Extension of Frequency Rectification to Other 3D Representations

Background

FrePolad (**f**requency-**r**ectified **po**int **la**tent **d**iffusion) [1] is proposed as a **point cloud** generation pipeline integrating a variational autoencoder (VAE) with a denoising diffusion probabilistic model (DDPM) for the latent distribution. FrePolad simultaneously achieves high quality, diversity, and flexibility in point cloud cardinality for generation tasks while maintaining high computational efficiency. The improvement in generation quality and diversity is achieved through (1) a novel **frequency rectification** via **spherical harmonics** designed to retain high-frequency content while learning the point cloud distribution; and (2) a latent DDPM to learn the regularized yet complex latent distribution. While FrePolad has demonstrated great success in **3D point cloud generation**, it raises an intriguing question: can these **frequency rectification techniques** be successfully applied to various 3D data representations beyond point clouds, such as meshes, voxels, signed distance functions (SDFs)?

Goal

This project aims to investigate the application of **frequency rectification** techniques on various 3D data representations beyond point clouds, such as meshes, voxels, signed distance functions (SDFs), etc. The goal is to explore how frequency-based information can enhance the reconstruction and generation capabilities of these representations.

The successful completion of this project will lead to an advanced pipeline for 3D generation and reconstruction that leverages frequency rectification techniques on non-point-cloud data representations. This exploration has the potential to unlock new methods for improving 3D model detail, structure coherence, and overall quality across a range of applications, from game development to virtual environments and simulation systems.

Tasks

1. **Background review**:
   - **FrePolad [1]**: Thoroughly understand the core concepts of FrePolad without the need to run the code. Gain an understanding of how frequency rectification is applied to point clouds in FrePolad.
   - **Fourier transforms & spherical harmonics**: Familiarize yourself with Fourier transforms and spherical harmonics (spherical harmonics, used in FrePolad, are essentially Fourier transforms applied on the spherical domain and which are used in FrePolad [1]), understanding their applications in data processing, particularly how these transformations facilitate the extraction of frequency information from complex data.
   - **Literature review**: Conduct a review of key works in 3D generation and reconstruction. Also pay attention to the methods used to process

various 3D data representations such as meshes, voxels, and SDFs. Identify how frequency-based techniques are currently utilized in these domains, if at all, and look for opportunities to apply frequency rectification to enhance these methods.

2. **Identify and understand a baseline model**: Identify an existing 3D reconstruction or generation model that uses a data representation other than point clouds (e.g., mesh, voxel, or SDF). This model will serve as the baseline for applying frequency rectification. Study the chosen model in detail, ensuring that you fully understand its structure, methodology, and data representation. Familiarize yourself with its codebase and make sure you can successfully run it.

3. **Dataset, visualization, and evaluation**: Typically, you will reuse the datasets, visualization/rendering pipeline, and evaluation metrics used in the original work. However, depending on your chosen model and data representation, you may need to make necessary adjustments to accommodate frequency rectification techniques. This may involve creating new evaluation metrics specifically aimed at assessing the impact of frequency information on reconstruction accuracy or visual quality.

4. **(Main Task) Design and develop the pipeline**: Based on your chosen model, design a pipeline that applies frequency rectification to your selected 3D data representation. Keep in mind that the approach used in FrePolad [1], which leverages spherical harmonics to process point clouds, may not work directly for other representations due to the inherent differences in data structure. You might want to approach the task in the following two ways:

   o **How to extract?:** Innovatively think on how to extract frequency information from the specific data structure. For example, if working with meshes, consider whether you can adapt the frequency rectification approach by using a similar technique or need to develop a new way of analyzing vertex or face frequencies. For voxels or SDFs, identify how the grid-like structure can be used to extract frequency information efficiently.

   o **How to use?:** Discuss and decide how the frequency information will be incorporated into the model's generation or reconstruction process. Will it be used for regularization, enhanced detail generation, or another purpose? Ensure that the pipeline allows for smooth integration of frequency features without significantly impacting model performance or complexity.

Possible Extensions

- **Hybrid representation pipeline**: Explore the possibility of building a hybrid pipeline where different 3D data representations are combined to improve the overall performance of the generation model. Frequency rectification could be applied selectively to each representation depending on the specific characteristics of the data.

- **Multi-scale frequency representation**: Consider incorporating multi-scale frequency features, where the pipeline can analyze and manipulate frequency information at various levels of detail within the data. This can be particularly useful in hierarchical 3D structures or when generating complex scenes with varying spatial resolutions.

References

[1] https://chenliang-zhou.github.io/FrePolad/