Biologically Inspired Computing: Neural Computation

GasNets

Invited Lecture

Renan C. Moioli

Lecture 6

I. GasNet models
II. Evolving Artificial Neural Networks
    I. MLPs
    II. GasNet models
III. Examples

INSTITUTO
SANTOS DUMONT
ENSINO E PESQUISA

CENTRO DE
EDUCAÇÃO CIENTÍFICA
Escola Alfredo J. Monteverde

CENTRO DE
EDUCAÇÃO CIENTÍFICA
Serrinha – BA

CEC Natal /RN

8270 students

CEC Serrinha/BA

CEC Macaíba/RN

CENTRO DE
EDUCAÇÃO CIENTÍFICA
Escola Alfredo J. Monteverde

CENTRO DE
EDUCAÇÃO CIENTÍFICA
Serrinha – BA

CENTRO DE
EDUCAÇÃO E PESQUISA EM SAÚDE
Anita Garibaldi

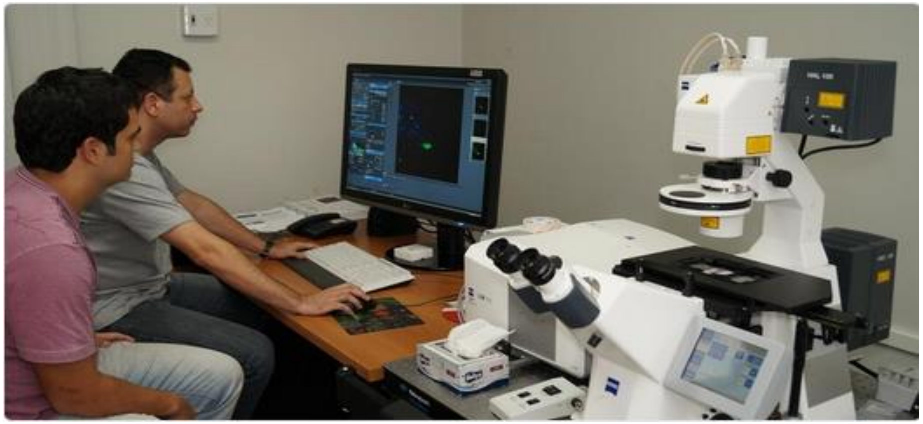
2008	3000
2009	8400
2010	12700
2011	12104
2012	13200
2013	10045
2014	13273
Total	**72722**

Macaíba = 70.000

IINELS
INSTITUTO INTERNACIONAL DE NEUROCIÊNCIA
Edmond e Lily Safra

- Molecular and cellular neurobiology
- Animal behaviour
- electrophysiology
- neuroprosthetics
- microscopy
- EEG/EMG

IINELS
INSTITUTO INTERNACIONAL DE NEUROCIÊNCIA
Edmond e Lily Safra








CAMPUS DO CÉREBRO

ESCOLA DE
ENSINO BÁSICO
Lygia Maria Rocha Laporta

100 ha
School= 14000 m² Research = 12000 m²

IINELS
INSTITUTO INTERNACIONAL DE NEUROCIÊNCIA
Edmond e Lily Safra

Behavioural Brain Research 290 (2015) 90–101

Contents lists available at ScienceDirect

Behavioural Brain Researc

journal homepage: www.elsevier.com/loc

ELSEVIER

Research report

Characterization of long-term motor deficits in the 6- Parkinson's disease in the common marmoset

M. Santana[a,d,g], T. Palmér[b,c], H. Simplício[a,e], R. Fuentes[a,f], P. Peterss

[a] Edmond and Lily Safra International Institute of Neuroscience, Santos Dumont Institute, Macaíba/RN 59280-000, Bra
[b] Integrative Neurophysiology and Neurotechnology, Neuronano Research Center, Department of Experimental Medic Medicon Village, Building 404 A2 Scheelevägen 8, 223 81 Lund, Sweden
[c] Mathematics LTH Centre for Mathematical Sciences, Faculty of Engineering, Lund University, S-22184 Lund, Sweden
[d] Psychobiology Program, Federal Univ. of Rio Grande do Norte, Natal, 59078-970, Brazil
[e] State Univ. of Rio Grande do Norte, Mossoró/RN, 59610-210, Brazil
[f] Programa de Fisiologa y Biofísica, Instituto de Ciencias Biomédicas, Facultad de Medicina, Universidad de Chile, Indep Chile
[g] Bacharelad

SCIENTIFIC REPORTS

Home | For Authors | For Referees | About Scientific Reports

Search > 2014 > January > Article

Take part in Nature Publishing Group's annual reader survey here for the chance to win a Macbook Air.

SCIENTIFIC REPORTS | ARTICLE OPEN

Chronic Spinal Cord Electri Protects Against 6-hydroxyd

Amol P. Yadav, Romulo Fuentes, Hao Zhang, Thai M. Freire & Miguel A. L. Nicolelis

Affiliations | Contributions | Corresponding auth

Scientific Reports 4, Article number: 3839 | doi:10.1(

Received 11 June 2013 | Accepted 06 January 2014

SCIENTIFIC REPORTS

Home | For Authors | For Referees | About Scientific Reports

Search > 2013 > February > Article

Take part in Nature Publishing Group's annual reader survey here for the chance to win a Macbook Air.

SCIENTIFIC REPORTS | ARTICLE OPEN

A Brain-to-Brain Interface for Real-Time Sharing of Sensorimotor Information

Miguel Pais-Vieira, Mikhail Lebedev, Carolina Kunicki, Jing Wang & Miguel A. L. Nicolelis

Affiliations | Contributions | Corresponding author

Scientific Reports 3, Article number: 1319 | doi:10.1038/srep01319

Received 20 December 2012 | Accepted 08 February 2013 | Published 28 February 2013

plos.org

PLOS | ONE

OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

Comprehensive Analysis of Tis Quality from Chronic Multielect

Marco Aurelio M. Freire, Edgard Morya, Jean Faber, Jose Koichi Sameshima, Antonio Pereira, Sidarta Ribeiro, Migue

Published: November 9, 2011 • DOI: 10.1371/journal.pone.

Please cite this article in press as: Santana et al., Spinal Cord Stimulation Alleviates Motor Deficits in a P (2014), http://dx.doi.org/10.1016/j.neuron.2014.08.061

Neuron

Report

Spinal Cord Stimulation Alleviates Mo in a Primate Model of Parkinson Disease

Maxwell B. Santana,[1,7,9] Pär Halje,[2,9] Hougelle Simplício,[1,8] Ulrike Richter,[2] Marco Aurelio M. Freire,[1] Per Petersson,[2,10] Romulo Fuentes,[1,10] and Miguel A.L. Nicolelis[1,3,4,5,6,10,*]
[1]Edmond and Lily Safra International Institute of Neuroscience of Natal, 590660 Natal, Brazil
[2]Integrative Neurophysiology and Neurotechnology, Neuronano Research Center, Department of Experimental Medical Sciences, Lund University, BMC F10, 221 84 Lund, Sweden
[3]Biomedical Engineering
[4]Center for Neuroengineering
[5]Department of Neurobiology
[6]Department of Psychology and Neuroscience
Duke University, Durham, NC 27708, USA
[7]Psychobiology, Federal University of Rio Grande do Norte, 59072 Natal, Brazil
[8]State University of Rio Grande do Norte, RN 59607-360 Mossoro, Brazil
[9]Co-first author
[10]Co-senior author
*Correspondence: nicoleli@neuro.duke.edu
http://dx.doi.org/10.1016/j.neuron.2014.08.061

INSTITUTO
SANTOS DUMONT
ENSINO E PESQUISA

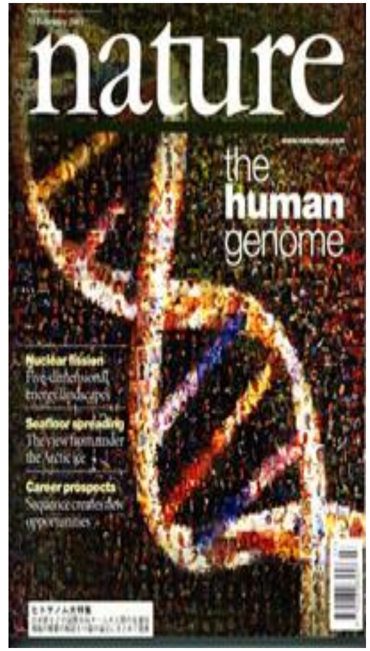
www.isd.org.br

Human Brain Project

- ~ € 3 billion
- 2013-2023
- 112 institutions
- 24 countries

BRAIN INITIATIVE
BRAIN RESEARCH THROUGH ADVANCING INNOVATIVE NEUROTECHNOLOGIES

- ~ € 4,5 billion
- 2013-2023



1988-2003

$ 3,8 billion invested

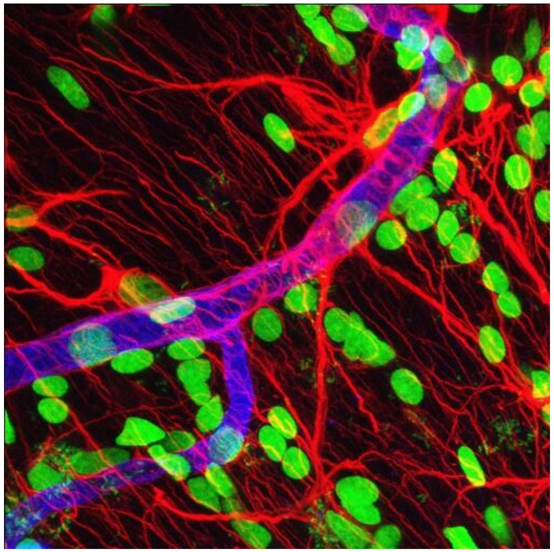
$ 796 billion income in 11 years

$141 for every $1 invested

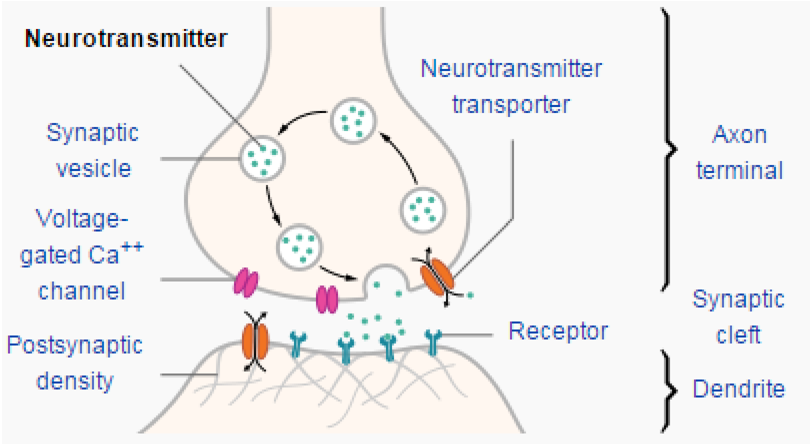
http://www.whitehouse.gov/share/brain-initiative

What's in the brain?

http://www.nicabm.com/brain-2012-new/



https://med.uth.edu/ibp/education/crb/innovative-program-technology/



wikipedia.org

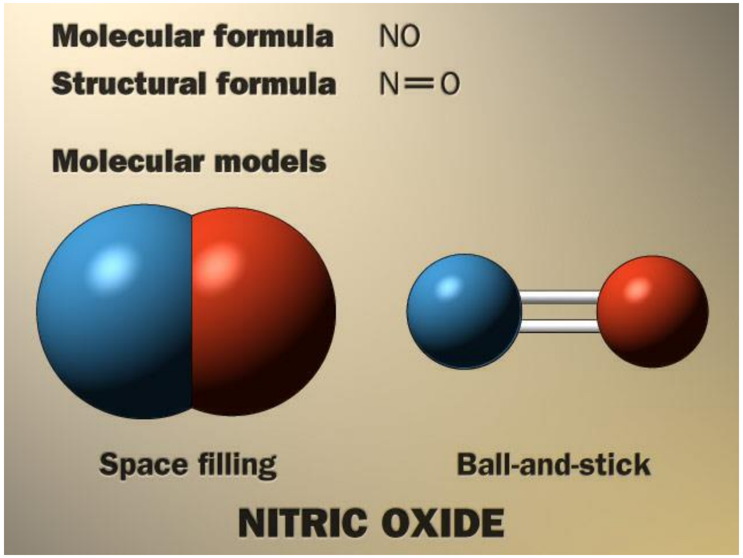
GasNets

- class of artificial neural networks (ANNs)
- incorporates an abstract model of a gaseous diffusing neuromodulator into a more standard ANN[1]

Nitric Oxide: NO

[1]Husbands, Phil, Smith, Tom, Jakobi, Nick and O'Shea, Michael (1998) *Better Living Through Chemistry: Evolving GasNets for Robot Control.* Connection Science, 10 (3-4). pp. 185-210. ISSN 09540091

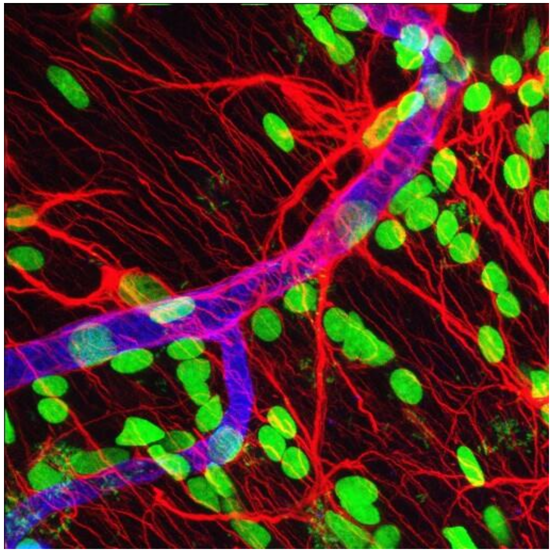
Why NO?



