Computational Diagnostics
& Biocybernetics Unit

Neuro Signal Analysis and Modeling

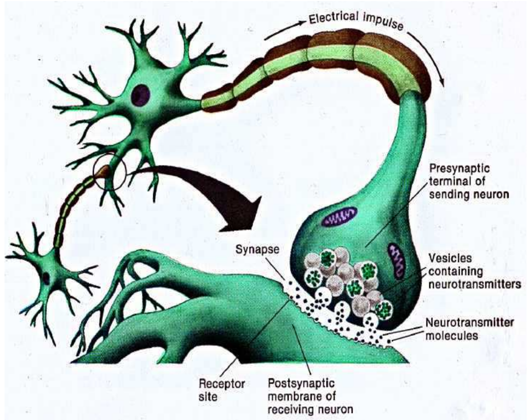
BMT922

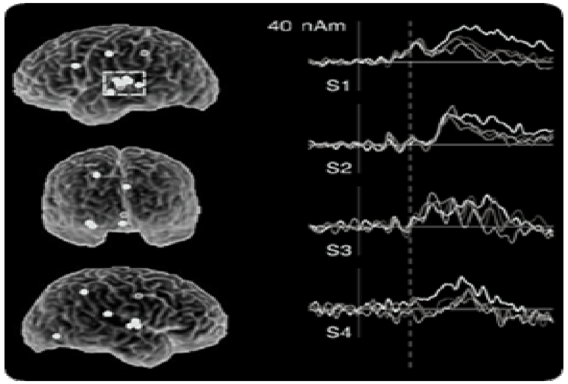
Instructor:

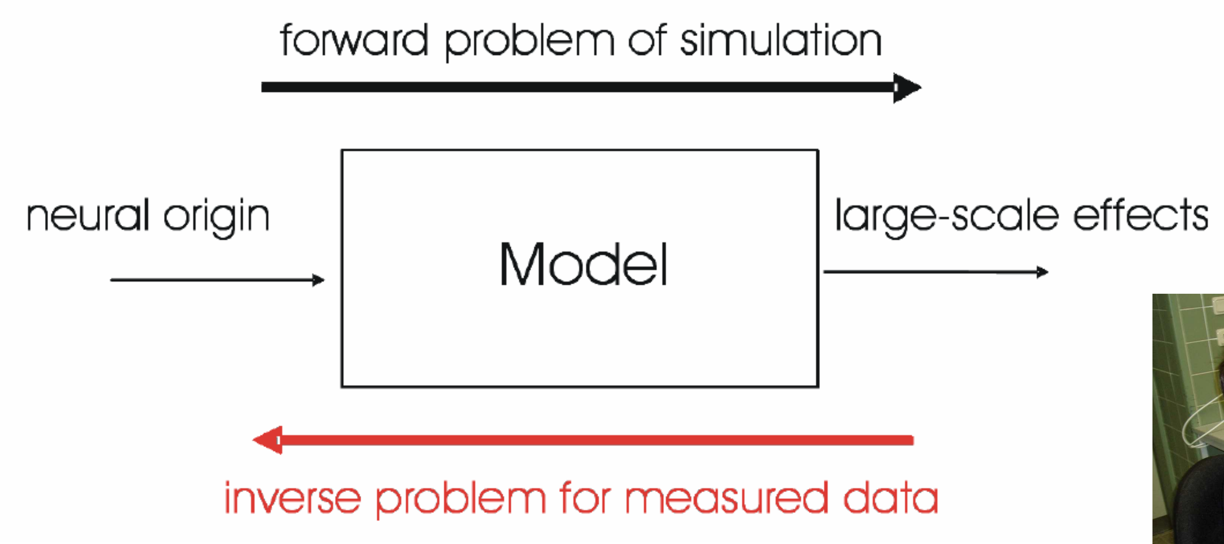
Carlos Trenado

**Saarland University, Saarland University Hospital,
and Saarland University of Applied Sciences, Germany**

Introductory Remarks

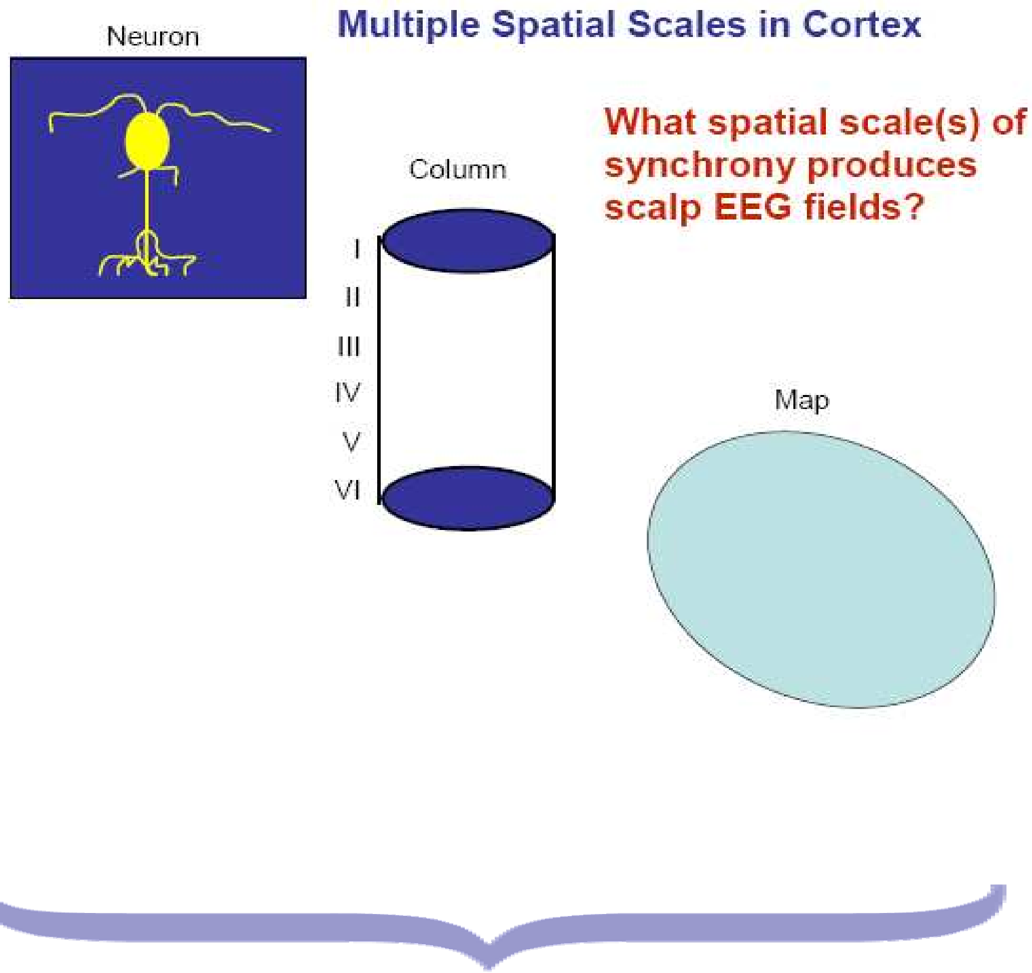






Large Scale Neural Correlates

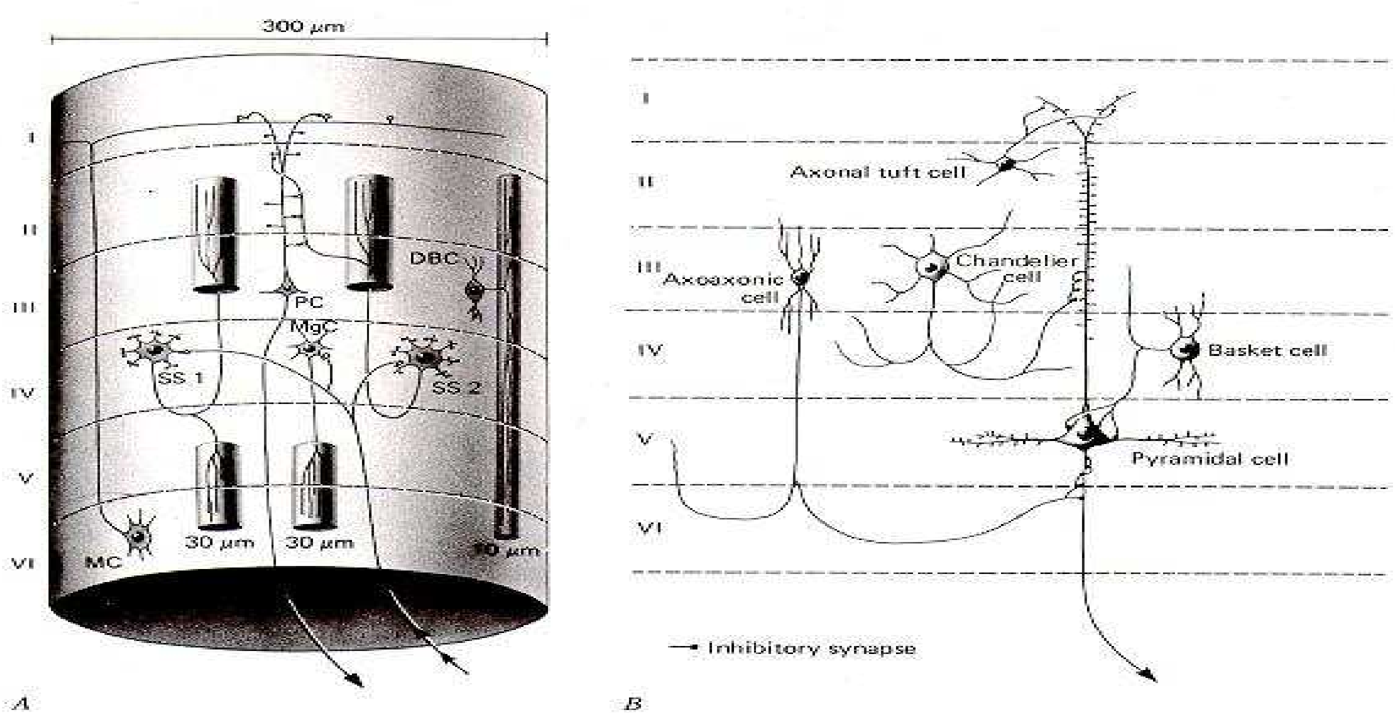
Different Scales



MULTISCALE SYSTEM

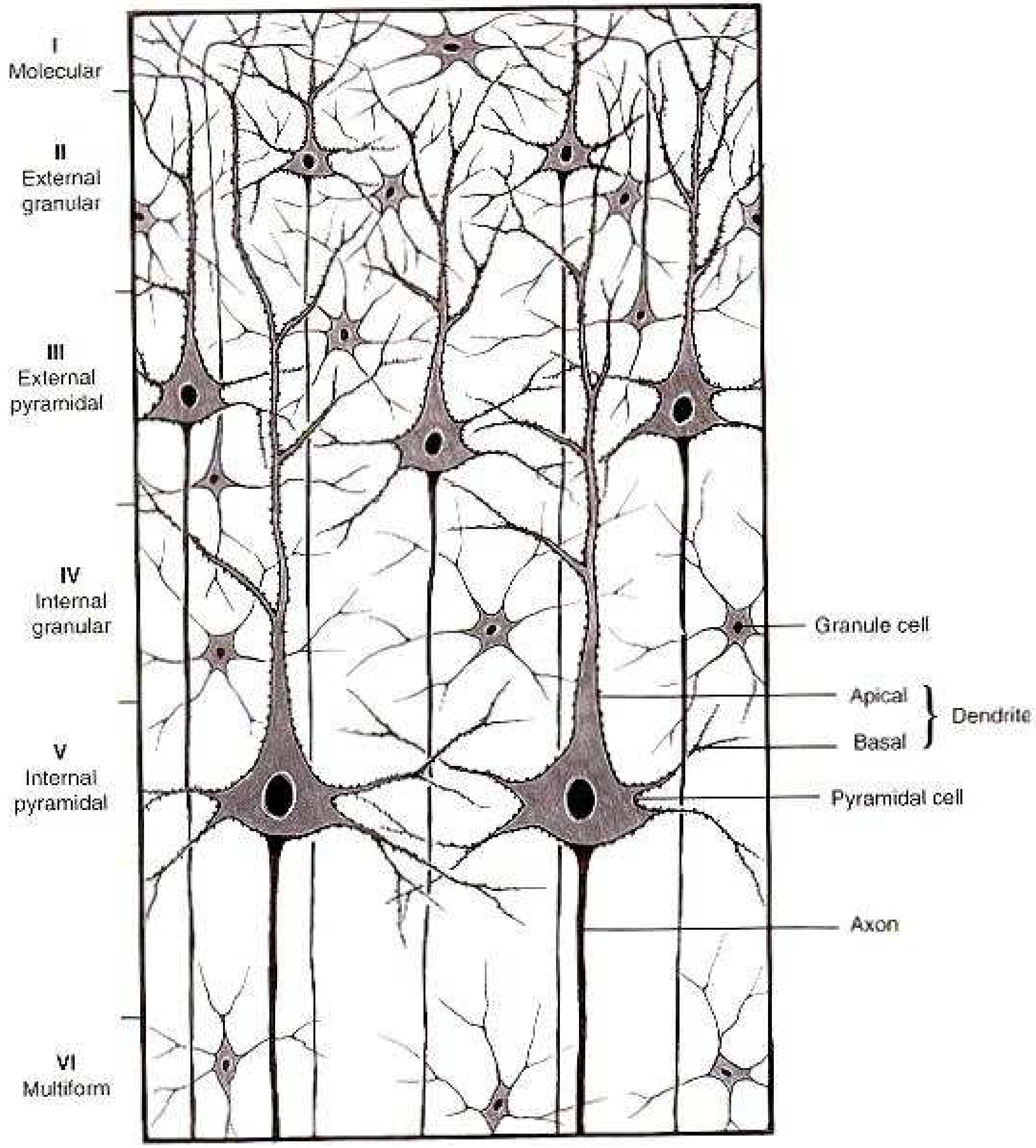
Cortical Columns

- Columns are vertically oriented groups of thousands of neurons in synaptic contact
- Main input layer is layer IV which receives thalamic input
- Thalamus is the main source of input to the cortex



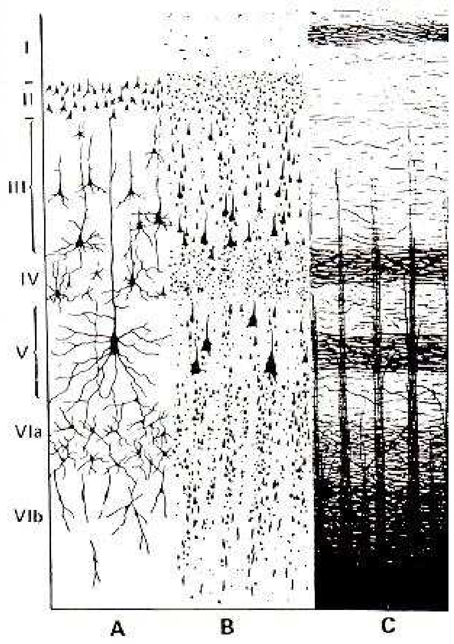
Functional Histology of the Cerebral Cortex

- Neocortex has 6 layers designated I, II, III, IV, V, VI
- Pyramidal cells predominate in layers III and V
- Granule cells in layers II and IV



Types of Cortex

- Cytoarchitecture varies in different areas
- Number and size of cells
- Thickness of layers



