Influences on Consciousness From Multiple Scales of Neocortical Interactions

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Mind Over Matter

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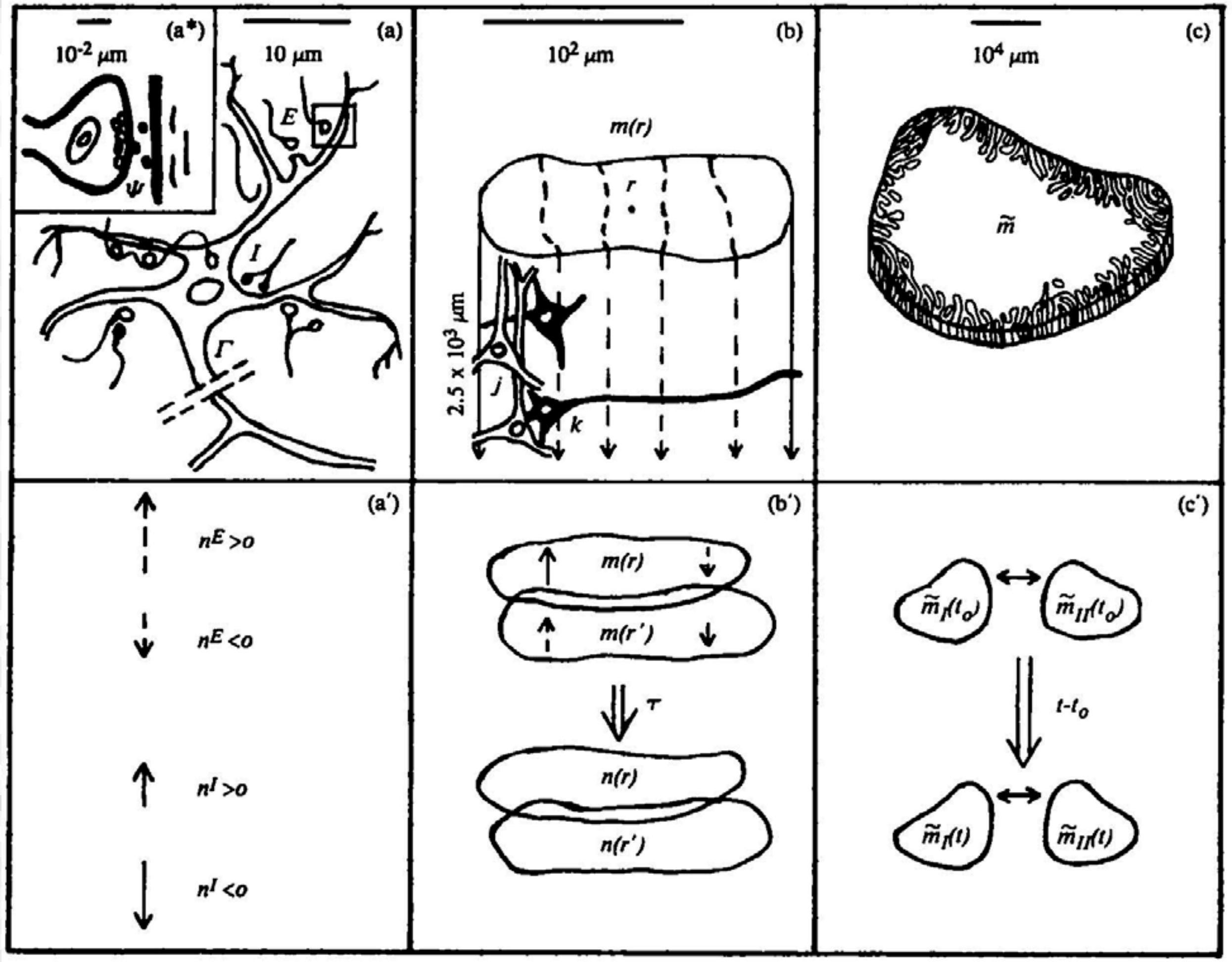
Recursive Interactions

