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Editorial: Mathematical and empirical foundations of models of consciousness

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Editorial on the Research Topic
Mathematical and empirical foundations of models of consciousness

The scientific study of consciousness has long been recognized as defying the borders of scientific disciplines. Joint efforts of philosophers, neuroscientists, physicists, and computer scientists have advanced the field considerably in the past decades and resulted in a plethora of available data and numerous theoretical models. However, what is missing is a comprehensive foundational framework that brings together mathematical and empirical approaches to consciousness, akin to the role that theoretical physics or computational biology plays in their respective disciplines. This Research Topic aims to bridge this gap by bringing together the growing number of investigations on formal and empirical approaches to the problem of consciousness.

The article by Kleiner and Tull provides a formalization of the mathematical structure of Integrated Information Theory (IIT), one of the leading models of consciousness. IIT aims to describe both the quality and quantity of the conscious experience of a physical system, such as the brain, in a particular state. Kleiner and Tull propound the mathematical structure of the theory, separating the essentials from auxiliary formal tools. They provide a definition of a generalized IIT which includes IIT 3.0 [1] as well as Quantum IIT [2] as special cases. This provides an axiomatic definition of the theory which may serve as the starting point for future formal investigations and as an introduction suitable for researchers with a formal background.

The article by Grindrod and Lester investigates cortex-like complex systems in the form of strongly connected, directed networks-of-networks. Such networks are studied with spiking dynamics at each node, with non-trivial time-lags associated with directed edges. The connections of the outer network are taken to be sparse, while the many inner networks, or modules, are dense. This paper considers a network with ∼10 billion nodes simulating the human cerebral cortex. It has recently been argued that such a system's responses to a wide range of stimulations may be classified into a number of latent, internal dynamical modes. Such modes have been interpreted as focusing and biasing the system's short-term dynamical system responses to any further stimuli. This work illustrates how latent modes may be shown to be both present and significant within very large-scale simulations for a wide and appropriate class of complex systems. It is further argued that they may explain the inner experience of the human brain.

The first article by Rolls(a) proposes a neuroscience approach to the relation between the brain and the mind in which events at the sub-neuronal, neuronal, and neuronal network levels take place simultaneously to perform a computation that can be described at a high level as a mental state, with content about the world. It is argued that as the processes at the different levels of explanation take place at the same time, they are linked by a non-causal supervenient relationship: causality can best be described in brains as operating within but not between levels. This allows the supervenient (e.g., mental) properties to be emergent, though once understood at the mechanistic levels they may seem less emergent, and expected. This approach may provide a way of thinking about brains and minds that is different from dualism and from reductive physicalism, and which is rooted in the computational processes that are fundamental to understanding brain and mental events, and that mean that mental and mechanistic levels are linked by the computational process being performed.

The second article by Rolls(b) develops implications of this mind-brain relation. It is proposed that causality, vis-a-vis the brain, should satisfy three conditions. First, interventionist tests for causality must be satisfied. Second, causally related events should be at the same level of explanation. Third, a temporal order condition must be satisfied, with a suitable time scale in the order of 10 ms. Although it may be useful for different purposes to describe causality involving the mind and brain at the mental level, or at the brain level, it is argued that the brain level may sometimes be more accurate, for sometimes causal accounts at the mental level may arise from confabulation by the mentalee, whereas understanding exactly what computations have occurred in the brain that result in a choice or action will provide the correct causal account for why a choice or action was made. It is also argued that possible cases of "downward causation" can be accounted for by a within-levels-of-explanation account of causality. This computational neuroscience approach provides an opportunity to proceed beyond Cartesian dualism and physical reductionism in considering the relations between the mind and the brain.

The article by Safron expands on integrated world modeling theory (IWMT) as a synthetic theory of consciousness that uses the free energy principle and active inference (FEP-AI) framework to combine insights from integrated information theory (IIT) and global neuronal workspace theory (GNWT). Elaborating upon IWMT's integrative perspective, the article describes predictive processing models of brains and their connections to machine learning architectures, with particular emphasis on autoencoders, turbo-codes, and graph neural networks. Furthermore, future directions for IIT and GNWT are considered by exploring ways in which modules and workspaces may be evaluated as both complexes of integrated information and arenas for iterated Bayesian model selection. Based on these considerations, Safron suggests ways in which integrated information might be estimated using concepts from probabilistic graphical models, flow networks, and game theory. Mechanistic and computational principles are also considered with respect to the ongoing debate between IIT and GNWT regarding the physical substrates of different kinds of conscious and unconscious phenomena. The article also explores how ideas in IWMT may relate to the "Bayesian blur problem;" and addresses potential critiques of causal structure theories based on network unfolding. Finally, future directions for work centered on attentional selection and the evolutionary origins of consciousness as facilitated "unlimited associative learning" are discussed, thus positioning IWMT as a unifying model of consciousness

Finally, the opinion piece by Jost approaches consciousness from the conceptual framework of information theory with the objective of clarifying important conceptual issues in the field. Jost remarks that consciousness integrates information that is distributed in the brain and in the immediate environment and that includes the recent past and anticipates the near future, on a timescale that is adapted to the requirements for reactions to external stimuli, in order to select a single action on the basis of a probability distribution of possible stimulus interpretations. The author argues that this is quantifiable by complexity measures. Furthermore, the development of consciousness depends on resonances between sensory inputs and actions, and self-consciousness therefore can only emerge in the context of interactions with other conscious individuals. Concerning the feeling of qualia, Jost posits that this results from an efficient compression of information about prior experiences.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

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References

1. Oizumi M, Albantakis L, Tononi G. From the phenomenology to the mechanisms of consciousness: Integrated information theory 3.0. *PLoS Comput Biol.* (2014) 10:e1003588. doi: 10.1371/journal.pcbi.1003588

2. Zanardi P, Tomka M, Venuti LC. *Quantum Integrated Information Theory*. ArXiv preprint arXiv: 1806.01421. (2018).