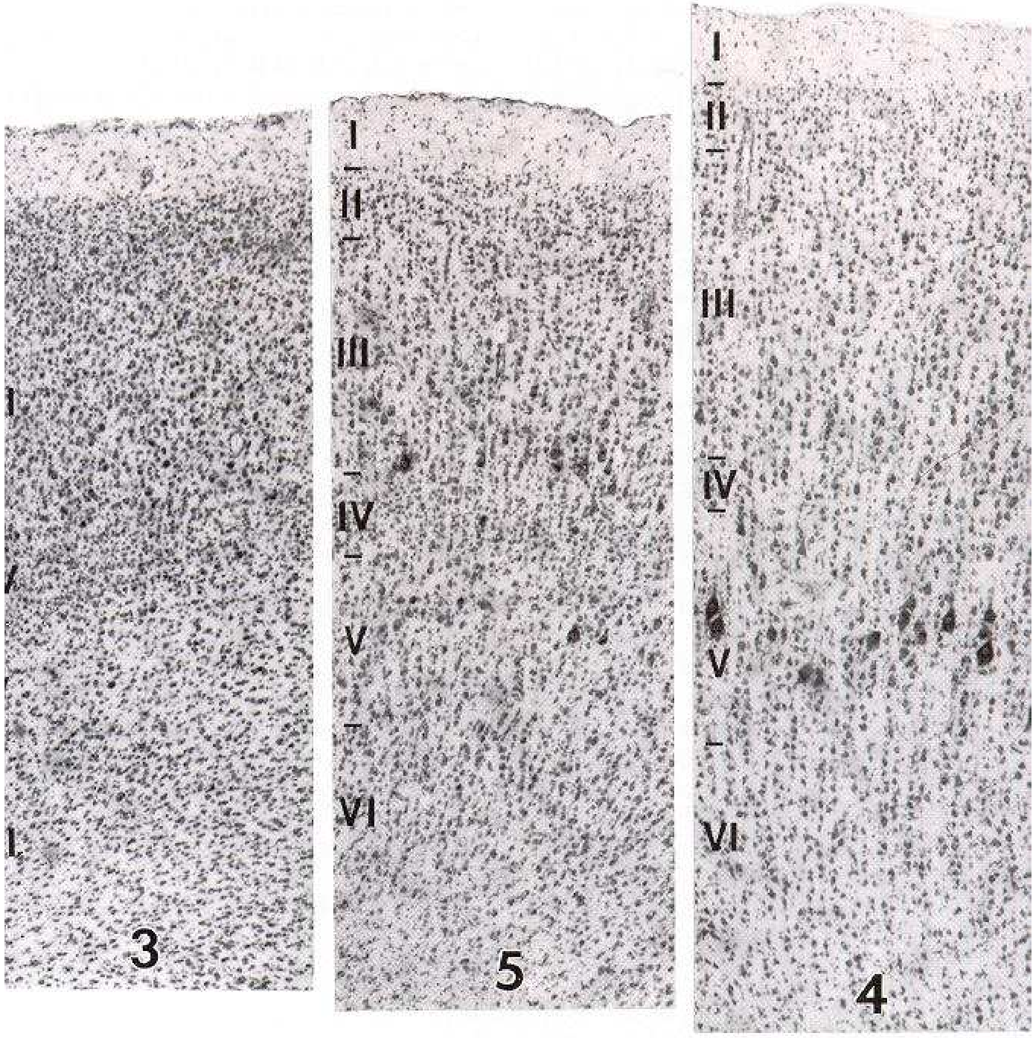
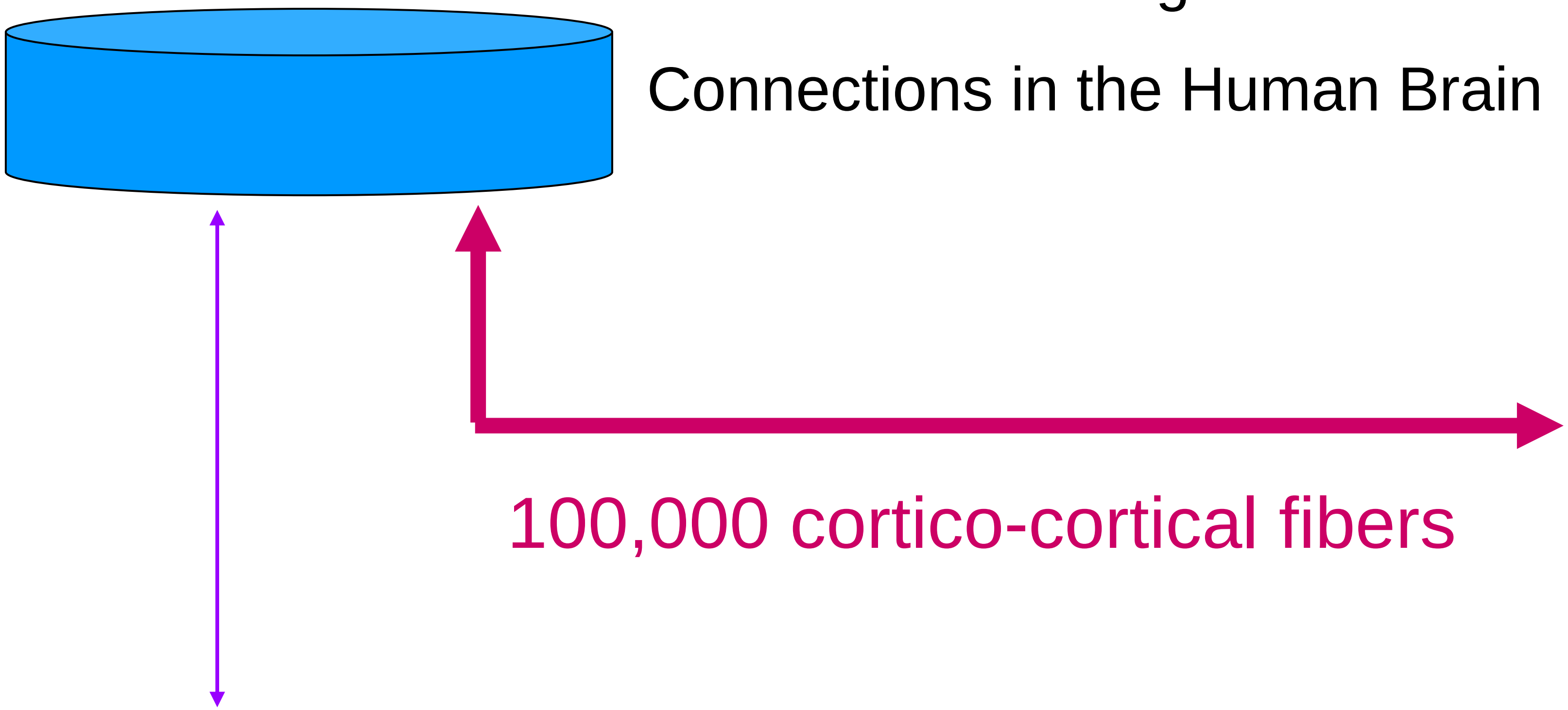


Figure 17-5
Photomicrographs of Nissl-stained sections through three sensorimotor areas to show differences in cytoarchitectural organization: primary somatosensory cortex (*area 3*); first somatosensory association cortex (*area 5*); motor cortex (*area 4*). Notice the highly graunular layers II and IV in area 3 and large pyramidal neurons in the deep part of layer III in area 5 and in layer V of area 4.

1 mm diameter cortical macrocolumn

Dominance of Tangential Over Radial

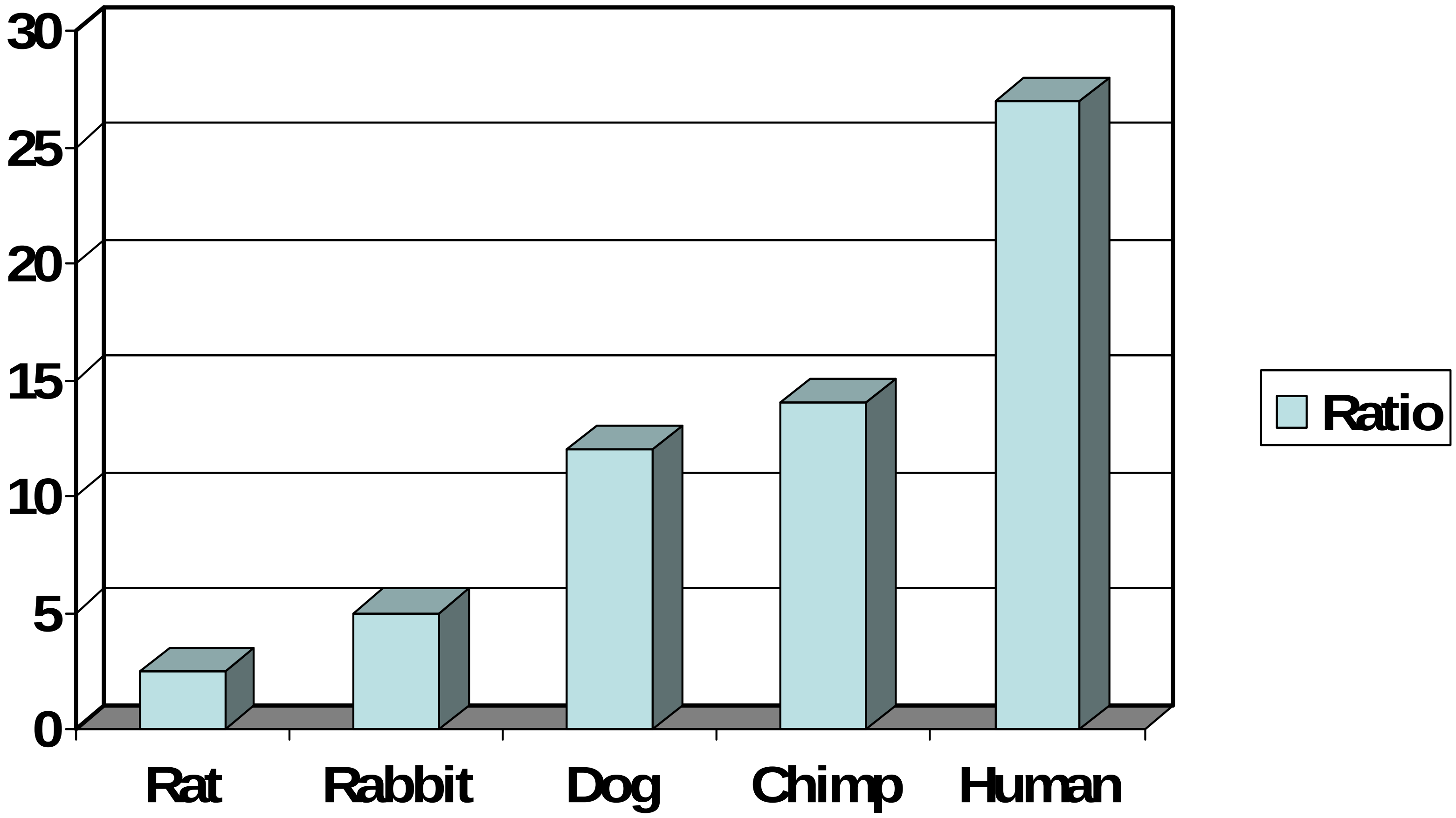
Connections in the Human Brain



100,000 cortico-cortical fibers

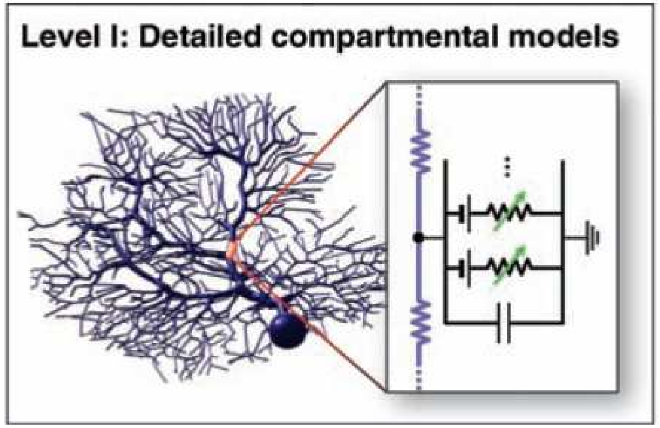
2,000 thalamocortical fibers

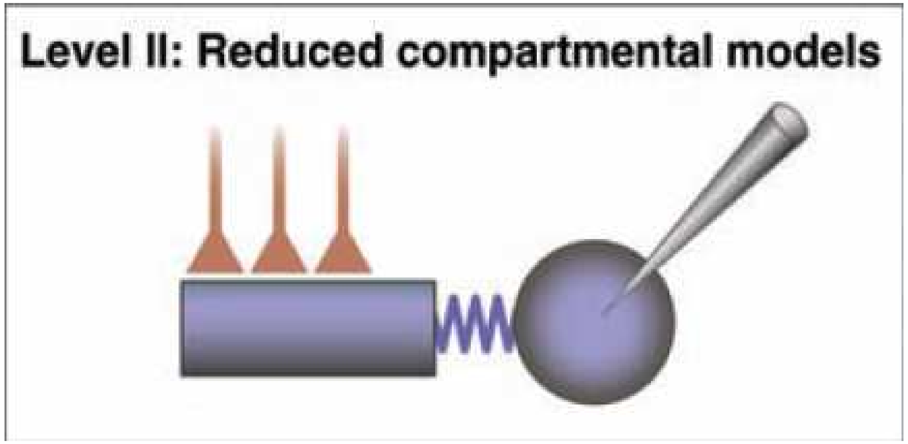
Ratio of cortico-cortical input fibers to thalamocortical input fibers

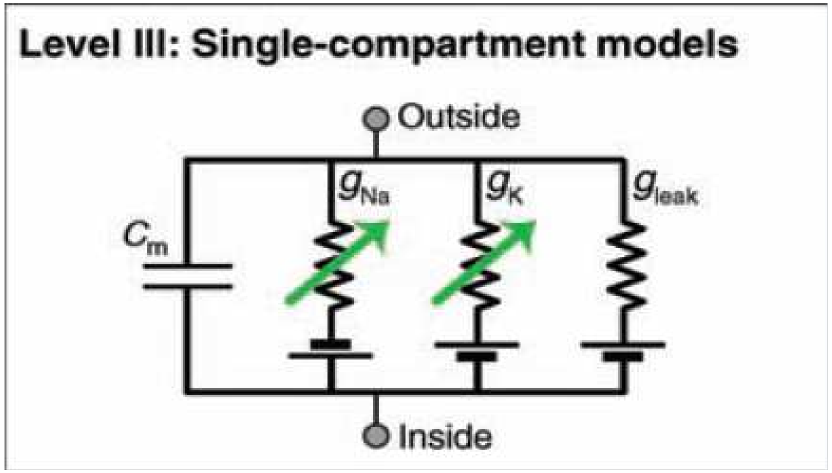


Neural Systems Modeling and Scale

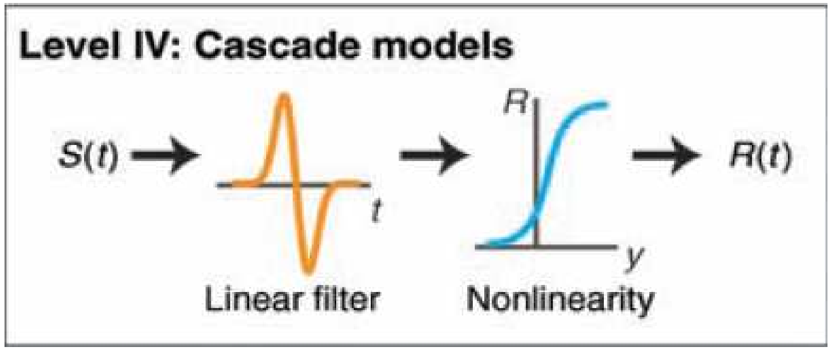
1) A compromise between detail and abstraction:

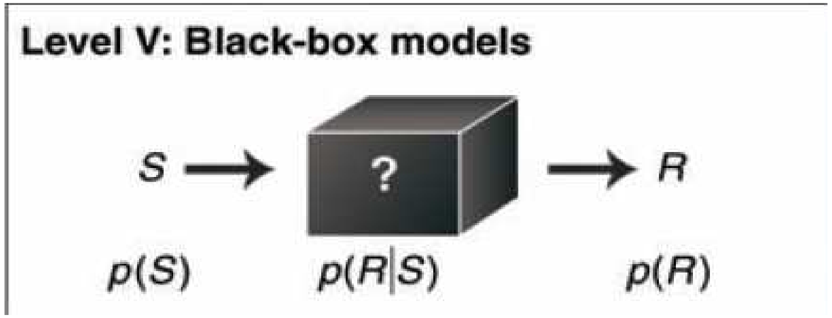


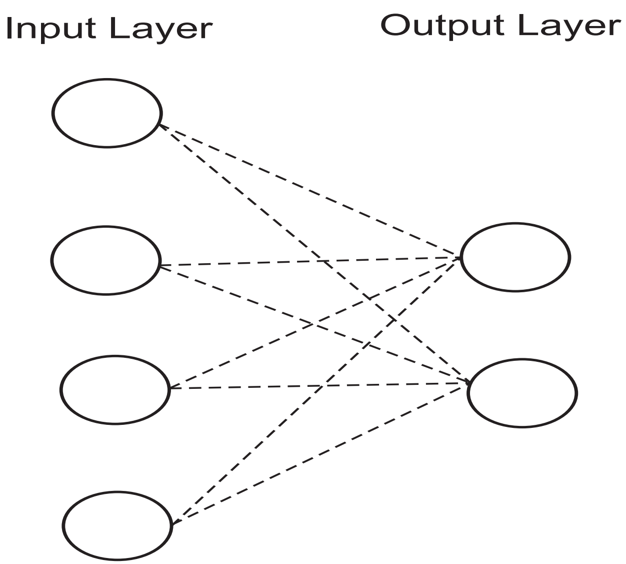




Introductory Remarks: Neural Systems Modeling







Neural Networks

Example: Stereotype Integrate and Fire Network Model (Neural Network Level)

Integrate and Fire Network

The total potential of the neuron at each time instant is simply obtained by

$$P(t+1) = \sum_j PSP^j(t+1) + N(t+1) + V(t+1) + I_{ext}(t+1)$$

The firing decision is as follows:

$$\text{if } P(t+1) > r(t+1), \quad \text{then} \quad t_{sp} = t+1$$

i.e. if the total potential exceeds the threshold value the latest spike time (t_{sp}) is updated to the next time interval. This has the effect of resetting the threshold and soma membrane potential terms that begin to decay from a fixed value after every spike.