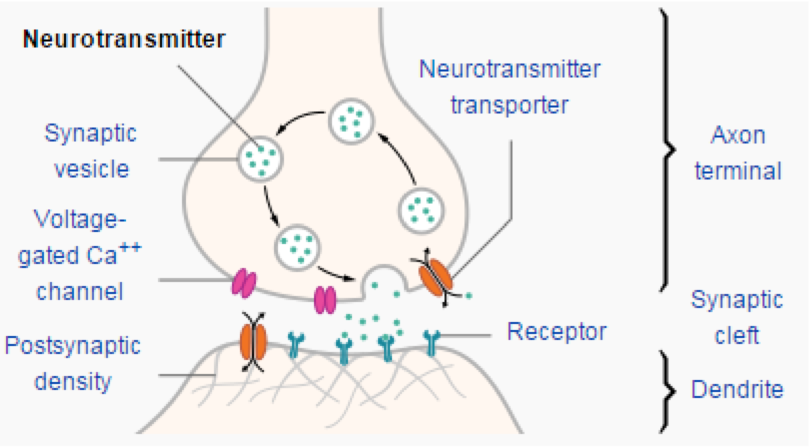
plasmavet.com

- Breakthrough of the year (1992) - *Science*
- Nobel Prize (Ignarro & Murad, 1998) *"for their discoveries concerning nitric oxide as a signalling molecule in the cardiovascular system"*
- intercellular signalling molecule in the nervous system (Garthwaite *et al.*, 1988)

Why NO?



https://med.uth.edu/ibp/education/crb/innovative-program-technology/



wikipedia.org

- very small and nonpolar molecule, capable of spreading away from a site of synthesis regardless of intervening cellular or membrane structures

- The whole surface of the neuron is a potential release site for NO

NO modulation is not necessarily confined to the immediate postsynaptic neuron:

gaseous diffusion

GasNet models

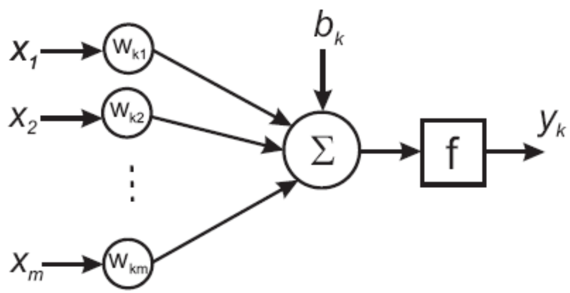
Original

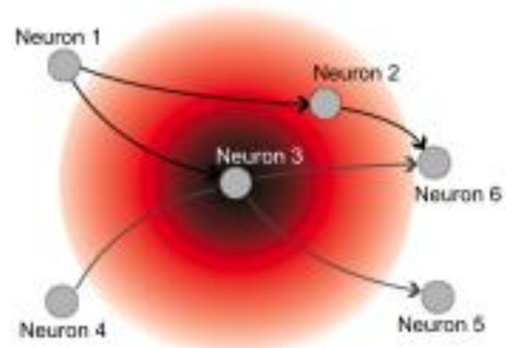
Plexus

Receptor

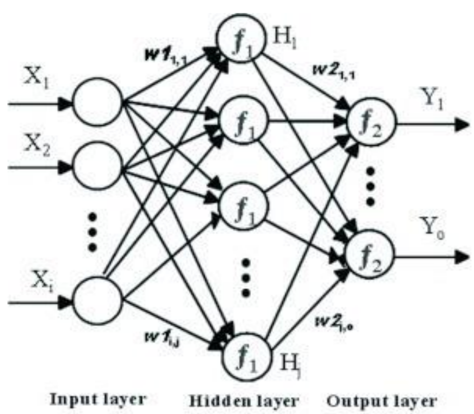
NSGasNet

Classical ANN x GasNet Models

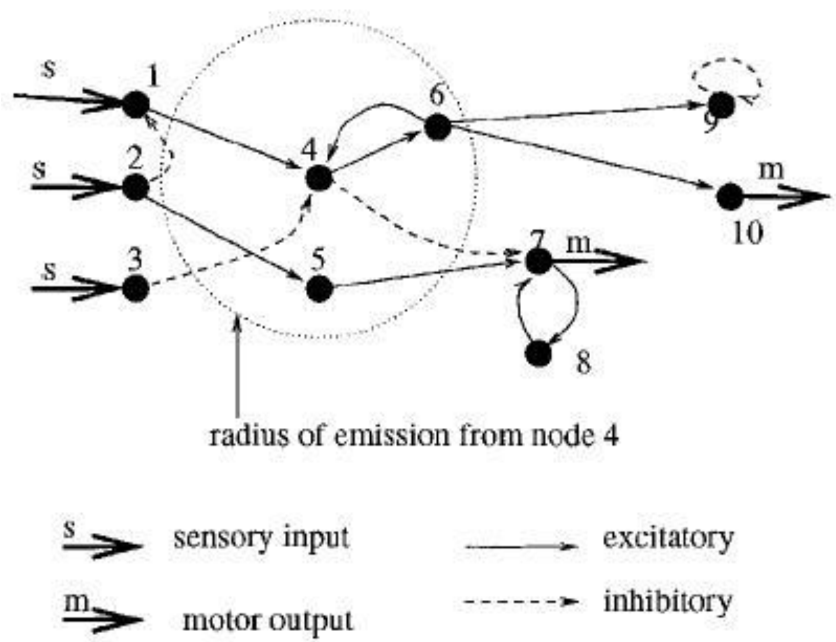




$$y_k = tanh[(\sum_{j=1}^{m} w_{kj}x_j) + b_k]$$

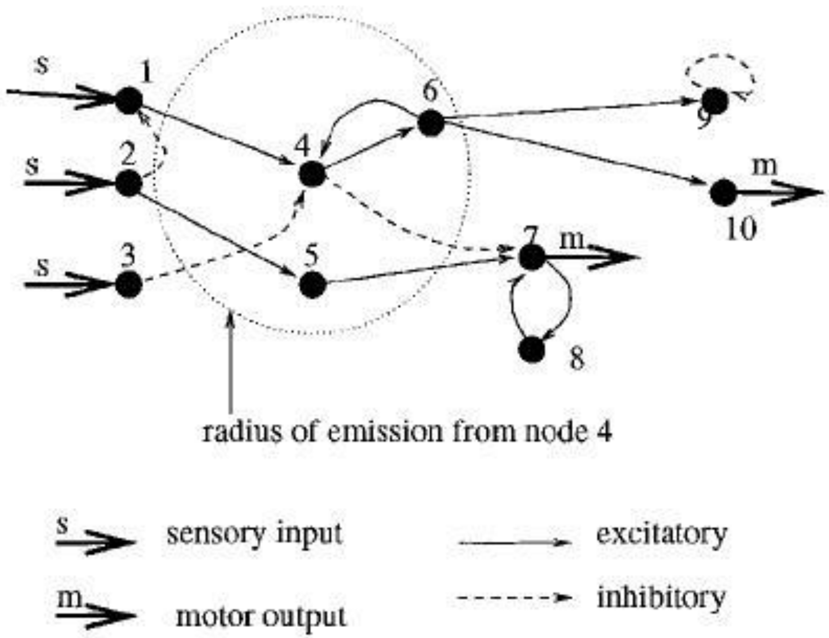


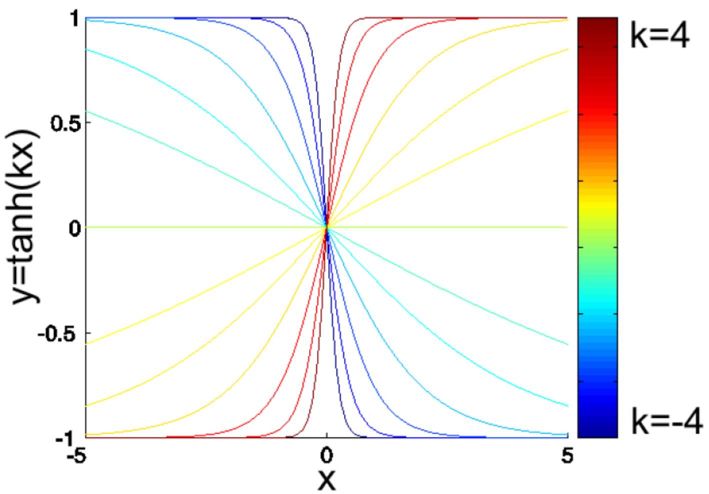
J. Insect Sci. (2010)



Original GasNet Model

$$O_i^n = \tanh\left[k_i^n\left(\sum_{j \in C_i} w_{ji} O_j^{n-1} + I_i^n\right) + b_i\right] \qquad k_i^n = k_i^0 + \alpha C_1^n - \beta C_2^n$$





Original Model

$$k_i^n = k_i^0 + \alpha C_1^n - \beta C_2^n$$

$$C(d,t) = \begin{cases} e^{-2d/r} \times T(t), d < r \\ 0, \qquad \text{else} \end{cases}$$

Original Model

$$C(d,t) = \begin{cases} e^{-2d/r} \times T(t), & d < r \\ 0, & \text{else} \end{cases}$$

$$T(t) = \begin{cases} H\left(\frac{t-t_e}{s}\right), & \text{emitting} \\ H\left[H\left(\frac{t_s-t_e}{s}\right) - H\left(\frac{t-t_s}{s}\right)\right], & \text{not emitting} \end{cases}$$

t_e : time at which emission was last turned on

t_s : time at which emission was last turned off

Original Model

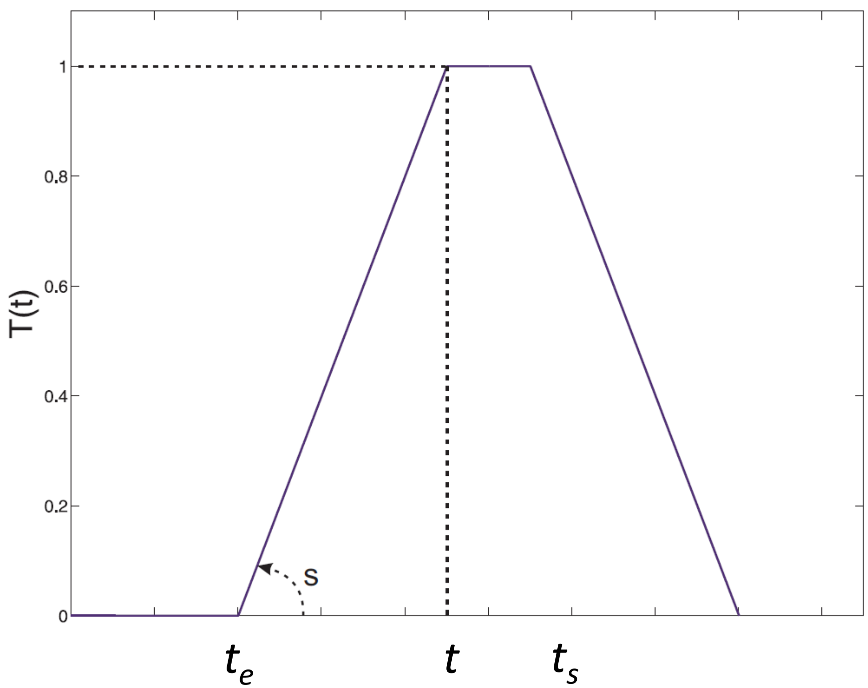
$$T(t) = \begin{cases} H\left(\frac{t-t_e}{s}\right), & \text{emitting} \\ H\left[H\left(\frac{t_s-t_e}{s}\right) - H\left(\frac{t-t_s}{s}\right)\right], & \text{not emitting} \end{cases}$$

