The Role of Noise in Living Systems

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Dedicated to my Beloved Friend Vito
OVERVIEW

- Why we Need to Understand Noise?
- Mathematical description of noise.
- Origins of Noise
- Stochastic Resonance and Physical System
- Stochastic Resonance and Biological System
- Principle of Least Time and Sum Over History Approach
- Cancellation of Internal and External Noises in Brain
Collaborators

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Why we Need to Understand Noise

- Noise is often a **limiting factor for the performance** of a device or system.
  Examples: transmission rate of telecommunication system limited by the need to keep the bit error rate low enough; sensitivity of measurements is limited by noise.
- Efficient product development often requires
  - quantification of noise from components
  - calculation of noise effects on system performance
- Noise issues can have an important impact on system cost.
  Example: by choosing the right measurement scheme, which is less sensitive to noise, one might do the job with a less costly laser system.
Definition of Noise

- Noise is a *RANDOM PROCESS*
- The value of noise can *not* be predicted at any time
- The *average power* for most types of noise is predictable by observing noise over a long time
Mathematical Description of Noise

- Noise of devices or systems needs to be reliably quantified. Reason: designs based on properly quantified noise properties save development time and cost by eliminating trial & error.
- This requires correct measurements, but also correct and helpful specifications.
- Specification and comparison of noise properties is not trivial due to:
  - manifold types of quantities
    (power spectral densities, correlation functions, probability distributions, etc.)
  - mathematical difficulties
    (related to divergent quantities, required approximations, statistics, etc.)
  - inconsistent notations in the literature
    (different sign conventions, one- or two-sided power spectral densities, $f$ or $\omega$ variables, $2\pi$ issues, etc.)

Only a real expert can do reliable and efficient work in this field.
Quantitative Definition of Noise Statistical Models

Probability Density Function (PDF): $p(n)$

$p(n) \, dn = \text{probability of \ } n_1 < n < n_1 + dn$

$$\int_{n_1}^{n_2} p(n) dn = P( n_1 < n < n_2 )$$

$$\int_{-\infty}^{+\infty} p(n) dn = 1$$
Average Noise Power

For a periodic \((T)\) voltage signal \(v(t)\) across a load \(R_L\):

\[
P_{av} = \frac{1}{T} \int_{-T/2}^{+T/2} \frac{v^2(t)}{R_L} dt
\]

\[
P_{av} = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{+T/2} \frac{x^2(t)}{R_L} dt
\]

\[
P_{av} = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{+T/2} \frac{x^2(t)}{R_L} dt
\]

\[
\overline{n^2(t)} = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{+T/2} n^2(t) dt
\]
Mathematical Description of Noise

\[ S(\omega) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} G(\tau) e^{i\omega \tau} \, d\tau \]

\[ G(\tau) = \langle P(t)P(t+\tau) \rangle \]

\[ \sigma_P^2 \equiv \left\langle P(t)^2 \right\rangle = G(0) = \int_{-\infty}^{+\infty} S(\omega) \, d\omega \]

\[ \left\langle |\phi(T) - \phi(0)|^2 \right\rangle = 2T / \tau_{\text{coh}} \]

\[ \sigma_{ec}^2 = \frac{1}{f_0^4} \int_{-\infty}^{+\infty} f^2 S_{\phi}(f) \operatorname{sinc}^2 \left( \pi \frac{f}{f_0} \right) \, df \]
Distribution of Probability Density Function (PDF): $p(n)$

$$p(n) = \frac{1}{\sqrt{2\pi}\sigma_n} \exp\left[-\frac{1}{2} \frac{n^2}{\sigma_n^2}\right]$$

$$\int_{-\sigma_n}^{+\sigma_n} p(n) \, dn = 0.68$$

$$P(-\sigma_n < n < +\sigma_n) = 0.68$$
Noise in Time Domain

Noise is expressed as a Fourier Series over a period $T$:

$$n(t) = \sum_{K=-\infty}^{K=\infty} X_K \exp\left[j \frac{2\pi K}{T} t \right]$$

$$\overline{n(t)} = \sum_{K=-\infty}^{K=\infty} X_K \exp\left[j \frac{2\pi K}{T} t \right] = \overline{X_0}$$

$$\overline{n^2(t)} = \overline{X_0^2} + 2 \sum_{K=1}^{K=\infty} \overline{X_K X_K^*}$$
Noise in the Frequency Domain

