across the gap and chemically activate gates on the dendrites, that allows *charged ions to flow*
 - the flow of ions alters the potential of the dendrite and provides a voltage pulse on the dendrite (*post-synaptic potential, PSP*)
 - some synapses *excite* the dendrite they affect, while others *inhibit* it
 - synapses determine the strength and the polarity of the new input signal
- each PSP travels along its dendrite and spreads over the soma
- the soma sums the effects of thousands of such PSP; if the resulting potential exceeds a threshold, the cell (neuron) fires and generates an action potential



More about biological neurons: basic neuroscience slides by Ione Fine
<http://www-psy.ucsd.edu/%7Eifine/psych1.pdf>

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Neurotransmitters

- Each neuron is connected with 10 000 other neurons
- These connections use different neurotransmitters
- Differ in strength, timing, and polarity
- Drugs affect neurotransmitters in several ways, e.g.
 - Blocking release of neurotransmitters into synapse
 - Inhibiting enzymes that synthesize neurotransmitters
 - Blocking neurotransmitter uptake
 - Blocking enzymes that degrade neurotransmitters

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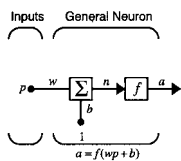
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Brain plasticity

- At the early stage of the human brain development (first 2 years from birth) about 1 million synapses are formed per second
- Synapses are then modified through the learning process (plasticity of a neuron)
- In an adult brain plasticity is achieved by
 - creation of new synaptic connections between neurons
 - modification of existing synapses
- The synapses are thought to be mainly responsible for learning
- 1949, Hebb proposed his famous learning rule:
The strength of a synapse between 2 neurons is increased by the repeated activation of one neuron by the other across the synapse

Single-Input Neuron

- an input p * weight $w = wp$
- bias (offset) b
 - it's like a weight except that it has a constant input of 1
 - a neuron may have or may not have a bias
- n - summer output (net input)
- f - transfer function (activation function)
- a - neuron output



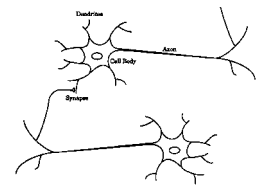
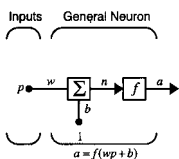
$$a = f(wp + b)$$

e.g. $w = 3, p = 2, b = -1.5$:
 $a = f(3 * 2 - 1.5) = f(4.5)$

- w and b are adjustable scalar parameters of the neuron (by a learning rule)
- f is chosen by the designer

Correspondence Between Artificial and Biological Neurons

- How this simple neuron relates to the biological one?
 - w - strength of the synapse
 - summer & transfer function - cell body
 - neuron output a - signal at the axon



What is Machine Learning?

- NNs are *Machine Learning (ML)* systems
- Operational definition of ML: *Machine Learning* denotes changes in the system that are adaptive in the sense that they enable the system to do the same task or tasks drawn from the same population more efficiently and more effectively the next time (Simon, 84)
 - i.e. computers (things) learn when they change their behavior in a way that makes them perform better in future
- ML is the core of Artificial Intelligence – without ability to learn a system cannot be considered intelligent
- NNs are *inductive (empirical)* learning systems – they learn from examples

Examples of Learning Tasks (and Neural Networks Applications) – Technical Diagnosis

from <http://www.site.uottawa.ca/~nat/Courses/csi5387.html>

- Malfunctioning gearboxes have been the cause for CH-46 US Navy helicopters to crash
- Such faults can be diagnosed by a mechanic prior to a helicopter's take off, but they are impossible to detect by humans in flight
- Assuming that functioning and malfunctioning gearboxes emit different noises, a learning system (e.g. a NN) can be trained to distinguish between these 2 patterns from a set of pre-classified examples of these 2 categories
 - sounds can be represented as wave patterns, that in turn can be represented as a series of real numbers
 - the strings of numbers representing these noises have different characteristics



Technical Diagnosis Example – cont.