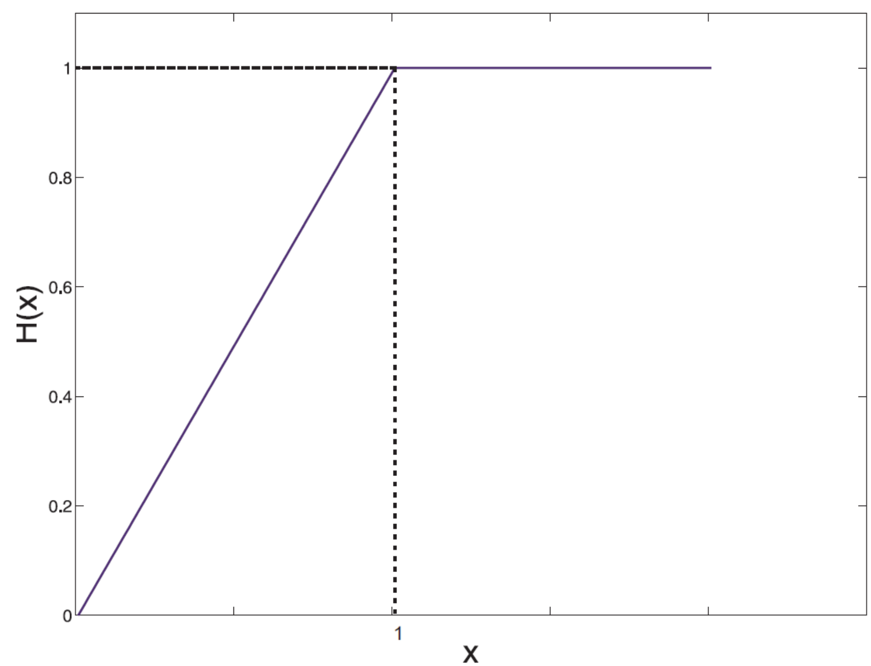
$$H(x) = \begin{cases} 0, & x \leq 0 \\ x, & 0 < x < 1 \\ 1, & \text{else} \end{cases}$$

Original Model

$$C(d,t) = \begin{cases} e^{-2d/r} \times T(t), d < r \\ 0, \qquad\qquad \text{else} \end{cases}$$

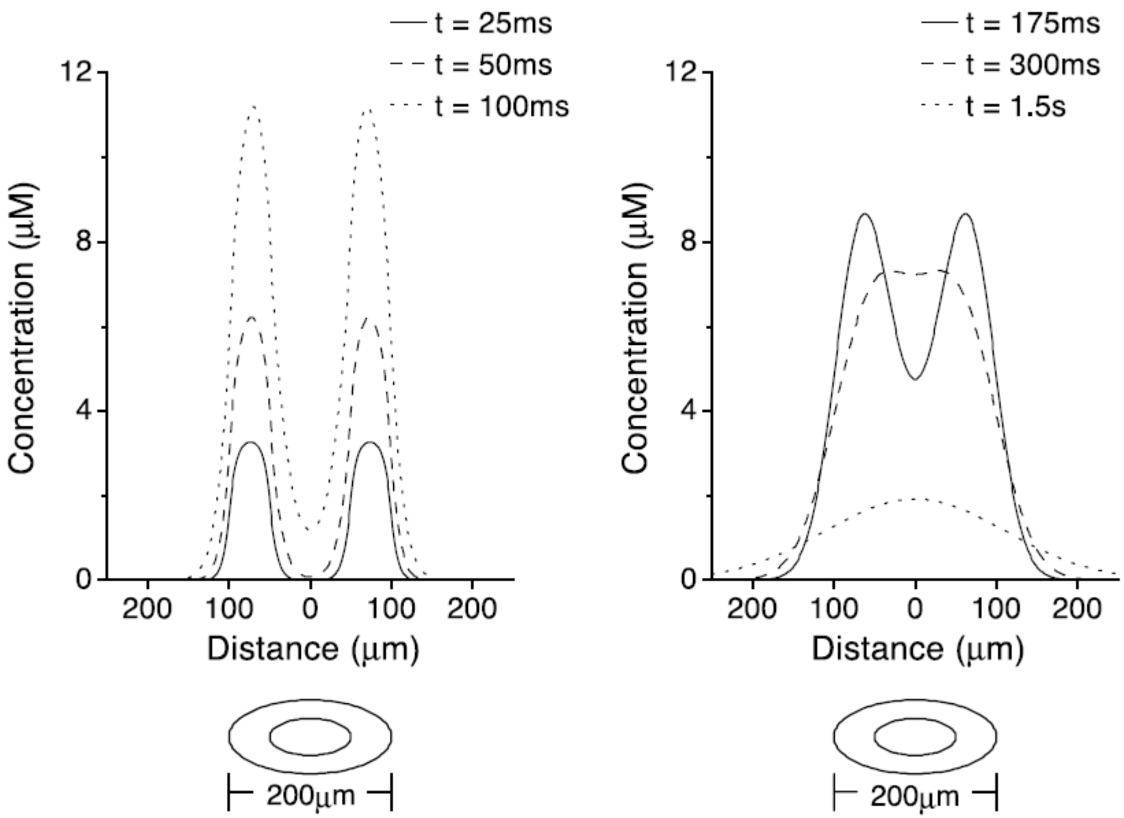
$$T(t) = \begin{cases} H\left(\frac{t-t_e}{s}\right), & \text{emitting} \\ H\left[H\left(\frac{t_s-t_e}{s}\right) - H\left(\frac{t-t_s}{s}\right)\right], & \text{not emitting} \end{cases}$$





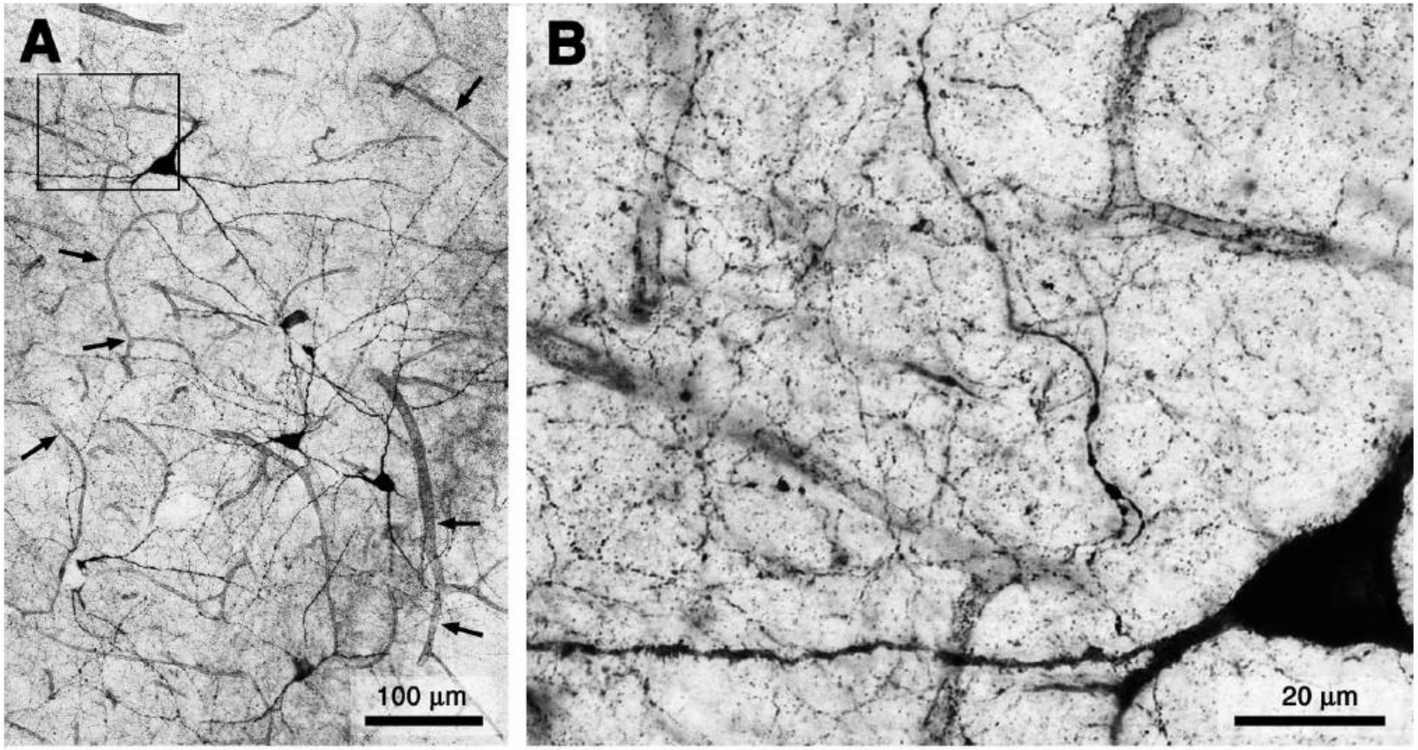
Original Model

Gas diffusion profile

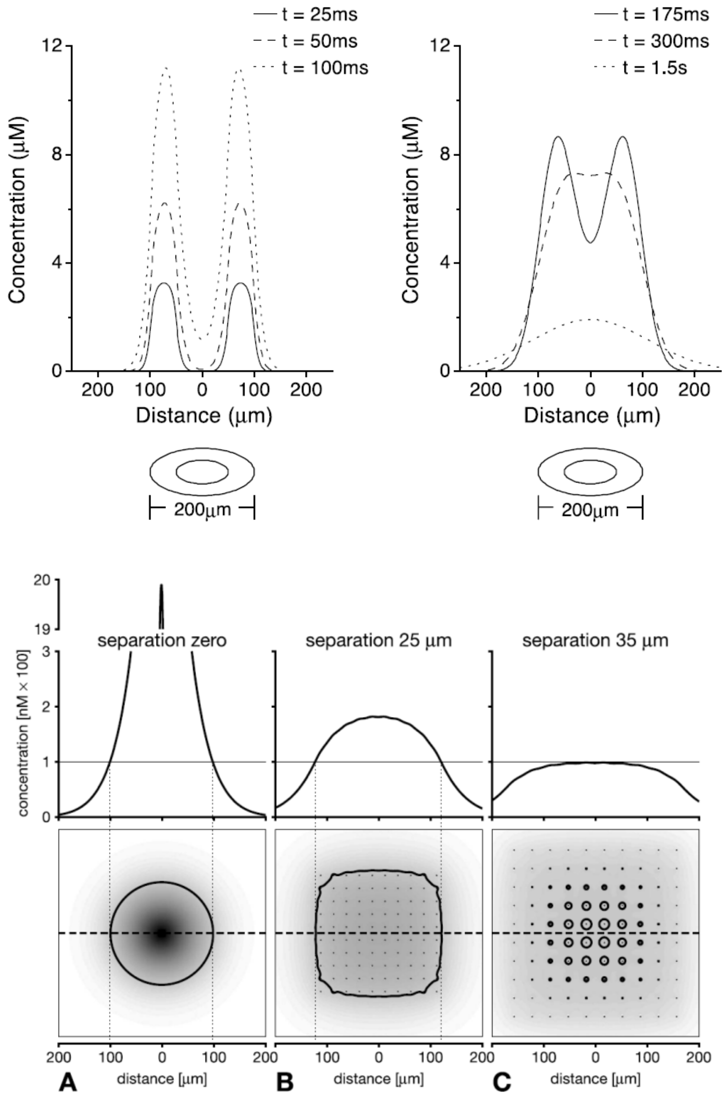


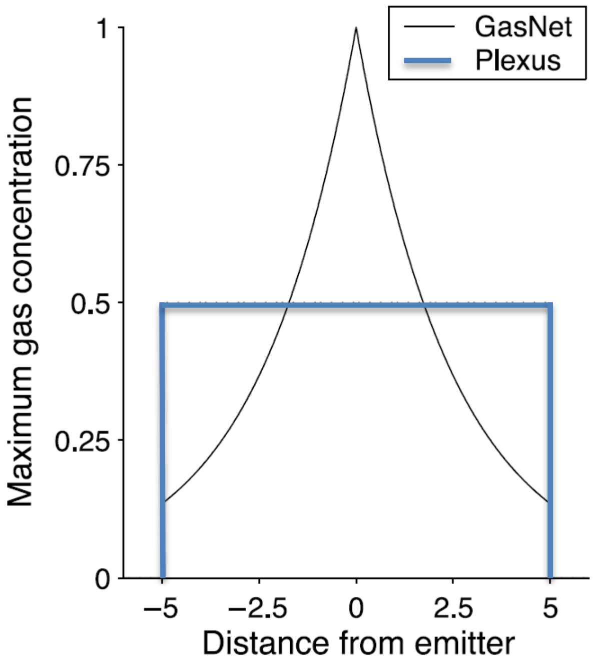
Plexus Model

Plexus: an intricate network or web-like formation



Original X Plexus





Plexus Model

Gas dispersion NOT centred on the node

$$C(d,t) = \begin{cases} e^{-2d/r} \times T(t), d < r \\ 0, \quad \text{else} \end{cases}$$

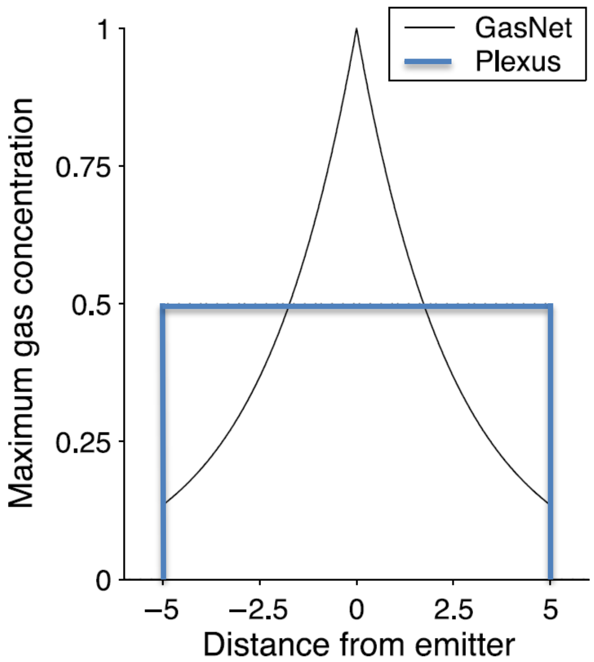
$$C(d,t) = \begin{cases} 0.5 \times T(t), d < r \\ 0, \quad \text{else} \end{cases}$$

Original

$$C(d,t) = \begin{cases} e^{-2d/r} \times T(t), d < r \\ 0, \quad \text{else} \end{cases}$$

Plexus

$$C(d,t) = \begin{cases} 0.5 \times T(t), d < r \\ 0, \quad \text{else} \end{cases}$$



Receptor Model

Site specific modulations

$$C(d,t) = \begin{cases} e^{-2d/r} \times T(t), d < r \\ 0, \qquad\qquad\qquad \text{else} \end{cases}$$

$$\Delta M_j^n = \rho_i C_i^n R_j$$

R_j: specific receptor quantity

Action of receptor1: Increase gain of node transfer function as in original GasNet.