Noise average power in a 1 Hz bandwidth around a frequency $f_1$: $S_n(f_1)$
Origins of Noise

- **Thermal fluctuations**: often an important source of noise in electronic circuits, e.g. in photodiode preamplifiers
- **Other electronic noise**, e.g. flicker noise: various sources; may critically depend on parts used
- **Quantum noise**: often important in optical devices, e.g. shot noise in photodetection or intensity and phase noise in lasers
- **Mechanical noise**: e.g. in the form of vibrations which can couple to optical or electronic parameters
Types of Noise

• **External Noise**
  – May be of random or regular nature from outside sources
  – Interaction between the circuit and the outside world
  – Interaction between different parts of circuit

• **Internal Noise**
  – Random signals due to the natural phenomenon
Spectral density functions of above noise samples:

- notice log-scale on both axes → slope gives exponent $\gamma$
- different power law behavior of noise samples is apparent
- numerical analysis confirms exponents that are suggested by creator
Comparison to Other Types of Noise

Comparison of white noise, pink noise and red noise:
Let’s look at and listen to some signals
(from http://whitenoisemp3s.com, length: 1 second)

- White noise ($\gamma = 0$); constant variance, correlation function is $\sim \delta(t)$

- Pink noise ($\gamma = -1$); variance increases like $1 + \ln(t/\tau)$, correlation function decreases only slowly

- Red noise ($\gamma = -2$, ”Random Walk”); variance increases linearly with time, constant correlation function
Astronomers refer to these stochastic fluctuations as “signal” while the most common terminology for this in other fields known as “noise”.

**FIGURE 3** Random-walk noise. The derivative of this noise is white noise as in Figure 2. Random-walk noise has a power spectrum $= 1/f^1$.

**FIGURE 4** Flicker noise or $1/f$ noise. The power spectrum of this noise ($= 1/f$) has a divergent integral at both high and low frequencies.
Flicker Noise in AStronomy

*FIGURE 1*  Light curve of the quasar 3C273 over a period of 80 years, from 1887 to 1967. The data of Kunkel is here plotted by hundred-day averages; the ordinate is in arbitrary intensity units. (Reproduced from Pohlmann and Ulrych).
Names and Terminology

Other common names for 1/f noise in literature:
- 1/f type noise, $S(f) \sim f^\gamma$, with $\gamma \approx -1$
- low frequency noise
- pink noise (analogy to optic spectra)
- excess noise
- flicker noise

What do we mean by "low frequencies"?

1/f type noise is typically dominant below corner frequency $f_c \lesssim 10^2 \ldots 10^6$ Hz.
Occurrence of $1/f$ Noise

Where does $1/f$ noise occur? What quantities are affected? – Answer: Almost everything you can imagine!
Examples:

- measured quantities of electric circuits and components $(I, U, R)$
- frequency of quartz crystal oscillators; affects time measurement precision
- rate of traffic flow on highways
- astronomy: number of sunspots apart from regular cycles, light intensity of stellar objects (e.g. quasars)
- loudness and pitch of music and speech
- economic and financial data
- biological systems
- and many, many more...
Statistical Properties of 1/f Noise

Paradox of infinite power:

- variance = total power contained in fluctuations of $x$

$$\sigma_x^2(f_l, f_h) = \int_{f_l}^{f_h} S_x(f) df \sim \ln \frac{f_h}{f_l}$$

- $\Rightarrow$ total power diverges at both frequency limits $f_l \to 0$ and $f_h \to \infty$
- this paradox has not yet been resolved!
- upper limit not a problem, since $f_h$ never accessible to measurement due to dominant white noise
- for lower limit, no cutoff frequency was ever observed; analyses have shown no deviations down to $10^{-6.3}$Hz in operational amplifiers [Caloyannides, 1974]
Noise Modeling

