Computers with Brains? A neuroscience perspective

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October 18th , 2011.

https://www.cs.tcd.ie/Khurshid.Ahmad/Teaching/ComputersBrains.pdf

Real Neuroscience

<u>To compute is to:</u>

To determine by arithmetical or mathematical reckoning; to calculate, reckon, count. In later use chiefly: to ascertain by a relatively complex calculation or procedure, typically using a computer or calculating machine.

<u>But the human brain :</u>

is considered as the centre of mental activity; the organ of thought, memory, or imagination.

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Real Neuroscience

<u>I am (intelligent) because:</u>

I can converse in natural languages;
I can analyse images, pictures (comprising images), and scenes (comprising pictures);
I can reason, with facts available to me, to infer new facts and contradict what I had known to be true;
I can plan (ahead);
I can use symbols and analogies to represent what I know;
I can learn on my own, through instruction and/or experimentation;
I can compute trajectories of objects on the earth, in water and in the air;
I have a sense of where I am physically (prio-perception)
I can deal with instructions, commands, requests, pleas;
I can 'repair' myself;
I can understand the mood/sentiment/affect of people and groups
I can debate the meaning(s) of life;

3

Real Neuroscience

<u>But I cannot compute or *reckon intensively* beacuse:</u>

I cannot add/subtract/multiply/divide with consistent accuracy;
I forget some of the patterns I had once memorised;
I confuse facts;
I cannot recall immediately what I know;
I cannot solve complex equations;
I am influenced by my environment when I make decisions, ask questions, pass comments;
I will (eventually) loose my faculties and then die!!

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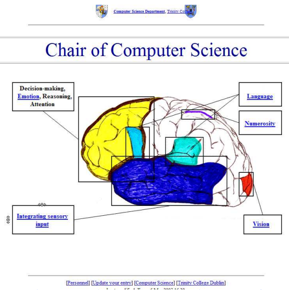
Computation and its neural basis
(the world according to Khurshid Ahmad)

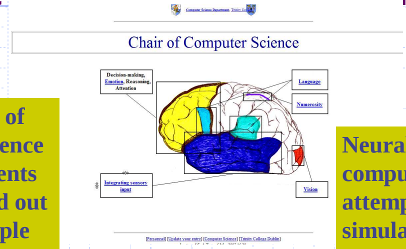
Much of modern computing relies on the discrete serial processing of uni-modal data



Much of the computing in the brain is on sporadic, multi-modal data streams

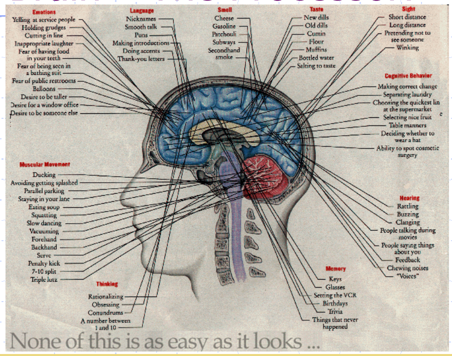
Computation and its neural basis
(the world according to Khurshid Ahmad)

Analysis of neuroscience experiments is carried out with simple models without the capability of learning



Neural computing attempts to simulate aspects of human/ animal learning

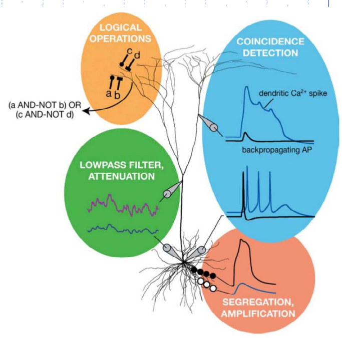
Brain – The Processor!



http://www.cs.duke.edu/brd/Teaching/Previous/AI/pix/noteasy1.gif

What animals do?

Neurons, and indeed networks of neurons perform highly specialised tasks. The dendrites bring the input in, the soma processes the input and then the axon outputs.

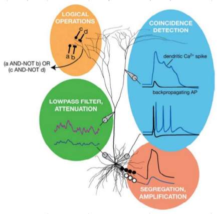


London, Michael and Michael Häusser (2005). Dendritic Computation. *Annual Review of Neuroscience*. Vol. 28, pp 503–32

What animals do?

Neurons, and indeed networks of neurons perform highly specialised tasks. The dendrites bring the input in, the soma processes the input and then the axon outputs.

