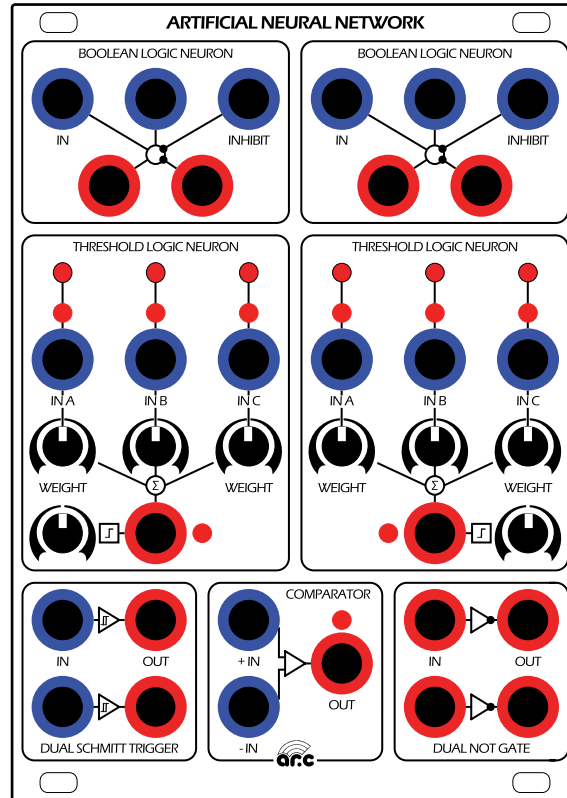




ARTIFICIAL NEURAL NETWORK



Power Warning

This instrument is intended for use in the eurorack modular system. Please use all precautions and correct orientation when connecting this module to your enclosure and power supply.

Due to the extremely varied nature of the eurorack ecosystem, no warranty can be extended for damage caused by faulty or overloaded power supplies, incorrect orientation of power connections, etc. For more information on the eurorack technical standards, please visit the Doepfer website at: www.doepfer.de



Specifications

Module Width:..... 18hp

Mounting Depth:.....25mm

Current Draw:

+12V..... 100mA
 -12V..... 10mA
 +5V.....0mA

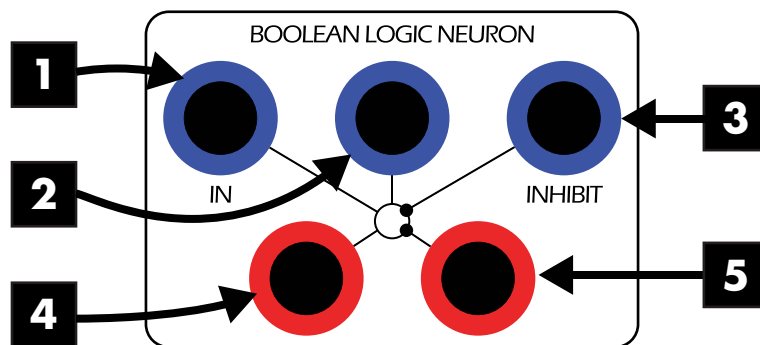
Manufactured by ARC in the
 United States of America
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Introduction

ARC's Artificial Neural Network (ANN) is a metamodule comprised of several programmable logic, control voltage processing and waveshaping submodules for use in the eurorack modular system. The submodules are discussed in more detail below, and some patch ideas are explored. Please see the Further Reading section at the end of the manual to learn more about the history and application of artificial neurons in the fields of cybernetics, artificial intelligence and machine learning.

Boolean Logic Neuron Submodule

The ANN features two identical Boolean Logic Neuron submodules. The design of these submodules is based on the Dual Logic Unit found on the Electronic Associates of Berkeley modular video synthesizer; specifically the EAB Videolab Series 2 Module-A. Each Boolean Logic Neuron functions as a two-input AND/NAND gate with an inhibit input and complementary (non-inverted and inverted) outputs.



1 AND Gate Input

Shown on Truth Table below as Input A.

2 AND Gate Input

Shown on Truth Table below as Input B.

3 Inhibit Input

This input squelches the Boolean function.

4 Non-Inverted Output

The AND logic gate is output as a 0 or +5V signal.

5 Inverted Output

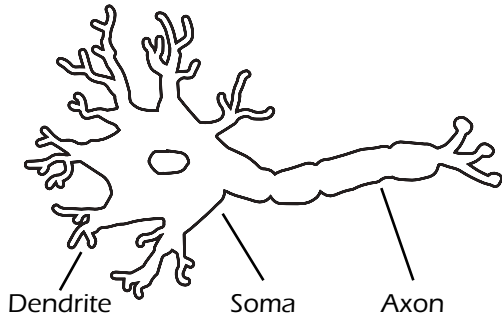
NAND gate output, shown on the Truth Table below as Output \bar{X} .