The graph shows the noise power relative to QNL in dB as a function of frequency (Hz). The graph includes the following components:

- **Red line (pump noise, +30 dB)**
- **Blue line (quantum noise)**
- **Black line (total)**

The graph highlights the following contributions:

- Dipole fluctuations & vacuum fluctuations from OC
- Vacuum fluctuations from OC

The x-axis represents frequency in Hz, and the y-axis represents noise power relative to QNL in dB.
Intrinsic Noise

- Thermal Noise
- Shot Noise
- Flicker Noise (1/f)
- Burst or Popcorn Noise
A *thermally* (thermal energy) generated noise due to *random motion* of the charge carriers; electrons

The average noise power is proportional to:
- Temperature
- Frequency bandwidth (spectrum) of the thermal noise

\[ P_n = KB = KT \Delta f \quad \text{(Watt)} \]

Power Spectrum Density:

\[ S_n = \frac{P_n}{\Delta f} = KT \quad \text{(Watt/Hz)} \]

\[ K = 1.38 \times 10^{-23} \text{ J/}^\circ\text{K} \]
Flicker Noise, (1/f) Noise

- Associated with the fluctuation in carrier density due to trapped electrons “Crystal defects”, for example, the dangling bonds existing in the MOS oxide-substrate interface.

\[ \bar{I}_n^2 = K_f \frac{I^n}{f^\beta} \Delta f \quad (A^2) \]

- \( K_f \): constant for a particular device
- \( \alpha \): constant in the range 0.5 to 2
- \( \beta \): constant of about unity

\[ I_{n,rms} = \sqrt{K_f \frac{I^n}{f^\beta} \Delta f} \]
Flicker Noise

- Flicker noise or Contact noise occur due to the imperfect contact “Contamination” between two conducting materials that causes the conductivity to fluctuate in the presence of a dc current.

- Mean-square flicker noise current in 1 Hz frequency band: \( \overline{i_f^2} = \frac{K_f I^m}{f^n} \) \((A^2/Hz)\)

- Where \( K_f \) is the flicker noise coefficient, \( I \) is the dc current, \( m \) is the flicker noise exponent, and \( n \approx 1 \).

- Flicker noise is modeled by a noise current source in parallel with the device.

One-over-f-noise/ low frequency noise/ pink noise
Consider the position of a simple harmonic oscillator of mass $m$ and frequency $\omega$. The oscillator is maintained in equilibrium with a large heat bath at a temperature $T$. The solutions of the Heisenberg equations of motion are the same as the classical case but with initial position $x$ and momentum $p$ replaced by corresponding operators. The position autocorrelation function is

$$G_{xx}(t) = \langle \hat{x}(t)\hat{x}(0) \rangle$$

$$= \langle \hat{x}(0)\hat{x}(0) \rangle \cos(\Omega t) + \langle \hat{p}(0)\hat{x}(0) \rangle \frac{1}{M\Omega} \sin(\Omega t).$$
Classically the 2\textsuperscript{nd} term in RHS vanishes because in thermal equilibrium $x$ and $p$ are uncorrelated random variables. In quantum case the canonical commutation relation between position and momentum implies that there should be a correlation between the two i.e.

$$\langle \hat{x}(0)\hat{p}(0) \rangle - \langle \hat{p}(0)\hat{x}(0) \rangle = i\hbar.$$ 

In terms of harmonic oscillators in thermal equilibrium it is easily found as

$$\langle \hat{p}(0)\hat{x}(\hat{0}) \rangle = -i\frac{\hbar}{2} \text{ and } \langle \hat{x}(0)\hat{p}(0) \rangle = +i\frac{\hbar}{2}.$$ 

The autocorrelation function becomes

$$G_{xx}(t) = x_{ZPF}^2 \left\{ n_B(\hbar\Omega)e^{+i\Omega t} + [n_B(\hbar\Omega) + 1]e^{-i\Omega t} \right\}.$$ 

