UNIVERSITI PUTRA MALAYSIA

AUTOMATED BILATERAL NEGOTIATION WITH INCOMPLETE INFORMATION IN THE e-MARKETPLACE

HAMID JAZAYERIY

FSKTM 2011 24

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By

HAMID JAZAYERIY

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2011

DEDICATION

To

My dear wife for her encouragement,

My parents who have devoted their life to their children,

My brother and sister,

and

To all people who live with peace and wisdom.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

AUTOMATED BILATERAL NEGOTIATION WITH INCOMPLETE INFORMATION IN THE e-MARKETPLACE

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HAMID JAZAYERIY

June 2011

Chair: Masrah Azrifah Azmi-Murad, PhD

Faculty: Computer Science and Information Technology

Automated negotiation is a basic element in multi-agent systems (MAS), which helps autonomous agents to find a mutual agreement by resolving conflicts. Research on automated negotiation can highly affect the quality of e-marketplaces where autonomous agents buy/sell on behalf of their owners.

Pareto-efficiency is a seminal property of the negotiation outcome (an outcome is Pareto-optimal if there is no other outcome that makes an agent better off without making the other agent worse off). Unfortunately, reaching to a Pareto-optimal agreement is a complex problem, particularly when agents negotiate over multiple issues (such as price, warranty and delivery) with incomplete information about each other's preferences.

Although an extensive academic research has explored the single issue negotiation, much less research investigated the multi-issues negotiation with incomplete information. So far, using fuzzy similarity with smart trade-offs was a useful ap-

proach to generate near Pareto-optimal offers in multi-issues negotiation. In this approach, a pool of random offers helps an agent to find the most similar one with the last received offers. However, this approach has a high time-complexity.

The main purpose of this thesis is to generate Pareto-optimal offers in multi-issues bilateral negotiation with incomplete information. To study this problem, at first, negotiations should be grounded on a model that governs the interactions and determines relation between agents.

Given this background, the following objectives are considered to be carried out in this study: (*i*) forming a multi-issues bilateral negotiation model by adapting existing single-issue models. (*ii*) generating Pareto-optimal offers with one-side incomplete information. (*iii*) generating Pareto-optimal offers with both-sides incomplete information. To fulfill the first objective, each negotiation issue is modeled by a *split the pie of size 1* game where the total negotiation is a non-zero-sum game. In addition, the well-known *alternating-offers protocol* is used to govern the interactions.

To generate Pareto-optimal offer with one-side incomplete information, at first, an algorithm is presented to generate multi-issue offers with perfect (complete) information. This algorithm is called maximum greedy trade-offs (MGT) and can generate offers at given aspiration-level (target utility) in $O(n)$. The MGT algorithm is useful to explore the properties of the Pareto-optimal offers. This algorithm comes with some corollaries that form a learning approach in one-side incomplete problem. The advantage of the MGT algorithm is that it does not

need the exact opponent's preferences to generate Pareto-optimal offers, instead, it works with a greedy sequence. An agent with incomplete information can find an estimation of the optimal offer in early rounds of the negotiation, however as time passes, it can likely generate Pareto-optimal offer by learning the greedy greedy sequence. In this case, the agent with incomplete information can learn the greedy sequence in $O(n \log n)$. In one-side incomplete information problem, comparison between MGT algorithm and *smart random trade-offs* (SRT) algorithm indicates that MGT outperforms SRT.

Finally, the problem of finding Pareto-optimal offers in both sides with incomplete information is investigated. In this case, agents need to be tailored by a learning capability that explores the opponent's preferences. To this end, we have developed an incremental learning approach using soft-computing techniques to learn opponent's preferences in multi-issue negotiation with incomplete information. In this learning approach, firstly, the size of possible preferences is reduced by encoding the uncertain preferences into a series of fuzzy membership functions. Then, the process of searching the best fuzzy preferences that articulates the opponent's intention is conducted by genetic algorithm. Whenever an agent receives an offer it forms a constraint and updates the fitness of individuals in the given population of preferences based on the degree of the constraint satisfaction. Experimental results show that our learning approach can estimate the opponent's preferences effectively. Moreover, results indicate that agents equipped by this learning capability can generate Pareto-efficient offers by MGT algorithm. Results, in both-sides incomplete information problem, indicate that MGT out-

performs SRT. The reason is that, SRT algorithm is sensitive to the accuracy of the learned preferences while MGT algorithm can generate Pareto-optimal offers even with an approximation of the learned preferences.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

RUNDINGAN DUA HALA AUTOMATIK DENGAN MAKLUMAT TAK LENGKAP DI DALAM e-PASARAN

Oleh

HAMID JAZAYERIY

Jun 2011

Pengerusi: Masrah Azrifah Azmi-Murad, PhD

Fakulti: Sains Komputer dan Teknologi Maklumat

Perundingan automatik merupakan elemen asas dalam sistem multi-agen (MAS) yang membantu agen-agen autonomi untuk mencari kesepakatan dalam perjanjian dengan menyelesaikan konflik. Penyelidikan dalam perundingan automatik amat mempengaruhi kualiti e-pasaran di mana agen-agen autonomi boleh membeli/menjual atas nama pemiliknya.