- “Mind” ⇔ attention to short-term memory (STM) ⊂ Consciousness
- Some STM belong to synchronized firings measured by scalp EEG
- Synchronized firings → widespread magnetic vector potential **A**
- Ingber *et al* (2014)** calculate influence of **A** on momentum **p** of Ca^{2+} waves at astrocyte-neuron sites
- EEG → **A** → **p** → synaptic interactions → EEG

** http://ingber.com/smni14_eeg_ca.pdf doi:10.1016/j.jtbi.2013.11.002

Scales of Neocortical Interactions

Neuronal Scales of Neocortical Interactions



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SMNI

- Statistical Mechanics of Neocortical Interactions (SMNI)
  - Progression of aggregation of probability distributions
- Synaptic interactions via quantal transmissions
- Neuron-neuron interactions across minicolumns & macrocolumns
  - Minicolumn of hundreds of neurons
  - Macrocolumn of thousands of minicolumns
- Macrocolumnar aggregation to regions (scalp EEG scales)
  - Region of thousands of macrocolumns
  - About 15-20 billion neurons in cerebral cortex

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Interactions Among Scales

- Include molecular and quantum scales
  - Ca^{2+} ions
- Research into interactions across multiple scales
  - Interactions between the largest scalp EEG scale and the smallest Ca^{2+} scale?

SMNI Successes

- Short-term memory (STM) is calculated
- STM duration and stability
- STM capacity rules of 7±2 (auditory) and 4±2 (visual)
- STM primacy versus recency rule (first > last > middle)
- Hick’s law: g-factor linear time to access sets of STM
- Rate of minicolumnar information diffusion (nearest neighbors)
  - Short-ranged unmyelinated within epochs of long-ranged myelinated fibers
- Scaled up to fit scalp EEG data

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Coding of Neuronal Information

- Firing patterns among neurons
  - Assumed by SMNI since 1980
  - Recent experimental confirmation
- Synfire synchronized firings in laminae
- Astrocytes (a class of glial cells)
  - Paramagnetic and diamagnetic encoding
- Quantum-mechanical encoding in microtubules
- Etc.

Tripartite Neuron-Astrocyte-Neuron

- Astrocytes are an important class of glial cells that nourish neurons
- They are a major source of Ca^{2+} waves
  - Up to tens of thousands of free unbuffered ions represent ~ 1% of wave
  - Concentrations up to 5 μM (μM = 10^{-3} mol/m^3)
  - Range up to 250 μm with duration up to 500 ms
  - speed 50-100 μm/s
- Influence Glutamate quantal (integral) concentrations in synaptic gaps
  - Primary excitatory neurotransmitter depolarizes and excites neurons

$\mathbf{p} + q\,\mathbf{A}$ Interactions

Regional Magnetic Vector Potential **A**

- Neocortical current **I** due to coherent synchronized firings
  - Observed values → includes all theoretical screening, etc.
- Wire model of minicolumns fit to **I** has log dependence on *r*

$$\mathbf{A} = \frac{\mu}{4\pi}\mathbf{I}\log\left(\frac{r}{r_0}\right)$$

$$\mathbf{E} = \frac{ic}{\omega}\nabla \times \mathbf{B} = \frac{ic}{\omega}\nabla \times \nabla \times \mathbf{A}$$

- Magnetic vector potential **A** ∝ **I**

Molecular Ca^{2+} Wave

- Consider only sources from regenerative processes from internal stores
  - Process involves Ca^{2+} released from IP_3R acting on other IP_3R sites
  - Process requires or affects other processes, e.g., IP_3, mGluR, mAChR, etc.
- Momentum of Ca^{2+} ions in wave with mean **p**
- $|\mathbf{p}| = 10^{-30}$ kg-m/s
- $|\mathbf{p}| < |q\mathbf{A}| = 10^{-28}$ kg-m/s

  q = -2 e where e = -1.6 10^{-19} C (charge of electron)

