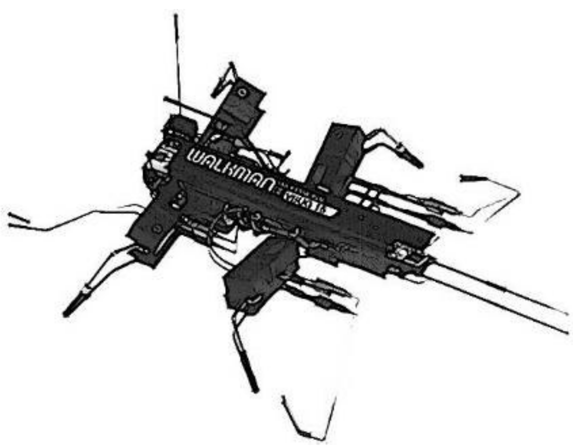
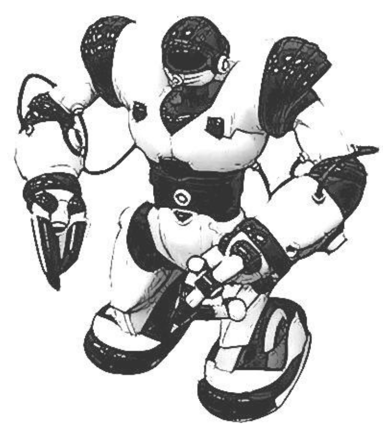
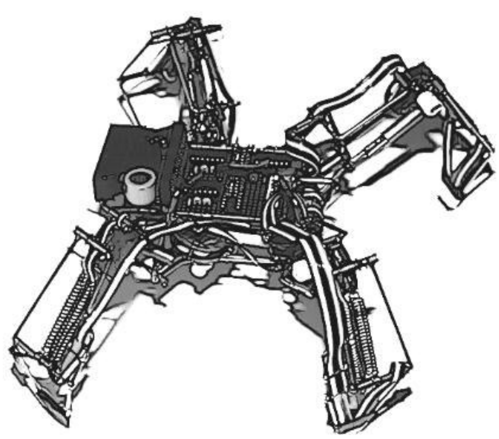
BEAM Biomorphic Robotics and Nervous Nets

A BEAM Biomorphic robot is one that walks, crawls, climbs or slithers along the path of least resistance. Its mechanics are such that motor load corresponds to limb position. The load increases as the limb moves away, decreases as it moves back towards an ideal position.

The biggest difference between a traditional robot limb and a biomorphic limb is in the replacement of the accurately measuring servo with chaotically reacting DC motor load.







Biomorphic robots tend to adjust their gait toward a least energy state. Obstacles and changes in the terrain bump the robot out of the state, leading the walking pattern to adapt. Such adaptation is implicit within the machine's mechanics.

Biomorphic Motor Controller

Biomorphic controllers have two requirements. First, it must be responsive to motor load. The Abcore motor driver provides an excellent example.

Without any input or bias, the Abcore's oscillation will depend entirely upon motor load. A limb attached to such a motor will automatically conform to the environment, seeking a state wherein the motor is under the least load.

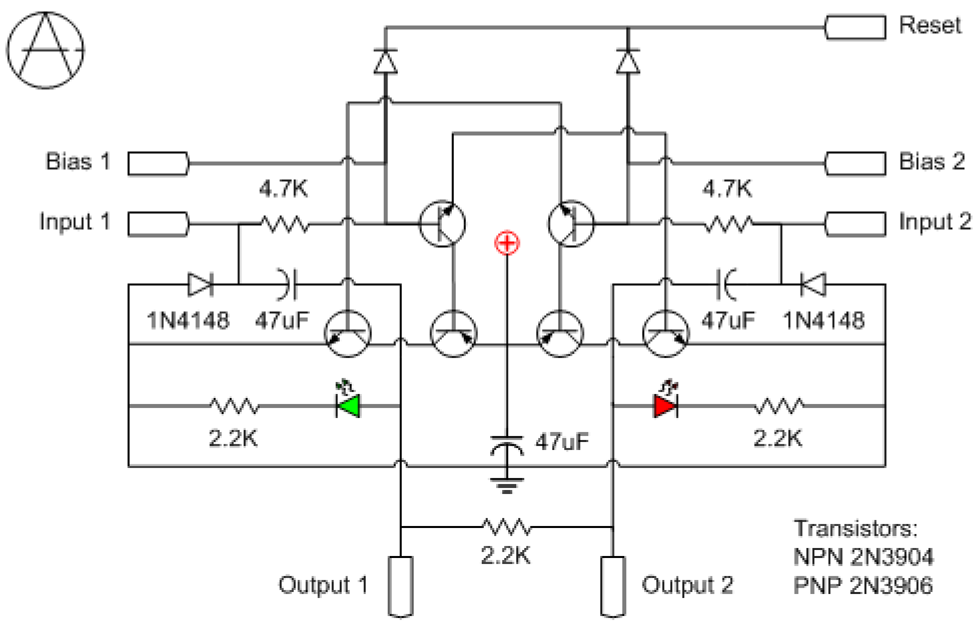
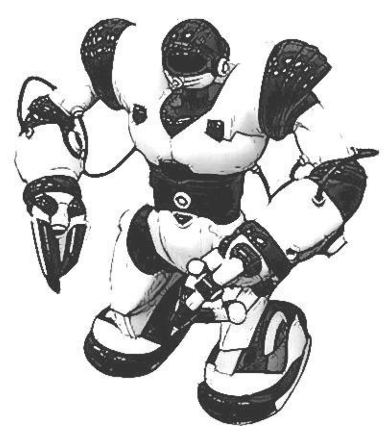


Figure 1: Adaptive Bicore Biomech Motor Controller (Abcore)

Mark Tilden's Robosapien prototypes used the Abcore as the primary controller. The arms place a load on the waist motor, causing the biped to turn from objects without explicit sensor feedback.



BEAM Neurons

The second requirement of a biomorphic controller is to drive a series of motors in a given sequence. That is to say, a biomorphic controller is essentially a central pattern generator.

The BEAM Nervous Net is the preferred biomorphic controller. It is the easiest to understand, design, build, and troubleshoot. The Nv Net requires minimal parts and power.

Nv Nets are comprised of several analog neurons. The BEAM neuron has several inputs that form a RC network of resistors (R) and capacitors (C). Signal and reference voltages on the inputs create charging and discharging voltages in the RC network. Protection diodes keep these voltages between the logic gate's Vcc and Gnd. A logic gate sums the RC network and generates Vcc or Gnd pulses at the neuron output.

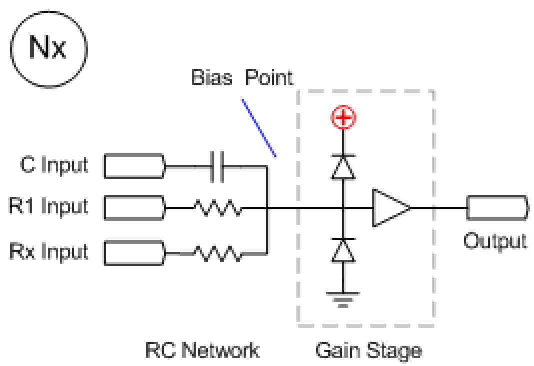


Figure 2: Universal BEAM Neuron

There are four common instances of this universal neuron: Nv-, Nv+, Nu-, and Nu+.