Integrate and Fire Network

$$r(t+1) = (r_{max} - r_{\infty})\exp\left(\frac{-(t - t_{sp})}{\alpha_{th}}\right) + r_{\infty}$$

Next, the inputs from the other neurons in the population are considered. This is called the post-synaptic-potential (PSP):

$$PSP^j(t+1) = PSP^j(t)\exp\left(\frac{-1}{\alpha^j_{PSP}}\right) + a$$

$$a = \begin{cases} w^j & \text{if } t^j_{sp} + \tau^j = t + 1 \\ 0 & \text{else} \end{cases}$$

The term τ^j is the propagation delay of the message.

Integrate and Fire Network

A noise term is defined:

$$N(t+1) = N(t)\exp\left(\frac{-1}{\alpha_N}\right) + \xi, \qquad \xi \epsilon N(0,\sigma)$$

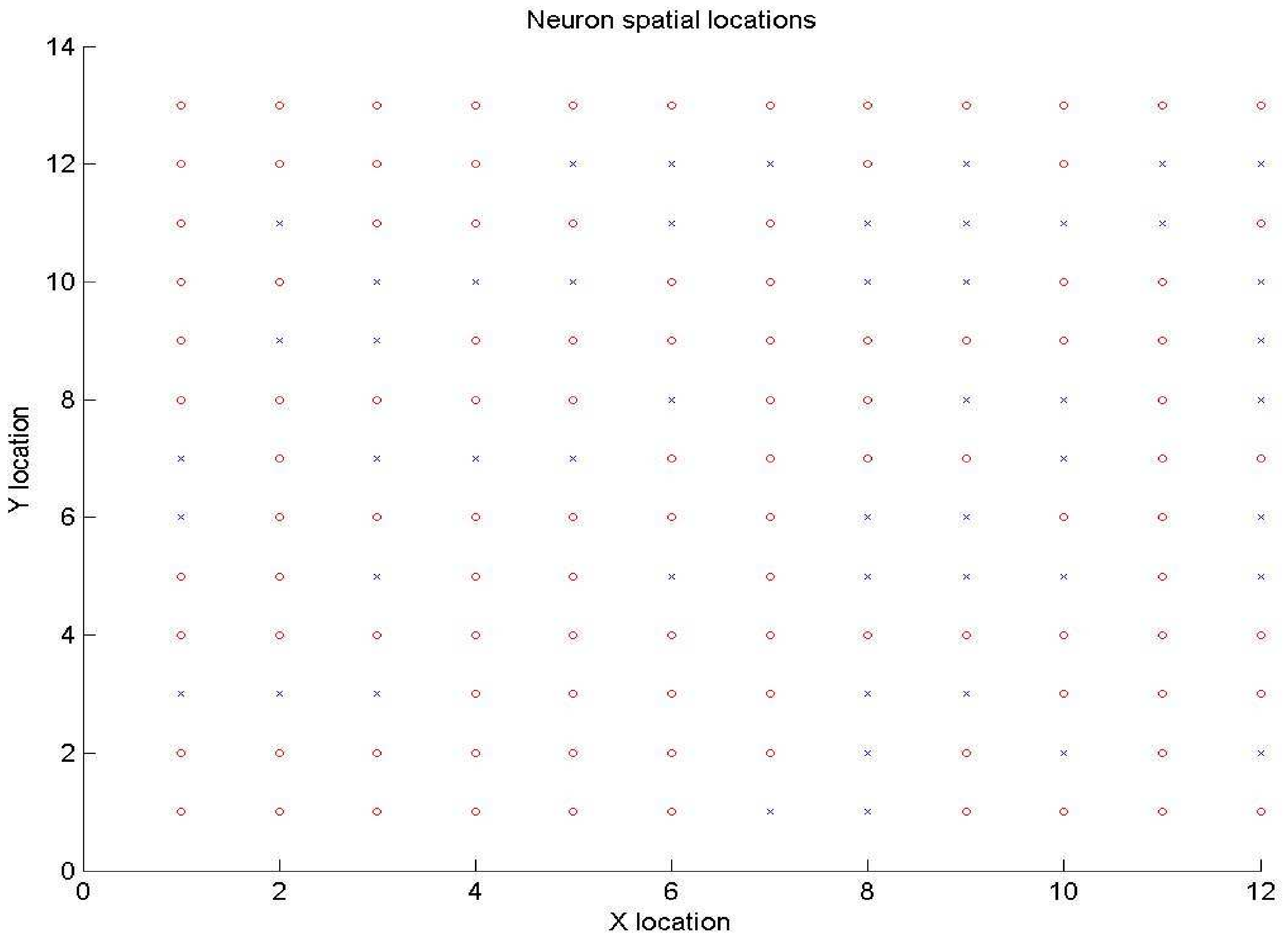
The soma's membrane potential is defined:

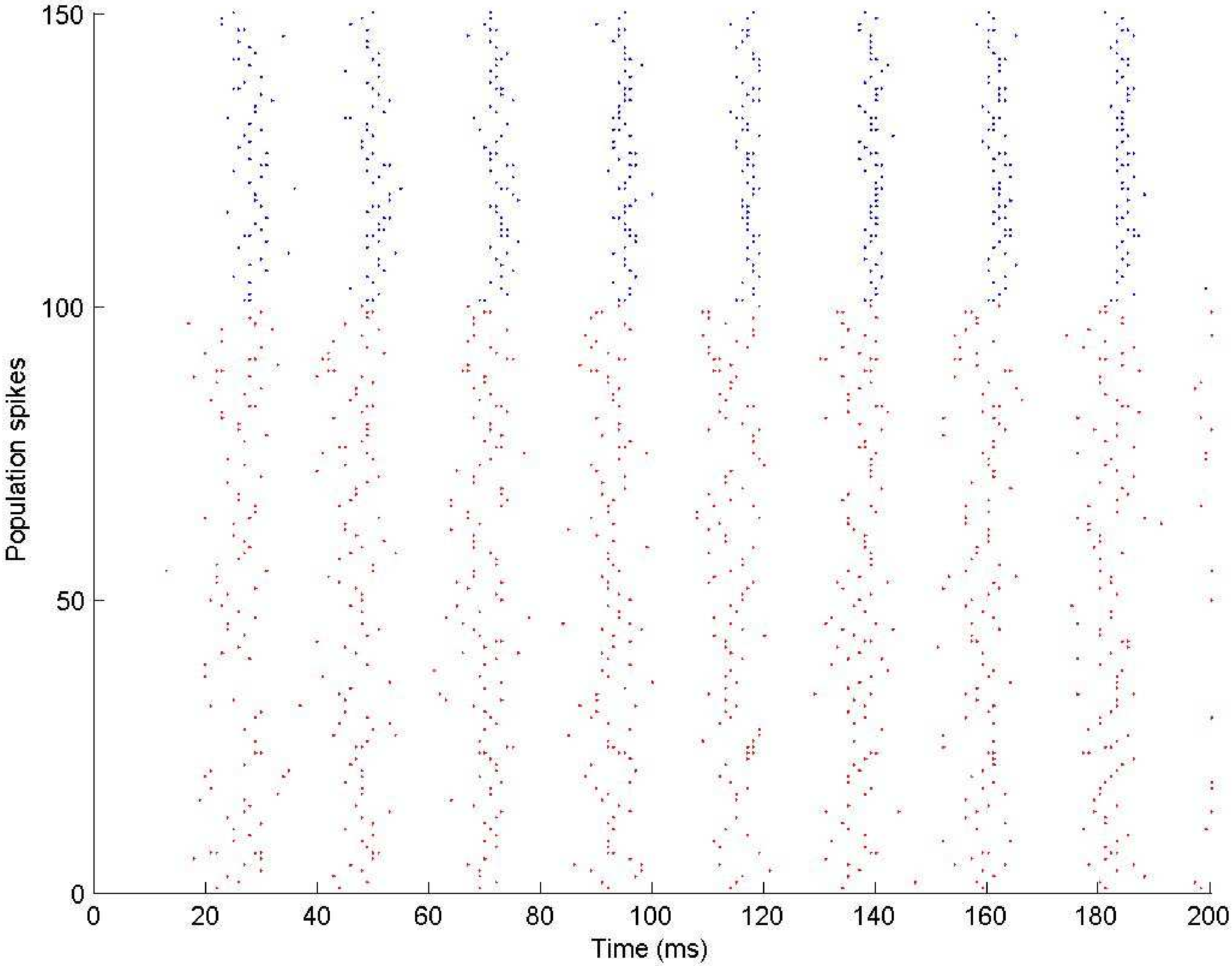
$$V(t+1) = V_{AHP}\exp\left(\frac{-(t - t_{sp})}{\alpha_V}\right)$$

Finally, each neuron has an external input. This is by default a small, constant, value, however the effect of a larger time-varying external input is later investigated.

Computational Diagnostics & Biocybernetics Unit

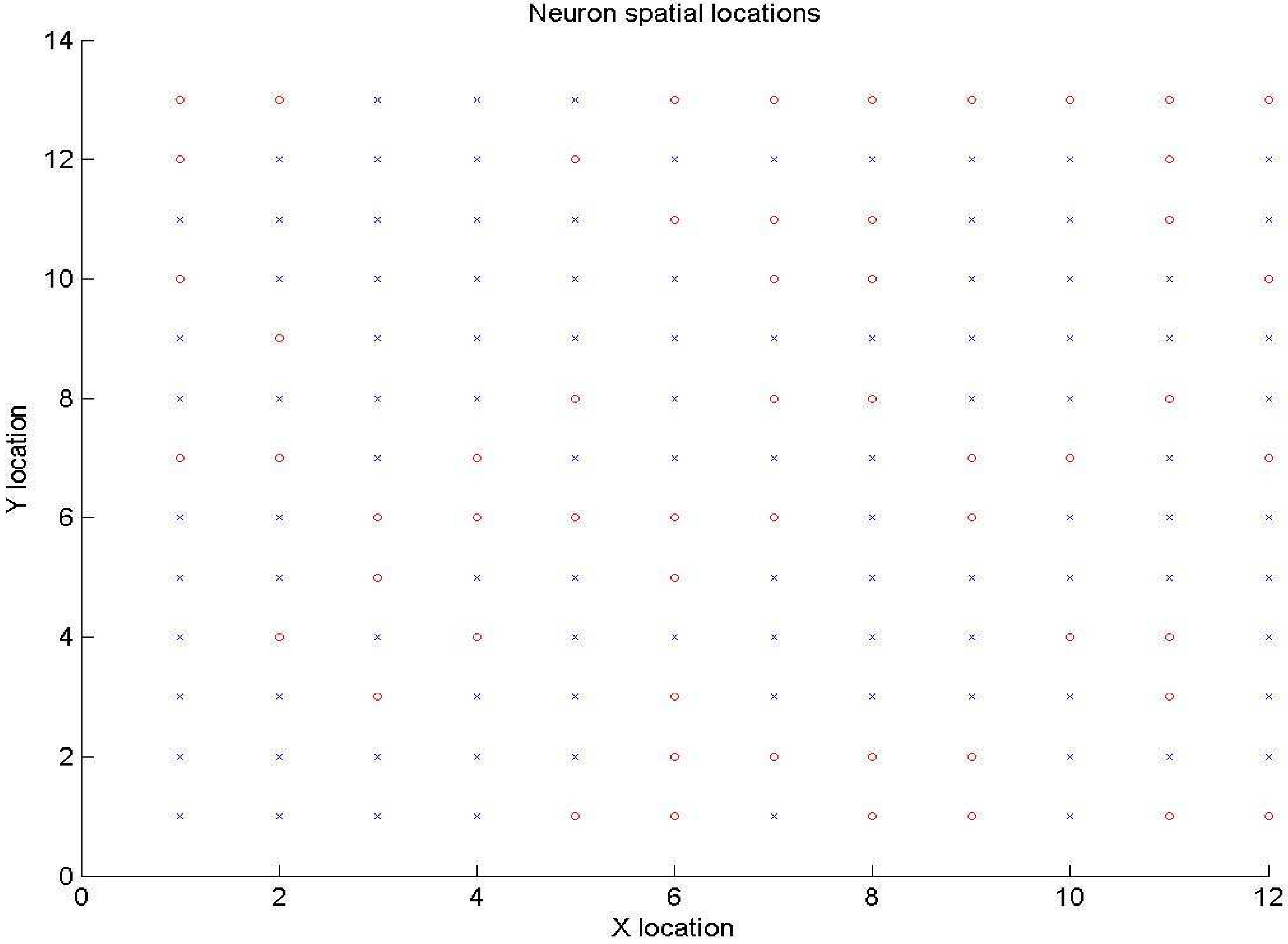
Integrate and Fire Model (100 Exc-50 Inh)

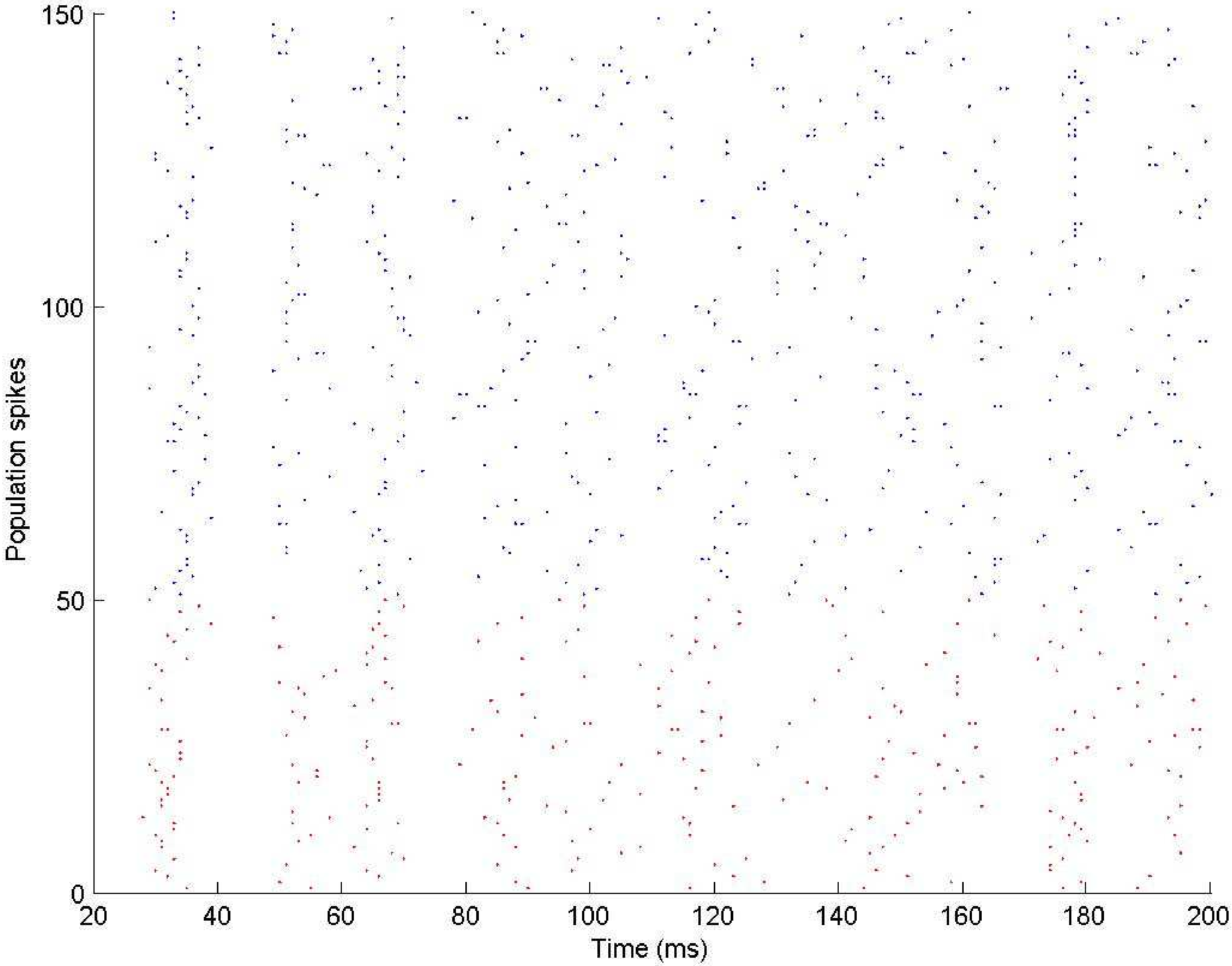




150
100
50
0
Population spikes
0
20
40
60
80
100
120
140
160
180
200
Time (ms)

