Connectionism

- Computer models of cognitive processing and representation that were partially inspired by neurons in the brain.
- A.K.A. Artificial Neural Networks (ANN)
- Before examining ANN in depth, let’s look (briefly) at how neurons in the brain work, and at the similarity between neurons in the brain and the processing units ANN.

The Nervous System

- **Central Nervous System**
  - Brain & Spinal Cord

- **Peripheral Nervous System**
  - All nerves outside of the brain & spinal cord (in the “body”).

Cells in the Nervous System

- **Glia**
  - Smaller brain cells that support brain function:
    - Supply nutrients.
    - Remove waste materials.

- **Neurons**
  - Basic processing unit of the nervous system.
  - Provides communication between the brain and the body.
  - Communication involves the reception, conduction, and transmission of electrochemical signals.

Types of Neurons

- **Sensory Neurons**
  - Conduct sensory impulses in from the sense organs to the Central Nervous System (CNS).

- **Motor Neurons**
  - Conduct motor impulse out from the CNS to muscles and organs.

- **Interneurons**
  - Connect one neuron to another.
  - Relay information between sensory and motor neurons.
  - Control reflexes in the spine.
Structure of the Neuron

- **Soma** or Cell body
  - Contains *nucleus* of the cell
  - Manufactures enzymes and molecules to *maintain cell life*.
- **Dendrites**
  - Filaments that *receive information* from other neurons.
- **Axon**
  - Filament that *transmits information* to the dendrites or soma of other neurons.

How Neurons Fire [DVD]

- **Electrochemical process**
  - **Electrical**
    - Propagation of impulse *within neuron*
  - **Chemical**
    - Transmission of impulse *between neurons*

Propagation of impulse *within the neuron*

- **Electrical process**
  - **Resting Potential**
    - Neuron *at rest; Not* firing
    - Stable, negative charge (-70 millivolts) inside neuron relative to outside.
Propagation of impulse within the neuron

• **Action Potential**
  - Neuron receives sufficient *stimulation*.
  - *Depolarization* occurs
    - Interior of axon becomes *positive* relative to the outside.
  - This release of energy *passes down the axon* and is the *firing of the neuron*.
  - Once neuron fires, *Repolarization* occurs
    - Return to resting potential (“- charged state”)
    - “Refractory Period” (1/1000 of a second).

The “Chemical” Part of Transmission

• **Axon terminal**
  - The end of the axon.

• **Synapse**
  - Small *gap* between the axon of one neuron and the dendrite of another.

The “Chemical” Part of Transmission

• **Axon terminal**
  - Contains *synaptic vesicles*
  - In the vesicles are neurotransmitters (chemicals).
  - Taken up by the axon of the *receiving neuron* at special receptor sites (“Lock & Key”)

The “Chemical” Part of Transmission

• Once the receptor site has been “unlocked”
  - A change in that neuron occurs.
    • Depolarizes (fires)
    • Hyperpolarizes (prevents firing)
  - Re-uptake occurs
    • Leftover neurotransmitter is *reabsorbed* into the presynaptic neuron.
An alternative to the symbolic approach

- Artificial Neural networks
- (a.k.a.) Connectionist Models
- (a.k.a.) Parallel Distributed Processing

ANNs utilize a processing strategy in which large numbers of computing units perform their calculations simultaneously. This is known as parallel distributed processing.

In contrast, traditional computers are serial processors, performing one computation at a time.

General characteristics

- Connectionist models work in a manner *loosely* based on the way neurons work in the brain.
- All artificial neural networks contain the same basic parts:
  - Nodes
  - Weighted connections
  - A way to change the weights on the connections
    - By hand
    - “Learning” algorithm, or rule

A node is a basic computing unit.

A link is the connection between one node and the next.

Weights specify the strength of connections.

A node fires if it receives activation above threshold.
Nodes

• Take information presented to them (activation), transform that information in some way (linear function), and then send that modified information onwards.

Nodes

• Input units
  – Receive information from the “environment” and pass that information onto the rest of the model.

• Output units
  – Receive information from (hidden units or) input units and “perform” some sort of “action.”