Inputs			Outputs	
A	B	Inhibit	X	\bar{X}
0	0	0	0	1
0	1	0	0	1
1	0	0	0	1
1	1	0	1	0
0	0	1	0	1
0	1	1	0	1
1	0	1	0	1
1	1	1	0	1

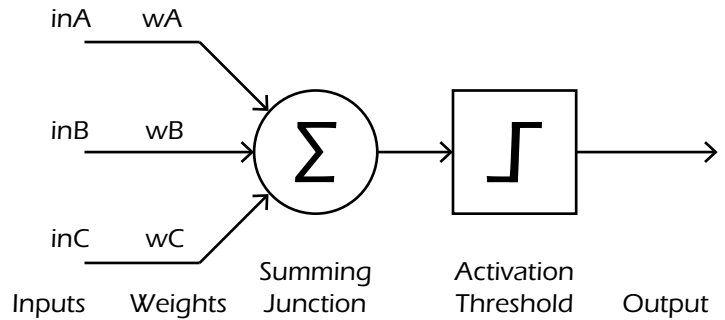


Threshold Logic Neuron Submodule

The ANN features two identical Threshold Logic Neuron submodules, based on the design of the McCulloch-Pitts "Threshold Logic Unit" nervous system model of the 1940s. An artificial neuron receives information at the inputs (synapse), the priority of this information is weighted (dendrites); then it fires a pulse when those summed inputs (soma) meet a specified threshold (axon).

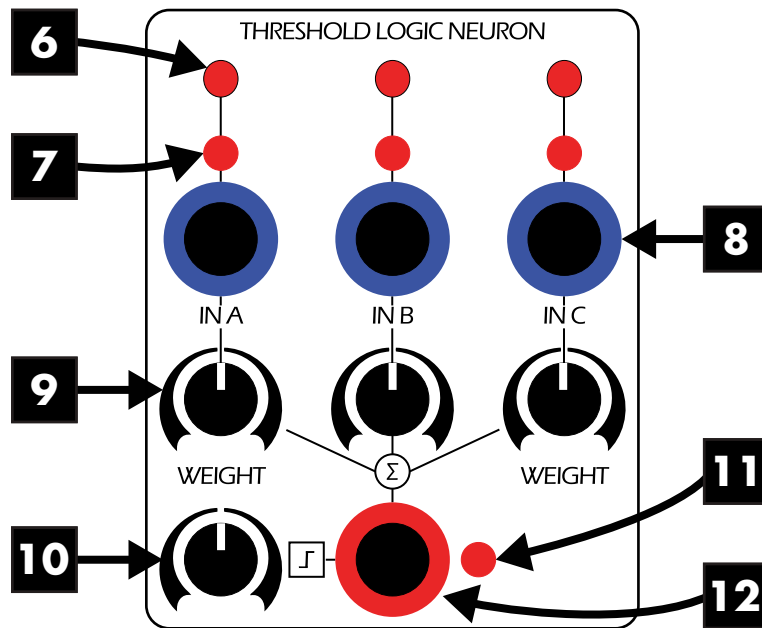


Biological Neuron



Artificial Neuron

It was quickly realized that a model like this could be configured to perform numerous logic gate functions, and it was exploited in the fields of machine learning, artificial intelligence, biomimetic engineering, etc. For the purposes of modular synthesis, the Threshold Logic Neuron represents a flexible patch-programmable logic gate. Interaction between the two Threshold Logic Neurons and various other submodules of the ANN can create and process complex pulse patterns.



6 Manual Gate

Push-button manually gates a +5V signal to the associated input.

7 Input Indicator Lamp

LED visual indicator for the associated input channel.

8 Neuron Input

Each neuron has three input channels.

9 Input Weight Control

These potentiometers control the amount of influence each input has.

10 Neuron Threshold Control

This potentiometer sets the neuron's threshold activation value.