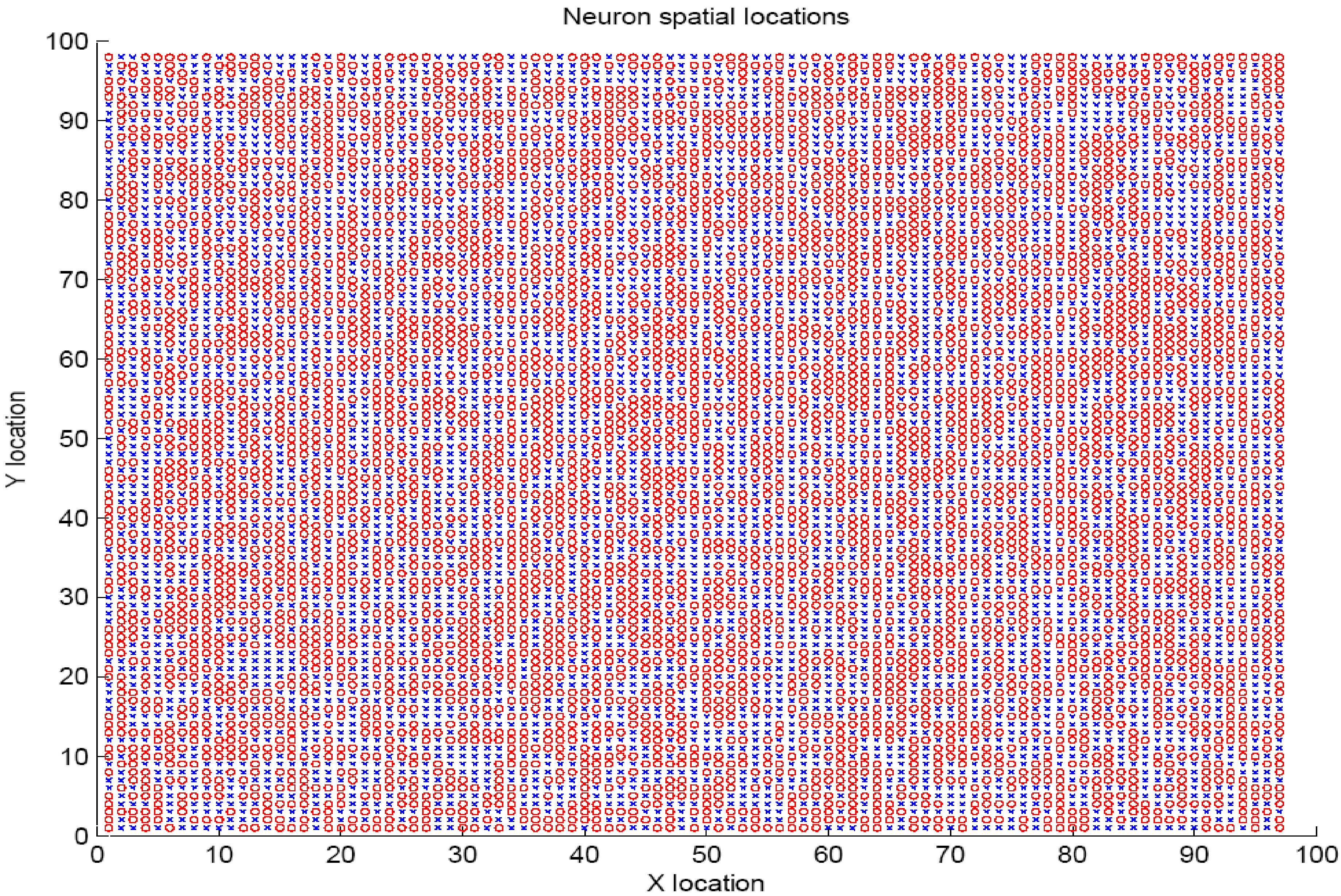
Integrate and Fire Model (50 Exc-100 Inh)

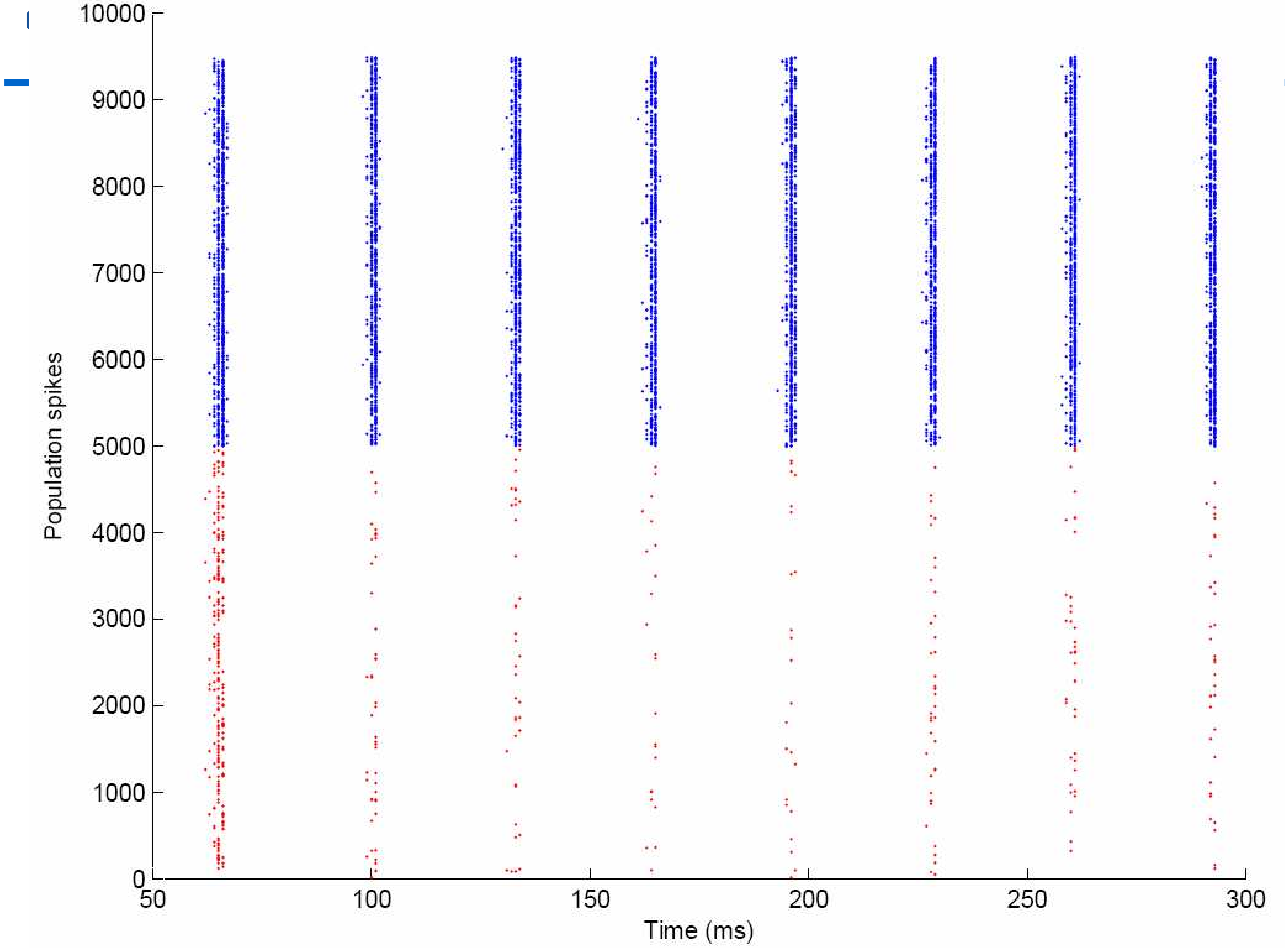




150
100
50
0
Population spikes
20
40
60
80
100
120
140
160
180
200
Time (ms)

Integrate and Fire Model (5000 Exc-4500 Inh)

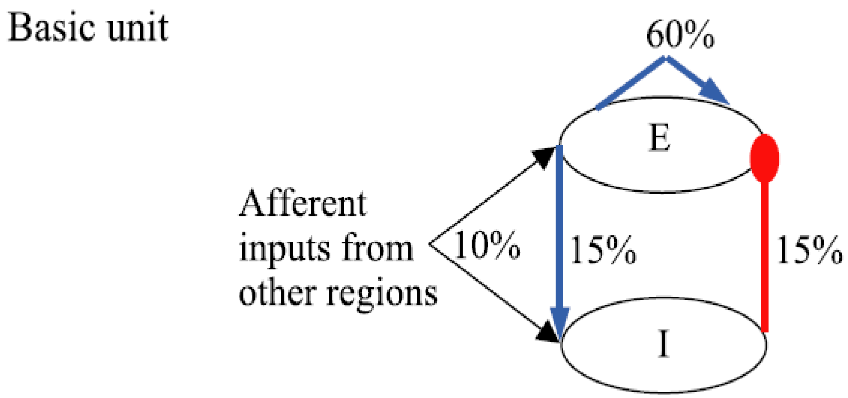




10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Population spikes
50
100
150
200
250
300
Time (ms)

Example: Cortical Column Level

Basic Unit Model Tagamets and Horwitz (1998)



$$\frac{\mathrm{d}E_i(t)}{\mathrm{d}t} = \Delta\left(\frac{1}{1+e^{-K_E[w_{\mathrm{EE}}E_i(t)+w_{\mathrm{IE}}I_i(t)+\mathrm{in}_{i\mathrm{E}}(t)-\tau_{\mathrm{E}}+N(t)]}}\right) - \delta E_i(t)$$

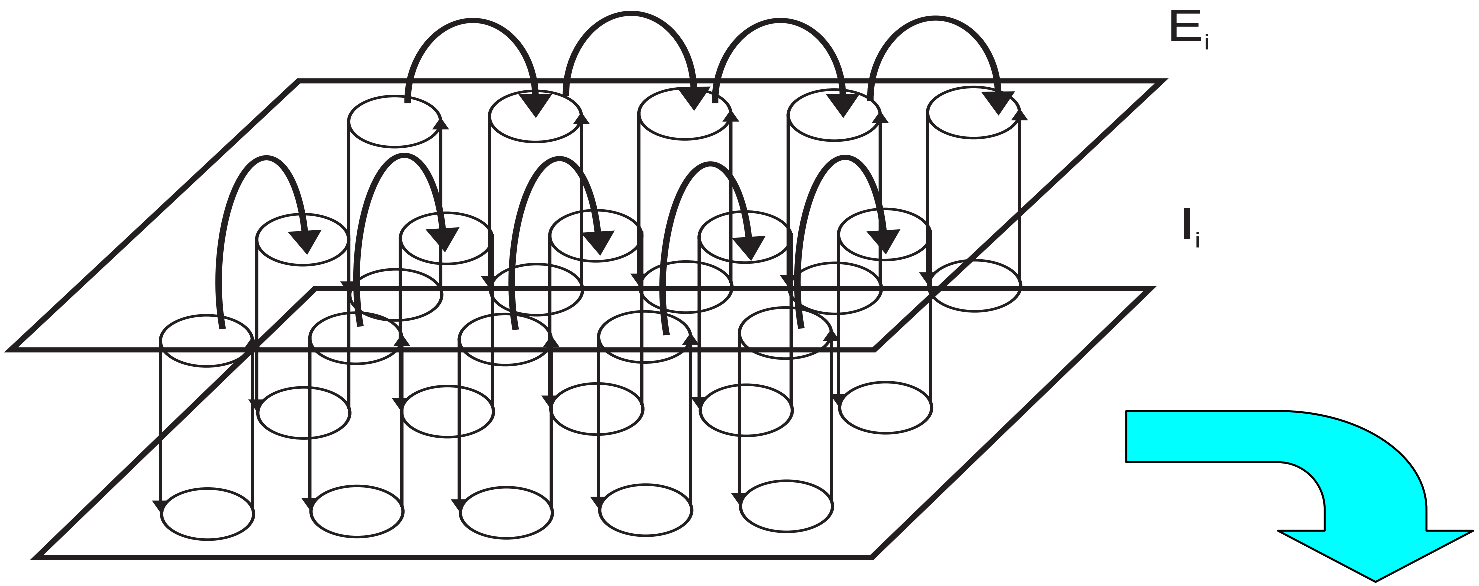
$$\frac{\mathrm{d}I_i(t)}{\mathrm{d}t} = \Delta\left(\frac{1}{1+e^{-K_I[w_{\mathrm{EI}}E_i(t)+\mathrm{in}_{i\mathrm{I}}(t)-\tau_{\mathrm{I}}+N(t)]}}\right) - \delta I_i(t)$$

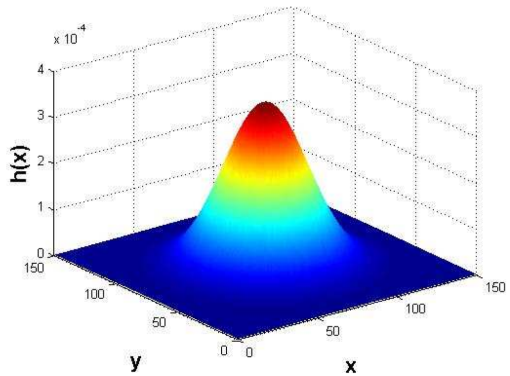
$$\mathrm{in}_{i\mathrm{E}}(t) = \sum_j w_{\mathrm{ji}}^{\mathrm{E}} E_j(t) + \sum_j w_{\mathrm{ji}}^{\mathrm{I}} I_j(t)$$

$$\mathrm{in}_{i\mathrm{I}}(t) = \sum_k w_{\mathrm{ki}}^{\mathrm{E}} E_k(t) + \sum_k w_{\mathrm{ki}}^{\mathrm{I}} I_k(t)$$