- Why employing a learning system?
- The exact characteristics of these two categories are unknown and/or are too difficult to describe
 - => they cannot be programmed, but rather, they need to be learned by the computer

More Examples

- **Medical diagnosis**

- **Data:** 9714 patient records, each describing a pregnancy and birth; each patient record contains 215 features
- **Task:** Learn to predict classes of future patients at high risk for emergency C-section

Patient101 time=2
 Age: 23
 FirstPregnancy: no
 Anemia: no
 Diabetes: YES
 PreviousPrenatalVisits: no
 Ultrasound: abnormal
 Elective C-Section: no
 Emergency C-Section: ?
 ...

- **Credit card application approval**

- **Data**

Customer101: UMEN01 Years of credit: 9 Loan balance: \$2,400 Income: \$50k Own House: Yes Other delinquent accts: 2 Max billing cycle late: 3 Profitable customer?: ? ...	Customer102: UMEN11 Years of credit: 9 Loan balance: \$3,250 Income: ? Own House: Yes Other delinquent accts: 2 Max billing cycle late: 4 Profitable customer?: ? ...	Customer103: UMEN09 Years of credit: 9 Loan balance: \$4,500 Income: ? Own House: Yes Other delinquent accts: 3 Max billing cycle late: 6 Profitable customer?: No ...
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- **Task:** Learn to predict if to accept or deny credit card applications

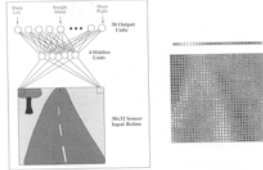
More Examples – cont. 1

- **Driving Vehicles, Pomerleau, 93**

- ALVINN system uses backpropagation neural network to learn to steer a vehicle driving at speed up to 70 miles per hour



- Useful for hazardous missions



More Examples – cont. 2

- **Pronunciation of written English, Sejnowski and Rosenberg 87**

- Fascinating problem in linguistics and task with high commercial profit
- **How?**
 - Mapping the text stream to phonemes
 - Passing the phonemes to speech generator
- **Task for the NN:** learning to map the text to phonemes
 - Good task for a NN as most of the rules are approximately correct
 - E.g. cat [k], century [s]
- **Input:** string of text
- **Output:** a phoneme corresponding to the letter in the center
- **Data given:** set of words hand transcribed into phonemes

Even More ML Applications

- **Marketing and Sales Analysis**
 - **Data sources:** credit card transactions, discount coupons, customer complaint calls, lifestyle studies, shop transactions
 - **Tasks:**
 - **Target marketing** – find clusters of customers who share the same characteristics: interest, income level, spending habits, etc.
 - **Customer profiling** – what types of customers buy what products
 - Focusing promotional mailouts (targeted campaigns are cheaper than mass-marketed ones)
 - **Identifying customer requirements**
 - What are the best products for different customers?
 - What factors will attract new customers?
 - **Market-basket analysis** - which items sold well together?
 - **Customer loyalty** – identify customers that are likely to defect by detecting changes in their behavior (e.g. banks, phone companies)

Even More ML Applications – cont.

- **Fraud Detection**
 - **Applications**
 - health care - medical insurance fraud, inappropriate medical treatment
 - Credit card services, phone card and retail fraud
 - **Data:** historical transactions and other data
- **Sports**
 - analyzing game statistics (shots blocked, assists, and fouls) to gain competitive advantage
- **Astronomy**
 - JPL and the Palomar Observatory discovered 22 quasars with the help of data mining
- **Web applications**
 - Mining web logs to discover customer preferences and behavior, analyze effectiveness of web marketing, improve web site organization

When Can NNs (ML) Help?