However, it appears that the dendrites also have processing power: it is the equivalent of the wires that connects your computer to its printer and the network hub performing computations – helping the computer to perform computations!!!

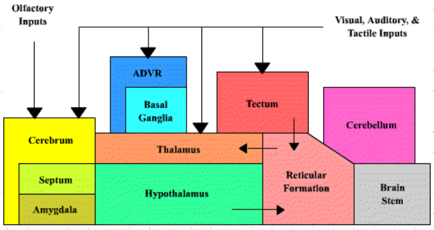


London, Michael and Michael Häusser (2005). Dendritic Computation. *Annual Review of Neuroscience.* Vol. 28, pp 503–32

Brain – The Processor!

http://www.neurocomputing.org/Comparative.aspx

The brain is like a puzzle in that one cannot understand any one region completely unless one understands how that region fits into the brain's overall functional information processing architecture.



Brain – The Processor!

The brain is like a puzzle in that one cannot understand any one region completely unless one understands how that region fits into the brain's overall functional information processing architecture.

The Hypothalamus is the core of the brain having spontaneously active neurons that "animate" everything else. Other brain regions just layer on various constraints to these basic animating signals.

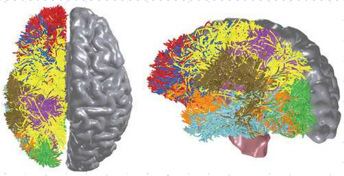
The Thalamus (Diencephalon) seems to have started out as a contra-indicator center and later became mostly an attention controller. It does this by inhibiting brain circuits that are activated from other regions.

The Tectum (Optic Lobe) localizes interesting (innately defined for the most part) motions to the animal.

The Cerebellum is an adaptive predictive (feedforward) control system. As such it modifies the motor patterns generated in the brain stem and spinal cord.

http://www.neurocomputing.org/Comparative.aspx

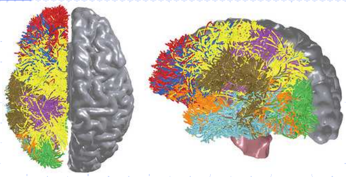
Brain – The Processor!



BlueMatter, a new algorithm created in collaboration with Stanford University, exploits the Blue Gene supercomputing architecture in order to noninvasively measure and map the connections between all cortical and sub-cortical locations within the human brain using magnetic resonance diffusion weighted imaging.

http://www-03.ibm.com/press/us/en/pressrelease/28842.wss#resource

Brain – The Processor!



Mapping the wiring diagram of the brain is crucial to untangling its vast communication network and understanding how it represents and processes information.

http://www-03.ibm.com/press/us/en/pressrelease/28842.wss#resource

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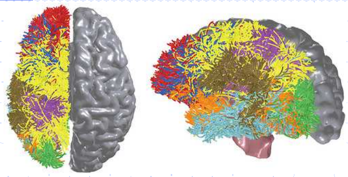
Brain – The Processor!



IBM announced [...] in November 2009 that it has a computer system that can simulate the thinking power of a cat's brain with 1 billion neurons and 10 trillion synapses. At just 4.5 percent of a human brain, the computer can sense, perceive, act, interact and process ideas without consuming a lot energy. Being able to mimic the low-energy, high-processing capability of a brain is something researchers have been striving to achieve in computing for years.

http://www-03.ibm.com/press/us/en/pressrelease/28842.wss#resource

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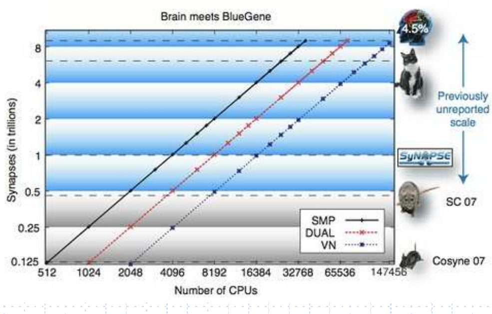
Brain – The Processor and the Artificial Cat's Brain