RC Timing

Generally, the shorthand equation is sufficient for designing Nv Nets.

$T = RC$

Where:

T = Time in seconds
R = Resistance in megohms
C = Capacitance in microfarads

The detailed equation may also be used, particularly when the RC network is not completely charging or discharging. This equation is:

$T = RC \log e (1/((Vth-Vmin)/(Vmax-Vmin)))$

Where:

T = Time in seconds
R = Resistance in megohms
C = Capacitance in microfarads
Vth = Threshold voltage, input switching
Vmin = Minimum Voltage
Vmax = Maximum Voltage

This still yields only an estimate because motor loading and transient electrical conditions can drastically cut the time. It is always best to socket your capacitors and resistors for tuning under real world conditions.

For simplicities sake, the condensed T=RC formula will be used in the following pages.

Nervous (Nv-) Neurons

The Nv- neuron has a capacitive input and a resistor referencing Gnd. It activates immediately and fires for the time determined by RC. Afterwards, it deactivates and will not fire again until the input is reset.

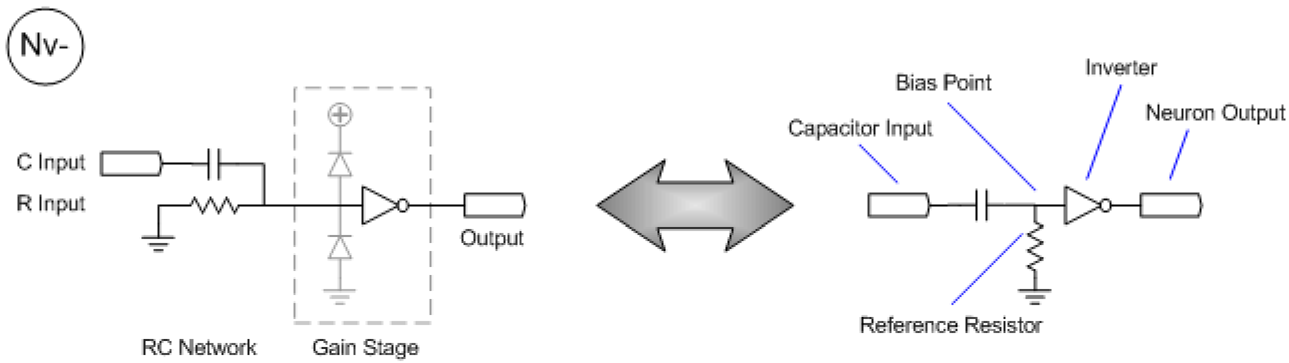


Figure 3: Nervous (Nv-) Neuron

Trigger Input Vcc
Active Time............... 0 (Immediate)
Active Output .... Gnd

Reset Input............... Gnd
Deactivate Time......... 0 (Immediate)
Inactive Output Vcc

Timeout................... T=RC

Nervous (Nv+) Neurons

The Nv+ neuron has a capacitive input and a resistor referencing Vcc. It activates immediately and fires for the time determined by RC. Afterwards, it deactivates and will not fire again until the input is reset.

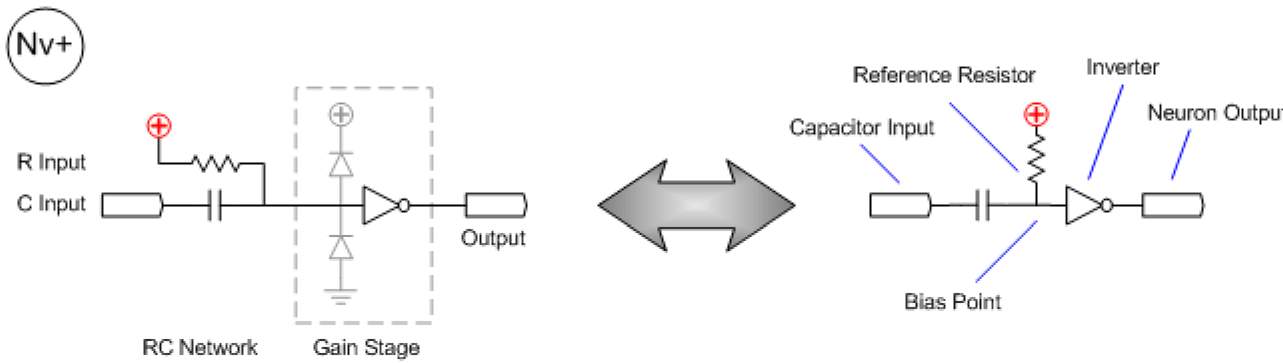


Figure 4: Nervous (Nv+) Neuron

Trigger Input ....Gnd
Active Time...............0 (Immediate)
Active Output Vcc

Reset Input...............Vcc
Deactivate Time.........0 (Immediate)
Inactive Output ....Gnd

Timeout...................T=RC

Neural (Nu-) Neurons

The Nu- neuron has a resistor input and a capacitor referencing Gnd. The capacitor is in effect charging or discharging through the resistor. It activates after the T=RC and remains active until the input signal changes.

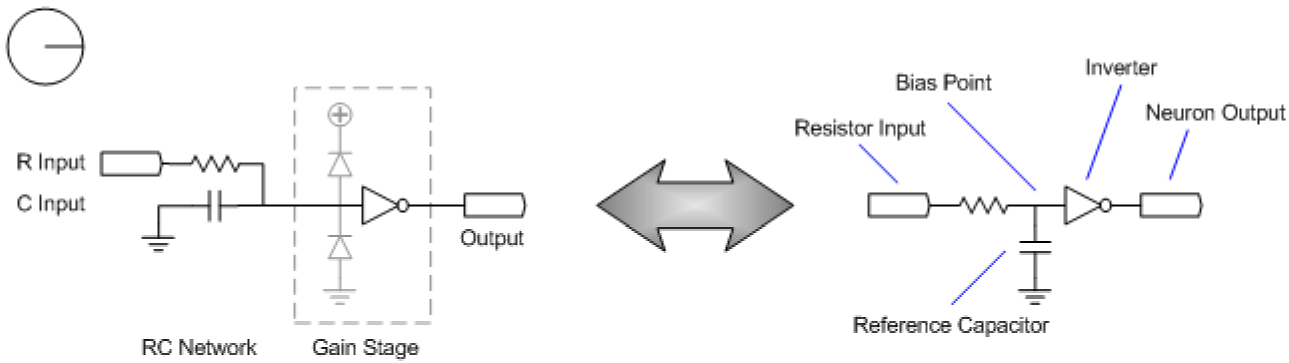


Figure 5: Neural (Nu-) Neuron

Trigger Input Vcc
Active Time............... T=RC
Active Output .... Gnd

Reset Input............... Gnd
Deactivate Time......... T=RC
Inactive Output Vcc

Timeout.................... n/a (output will not change until the input changes)

Neural (Nu+) Neurons

The Nu+ neuron has a resistor input and a capacitor referencing Vcc. The capacitor is in effect charging or discharging through the resistor. It activates after the T=RC and remains active until the input signal changes.

