Master's Thesis at Pattern Recognition Lab, FAU Erlangen-Nuremberg

CADGLM - Integrating Graph Neural Networks and Large Language Models to Predict Machining Information from Graph Representations of 3D Models

Deep learning has been applied to tasks like image classification, video processing, speech recognition, and natural language understanding, typically using data in Euclidean space. However, many applications involve non-Euclidean data, represented as graphs with complex relationships and dependencies between objects. Examples include citation networks, molecule structure in chemistry and user-item relation in e-commerce. Graph Neural Network (GNN) algorithms have recently emerged as effective tools for analyzing and modeling non-Euclidean data structures [1]. GNNs focus on generating effective node and graph representations, which can be adaptively applied to various downstream tasks [2].

GNNs shows potential to learn geometric description of surfaces, edges, and vertices of 3D models [3]. Common 3D shape representations in CAD (Computer-Aided Design) includes discrete structures such as voxels, point clouds and meshes. These representations contain little information about shape and consist of many discrete elements which makes training on these models resource-intensive. In this work, CAD shapes are represented as graphs based on B-Rep (Boundary Representation) models because it's a more efficient method. GNNs can learn connectivity and relationship between nodes and edges, where nodes correspond to vertices or faces of the model, and edges represent their connectivity [4]. After model training, the derived representations can be adaptively coupled with various downstream tasks and applications.

The purpose of this work is to support human-machine collaboration in design and engineering, resulting in improved productivity. Large Language Models (LLMs) are well-suited for this purpose, because of their ability to assist in a wide range of tasks. Combining LLMs with graph learning techniques will be explored to enhance performance in graph learning tasks [5]. Pre-trained LLMs will be fine-tuned on industrial CAD-CAM (Computer-Aided Manufacturing) data to incorporate LLMs with industrial domain knowledge.

The workflow involves generating synthetic 3D CAD-CAM data, if needed, and obtaining geometrically structured graph data of all available 3D models. Several existing GNN architectures will be implemented to explore what type of GNN can learn geometrical and structural properties of 3D models. Generated embeddings from investigated GNNs will be evaluated and compared using different metrics such as link prediction performance. After finalizing meaningful embeddings and machining information (i.e. feature description, tools and operations used to manufacture the 3D model), these will be used to fine-tune pre-trained LLMs to generate natural language descriptions of 3D models and predicting suitable manufacturing processes.

The thesis consists of the following milestones:

- Extract graph representations from 3D CAD models and its machining information.
- Experiment with different GNN architectures for graph embedding generation that capture the structural properties of 3D models.
- Integrate the generated graph embeddings with the machining information to fine-tune a pre-trained LLM for 3D model understanding and processing.

- Validate the results by testing on new 3D models and machining tasks.

The implementation would be done in Python.

Supervisors:	Mathias Zinnen, M. Sc., Prof. Dr.-Ing. habil. A. Maier - FAU, Department of Computer Science Hermann Mayer - Siemens AG
Student:	Vishal Hiteshbhai Patoliya
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