The autocorrelation function is complex because the operator $x$ does not commute with itself at different time. The spectral density can be written as

$$S_{xx}[\omega] = 2\pi x_{ZPF}^2 \times \left\{ n_B(\hbar\Omega)\delta(\omega + \Omega) + [n_B(\hbar\Omega) + 1]\delta(\omega - \Omega) \right\}.$$ 

In high temperature limit $k_B T \gg \hbar\Omega$, the spectral density coincides with that in classical case.
Noise sometimes benefit detection of weak signals. Stochastic Resonance is such a counter intuitive phenomena. SR not only benefits to nonlinear classical systems from neurons to crayfish but also for some quantum systems. Thermal noise generally creates decoherence to quantum systems. However, SR benefits quantum phenomena like squeezed light, tunneling, quantum jumps in micromaser, electron shelving and entanglement.

Even a small amount of classical noise can enhance the fidelity of quantum teleportation.

The marvelous biological system

... A biological system can be exceedingly small. Many of the cells are very tiny, but they are very active; they manufacture various substances; they walk around; they wiggle; and they do all kinds of marvelous things - all on a very small scale. ....

There's Plenty of Room at the Bottom

An Invitation to Enter a New Field of Physics

Dec 29th 1959, APS meeting at CALTECH
In the context of living organisms the term “noise” refers to the variance amongst measurements obtained from identical experimental conditions or from output signals from these systems which are universally characterized by having background fluctuations.

The question now to what extent is biological function dependent on random noise, and a corollary to that question: is the significance of noise that depends on intrinsic system properties more meaningful than the noise brought in from the environment.
In Biological systems *noise refers to variability*:

- Variability in behavior
- Variability at Neuronal Level
- Variability at the level of Gene Expression

For example:

- *The time interval between adjacent spikes is roughly comparable to the mean interval itself.*
- *The response to the cell for the same stimulus is reproducible only up to certain extent and there is variability from trial to trial.*
- *There is variation of gene expression for genetically identical cells and organisms under identical histories of environments.*
Main Sources of Noise in Biology

- **Physical**: Thermodynamics and Quantum Theory put physical limit to the efficiency of all information handling systems both physical as well as biological systems.

- **Sensory**: Thermodynamics or quantum theory puts limit to the external stimuli and hence they are intrinsically noisy. During the process of perception the energy in the stimuli is either converted to chemical energy or to mechanical energy which is being amplified and transformed to electrical signal. The noise which was already present in the external stimuli will be amplified as well as some noise will be generated due to amplification process (transducer noise).

- **cellular**: the ion channels, synapses and network feedback.
- **motor**: motor neurons, twitches, contraction of muscle fibers.
- **trial-to-trial variability in behavior**
Sources of noise

Intrinsic noise

Noise resulting from the probabilistic character of the (bio)chemical reactions. It is particularly important when the number of reacting molecules is low. It is inherent to the dynamics of any genetic or biochemical systems.

Extrinsic noise

Noise due to the random fluctuations in environmental parameters (such as cell-to-cell variation in temperature, pH, kinetics parameters, number of ribosomes,...).

Both intrinsic and extrinsic noise lead to fluctuations in a single cell and results in cell-to-cell variability.
Two Distinct Sources Behind Trail to Trial Variability

- **Non-Linear Dynamics**: within the paradigm of deterministic systems, the systems are very sensitive to the initial conditions and Chaotic behavior appear for the variability of initial conditions.

- **Stochastic**: irregular fluctuations or stochasticity which might be intrinsic or be present in the external world.

Though these two sources generate noise from the time series of chaotic system as well as that of stochastic process yet they share some indistinguishable properties. However, it is possible to distinguish the “noise” from chaos as well as that from stochastic processes.

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Noise in Gene Transcription

Gene transcription involves the process where RNA polymerase (RNAP) transcribes a gene into messenger RNA (mRNA). Proteins and ribosomes are involved in the translation of mRNA into proteins.