James Cascio. http://ieet.org/index.php/IEET/print/3540

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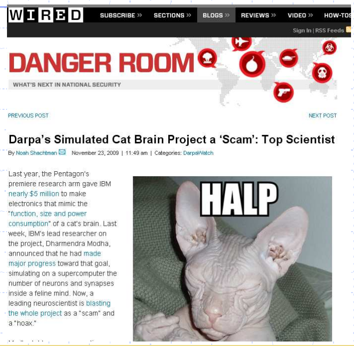
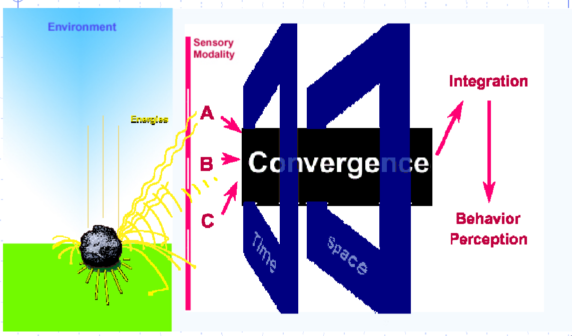
Brain – The Processor!



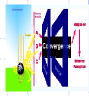
http://www.wired.com/dangerroom/2009/11/darpas-simulated-cat-brain-project-a-scam-top-neuroscientist/

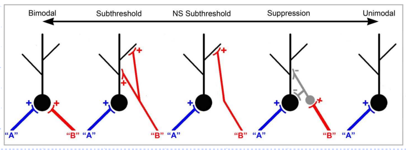
What humans do?



The real neurons are different!

Real neurons co-operate, compete and inhnbit each other. In multi-modal information processing, convergence of modalities is critical.





Multisensory Enhancement | Cross-modal Facilitation | Cross-modal Facilitation Inhibition-Dependent | Cross-modal Suppression

From Alex Meredith, Virginia Commonwealth University, Virginia, USA

What computer scientists do?

The study of the behaviour of neurons, either as 'single' neurons or as cluster of neurons controlling aspects of perception, cognition or motor behaviour, in animal nervous systems is currently being used to build information systems that are capable of autonomous and intelligent behaviour.

Brain – The Multi-sensory Processor!

Neural computing systems are trained on the principle that if a network can compute then it will learn to compute.

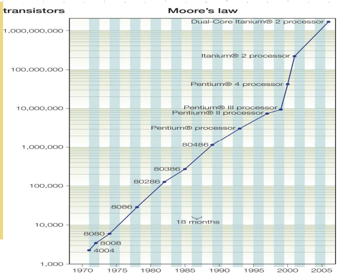
Multi-net neural computing systems are trained on the principle that if two or more networks learn to compute simultaneously or sequentially , then the multi-net will learn to compute.

I have been involved in building a neural computing system comprising networks that can not only process unisensory input and learn to process but that the interaction between networks produces multisensory interaction, integration, enhancement/suppression, and information fusion.

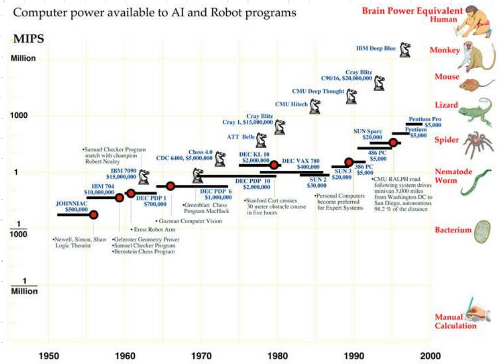
Jacob G. Martin, M. Alex Meredith and Khurshid Ahmad, Modeling multisensory enhancement with self-organizing maps, *Frontiers in Computational Neuroscience*, 8, (3), 2009;
Matthew Casey & Khurshid Ahmad, A competitive neural model of small number detection, *Neural Networks*, 19, (10), 2006, p1475 - 1489

How do computers do what computers do?

The number of chips on the same area has doubled every 18-24 months; and has increased exponentially. However, the R&D costs and manufacturing costs for building ultra-small, high-precision circuitry and controls has had an impact on the prices



The ever growing computer systems (1997)

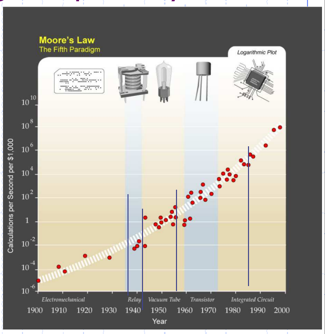


http://www.transhumanist.com/volume1/moravec.htm

The ever growing computer systems

The cost of computation is falling dramatically – an exponential decay in what we can get by spending $1000 (calculations per second):