Architecture of Cortical Columns

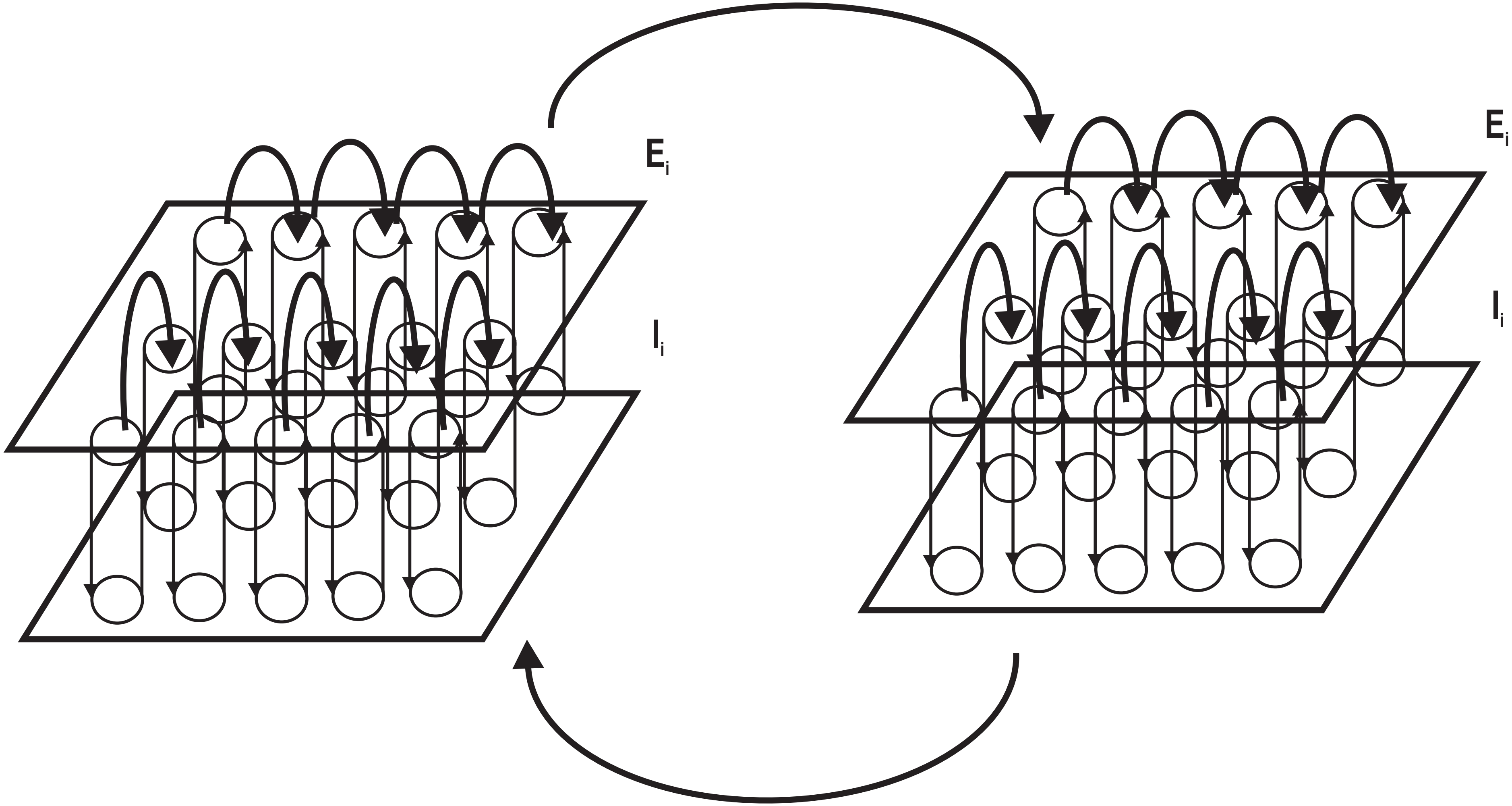
CORTICAL COLUMNS

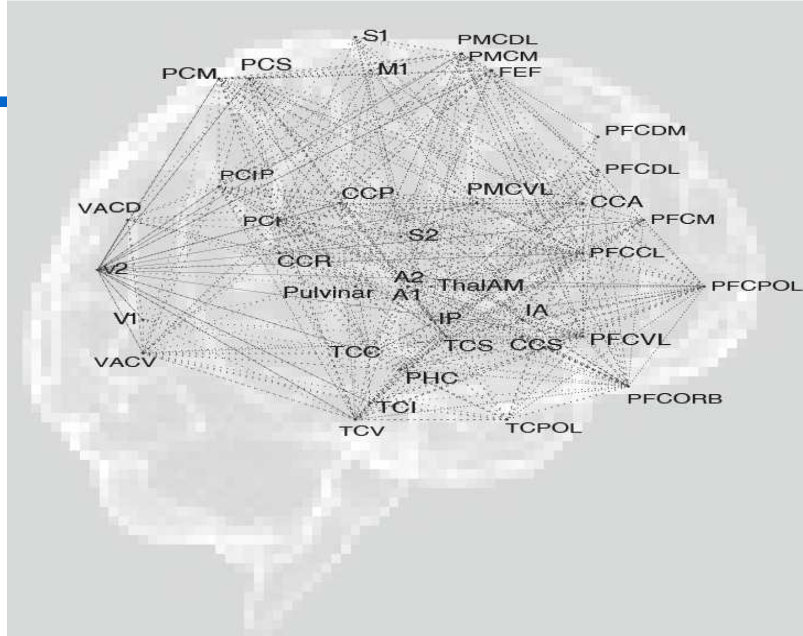


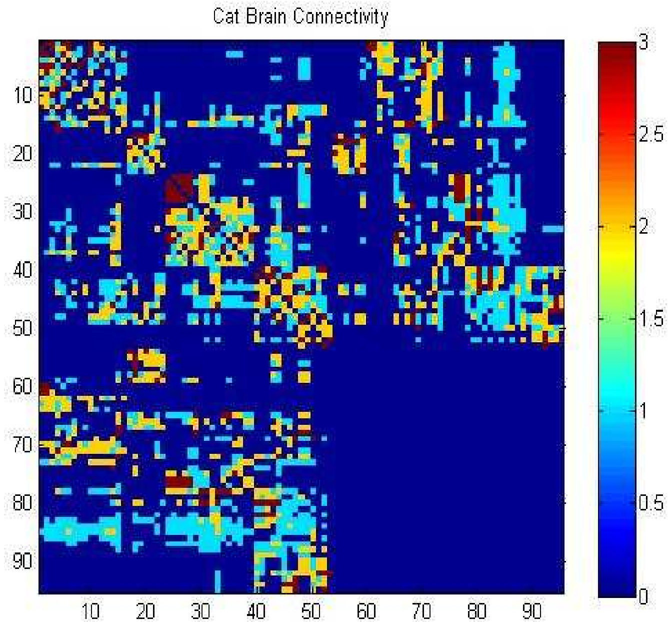


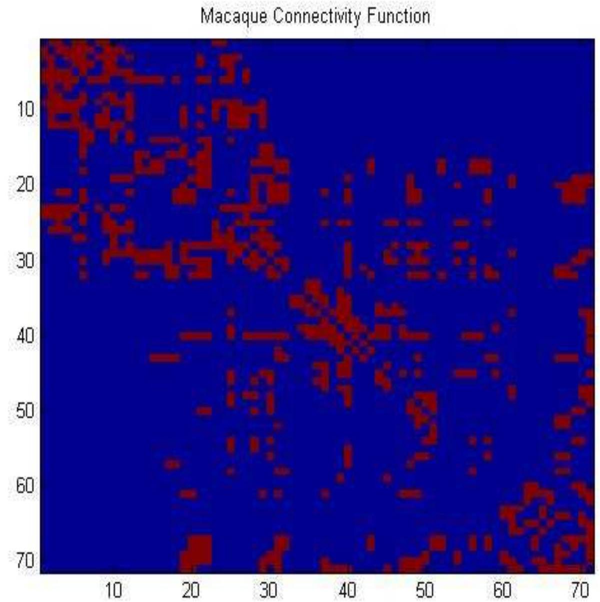
Architecture of Cortical Patches

CORTICAL COLUMNS



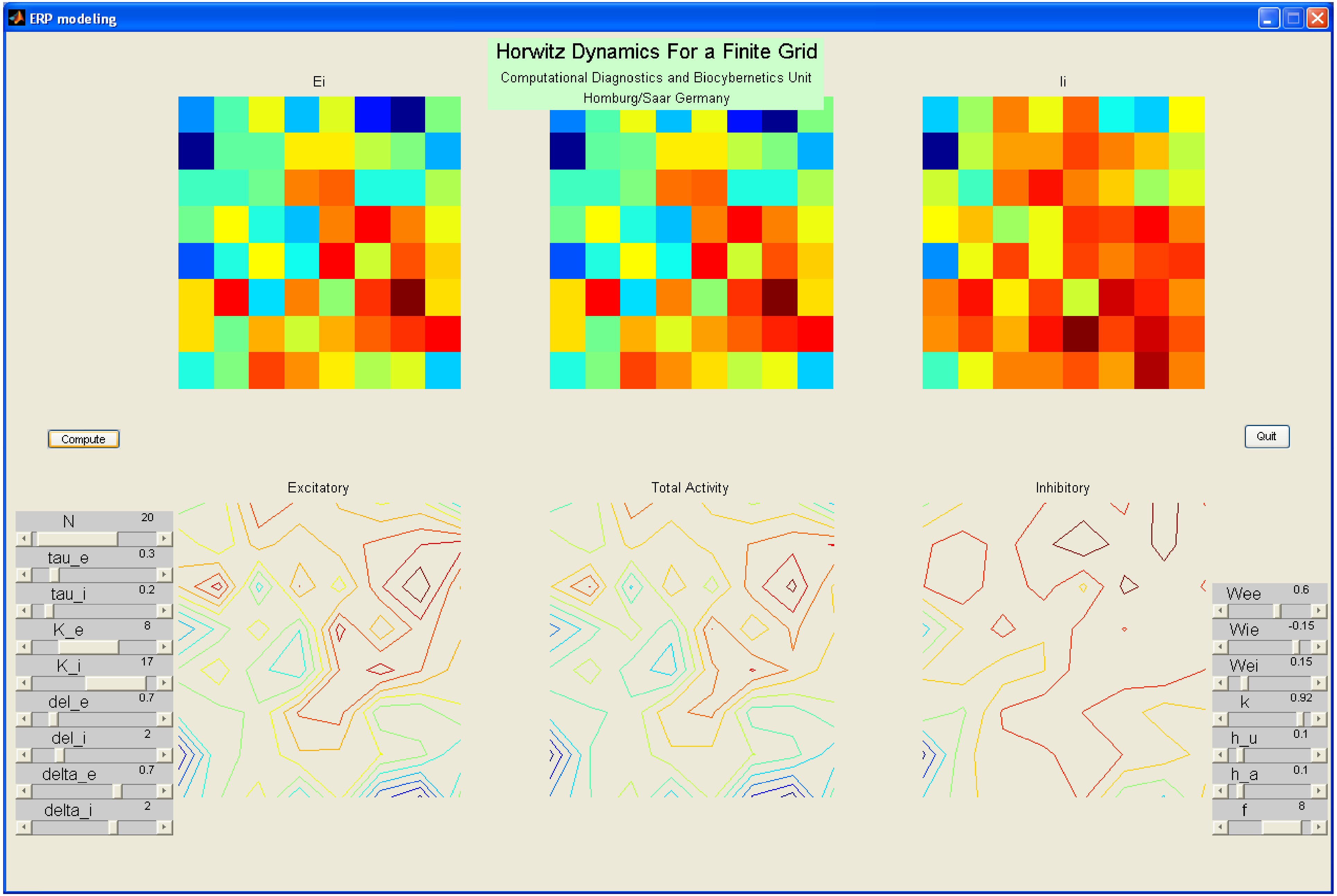

S1
PMCDL
PMCM
FEF
PCM
PCS
M1
PFCDM
PFCDL
PCIP
VACD
CCP
PMCVL
CCA
PFCM
PCI
S2
PFCCL
V2
CCR
A2
ThalAM
PFCPOL
Pulvinar
A1
IP
IA
V1
TCS
CCS
PFCVL
VACV
TCC
PHC
PFCORB
TCI
TCV
TCPOL


Cat Brain Connectivity
10
20
30
40
50
60
70
80
90
10 20 30 40 50 60 70 80 90
3
2.5
2
1.5
1
0.5
0


Macaque Connectivity Function
10
20
30
40
50
60
70
10 20 30 40 50 60 70

Computational Diagnostics & Biocybernetics Unit

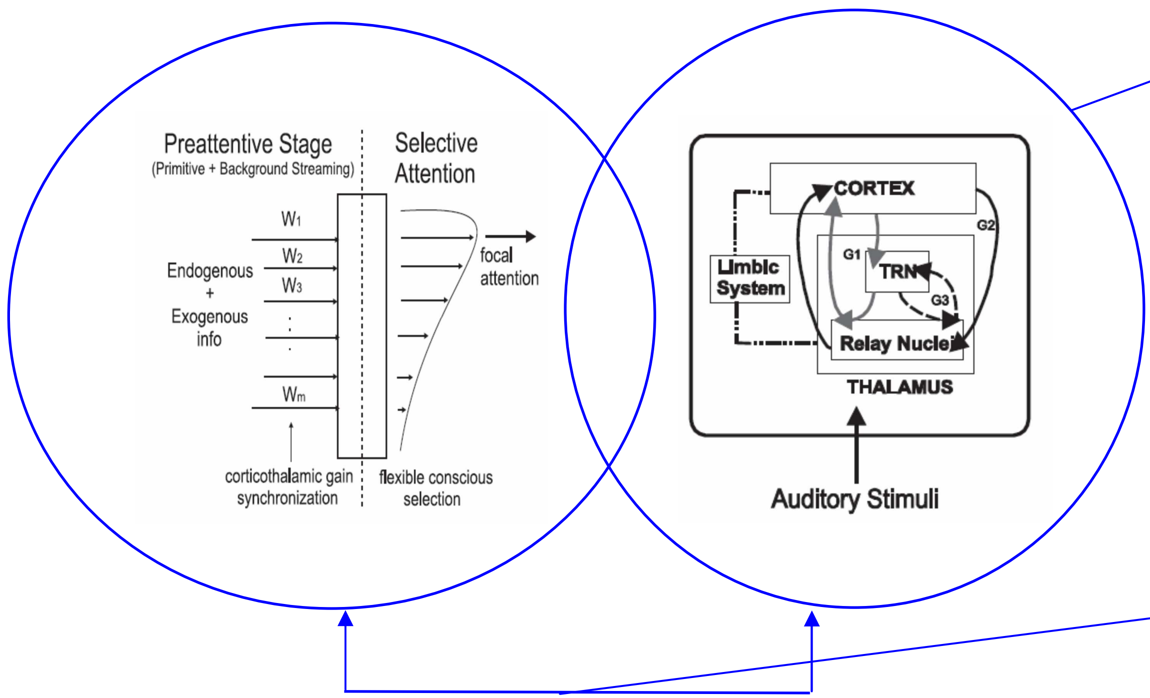
Simulation Example

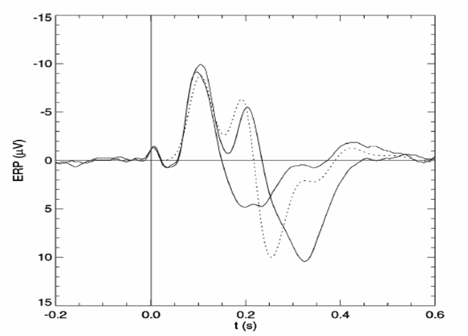


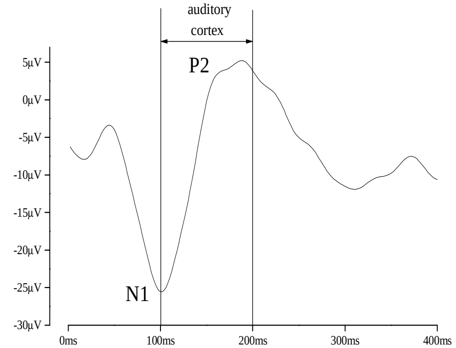
Example: Large-Scale Level:
Modeling Neural Correlates of Selective Attention
(Focusing on the auditory modality)

Introduction: Objective

- To gain insight into the neurodynamics of auditory selective attention.
- To study the influence of relevant corticothalamic loops on neural correlates of auditory selective attention by means of computational models.

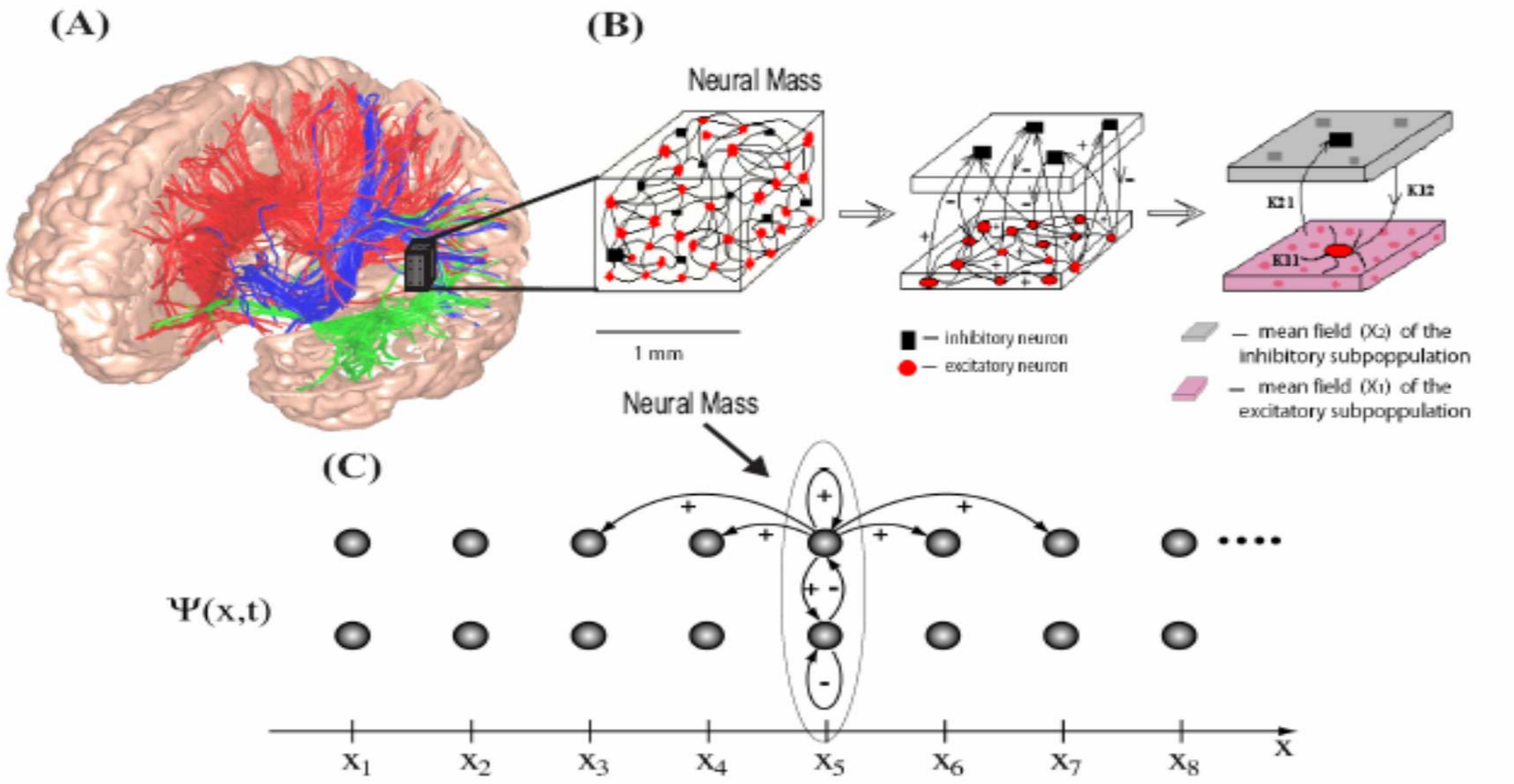






Hillyard et. al. Electrical signs of selective attention in the human brain. Science. 182:177-180, (1973)

Introduction: Neural Field Approach



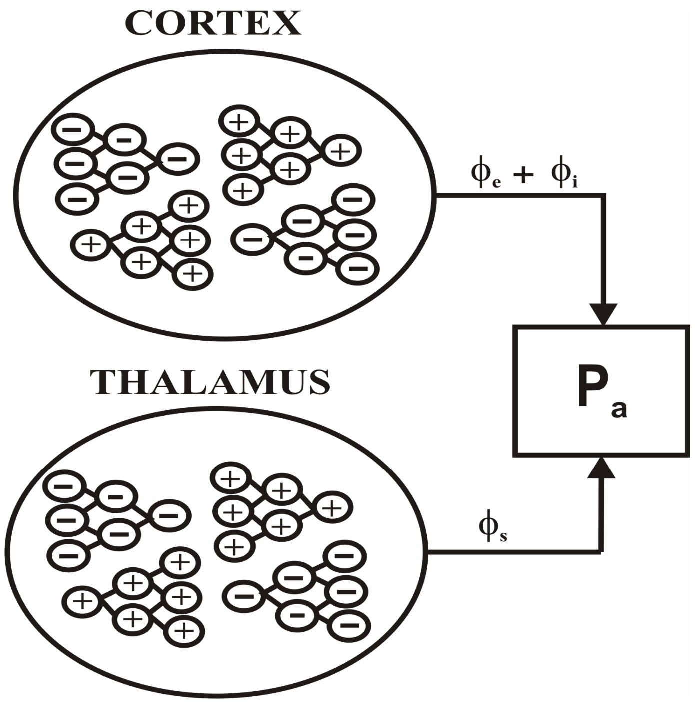
Neural mass actions on a spatially continous medium:

(Beurle 1956; Griffith 1963; Wilson & Cowan, 1973; Nunez, 1974; Freeman 1975; Amari 1977; van Rotterdam et al., 1982; Jirsa & Haken, 1996; Wright & Liley, 1996; Robinson et al., 1997, 2001, 2005; Liley et al., 2002).