Action of receptor2: Decrease gain of node transfer function as in original GasNet.

Action of receptor3: Increase proportion of retained node activation from last time step

Action of receptor4: If above a threshold, switch transfer function of node

NSGasNet Model

Nodes do NOT necessarily have a spatial relation

Original

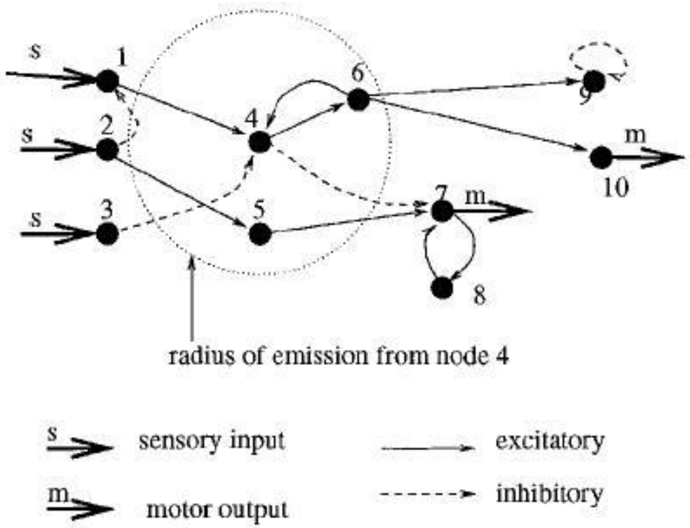
$$C(d,t) = \begin{cases} e^{-2d/r} \times T(t), d < r \\ 0, \qquad\qquad\qquad \text{else} \end{cases}$$

NSGasNet

$$C(t) = Mbias \times T(t)$$

Mbias [0,1]: Modulator bias

GasNets



$$O_i^n = \tanh\left[k_i^n\left(\sum_{j \in C_i} w_{ji} O_j^{n-1} + I_i^n\right) + b_i\right]$$

Original

$$C(d,t) = \begin{cases} e^{-2d/r} \times T(t), d < r \\ 0, \qquad \text{else} \end{cases}$$

Plexus

$$C(d,t) = \begin{cases} 0.5 \times T(t), d < r \\ 0, \qquad \text{else} \end{cases}$$

Receptor

$$\Delta M_j^n = \rho_i C_i^n R_j$$

NSGasNet

$$C(t) = Mbias \times T(t)$$

Performance Comparison

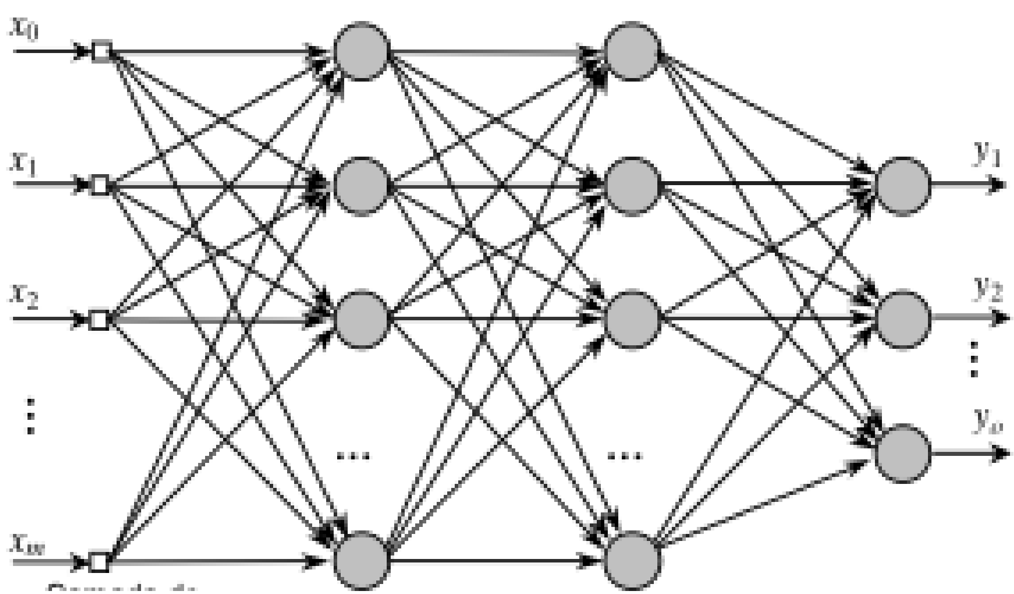
	Original	Plexus	Receptor
No. of runs	40	40	40
No. of generations			
Mean (s.d.)	3,042 (3,681)	1,579 (2,609)	82 (102)
Median	1201	512	47
Best	136	101	13
Worst	>10,000	>10,000	512

Pattern	Eleven-Seven	Eleven-Five	Ten-Four	Seven-Five
Original				
Mean/n	23310/21	15048/21	20085/20	33218/22
(Std) Median	(29123) 12200	(15343) 7600	(23924) 7350	(31001) 15500
NSGasNet				
Mean/n	11231/36	15691/34	11845/31	9252/34
(Std) Median	(18209) 3050	(22105) 6050	(16395) 4000	(15523) 3200

GasNets lead to good solutions faster!

Evolving ANNs

I. MLPs
   I. Topology and weights
   II. Example: Evolving (training) MLPs to learn some functions



Evolving ANNs

I. GasNet models

   I. Topology + all network parameters + task dependent parameters

$$< genotype >:: (< gene >)^*$$

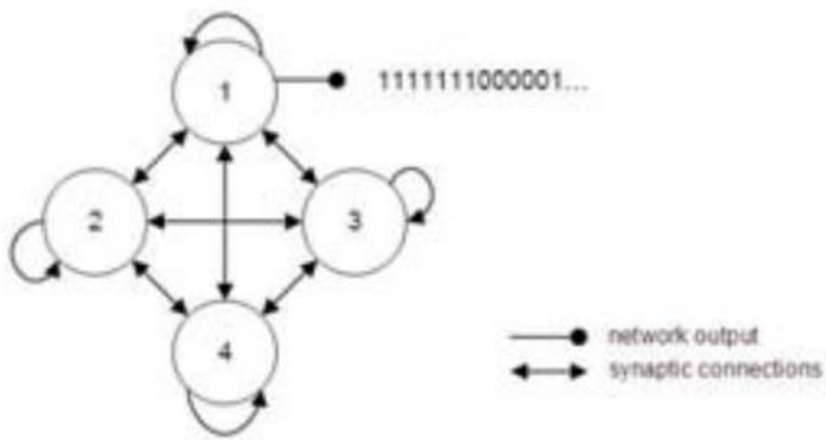
$$< gene >::< x >< y >< R_p >< \Theta_{1p} >< \Theta_{2p} >< R_n >< \Theta_{1n} >< \Theta_{2n} >< vis_{in} >< vis_r >< vis_\theta >$$
$$< vis_{thr} >< rec >< TE >< CE >< s >< R_e >< index^0 >< bias >$$

$$< 91 >< 28 >< 46 >< 73 >< 28 >< 18 >< 53 >< 22 >< 74 >< 76 >< 76 >< 84 >< 24 >$$
$$< 62 >< 16 >< 1 >< 7 >< 86 >< 38 >< 81 >< 63 >< 50 >< 87 >< 0 >< 53 >< 55 >$$
$$< 90 >< 42 >< 3 >< 18 >< 46 >< 70 >< 97 >< 72 >< 80 >< 27 >< 36 >< 95 >< 27 >$$
$$< 81 >< 36 >< 30 >< 44 >< 16 >< 35 >< 52 >< 65 >< 1 >< 47 >< 96 >< 87 >< 88 >$$

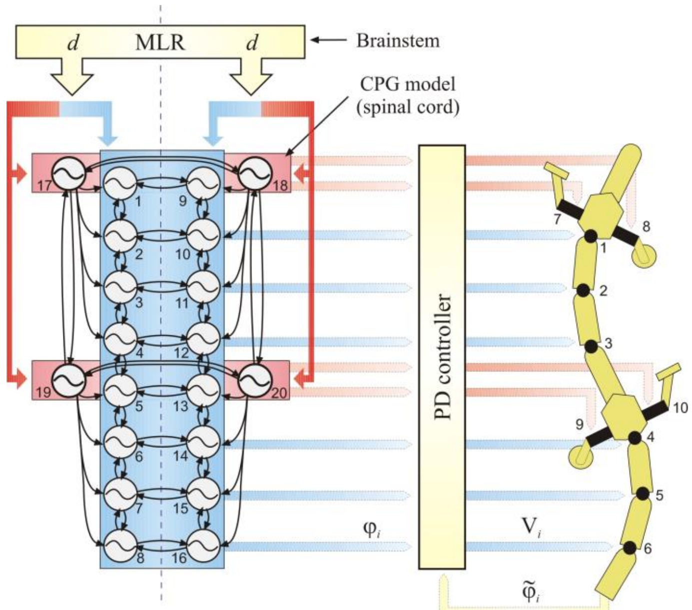
Node variables	Description	[Range]DiscreteValues	Gene locus	Description
Coordinates	Node coordinates on the Euclidean plane (100x100)	[0, 99] [0, 99]	$< x >$ $< y >$	$< x\ value >$ $< y\ value >$
Electrical connectivity	Defines the parameters of the two segments of circle centred on the node that will determine the excitatory and inhibitory links	[0, 50] [0, 2π]	$< r_p >$ $< r_p >$ $< \theta_e >$ $< \theta_e >$ $< \theta_p >$ $< \theta_p >$	$< radius >$ $< angular\ extent >$ $< orientation >$
Recurrence status	Determines whether the node has an inhibitory, none or excitatory recurrent connection	{-1,0,1}	$< rec >$	$< recurrent\ status >$
Emitting status	Determines the circumstances under which the node will emit gas {none, electrical, gas}	{0,1,2}	$< E_s >$	$< emitting\ status >$
Type of gas	Determines which gas the node will emit	{1, 2}	$< G_t >$	$< gas\ type >$
Rate of build up/ decay	Determines the rate of gas build up and decay	[1, 11]	$< s >$	$< build\ up/$ $decay\ rate >$
Radius of emission	Maximum radius of gas emission	[10%,60%]* * of plane dimension 100x100	$< G_r >$	$< gas\ radius >$
Transfer function parameter default value K_i^0	Used in (2) to determine the transfer parameter value K_i^n	[1, 11]	$< K^0 >$	$< transfer\ function$ $default\ value >$
Bias	The b_i term ? on 1	[−1.0, 1.0]	$< b >$	$< bias\ value >$
Task parameters	Parameters which depend on the task, e.g. a robot vision sensors input area ([1])	?	$<? >$	?