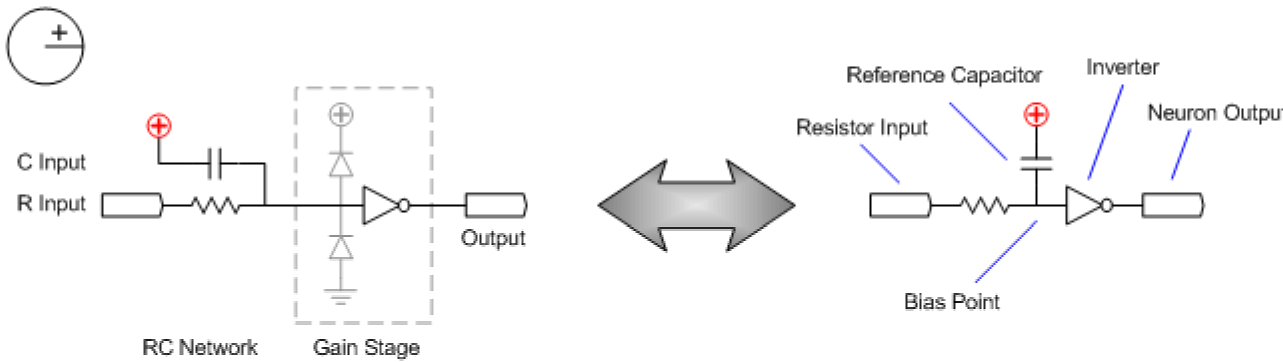


Figure 6: Neural (Nu+) Neuron

Trigger Input .... Gnd
Active Time............... T=RC
Active Output Vcc

Reset Input............... Vcc
Deactivate Time......... T=RC
Inactive Output .... Gnd

Timeout.................... n/a (output will not change until the input changes)

Nv Net Topologies

BEAM Neurons are strung together to form central pattern generators for biomorphic robots.

There are three general types of topologies: lined up in a chain, branched, or ringed in a core.

Most commonly, the neuron of choice is the Nv- and the topology is the core.

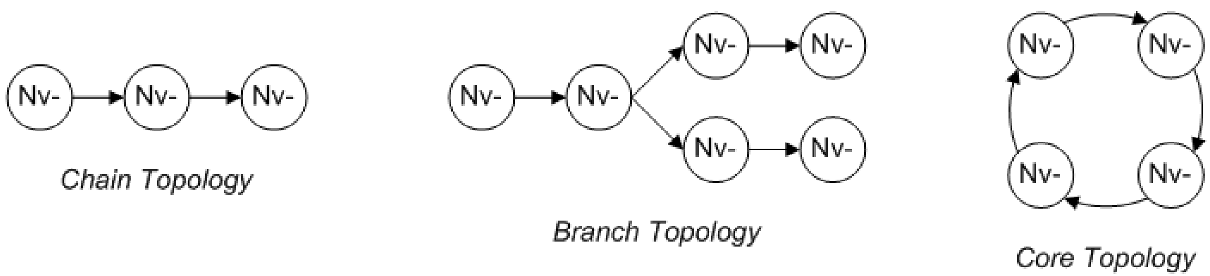


Figure 7: Nervous Net Topologies: Chain, Branch, and Core

Bicore: Grounded, Suspended, and Phototropic

Two Nv- neurons can be grouped in to a two node core or Bicore. This has the benefit of being self-seeding. That is, anything change in timing on one node is immediately affects the next node and thereby affects itself.

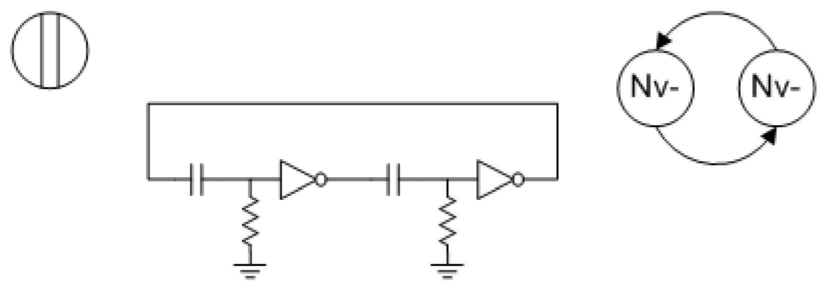


Figure 8: Two Nv- Neuron Loop (Bicore)

One can suspend a Bicore by linking the Nv- neurons reference resistors to each other rather than Gnd. This has two consequences. One, it decreases the part count (the two resistors can be substituted for one resistor of the sum value). Second and more importantly, it increases the Bicore's sensitivity to motor loading.

A suspended Bicore can be made sensitive to light by replacing the reference resistors with photodiodes. This is useful for adding phototaxis to biomorphic robots.

