

PhD in Mathematics – Cycle 39 Research topics 2023

Bando 2023/Call 2023

Fondazione Bruno Kessler – FBK
Borsa di studio/ Scholarship

F	Bayesian Neural Networks with applications in Health Sciences
<p>Topic: The objective of this thesis is to advance the mathematical theory of Bayesian Neural Networks for both shallow and deep networks. These networks show promises both for their flexibility in modeling the phenomenon under study and for their ability to return accuracy measures of the estimated quantities - a problem not well understood in classical network theory and that would be investigated in this thesis. Methods to tackle the computational issues associated to neural networks are another aspect covered by this thesis since standard methods for network training are not suitable for complex real applications. The final objective of this thesis is the application of the proposed methodology to important problems in health sciences, e.g., those involving the analysis of omics or bioimaging data. The study will need expertise in several topics including Bayesian non-parametrics methods, variational inference, information geometry, Monte Carlo methods as well as standard methods in deep learning.</p>	
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<p>Synthetic description of the activity and expected research outcome</p> <p>The research aims to contribute to the understanding of the mathematical and statistical properties of Bayesian Neural Networks (BNN). Initially, the project will focus on shallow networks and later it will expand to deep networks. We are particularly interested in the following aspects:</p> <ul style="list-style-type: none"> (i) Constructing sensible priors for the parameters and assessing their impact on the posterior distributions (ii) Building credible intervals to quantify uncertainty in the estimated quantities (iii) Obtaining predictive distributions for improved inference. <p>Given that our intended applications involve image classification, one of the project goals is to develop Bayesian convolutional layers and explore their theoretical properties.</p> <p>Once these results are obtained, the focus will shift towards constructing self-adaptive BNNs. These networks will have the ability to automatically select, based on the complexity of the problem: (i) the connections between nodes, (ii) the number of nodes in each layer, and (iii) the overall network structure.</p> <p>To investigate the above problems, we will employ Bayesian non-parametric techniques, variational inference and information geometry as our primary tools. The project will also address computational challenges. Training BNNs is not a straightforward task, as conventional methods like Markov Chain Monte Carlo (MCMC) are generally infeasible due to the high number of unknown parameters involved. Thus, alternative strategies will need to be explored in order for BNN to become an effective tool available to researchers.</p> <p>Applications will be mostly drawn from the health/life sciences realm: the developed BNNs will be used to tackle tasks in computational biology and health(care). In particular, as input data the networks will be fed by EHRs, (several levels of) omics data and different bioimages (e.g., PET, CT, US and WSIs), both separately and integrated. The data will be either publicly available (e.g., from TCGA, TCIA) or generated by partnering labs. The analysis path will be carried out in strict collaboration with expert</p>	



clinician and biologists, with a particular attention towards the aspects of model reproducibility and interpretability.

References

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Goan and Fookes. "Bayesian neural networks: An introduction and survey". In: Case Studies in Applied Bayesian Data Science. Springer (2020), pp. 45-87.
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Neal. Bayesian learning for neural networks. Springer Science & Business Media (2012).
Zhang et al. "Noisy natural gradient as variational inference". In: International Conference on Machine Learning. PMLR. (2018), pp. 5852-5861.

Ideal candidate

Master in Mathematics, Statistics or Physics
Strong Mathematical background
Attitude towards analytical thinking
Software development skills (preferably Python/R)
Good knowledge and proficiency of the English language
Team working attitude
Good communication and relation skills