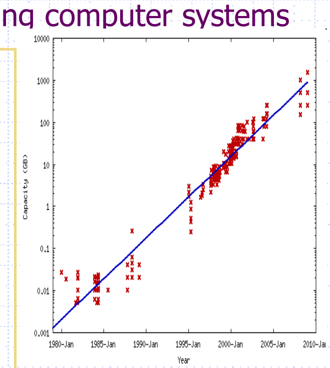
In 1940:	**0.01**
In 1950:	**1**
In 1960:	**100**
In 1970:	**500-1000**
In 1980:	**10,000**
In 1990:	**100,000**
In 2000:	**1,000,000**



The ever growing computer systems

The cost of data storage is falling dramatically – an exponential decay in what we can get by spending the same amount of money:

In 1980:	0.001 GB
In 1985:	0.01
In 1990:	0.1
In 1995:	1
In 2000:	10
In 2005:	100
In 2010:	1000



The ever growing computer systems: Supercomputers of today

Rank	Rmax Rpeak (Tflops)	Name	Computer Processor cores	Maker	Site Country, Year
1	1105.00 1456.70	Roadrunner	BladeCenter QS22/LS21 129600 (Cell/Opteron)	IBM	Los Alamos National Laboratory United States, 2008
2	1059.00 1381.40	Jaguar	Cray XT5 150152 (Opteron)	Cray	Oak Ridge National Laboratory United States, 2008
3	825.50 1002.70	JUGENE	Blue Gene/P Solution 294912 (Power)	IBM	Jülich Research Centre Germany, 2009
4	487.01 608.83	Pleiades	SGI Altix ICE 8200EX 51200 (Xeon), InfiniBand	SGI	NASA/Ames Research Center United States, 2008
5	478.20 596.38	Blue Gene/L	eServer Blue Gene Solution 212992 (Power)	IBM	Lawrence Livermore National Laboratory United States, 2007
6	463.30 607.20	Kraken	Cray XT5 66000 (Opteron)	Cray	National Institute for Computational Sciences United States, 2008
7	458.61 557.06	Intrepid[4]	Blue Gene/P Solution 163840 (Power)	IBM	Argonne National Laboratory United States, 2007
8	433.20 579.38	Ranger	Sun Constellation System 62976 (Opteron), Infiniband	Sun	Texas Advanced Computing Center United States, 2008
9	415.70 501.35	Dawn	Blue Gene/P Solution 147456 (Power)	IBM	Lawrence Livermore National Laboratory United States, 2009
10	274.80 308.28	JUROPA	Sun Constellation System 26304 (Xeon), Infiniband	Bull	Jülich Research Centre Germany, 2009

300 to 1400 Trillion Floating Point Operations per Second

http://www.transhumanist.com/volume1/moravec.htm

What computers cannot do?

The Vision Problem 1967-1997

Thirty years of computer vision reveals that

1 MIPS can extract simple features from real-time imagery--tracking a white line or a white spot on a mottled background.

10 MIPS can follow complex gray-scale patches--as smart bombs, cruise missiles and early self-driving vans attest.

100 MIPS can follow moderately unpredictable features like roads--as recent long NAVLAB trips demonstrate.

1,000 MIPS will be adequate for coarse-grained three-dimensional spatial awareness--.

10,000 MIPS can find three-dimensional objects in clutter--

Hans Moravec (1998). When will computer hardware match the human brain? Journal of Evolution and Technology. 1998. Vol. 1 (at http://www.transhumanist.com/volume1/moravec.htm)

What computers cannot do?

The Vision Problem – The story continues (2009)

VC4458

The VC4458 is one of the world's fastest and most excellent smart cameras with computational power of 8000 MIPS rivalling a 7.2 GHz Pentium. It has 64 MB DRAM, 4 MB Flash EPROM for program and data storage (Expanded by the standard 512 MB SD card inside).
It can acquire full frame 640 x 480 pixels at 242 frames per second!
The own internal operating system "VCRT" of the VC4458 is multitasking. This means that multiple processes can be executed in parallel.
The camera has also a High Speed Trigger input with absolute constant capture delay, which allows absolutely jitter-free image acquisition even at very high speed processes.
And whereas a standard progressive scan camera gets a trigger, starts exposure and then reads out the pixel data, the VC4458 has optimized the image acquisition process so that exposure, readout and the image processing can be done in parallel.
It has an 8 bit colour overlay which can operate in opaque or semi-transparent mode so that you can block out or still

http://www.electronicspecifier.com/Industry-News/New-SH7724-processors-add-HD-video-playback-and-recording-support-to-Renesas-Technologys-popular-SH772x-series-of-low-power-multimedia-processors.asp

What computers cannot do?

