Neural Networks - Basis

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Why learning?

- **Simple** organisms vs. **complex** species
- Functionality can be **wired up**, but in complex organisms this is infeasible. We need a mechanism to **learn** from experience.
- So what is **wired up** is a **mechanism to learn** from experience
- Ability to learn can be good even for computers!
What is a Neural Network?

- **Brain** – highly complex, non-linear and parallel information processing system (computer)
- Composed of **neurons**
- On certain tasks it is much faster than supercomputers of today. E.g. recognize a familiar face in an unfamiliar scene in 100-200 ms.
- At birth brain is already highly structured, but dramatic development continues for the first 2 years.
- **Plasticity** of the neural network constituents
Human Brain

- Typically, neurons ($10^{-3}$ sec range [ms]) are 5-6 orders of magnitude slower than silicon logic gates ($10^{-9}$ sec range [ns])

- Huge number of interconnected neurons.
  10 billion neurons in the human cortex.
  60 trillion synapses (connections).

- 10 orders of magnitude more energy efficient than computer.
Neuron - Synapse

- **Synapses** mediate the interaction between neurons. Presynaptic process liberates a **transmitter** substance. The substance diffuses across the **synaptic junction** between neurons and then acts on a **postsynaptic** process.

- Synapse converts presynaptic electrical signal into a **chemical** signal and then back into a postsynaptic electric signal.

- Synapse can be viewed as a simple connection that can impose **excitation** or **inhibition**, but not both on a receptive neuron.
Plasticity

- **Plasticity** permits nervous system to adapt to its environment.

  Two mechanisms:
  
  1. creation of new synaptic connections between neurons
  2. modification of existing synapses

- **Axons** – transmission lines.
  - Smooth surface, few branches, long.

- **Dendrites** – receptive zones.
  - Irregular surface, many branches, short.

- Majority of neurons encode their outputs as a series of spikes (voltage pulses).
Extensive synaptic connectivity is a hallmark of neural circuitry.
• **Figure A:**
  A cortical pyramidal cell.
  These are the primary excitatory neurons.
  Branch locally, sending axon collaterals to synapse with nearby neurons.
  Also project more distally to conduct signals to other parts of the brain.

• **Figure B:**
  A Purkinje cell.
  Receive 100,000 of synaptic inputs.
  Axons transmit the output of the cerebellar cortex.

• **Figure C:**
  A stellate cell.
Action potential recorded from a rat neocortical pyramidal cell.
• **Axon terminal** is at the end of the axonal branch seen entering from the top.

• It is filled with synaptic vesicles containing neurotransmitter that is released when an action potential arrives from the presynaptic neuron. Transmitter crosses the synaptic cleft and binds to receptors on the dendritic spine. Process roughly 1mm long.

• Excitatory synapses onto cortical pyramidal cells form on dendritic spines. Other synapses form directly on the dendrites or soma of the postsynaptic neuron.
When does a neuron ‘fire’?

- stimulation of a neuron requires usually either
  (1) repetition of impulses in time at the same synapse (temporal summation), or
  (2) simultaneous arrival of impulses at a sufficient number of adjacent synapses to make the ”density” of excitation high enough at some region of the neuron.

- When synaptic excitation takes place, the passage of the impulse across the synapse consumes time (synaptic delay).

- The arrival of impulses at synapses may have the opposite effect, i.e., it may render the element less excitable to other stimuli (inhibition).
Measuring neural activations

- Membrane potentials are measured intracellularly by connecting a hollow glass electrode filled with a conducting electrolyte to a neuron, and comparing the potential it records with that of a reference electrode placed in the extracellular medium.

- **Intracellular recordings** are made e.g. with sharp electrodes inserted through the membrane into the cell.

- Intracellular recording is more commonly used for in vitro preparations, such as slices of neural tissue.
Measuring neural activations

- In **extracellular recording** the electrode is placed near a neuron, but it does not penetrate the cell membrane. Such recordings can reveal action potentials fired by a neuron, but not its subthreshold membrane potentials.

- Extracellular recordings are typically used for in vivo experiments, especially those involving behaving animals. Intracellular recordings are sometimes made in vivo, but this is difficult to do.
Communicating through signals

simulated recordings from a neuron.
- **Top trace:**
  Recording from an intracellular electrode connected to the soma of the neuron.
  The recording shows rapid spikes riding on top of a more slowly varying subthreshold potential.

- **Bottom trace:**
  Recording from an intracellular electrode connected to the axon some distance away from the soma.
  The subthreshold membrane potential waveform, apparent in the soma recording, is completely absent on the axon due to attenuation, while the action potential sequence in the two recordings is the same.

- **Middle trace:**
  A simulated extracellular recording.
In the end it is down to spikes...

- The previous example illustrates an important point: Spikes, but not subthreshold potentials, propagate regeneratively down the axons.