Repression and Activation:

Repressor proteins bind to regulatory and RNA binding sites (promoter) to block transcription, while activator proteins bind to these sites to promote transcription.
Cells or organisms with the same genes, in the same environment with the same history, display variations in form and behavior that can be subtle or dramatic. Such variability is shown to be inevitable in biological systems because of random nature of chemical reactions within a cell. So apart from the differences in environment and history the intrinsic variability due to random chemical reactions may lead to variability in cellular phenotype.

Gene expression as defined by a set of reactions that control the abundances of gene products, influences most aspects of cellular behavior and its variation is often invoked to explain phenotype differences.

Noise in biology

Noise—producing steps in biology

Exploiting Noise

- noise causes mutations \(\rightarrow\) evolutionary principle that sustains survival

- noise enables task performance for subthreshold input: stochastic resonance (SR)

- noise improves reconstruction of suprathreshold stimuli via an ensemble of threshold units: suprathreshold stochastic resonance (SSR)
Stochastic Resonance (SR) is a phenomenon observed in non-linear systems whereby introduction of noise enhances detection of sub threshold signals.
Noise enhanced phase synchronization occur in case of array of nonidentical noisy oscillators, for example in case of cardio respiratory synchronization. But the issue which has not been resolved is the following: *Whether SR occur at the level of single ion channel or for an ensemble of channels?*

Next issue:

*Whether SR is exploited by CNS and brain as a part of neural code.*

Answer is: *Yes*

It has been recently demonstrated that in the absence of T or P type calcium channels result in modification of coupled network oscillatory characteristics and in abnormal motor behavior.

Stochastic resonance is the phenomenon whereby the addition of an optimal level of noise to a weak information-carrying input to certain nonlinear systems can enhance the information content at their outputs.

Use of SR by Paddle fish for feeding


“We demonstrate significant broadening of the spatial range for the detection of plankton when a noisy electric field of optimal amplitude is applied in the water. We also show that swarms of *Daphnia* plankton are a natural source of electrical noise. Our demonstration of stochastic resonance at the level of a vital animal behaviour, feeding, which has probably evolved for functional success, provides evidence that stochastic resonance in sensory nervous systems is an evolutionary adaptation”
Here, we show that stochastic resonance enhances the normal feeding behaviour of paddle fish (*Polyodon spathula*) which use passive electroreceptors to detect electrical signals from planktonic prey (*Daphnia*).
Sources of Noise in Brain Function

- **Stimulus Noise**: During the process of perception the stimulus energy is either converted directly to chemical energy (photoreception) or to mechanical energy which is amplified and transformed to electrical signals. The intrinsic noise in the stimulus (due to Thermodynamics or Quantum theory).
- **Ion Channel noise**: voltage, ligand and metabolic activated channel noise.
- **Cellular Contractile and sensory noise**: muscles and glands
- **Macroscopic behavioral execution noise**.
Among living systems producing noise is the brain. In some studies, “channel noise” in neurons, which is thought to arise from the random opening and closing of ion channels in the cell membrane, is seen to be. One possible mechanism for this is a model of the vibration of hydrocarbon chains in cell membrane lipids that affects the conductance of potassium ions (Lundström and McQueen 1974). Musha (1981) showed that the series of fluctuations in the time density (the inverse of transmission speed) of action potentials traveling down the squid giant axon have an approximately power spectrum below about 10 Hz (Figure 2D). Novikov et al. (1997) found that the activity of ensembles of neurons in the brain, recorded from relaxed human subjects by the magnetoencephalogram, shows a power spectrum (Figure 2E). The log–log spectrum in Figure 2E has a slope of −1.03 over the range 0.4 to 40 Hz. Electroencephalogram recordings also display noise in the brain. Ward (2002) described an unpublished study by McDonald and Ward (1998) in which a series of large event-related potentials were evoked by a 50–ms 1000–Hz tone burst at 80 dB from a human subject seated in a very quiet (35 dB background noise) sound-attenuating room. The power spectrum of the series obtained by sampling the EEG record at a time point in the pre–stimulus period, and that for obtained by sampling the EEG record at the peak of the earliest negative–going event–related potential component, were both approximately.

