

# Why Noise and Fluctuations Can Make Life Simpler

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## ABSTRACT

Noise and Fluctuations are usually considered obstacles in the operation of electronic and mechanical devices, and most strategies to deal with them aim to maximize the Signal/Noise ratio. This presentation gives a short overview of systems that follow a different scenario: such systems exploit noise and fluctuations in order to improve their efficiency of operation. A key element in these systems is the ability of noise and fluctuation to work as a stochastic search process that is able to explore a solution space and settle on a suitable solution. The attraction of this strategy is that it simplifies the mechanisms required to accomplish a task. This presentation reviews an example in computation and speculates about the likely use of this strategy in biological organisms.

## Keywords

Noise, Fluctuations, Nanoelectronics, Molecular motors

## 1. INTRODUCTION

Biological organisms exhibit a wide variety of complex behaviors that have fascinated researchers over centuries. Our technology has vastly improved since early times, but the fascination has remained, though it is nowadays mostly directed at the efficiency at which processes at micrometer and nanometer scales take place in organisms. The mechanical machines constructed by mankind have grown in impressiveness with the passage of time, but they are no match for the intricate machinery found in biology. The efficiency and flexibility by which our muscles operate, for example, has no true counterpart in the world of robotics. Molecular motors, for example, which lie at the base of muscle movements, are able to operate with extremely low energy consumption. At the same time, the employed mechanisms – though not fully understood yet – are relatively simple in nature, taking mostly place on the scales of molecules. This simplicity implies that the control of these mechanisms should necessarily have limited complexity, because the control mechanisms themselves are subject to similar requirements as the non-control mechanisms.

The question as to what type of control mechanisms plays a role in the molecular processes of biological organisms is an important one, because understanding its answer will bring us one step closer to the realization of applications that require precise control at molecular scales, like molecular self-assembly of circuits.

In this presentation, we explore the possibility that a key element in the control of processes at molecular scales is noise and fluctuations. It is known that Brownian motion plays an

important role in the operation of molecular motors, but it is less-well known what specific characteristics of such random fluctuations make them so important. We draw some parallels with token-based circuits, in which tokens, which act as signals, are subject to Brownian motion. We discuss the observation that Brownian motion of the tokens adds to the computational power and functionality of this type of circuit.

## 2. BROWNIAN MOTION

Key to the power of Brownian motion in the context of token-based circuits is its ability to *search* a space of possible states for a solution that matches certain conditions. We will show a token-based circuit that cannot avoid deadlocks if tokens are like in traditional token-based circuits – i.e., without Brownian motion – but that can resolve deadlocks if tokens are subject to Brownian motion. The search ability of Brownian motion is used as follows. Once a token is in a deadlock, it cannot move forward or backward in traditional circuits, and that is usually the end of the story. With Brownian motion, however, the token gains the ability to backtrack out of the deadlock, and to search for locations in the circuit where it can freely move forward without any deadlock occurring. This phenomenon can thus be exploited in the design of token-based circuits, and it tends to result in systems with reduced complexity, as we will show.

## 3. MOLECULAR MOTORS

It is very likely that biological organisms have invented a similar trick in the course of their evolution. Evolution takes place in a noisy environment and it appears plausible that exploitation of noise has become part of the solution underlying the operation of organisms. In the context of molecular motors, the term *Search and Catch* has been proposed [1]. This term means that the arm of a molecular motor searches for a position to bind according to a stochastic search mechanism, and once it encounters a suitable position for such a molecular binding, it catches it. This mechanism offers a remarkable simple solution for the control of the arm. Rather than a complex mechanism to determine the position at which an arm can bind, it requires merely a (less accurate) mechanism to facilitate the search process.

## 4. CONCLUSIONS

Noise and fluctuations can thus be a powerful source driving the operation of complex systems. Consequently, it makes sense to explore how we can exploit this resource in the design of micro-

and nano-systems. Possible applications include robotic systems (on micro- as well as on macro-scales), information systems (e.g. nanoelectronics), and communication systems (e.g. sensor networks).

## **5. REFERENCES**

- [1] Yanagida, T., Personal communication, Nov. 2007.