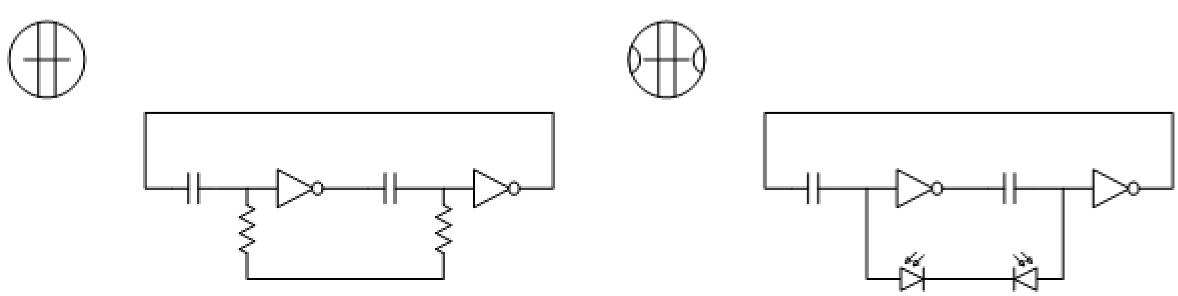
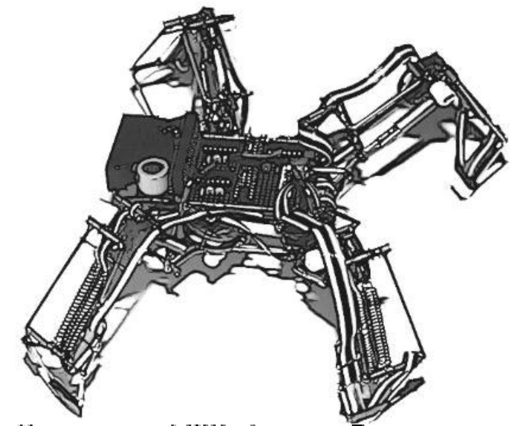
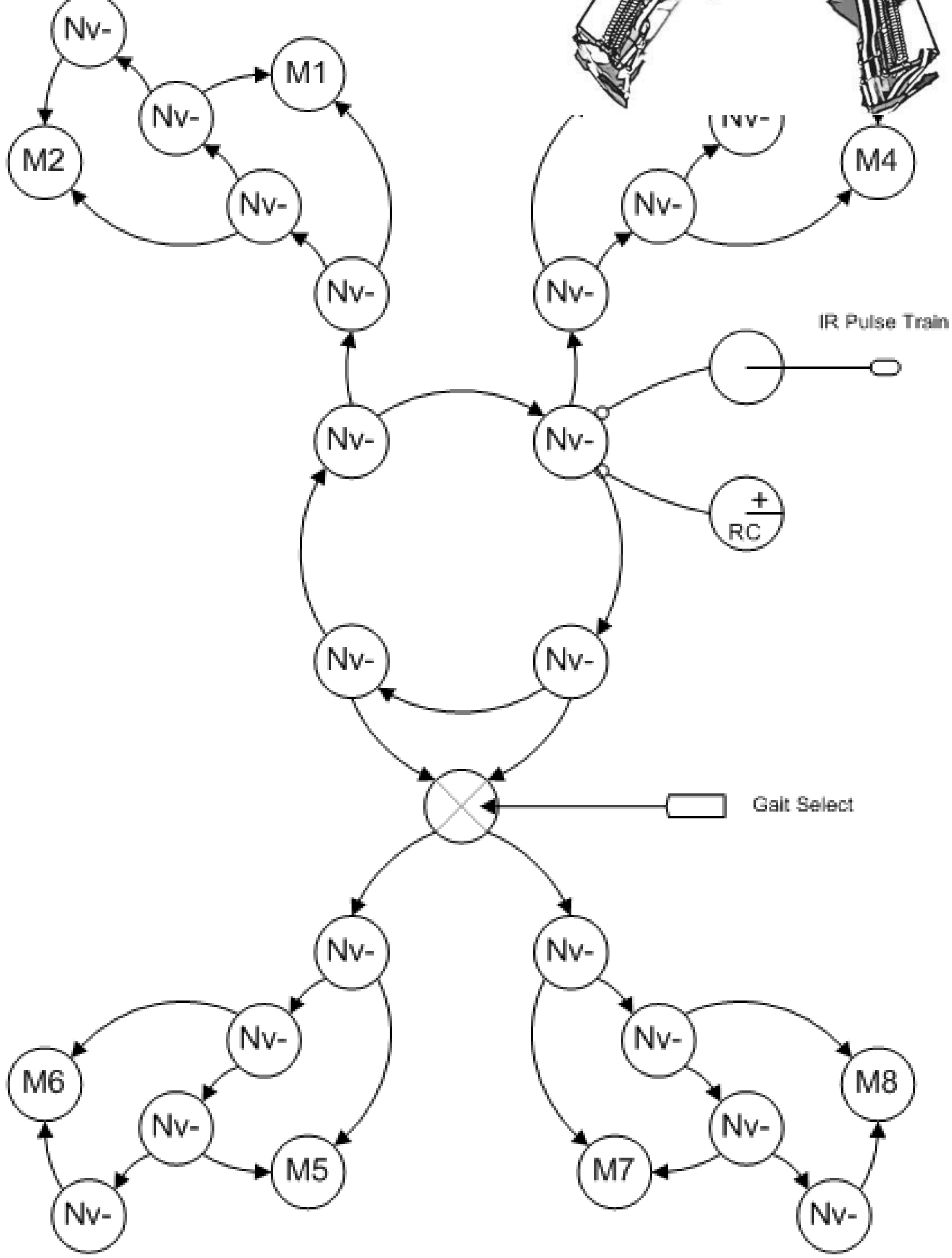


Figure 9: Suspended Bicore and Phototropic Suspended Bicore

Vbug 1.1 "Spyder"