11 Output Indicator Lamp

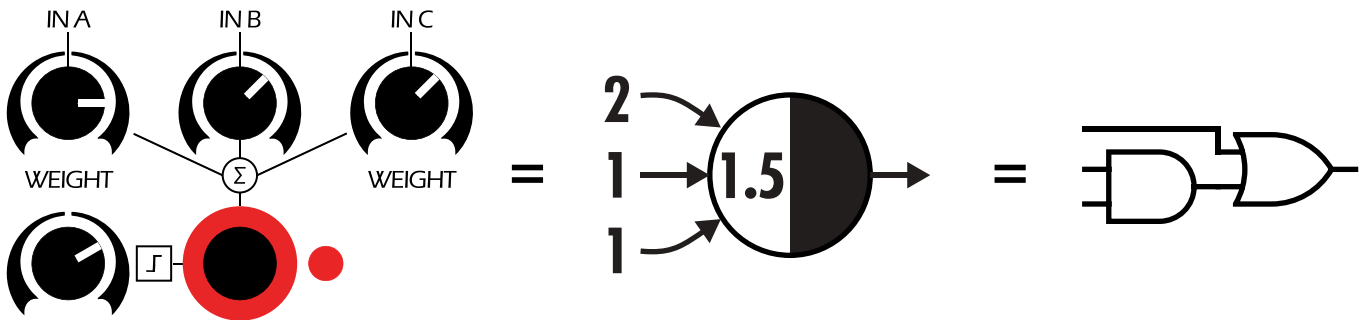
LED visual indicator for the output.

12 Neuron Output

Outputs the result of the transfer function based on the interaction of the weighted inputs and threshold.

? Programming the Threshold Logic Neuron

The Threshold Logic Neurons can be programmed to perform a great number of Boolean logic functions. Let's look at a simple Boolean expression: $A+(BC)$. To perform this with the Threshold Logic Neuron we must consider the interaction of the summed inputs versus the threshold level we will set. If we suppose that setting a potentiometer to the clockwise position has a value of 3.5, noon a value of 0 and counterclockwise -3.5; then with the controls set as illustrated, our neuron model would look like this:



The Boolean expression shown as Threshold Logic Neuron panel settings, neuron model and circuit symbol

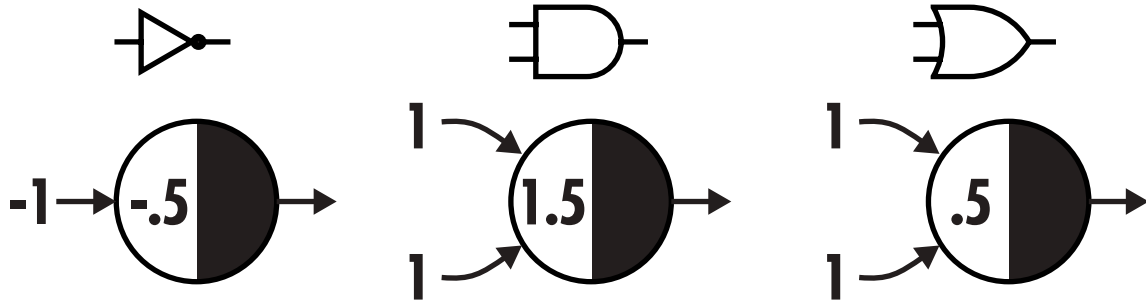
A pulse to the A input with a weight of 2 would overcome the activation threshold of 1.5 and we would have a pulse at the output, making the statement true. Pulses sent to B or C with a weight of 1 would not overcome the threshold, making the statement false. However, pulses at both B and C would have their weight summed (1+1), satisfying the expression and giving us a pulse at the output. A three input neuron has 8 possible input state permutations, so let's look at the truth table for the expression we have set up:

A+(BC)				
A	B	C	Sum	Out
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	2	1
1	0	0	2	1
1	0	1	3	1
1	1	0	3	1
1	1	1	4	1

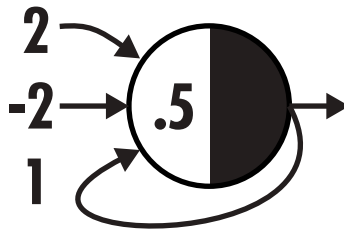


Programming the Threshold Logic Neuron (cont.)