• Hidden units
  – Found in some but not all networks.
  – Between input and output units
  – Allows the model to represent information “internally”

Weighted Connections

• The pattern of the weights in the model is how information is represented or stored in the “memory” of the model.

• Knowledge is implicit and dynamic not explicit and static.
  Knowledge = processing

A way to change the weights

• Done to learn or acquire new information.
  – Some models do not learn; the weights do not change so they are “set by hand.”
Perceptrons

- An early and simple neural network
  - Input & output nodes
  - Connections were set with the “perceptron convergence rule” [a linear “gradient descent” algorithm]
    - Guaranteed to find a solution if it exists
    - But no telling how soon, or how intuitive the solution is.

Perceptrons

- Analyzed by Minsky & Papert (1969):
  - Hoped to better understand general theory of computation by exploring “a class of computations that make decisions by weighing evidence.”
  - Hoped to illustrate how such a theory might begin and lay out strategies that could lead to it.

tLearn Demo

FREE neural network simulator
- Limited architecture & algorithms
- Available from the Center for Research in Language (UCSD) at:

http://crl.ucsd.edu/software/

If the object is red AND a square = A
Else = B
If the object is red OR a square = A
Else = B

If the object is red OR a square, but not both = A
Else = B

If the object is red OR a square, but not both = A
Else = B
Perceptrons

- These simple networks with linear functions can only solve problems that are “linearly separable”:
  - Logical AND
  - Logical OR
- They can not solve non-linearly separable problems:
  - Logical X-OR

“[We believe] but did not actually prove] that the deeper limitations extend also to the variant of the perceptron proposed by A. Gamba.”

The result was they almost killed research in this area!!!!

Possible solutions to the perceptron problem

- Use nonlinear activation functions
- Use different “learning” algorithms
  - Unsupervised learning rules
- Use “hidden units”
  - Modify PCR to delta rule (back-prop)

Backpropagation learning in ANNs

- An ANN can learn to make a correct response to a particular stimulus input.
- The initial response is compared to a desired response represented by a teacher.
- The difference between the two, an error signal, is sent back to the network.
- This changes the weights so that the actual response is now closer to the desired response.
Many different kinds of Networks

- Representations
  - Distributed: Pattern = object
  - Local: Node = object
- Learning Algorithm
  - Supervised: PCR, back-prop
  - Unsupervised: Competitive, Hebbian
  - Reinforcement
  - Genetic

Advantages of this approach

- Biological plausibility
- Capture patterns in the environment that may not be easily described by a rule.
- Can operate when *multiple constraints* must be satisfied.
- Can operate in an environment with incomplete or ambiguous information.

Advantages of this approach

- Content addressable memory
  - Access information based on any attribute of the representation we are trying to retrieve.
- Graceful degradation
  - Best match is activated; errors will not be fatal
- Default assignment
  - Fill in information based on similar instances.
- Spontaneous generalization
  - Retrieve what is common (prototypes)

Advantages of this approach

- It can do things symbolic models can’t:
  - Speech recognition
  - Motor control
  - Object manipulation
  - Association
    - Many applications use ANN
      - Games
      - Medicine/radiology
      - Department of Defense
Advantages of this approach

- Psychological & computational appeal
  - “Learns” without explicit instruction
  - Similar to processes that neurons do
  - Complex behaviors emerge out of simple units that interact in a local, non-linear way
    - Free throws at basketball games
  - Provide mechanistic accounts
    - Your theory must be more specific than verbal or “box” models common to IP [Lewandowsky]

Disadvantages of this approach

- Massive parallelism in brain but not in models (scalability issue).
- Convergent dynamics settle into stable states
  - This may/may not occur in the brain
- Stimuli/problem distributed over time
- Stability-plasticity dilemma
  - Catastrophic interference
  - cf., Grossberg Adaptive Resonance Theory (ART)

Symbolic Processing vs. Connectionism

- Lead to HUGE debate
  - How are regular & irregular verbs processed?
    - Pinker, Prince (symbolic approach)
      - Rules for regular verbs
      - Memorize irregular verbs
    - McClelland & Rumelhart (PDP)
      - One mechanism can do both by extracting the important pattern (not an explicit rule) from the input.
- Paradigm shift?