Similarly, Linkenkaer-Hansen at el. (2001) showed that both MEG and EEG recordings of spontaneous neural activity in humans displayed −1-like power spectra in the , and frequency ranges, although the exponents tended to be somewhat less than 1 and differed across the frequency ranges. They suggested that the power-law scaling they observed arose from self–organized criticality occurring within neural networks in the brain. It is possible, however, this inference is not necessarily warranted. One recent study (Bedard et al., 2006) showed that the scaling of brain local field potentials does not seem to be associated with critical states in the simultaneously-recorded neuronal activities, but rather arises from filtering of the neural signal through the cortical tissue.
$1/f$ Noise
Variability in perception and action is observed even when external conditions such as the sensory input or task goal, are kept as constant as possible. Such variability is also observed at neuronal level. What are the sources of such variability?

In the neuronal level, the term variability refers to the changes in of the quantity like spike timing or movement duration.

Two sources of variability:

1. **Deterministic System**: if the system dynamics is highly sensitive to the initial conditions.
2. **Noise or irregular fluctuations**.

Nervous system use the benefits of noise instead of its detrimental effect using the stationary phase principle which is essentially related to Principle of Least Time and Sum Over Histories.
The effect channel noise on the miniaturization of brain wiring has been investigated by Faisal et al. (A.A.Faisal et al: Current Biology Vol. 15(2005) p.1143-1149.). They suggested that the channel noise may put the limit to axon diameter given the limitations inherent by length and time constants of the nerve cable properties.
**Principle of Least Time and Sum Over Histories**

**Fermat** introduced the principle of least time (PLT) as the shortest time taken by light to travel along a path between the source and the receptor. Snell’s law can be derived from Fermat PLT. Fermat was the first to investigate variational principle in general.

**Feynman** formulated the path integral approach to Quantum Mechanics using the concept of all possible paths within Fermat paradigm. Usually the concept of all possible paths is closely related to two basic tenets:

1. Meaning of exploring all possible paths
2. How everyday objects like stone as well as light ray follow a particular path.

As Feynman noticed, the Maupertuis variational principle in Physics can be understood in quantum terms, it becomes a version of mathematical *stationary phase principle*.

It is not the exclusive property of Quantum physics, it is also present in ordinary geometrical optics.
We will reformulate sum over histories in case of brain in the spirit of Feynman concerning the reflection and refraction of light. Feynman emphasized how quantum principles through the superposition of multiplications of unitary complex factors along all possible paths of photon resulting in light travel between source to detector in the least possible time. Thus for light, a sum of history results in least time displacement.

By contrast, axonal paths with different conduction velocities can mimic light transmission in space. Viewed from a morpho-functional perspective, informational conduction in CNS is associated with distinct and particular conduction path ways with specific conduction properties. Thus in the brain the set of different histories corresponding to different axonal paths sum in individual neurons to represent the external world. We suggest (Llinas and Roy, Phil.Tran.Royal Soct. B vol.364 p.1301(2009)) these conduction properties express a stochastic, a priori description of the world, consistent with a Bayesian perspective for brain function.

Anatomically, brain pathways connect functional spaces to one another, it is here then that the sum of history principle and the resulting least time principle due to the oscillatory grains, can support quantum cognition by synchronization.
The rule of probability can be used to define certain class of paths. The issue lies in attaching a positive real number \( p \) to each history and assigning to the class \( H \) a composite probability \( p(H) \) as

\[
p(H) = \sum_{\gamma \in H} p(\gamma)
\]

Because the paths are unbounded in time, individual probability does not exist. Well defined individual probabilities can be obtained by truncating the histories as some final time, however, class probability is parameter of interest, and so, it is not necessary to have well defined individual probabilities. In brain the paths are inherently truncated in time when cognition occurs. This is similar to the quantum situation where one is interested in truncated paths or histories at time \( T \) known as collapse time. It is well known that the sum of excitatory and inhibitory synaptic currents and the intrinsic electrical properties of neuron are the fundamental to the CNS decision making process. This decision effect is closely related to the concept of collapse and is responsible for the recognition of any event.
Cancellation of Noise and Stationary Phase Trajectory

