Environmental Computational Science
and Earth Observation Laboratory

Student Project

Analysis of Hyperbolic Embedding Spaces for Remote Sensing Change Detection

Context

Change detection (CD), which aims at identifying what has changed and where in an aerial image, is a fundamental task in remote sensing and enables the monitoring of urban and natural transformations over time [1].

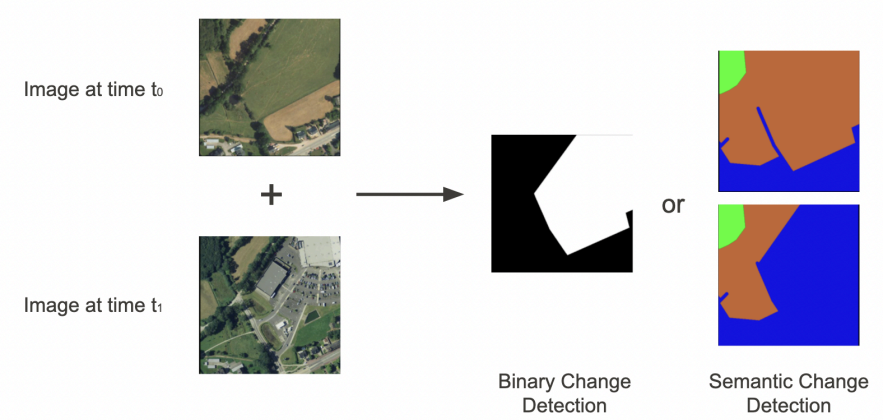

Figure 1. Schematic overview of the task of CD. Based on a pair of bitemporal images, the goal is to predict a binary change map highlighting changes. For semantic CD, the land cover maps for both images are also predicted, enabling identification of the nature of changes (e.g., from “forest” to “building”).

Hyperbolic neural networks [2] are a class of machine learning models that operate in hyperbolic space, a non-Euclidean geometric setting. They have received growing attention for their ability to represent complex, hierarchical, and structured data in a more compact and efficient way than traditional Euclidean spaces [7]. Moreover, hyperbolic spaces present interesting properties, not only in terms of performance but also for interpretability. In particular, embedding representations learned in hyperbolic space lead to better class separation highlighting the hierarchical structure of the underlying data, as shown in Figure 2.

ECEO
EPFL ENAC IIE
Devis Tuia, Prof.
Rue de l’Industrie 17
Case Postale 440
CH – 1951 Sion
Téléphone : +41 21 69 382 83 (secr).
E-mail : devis.tuia@epfl.ch

They also provide information on uncertainty and confidence of models [3], which is essential in many real-life scenarios.

In computer vision, hyperbolic embeddings received growing attention for their ability to enhance tasks such as image classification [4], object detection [5, 6], or image segmentation [3]. However, while the hierarchical structure of concepts in remote sensing images suggests potential utility for change detection, their application to change detection and remote sensing in general remains largely unexplored.

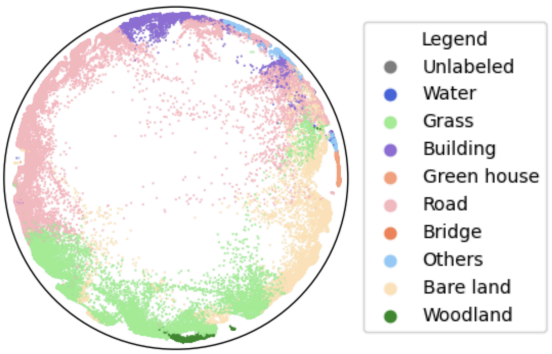

Figure 2. Visualization of semantic segmentation class embeddings in hyperbolic space. Despite the absence of explicit guidance on the semantic hierarchy of classes during training, the model appears to have inferred a form of hierarchical structure. For instance, it groups roads and buildings together, and treats forests as a subset of grassy areas.

Project

This project is part of a bigger study investigating the use of hyperbolic spaces in change detection. Beyond simple performance improvement, the focus in this project will be on hyperbolic embeddings, with the goal of understanding and interpreting the learned representations. The goal is to explore what hyperbolic embeddings reveal about semantic structure, uncertainty and functioning of change detection models.

After a first familiarization with hyperbolic spaces and hyperbolic neural networks, and building upon prior work in change detection using hyperbolic spaces, the project may include (but is not restricted to):

- Training a change detection pipeline in hyperbolic space and extracting embeddings. A base code will be provided.
- Quantifying how well hyperbolic embeddings reflect the known hierarchy of change types.
- Investigating how intermediate points between two change-type embeddings in hyperbolic space correspond to “mixed” or uncertain semantic concepts.
- Exploring the uncertainty derived from the hyperbolic embeddings.
- Visualizing errors of the model in the hyperbolic embedding space to understand misclassifications.

Requirements

- Experience in deep learning
- Proficiency in Python and relevant libraries such as Pytorch
- Ability to understand and work with abstract concepts and mathematical foundations.
- Strong willingness to learn and ability to work independently

ECEO
EPFL ENAC IIE
Devis Tuia, Prof.
Rue de l’Industrie 17
Case Postale 440
CH – 1951 Sion
Téléphone : +41 21 69 382 83 secr.
E-mail : devis.tuia@epfl.ch

Literature

[1] Jiang et al. *A survey on deep learning-based change detection from high-resolution remote sensing images.* Remote Sensing, 14(7), 2022.
[2] Ganea et al. *Hyperbolic neural networks*. Advances in neural information processing systems (31), 2018.
[3] Atigh et al. *Hyperbolic image segmentation.* Proceedings of the IEEE/CVF conference on computer vision and pattern recognition, 2022.
[4] Khrulkov et al. *Hyperbolic Image Embeddings*. Proceedings of the IEEE/CVF conference on computer vision and pattern recognition, 2020.
[5] Lang et al. *On Hyperbolic Embeddings in Object Detection.* Pattern Recognition, 2022.
[6] Liu et al. *Hyperbolic Visual Embedding Learning for Zero-Shot Recognition.* Proceedings of the IEEE/CVF conference on computer vision and pattern recognition, 2020.
[7] Wei Peng et al. *Hyperbolic Deep Neural Networks: A Survey.* 2022.

Contact

Prof. Devis Tuia, devis.tuia@epfl.ch