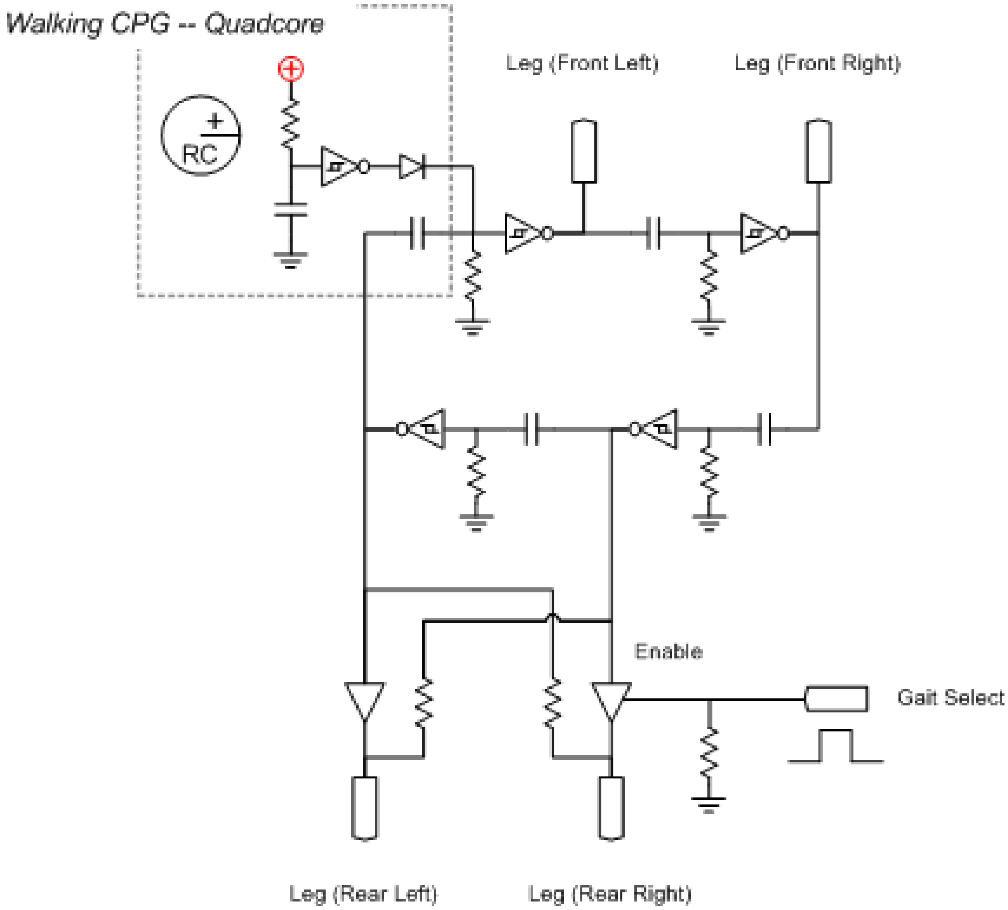


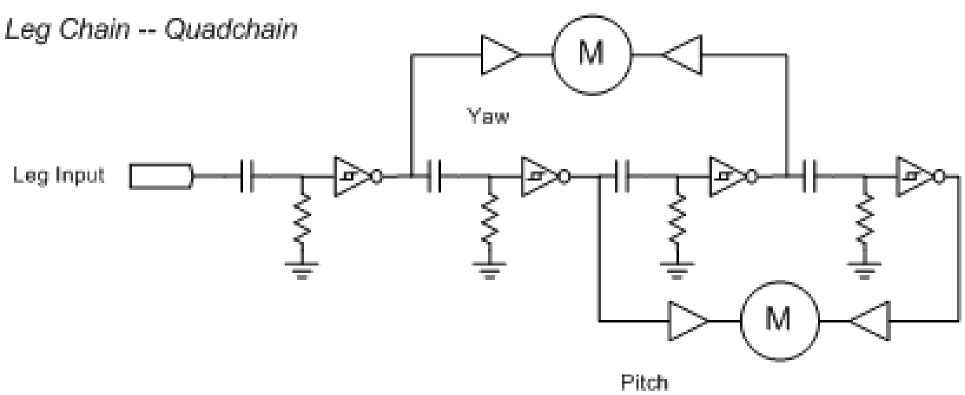
VBug 1.1 "Spyder" Biomorphic Map



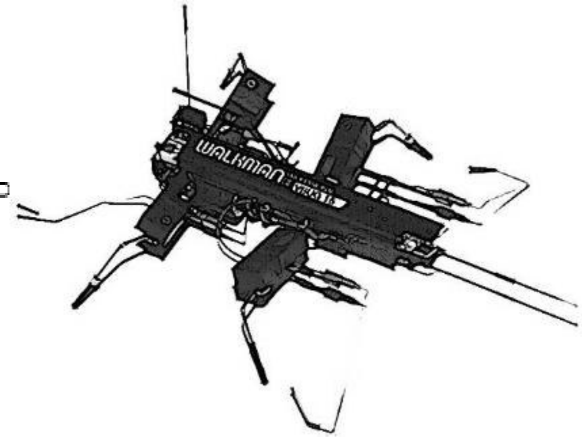
VBug 1.1 "Spyder" Circuit Schematic

Equivalent Nv Net, may differ from the original.

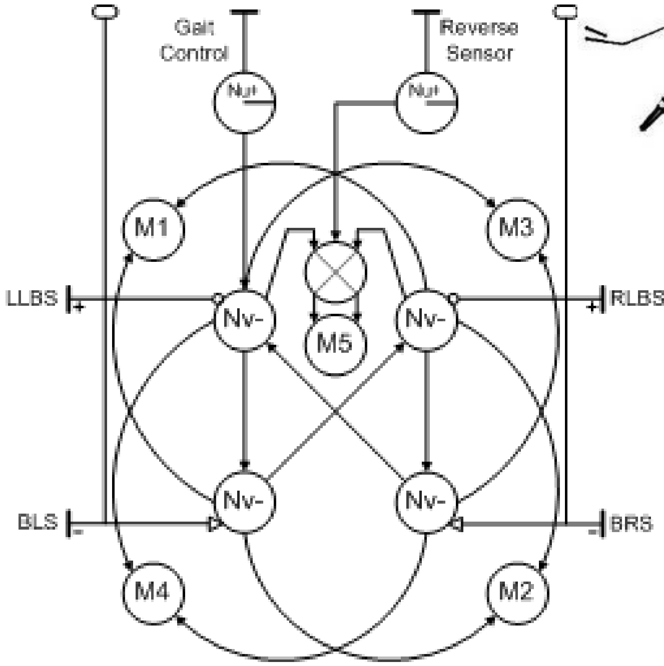




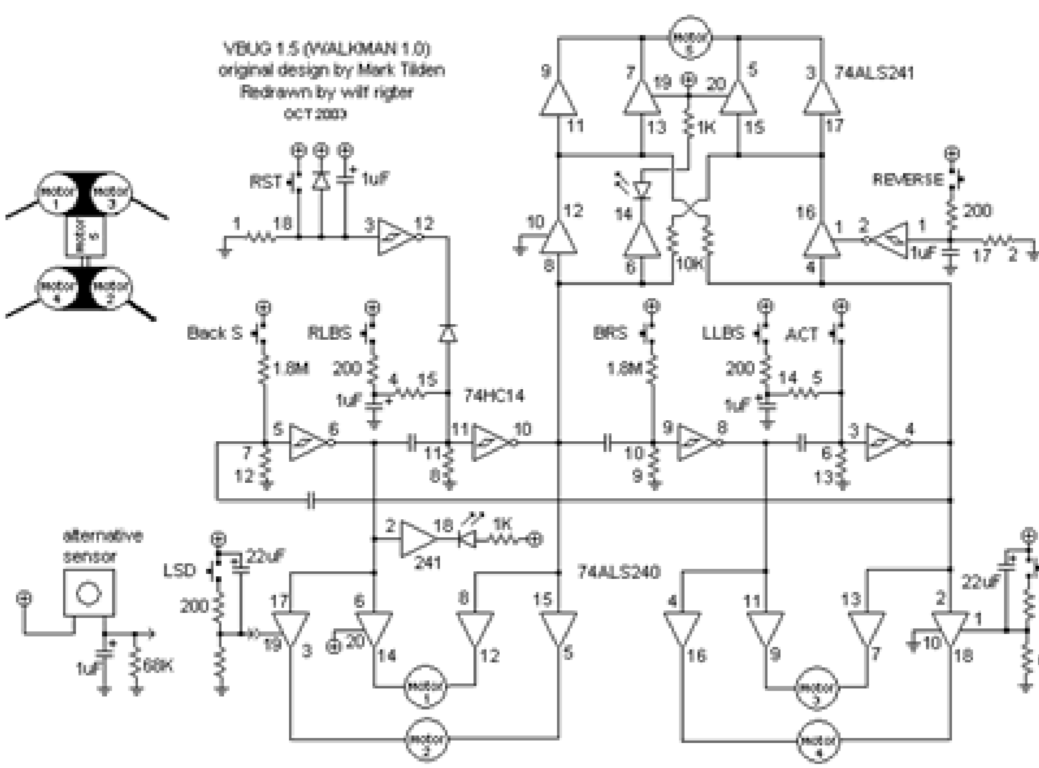
Vbug 1.5 "Walkman"