Example 1: Central Pattern Generators

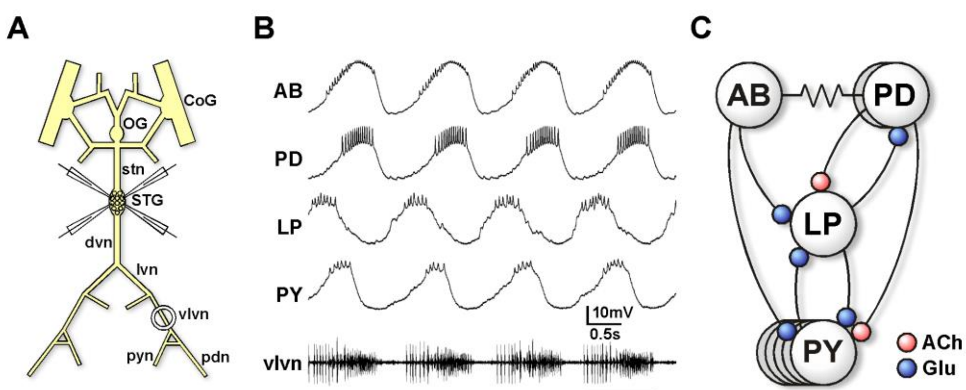
Ten:Four	Eleven:Five	Eleven:Seven	Seven:Five
1111111111:0000	11111111111:00000	11111111111:0000000	1111111:00000



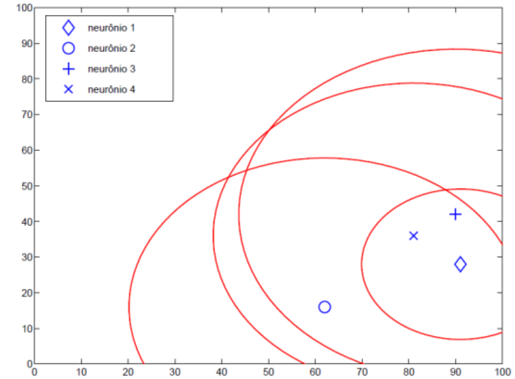
Pattern	Eleven-Seven	Eleven-Five	Ten-Four	Seven-Five
Original				
Mean/n	23310/21	15048/21	20085/20	33218/22
(Std) Median	(29123) 12200	(15343) 7600	(23924) 7350	(31001) 15500
NSGasNet				
Mean/n	11231/36	15691/34	11845/31	9252/34
(Std) Median	(18209) 3050	(22105) 6050	(16395) 4000	(15523) 3200

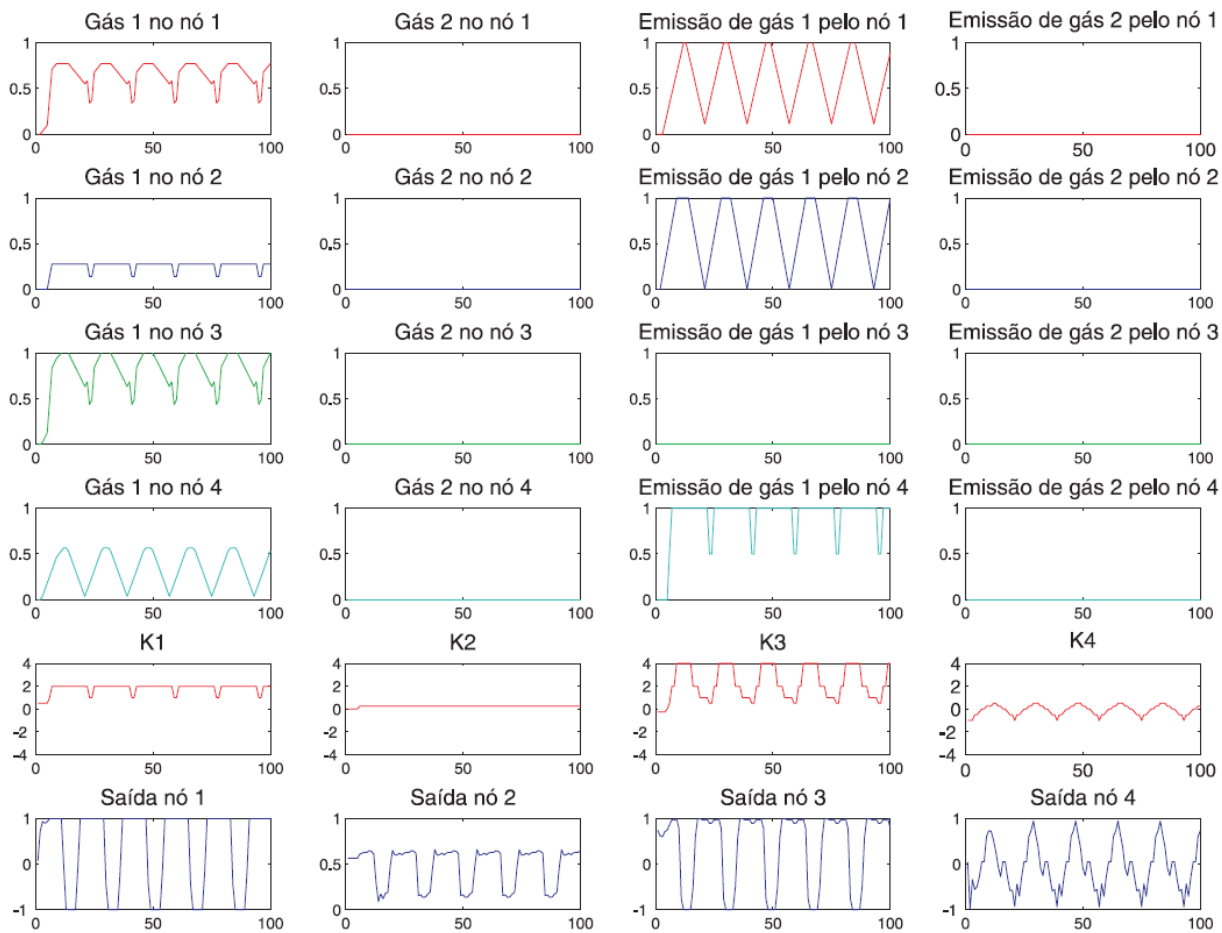


http://biorob.epfl.ch/salamandra

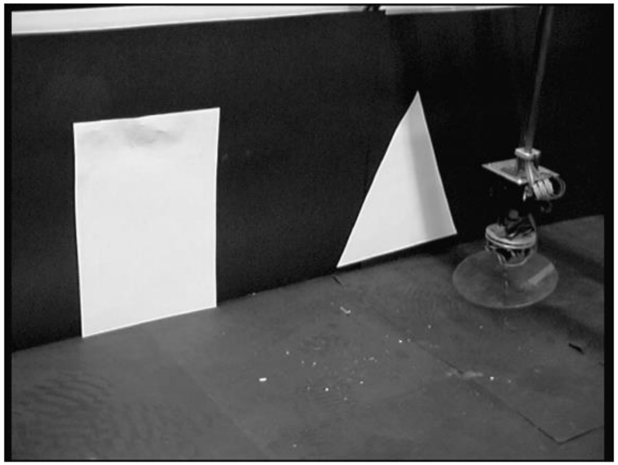


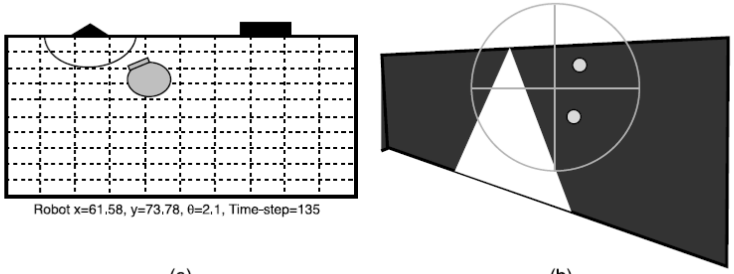
https://blogs.brandeis.edu/marderlab/research/


neurônio 1
neurônio 2
neurônio 3
neurônio 4


Gás 1 no nó 1
Gás 2 no nó 1
Emissão de gás 1 pelo nó 1
Emissão de gás 2 pelo nó 1
Gás 1 no nó 2
Gás 2 no nó 2
Emissão de gás 1 pelo nó 2
Emissão de gás 2 pelo nó 2
Gás 1 no nó 3
Gás 2 no nó 3
Emissão de gás 1 pelo nó 3
Emissão de gás 2 pelo nó 3
Gás 1 no nó 4
Gás 2 no nó 4
Emissão de gás 1 pelo nó 4
Emissão de gás 2 pelo nó 4
K1
K2
K3
K4
Saída nó 1
Saída nó 2
Saída nó 3
Saída nó 4

