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International Max Planck Research School for Intelligent Systems

Dear Admissions Board,

I am writing this letter to express my interest in the CLS PhD fellowship program, since I consider it the perfect opportunity to learn the theoretical foundations of machine learning, one of the most promising current research areas. To me, the most fascinating aspect of machine learning is that its methods find applications in vastly different domains that do not seem to have anything in common. There is a deep beauty in finding common underlying patterns, which is very much in parallel with the elegant and prolific method of abstraction employed in natural science. Especially from a mathematician's point of view, identification and exploration of such fundamental laws and dependencies is highly exciting.

The excellence of both constituent institutions of the CLS makes the program a research environment as perfect as it can be for doing my PhD studies. Especially attractive is the opportunity to be integrated in two research groups at different locations, as well of course as the various events of the program that give impulses from applications of the foundations that I hope to do my main work on. The methods of causal inference that are strongly represented both in Tübingen and Zürich are from my point of view the best approaches improving various aspects of machine learning, and also an interesting research area by themselves. Albeit my university studies weren't focused on statistics very much – I took a year of lectures on stochastics culminating in Ionescu-Tulcea and martingals and a physics lecture on statistical mechanics – I have been gathering knowledge in the field via self-study. Due to my background in algebraic geometry and topology, the field of algebraic statistics and especially information geometry has been very inspiring for me. So far, I have found a great overview on information geometry in an article series by John Baez, and further in publications by Giovanni Pistone on applications of algebraic geometry in statistical models and by Frank Hansen their connection to quantum physics. As some of your research endeavors are situated in the mentioned areas, I would be very happy to bring my geometric knowledge and intuitions into a pursuant research group. Another idea that attracts me is figuring out what can be done with linking general network theory with Bayesian and causal networks.

Recently, the field of algebraic statistics has found some interesting approaches to help with the improvement of machine learning in regards of both the aforementioned issues and boosting general performance. Especially the related area of information geometry seems very promising in tackling the problem of steering an algorithm in a desired direction as well as limiting it to a space of acceptable outcomes. During my university studies in mathematics, I have gathered profound knowledge in algebra and geometry. I am eager to combine these skills with the statistical methods that are the core of machine learning theory and in many ways related to the statistics of condensed matter physics I have done research on during my physics studies.

I consider the research on causal inference and its applications in machine learning a particularly interesting research area. The first reason for the attractiveness of this domain is its utility that has proven effective in certain use cases in machine learning. Another reason is more of a philosophical one, in the sense that statistical methods of causal inference can give a precise definition of causality and make it possible to discover as well as substantiate causal relations in the real world. Furthermore, the examination of causality in the context of machine learning sparks my interest because I think it is beneficial to apply it to neural networks themselves. This way, it can help finding out why an algorithm yields certain results given certain inputs. Since I worked on topos theory extensively, which serves for finding the fitting logical framework for implementing a given theory, I have developed an expertise in the domain of mathematical logic. I would be intrigued to explore the possible applications of manipulating the underlying logical structure of an inference procedure or a machine learning tool.

Over university courses and a summer school of the EUTypes program, I gained experience in the use of automated theorem provers that can be used both for showing theoretical results and verifying algorithm correctness. I think that these techniques might be helpful to assure the soundness of applied methods around machine learning algorithms. On the other side, it might be very fruitful to improve those provers themselves with powerful machine learning methods in the future.

I have completed a master's degree in mathematics at École Polytechnique with a thesis on homology of simplicial sheaves that was supervised by Prof. Fabien Morel. A simplicial sheaf is a geometric object that varies over a ground space: around a single vantage point one sees a fixed shape, however, when moving to another position, this shape continuously changes. Such a sheaf is a geometric space itself, in a similar way like for example a vector field over a manifold can be examined using geometric methods. In the thesis, I developed a proof that two different topological characteristics of a simplicial sheaf – homology and homotopy groups – coincide with respect to a certain reference. In my physics bachelor thesis with Prof. Jörg Schmalian, I examined a question arising in an often-used method to calculate path integrals: by rotating the time axis by ninety degrees in the complex plane, a path integral can easily be solved and then rotated back to real time. However, these rotations are not obviously justified to physically or logically make sense. I showed that a much smaller rotation – even an infinitesimal one – suffices for the calculation, and proposed to justify that small rotation by quantum mechanical fluctuations.

After working with the powerful tools related to partition functions in statistical physics, I was inspired by their role in information geometry. As I wanted to learn more about this topic, I have put a lot of effort into gathering knowledge of this theory with self-study. I have found the article series by John Baez to give a great overview on information geometry. My interest was enhanced further by publications of Giovanni Pistone on the applications of algebraic geometry in statistical models and by Frank Hansen on their connection to quantum physics. I was excited to encounter geometric group theory and quantum groups in statistics, as they are mathematical topics that I have already given student seminar talks on. At the moment, I am seeking to deepen my knowledge on algebraic statistics by working through a book by Akimichi Takemura on Markov bases. Additionally, I have completed the Coursera course on machine learning taught by Andrew Ng.

During my university studies, I have worked in different areas of both mathematics and physics. At École Polytechnique, I have gathered valuable experience abroad and earned a command of French enabling me to understand as well as write academic manuscripts in this language. I have always enjoyed teaching and working with students. For this reason, I have been working as a lecturer for the Karlsruhe University of Applied Sciences, teaching both physics and maths to enrolling students of different subjects. I am looking forward to participating in the various seminars and workshops offered by the IMPRS-IS and would be delighted to learn and work in this interdisciplinary and international community. After my PhD, my dream is to teach university level mathematics professionally, which is one of the main reasons for me to earn a PhD.

Thank you in advance for considering my application.

Best regards,

Julian Bitterwolf