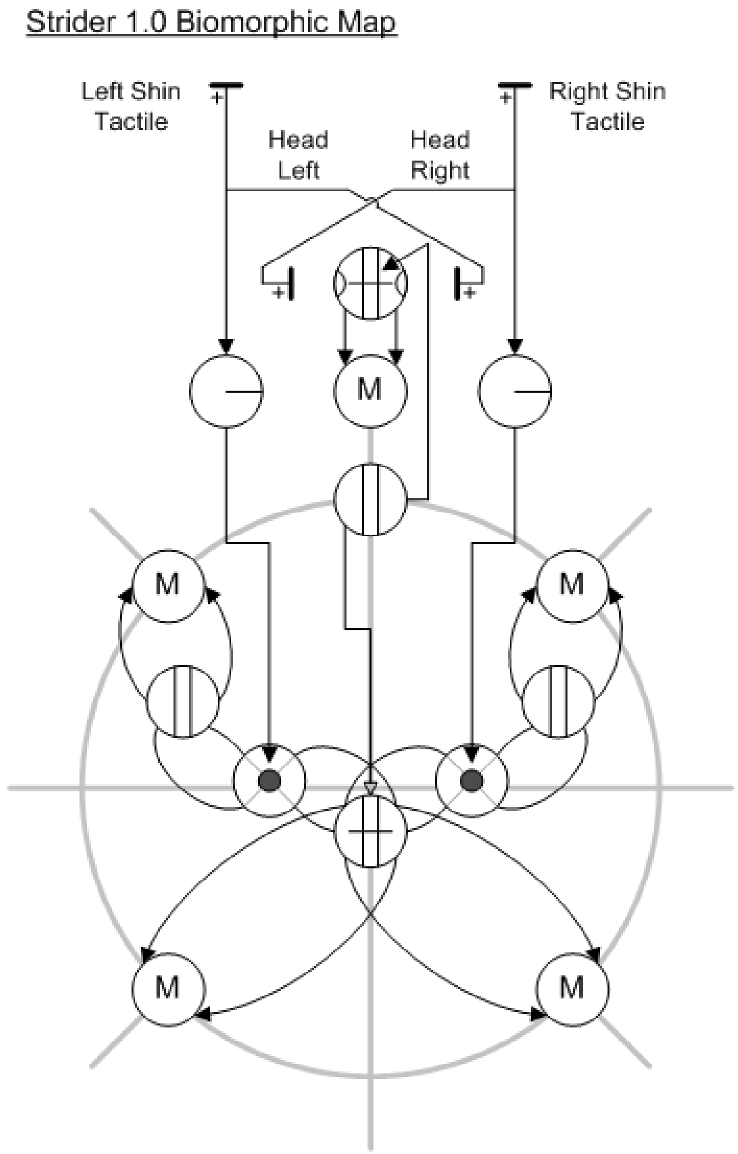
VBug 1.5 "Walkman" Biomorphic Map



VBug 1.5 "Walkman" Circuit Schematic

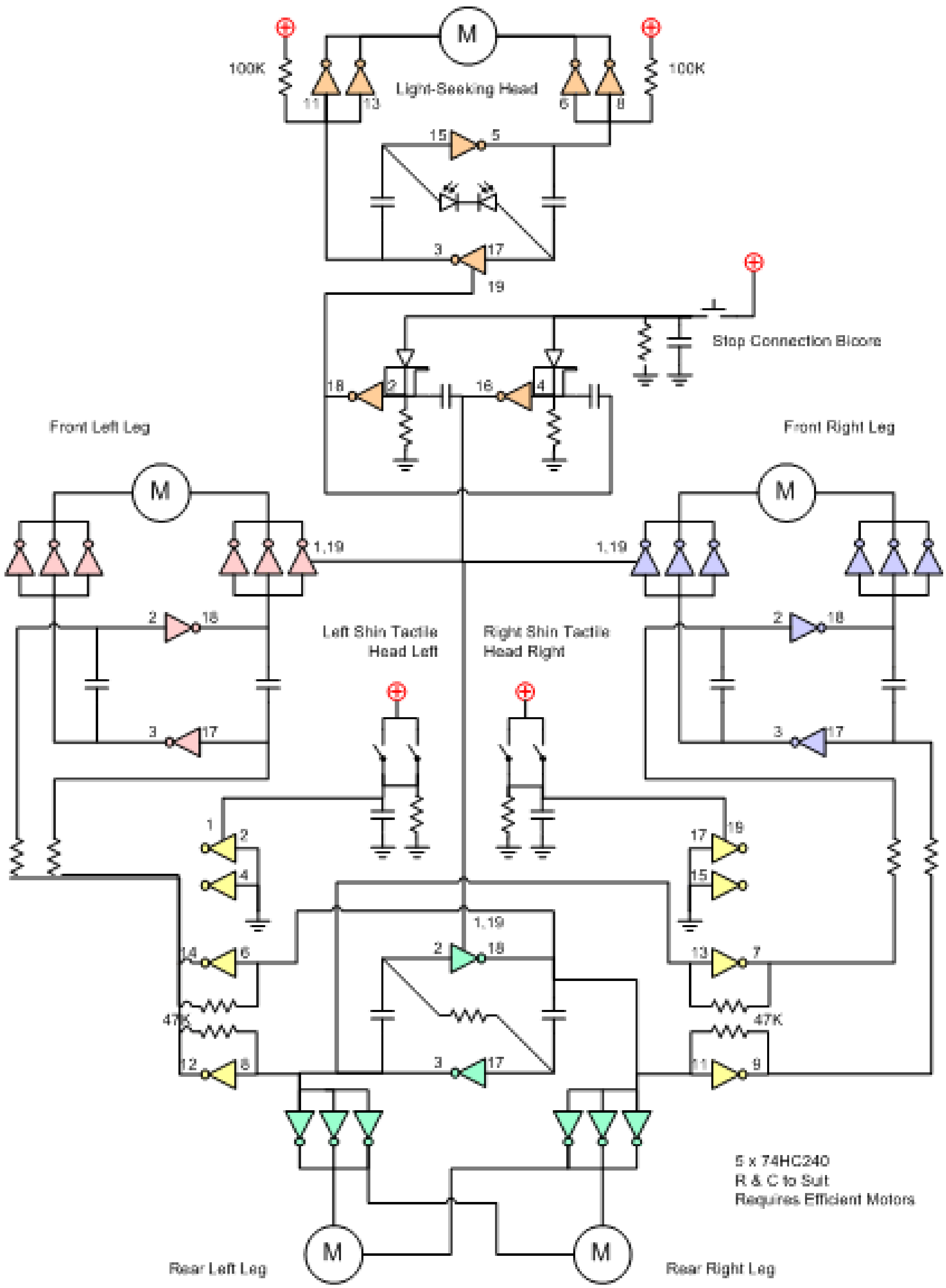


Mark Tilden's Strider

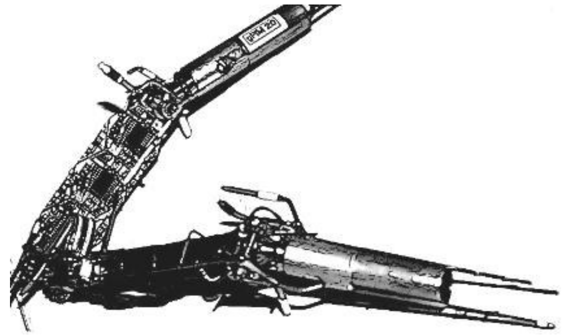


Strider 1.0 Circuit Schematic

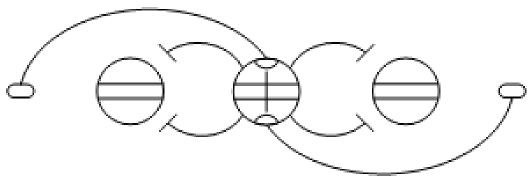
Equivalent Nv Net, may differ from the original.



