

**Semantic-Enhanced Hybrid Recommender  
Systems for Personalised E-Government Services**

A Thesis Submitted for the Degree of  
Doctor of Philosophy

By  
Malak Al-Hassan

In

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY  
UNIVERSITY OF TECHNOLOGY, SYDNEY  
AUSTRALIA  
2014

©Copyright by Malak Al-Hassan, 2014

# CERTIFICATE

Date: July 2014

Author: **Malak Al-Hassan**

Title: **Semantic-Enhanced Hybrid Recommender Systems for  
Personalised E-Government Services**

Degree: **Ph.D.**

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 Author

## **Acknowledgments**

I would like to express my gratitude to many people who have inspired me both personally and professionally. First and foremost, I would like to thank my supervisors, Prof. Jie Lu and Dr. Hai Yan (Helen) Lu. They introduced me to the field of Information System (e-Service). I never would have had the courage to go forward with the methodology and theoretical research without their tremendous confidence in me. I can hardly think of anything that has been achieved without their help, as they offered me the freedom to autonomously explore new ideas.

I would also like to acknowledge the **Faculty of Engineering and IT at the University of Technology, Sydney**, for offering me a quality research environment. I am also grateful to my fellow students, for their encouragement and friendship. I would like to express my appreciation to all my friends and members of the Decision System and e-Service Intelligence (DSeSL) lab for their help, support and valuable insights throughout my study.

I gratefully acknowledge the funding sources that made my PhD work possible, as I am sponsored by the **Faculty of IT, Jordan University** - Jordan. My work was also supported by the **Faculty of Engineering and IT at UTS**. In terms of external datasets that have been used in this research study, I acknowledge the Australian Tourism Data Warehouse (ATDW) for providing the dataset used in this study.

I would like to express my deep gratitude to my parents, brothers and sisters for their constant support and encouragement, and more importantly their faith in me over the course of many years. My parents, I can never thank you enough for what you have done for me. My great appreciation is also extended to my beloved husband Ahmad, who has been with me for nearly 5 years and has sacrificed so much in helping me to pursue my academic pathway. Thank you for your patience and care. Finally, I would like to express my love to my beautiful daughter, Tala, for her patience and understanding over the time that I have spent away from her during my PhD journey.

Sydney, Australia, 2014.

*To My Family,*

*My Husband and Our Angel, Tala.*

# Table of Content

<b>List of Tables</b> .....	ix
<b>List of Figures</b> .....	x
<b>Abstract</b> .....	xiii
<b>Chapter 1 Introduction</b> .....	<b>1</b>
1.1 Research Questions .....	5
1.2 Research Objectives .....	6
1.3 Research Significance and Contributions .....	6
1.4 Organisation of the Thesis .....	10
1.5 Publications Related to this Thesis .....	13
<b>Chapter 2 Literature Review and Background</b> .....	<b>14</b>
2.1 E-Government .....	14
2.1.1 E-Government Definition .....	15
2.1.2 E-Government Benefits .....	16
2.1.3 E-Government Activities .....	17
2.1.4 Models of E-Government Development Stages .....	18
2.1.5 E-Government Development Models – Discussion .....	22
2.2 Web Personalisation .....	23
2.2.1 Personalisation Definition and Benefits .....	23
2.2.2 Personalisation Classification and Examples .....	24
2.2.3 Web Personalisation Process .....	26
2.3 Recommender Systems .....	27
2.3.1 Content-based Recommendation Techniques .....	27
2.3.2 Collaborative Filtering Recommendation Techniques .....	29
2.3.3 Knowledge-based Recommendation Techniques .....	40
2.3.4 Hybrid Recommendation Systems .....	42
2.3.5 Evaluating Recommendation Techniques .....	46
2.4 Ontology .....	47
2.4.1 Ontology Definition .....	47
2.4.2 Ontology Languages .....	48
2.4.3 Ontology Development Process .....	50
2.4.4 Semantic-based Similarity Measures .....	52

2.4.5	Semantic Recommendation Systems .....	59
2.5	Tourism Recommender Systems.....	61
2.5.1	Online Tourism Services.....	61
2.5.2	Tourism Recommender System Examples .....	62
2.5.3	E-Government Tourism Services.....	64
2.6	E-Government Tourism – Case Study .....	65
2.7	Summary .....	65
<b>Chapter 3</b>	<b>A Personalised e-Government Services Framework from a Citizen-Centred Approach.....</b>	<b>66</b>
3.1	A Personalised Domain Specific E-Government Service Framework .....	67
3.1.1	User Interface Component .....	69
3.1.2	User Data Collector.....	70
3.1.3	Data Source Repository.....	71
3.1.4	Intelligent Recommendation Engine.....	73
3.2	Special Feature of the IPe-Gov Framework.....	75
3.3	Cases Illustration of the Framework’s Workflow.....	77
3.4	Summary and Discussion.....	80
<b>Chapter 4</b>	<b>A Framework for Delivering Personalised e-Government Tourism Services .....</b>	<b>81</b>
4.1	Framework of IPe-Government Tourism Service.....	82
4.1.1	User Interface Layer.....	84
4.1.2	Knowledge Repository Layer .....	85
4.1.3	Intelligent Recommendation Layer.....	88
4.2	Workflow of the IPe-Gov Tourism Service System .....	93
4.3	Summary and Discussion.....	96
<b>Chapter 5</b>	<b>A Hybrid Recommendation Approach Using Ontology-based Semantic Similarity for e-Government Personalised Services .....</b>	<b>98</b>
5.1	An Enhanced Semantic-based Hybrid CF Recommendation Approach.....	100
5.1.1	E-Government Service Domain Ontology .....	101
5.1.2	Ontology-based Semantic Similarity Measure .....	107
5.1.3	Recommendation Procedure of the SBCF-OBSS Approach.....	117
5.2	Experimental Evaluation and Settings .....	121
5.2.1	Experimental Design.....	122

