ECE/CS 559 - Neural Networks Lecture Notes #1
Neural networks: Definitions, motivation, properties

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1 Neural networks: Definitions and motivation

- Neural: Of, or related to nerves, neurons.
- Neuron: A highly-specialized cell that can transmit and receive information through electrical/chemical signaling. The fundamental building block of the brain.
- Nerve: A bundle of several neurons (more precisely, bundle of axons of several neurons).
- Network: A set of nodes and the connections between them.
- Biological neural network: The structure formed by many neurons and the connections between them.
- Artificial neural network (or just "neural networks" from now on): Mathematical models of biological neural networks.
- Why study neural networks?
  - Human brain is very successful at certain tasks that prove to be very difficult to accomplish on a classical computer: Learning, pattern recognition,... For example, think about what we call a generic classification example: When I show you the picture of an apple, you immediately recognize it as an apple. Or, as I speak, you recognize what I say. Computers usually are terrible at such tasks. E.g. even with todays' technology, most commercial speech recognizers still cannot get all of what you say because of e.g. your accent. So, it makes sense to look at how brain or the human neural network works.
  - So, why would human brain be much better at certain tasks compared to computers? Can it be about speed? No, a transistor can switch in nanoseconds, but if you put a needle to your leg, it takes a few milliseconds for your brain to realize what is going on. So, it is not necessarily the speed. What brain lacks in speed, it compensates with the number of processing elements, and their massive interconnected nature and everything running in parallel as opposed to the serial operation of the computer. Another important issue is that the human brain is constantly evolving in the sense that the way it operates can be modified through a learning process, while the physical structure of the CPU of a computer is fixed and does not change over time.
- Thus, to summarize: Classical computer: Almost serial operation (think about running a program for example and ignore possible pipelining), each operation can however be performed extremely fast ($<$ nanoseconds per operation.).
- Neural network: Massively parallel operation, may be more powerful than the classical computer despite the fact that a given neuron is relatively "slow." (A neuron can fire at most hundreds of times per second $\rightarrow$ milliseconds per "operation").
- Motivation: Perhaps, by imitating the brain's operation (by building artificial neural networks), we will be able to solve complex tasks that are not easily doable by classical computers.
  - Arguably the most important motivating factor for the developments in the field.

  - Other motivations: Understand how the brain and the nervous system work.

- Hence, to summarize, neural networks:

  1. Are massively parallel distributed processors that are made up of simple processing units (mathematical neurons) and the connections between these processing units.
  2. Can store and utilize experiential knowledge through a learning process.

- An artificial neural network resembles the brain in two respects:

  - Knowledge is acquired by the network from its environment through a learning process.
  - Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.

2 Purposes

Neural networks can be used for a variety of purposes, e.g. classification (identifying the label/class of an input among a given set of labels/classes), clustering (finding different classes among unlabeled data), prediction (estimating the future values of a process given past values), strategic decision making, so on. But in general, mathematically, we have an input, the network, and an output...

3 Some properties of artificial neural networks:

- Non-linearity: The relationship between the input and the output of the network is not a linear relationship.
- Learning.
  - Supervised learning: Learning with a teacher. Involves modification of the parameters of the network through a set of training samples, with each sample consisting of an input pattern and associated desired response.
  - Unsupervised learning.
- Adaptivity: Adaptation of the free parameters to the changes in the environment.
- Evidential Response: The network can also provide a confidence level to its decision regarding the input pattern.
- Fault tolerance: When you get hit in the head, many of your neurons die, but you may still continue your daily routine. On the other hand, kill a transistor in a CPU, and the entire CPU is dead too. Thus, in principle, a neural network exhibits a graceful degradation in performance rather than catastrophic failure.
- VLSI implementability. Massively parallel nature of neural networks makes it a successful candidate for VLSI implementations.
- Neurobiological analogy: Neurobiologists look to (artificial) neural networks as a research tool for the interpretation of neurobiological phenomena. On the other hand, engineers look to neurobiology for new ideas to solve problems more complex than those based on conventional hardwired design.

4 Our approach in this course:

- Find mathematical models describing how the neuron (the basic building element of the brain) works.
- Find an appropriate network of such mathematical neurons that can perform the given task.