Methods: Math Model

(1) Combination of incoming activities from excitatory and inhibitory neural populations as well as subcortical contributions.

$$P_a = N_{ae} s_e \phi_e + N_{ai} s_i \phi_i + N_{as} s_s \phi_s$$



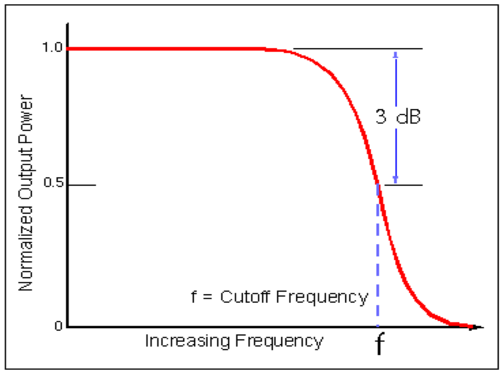
(2) Mean Soma Potential

$$V_a(\mathbf{r},t) = \int_{-\infty}^{\infty} L(t-t') P_a(\mathbf{r},t') dt'$$

Low Pass Filter (Dendritic Effects)

$$L(u) = \frac{\alpha\beta}{\beta-\alpha}\left(e^{-\alpha u} - e^{-\beta u}\right)\Theta(u)$$

$$L(\omega) = (1 - i\omega/\alpha)^{-1}(1 - i\omega/\beta)^{-1}$$

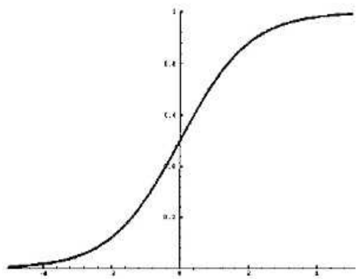


low pass filter

Methods: Math Model

(3) Mean Firing Rate

$$S[Va(r,t)] = \frac{Q_{max}}{1 + exp\{-[V_a(r,t) - \theta]/\sigma'\}}$$

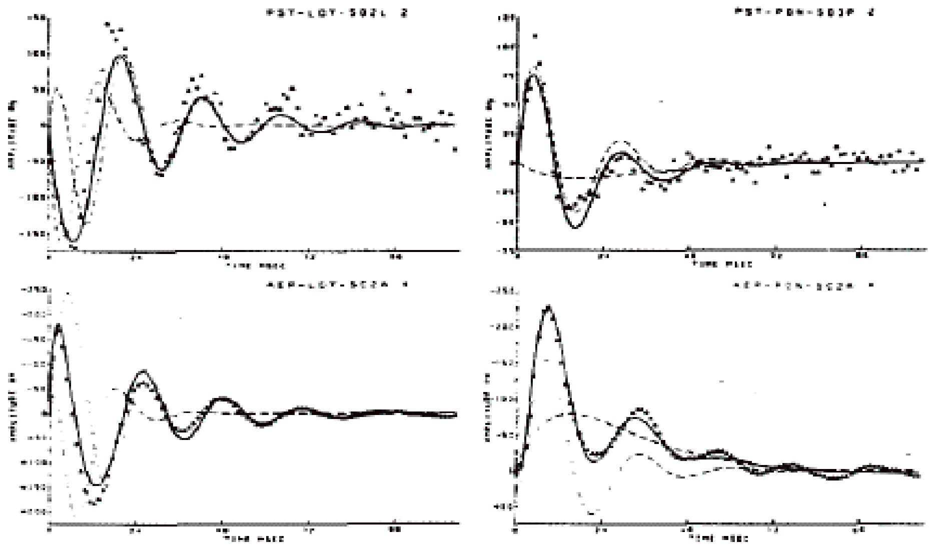


$f(x) = \frac{1}{1+e^{-x}}$

(4) Propagation of activity is given by:

$$D_a \phi_a(\mathbf{r},t) = Q_a(\mathbf{r},t),$$

$$D_a = \frac{1}{\gamma_a^2}\left[\frac{\partial^2}{\partial t^2} + 2\gamma_a \frac{\partial}{\partial t} + \gamma_a^2 - v^2 \nabla^2\right],$$



Robinson, et. al. Multiscale Brain Modeling. Philosophical Trans. Royal Society of London (2005) 360: 1043-1050.

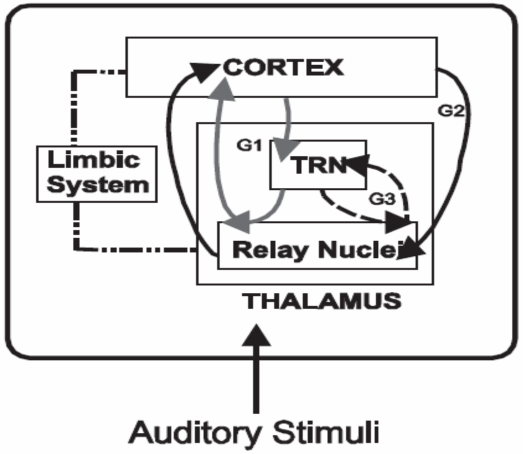
Methods: Math Model

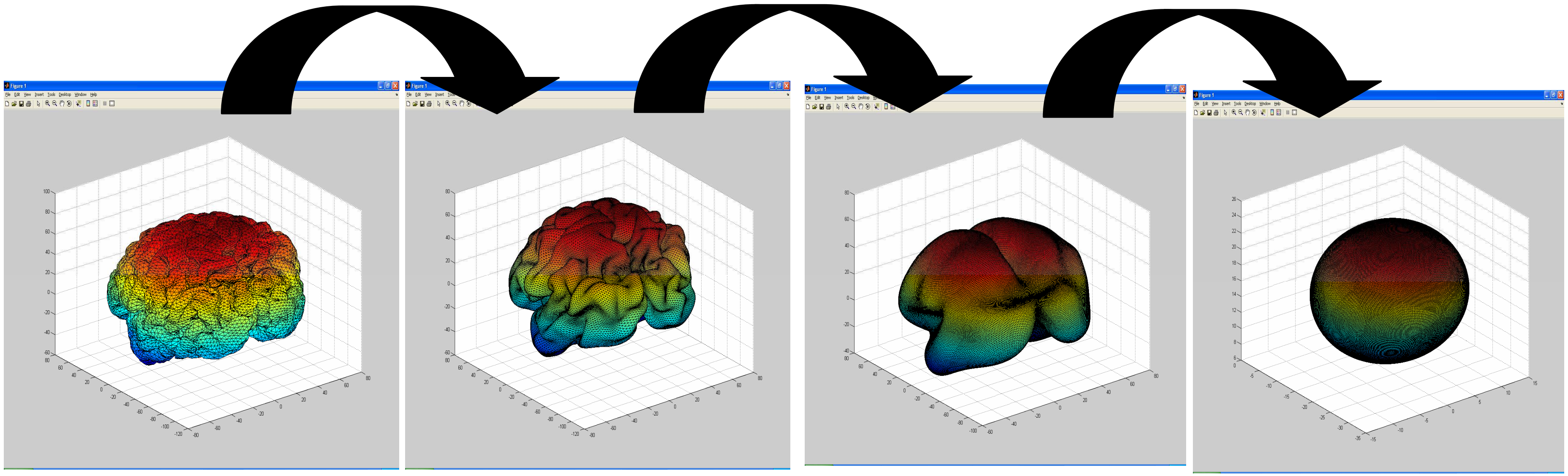
(5) Cortico-ThalamicModulation

$$\frac{\phi_l}{\phi_n} = G_{ls}G_{sn}\frac{L_l}{1 - L_l G_{ll} - L_i G_{ii}}\frac{\wp}{G_{sn}} \times$$

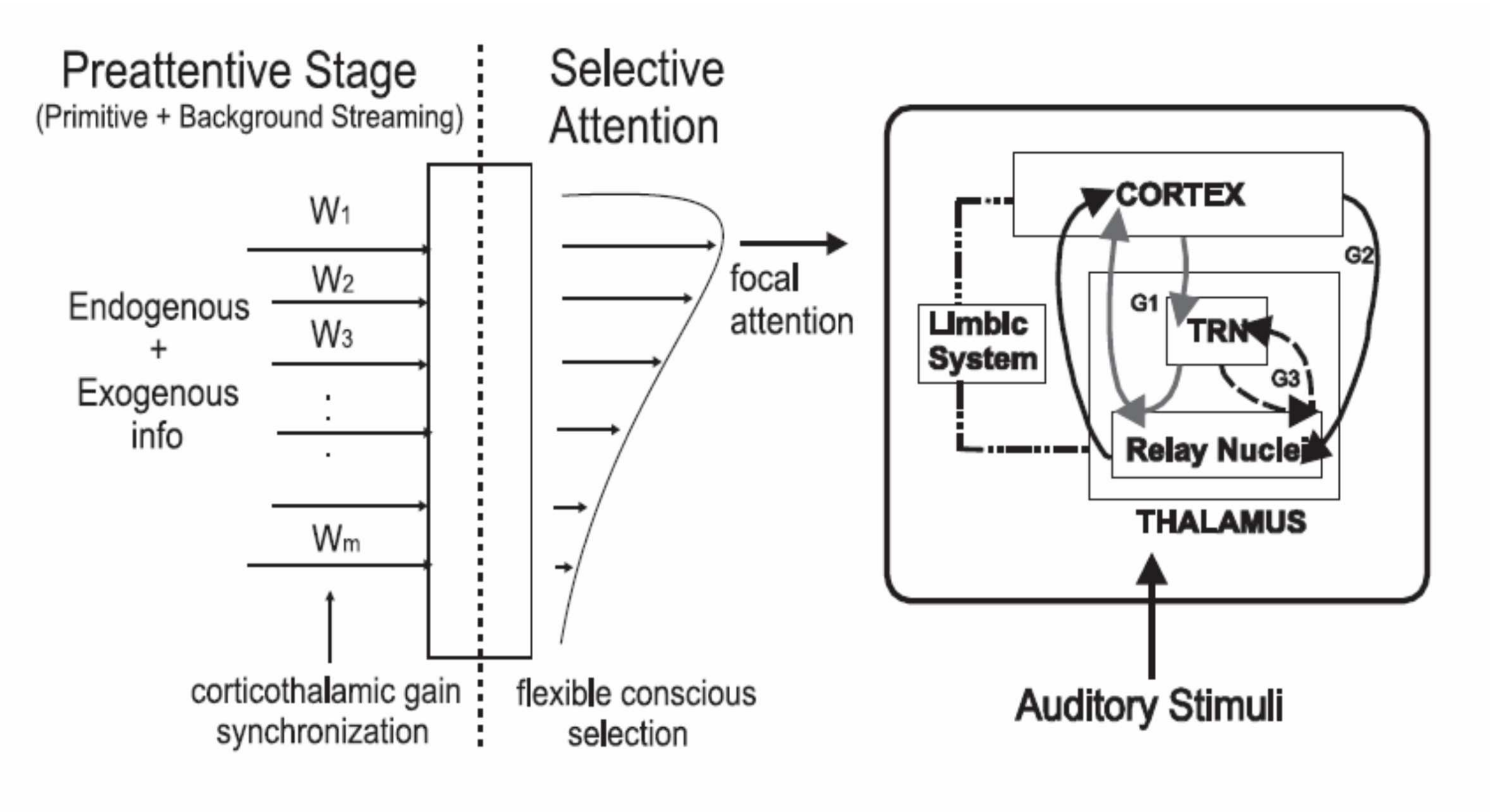
$$[1 + \frac{L_e}{1 - L_l G_{ll} - L_i G_{ii}}(G_{ee} + G_{es}\zeta)\frac{1}{k^2 r_e^2 + q^2 r_e^2}]$$

$$G(r, w) = \int_0^{\infty} \frac{kdk}{2\pi}\frac{\phi_l}{\phi_n} e^{-1/4k^2 r_s^2} J_0(k|r - r_{0s}|)$$





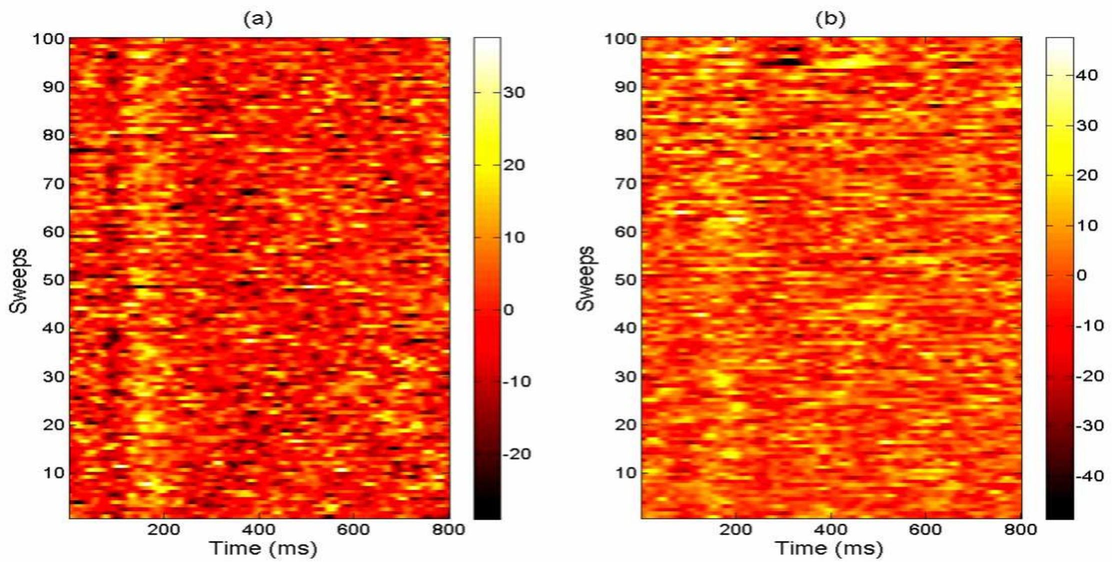
Methods: Math Model



C Trenado, L Haab, DJ Strauss. Corticothalamic Feedback Dynamics for Large-Scale Neural Correlates of Selective Attention. IEEE TNSRE (2009)