$\mathbf{p} + q\mathbf{A}$ Interaction

- Canonical momentum $\mathbf{\Pi} = \mathbf{p} + q\ \mathbf{A}$
  - Established in both classical and quantum physics
- Classical comparison of magnitudes of molecular $\mathbf{p}$ and regional $q\mathbf{A}$
- Quantum treatment of $\mathbf{p} + q\mathbf{A}$ for wave packet in $\mathbf{p}$-space
  - SI units ($\mathbf{p} + q/c\ \mathbf{A}$ in Gaussian units, c = light speed)
  - Many-body $\mathbf{p}$ effects not yet considered

$\mathbf{p} + q\mathbf{A}$ $\mathbf{p}$-Space Wave Function

$$\phi(p,0) = (2\pi(\Delta\mathbf{p})^2)^{-3/4} e^{-(\mathbf{p}-\mathbf{p}_0)^2/(4(\Delta\mathbf{p})^2)}$$

$$U(p,t) = e^{-i((\mathbf{p}+q\mathbf{A})^2 t)/(2m\hbar)}$$

$$\phi(p,t) = \phi(p,0)U(p,t)$$

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$\mathbf{p} + q\mathbf{A}$ $\mathbf{r}$-Space Wave Function

$$\psi(r,t) = (2\pi\hbar)^{-3/2} \int_{-\infty}^{\infty} d^3\mathbf{p}\phi(p,t)e^{i\mathbf{p}\cdot\mathbf{r}/\hbar} = \alpha^{-1}e^{-\beta/\gamma-\delta}$$

$$\alpha = (2\hbar)^{3/2}(2\pi(\Delta\mathbf{p})^2)^{3/4}\left(\frac{it}{2m\hbar} - \frac{1}{4(\Delta\mathbf{p})^2}\right)^{3/2}$$

$$\beta = \left(\mathbf{r} - \frac{q\mathbf{A}t}{m} - \frac{i\hbar\mathbf{p}_0}{2(\Delta\mathbf{p})^2}\right)^2$$

$$\gamma = 4\left(\frac{it\hbar}{2m} + \frac{\hbar^2}{4(\Delta\mathbf{p})^2}\right)$$

$$\delta = \frac{\mathbf{p}_0^2}{4(\Delta\mathbf{p})^2} + \frac{iq^2\mathbf{A}^2t}{2m\hbar}$$

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Quantum Effects in **r**-Space

- **A** influences real part of wave function ψ in **r**-space
  - Not Aharonov-Bohm effect (phase of ψ)
- Note $\mathbf{r} \rightarrow \mathbf{r} - q\,\mathbf{A}\,t\,/\,m$
- *If* persisted100 ms → displacement of 10^{-3} m = mm (macrocolumn)
  - Synaptic extent (not gap ~ nm) ~ 10^4 Å (Å = 10^{-10} m) = μm

Possible Long Time Quantum Coherence

- Several examples of extended quantum coherence in “wet” media
- Bang-bang (BB) kicks or quantum Zeno effect (QZE)

$$U_n(p,t) = [U_k U(p,t/n)]^n$$

  - A mechanism sometimes used in quantum computation
- Regenerative Ca^{2+} process is a possible mechanism for coherence

Classical and/or Quantum Effects

- Alignment of Ca^{2+} waves along **A** || **I**

$$\mathbf{\Pi} = p_x \hat{\mathbf{x}} + p_y \hat{\mathbf{y}} + (p_z + qA_z)\hat{\mathbf{z}}$$

- **A** influence on regional-averaged synaptic quantal transmissions
  - Ca^{2+} waves influence quantal transmissions influence synaptic background
  - **A** affects **p** of Ca^{2+} waves
  - **A** therefore affects background synaptic activity

