

## **New Neural Network Architecture and Logic Extraction for Compact/Green AI**

The School of Physical and Mathematical Sciences (SPMS) and the School of Computer Science and Engineering (SCSE) at Nanyang Technological University (NTU) in Singapore, is seeking highly motivated candidates for several Ph.D. student positions in the areas of machine learning and/or cryptography. Interested applicants should send their detailed CVs to Prof. Thomas Peyrin (thomas.peyrin@ntu.edu.sg) preferably as soon as possible and before end of March 2024 (for August 2024 intake). The scholarship provides support for up to 4 years of PhD studies including tuition fees and a monthly stipend.

Candidates are expected to hold a Bachelor or a Master's degree in Computer Science or Mathematics, and to have a strong experience with machine learning and/or cryptography. Exposure to computer security is a plus.

More general information about graduate admissions at NTU can be found here: <https://www.ntu.edu.sg/admissions/graduate/radmissionguide>

### **Research context.**

We have developed in NTU a new neural network architecture, so-called “Truth Table Deep Convolutional Neural Networks” or TTnets (<https://arxiv.org/abs/2208.08609>), that is very promising for many real-life scenarios. They can be seen as compressed neural networks (NN) based on small lookup tables and they allow the transformation of the inference into a small system of SAT equations or into a compact collection of small circuits after learning. TTnet are very simple NNs (easier to interpret and work with, essentially very generalized decision trees), while still providing a good accuracy and scaling to large datasets. Thus, they are very well suited for example in constrained environments such as embedded systems, mobile phones, etc., and present other interesting properties like formal complete verifiability. They are, in addition, the first global and exact explainable NNs that scale to large datasets, such as CIFAR-10 or ImageNET.

### **PhD research topic.**

The goal of this PhD proposal is to exploit and extend the capabilities of TTnets with regards to compact AI (for cheap microcontrollers or hardware) and green AI (for low energy and low power consumption). Deployment of AI models in embedded systems and edge computing is getting more and more traction in industry. Due to the important practical impact and strong possibility for value creation, there is currently a race towards such efficient models. Current TTnet implementations already rank as the most compact models for both software and

hardware on classical image datasets such as CIFAR-10. Yet, we believe many improvements are possible.

This compact/green AI research can be conducted from different and non-exclusive directions:

- improving the method of extraction of the circuits from the TTnet lookup tables. Currently, the Quine–McCluskey algorithm is used to produce an optimal implementation of the lookup tables, but its complexity grows exponentially with the table's input size. This point is limiting the size of the tables used in TTnet and its ability to scale to very large datasets. Creating heuristics to generate close-to-optimal circuits would allow the utilization of larger tables in TTnets and more compact/efficient neural networks. Interestingly, “fuzzy synthesizers” (compact and approximate logic implementation of a large function) would be extremely interesting algorithms here, which haven't been much explored yet.
- improving the strategies that helps the final neural network to be compact while maintaining a good accuracy (pruning of weights, dropping or rules post-training, forcing low complexity tables during training, ...).
- adapting the TTnet architecture for specific targets. TTnet is naturally optimized for ASIC hardware as it can directly be transformed into a very compact and efficient Boolean circuit. While excellent performances are also observed on small microcontrollers, we believe the general TTnet architecture can be greatly optimized to fit specific use cases (FPGA, low-RAM/ROM software implementations).
- on a more theoretical approach, efficiently approximating large table lookups with a limited number of small ones is an open problem. A heuristic in this domain would again allow more compact and efficient models.

Of course, the candidate will have the freedom to explore other directions if willing to do so.

### **About NTU.**

Nanyang Technological University (NTU) is a research-intensive university with globally acknowledged strengths in science and engineering. The university provides a high-quality global education to more than 33,500 undergraduate and postgraduate students. Hailing from more than 66 countries, the university's 3,600-strong teaching and research staff bring dynamic international perspectives and years of solid industry experience. NTU is ranked 19<sup>th</sup> in the world (QS World University Rankings 2022) and 1<sup>st</sup> among the world's best young universities (QS World University Rankings and Times Higher Education World University Rankings 2023). Notably, its computer science and engineering schools have been ranked in top 15 in the world (QS World University Rankings and Times Higher Education World University Rankings 2023).



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