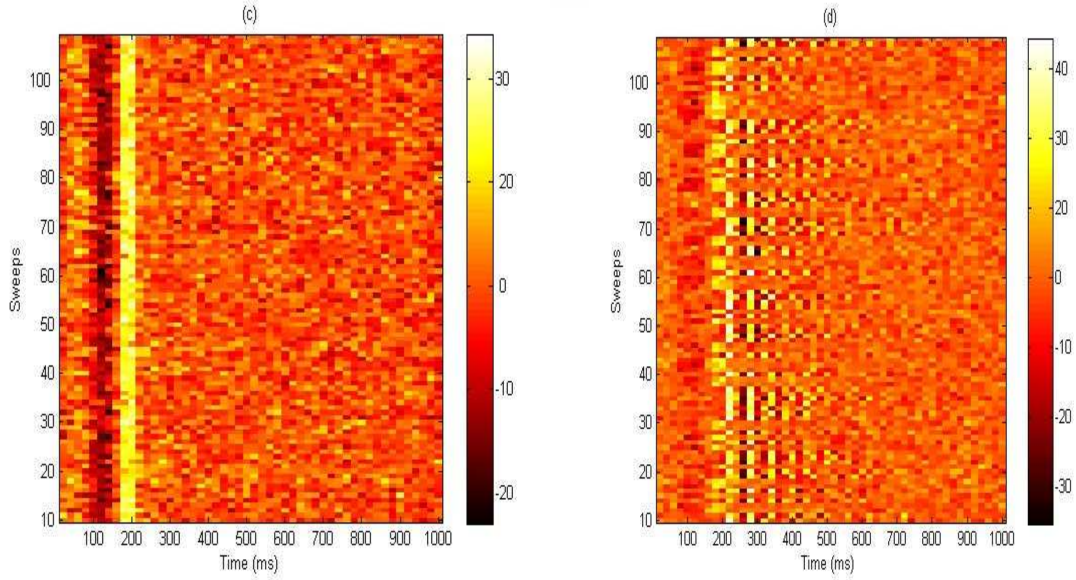
Results: Selective attention

Attended   Unattended



Experiment

YF Low, FI Corona–Strauss, DJ Strauss. Extraction of Auditory Attention Correlates in Single Sweeps of Cortical Potentials by Maximum Entropy Paradigms and its Application. IEEE NER (2007)

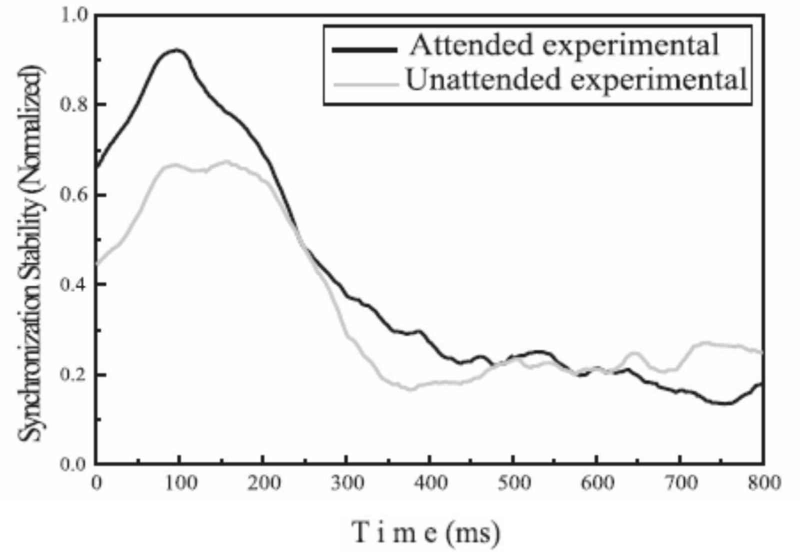


Model Simulations

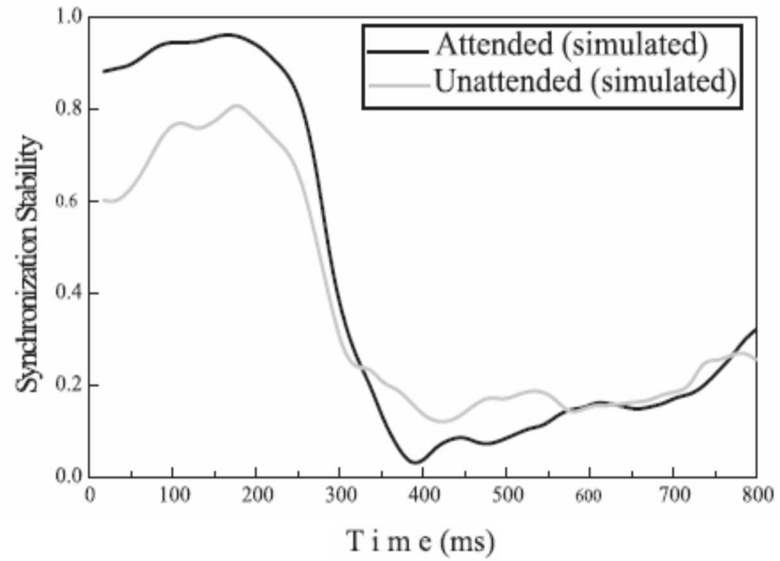
C Trenado, L Haab, W Reith, DJ Strauss. Biocybernetics of attention in the tinnitus decompensation. JNM (2009)

Results: Selective attention

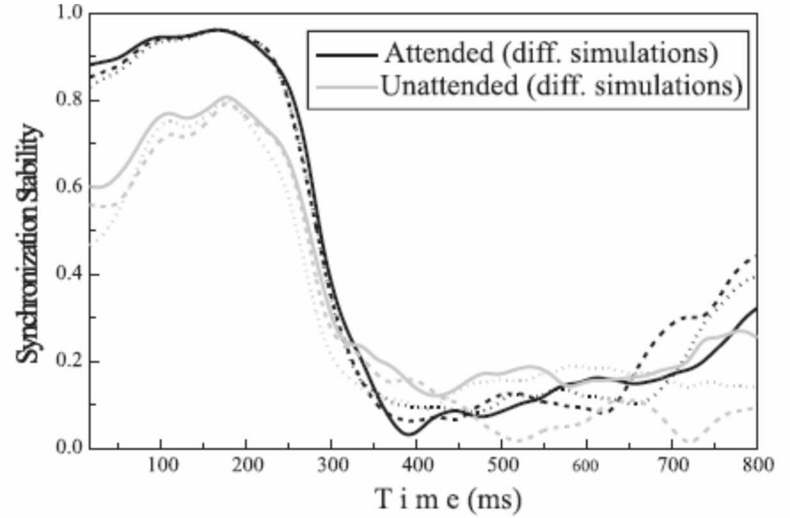
Experiment



Model Simulations



Model Simulations

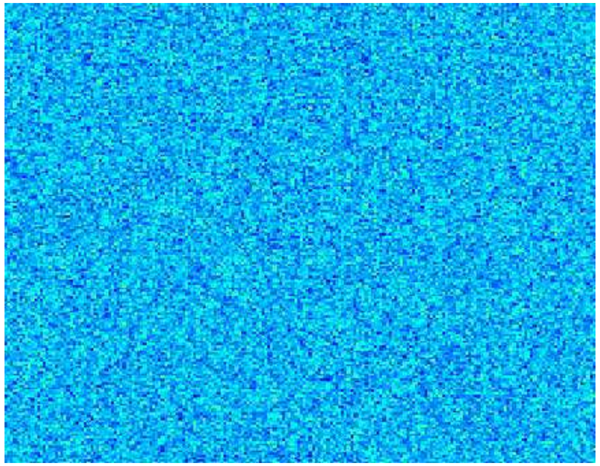
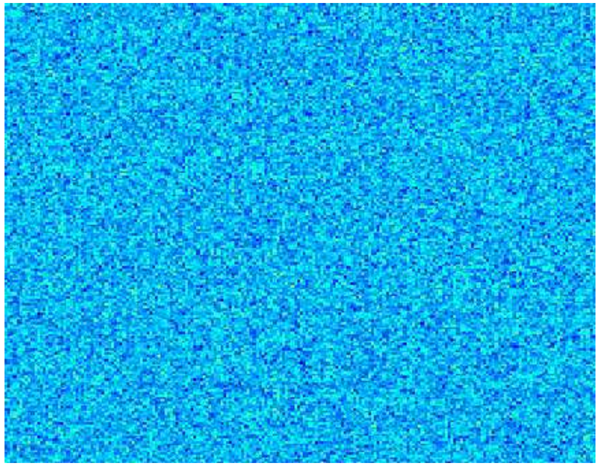
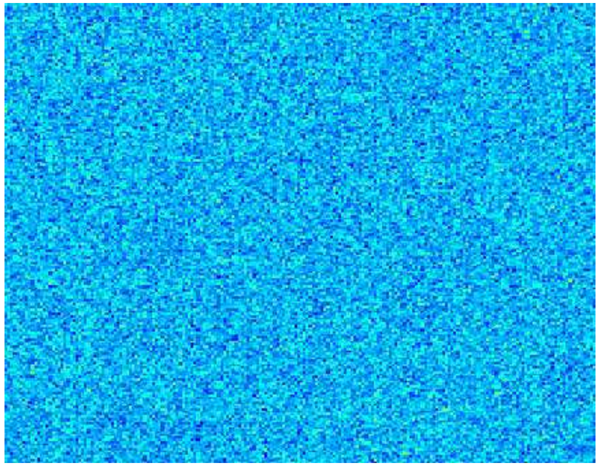
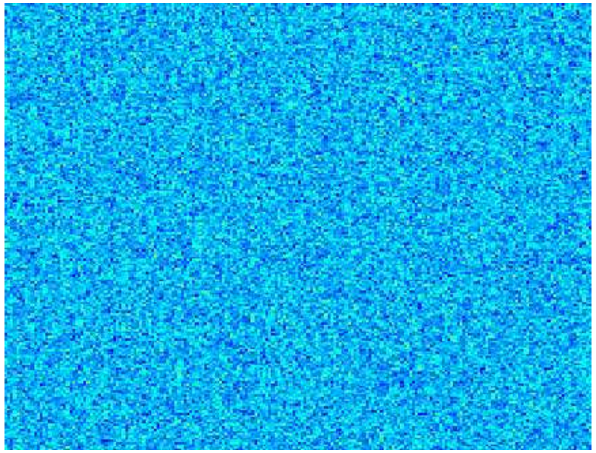


Synchronization Stability Measure

$$\Gamma_{a,b}(\mathcal{X}) := \frac{1}{M} \left| \sum_{m=1}^{M} e^{\imath \arg((\mathcal{W}_\psi x_m)(a,b))} \right|$$

DJ Strauss, W Delb, R D'Amelio, YF Low and P. Falkai. Objective quantification of the tinnitus decompensation by synchronization measures of auditory evoked single sweeps. IEEE TNSRE (2008)

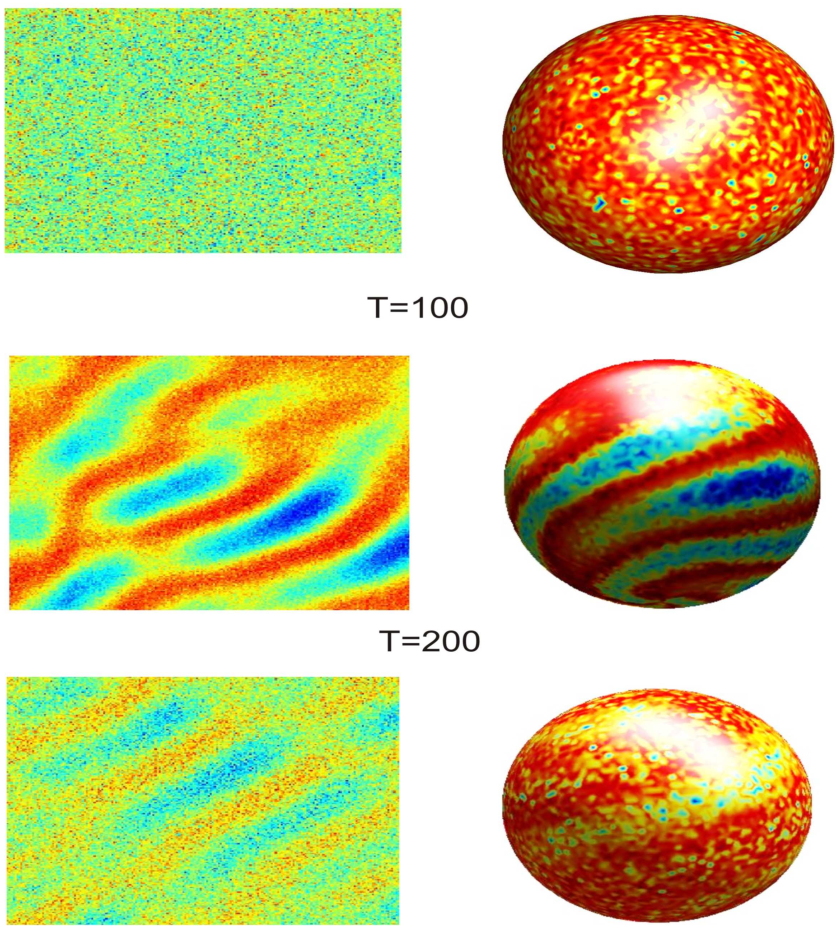
Results: cortical activity

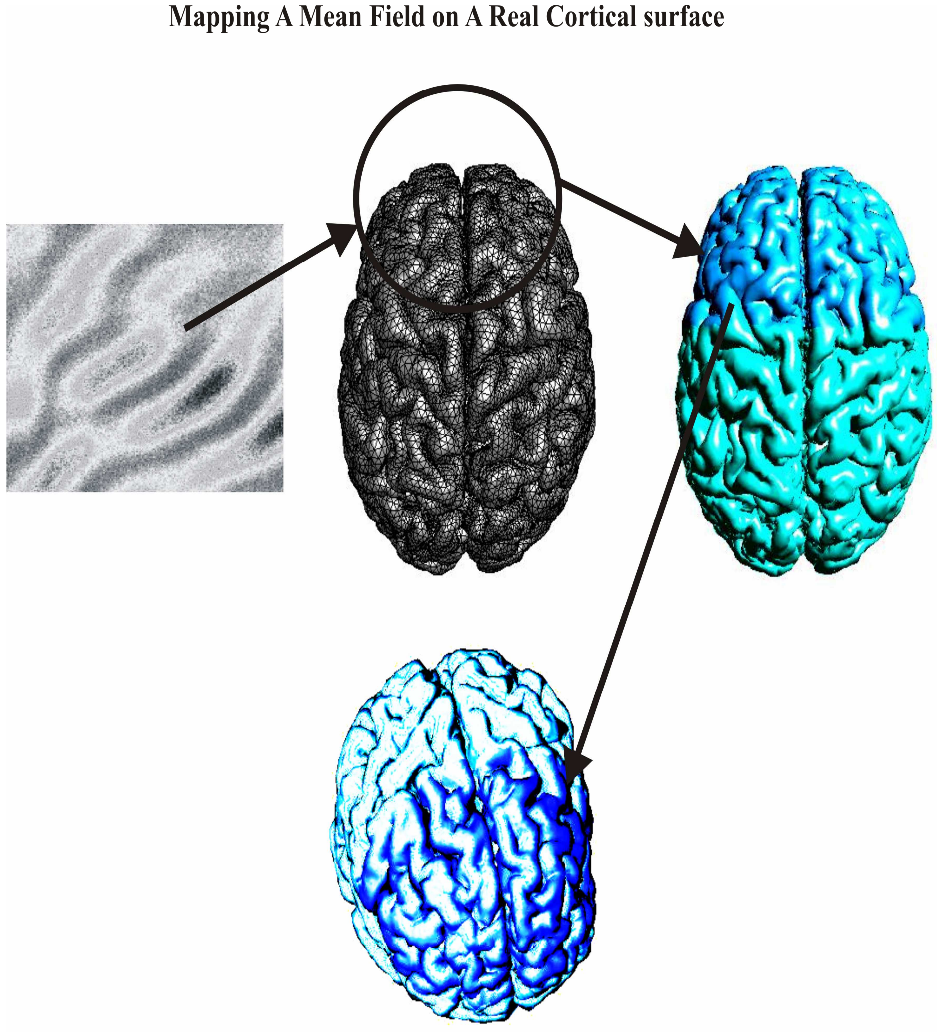
	Excitatory	Inhibitory
Attended		
Unattended		