5.2.2	Experimental Dataset .....	123
5.2.3	Experimental Evaluation Metrics.....	124
5.2.4	Determination of Experimental Parameters .....	124
5.2.5	Eliminate the Randomness .....	125
5.2.6	Settings for Addressing the Sparsity Problem .....	125
5.2.7	Settings for Addressing the Cold-start item Problem .....	126
5.3	Experimental Results .....	126
5.3.1	Sensitivity of the Semantic Combination Parameter and Neighbourhood Size .....	126
5.3.2	Effectiveness of the New Hybrid Approach on the Prediction Accuracy.....	128
5.3.3	Effectiveness of the Proposed Hybrid Approach on the Quality of Generated Recommendations.....	129
5.3.4	Effectiveness of the SBCF-OBSS Approach in Dealing with the Sparsity Problem .....	130
5.3.5	Effectiveness of the SBCF-OBSS Approach in Dealing with the Cold-start Item Problem .....	132
5.4	Summary and Discussion.....	132
<b>Chapter 6 A Hybrid Recommendation Approach Using An Inferential Semantic Similarity for e-Government Personalised Services .....</b>		<b>134</b>
6.1	New Ontology-based Semantic Similarity Measure .....	136
6.1.1	Terms used in Defining the New Semantic Similarity Measure.....	137
6.1.2	The New Semantic Similarity (IOBSS) Measure .....	148
6.1.3	The Algorithmic Procedures of the IOBSS Measure.....	148
6.1.4	Remarks.....	152
6.2	An Enhanced Semantic Hybrid Recommendation Approach.....	153
6.3	Computational Complexity Analysis .....	156
6.4	Experimental Evaluation and Analysis .....	158
6.4.1	Experimental Design.....	158
6.4.2	Dataset and Evaluation Metrics .....	158
6.4.3	Experimental Parameters and Settings.....	159
6.4.4	Experimental Results .....	159
6.5	Summary and Discussion.....	165
<b>Chapter 7 An Improved Switching Semantic-Enhanced Hybrid Recommender System.....</b>		<b>168</b>

7.1	Cluster-based semantic enhanced CF approach.....	170
7.1.1	Semantic-based Clustering Component.....	171
7.1.2	Neighbourhood Formation and Prediction Component.....	178
7.1.3	Addressing the New User Problem.....	181
7.2	A Switching-based Semantic Enhanced Hybrid Recommender System.....	183
7.2.1	Switching Criteria.....	184
7.2.2	Algorithmic Procedure of the SeHR System.....	184
7.3	Computational Complexity Analysis.....	186
7.4	Experimental Evaluation and Results.....	187
7.4.1	Experimental Design.....	187
7.4.2	Experimental Dataset and Metrics.....	188
7.4.3	Experimental Parameters and Settings.....	188
7.4.4	Experimental Results and Analysis.....	190
7.5	Summary and Discussion.....	199
<b>Chapter 8</b>	<b>Conclusion and Future Directions.....</b>	<b>201</b>
8.1	Conclusion.....	201
8.2	Limitations and Future Directions.....	206
<b>Bibliography</b>	<b>.....</b>	<b>208</b>



## List of Tables

Table 2.1: A Comparison between standard recommendation system techniques .....	42
Table 2.2: Example of hybrid recommendation systems .....	44
Table 4.1: Part of a user profile.....	88
Table 5.1: Characteristics of the proposed approach and the competing approaches...	122
Table 5.2: The best neighbourhood size $K$ that achieves the minimum $MAE$ for each distinct $\alpha$ value .....	127
Table 5.3: Optimal vales of the parameters used in experiments .....	128
Table 6.1: Parameters of the associate network of instance $I_x$ .....	142
Table 6.2: Parameters of the associate network of instance $I_y$ .....	142
Table 6.3: The common associate set of the instances $I_x$ and $I_y$ . .....	151
Table 6.4: Structure-based and datatype-based similarities of elements in the common associate pair set of $I_x$ and $I_y$ .....	152
Table 6.5: The best neighbourhood size $K$ that achieves the minimum $MAE$ for each distinct $\alpha$ value .....	160
Table 6.6: Optimal values of parameters that are used in experiments .....	161
Table 7.1: Membership degrees of five users to four clusters .....	189
Table 7.2: The best neighbourhood size $K$ for each cluster .....	192
Table 7.3: Comparing the accuracy improvement of the proposed CSeCF approach and other compared approaches on different sparsity levels .....	193
Table 7.4: Optimal parameters of the SBCF-IOBSS and the CSeCF-MC .....	195