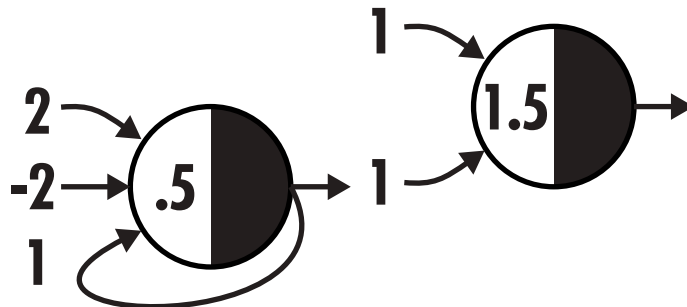
Of course, fewer than three inputs can be used. A NOT gate can be implemented with one input; AND and OR with two:



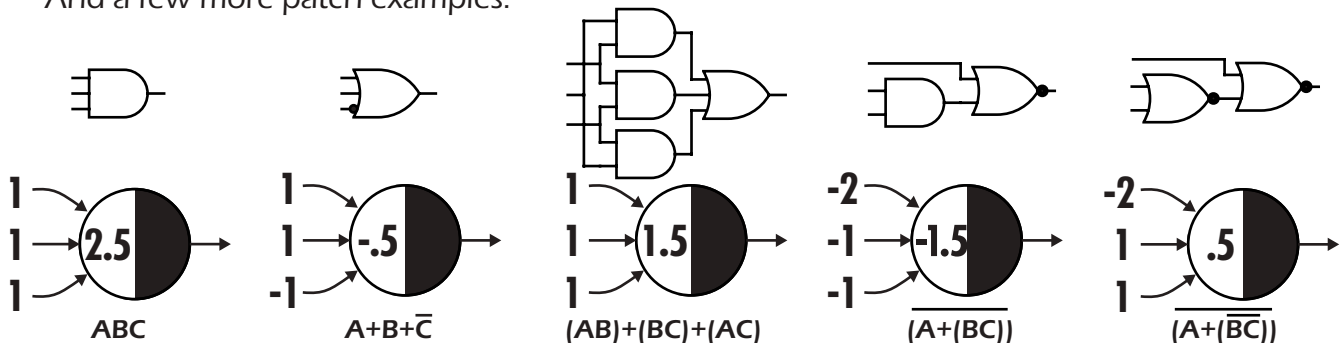
Conversely, much more complex expressions can be solved by inter-patching submodules of the ANN (or any number of additional ANN modules). Utilizing a mult, or patch cables that can be stacked, we can also explore sequential logic and delay gates, creating a single-bit memory!



As you can see, we have fed the output of the neuron back into the C input. A pulse of any duration at the A input will start a loop that can only be stopped by pulsing the B input. Stacking neurons in this configuration will create a delay of n time periods. To create a latch, we can take one of our single-bit memory circuits and send its output to a second neuron:

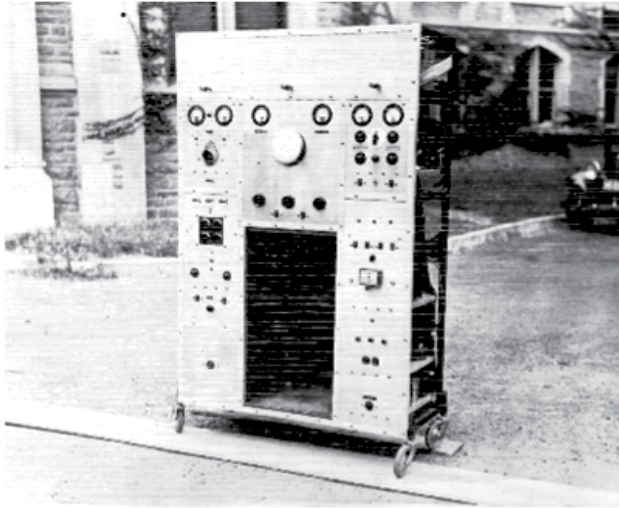


And a few more patch examples:



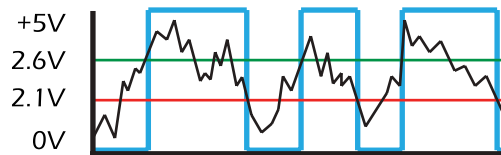
Q Dual Schmitt Trigger Submodule

This submodule contains two identical Schmitt Triggers. Dr. Otto H. Schmitt developed the thermionic trigger that would come to bear his name while researching squid axon in the 1930s.

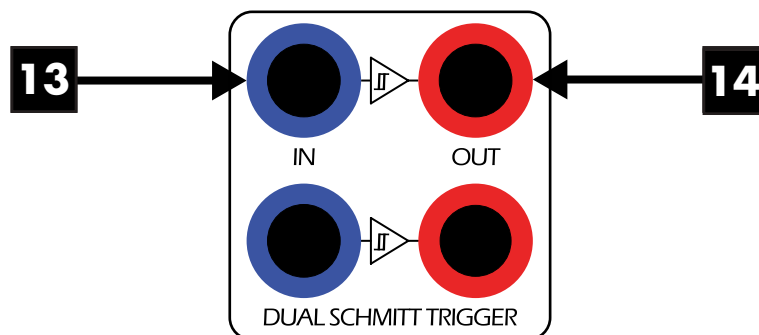


Schmitt's analogue computer "Nerve Axon Simulator" circa 1937

The Schmitt Trigger is a comparator with hysteresis. The input signal is compared against an internal upper and lower threshold. When the input crosses the upper threshold (approximately 2.6V) the output is held high (+5V); when it crosses the lower threshold (approximately 2.1V) it is held low (0V), regardless of fluctuations above or below these thresholds.



