Higher order informational circuits in neuroscience

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High-order, beyond-pairwise interdependencies are at the core of biological complex systems, and their adequate analysis is paramount to understand, engineer, and control such systems. Indeed, some important questions about complex systems cannot be properly addressed by dyadic representations, and require to take into account higher-order interactions involving more than two elements.

A powerful addition in this sense have been the description of systems as hypergraphs that can be studied via topological data analysis to reveal its structure. A complementary line of research focuses on emergent properties of systems and characterises its high-order behavior from observed data identifying functional hyper-links and describing their synergistic or redundant nature. In this context, redundancy corresponds to information which can be retrieved from more than one source, while synergy corresponds to statistical relationships that exist in the whole but cannot be seen in the parts. A major role in this literature is played by the framework of partial information decomposition (PID) and its subsequent developments, which exploit information-theoretic tools to evidence high-order dependencies in groups of three or more variables. Another popular computational tool is the O-information, which captures the overall balance between redundant and synergistic high-order dependencies in complex systems, whereas a positive (negative) O-information means that the multiplet of variables at hand is dominated by redundant (synergistic) dependencies.

Applications of these principles will be described in neuroscience, a field where multivariate information theory is seen as a promising tool to advance our understanding of brain and cognition. Firstly we will describe applications of a framework to measure high-order interdependence that disentangles their effect on each individual pattern. Then, we will describe the gradients of the O-information as low-order descriptors that can characterize how high-order effects are localized across a system of interest. Finally, a framework for the assessment of high-order interactions, in the frequency domain, will be introduced.

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References

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