Mark Tilden's gPim 2.0

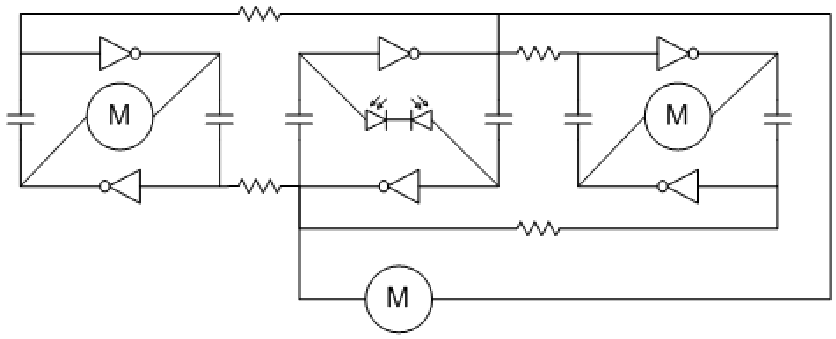


gPim 2.0 "Snakebot" Biomorphic Map

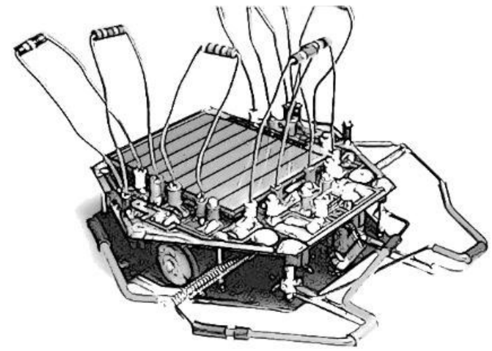


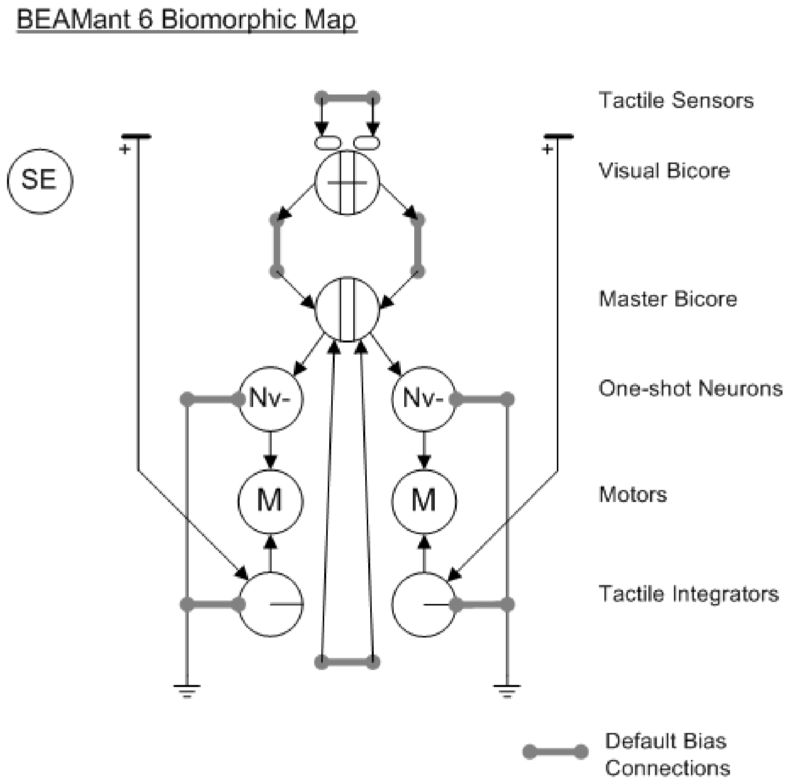
gPim 2.0 "Snakebot" Circuit Schematic

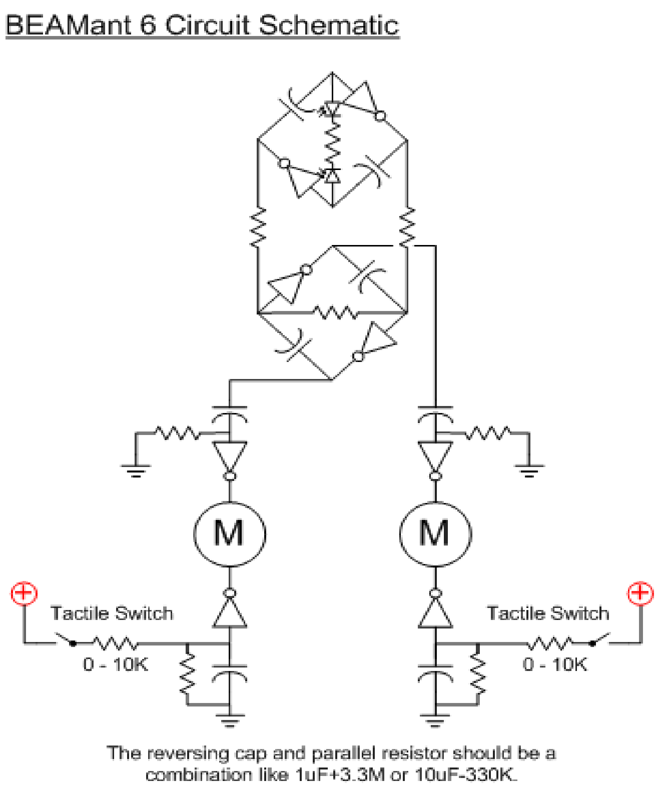
Equivalent Nv Net, may differ from the original.



