Research Statement

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My academic pursuits lie at the intersection of **theoretical computer science**, **mathematical logic**, and **machine learning**, driven by a fundamental curiosity about the equivalence and transformation of mathematical structures, particularly in computational and problem-solving contexts. My ultimate aim is to contribute foundational insights into theoretical computer science while exploring interpretability and causality in machine learning to ensure these systems are not only powerful but also understandable and trustworthy.

Equivalence in Computational and Mathematical Structures

A central question in my research is: *When are two mathematical structures the same, and under what conditions can they be represented equivalently in computational systems?* This inquiry directly ties to the broader problems of reducibility and equivalence in computational theory. Specifically, I am fascinated by how problems A and B can be shown to be equivalent, whether through **Turing reductions**, **categorical isomorphisms**, or other formal transformations. My goal is to develop rigorous mathematical frameworks that classify and characterize these equivalences, thereby advancing our understanding of problem-solving paradigms and complexity classes.

A pivotal tool in this investigation is **category theory**, whose elegant abstractions provide a unifying framework for diverse areas of computation. By exploring the role of categorical constructs such as *functors*, *natural transformations*, and *adjunctions*, I aim to elucidate the deeper mathematical connections that underlie computational equivalence and representational transformations. I am particularly interested in how category theory can unify seemingly disparate models of computation, such as automata, lambda calculus, and functional programming, and how it offers a structural lens to study the essence of computation itself.

Interpretability and Causality in Machine Learning

In machine learning, I am driven by questions of **interpretability** and **causality**. With machine learning models increasingly serving as decision-making tools, understanding when two models are "essentially the same" in their outputs, causal structures, or decision boundaries is a pressing challenge. I aim to leverage theoretical tools such as **category theory** and **structural causal models** to formalize equivalence notions in ML. By representing neural networks and data pipelines as *functors* or *morphisms* in categorical frameworks, I hope to derive insights into their inner workings, interpretability, and generalization properties.

Category theory's emphasis on morphisms and transformations offers an exciting opportunity to formalize machine learning pipelines as compositional systems, enabling a principled approach to understanding their representational power and limitations. Furthermore, this perspective may provide new methods to study generalization, robustness, and transfer learning, particularly in the context of modern deep learning architectures.

Causality provides another rich area of exploration. I am particularly interested in connecting **causal inference** with **computability theory**. For instance, under what conditions can causal relationships be computed, represented equivalently, or used to infer underlying structures in datasets? I envision using computational equivalences to formalize and enhance causal representation learning and decision-making in AI.

Broader Impact and Aspirations

I view my research as a confluence of deep mathematics and impactful applications. By addressing foundational questions about equivalence and representation, particularly through the lens of **category theory**, I aim to provide new tools for theoretical computer science while contributing to practical areas such as algorithm design, ML interpretability, and causal AI. My broader aspiration is to ensure that the systems we build not only solve problems efficiently but also reflect the **elegance and structure of the mathematical foundations** underlying them.

I am eager to engage in cutting-edge research at institutions where the interplay of **category theory**, **computability**, and **machine learning** is at the forefront, collaborating with like-minded researchers to advance these foundational questions.