Efficient Computation of Casuality in Globally-Hyperbolic Spacetimes Using Link Invariants

Zhang, Justin (School: Bergen County Academies)

Suppiah, Mark (School: Bergen County Academies)

Pitcock, Jeremy (School: Bergen County Academies)

The concept of causality allows physicists to study the universe under the lens of cause-and-effect relations, to achieve a deeper understanding of the connections between events. More formally, causality is a property between points in spacetime where a path between them can be traveled at a speed less than light, allowing information to travel between them and ensuring they can influence each other. Because of its fundamental significance, numerous attempts have been made in the literature to detect causality, but were infeasible due to their inaccuracy or inefficiency. We tested our hypothesis that an efficient causality detection algorithm in globally-hyperbolic spacetimes could be constructed using mathematical link invariants. The Low Conjecture, a powerful result that represents relationships between points in spacetime using links, was used to encode all data in terms of purely accurate mathematical link diagrams. Fundamental generator data was derived for non-causal control and causal experimental links, later utilized in the calculation of the Cocycle Invariant. Numerous iterations of algorithmic redesign and refinement followed. Data and performance were then analyzed using rigorous interpolation methods, mathematical induction, and run-time classification. The results showed a clear distinction between the control and experimental groups, and the novel use of a queue and constant term reduction significantly improved efficiency. Combining this differentiation with data from the Alexander Conway Invariant yielded a highly efficient and accurate algorithm for causality detection. This study significantly improved algorithms in the literature, with potential applications in quantum theory and computing, GPS systems, and gravitational wave detection.