Thesis Proposal: Enhancing Explainable Job Recommender Systems Using Knowledge Bases and Smart Graph Sampling

Title in french: Amélioration des Systèmes de Recommandation de Postes Explicables à l'Aide de Bases de Connaissances et de Méthodes Intelligentes d'Échantillonnage de Graphes

Please note that this thesis proposal is exclusively open to students from École Polytechnique.

1. Background and Motivation

Recommender systems are crucial in filtering information and providing users with tailored suggestions across various domains, including recruitment, health, and e-commerce [3]. In the professional recruitment sector, recommenders can significantly streamline the process, aiding recruiters in matching candidates to suitable positions. In the health domain, a recommender system can recommend to doctors which questions to ask depending on the patient's history. The *TIMBRE* [1] model has demonstrated promising results in job recommendation by employing temporal heterogeneous graphs that capture complex relationships among entities over time.

However, recommendation systems face several challenges, including the need for explainability [4], efficient sampling to handle large datasets, and bias mitigation to ensure fairness in recommendations. These challenges must be addressed to support decision-making in high-stakes areas like recruitment and health, where the societal impact of algorithmic decisions is considerable. This thesis proposes to address these gaps by extending the TIMBRE framework, focusing on explainable recommendations, enhanced sampling strategies, and discrimination detection mechanisms.

2. Objective

The primary objective of this thesis is to develop an explainable and performant recommender system using knowledge graphs [5], which will incorporate a smart sampling strategy optimized for temporal and heterogeneous data structures. The enhanced system aims to:

- Improve the explainability of recommendations to facilitate the user's understanding and trust in the model’s output.
- Implement an advanced graph sampling technique that prioritizes informative nodes and edges, balancing accuracy with computational efficiency.
- Integrate mechanisms for detecting and mitigating discriminatory patterns to promote fairness in recommendation.

3. Research Questions

The project seeks to address the following research questions:

- How can we enhance explainability in knowledge-based recommender systems by leveraging the structural insights of heterogeneous temporal graphs?
- What smart sampling strategies can be adapted to improve the scalability and performance of explainable recommenders on large datasets?
- How can we detect and mitigate discriminatory patterns in recommendation systems while preserving recommendation quality?

4. Proposed Methodology

The proposed methodology extends *TIMBRE* by integrating three core innovations: explainability through feature-level insights, efficient sampling for temporal graphs, and discrimination detection.

A. Explainability through Feature-Level Insights

We will implement explainability layers within the graph model to provide users (e.g., recruiters or doctors) with interpretable insights into each recommendation. This will be achieved by:

- *Node and Edge Attribution*: Analyzing which nodes (e.g., candidate skills, previous positions) and edge types (e.g., industry experience, time of application) contribute most to a specific recommendation.
- *Path-based Explanation*: Displaying the reasoning paths in the knowledge graph, showing how connections between different nodes (e.g., candidates, positions, and relevant qualifications) lead to recommendations.

Example: A recruiter querying the system for candidates for a data scientist role would see not only the list of top-matched candidates but also explanations showing that a particular candidate's strong data analytics background and prior experience in the technology sector contributed to their high ranking.

B. Smart Graph Sampling for Improved Performance

We will design a smart sampling mechanism that allows the system to focus on the most relevant parts of the graph efficiently:

- *Selective Depth Sampling*: Building upon *TIMBRE's* depth-based sampling, this approach will focus on significant nodes (e.g., candidates' current job roles) and filter out less impactful ones (e.g., minor courses).
- *Importance-based Sampling using PASS* [2]: Adapting the PASS sampling technique for temporal heterogeneous graphs allows prioritizing nodes based on their relevance to the recommendation task.

Example: In a dataset with thousands of candidates and job listings, the model would efficiently narrow its focus to critical experience-related nodes within a candidate's professional history, ensuring that only the most relevant information is processed without compromising recommendation quality.

C. Discrimination Detection and Mitigation

The thesis will incorporate methodologies to identify and counteract bias within the recommendation system:

- *Bias Detection Module*: By examining feature contributions across demographic groups (e.g., age, gender, ethnicity), we will assess potential biases that may disadvantage certain groups.
- *Fairness Constraints*: Introduce constraints that balance recommendation quality with fairness, reducing discriminatory effects without sacrificing model accuracy.