SMNI Fits to EEG

Synaptic Interactions -> Neuron Firing

$$p_{\sigma j} \approx \frac{\exp(-\sigma_j F_j)}{\exp(F_j)+\exp(-F_j)}$$

$$F_j = \frac{(V_j - \sum_k a_{jk} v_{jk})}{((\pi/2)\sum_{k'} a_{jk'}(v_{jk'}^2 + \phi_{jk'}^2))^{\frac{1}{2}}}$$

$$a_{jk} = \frac{1}{2} A_{jk} + B_{jk}$$

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SMNI Lagrangian

$$P = \frac{1}{\sqrt{(2\pi dtg)}} \exp(-Ldt)$$

$$L = \sum_{G,G'} (2N)^{-1}(\dot{M}^G - g^G) g_{GG'} (\dot{M}^{G'} - g^{G'})/(2N\tau) - V'$$

$$g^G = -\tau^{-1}(M^G + N^G \tanh F^G)$$

$$g^{GG'} = (g_{GG'})^{-1} = \delta_G^{G'} \tau^{-1} N^G \text{sech}^2 F^G$$

$$g = \det(g_{GG'})$$

$$G = \{E, I\}$$

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SMNI Threshold Factor

$$F^G = \sum_{G'} \frac{\nu^G + \nu^{\ddagger E'}}{\left((\pi/2)[(v^G_{G'})^2 + (\phi^G_{G'})^2](\delta^G + \delta^{\ddagger E'})\right)^{1/2}}$$

$$\nu^G = V^G - a^G_{G'} v^G_{G'} N^{G'} - \frac{1}{2} A^G_{G'} v^G_{G'} M^{G'}$$

$$\nu^{\ddagger E'} = -a^{\ddagger E}_{E'} v^E_{E'} N^{\ddagger E'} - \frac{1}{2} A^{\ddagger E}_{E'} v^E_{E'} M^{\ddagger E'}$$

$$\delta^G = a^G_{G'} N^{G'} + \frac{1}{2} A^G_{G'} M^{G'}$$

$$\delta^{\ddagger E'} = a^{\ddagger E}_{E'} N^{\ddagger E'} + \frac{1}{2} A^{\ddagger E}_{E'} M^{\ddagger E'}$$

$$a^G_{G'} = \frac{1}{2} A^G_{G'} + B^G_{G'} \,, \; a^{\ddagger E}_{E'} = \frac{1}{2} A^{\ddagger E}_{E'} + B^{\ddagger E}_{E'}$$

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Intuitive Lagrangian L of Firings M

$$\text{Mass} = g_{GG'} = \frac{\partial^2 L}{\partial(\partial M^G/\partial t)\partial(\partial M^{G'}/\partial t)}$$

$$\text{(Canonical) Momentum} = \Pi^G = \frac{\partial L}{\partial(\partial M^G/\partial t)}$$

$$\text{Force} = \frac{\partial L}{\partial M^G}$$

$$\delta L = 0 = \frac{\partial L}{\partial M^G} - \frac{\partial}{\partial t}\frac{\partial L}{\partial(\partial M^G/\partial t)}$$

