Azrieli
College of Engineering
Jerusalem
עזריאלי
מכללה אקדמית להנדסה
ירושלים

המחלקה להנדסת תוכנה

פרויקט גמר – ה'תשפ"ה

רשתות נוירונים ניתנות לפירוש עבור בעיית מסילה המילטונית

Interpretable Neural Networks for Tackling Hamiltonian Path Problems

מאת

אנדרי טמס

ת.ז. 322341173

טוני בגאלי

ת.ז. 322342205

מנחה אקדמי: ד"ר לוריא צור.

24.11.2024

Ramat Bet Hakerem, P.O.B 3566, Jerusalem 9103501 רמת בית הכרם, ת.ד. 3566, ירושלים מיקוד
Tel. +972-2-6588000 | Fax. +972-2-6588001 | Email: info@jce.ac.il | Web: www.jce.ac.il

Introduction

The Hamiltonian Path Problem (HPP) is a classical and computationally challenging problem in graph theory and computer science. It involves determining whether a path exists in a given graph that visits each vertex exactly once. This project focuses on leveraging neural networks (NNs) to address Hamiltonian-type problems, including specific instances such as the Knight’s Tour Problem with obstacles and the Traveling Salesman Problem (TSP). As these problems are NP-complete, their complexity grows exponentially with random obstacles, which is necessary for innovative approaches with efficient solutions.

The primary goal of this project is to train a neural network to solve Hamiltonian path-type problems efficiently while maintaining interpretability; because it is critical as it allows us to understand and analyze what the algorithm is "really doing" when solving these types of problems. This is particularly valuable for gaining insights into the heuristics and rules the NN develops, potentially leading to generalizable and human-comprehensible strategies.

Furthermore, we aim to utilize the NN to discover simple and efficient heuristics for these problems. For example, in the Knight's Tour Problem, a well-known heuristic called Warnsdorff’s Rule offers an elegant solution by prioritizing moves that lead to fewer onward paths. A key motivation for this project is to determine whether such heuristics can be rediscovered by the NN, providing both validation of its interpretability and potential discovery of novel strategies.

This approach is inspired also by previous work, such as the NASA Technical Paper, which demonstrated the discovery of the min-conflicts algorithm, a heuristic that generalizes across various constraint satisfaction problems. Similarly, we aim to train in an interpretable architecture that not only solves specific instances of HPP but also reveals the heuristics underlying its decision-making process.

By emphasizing interpretability, efficiency, and heuristic discovery, this project aims to make significant contributions in utilizing neural networks to uncover and address solutions for Hamiltonian-type problems, by seeking to understand the underlying behavior of these networks, enabling direct problem-solving methods without relying entirely on the NN.

Azrieli College of Engineering Jerusalem
עזריאלי מכללה אקדמית להנדסה ירושלים

Problem Requirements and Characterization

This project focuses on addressing the Hamiltonian Path Problem (HPP) and similar combinatorial optimization problems by using neural networks to discover efficient and interpretable solutions. The solution must prioritize computational efficiency, by minimizing reliance on iterative or exhaustive methods. It should be adaptable to different challenging structures, including those with constraints like blocked paths or weighted edges, as seen in problems such as the Knight's Tour or the Traveling Salesman Problem (TSP).

The Problem from a Software Engineering Perspective

From a software engineering perspective, the project faces unique challenges. The algorithm design would require a careful balance of speed, accuracy, and interpretability, ensuring that heuristics like Warnsdorff's Rule can be effectively captured without resorting to brute-force methods.

The project must integrate various tools and frameworks effectively, in cases of implementing the neural network and ensuring interpretability for easy adaptation to related problems such as TSP or constrained Knight's Tour scenarios.

Azrieli College of Engineering Jerusalem
עזריאלי מכללה אקדמית להנדסה ירושלים

Solution Description

The proposed solution revolves around designing a system architecture that emphasizes interpretability and heuristic discovery for solving Hamiltonian-type problems such as the Knight's Tour with obstacles and (TSP). The goal is to understand the behavior that neural network does in a system to reveal the reasoning behind its decisions, enabling to extract, understand and to create simple algorithms dealing with efficient heuristics that could generalize to broader problem classes.

Interpretability is a key aspect, as the neural network's decision-making process needs to be transparent, offering insights into the heuristics it uses. This transparency will not only validate the network's effectiveness but also make its strategies comprehensible and generalizable. The solution should be versatile enough to apply to a variety of Hamiltonian-type problems.

System Architecture

The proposed system architecture aims to solve Hamiltonian-type problems by focusing on neural network interpretability and heuristic discovery. The system consists of four core modules:

1. Problem Representation: Encodes problem-specific data for neural network input.
2. Neural Network: Trains a model to find efficient solutions.
3. Heuristic Extraction: Analyzes the network's decisions to derive interpretable heuristics (e.g., rediscovering Warnsdorff's rule).
4. Evaluation: Validates the model's effectiveness and generalization on varied problem instances.

The goal is to train a neural network to efficiently solve Hamiltonian path problems while ensuring interpretability, ultimately replacing the solution with a simple algorithm without relying on exhausting methods like the iterative approaches.

מערכות ניהול הפרויקט:

#	מערכת	מיקום
1	מאגר קוד	https://github.com/Ansalos/Graduation-Project
2	יומן	https://github.com/Ansalos/Graduation-Project/issues

מידע נוסף:

סוג הפרויקט	מחקרי ממרצה במכללה
אם זה פרויקט ממשיך?	זה פרויקט חדש

Articles:

Article	Summary	Relevance to the Project
Learning Improvement Heuristics for Solving Routing Problems	This paper explores how neural networks can be used to solve the Traveling Salesman Problem (TSP), including methods for training and optimizing NN models for combinatorial optimization tasks.	The paper provides insights into using neural networks for combinatorial problems like TSP, which is directly related to our goal of solving Hamiltonian path-type problems using neural networks.
NASA Technical Paper on Min-Conflicts Algorithm	This document discusses the min-conflicts algorithm for constraint satisfaction problems, highlighting heuristic-based approaches to problem-solving.	The min-conflicts algorithm's heuristic nature is relevant for our project's focus on discovering and extracting efficient heuristics for problems like Knight's Tour and TSP.
A Survey on Neural Network Interpretability	This paper reviews deep learning approaches applied to NP-hard problems, offering techniques for improving the efficiency of solving such problems.	The methods explored in this paper could guide the neural network architecture and training strategies to efficiently solve Hamiltonian path problems, aligning with our goal to optimize and interpret neural network solutions.
Acquisition of chess knowledge in AlphaZero	The paper focuses on making AI models, especially deep learning, interpretable in the context of optimization, explaining the decision-making process.	This paper aligns with our project's emphasis on interpretability, offering methods and frameworks to explain neural network decisions in solving complex optimization problems.

Ramat Bet Hakerem, P.O.B 3566, Jerusalem 9103501 רמת בית הכרם, ת.ד. 3566, ירושלים מיקוד
Tel. +972-2-6588000 | Fax. +972-2-6588001 | Email: info@jce.ac.il | Web: www.jce.ac.il