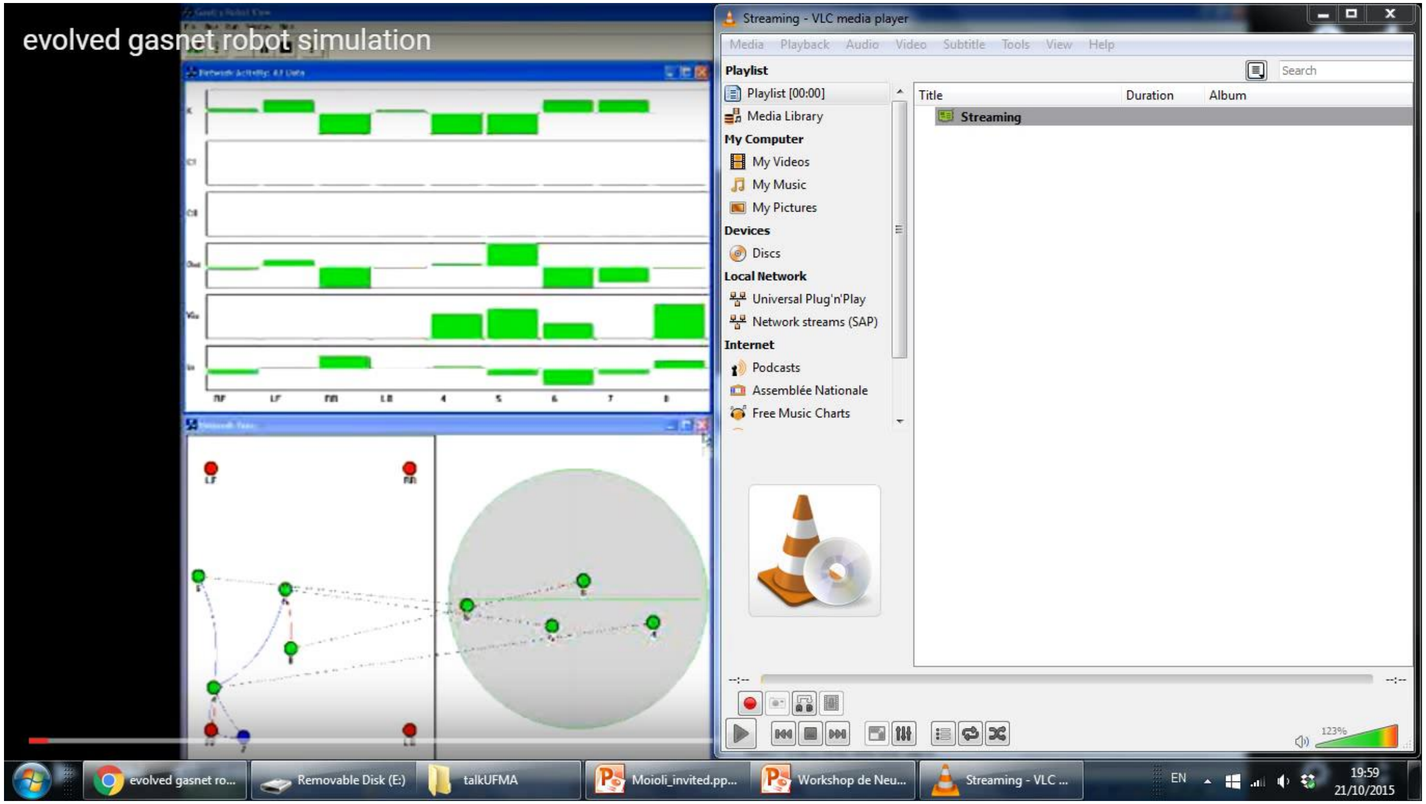
Example 2: Robotic Control

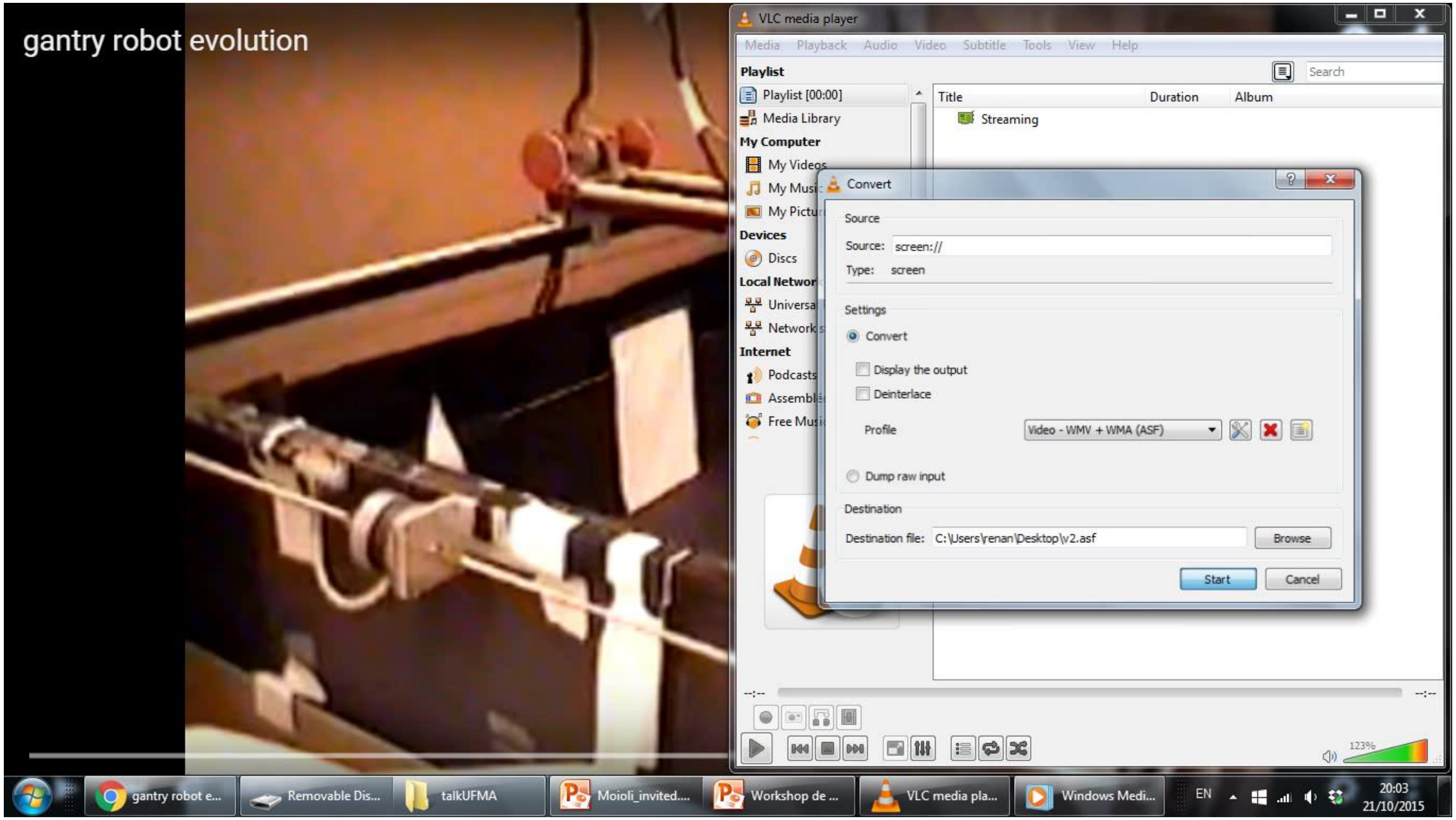




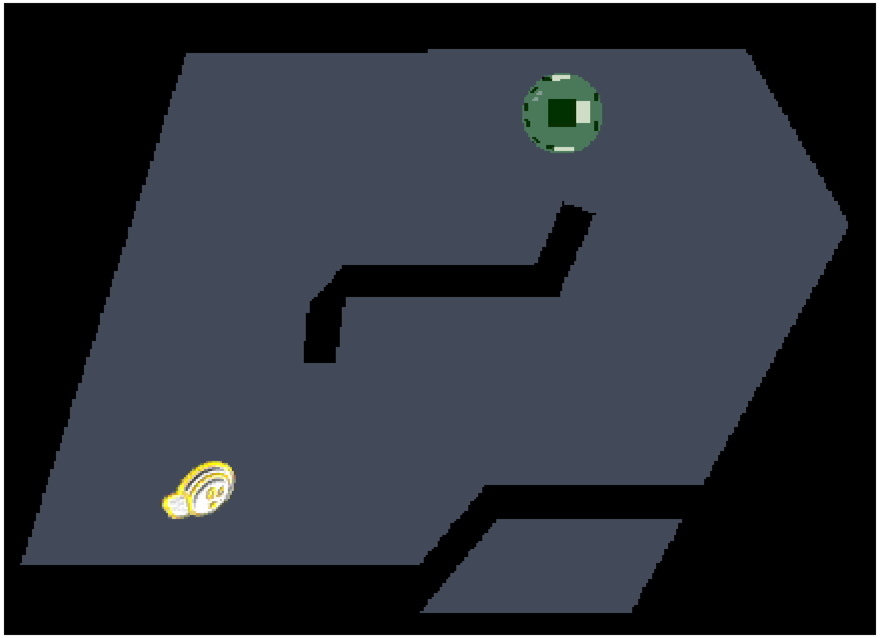
(a) (b)

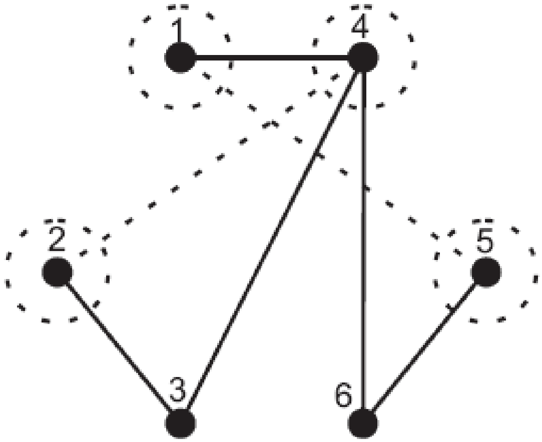
Run	Segs. w. gas	Segs. w/out gas	Points w. gas	Points w/out gas
1	300	1000	200	900
2	300	1000	400	1000
3	350	2000	450	1500
4	500	2400	500	2000
5	600	2800	700	2000
6	1500	3200	950	6000
7	1600	3300	1000	10000
8	2000	3950	1400	10000
9	2800	6400	1800	10000
10	3100	7000	2300	10000
Mean	1305	3305	970	5340
SD	1062	2029	677	4254
Median	1050	3000	825	4000
Best	300	1000	200	900
Worst	3100	7000	2300	10000

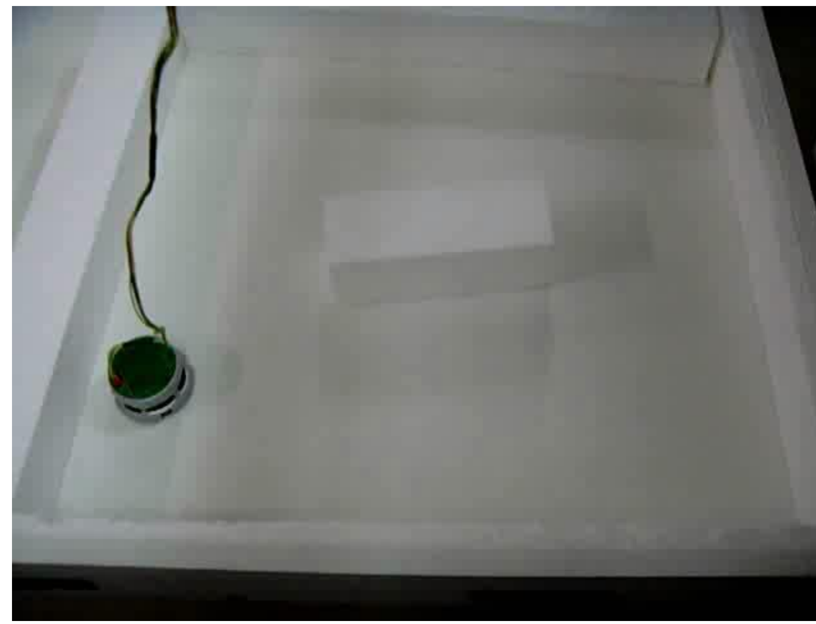

evolved gasnet robot simulation
Streaming - VLC media player
Media Playback Audio Video Subtitle Tools View Help
Playlist
Playlist [00:00]
Media Library
My Computer
My Videos
My Music
My Pictures
Devices
Discs
Local Network
Universal Plug'n'Play
Network streams (SAP)
Internet
Podcasts
Assemblée Nationale
Free Music Charts
Title
Duration
Album
Streaming
evolved gasnet ro...
Removable Disk (E:)
talkUFMA
Moioli_invited.pp...
Workshop de Neu...
Streaming - VLC ...
19:59
21/10/2015

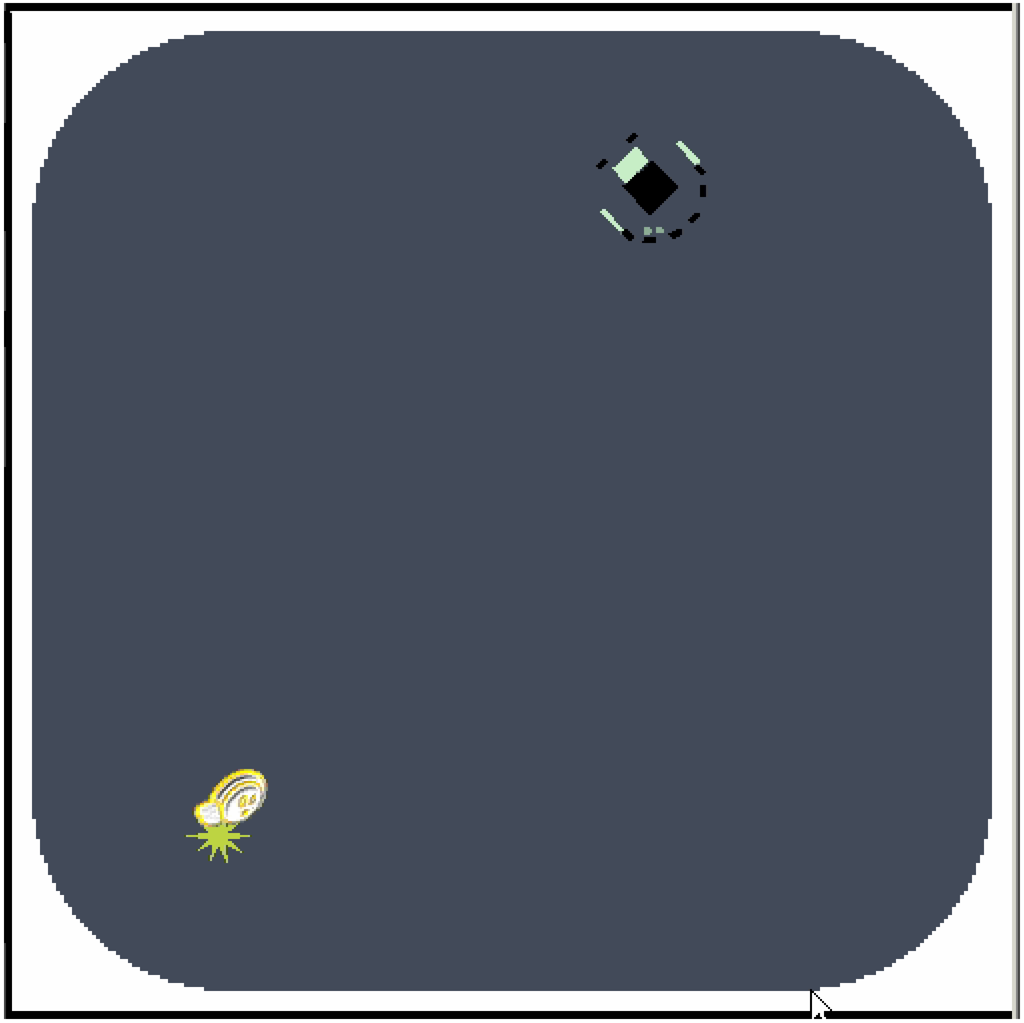

gantry robot evolution
VLC media player
Media Playback Audio Video Subtitle Tools View Help
Playlist
Playlist [00:00]
Media Library
My Computer
Devices
Discs
Internet
Title Duration Album
Streaming
Convert
Source
Source: screen://
Type: screen
Settings
Convert
Display the output
Deinterlace
Profile
Video - WMV + WMA (ASF)
Dump raw input
Destination
Destination file: C:\Users\renan\Desktop\v2.asf
Browse
Start
Cancel
20:03
21/10/2015