$$\text{F} - \text{ma} = 0$$

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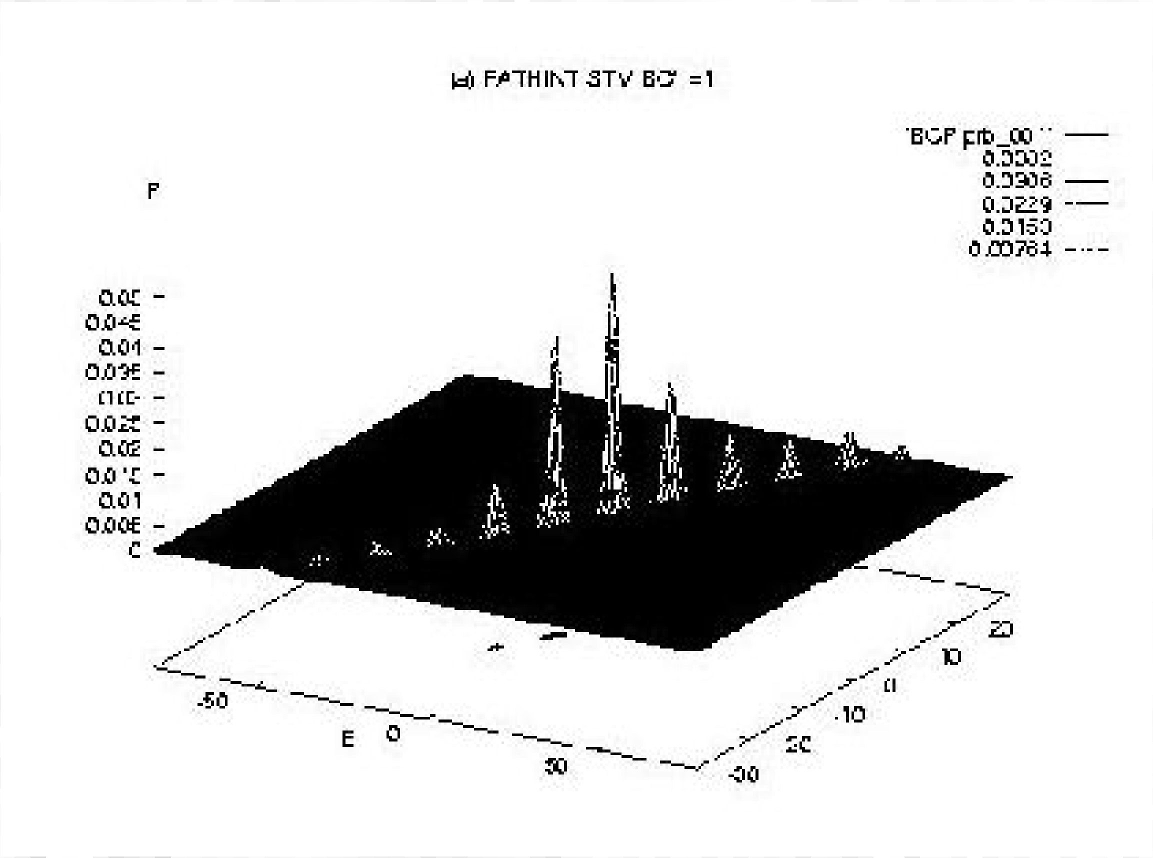
Fits to EEG to Test **A** Influences

- SMNI conditional probability of firing *P*
  - SMNI Lagrangian *L* function of firings *M(t)*
    - All parameters taken within experimentally observed ranges
  - SMNI "threshold factor" F^G argument of nonlinear means and covariance
    - Columnar parameters in F^G have audit trail back to neuronal parameters in F_j
- Scales of application of Lagrangian
  - STM mesocolumn (converge to minicolumn; diverge to macrocolumn)
  - SMNI *L* scaled to scalp EEG using Canonical Momentum Indicators (CMI)

Centering Mechanism (CM)

- Shift background noise *B* in synaptic interactions
  - Shifts are consistent with experimental observations of selective attention
- Shift *B* to keep $F \propto M$ in numerator (no constant offset)
  - Minima typically driven to small values of $A_E^{\ E} M^E - A_I^{\ E} M^I$
    - Defines “trough” along line in *M* firing space
  - Maximizes number of minima within firing boundaries
  - STM firing patterns appear within a sea of “noise”