- **When we can't formulate an algorithmic solution**
 - Some tasks cannot be defined well, except by examples (e.g. recognizing people)
 - The amount of knowledge available about certain tasks might be too large for explicit encoding by humans (e.g., med. diagnostic)
- **When we can get lots of examples of the behaviour we require/do not require**
- **When we need to find out the structure from given data**
 - relationships and correlations can be hidden within large amounts of data
- **When learning is needed**
 - machines that do not work as well as desired in the environments in which they are used
 - environments change over time
 - New knowledge about tasks is constantly being discovered by humans; it may be difficult to continuously re-design systems by-hand

Inductive ML – Terminology

- (target) concept - the thing to be learned
- concept description - the output produced by the learning method
 - can be represented as a set of rules, decision tree, neural network...
- instances (examples, samples) - the things that are used for learning
- each instance is characterized by the values of a set of predetermined features called attributes
- input to a learning algorithm – a set of examples represented as a single relation (flat file)
- 2 types of attributes:
 - numeric - their values are numbers
 - categorical - their values belong to a pre-specified, finite set of possibilities

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Simple ML Benchmark Databases

Weather (Play Tennis)

outlook	temp.	humidity	windy	play	outlook	temperature	humidity	windy	play
sunny	hot	high	false	no	sunny	85	85	false	no
sunny	hot	high	true	no	sunny	80	90	true	no
overcast	hot	high	false	yes	overcast	83	88	false	yes
rainy	mild	high	false	yes	rainy	70	96	false	yes
rainy	cool	normal	false	yes	rainy	68	90	false	yes
rainy	cool	normal	true	no	rainy	65	70	true	no
overcast	cool	normal	true	yes	overcast	64	65	true	yes
sunny	mild	high	false	no	sunny	72	95	false	no
sunny	cool	normal	false	yes	sunny	69	70	false	yes
rainy	mild	normal	false	yes	rainy	75	80	false	yes
sunny	mild	normal	true	yes	sunny	75	70	true	yes
overcast	mild	high	true	yes	overcast	72	90	true	yes
overcast	hot	normal	false	yes	overcast	81	75	false	yes
rainy	mild	high	true	no	rainy	71	91	true	no

Iris

sepal length	sepal width	petal length	petal width	iris type
5.1	3.5	1.4	0.2	iris setosa
4.9	3.0	1.4	0.2	iris setosa
4.7	3.2	1.3	0.2	iris setosa
6.4	3.2	4.5	1.5	iris versicolor
6.9	3.1	4.9	1.5	iris versicolor
5.5	2.3	4.0	1.3	iris versicolor
6.5	2.8	4.6	1.5	iris versicolor
6.3	3.3	6.0	2.5	iris virginica
5.8	2.7	5.1	1.9	iris virginica
...				

• NNs learn from numeric data => if the data is categorical it should be converted to numeric

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Inductive Learning by Examples – Types of Learning

- 3 main types of learning
 - Supervised learning
 - given a set of pre-classified examples, learn a concept description which encapsulates the information in these examples and can be used predictively
 - i.e. the ML algorithm is provided with a set of examples (training set) of proper behaviour: $\{p_1, t_1\}, \{p_2, t_2\}, \dots, \{p_n, t_n\}$
 - p_i - input, t_i - corresponding (target) output
 - classification - predict the class of unseen examples
 - numeric prediction - predict not a discrete class but a numeric value
 - Success can be measured on fresh data for which class labels are known (test data)
 - perceptron, ADALINE, backpropagation, LVQ

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Types of Learning – cont.

- **Reinforcement learning**
 - each example has a score (grade) instead of correct output
 - much less common than supervised learning
 - most suited to control systems applications
- **Unsupervised learning**
 - given a collection of unclassified data, search for regularities
 - no target outputs, only inputs are available: p_1, p_2, \dots, p_n
 - the ML classifier learns to categorize (cluster) the input patterns into a finite number of classes
 - k-means, self-organizing feature maps, growing cell structures, growing neural gas

Taxonomy of NNs

- **From the point of view of their active phase**
 - feedforward
 - recurrent (feedback)
- **From the point of view of their learning phase**
 - supervised
 - unsupervised
- **Feedforward supervised networks**
 - typically used for classification and function approximation
 - examples: perceptrons, ADALINES, backpropagation networks, RBF, LVQ networks

Taxonomy of NNs (cont.)