Kecekapan Pareto merupakan sifat-sifat utama daripada hasil perundingan (satu hasil adalah optimum Pareto jika tidak ada hasil yang lain yang boleh mengakibatkan satu agen mencapai keuntungan tanpa mengakibatkan agen yang lain mencapai kerugian). Malangnya, pencapaian kesepakatan optimum Pareto adalah satu masalah yang kompleks, terutamanya apabila agen membuat perundingan di atas beberapa isu (seperti harga, jaminan dan penghantaran) dengan memegang maklumat yang tidak lengkap tentang kecenderungan satu sama lain.

Walaupun penyelidikan akademik yang luas telah diperlaksanakan untuk menjelajah perundingan yang melibatkan satu isu, kurang penyelidikan telah diperlaksanakan untuk menyiasat perundingan yang melibatkan multi-isu. Setakat ini, penggunaan keserupaan kabur dengan keseimbangan bijak merupakan kaedah berguna untuk menjana tawaran Pareto-optimal hampir di dalam berbilang isu. Di dalam kaedah ini, satu kumpulan tawaran secara rawak menolong ejen untuk mencari tawaran yang paling serupa dengan tawaran terakhir yang diterima. Walau bagaimanapun, kaedah ini mempunyai kerumitan masa yang tinggi.

Tujuan utama tesis ini adalah untuk menghasilkan tawaran optimum Pareto dalam perundingan bilateral yang melibatkan multi-isu di bawah keadaan ketidaklengkapan maklumat. Untuk menyiasat masalah ini, pada awalnya, perundingan harus didasarkan pada satu model yang mengendalikan interaksi dan menentukan hubungan antara agen.

Dengan latar belakang ini, matlamat-matlamat berikut dianggap akan dilakukan dalam kajian ini: (*i*) membentuk satu model perundingan bilateral yang melibatkan multi-isu dengan mengadaptasikan model-model isu-tunggal yang sedia ada. (*ii*) menghasilkan tawaran optimum Pareto di bawah keadaan di mana salah satu agen memegang maklumat yang tidak lengkap (*iii*) menghasilkan tawaran optimum Pareto di bawah keadaan di mana kedua-dua agen memegang maklumat yang tidak lengkap. Untuk memenuhi matlamat yang pertama, setiap isu perundingan dimodelkan oleh permainan *split the pie of saiz 1* di mana keseluruhan perundingan merupakan satu permainan non-zero-sum. Selain itu, pro-

tokol alternating-offers yang terkenal digunakan untuk mengendalikan interaksi.

Untuk menghasilkan tawaran optimum Pareto di bawah keadaan salah satu agen memegang maklumat yang tidak lengkap, pada awalnya, satu algoritma ditunjukkan untuk menghasilkan tawaran multi-isu dengan maklumat yang sempurna (lengkap). Algoritma ini dinamakan sebagai maximum greedy trade-off (MGT) dan boleh menghasilkan tawaran berdasarkan tahap aspirasi (sasaran utility) dalam $O(n)$ yang diberikan. Algoritma MGT adalah berguna untuk menjelajah sifat-sifat tawaran optimum Pareto. Algoritma ini dilengkapi dengan beberapa korolari yang membentuk satu pendekatan pembelajaran dalam masalah di mana satu agen memegang maklumat yang tidak lengkap. Kelebihan daripada algoritma MGT adalah ia tidak memerlukan maklumat yang tepat tentang kecenderungan pihak lawan untuk menghasilkan tawaran optimum Pareto, sebaliknya, ia memerlukan kehadiran jujukan rakus. Agen dengan maklumat yang tidak lengkap boleh mencari estimasi tawaran optimum dalam pusingan awal rundingan, namun selepas satu masa yang tertentu, agen tersebut mungkin boleh menghasilkan tawaran optimum Pareto melalui pembelajaran jujukan rakus. Bagi kes sebegini, agen dengan maklumat yang tidak lengkap boleh mempelajari urutan serakah dalam $O(n \log n)$. Dalam masalah di mana salah satu agen memegang maklumat yang tidak lengkap, perbandingan di antara algoritma MGT dan algoritma *smart random trade-offs* (SRT) menunjukkan bahawa MGT mencapai prestasi yang lebih tinggi daripada SRT.