In a modular synthesizer a Schmitt Trigger can be useful for squaring up waveforms, extracting gates from CV or audio sources (commonly paired with an envelope follower), as a utility waveform generator, etc.



13 Input

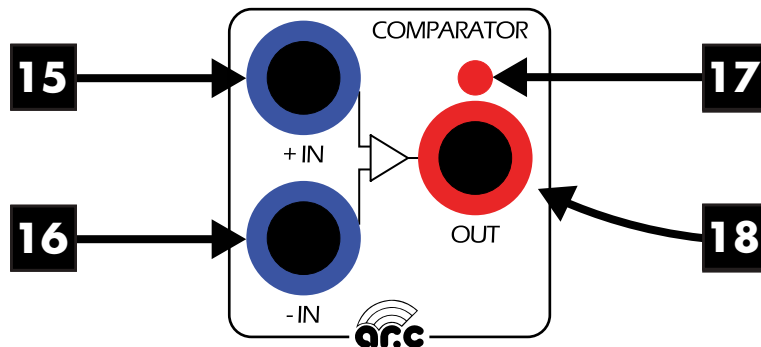
Input is compared against the internal thresholds.

14 Output

Square wave logic level output (0 or +5V)

Comparator Submodule

The comparator takes two analogue input signals and outputs a logic level signal indicating which of the two inputs is greater.



15 + Input

Input compared to reference voltage.

17 Output Indicator Lamp

LED visual indication for the output.

16 - Input

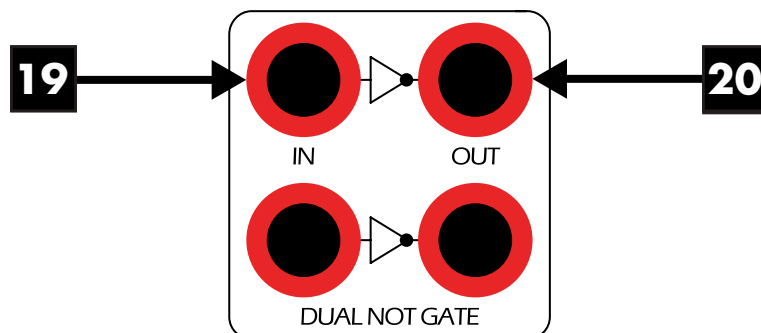
This input is normalled to +5V. Inserting an external signal sets the reference voltage.

18 Output

Square wave logic level output (0 or +5V)

Dual NOT Gate Submodule

This submodule contains two identical logic level inverters. If the input is high (+5V) then the output will be low (0V), conversely if the input is low (0V) then the output will be high (+5V).



19 Input

Logic level input.

20 Output

The inverted signal.

Hints & Tips

All other Boolean logic gates can be made using only NAND building blocks. The ANN was designed to be functionally complete in this regard. It is also possible to program XOR and XNOR using only two Threshold Logic Neurons.

A 3 input AND gate can be made by cross patching the two input Boolean Logic Neurons.

With no inputs present, the Boolean Logic Neuron NAND out and Dual NOT Gate out can be used as +5V reference signals for other analogue computer functions.

The Dual Schmitt Trigger is provided to condition analogue signals for use with the logic sub-modules. It can also be used for audio waveshaping etc.

Further Reading

Schmitt, Otto H. "A Thermionic Trigger." *Journal of Scientific Instruments* 15.1 (1938): 24-26.

Schmitt, Francis O., and Otto H. Schmitt. "Partial Excitation and Variable Conduction in the Squid Giant Axon." *The Journal of Physiology* 98.1 (1940): 26-46.

McCulloch, Warren S., and Walter Pitts. "A Logical Calculus of the Ideas Immanent in Nervous Activity." *Bulletin of Mathematical Biophysics*. 5 (1943).

Weiner, Norbert. *Cybernetics: Or Control and Communication in the Animal and the Machine*. 1948.

Minsky, Marvin, and Seymour Papert. *Perceptrons: An Introduction to Computational Geometry*. 1969.