Quantum Variables in Finance and Neuroscience
Lester Ingber ***https://www.ingber.com***

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1. Abstract

Quantum computation is here, and the use of quantum variables per se in everyday life is not far behind. Enhancing classical algorithms with quantum variables illustrates applications to (a) quantum options on quantum money — featuring more efficient encryption and verification, and to (b) describing quantum astrocyte-neuron interactions with classical synchronous EEG — with potential for nano-robotic enhancement of brain physiology. Each system contributes to the use of these algorithms to the other system.

$Id: https://www.ingber.com/path18_qpathint_lecture.pdf 1.19 2017/11/15 17:08:00 ingber Exp ingber $

2. Quantum Computing is Here

D-WAVE (Canada)
DeepMind (Canada)
Facebook
Google
IBM
Intel
Microsoft
National Laboratory for Quantum Information Sciences (China)
NOKIA Bell Labs
NSA
Post-Quantum
Rigetti
Russian Quantum Center
Toshiba
Quantum Circuits
Quantum Technologies (European Union)

3. Quantum Variables are Coming

3.1. Finance

3.1.1. Quantum Money

3.1.2. Quantum Options on Quantum Money

3.2. Neuroscience

3.2.1. Quantum Processes at Neuronal Synapses

Interactions with Synchronous Neuronal Firings

3.2.2. Nano-Robotic Applications

3.3. Cross-Discipline Common Algorithms — Lessons Learned

4. Statistical Mechanics of Financial Markets (SMFM)

4.1. Previous Applications — PATHINT

4.1.1. American Options

4.1.2. Volatility of Volatility

4.2. Quantum Money

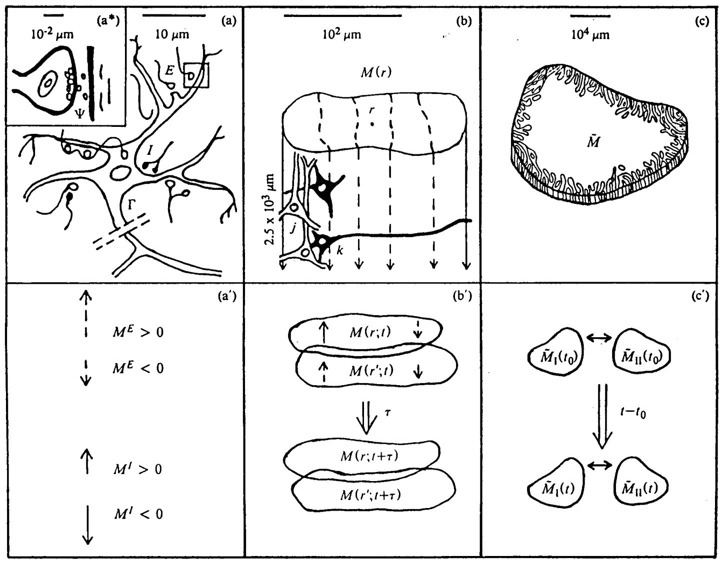
Enhanced Security
Efficient Verification

4.3. Quantum Options — qPATHINT

4.3.1. Extend PATHINT with Quantum Variables

5. Statistical Mechanics of Neocortical Interactions (SMNI)

Artificial Neural Nets (ANN) — Impressive, Not Human
Include Patterns of Highly Synchronous Neural Firings
Include Astocytes



5.1. Previous Applications

5.1.1. Short-Term Memory

Capacity, Duration, Hick's Law

5.1.2. Electroencephology (EEG)

Fit Highly Synchronous Waves (P300) During Attentional Tasks

5.2. Include Tripartite Interactions — Neuron<->Astrocyte<->Neuron

Regenerative Ca^{2+} Waves

6. qPATHINT

6.1. Path Integrals

For conditional probability distributions or for wave functions:

$$P[q_t|q_{t_0}]dq(t) = \int \cdots \int Dq \exp\left(-\min \int_{t_0}^{t} dt' L\right)\delta(q(t_0) = q_0)\delta(q(t) = q_t)$$

$$Dq = \lim_{u\to\infty} \prod_{\rho=1}^{u+1} g^{1/2} \prod_i (2\pi\Delta t)^{-1/2} dq_\rho^i$$

$$L(\dot{q}^i, q^i, t) = \frac{1}{2}(\dot{q}^i - g^i)g_{ii'}(\dot{q}^{i'} - g^{i'}) + R/6$$

$$g_{ii'} = (g^{ii'})^{-1} \ , \ g = \det(g_{ii'})$$

Here the diagonal diffusion terms are g^{ii} and the drift terms are $g^i = -\partial\Phi/\partial q^i$. If the diffusions terms are not constant, then there are additional terms in the drift, and in a Riemannian-curvature potential $R/6$ for dimension > 1 in the midpoint Stratonovich/Feynman discretization.

Three basic different approaches are mathematically equivalent: (a) Fokker-Planck/Chapman-Kolmogorov partial-differential equations; (b) Langevin coupled stochastic-differential equations; (c) Lagrangian or Hamiltonian path-integrals.