Akhirnya, masalah untuk mencari tawaran optimum Pareto dalam keadaan di

mana kedua-dua agen memegang maklumat yang tidak lengkap disiasat. Dalam kes ini, agen perlu dilengkapkan dengan kemampuan pembelajaran untuk menjelajah kecenderungan pihak lawan. Untuk tujuan ini, kami telah membangunkan satu pendekatan pembelajaran tokokan dengan menggunakan teknik pengkomputeran-lembut untuk mempelajari kecenderungan pihak lawan dalam perundingan multi-isu di bawah keadaan maklumat yang tidak lengkap. Dalam pendekatan pembelajaran ini, pertama, saiz kecenderungan yang bermungkinan dikurangkan dengan mengenkodkan kecenderungan yang tidak menentu kepada satu siri fungsi keahlian fuzzy. Kemudian, proses untuk mencari kecenderungan fuzzy terbaik yang mengartikulasikan niat pihak lawan dilakukan oleh algoritma genetik. Setiap kali agen menerima tawaran, agen tersebut boleh membina satu sekatan dan mengemaskinikan kesesuaian individu dalam populasi kecenderungan yang diberikan berdasarkan tahap kepuasan ke atas sekatan. Keputusan kajian menunjukkan bahawa pendekatan pembelajaran kami dapat menganggarkan kecenderungan pihak lawan dengan berkesan. Selain itu, keputusan menunjukkan bahawa agen yang dilengkapi dengan kemampuan pembelajaran ini dapat menghasilkan tawaran kecekapan Pareto dengan menggunakan algoritma MGT. Bagi kes di mana kedua-dua agen memegang maklumat yang tidak lengkap, keputusan menunjukkan bahawa MGT mencapai prestasi yang lebih tinggi daripada SRT. Alasannya adalah algoritma SRT adalah sensitif kepada ketepatan kecenderungan yang telah dipelajari sedangkan algoritma MGT dapat menghasilkan tawaran otimum Pareto walaupun dengan menggunakan penganggaran kecenderungan yang telah dipelajari.

ACKNOWLEDGEMENTS

First and foremost, all praise to the almighty God for his blessings and merciful that enable me to learn. This thesis is the result of almost four years of work where I have been accompanied by some people. I now have the pleasant opportunity to express my gratitude to all of them.

I am sincerely grateful to my supervisor, Dr. Azrifah Masrah Azmi-Murad, for giving me the opportunity to work under her supervision, for her genuine interest in my research and career, for never being too busy to set regular time aside for getting together, for stimulating conversations and valuable advice on many topics and for her patience. Moreover, I would like to express my sincere thanks and appreciation to the supervisory committee members, Assoc. Prof. Dr. Md. Nasir Sulaiman and Dr. Nur Izura Udzir for their guidance, valuable suggestions and advice throughout this work in making this a success.

My PhD study was supported by a grant fellowship from the School of Graduate Studies at University Putra Malaysia. I would like to take this opportunity to thank the university for the financial support.

I cannot end without thanking my family. I owe so much to my dear mother and father, who are always my source of inspiration and encouraged me to learn and supported me throughout my life. Moreover, I would like to thank my wife for her help, and my brother and sister for their patience.

APPROVAL

I certify that an Examination Committee has met on **09/06/2011** to conduct the final examination of Hamid Jazayeriy on his Doctor of Philosophy thesis entitled **"Automated Bilateral Negotiation with Incomplete Information in the e-Marketplace"** in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Examination Committee were as follows:

Hamidah Ibrahim, PhD
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Chairman)

Rusli Abdullah, PhD
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Internal Examiner)

Norwati Mustapha, PhD
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Internal Examiner)

Norman Yeow-Khean Foo, PhD
Emeritus Professor
School of Computer Science and Engineering
University of New South Wales
Australia
(External Examiner)

NORITAH OMAR, PhD
Assoc. Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of Supervisory Committee were as follows:

Masrah Azrifah Azmi-Murad, PhD
Senior Lecturer
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Chairman)

Md. Nasir Sulaiman, PhD
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

Nur Izura Udzir, PhD
Senior Lecturer
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

HASANAH MOHD. GHAZALI, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

HAMID JAZAYERIY

Date: 9 June 2011

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