The Vision Problem – The story continues (2009)

Processors add HD video playback and recording support to Renesas Technology's popular SH772x series of low power multimedia processors

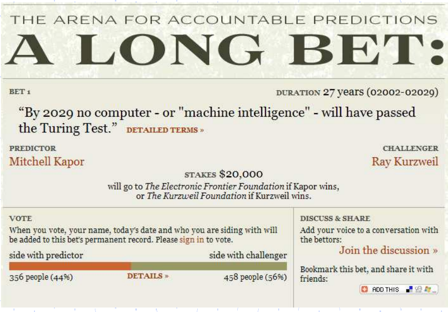
News Release from: Renesas Technology Europe Ltd
27/05/2009

Renesas has announced the release of the SH7724, the third product in the SH772x series of low power application processors designed for multimedia applications such as audio and video for portable and industrial devices.

When operating at 500 MHz, general processing performance is 900 million instructions per second (MIPS) and FPU processing performance is 3.5 giga [billion] floating-point operations per second (GFLOPS).

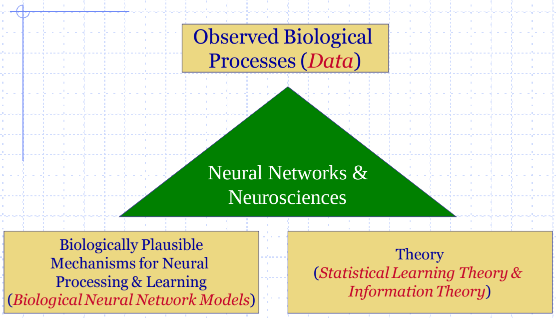
http://www.electronicspecifier.com/Industry-News/New-SH7724-processors-add-HD-video-playback-and-recording-support-to-Renesas-Technologys-popular-SH772x-series-of-low-power-multimedia-processors.asp

What humans think about what computers will do?



http://www.longbets.org/1

Neural Nets and Neurosciences



http://en.wikipedia.org/wiki/Neural_network#Neural_networks_and_neuroscience

Real Neuroscience

Cognitive neuroscience has many intellectual roots.

The experimental side includes the very different methods of systems neuroscience, human experimental psychology and, functional imaging.

The theoretical side has contrasting approaches from neural networks or connectionism, symbolic artificial intelligence, theoretical linguistics and information-processing psychology.

Tim Shallice (2006). From lesions to cognitive theory. *Nature Neuroscience* Vol 6, pp 215
(Book Review: Mark D'Esposito (2002). *Neurological Foundations of Cognitive Neuroscience*

Real Neuroscience

Brains compute?

This means that they process information, creating abstract representations of physical entities and performing operations on this information in order to execute tasks. One of the main goals of computational neuroscience is to describe these transformations as a sequence of simple elementary steps organized in an algorithmic way.

London, Michael and Michael Häusser (2005). Dendritic Computation. *Annual Review of Neuroscience*. Vol. 28, pp 503–32

Real Neuroscience

Brains compute?

The mechanistic substrate for these computations has long been debated. Traditionally, relatively simple computational properties have been attributed to the individual neuron, with the complex computations that are the hallmark of brains being performed by the network of these simple elements.

London, Michael and Michael Häusser (2005). Dendritic Computation. *Annual Review of Neuroscience*. Vol. 28, pp 503–32

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DEFINITIONS: Artificial Neural Networks

Artificial Neural Networks (*ANN*) are computational systems, either hardware or software, which mimic animate neural systems comprising biological (*real*) neurons. An ANN is architecturally similar to a biological system in that the ANN also uses a number of simple, interconnected artificial neurons.

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DEFINITIONS: Artificial Neural Networks

Artificial neural networks emulate threshold behaviour, simulate co-operative phenomenon by a network of 'simple' switches and are used in a variety of applications, like banking, currency trading, robotics, and experimental and animal psychology studies.

These information systems, neural networks or neuro-computing systems as they are popularly known, can be simulated by solving first-order difference or differential equations.

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What computers can do? Artificial Neural Networks

Intelligent behaviour can be simulated through computation in massively parallel networks of simple processors that store all their long-term knowledge in the connection strengths.

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What computers can do? Artificial Neural Networks

According to Igor Aleksander, Neural Computing is the study of *cellular networks* that have a natural propensity for storing experiential knowledge.