The path-integral approach is particularly useful to precisely define intuitive physical variables from the Lagrangian L in terms of its underlying variables q^i:

Momentum: $\Pi^i = \dfrac{\partial L}{\partial(\partial q^i/\partial t)}$

Mass: $g_{ii'} = \dfrac{\partial L}{\partial(\partial q^i/\partial t)\partial(\partial q^{i'}/\partial t)}$

Force: $\dfrac{\partial L}{\partial q^i}$

$F = ma$: $\delta L = 0 = \dfrac{\partial L}{\partial q^i} - \dfrac{\partial}{\partial t}\dfrac{\partial L}{\partial(\partial q^i/\partial t)}$

7. Lessons Learned

7.1. SMFM

$$d\Pi = \sigma\left(\frac{\partial V}{\partial S} - \Delta\right)dX + \left(\mu S \frac{\partial V}{\partial S} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + \frac{\partial V}{\partial t} - \mu \Delta S\right)dt$$

$$\Gamma = \frac{\partial^2 \Pi}{\partial S^2}\ , \ \Theta = \frac{\partial \Pi}{\partial t}\ , \ \Upsilon = \frac{\partial \Pi}{\partial \sigma}\ , \ \rho = \frac{\partial \Pi}{\partial r}$$

The portfolio Π to be hedged is often considered to be "risk-neutral," if Δ is chosen such that $\Delta = \frac{\partial V}{\partial S}$.

Calculate at Each Node of Each Time Slice — Back in Time
SMNI => Require Broad Band
PATHTREE Comparison

7.2. SMNI

After a statistical-mechanical aggregation of synaptic, neuronal and columnar scales, the SMNI Lagrangian L in the prepoint (Ito) representation is

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

$$g^G = -\tau^{-1}(M^G + N^G \tanh F^G)\ , \ g^{GG'} = (g_{GG'})^{-1} = \delta_G^{G'} \tau^{-1} N^G \operatorname{sech}^2 F^G\ , \ g = \det(g_{GG'})$$

where $G = \{E, I\}$ for chemically independent excitatory and inhibitory synaptic interactions. All values of parameters were taken within ranges of experimental data.

Without random shocks, the wave function ψ_e representing the interaction of the EEG magnetic vector potential $\mathbf{A}$ with the momenta $\mathbf{p}$ of Ca^{2+} wave packets was derived to be

$$\psi_e(t) = \int d\mathbf{r}_0\ \psi_0\ \psi_F = \left[\frac{1 - i\hbar t/(m\Delta \mathbf{r}^2)}{1 + i\hbar t/(m\Delta \mathbf{r}^2)}\right]^{1/4} \left[\frac{1}{\pi \Delta \mathbf{r}^2 [1 + (\hbar t/(m\Delta \mathbf{r}^2))^2]}\right]^{1/4} \exp\left[-\frac{[\mathbf{r} - (\Pi_0 + q\mathbf{A})t/m]^2}{2\Delta \mathbf{r}^2}\ \frac{1 - i\hbar t/(m\Delta \mathbf{r}^2)}{1 + (\hbar t/(m\Delta \mathbf{r}^2))^2} + i\ \frac{\Pi_0 \cdot \mathbf{r}}{\hbar} - i\ \frac{(\Pi_0 + q\mathbf{A})^2 t}{2\hbar m}\right]$$

where ψ_0 is the initial Gaussian packet, ψ_F is the free-wave evolution operator, $\hbar$ is the Planck constant, q is the electronic charge of Ca^{2+} ions, m is the mass of a wave-packet of 1000 Ca^{2+} ions, $\Delta \mathbf{r}^2$ is the spatial variance of the wave-packet, the initial canonical momentum is $\Pi_0 = \mathbf{p}_0 + q\mathbf{A}_0$, and the evolving canonical momentum is $\Pi = \mathbf{p} + q\mathbf{A}$. Detailed classical and quantum calculations have shown that $\mathbf{p}$ of the Ca^{2+} wave packet and $q\mathbf{A}$ of the large-scale EEG field make about equal contributions to Π.

SMFM => Calculate at Each Node of Each Time Slice — Forward in Time

8. Applications

8.1. SMNI

Torque-Sensitive Nano-Robots Directed to Ca^{2+}-Wave synapse-sites
Control of Synaptic Interactions Coupled to Highly Synchronous Neuronal Firing

8.1.1. Free Will

In addition to the intrinsic interest of researching STM and multiple scales of neocortical interactions via EEG data, there is interest in researching possible quantum influences on highly synchronous neuronal firings relevant to STM to understand possible connections to consciousness and “Free Will” (FW).

If neuroscience ever establishes experimental feedback from quantum-level processes of tripartite synaptic interactions with large-scale synchronous neuronal firings, that are now recognized as being highly correlated with STM and states of attention, then FW may yet be established using the Conway-Kochen quantum no-clone “Free Will Theorem” (FWT).

Basically, this means that a Ca^{2+} quantum wave-packet may generate a state proven to have not previously existed; quantum states cannot be cloned.

8.2. SMFM

Market Place will Determine Traded Variables
VIX Example, Proxy for Volatility of Volatility of Specific Markets

8.2.1. Enhanced Security/Verification

As in SMNI, here too the core of the quantum no-clone “Free Will Theorem” (FWT) theorem can have important applications. Quantum currency cannot be cloned. Such currencies are exceptional candidates for very efficient blockchains, e.g., since each “coin” has a unique identity.

As in SMNI, here too there are issues about the decoherence time of such “coins”.