

From Neuron Models to Edge Intelligence: A Multi-Level Exploration of Neuromorphic Computing

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The work presented in this thesis falls within the field of neuromorphic computing, an emerging paradigm that offers an alternative to the traditional von Neumann model. Inspired by the functioning of the human brain, this approach aims to combine energy efficiency, massive parallelism and distributed robustness, opening up new perspectives for intelligent processing in real-world scenarios. The research was conducted on several complementary levels. At the low-level analysis, the research introduces the Neuronal Phase Map method for representing the dynamics of spiking models, facilitating their interpretation and design. On the higher level, neuromorphic applications were developed for combinatorial optimisation problems, such as MAX-CUT and the Latin Square Problem, demonstrating how spiking neural networks can implement dynamics inspired by simulated annealing and constraint satisfaction. In parallel, neuromorphic pipelines were designed and analysed for classification tasks, particularly in Human Activity Recognition and audio signal processing, evaluating different spike coding strategies and demonstrating the potential of SNNs as a compromise between accuracy and energy sustainability on edge devices. In addition, micro-benchmarking was initiated on the Lava framework and Loihi 2 hardware, aimed at systematically measuring performance at different architectural levels. Overall, the results obtained show that neuromorphic computing can offer concrete and efficient solutions in heterogeneous domains, confirming its relevance as an alternative and competitive paradigm. Future prospects are to be extended to more complex application scenarios, the development of more general design methodologies, and experimentation on multi-chip platforms, helping to bring these technologies from the laboratory to the real world.