Neural Computing Systems bear a resemblance to the brain in the sense that knowledge is acquired through *training* rather than *programming* and is retained due to changes in node functions.

Functionally, the knowledge takes the form of stable states or cycles of states in the operation of the net. A central property of such states is to recall these states or cycles in response to the presentation of cues.

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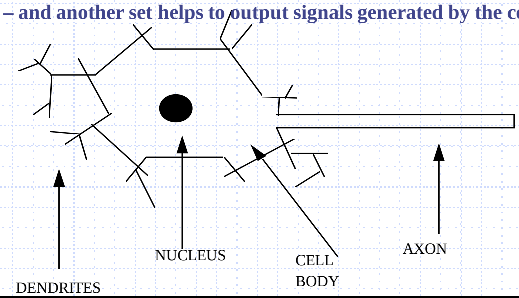
DEFINITIONS: Neurons & Appendages

A neuron is a cell with appendages; every cell has a nucleus and the one set of appendages brings in inputs – the dendrites – and another set helps to output signals generated by the cell



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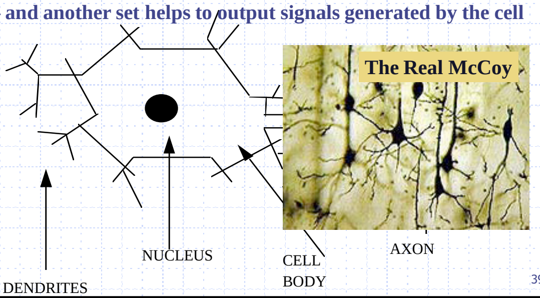

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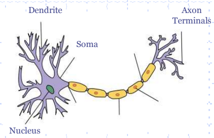
DEFINITIONS: Neurons & Appendages

The human brain is mainly composed of neurons: specialised cells that exist to transfer information rapidly from one part of an animal's body to another.

This communication is achieved by the transmission (and reception) of electrical impulses (and chemicals) from neurons and other cells of the animal. Like other cells, neurons have a cell body that contains a nucleus enshrouded in a membrane which has double-layered ultrastructure with numerous pores.

Neurons have a variety of appendages, referred to as 'cytoplasmic processes known as neurites which end in close apposition to other cells. In higher animals, neurites are of two varieties: Axons are processes of generally of uniform diameter and conduct impulses away from the cell body; dendrites are short-branched processes and are used to conduct impulses towards the cell body.

The ends of the neurites, i.e. axons and dendrites are called synaptic terminals, and the cell-to-cell contacts they make are known as synapses.



SOURCE: http://en.wikipedia.org/wiki/Neurons

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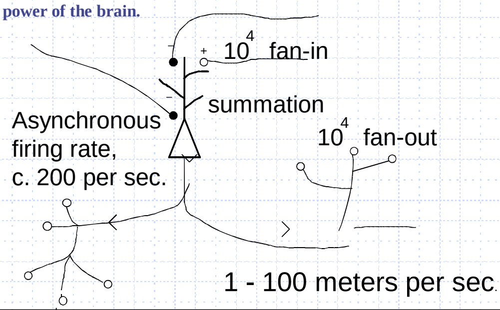
DEFINITIONS:
The fan-ins and fan-outs

10^{10} neurons with 10^4 connections and an average of 10 spikes per second = 1015 adds/sec. This is a lower bound on the equivalent computational power of the brain.



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Biological and Artificial NN's

Entity	Biological Neural Networks	Artificial Neural Networks
Processing Units	Neurons	Network Nodes
Input	Dendrites (Dendrites may form synapses onto other dendrites)	Network Arcs (No interconnection between arcs)
Output	Axons or Processes (Axons may form synapses onto other axons)	Network Arcs (No interconnection between arcs)
Inter-linkage	Synaptic Contact (Chemical and Electrical)	Node to Node via Arcs
	Plastic Connections	Weighted Connections Matrix

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Biological and Artificial NN's

Entity	Biological Neural Networks	Artificial Neural Networks
Output	Dendrites bring inputs from different locations: so does the brain wait for all the inputs and then start up the summing exercise or does it perform many different intermediate computations?	All inputs arrive instantaneously and are summed up in the same computational cycle: distance (or location) between neuronal nodes is not an issue.

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The McCulloch-Pitts Network

. McCulloch and Pitts demonstrated that any logical function can be duplicated by some network of all-or-none neurons referred to as an artificial neural network (ANN).