- **Feedforward unsupervised networks**
 - used to extract important properties of the input data and to map input data into a "representation" domain
 - two basic groups of methods
 - Hebbian networks used for associative learning
 - Competitive networks performing clustering, e.g. Self-Organizing Kohonen Feature Maps (SOM)
- **Recurrent networks**
 - used to learn or process the temporal features of the input data
 - examples: recurrent backpropagation, associative memories, adaptive resonance networks

Neural networks - Historical Sketch

Neurocomputing: Foundations of Research,
J. Anderson, E. Rosenfeld, MIT Press 1989

- Progress has not always been “slow but sure”; instead - periods of dramatic progress, periods where little has been accomplished
- Colorful, creative individuals from different fields; many of them struggled for decades to develop concepts that we now take for granted...
- Pre-1940: von Hemholtz, Mach, Pavlov, etc.
 - general theories of learning, vision, conditioning
 - no specific mathematical models of neuron operation



Historical Sketch - 2

- 1940s: Hebb, McCulloch and Pitts
 - mechanism for learning in biological neurons
 - the first artificial neuron
 - weighted sum of input signals is compared to a threshold to determine the output
 - when the sum is \geq to the threshold, the output is 1; else - 0
 - show that these neurons could compute any arithmetic function
 - unlike biological neurons, the parameters of the network had to be designed, as no training method was available
 - the connection between biology and digital computers generated a lot of interest!

Historical Sketch - 3

- 1950s: Rosenblatt, Widrow and Hoff
 - developed the perceptrons and linear NNs (ADALINE)
 - the neurons in them are similar to those of McCulloch and Pitts
 - key contribution: introduction of learning rule for training perceptrons and linear networks to solve pattern recognition problems
 - proved that the rule will always converge to correct weights, if such weights exist
 - learning: simple and automatic
 - perceptrons show great success for such a simple model
 - could even learn when initialized with random weights ...
 - great deal of interest in NN research

Historical Sketch - 4

- **1969 - Marvin Minsky and Seymour Papert - book "Perceptrons"**
 - widely publicized the limitations of the perceptrons
 - demonstrated that the perceptrons were not capable of implementing certain elementary functions - XOR
 - provided detailed analysis of the capabilities and limitations of perceptrons
 - Rosenblatt and Widrow were aware of these limitations and proposed new networks that would overcome them. But they were not able to successfully modify their learning algorithms to train these more complex nets
 - many people believed that further research on NNs was a dead end; lack of ideas + lack of powerful computers to experiment => research was largely suspended
 - mortal blow in the area; the majority of scientific community walked away from the field of neural networks...

Historical Sketch - 5

- **1970s: Kohonen, Anderson, Grossberg, Amari, Fukushima**
 - progress continues, although at a slower pace
 - NNs that act as memories, self-organising nets
- **1980s: Rumelhart and McClelland, Hopfield, etc.**
 - rebirth of NNs; new powerful computers widely available
 - backpropagation algorithm for training multilayer perceptrons - answer to the criticism of Minsky and Papert
 - use of statistical mechanics to explain the operation of a certain type of recurrent networks used as an associative memory
- **1990 -> :**
 - thousands of papers have been written
 - NNs have found many practical applications
 - It is not clear where all of this will lead us... :-)

Who is concerned with NNs?

- Computer scientists want to find out about the properties of non-symbolic information processing with NNs and about learning systems in general
- Statisticians use NNs as flexible, nonlinear regression and classification models
- Engineers exploit the capabilities of NNs in many areas, such as signal processing and automatic control
- Cognitive scientists view NNs as a possible apparatus to describe models of thinking and consciousness (high-level brain functions)
- Neuro-physiologists use NNs to describe and explore medium-level brain function (e.g. memory, sensory system, motorics)
- Physicists use NNs to model phenomena in statistical mechanics and for a lot of other tasks
- Biologists use NNs to interpret nucleotide sequences
- Philosophers and some other people may also be interested in NNs for various reasons
