Faculty of Engineering and Information Technology
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Learning Complex Relations for Session-based Recommendations

A thesis submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

by

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January 2019

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

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Dedication

To my parents and elder sisters for their love and support

Acknowledgments

Foremost, I would like to express my sincere gratitude to my supervisor Prof. Longbing Cao for his continuous support of my PhD study and research, for his patience, motivation, enthusiasm, and immense knowledge. His open and inclusive attitude has allowed me to become an interdisciplinary research student in data analytic and to build my own research capability step by step from scratch. His patient help has enlightened and encouraged me to rebuild my confidence when I lost confidence in research. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my PhD study.

I also would like to appreciate my co-supervisor Dr Wei Liu for providing me with continuous support throughout my PhD study and research, especially for his full guidance and unique help in the early stage. Without his professional guidance and persistent help, this thesis would not have been possible.

I thank my fellow labmates in Advanced Analytics Institute: Junfu Yin, Bin Fu, Fangfang Li, Guansong Pang, Chengzhang Zhu, Wei Wang, Thac Do, Xiaoshui Huang, Songlei Jian, Yan Xing, Sheng Luo, Qi Zhang, Ke Liu and Longxiang Shi for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had during my PhD period.

I place on record, my sense of gratitude to the key collaborator, Liang Hu in Advanced Analytics Institute for his expert and sincere help in my research. Without his professional guidance and persistent help, this thesis would not have been possible.

I am also grateful to those who provided help to my PhD study, including but not limited to: Associate Professor Ying Qian from Shanghai University, Professor Wanggen Wan from Shanghai University, Associate Professor Paul Kennedy from University of Technology Sydney, Dr Qinxue Meng from University of Technology Sydney, Associate Professor Defu Lian from University of Electronic Science and Technology of China, Associate Professor Wenpeng Lu, Associate Professor Quangui Zhang, Dr Jia Wu from Macquarie University, Dr Zhigang Zheng, Dr Peng Zhang, Dr Yonggang Huang and Dr Ting Zhang.

Last but not the least, I would like to thank my family for their unconditional support, both financially and emotionally throughout the whole PhD studying.

Shoujin Wang
August 2018 @ Analytics Cathedral,
Advanced Analytics Institute,
University of Technology Sydney, Sydney

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Papers Published

- **Shoujin Wang**, Wei Liu, Jia Wu, Longbing Cao, Qinxue Meng and Paul J. Kennedy (2016), Training Deep Neural Networks on Imbalanced Data Sets. *in 'Proceedings of the 29th International Joint Conference on Neural Networks* (**IJCNN2016**)' , pp. 4368-4374.

- Liang Hu, Longbing Cao, **Shoujin Wang** (2017), Diversifying Personalized Recommendation with User-session Context. *in 'Proceedings of the 26th International Joint Conference on Artificial Intelligence* (**IJCAI2017**)', pp. 1858-1864.

- **Shoujin Wang**, Longbing Cao (2017), Inferring Implicit Rules by Learning Explicit and Hidden Item Dependency. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 10.1109/TSMC.2017.2768547.

- **Shoujin Wang**, Liang Hu, Longbing Cao (2017), Perceiving the Next Choice with Comprehensive Transaction Embeddings for Online Recommendation. *in 'Proceedings of the 15th Joint European Conference on Machine Learning and Knowledge Discovery in Databases* (**ECML-PKDD2017**)', pp.285-302.

- **Shoujin Wang**, Liang Hu, Longbing Cao, Xiaoshui Huang, Defu Lian and Wei Liu (2018), Attention-based Transactional Context Embedding for Next-Item Recommendation. *in 'Proceedings of the 32nd*

AAAI Conference on Artificial Intelligence (**AAAI2018**)', pp.2532-2539.

Papers to be Submitted/Under Review

- **Shoujin Wang**, Longbing Cao, and Liang Hu (2018), HATE: Jointly Modeling Intra- and Inter-transaction Dependencies with Hierarchical Attentive Transaction Embeddings. *IEEE Transactions on Knowledge and Data Engineering*.

- **Shoujin Wang**, Longbing Cao, and Liang Hu (2018), A Survey on Session-based Recommender Systems. *ACM Computing Surveys*.

Abstract

In the era of big data, recommender systems (RSs) are a powerful engine to promote intelligent life by helping humans to make decisions concerning their daily necessities (e.g., food, clothes, and houses) much more efficiently and effectively, selecting from a large number of choices. Of the various types of recommender systems, session-based (SB) ones are of great value and significance, but they are not well studied.

The value of session-based recommender systems comes from two fold. From the research perspective, a SBRS takes a session as the basic unit for data organization and thus keeps the intrinsic nature of the original transaction-like data. As a result, the system effectively retains and models the rich information (e.g., intra-session dependency) embedded in a session structure to produce a more reliable recommendation. This modelling cannot be achieved by other types of recommender systems because they usually break down the original session data into multiple pair-wised user-item interactions to fit the models. From the business perspective, session data for session-based recommender systems is much more readily available than either the rating data or the item attribute data required by other recommender systems including content-based or collaborative filtering ones. This actually makes session-based RSs much more applicable in real-world business.

Though valuable, SBRSs are quite challenging. Generally, a hierarchical architecture consisting of five levels (cf. Figure 1.1) is built from the low-level feature values till to the high-level sessions in session data,as demonstrated in Chapter 1. The challenge arises mainly comes from three considerations: the heterogeneity of the elements in each level (e.g., there are both categorical and numerical features), the complex dependency within each level (e.g., the implicit inter-item relations), and the interactions between different levels (e.g., the inter-session dependency may affect the item occurrence). From my observation, the existing works mainly focus on the general item-level dependency modelling for session-based recommendations while ignoring other level relations as demonstrated in Chapter 3.

To bridge the huge gaps between the existing works and great challenges mentioned above, I build a systematic framework consisting of dependency modelling from the three core levels, i.e., feature-level, item-level and session-level (cf. Figure 1.1), for session-based recommendations. To the best of my knowledge, this is the first framework to systematically address various levels of challenges in session-based recommendations. Particularly, due to the limitations regarding space, I address one or two critical challenges in each level, as shown below.

In Chapter 4, to capture the implicit inter-item relations ignored by existing rule-based approaches, I proposed an implicit rule-based RS that first infers implicit rules and then applies the resultant rules for reliable rule-based recommendations, a basic approach for session-based recommendations.

In Chapter 5, I continue to work on item-level dependency modelling and focus on the issue of item heterogeneity, referring to different items with different levels of relevance to the next choice of an item. To this end, I build an attentive transaction-embedding model to discriminatively integrate multiple items in a transaction context into a unified context-embedding for next-item recommendations.

In Chapter 6, the feature-level dependency and feature-item interactions are modelled by a shallow neural network which takes both contextual items in a session and their corresponding features as the input. Accordingly, the cold-start issue in SBRSs has been well addressed.

In Chapter 7, the session-level (i.e.,transaction-level) dependency and session-item interactions are modelled. A hierarchical attentive transaction embedding model is built to jointly model the intra-session (item-level) and inter-session (session-level) dependency. Accordingly, the influence from previous sessions on a current session is incorporated for more accurate next-item recommendations.

All these models are applied to real-world transaction data, like Tmall and Tafang and they clearly outperform other representative SBRSs. More importantly, this thesis proposes a systematic framework to explore the driving force behind SBRSs, which provides some insights into both the researchers and engineers in this domain.