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.

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The Nervous System

- ***Central Nervous System***
  - Brain & Spinal Cord
- ***Peripheral Nervous System***
  - All nerves ***outside of*** the brain & spinal cord (in the "body").

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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 <u>electrochemical</u> signals.***

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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.

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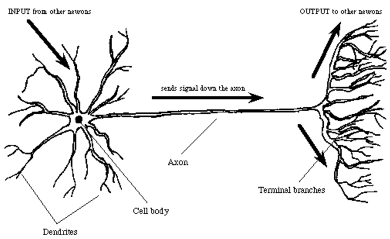
Structure of the Neuron



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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.

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How Neurons Fire [DVD]

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

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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.

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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).

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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.

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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")

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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.

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An alternative to the symbolic approach

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

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An alternative to the symbolic approach

- 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.

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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

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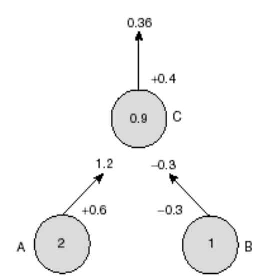
General characteristics

- 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*.



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Nodes

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

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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"

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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

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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."

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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.

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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.

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tLearn Demo

FREE neural network simulator

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

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

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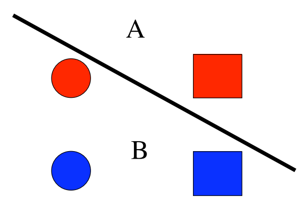

If the object is red AND a square = A
Else = B

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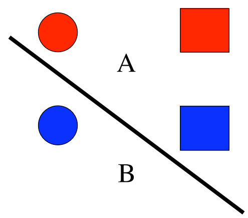

If the object is red OR a square = A
Else = B

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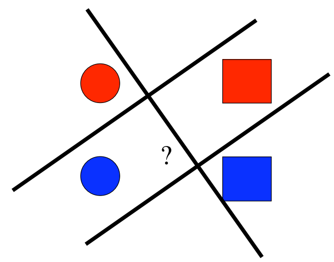

If the object is red OR a square, but not both = A
Else = B

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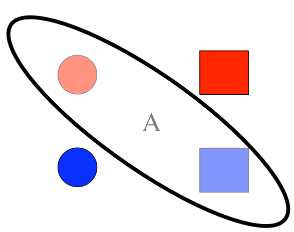

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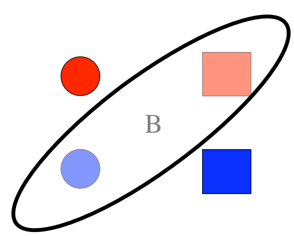

If the object is red OR a square, but not both = A
Else = B

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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

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Perceptrons

"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!!!!

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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)

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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.

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Many different kinds of Networks

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

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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.

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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)

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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

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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**]

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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)

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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?

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