Cortical Activity Mappings

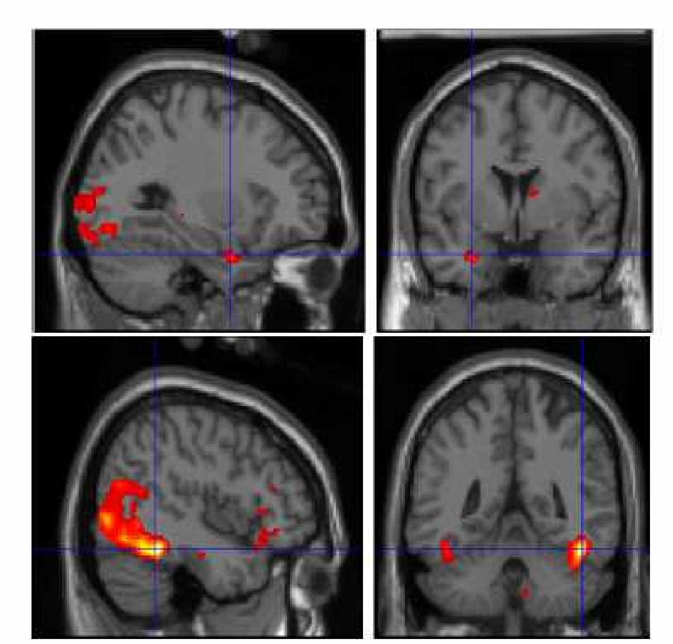
NEURAL EXCITATORY ACTIVITY
ON 2D (PLANE) AND SPHERICAL
CORTEX

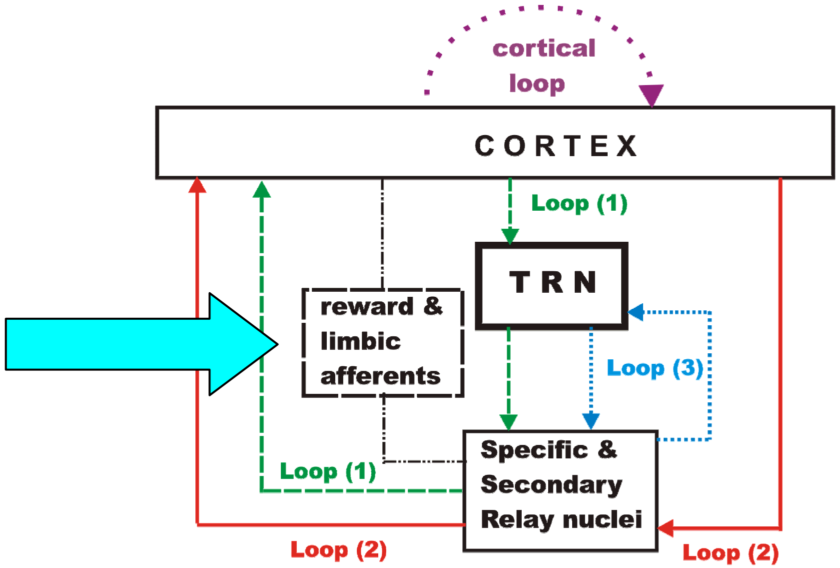
T=0-20





Large-Scale Evoked Potential Model

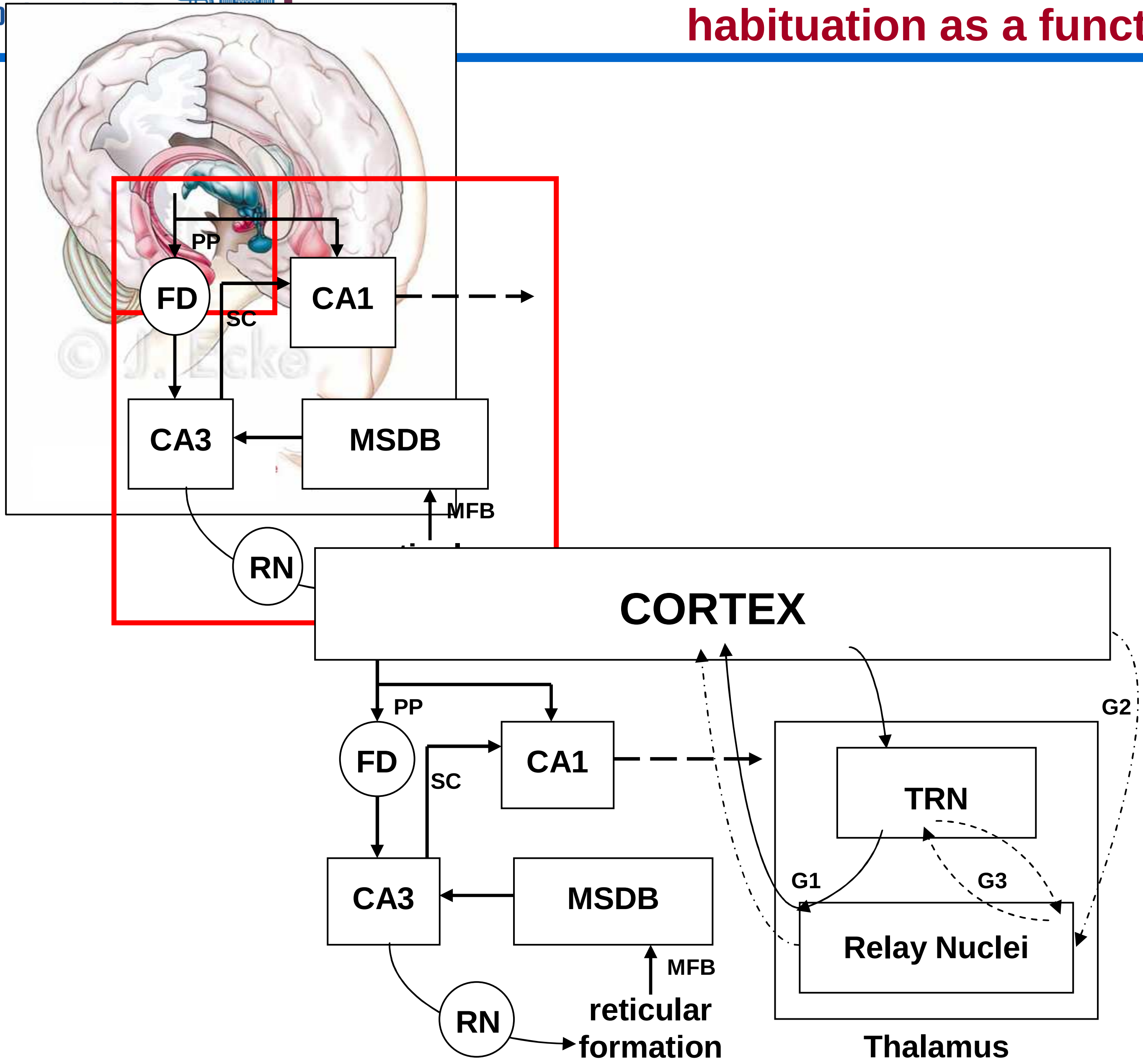




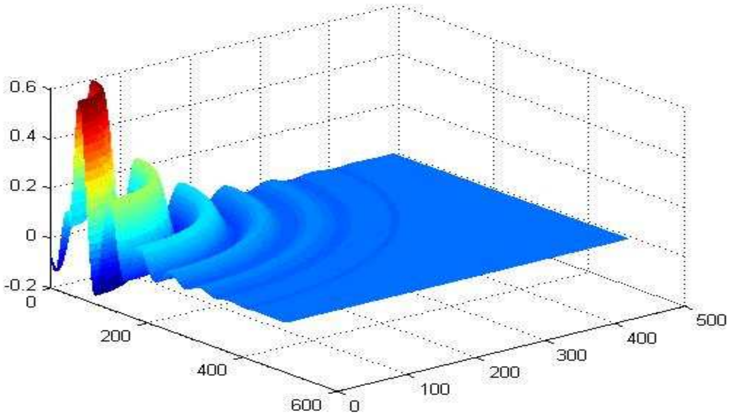
Trenado, Haab, and Strauss model.
2007

fMRI shows evidence of the involvement of the limbic system (Emotions)

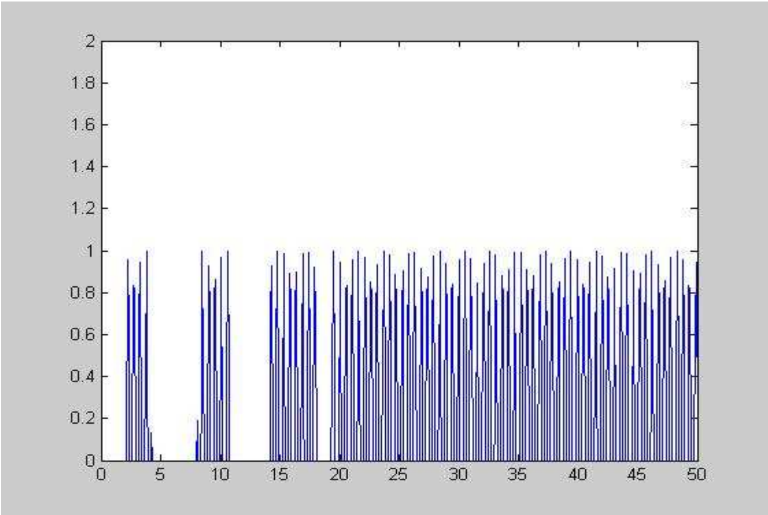
assembling a model of attention and habituation as a function of novelty



Habituation

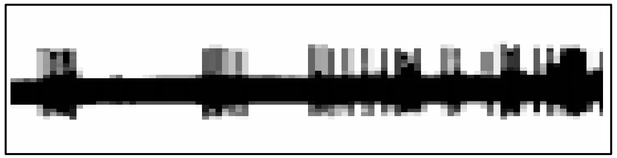


Examples of computational
hippocampal burst signals...



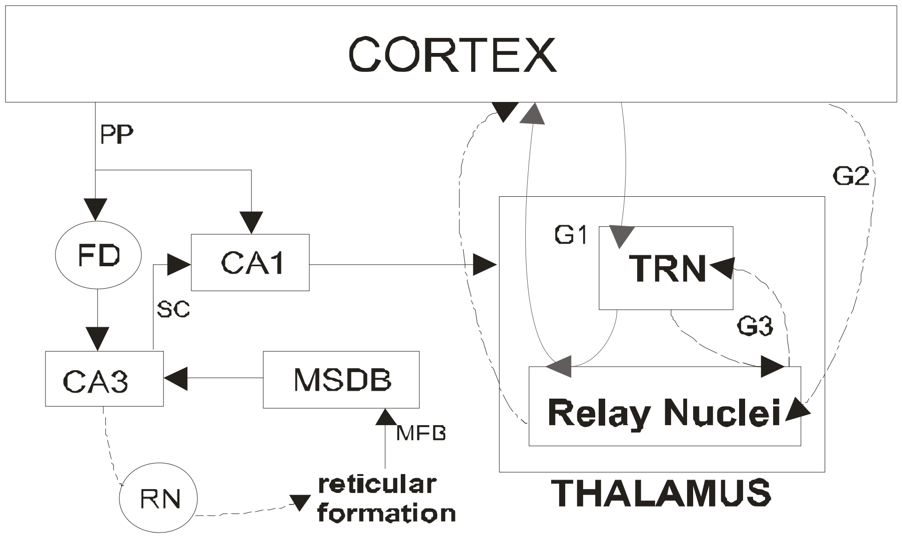
... and their experimental
analog.

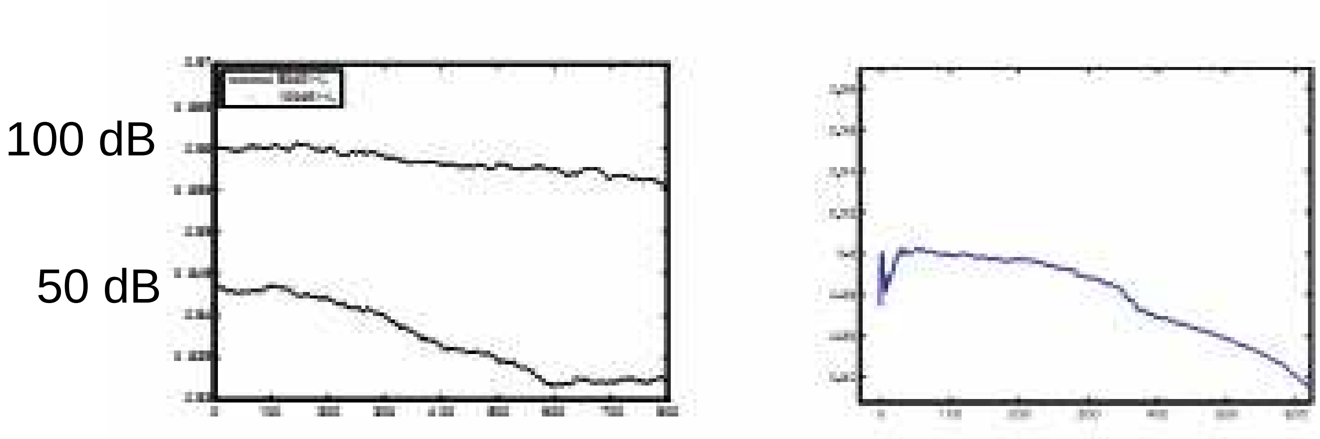
by Vinogradova et al. 2001



L Haab, C Trenado, DJ Strauss.
Neuropsychological Model of Large–Scale Correlates of Habituation and Selective Attention Driven by Stimulus Novelty. Submitted 2009

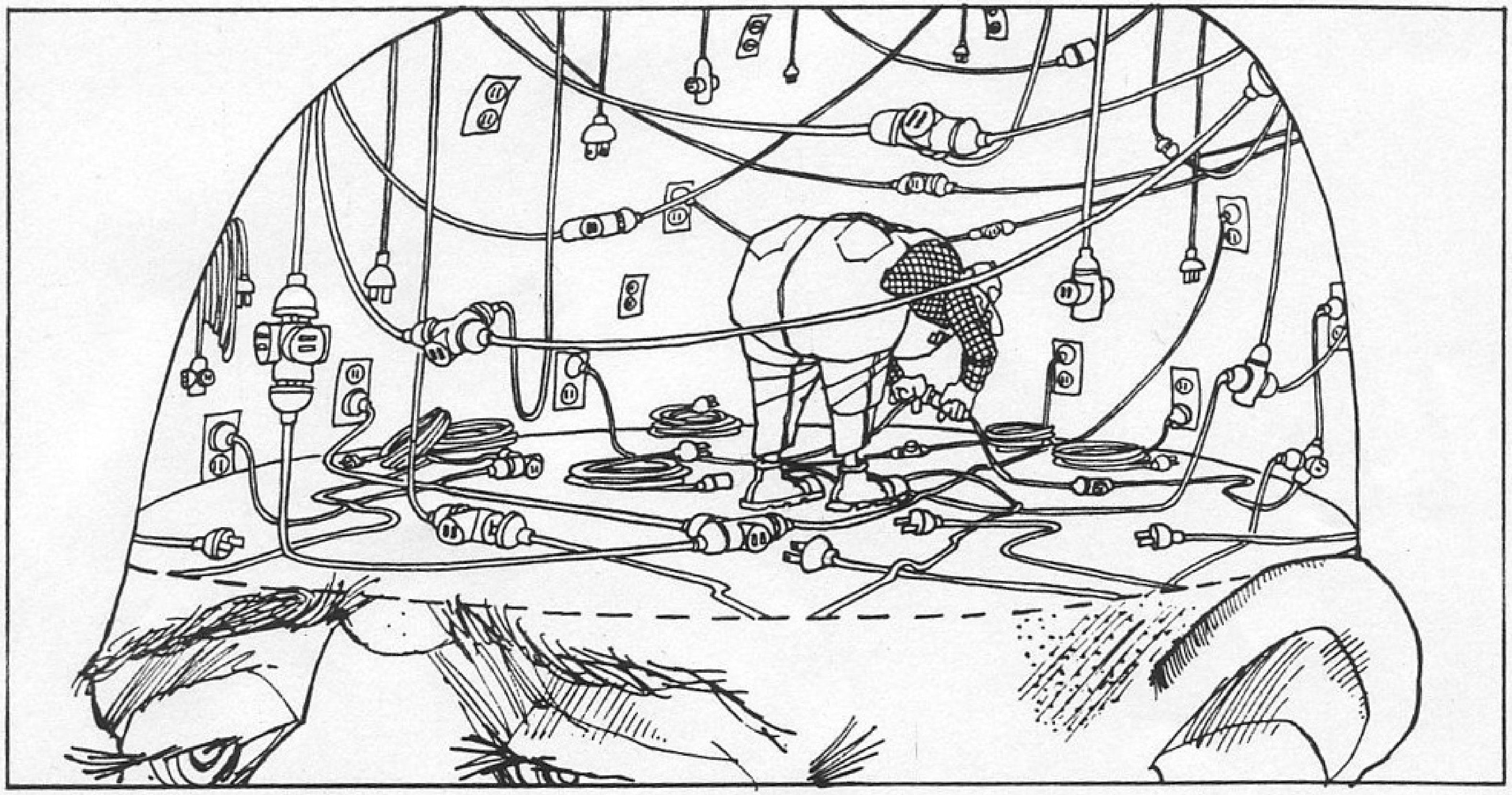
Habituation Analysis





M Mariam, W Delb, Fl. Corona-Strauss, M Bloching, DJ Strauss
Habituation of Late Latency Auditory Evoked Responses to soft and loud stimuli. Physiological Measurement. accepted 2008

My personal view about how the brain really works!!!!



How the brain works.