Example: Suppose the model consistently favors candidates from a specific demographic due to historical data patterns. In that case, the system will identify this bias and adjust the feature importance weights accordingly, ensuring recommendations remain equitable.

5. International Collaboration and Practical Applications

This project will be conducted in collaboration with two international academic partners: Universidade Federal do Rio Grande do Sul (UFRGS) in Brazil and the University of Dresden in Germany. The Ph.D. candidate will be able to work with experts in graph-based systems, explainable AI, and fairness in machine learning, fostering knowledge exchange and cross-cultural academic collaboration.

The project also includes potential applications with real-life datasets provided by industrial partners in recruitment and healthcare, enriching the model's applicability and impact. This partnership enables the student to gain practical experience with sensitive, real-world datasets, refining the model for industry adoption.

6. Expected Contributions and Impact

This thesis aims to make the following contributions:

- *Enhanced Explainability*: Develop methods that increase the transparency of recommendations, fostering trust among recruiters.
- *Optimized Graph Sampling Techniques*: Introduce scalable, efficient sampling strategies that maintain recommendation accuracy on large, heterogeneous temporal graphs.
- *Fairness and Bias Mitigation*: Provide robust discrimination detection and mitigation mechanisms that can be adapted to multiple domains, from recruiting to healthcare.

7. Evaluation Metrics

The proposed system will be evaluated using a set of performance and fairness metrics:

- *Recommendation Quality*: Precision, recall, and F1-score on various datasets.
- *Explainability*: User study assessments on clarity and trustworthiness of explanations.
- *Fairness*: Disparate impact ratio, demographic parity, and equalized odds.

8. Conclusion

This thesis proposal aims to develop an advanced explainable recommender system tailored to high-stakes applications like recruitment. The proposed system addresses scalability, transparency, and fairness challenges by incorporating smart sampling strategies, explainability mechanisms, and bias detection. With international collaboration and access to real-world data, this project holds the potential to contribute significantly to the fields of recommender systems, fairness in AI, and knowledge-based machine learning, ultimately aiding professionals in making informed, unbiased decisions.

9. Timeline

- *Year 1*: Literature review, model design, initial development of explainability, and sampling modules.
- *Year 2*: Implement discrimination detection, conduct preliminary experiments, and international collaboration (exchange program).
- *Year 3*: Finalize and validate the model on real-life datasets, conduct evaluation studies, and thesis writing.

10. Funding and Collaboration

This project will be financed by the AMX from IPParis and executed at Télécom SudParis, with international support from UFRGS (Brazil) and the University of Dresden (Germany). This global collaboration will provide the Ph.D. candidate with a unique research environment and hands-on experience with globally relevant datasets and methodologies.

11. Profile and Skills Required

Please note that this thesis proposal is exclusively open to students from École Polytechnique. The ideal candidate for this thesis project should possess a strong background in computer science or a related field, with a focus on machine learning, data science, or artificial intelligence. Essential skills and qualifications include:

- **Understanding of recommender systems** and machine learning algorithms, with a particular interest in graph-based and knowledge-based approaches.

- **Proficiency in programming** languages such as Python, along with experience using machine learning libraries (e.g., PyTorch, TensorFlow) and graph processing tools (e.g., NetworkX).
- **Familiarity with explainable AI** techniques and fairness in AI concepts is appreciated, ideally with some prior experience in ethical considerations for machine learning applications.
- **Analytical and research skills**, including experience with statistical analysis and handling large datasets.
- **Strong communication skills** for presenting complex ideas clearly, both in writing and verbally, as well as an ability to work collaboratively in international settings.

Candidates with prior experience in **temporal data modeling**, **heterogeneous graphs**, or **bias detection in AI** will have an advantage. Additionally, proficiency in English is required, as the student will be expected to participate in international collaborations and possibly conduct research exchanges with partner universities in Brazil and Germany.

Bibliography

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[2] M. Yoon, T. Gervet, B. Shi, S. Niu, Q. He, and J. Yang, “Performance-adaptive sampling strategy towards fast and accurate graph neural networks,” in SIGKDD, 2021.
[3] Aggarwal, C. C. (2016). *Recommender systems* (Vol. 1). Cham: Springer International Publishing.
[4] Adadi, A., & Berrada, M. (2018). Peeking inside the black-box: a survey on explainable artificial intelligence (XAI). *IEEE access*, *6*, 52138-52160.
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