PATHINT STM With CM



Dependence of Synaptic Background *B* on **A**

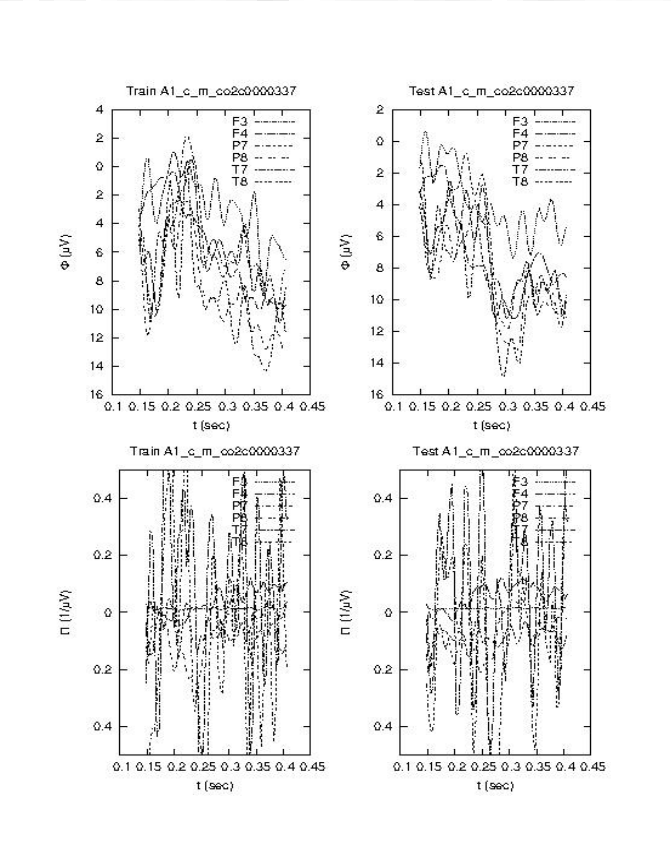
- Quantal mean of mesocolumnar average
  - $a = ½ A + B$
  - *A* is coefficient of firings
  - *B* is background "noise"
    - Influenced by astrocytes Ca^{2+} waves
- Model **A** influence as $B(\mathbf{A}) = B_0 + B_1 |\mathbf{A}| + \ldots$
  - $\mathbf{A} \propto \mathbf{I} \propto \mathbf{\Phi}$
    - $\mathbf{\Phi}$ is EEG electric potential at previous *t* for these fits
- **A** model uses Dynamic Centering Mechanism (DCM) at each *t*-epoch

Calculations

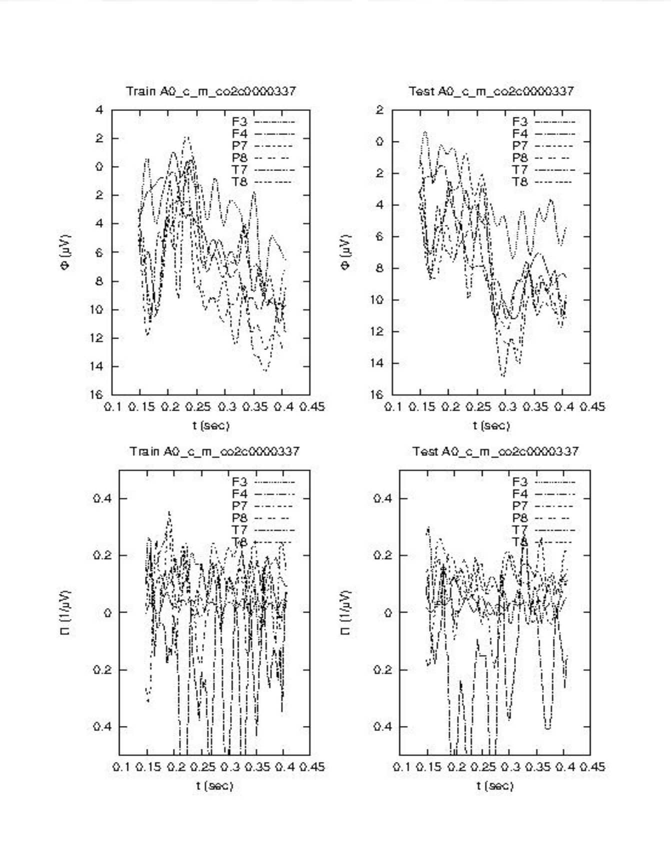
- EEG Data: http://kdd.ics.uci.edu/databases/eeg/
  - Collected by Henri Begleiter in large NIH alcoholism study
  - Entered into KDD database by Lester Ingber in 1997
    - Knowledge Discovery in Databases merged with http://archive.ics.uci.edu/ml/
  - Paradigms to test attentional states during P300 events
- Train in-sample to *L* and test out-of-sample
  - Sensitive Canonical Momenta Indicators (CMI)
- **A** model has stronger signal than no-**A** model
  - similar to aggregated data over 11,075 runs

A Versus No-**A** Models

A model



No-**A** model



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Supplementary Analysis

Marco Pappalepore and Ronald Stesiak:

See http://ingber.com/smni14_eeg_ca_supp.pdf

Careful examination of 60 sets of data for both Training and Testing evaluated the efficacy or improvements of the CMI when comparing to the raw EEG data

