Guest Editorial
Special Feature on Quantum Biology

I. Introduction

QUANTUM biology is not a new field of study: as the physicists' work on foundations of quantum theory matured, the question of linking it with the secrets of living organisms drew more and more attention. It was posed as a natural philosophy question as well, exploring the link of quantum randomness with the competing perceptions of the world, idealist and materialist. It also posed a question to what will later become known as systems theory: is reductionism ever warranted in complex systems? These first thoughts on quantum effects as underlying mechanisms of living organisms predate the modern molecular biology revolution.

After the discovery of DNA structure and the rapid increase in theoretical and experimental capacity of biology research, the quantum effects did not feature much, if at all, in the attempts to explain the key biological mechanisms. These macroscopic, classical interpretations have shown a great potential in explaining many of the phenomena we encounter in the study of life—but origins of certain mechanisms do remain unclear, even if they are commonly taken as widely understood. Popular examples cited in modern quantum biology are photosynthesis and bird's migration navigation. The reader has probably learned of these processes in school, and—as confidently as school textbooks present topics—may have thought that they are fully understood. In the case of photosynthesis, there is the whole chain of reactions we understand; for birds, it is often enough to say that they use the magnetic field of the Earth. The details of how these processes are set into motion, however, remain contested.

Quantum biology is an interdisciplinary field of research attempting to explain biological processes via quantum phenomena: quantum entanglement, superposition, tunneling are contextualised in events that take place in living cells, and produce macroscopic events. The field is seeing a revival in recent years, with new theoretical and practical developments coming from diverse teams of biologists, medical researchers, physicists and engineers. In the vision of quantum biology's further development and future applications in, e.g., healthcare there are major challenges ahead. Namely, experimental abilities to confirm quantum effects within a living cell are a milestone that is yet to be reached: confirmations at the level of an organic molecule are possible, and observation of macroeffects in the organism are of course there--but the key verification step is in-between the two, at the cellular level.

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II. Overview of Accepted Articles

We present this Special Section on Quantum Biology as the first organised venture of quantum biology into an engineering venue. The potential of quantum biology in engineering is wide, and yet to be explored—from the potential to control quantum processes and engineer living organisms, to having easily accessible, room temperature quantum resource for quantum computation, the engineering community can be an integral part of the quantum biology field.

The first paper in this Section, [A1] by Fields et al. is primarily tasked with providing context for the Part II of the work (which is the second paper in the Section). This paper contextualises free-energy principle, active inference, and the associated control problem before reviewing both classical and quantum formulations of these. While formalising the interpretations, the authors show that the control flow can be represented as switching between classical attractors, between quantum reference frames, and between computational processes which in turn can be represented by topological quantum field theories. This places the active inference of living systems into the quantum perspective.

The second paper, [A2] again authored by Fields et al. picks up where the Part I stopped: the previously discussed control flow gets a tensor network representation, which in turn is linked to topological quantum neural networks. The implications of this model of control flow for scale-free biology are many: the authors provide their perspective on where it fits in the grand plan of having seamless transitions from quantum-like to classical-like behaviour.

The third paper in the Section, [A3] by D'Acunto sets out to link biology with quantum engineering. With relatively complex and non-robust quantum computation systems we have today, the author of this paper suggests turning to how biological systems may be utilising quantum properties already, in high temperature and high noise environments. The paper presents a review of potential bio-inspired qubit design options, and how search problem in DNA might be a quantum process in itself, having a potential for development of quantum gates based on it.

Finally, in the fourth paper [A4] by Perez et al., the authors discuss ferritin protein complexes in living organisms exhibiting Coulomb blockade behaviour in tunneling, akin to that in quantum dots. Engineering ferritin protein nanoparticles and their biomedical applications are an important questions the authors address, after a detailed discussion of existing evidence of ferritin tunneling properties.

APPENDIX: RELATED ARTICLES

[A1] C. Fields et al., "Control flow in active inference systems—Part I: Classical and quantum formulations of active inference," *IEEE Trans. Mol. Biol. Multi-Scale Commun.*, vol. 9, no. 2, pp. 235–245, Jun. 2023.

[A2] C. Fields et al., "Control flow in active inference systems—Part II: Tensor networks as general models of control flow," *IEEE Trans. Mol. Biol. Multi-Scale Commun.*, vol. 9, no. 2, pp. 246–256, Jun. 2023.

[A3] M. D'Acunto, "Quantum computation by biological systems," *IEEE Trans. Mol. Biol. Multi-Scale Commun.*, vol. 9, no. 2, pp. 257–262, Jun. 2023.

[A4] I. D. Perez, S. Lim, C. A. Nijhuis, O. Pluchery, and C. J. Rourk, "Electron tunneling in ferritin and associated biosystems," *IEEE Trans. Mol. Biol. Multi-Scale Commun.*, vol. 9, no. 2, pp. 263–273, Jun. 2023.

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