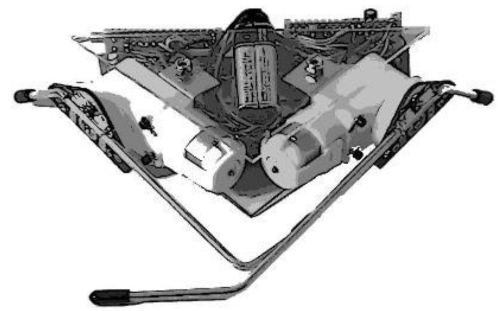
Mark Tilden's BeamAnt 6



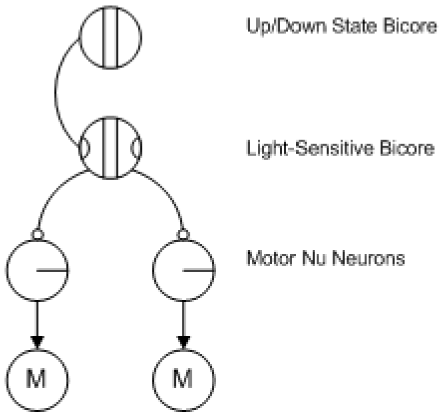




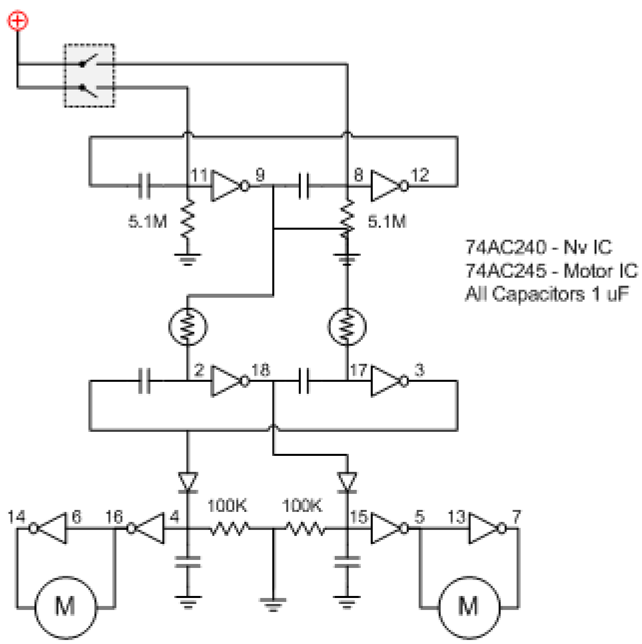
My Sarah Nv Net



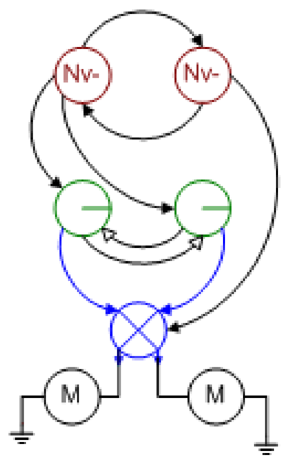
Sarah Turbot Biomorphic Map



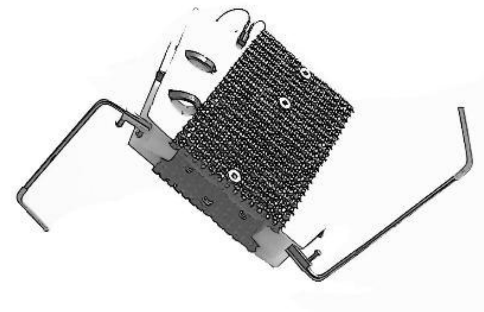
Sarah Turbot Circuit Schematic

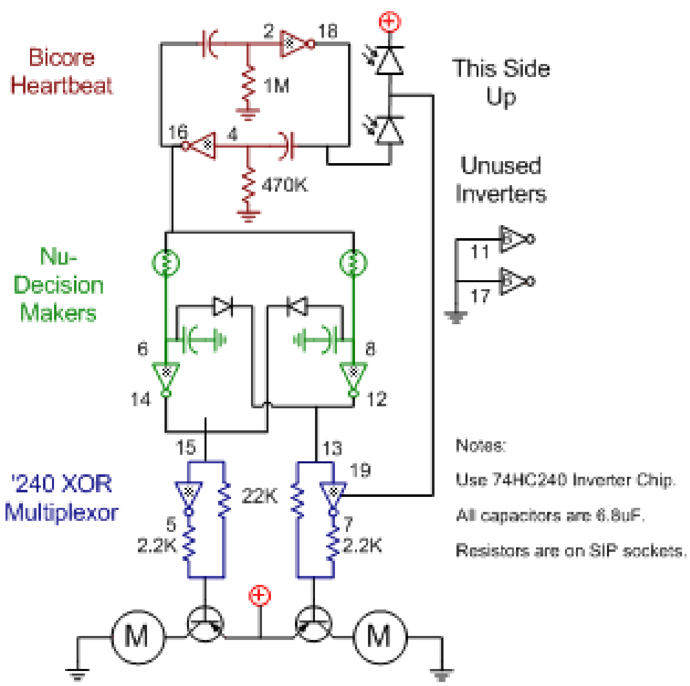


My Tumbler Nv Net



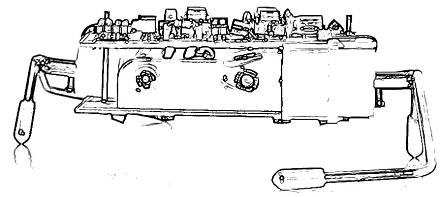
Tumbler Nervous Net: Biomorphic Map
T. Gray and J.W. Goerlich, 2004-09



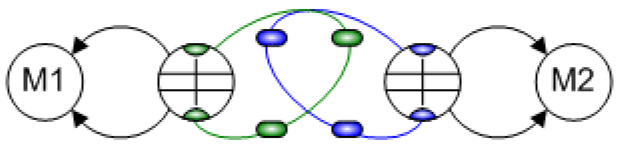


Tumbler Nervous Net – T. Gray and J.W. Goerlich, 2004-09
SERVO Magazine, "BEAM Robotics: Step by Step"

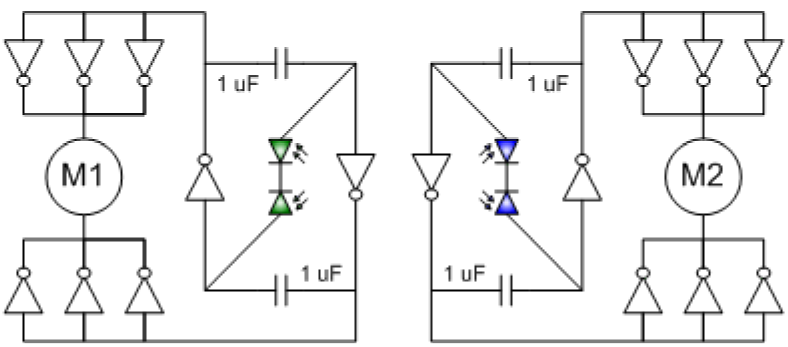
My Suspended Bicore Turbot



Suspended Bicore Turbot Biomorphic Map



Suspended Bicore Turbot Circuit Schematic



Credits

For BEAM Nervous Nets and their application to Biomorphic Robotics, we have Mark Tilden to thank.

J Wolfgang Goerlich assembled this handout for a talk given on June 10, 2006. This was at Steve Jones' BuildFest, held at Bug 'n' Bots. Unless otherwise noted, Wolfgang drafted the schematics.

Photographs of Mark Tilden's robotics come courtesy of Solarbotics. Please visit this site for photographs in color and higher resolution.

For further information, please visit the BEAM community sites and Wiki.

J Wolfgang Goerlich
jwgoerlich@gmail.com
http://jwgoerlich.solarbotics.net/

Steve Jones
stevejones@bugnbots.com
http://www.bugnbots.com/

Solarbotics
http://www.solarbotics.com/

BEAM Community
http://groups.yahoo.com/group/beam/
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