Proposal for a Ph.D. topic

Modular Geometric Machine Learning

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Research context

The proposed work is in the continuity of one of the major axes developed by the ADA component of the A3 team of LIPN for many years on unsupervised learning, and also in the continuity of research activities recently developed related to deep learning, self-supervised learning, and learning of representations.

Topic Description

Deep learning-based applications have seen a lot of success in recent years. Text, audio, image, and video have all been explored with great success using deep learning approaches. The use of convolutional neural networks (CNN) in computer vision, in particular, has yielded reliable results. The data in these applications, on the other hand, is generally defined in the Euclidean domain. However, how the type, quality, and complexity of the data influence the analysis is rarely considered. The necessity to evaluate non-Euclidean data such as graphs and manifolds has grown as these types of data have become more common. As a result, researchers are interested in investigating deep learning methods in non-Euclidean domains, often known as geometric deep learning. This research proposal will look into how different deep learning methods are affected by geometric aspects of data. This will be done in stages using case studies based on real-world data. Convolutions' effectiveness is due to its capacity to encode deeper, local information and features while also reducing the number of parameters by taking advantage of image stationarity due to shift-invariance. However, the major challenge with geometric objects, is that these properties are no longer valid. These objects are irregularly arranged and randomly distributed which presents a challenge in finding local patterns. We are interested in investigating 3D medical imaging for object detection and recognition. The latter is widely used in medical imaging to locate structures and classify objects and 3D data provides a wider range of information. For instance, ultrasound images allow a volumetric view of internal structures thus more effective in detecting infection, cancers, and abnormalities in blood vessels and organs. The 3D images are considered geometric objects modeled as Riemannian manifolds. Most studies conducted applied the classic CNN to 2D images taken from multiple angles, also called extrinsic properties. However, this approach can risk losing information and is sensitive to object position change and shape, thus not suitable for deformable shapes.

Objective

In this thesis, we propose to conduct a study to explore the generalization of deep learning techniques in object detection/recognition on 3D data while conserving the manifold properties since the shape contains information. The objective is to develop geometric deep learning algorithms for data represented by graphs and/or manifolds and to outline the practical difficulties and development directions in this new and rapidly growing field. A part of this work will be devoted to the practical implementation of object detection/recognition in the context of 3D visual data from endoscopic and ultrasound surgery. We aim to answer the following questions:

Q1 Can intrinsic properties outperform 2D methods while maintaining balanced ratio efficiency and computational cost?

Q2 How can we incorporate prior knowledge to develop context-based methods?

Q3 What properties of geometric information are problematic for the current deep learning approaches to handle and what is the reason for it?

Q4 How can the current deep learning methods be refined to handle the geometrical properties of the data, or do new methods have to be developed?

Q5 Can modular networks reduce complexity and improve efficiency?

Methodology

First, investigate the state-of-the-art of existing solutions on manifolds. Second, propose a first approach to the problem validate and compare it to the state-of-the-art methods. Then apply it to real-life applications in medical object detection.

Expected contributions and outreach

We expect from this Ph.D. proposal different types of contributions:

- **Scientific contributions in terms of journal papers and conference communications** in the field of Machine learning and data science, corresponding both to new learning-based schemes and models for the analysis of 3D visual data;
- **Algorithms and codes** using deep learning frameworks (eg, tensorflow, pytorch), which we expect to be of interest to develop an open sources 3D data analytics toolbox;
- **Datasets and associated benchmarking experiments** will be used to distribute a medical 3D data challenge.

In addition to these contributions, this Ph.D. will also contribute to outreach activities co-animated by Hôpital Avicenne AP-HP. We may also emphasize that we expect the proposed models and algorithms to be of broad interest beyond the considered case studies, which include applications to chirurgical datasets and a variety of 3D applications. Such applications may provide the basis for spin-off activities (e.g., internships, new collaborations, ...).

Desired skills

The targeted Ph.D. candidate shall have an MSc and/or engineer degree in Data Science with a strong interest in Machine Learning, possibly acknowledged by previous activities or experience. A dual degree in Machine Learning and data science as promoted by the EID^2 MSc program would be of key interest. Besides a strong theoretical background, computer skills, including first experience in using state-of-the-art deep learning frameworks (e.g., tensorflow, pytorch) and programming environment (e.g., python, git server), will be particularly expected.