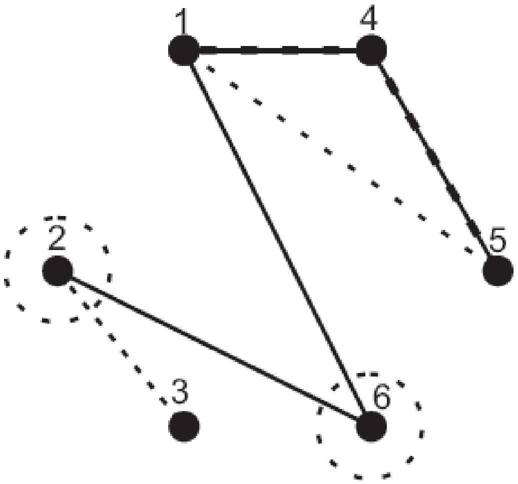
Example 3: Homeostasis and Robotics

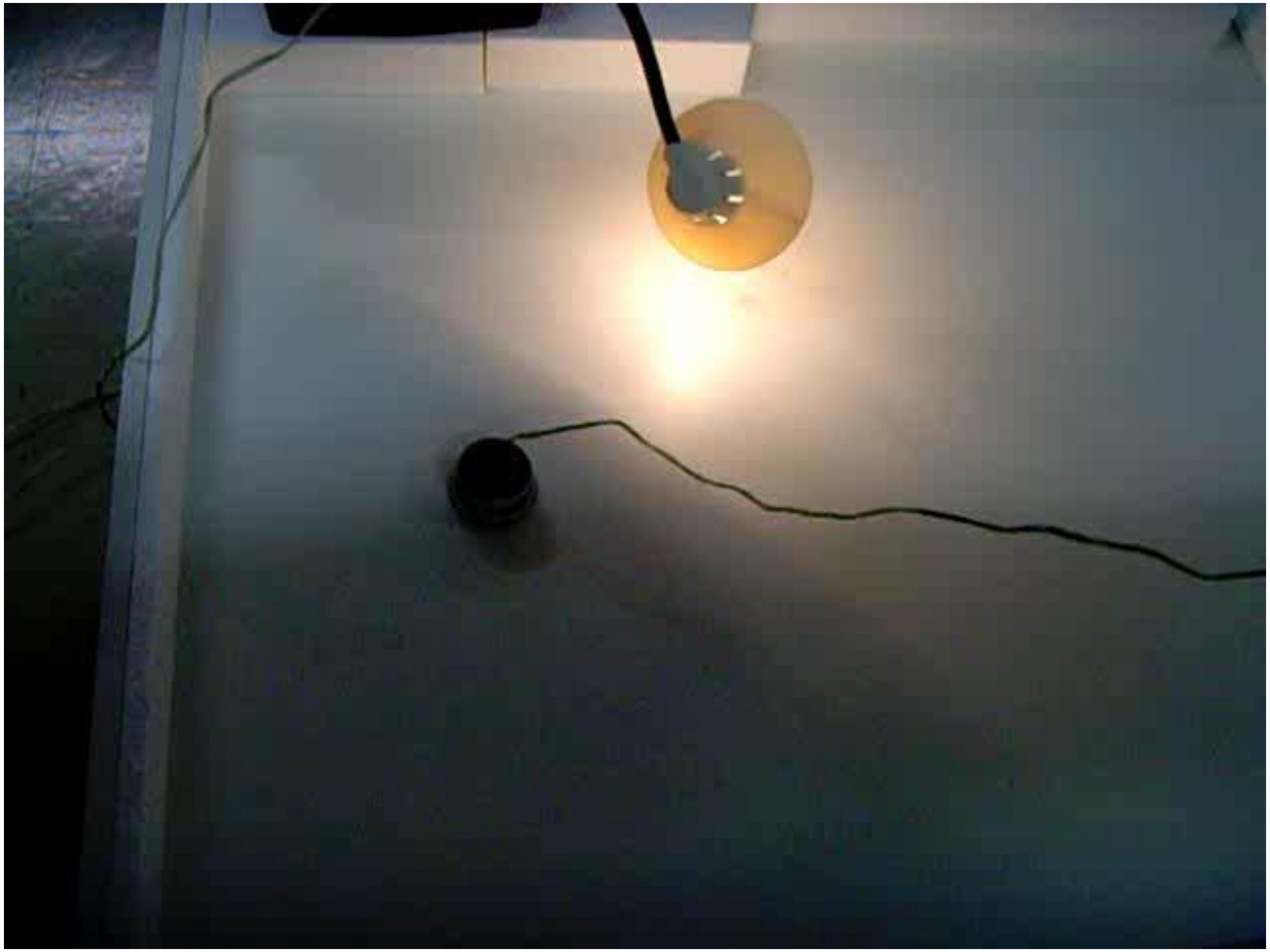


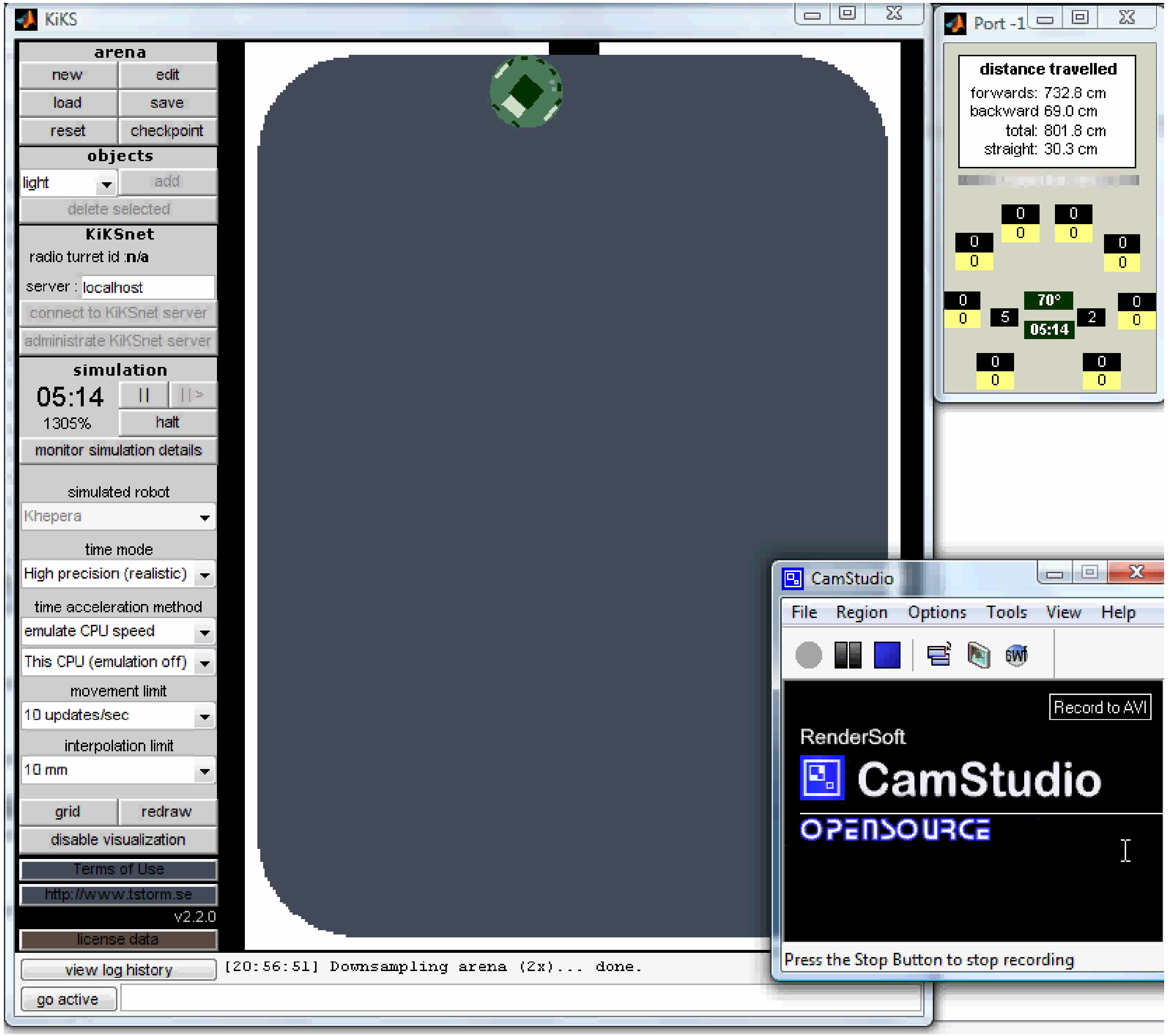


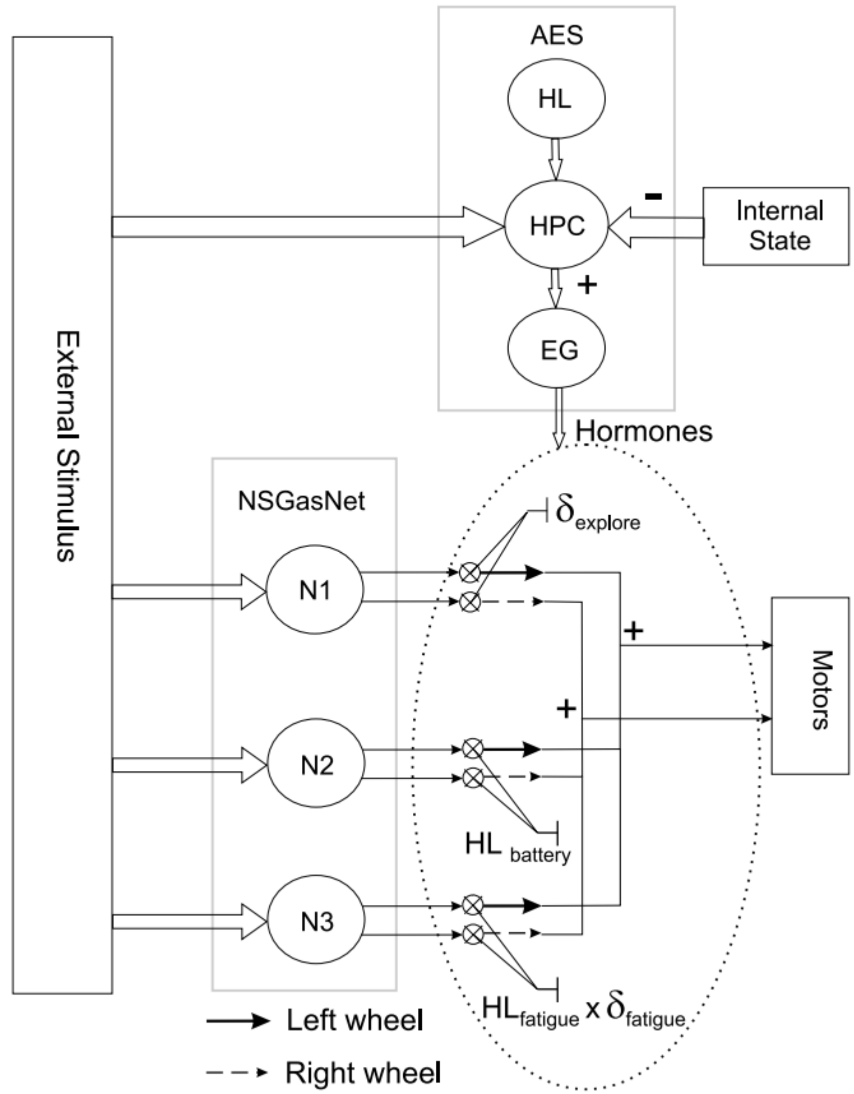


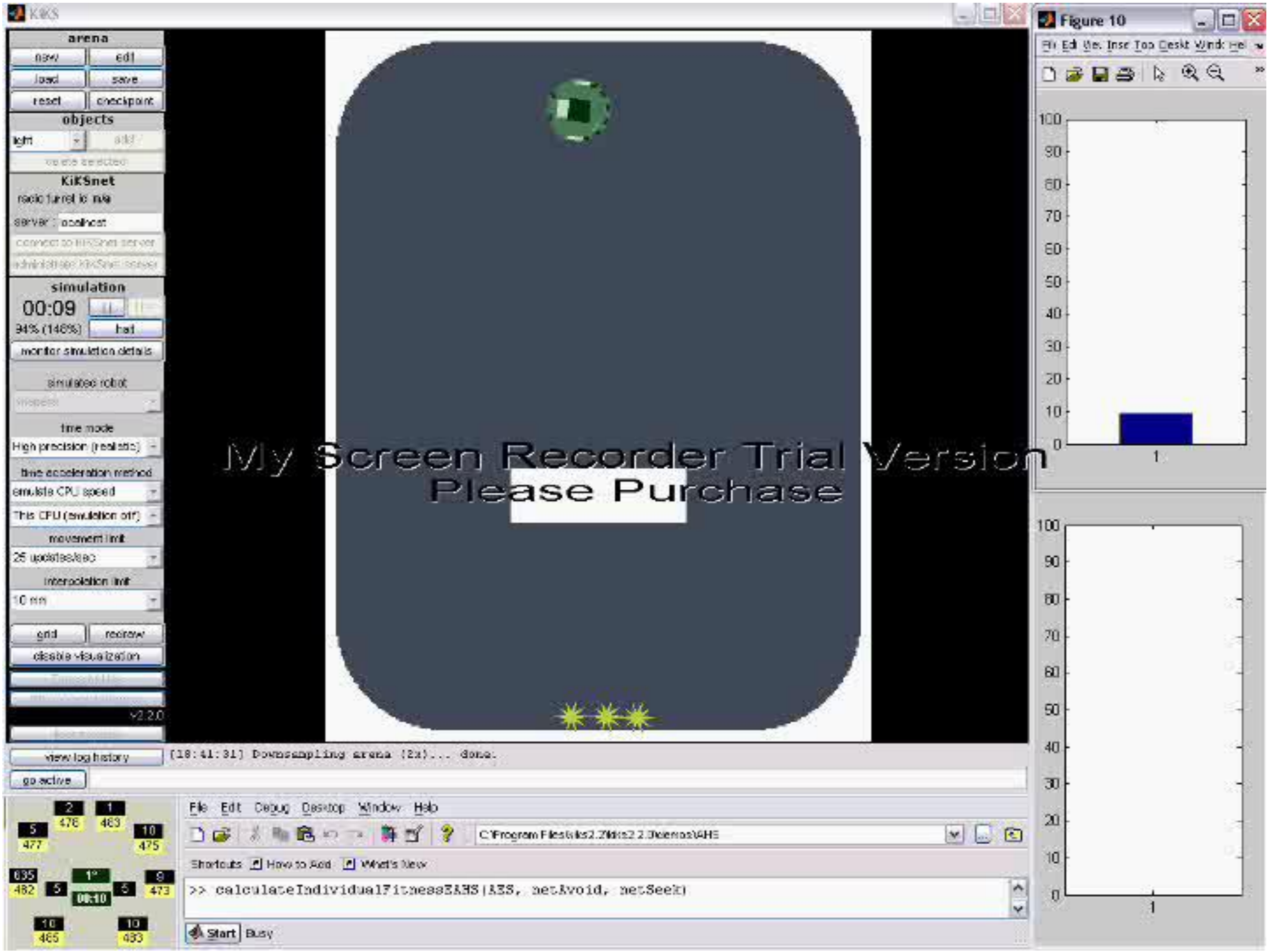


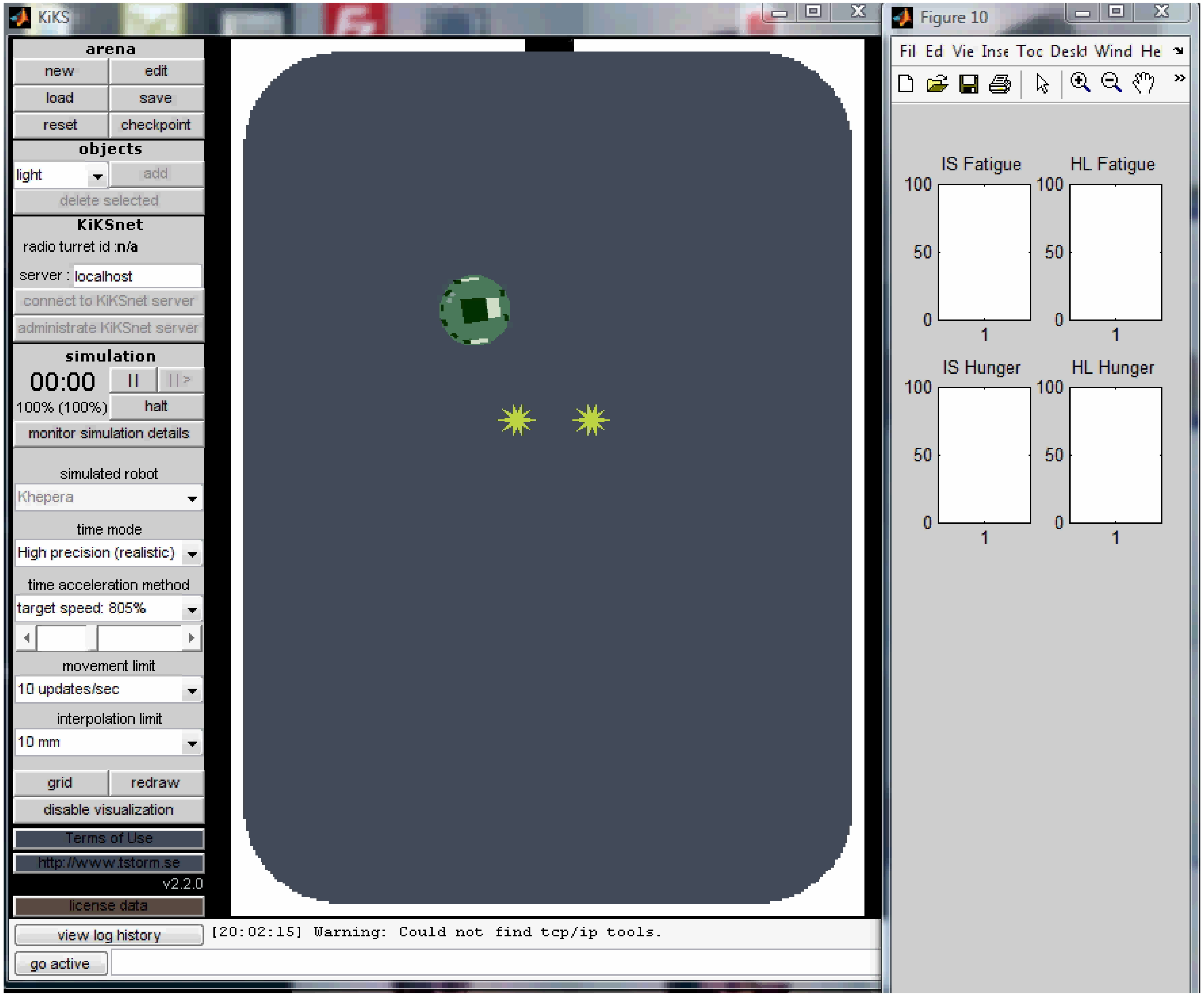

1
4
2
5
3
6




KiKS
arena
new
edit
load
save
reset
checkpoint
objects
light
add
delete selected
KiKSnet
radio turret id :n/a
server : localhost
connect to KiKSnet server
administrate KiKSnet server
simulation
05:14
1305%
halt
monitor simulation details
simulated robot
Khepera
time mode
High precision (realistic)
time acceleration method
emulate CPU speed
This CPU (emulation off)
movement limit
10 updates/sec
interpolation limit
10 mm
grid
redraw
disable visualization
Terms of Use
http://www.tstorm.se
v2.2.0
license data
view log history
go active
[20:56:51] Downsampling arena (2x)... done.
Port -1
distance travelled
forwards: 732.8 cm
backward 69.0 cm
total: 801.8 cm
straight: 30.3 cm
70°
05:14
CamStudio
File
Region
Options
Tools
View
Help
Record to AVI
RenderSoft
CamStudio
OPENSOURCE
Press the Stop Button to stop recording

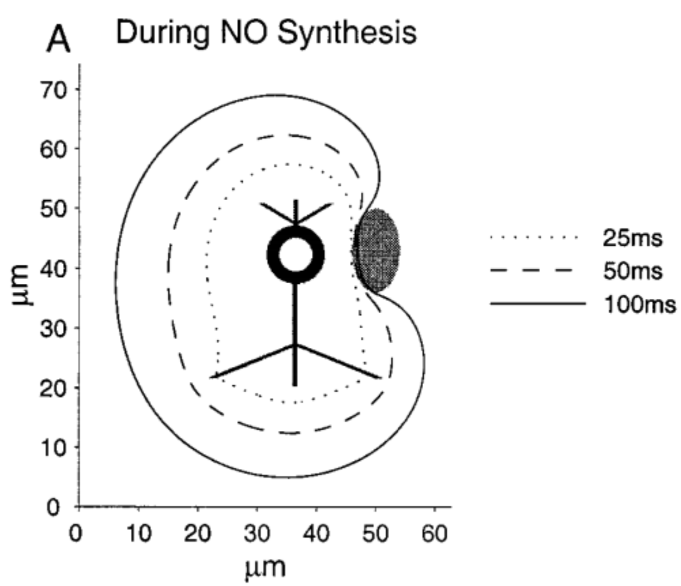

AES
HL
HPC
EG
-
+
Internal State
External Stimulus
Hormones
NSGasNet
N1
N2
N3
$\delta_{explore}$
+
+
Motors
HL battery
$HL_{fatigue} \times \delta_{fatigue}$
Left wheel
Right wheel

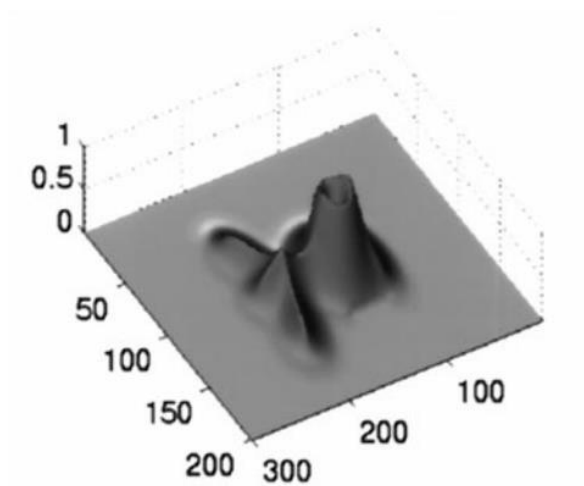

KiKS
arena
new
edit
load
save
reset
checkpoint
objects
KiKSnet
simulation
00:09
monitor simulation details
simulated robot
time mode
High precision (realistic)
time acceleration method
emulate CPU speed
movement limit
25 updates/sec
interpolation limit
10 mm
grid
redraw
disable visualization
v2.2.0
view log history
go active
My Screen Recorder Trial Version
Please Purchase
File Edit Debug Desktop Window Help
Shortcuts How to Add What's New
>> calculateIndividualFitnessZAHS(AZS, netAvoid, netSeek)
Start Busy
Figure 10


KiKS
arena
new
edit
load
save
reset
checkpoint
objects
light
add
delete selected
KiKSnet
radio turret id :n/a
server : localhost
connect to KiKSnet server
administrate KiKSnet server
simulation
00:00
100% (100%)
halt
monitor simulation details
simulated robot
Khepera
time mode
High precision (realistic)
time acceleration method
target speed: 805%
movement limit
10 updates/sec
interpolation limit
10 mm
grid
redraw
disable visualization
Terms of Use
http://www.tstorm.se
v2.2.0
license data
view log history
[20:02:15] Warning: Could not find tcp/ip tools.
go active
Figure 10
IS Fatigue
HL Fatigue
IS Hunger
HL Hunger

GasNets: final remarks

- Although NO-producing neurons account for only about 1% of cell bodies in the cerebral cortex, their processes spread so extensively that almost every neuron in the cortex is exposed to these small fibers
