

Hyperbolic Neural Networks: Theory, Architectures and Applications

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ABSTRACT

Recent studies have revealed important properties that are unique to graph datasets such as hierarchies and global structures. This has driven research into hyperbolic space due to their ability to effectively encode the inherent hierarchy present in graph datasets. However, a major bottleneck here is the obscurity of hyperbolic geometry and a better comprehension of its gyrovector operations. In this tutorial, we aim to introduce researchers and practitioners in the data mining community to the hyperbolic equivariants of the Euclidean operations that are necessary to tackle their application to neural networks. We describe the popular hyperbolic variants of GNN architectures and explain their implementation, in contrast to the Euclidean counterparts. Also, we motivate our tutorial through critical analysis of existing applications in the areas of graph mining, knowledge graph reasoning, search, NLP, and computer vision.

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1 INTRODUCTION

Current neural network architectures are predominantly based on Euclidean spaces primarily because of their popularity and intuitive definitions of algebraic operations. However, recent research [1, 2] shows that Euclidean spaces are not appropriate for all data structures. Specifically, hyperbolic spaces are found to be much better at capturing the latent hierarchical dependencies of graph datasets in a multitude of fields such as biology, e-commerce, network sciences, and computer vision. This has led to further research into the applications of hyperbolic space as the basis of neural network architectures. However, this topic remains underexplored relative to the research in Euclidean models which includes attention layers,

transformer architectures, and pre-trained global feature models. Hence, in this tutorial, we will introduce the audience to the fundamentals of hyperbolic geometry as well as explain the basic implementation techniques that will allow them to further apply the concepts to their own research. Additionally, the audience will also be introduced to the existing applications of hyperbolic networks and their advantages, especially in a graph setting.

2 TUTORIAL CONTENT AND IMPACT

Overall, the tutorial will consist of three major parts, described in Figure 1. The first part shall motivate the need for hyperbolic spaces and discuss the gyrovector operations. With the context of hyperbolic theory explained, the second part will describe the components of HNN architectures including the hyperbolic linear, recurrent, convolution, and transformer layers. The third section will analyze the existing HNN applications in the areas of graphs, search, natural language processing, and computer vision. Also, we finally conclude the tutorial with a summary and broader impact of this research and also future possibilities in this area.

Advancements in automatic graph analysis can promote several critical applications such as drug recommendation and search algorithms. Research into hyperbolic networks has significantly bolstered our understanding of the graph datasets and an expanse in its research community can help the topic develop further to solutions that can practically solve real-world applications. Researchers working on various scientific application domains can readily benefit from this tutorial since it will enable them to apply the hyperbolic techniques to their domain ontologies. The tutorial website and slides are available at <https://nurendra.me/hyperbolic-networks-tutorial/> and <https://bit.ly/hyperbolic-slides-full>, respectively. GraphZoo is available at <https://github.com/reddy-lab/GraphZoo> for further trial and development. Both the artifacts are released under GNU General Public License (GPL v3). The audience can also access several public benchmark datasets in pre-processed formats which will enable them readily apply the techniques discussed in this tutorial.

REFERENCES

- [1] Nurendra Choudhary, Nikhil Rao, Sumeet Katariya, Karthik Subbian, and Chandan K. Reddy. 2021. Self-Supervised Hyperboloid Representations from Logical Queries over Knowledge Graphs. In *Proceedings of the Web Conference 2021* (Ljubljana, Slovenia) (WWW '21). Association for Computing Machinery, New York, NY, USA, 1373–1384. <https://doi.org/10.1145/3442381.3449974>
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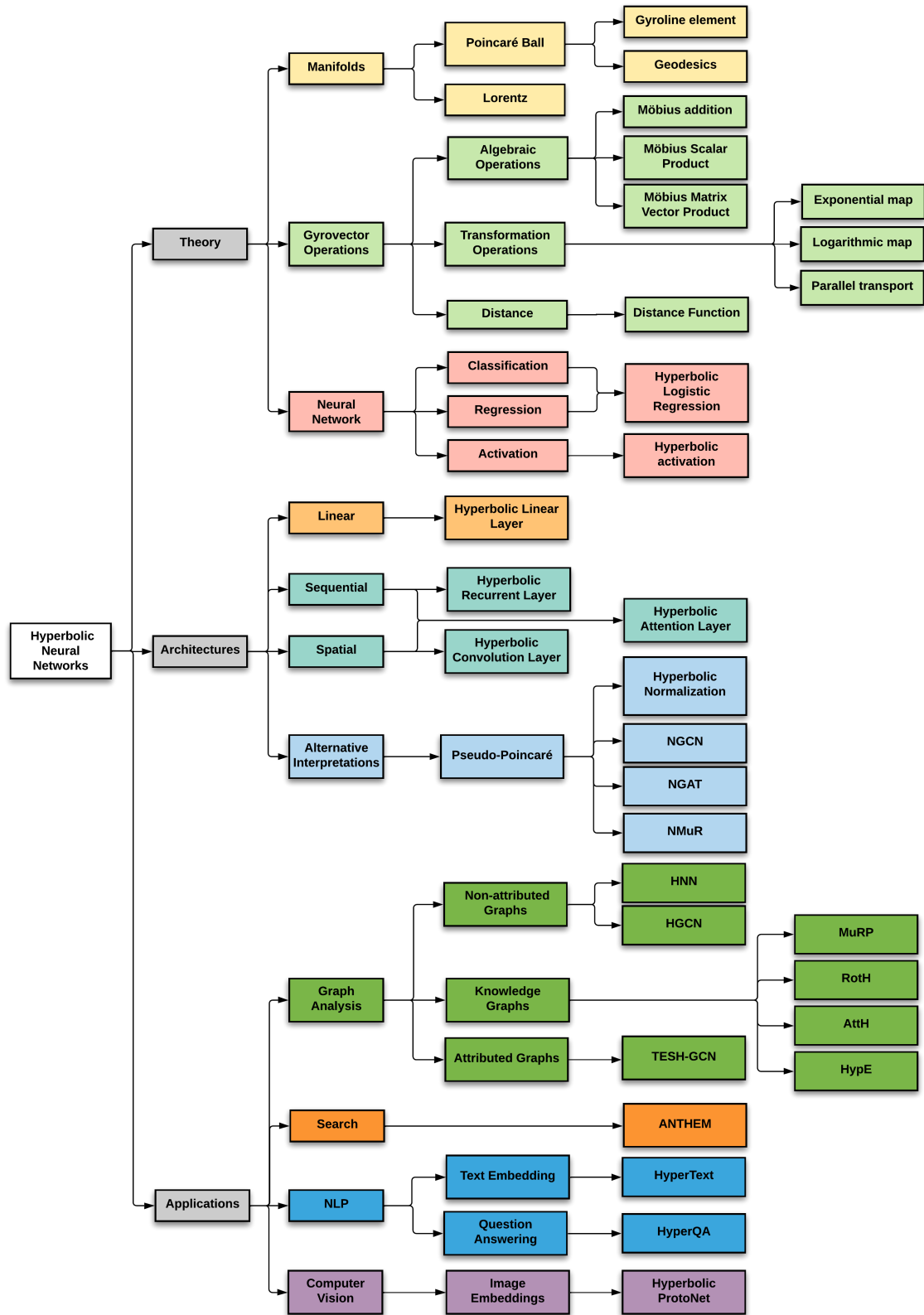


Figure 1: Taxonomy of research on Hyperbolic Neural Networks.