Thus, an artificial neuron can be embedded into a network in such a manner as to fire selectively in response to any given spatial temporal array of firings of other neurons in the ANN.

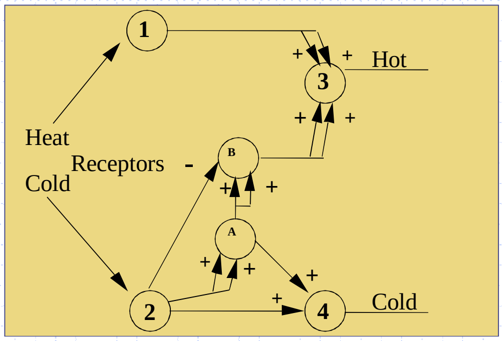
The McCulloch-Pitts Network

Consider a McCulloch-Pitts network which can act as a minimal model of the sensation of heat from holding a cold object to the skin and then removing it or leaving it on permanently.

Each cell has a threshold of **TWO**, hence fires whenever it receives two excitatory (+) and no inhibitory (-) signals from other cells at a previous time.

The McCulloch-Pitts Network

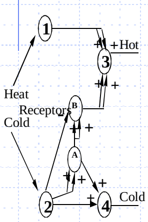
Heat Sensing Network



The McCulloch-Pitts Network

Heat Sensing Network

Truth tables of the firing neurons when the cold object contacts the skin and is then removed



Time	Cell 1 INPUT	Cell 2 INPUT	Cell a HIDDEN	Cell b HIDDEN	Cell 3 OUTPUT	Cell 4 OUTPUT
1	No	Yes	No	No	No	No
2	No	No	Yes	No	No	No
3	No	No	No	Yes	No	No
4	No	No	No	No	Yes	No

The McCulloch-Pitts Network

Heat Sensing Network

'Feel hot'/'Feel cold' neurons show how to create OUTPUT UNIT RESPONSE to given INPUTS that depend ONLY on the previous values. This is known as a *TEMPORAL CONTRAST ENHANCEMENT*.

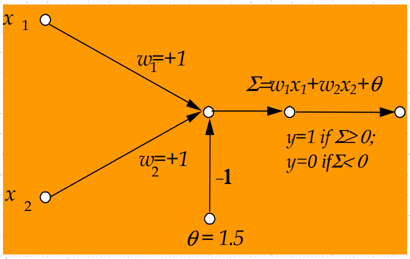
The absence or presence of a stimulus in the PREVIOUS time cycle plays a major role here.

The McCulloch-Pitts Network demonstrates how this ENHANCEMENT can be simulated using an ALL-OR-NONE Network.

Notes on Artificial Neural Networks: Rosenblatt's Perceptron

A single layer perceptron can perform a number of logical operations which are performed by a number of computational devices.

A hard-wired perceptron below performs the AND operation. This is hard-wired because the weights are predetermined and not learnt



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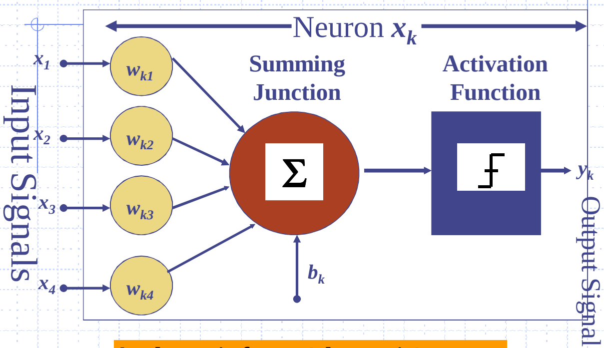
ANN's: an Operational View



A schematic for an 'electronic' neuron

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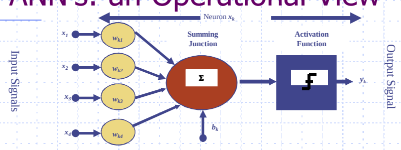
ANN's: an Operational View



Net input or weighted sum:

$net = w_1 * x_1 + w_2 * x_2 + w_3 * x_3 + w_4 * x_4$

Neuronal output

identity function $\Rightarrow y_1 = net$

non-negative identity function

$y_1 = 0$ *if* $net \leq THRESHOLD(\theta)$

$y_1 = net$ *if* $net > THRESHOLD(\theta)$

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Notes on Artificial Neural Networks: Rosenblatt's Perceptron

A single layer perceptron can carry out a number can perform a number of logical operations which are performed by a number of computational devices.