- Such structures are common across a range of species
- Flexible couplings => emergent dynamic properties





References

Husbands,P., Smith, T., Jakobi, N. and O'Shea, M. (1998). "Better living through chemistry: Evolving GasNets for robot control," Connection Science, vol. 10(3-4), pp. 185–210, 1998.

Philippides, P. Husbands, T. Smith, and M. O'Shea (1999) "Flexible couplings: Diffusing neuromodulators and adaptive robotics," Artificial Life, vol. 11, pp. 139–160, 2005.ciples and individual variability," Journal of Computational Neuroscience, vol. 7, pp. 119–147.

A Philippides, P Husbands, M O'Shea (2000) "Four-dimensional neuronal signaling by nitric oxide: A computational analysis", The Journal of Neuroscience 20 (3), 1199-1207

Smith, T. M. S. (2002). "The Evolvability of Artificial Neural Net- works for Robot Control". University of Sussex, Brighton, England, UK, 2002, PhD thesis.

Vargas, P.A., Di Paolo, E. A. & Husbands, P. (2007). "Preliminary Investigations on the Evolvability of a Non-spatial GasNet Model". In Proceedings of the 9th European Conference on Artificial life, ECAL'2007, Springer-Verlag, Lisbon, Portugal, September 2007, pp: 966-975.

Vargas, P.A., Di Paolo, E. A., & Husbands, P. (2008). "A study of GasNet spatial embedding in a delayed-response task". In the Proc. of ALIFE-XI'2008, England, UK, pp:640-647.

Moioli, R.C., **Vargas**, P. A., Von Zuben, F. J., Husbands, P. (2008) "Evolving an Artificial Homeostatic System". G. Zaverucha and A. Loureiro da Costa (Eds.): 19th Brazilian Symposium on Artificial Intelligence, LNAI 5249, Springer-Verlag Berlin Heidelberg

Moioli, R.C., **Vargas**, P. A., Von Zuben, F. J., Husbands, P. (2008) "Towards the evolution of an artificial homeostatic system". 2008 IEEE Congress on Evolutionary Computation, pages 4024–4031.

Moioli, R.C., **Vargas**, P. A., Husbands, P. A. (2009) " multiple hormone approach to the homeostatic control of conflicting behaviours in an autonomous mobile robot" IEEE Congress on Evolutionary Computation, 47-54

Vargas, P. A., Moioli, R.C., Von Zuben, F. J., Husbands, P. (2009) "Homeostasis and evolution together dealing with novelties and managing disruptions", International Journal of Intelligent Computing and Cybernetics 2 (3), 435-454

Husbands, P., Philippides, A., **Vargas**, P. A., Buckley, C, Fine, P., Di Paolo, E. & O'Shea, M. (2011). "Spatial, Temporal and Modulatory Factors affecting GasNet Evolvability", Complexity 16(2):35-44, Wiley Periodicals, Inc. (invited paper).

IIN-ELS
+55(84) 3271-1500
Rodovia RN 160, 3001
Distrito Jundiaí 59280-000
Macaíba – RN
www.institutosantosdumont.org.br

Renan Cipriano Moioli
moioli@isd.org.br