Choice of weightage to the paths:
Several choices can be made. Consider the oscillatory function as

\[ w(\alpha) = \exp(i\beta S(\alpha)) \]

where \( \beta \) is a large positive number and \( \alpha \) the range of the conduction speed as the weightage function one can recover path integral similar to Feynman path integral and by exponential weighting function it gives Einstein-Smoluchovsky path integral. In case of oscillatory weighting function the small change of the trajectory may lead to large change in the sine and cosine function in the phase. Thus even if the trajectories are very close, the contributions from the trajectories will cancel each other due to rapid oscillations in sine and cosine. On the other hand, for a stationary phase trajectory as formulated by Fermat leads to small changes in the phase and the they produce constructive interference.
Llinas et al demonstrated that single neurons behave like weakly chaotic oscillators. Intuitively the responsiveness to excitatory(e) and inhibitory(i) synaptic inputs play an important role in defining phase synchronization for rhythms that define global states i.e. presence of gamma band activity has been associated with wakefulness as well as in dream state. The interactive e-cells and i-cells bring the synchronous rhythm in neuronal networks. The mechanism of pyramidal interneuronal gamma(PING) rhythms which is related to activities of e-cells and i-cells is yet to be understood. The effect of noise plays an important role in understanding PING.
Llinas and Roy developed the idea that external noise is adapted to the internal noise fits well with Fisher’s idea within the framework of parametric statistics because noise is defined here as a family of hypotheses about the possible form of knowledge and the covariant metric is the measure of the difficulty in determining the exact form of knowledge. Actions are planned, at least in part, according to a minimum variance principle and their executions are conditioned by sensory information, at least in feedback. In some detection regimes (i.e. those involving many neurons, large time scales and facilitating synapses) the information gain in sensory areas follows the maximum of information metric.
VIDEO on DIATOM
More fundamentally the unicellular entities such as Diatom show Brownian like noise even after its death contrary to the fact that a directed transport motion is observed during its living state. Indeed, the ionic channels of Diatom remain active for the certain period of time following “death”. In its living state, the ion channels of Diatom may produce kind of synchronicity but becomes asynchronous after its death, with the Brownian like motion present till the functioning of the channels stop. However, a careful analysis of the noise is needed to understand this kind of phenomenology and its physical/biological significance. The analysis of the role of noise in Diatom may shed new light in understanding the distinction between the living and dead state. O
Synopsis

- Fluctuations are omnipresent in biology - no life without noise!

- Noise causes adaptability/flexibility - no survival without noise!

- Noise keeps dissipative linear systems in motion!

- Noise can cooperate with nonlinearity to enable/enhance vital functions

- Fluctuations in non-linear systems are particularly efficient in the vicinity of bifurcations (self tuned criticality)
Laws of Physics and Biology

Why do we study noise? The limitation put by laws of physics like Thermodynamics and Quantum Theory force us to think of noise as and when we try to design the electronic devices. This is essential to measure the physical world.

In the living systems, starting from unicellular object like Diatom -Bacteria to more complex object like the brain utilize noise, as defined in physics, for its functioning.

As neuroscience addresses molecular biology in search for answers, and molecular biology reaches into biophysics and then into submolecular function, it is at that point that the issue arises in full force. We have become aware that the stochastic properties found in physico-chemistry are actually ruling what we had expected long ago to be deterministic. Once it is clear that the uncertainty principle applies in biology as well as in fundamental physics, a new game is on. And so the analysis of biological noise is born and, more to the point, the differences between the biological and the non-biological realms begin to merge. Two clear implications seems evident:

(1)biology is a branch of physics and
(2)physics, defined as what physicists do, a branch of biology.
McCulloch asserted that reliability of CNS is a reflection of unreliability of neurons. His assertion based on the mechanism that cells can be arranged in such a way that, on the average, they agree but their combination of intrinsic noise and external noise insures their independency resulting in dividing the variance.
THANK YOU