A learning perceptron below performs the AND operation.

An algorithm: Train the network for a number of epochs
(1) Set initial weights w1 and w2 and the threshold θ to set of random numbers;
(2) Compute the weighted sum:
$x_1 * w_1 + x_2 * w_2 + \theta$
(3) Calculate the output using a delta function
$y(i) = delta(x_1 * w_1 + x_2 * w_2 + \theta)$;
delta(x)=1, if x is greater than zero,
delta(x)=0,if x is less than equal to zero
(4) compute the difference between the actual output and desired output:
$e(i) = y(i) - y_{desired}$
(5) If the errors during a training epoch are all zero then stop otherwise update
$w_j(i+1) = w_j(i) + \alpha * x_j * e(i)$, j=1,2

Notes on Artificial Neural Networks: Rosenblatt's Perceptron

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A single layer perceptron can carry out a number can perform a number of logical operations which are performed by a number of computational devices:

α=0.1
Θ=0.2

Epoch	X1	X2	$Y_{desired}$	Initial W1	Weights W2	Actual Output	Error	Final W1	Weights W2
1	0	0	0	0.3	-0.1	0	0	0.3	-0.1
	0	1	0	0.3	-0.1	0	0	0.3	-0.1
	1	0	0	0.3	-0.1	1	-1	0.2	-0.1
	1	1	1	0.2	-0.1	0	1	0.3	0.0

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Notes on Artificial Neural Networks: Rosenblatt's Perceptron

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A single layer perceptron can carry out a number can perform a number of logical operations which are performed by a number of computational devices.

Epoch	X1	X2	$Y_{desired}$	Initial W1	Weights W2	Actual Output	Error	Final W1	Weights W2
2	0	0	0	0.3	0.0	0	0	0.3	0.0
	0	1	0	0.3	0.0	0	0	0.3	0.0
	1	0	0	0.3	0.0	1	-1	0.2	0.0
	1	1	1	0.2	0.0	1	0	0.2	0.0

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Notes on Artificial Neural Networks: Rosenblatt's Perceptron

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A single layer perceptron can carry out a number can perform a number of logical operations which are performed by a number of computational devices.

Epoch	X1	X2	$Y_{desired}$	Initial W1	Weights W2	Actual Output	Error	Final W1	Weights W2
3	0	0	0	0.2	0.0	0	0	0.2	0.0
	0	1	0	0.2	0.0	0	0	0.2	0.0
	1	0	0	0.2	0.0	1	-1	0.1	0.0
	1	1	1	0.1	0.0	1	1	0.2	0.1

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Notes on Artificial Neural Networks: Rosenblatt's Perceptron

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A single layer perceptron can carry out a number can perform a number of logical operations which are performed by a number of computational devices.

Epoch	X1	X2	$Y_{desired}$	Initial W1	Weights W2	Actual Output	Error	Final W1	Weights W2
4	0	0	0	0.2	0.1	0	0	0.2	0.1
	0	1	0	0.2	0.1	0	0	0.2	0.1
	1	0	0	0.2	0.1	1	-1	0.1	0.1
	1	1	1	0.1	0.1	1	0	0.1	0.1

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Notes on Artificial Neural Networks: Rosenblatt's Perceptron

A single layer perceptron can carry out a number can perform a number of logical operations which are performed by a number of computational devices.

Epoch	X1	X2	$Y_{desired}$	Initial W1	Weights W2	Actual Output	Error	Final W1	Weights W2
5	0	0	0	0.1	0.1	0	0	0.1	0.1
	0	1	0	0.1	0.1	0	0	0.1	0.1
	1	0	0	0.1	0.1	0	0	0.1	0.1
	1	1	1	0.1	0.1	1	0	0.1	0.1

Computers and Brain: A neuroscience perspective

"Professor Jefferson's Lister Oration for 1949, from which I quote.

"Not until a machine can write a sonnet or compose a concerto because of thoughts and emotions felt, and not by the chance fall of symbols, could we agree that machine equals brain-that is, not only write it but know that it had written it.

No mechanism could feel (and not merely artificially signal, an easy contrivance) pleasure at its successes, grief when its valves fuse, be warmed by flattery, be made miserable by its mistakes, be charmed by sex, be angry or depressed when it cannot get what it wants."

Alan Turing (1950) 'Computer Machinery and Intelligence'. *Mind* Vol. LIX (No. 2236), pp 433-460.