Many definitively positive improvements with the **A** model were observed, both when comparing to the EEG data and the no-**A** model

Computational Algorithms

Adaptive Simulated Annealing (ASA)

- http://www.ingber.com
  - http://alumni.caltech.edu/~ingber
  - http://asa-caltech.sourceforge.net
  - https://code.google.com/p/adaptive-simulated-annealing
- C-language importance-sampling for global fit over *D*-dimensional space
- ASA annealing temperature exponentially decreasing *T* schedule
  - Faster than fast Cauchy annealing with polynomial decreasing *T* schedule
  - Much faster than Boltzmann annealing with logarithmic decreasing schedule
- Over 100 OPTIONS provide robust tuning since 1989 (VFSR → ASA)
- ASA_PARALLEL OPTIONS hooks uses OpenMP

PATHINT & PATHTREE

- Time path-integral of short-time conditional multivariate probability
- PATHINT parallel hooks developed as PI 1994 NSF PSC project
- PATHINT → PATHTREE is fast accurate binomial tree
- Natural metric of the space is used to lay down the mesh
- Short-time probability density accurate to O($\Delta t^{-3/2}$)
- Tested in finance, neuroscience, combat analyses, and selected nonlinear multivariate systems
- PATHTREE used extensively to price financial options

Calculations on XSEDE.org

- Author is PI of NSF.gov XSEDE.org supercomputer project
  - NSF Extreme Science & Engineering Discovery Environment

- Adaptive Simulated Annealing (ASA) fit SMNI to EEG data
  - 6 CPU-hrs for each of 120 train-test runs = cumulative CPU-month+
  - 6 CPU-hrs for all runs on XSEDE in parallel using MPI

Outlook

Tentative Conclusions

- Top-down interactions → "Mind Over Matter"
  - Regional patterns of coherent firings ⇔ Selective Attention
  - Attention ⊂ Consciousness
  - Attention influences molecular scales via $\mathbf{p} + q\mathbf{A}$
    - Certainly in domain of classical physics
    - Possibly in domain of quantum physics
- SMNI support for $\mathbf{p} + q\mathbf{A}$ interactions at tripartite synapses
  - DCM control of background synaptic activity B
  - Control of STM during states of selective attention

Future Research

- Tripartite models that influence synaptic background $B(\mathbf{A})$
  - Test models of **A** influences on *B* by fits to EEG data
- Coherence times for “beams” of Ca^{2+} waves
  - PATHINT and PATHTREE codes
- Experimental confirmation is essential
- Volunteers welcome on XSEDE.org platforms
  - http://ingber.com/lir_computational_physics_group.html

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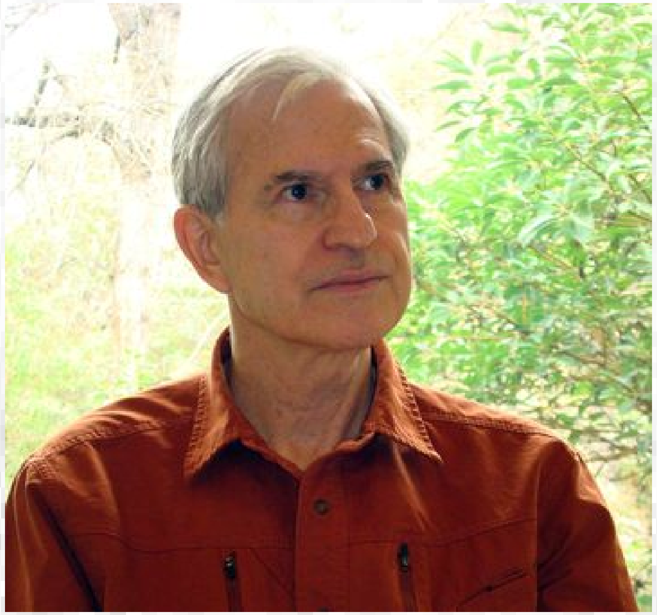
Lester Ingber

Published over 100 papers and books in:
theoretical nuclear physics, neuroscience, finance,
optimization, combat analysis, karate, and education



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