Faculty of Engineering and InformationTechnology
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Cross-market Behavior Modeling

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

by

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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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To My Parents and Xin

for your love and support

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Contents

List of Figures

List of Tables

List of Publications

Papers Published

- **Wei Cao**, Liang Hu, Longbing Cao (2015). Deep Modeling Complex Couplings within Financial Markets. *in* 'Proceedings of the the Twenty-Ninth AAAI Conference on Artificial Intelligence (**AAAI-15**)', full paper accepted.

- Zhigang Zheng, Wei Wei, Chunming Liu, **Wei Cao**, Longbing Cao, and Maninder Bhatia (2015). An Effective Contrast Sequential Pattern Mining Approach on Taxpayer Behavior Analysis, **World Wide Web (2015)**, pp.1-19.

- **Wei Cao**, Longbing Cao (2014). Financial Crisis Forecasting via Coupled Market State Analysis. **Intelligent Systems, IEEE**, 30 (2), pp.18-25 .

- Liang Hu, **Wei Cao**, Jian Cao, Guandong Xu, Longbing Cao, Zhiping Gu (2014). Bayesian Heteroskedastic Choice Modeling on Non-identically Distributed Linkages. *in* 'Proceedings of the IEEE International Conference on Data Mining (**ICDM 2014**)', short paper accepted.

- Liang Hu, Jian Cao, Guandong Xu, Longbing Cao, Zhiping Gu, **Wei Cao** (2014). Deep Modeling of Group Preferences for Group-Based Recommendation. *in* 'Proceedings of the the Twenty-Eight AAAI Conference on Artificial Intelligence (**AAAI-14**)', full paper accepted.

- **Wei Cao**, Longbing Cao, Yin Song (2013). Coupled Market Behavior Based Financial Crisis Detection. The 2013 International Joint Conference on Neural Networks (**IJCNN2013**)' , pp. 1-8.

- **Wei Cao**, Cheng Wang, Longbing Cao (2012). Trading Strategy Based Portfolio Selection for Actionable Trading Agent. Agents and Data Mining Interaction (**ADMI 2012**), pp. 191-202.

- Yin Song, Longbing Cao, Xuhui Fan, **Wei Cao**, Jian Zhang. Characterizing A Database of Sequential Behaviors with Latent Dirichlet Hidden Markov Models. arXiv:1305.5734v1 [stat.ML].

Papers to be Submitted/Under Review

- **Wei Cao**, Longbing Cao (2015). Coupled Cross-Market Behavior Analysis for Forecasting Financial Market Trends, to be submitted as a journal paper.

- **Wei Cao**, Longbing Cao. Multi-layer Coupled Hidden Markov Model for Cross-market Behavior Analysis and Trend Forecasting, to be submitted as a journal paper.

Research Reports of Industry Projects

- **Wei Cao**, Zhigang Zheng, Wei Wei, Maninder Bhatia. Action Response Model of Activity Statement – data mining modelling and evaluation report, Debt Collection and Optimisation Project, Australian Taxation Office, Nov 2013.

- **Wei Cao**, Zhigang Zheng and Wei Wei. Due-date Self-finalising Model of Income Tax – data mining modelling and evaluation report, Debt Collection and Optimisation Project, Australian Taxation Office, May 2014.

Abstract

During the 2007 global financial crisis which was triggered by subprime borrowers in the US mortgage markets, strong market linkages were observed between different financial markets. The sharp fluctuations in the global stock market, commodity market and interest market illustrate some of the coupled behaviors that exist between various markets, namely the crisis effect is passed from one market to another through couplings. Here coupled behaviors refer to the activities (e.g. changes of market indexes) of financial markets which are associated with each other in terms of particular relationships. Therefore, a good understanding of coupled behaviors is of great importance in cross-market applications such as crisis detection and market trend forecasting. For instance, if the coupled behaviors are properly understood and modeled, investors can predict financial crisis and avoid the big loss, by detecting the changes of coupled relations between financial crisis period and non-crisis period.

However, understanding and modeling coupled behaviors is quite challenging for following reasons: (1) The various coupled structures across financial markets (e.g. coupled relations between different types of markets, and coupled relations between the same type of market in different countries) bring challenges in terms of understanding and modeling them. (2) Various types of couplings. The typical forms are intra-coupling, inter-coupling and temporal-coupling. (3) The complex interactions between markets are driven by hidden features which cannot be observed directly from observation/data. (4) Different applications in cross-market analysis lead to the consideration

of input factors/variables selection.

All of these challenges the existing methods for cross-market analysis, which can be roughly categorized into two types: time series analysis represented by Logistic regression, Autoregressive Integrated Moving Average (ARIMA) and Generalized AutoRegressive Conditional Heteroscedasticity (GARCH) models. Model-based methods explore machine models such as Artificial Neural Networks (ANN) and Hidden Markov Models (HMM). The main limitations lie in their deficiencies: (1) Existing approaches are usually focused on the simple correlations of the cross-market, rather than coupled behaviors between markets. (2) State-of-the-art research work is usually built directly from the observation/data. Hidden features behind the observation/data are often ignored or only weakly addressed. (3) Some approaches follow assumptions that are too strong to match real financial markets.

Based on the above research limitations and challenges, this thesis reports state-of-the-art advances and our research innovations in understanding and modeling complex coupled behaviors for the purpose of cross-market analysis.

Chapter 3 presents a new approach, called Coupled Market Behavior Analysis (CMBA) for financial crisis detection. This caters for nonlinear couplings between major indicators selected from different markets, and it detects different coupled market behaviors at crisis and non-crisis periods. Chapter 4 seeks to overcome the limitations of most current methods which conduct financial crisis forecasting directly through observation and overlook the hidden interactions between markets. In this chapter, Coupled Market State Analysis (CMSA) is presented to build forecasters based on coupled market states instead of observation.

Chapter 5 reports a new approach for market trend forecasting by analyzing its hidden coupling relationships with different types of related financial markets. Chapter 6 proposes Hierarchical Cross-market Behavior Analysis (HCBA) to forecast a stock market's movements, by exploring the complex coupling relationships between variables of markets from a country (Layer-1 coupling) and couplings between markets from various countries (Layer-2

coupling). In addition, Chapter 7 designs a Coupled Temporal Deep Belief Network (CTDBN) which accommodates three different types of couplings across financial markets: interactions between homogeneous markets from various countries (intra-market coupling), interactions between heterogeneous markets (inter-market coupling) and interactions between current and past market behaviors (temporal coupling). With a deep-architecture model to capture the high-level coupled features, the proposed approach can infer market trends.

In terms of cross-market applications (i.e. financial crisis detection and market trend forecasting), our proposed approaches and frameworks for modeling coupled behaviors across financial markets outperform state-of-the-art methods from both technical and business perspectives. All of these outcomes provide insightful knowledge for investors who naturally seek to make profits and avoid losses. Accordingly, cross-market behavior modeling is a promising research topic with lots of potential for further exploration and development.