## List of Figures

Figure 2.1: Types of e-Government activities (Millard et al. 2004). .....	18
Figure 2.2: Development stages of e-Government services (UN Model 2002).....	19
Figure 2.3: Development model of e-Government services (Layne & Lee 2001).....	20
Figure 2.4: The EC progress achievement on a five-stage sophistication model. ....	21
Figure 2.5 : Web personalisation process (Markellou, Rigou & Sirmakessis 2004). ....	26
Figure 2.6: Ontology development process life cycle.....	51
Figure 3.1: The IPe-Gov framework.....	68
Figure 3.2: An example of e-Government service concepts.....	72
Figure 4.1: Framework of IPe-Government tourism service recommender system. ....	83
Figure 4.2: A portion of an e-Government tourism ontology schema. ....	86
Figure 4.3: A sample schema of ontological relations between tourism concepts. ....	87
Figure 4.4: A description scenario of the workflow of IPe-Gov tourism framework....	94
Figure 5.1: A portion of conceptual model of the Australian tourism service items. ...	104
Figure 5.2: A portion of the Australian tourism service OWL ontology. ....	106
Figure 5.3: A portion of the Australian tourism ontology schema. ....	107
Figure 5.4: The object properties of $I_x$ = Australian National Maritime Museum .....	114
Figure 5.5: The object properties of $I_y$ = Anzac Memorial Historic Building.....	115
Figure 5.6: The computational recommendation process of the proposed SBCF-OBSS approach. ....	118
Figure 5.7: Comparing the impact of the integration of the item-based CF and OBSS measure on prediction accuracy. ....	128
Figure 5.8: Comparison of prediction accuracy results of the proposed hybrid approach and the competing approaches. ....	129

Figure 5.9: Comparing the quality of generated recommendations of the proposed approach and competing approaches. ....	130
Figure 5.10: Improvement in prediction accuracy of the proposed SBCF-OBSS approach against competing approaches at different sparsity levels. ....	131
Figure 5.11: Comparing the prediction accuracy of the proposed hybrid approach against other competing approaches for new items. ....	132
Figure 6.1: Relationships around two ontological instances $I_x$ and $I_y$ in the target ontology. ....	138
Figure 6.2: The associate network of instance $I_x = \text{Australian National Maritime Museum}$ . ....	139
Figure 6.3: The associate network of instance $I_y = \text{Anzac Memorial Historic Building}$ . ....	140
Figure 6.4: Tree representation for the associate network of the instance $I_x$ . ....	141
Figure 6.5: Tree representation for the associate network of the instance $I_y$ . ....	141
Figure 6.6: The block diagram of the calculation procedure of the IOBSS measure. ..	149
Figure 6.7: The workflow of the recommendation computation procedure of the SBCF-IOBSS approach. ....	154
Figure 6.8: Comparison of the SBCF-IOBSS and the SBCF-OBSS approaches in terms of the impact of the $\alpha$ parameter on the prediction accuracy. ....	161
Figure 6.9: Comparison of prediction accuracy between the proposed SBCF-IOBSS and SBCF-OBSS approaches at different sizes of neighbourhood. ....	162
Figure 6.10: Improvement in prediction accuracy of the proposed SBCF-IOBSS approach over the SBCF-OBSS approach at different sparsity levels. ....	163
Figure 6.11: Comparison of prediction accuracy between the proposed SBCF-IOBSS approach and the SBCF-OBSS approach on new items problem. ....	164
Figure 6.12: Comparison of the <i>hit ratio</i> results of the proposed SBCF-IOBSS approach and the SBCF-OBSS approach. ....	165
Figure 7.1: Structural diagram of the CSeCF approach. ....	171

Figure 7.2: Semantic-based user profile modeling (example). .....	173
Figure 7.3: An example of updating a user profile of an active user using SA algorithm. .....	177
Figure 7.4: The flow diagram of the switching-based semantic-enhanced hybrid recommender system.....	183
Figure 7.5: Comparing the prediction accuracy of proposed the CSeCF approach and the other compared approaches with respect to the number of clusters.....	191
Figure 7.6: Comparison of the computational times of the CSeCF and other compared approaches.....	194
Figure 7.7: The effectiveness of the Switching SeHR system in resolving the cold-start user problem.....	196
Figure 7.8: The effectiveness of the SBCF-IOBSS and CSeCF with the Cold-start user with few ratings Problem .....	198
Figure 7.9 Comparison of prediction accuracy for the proposed Switching SeHR system, the SBCF-IOBSS approach and the CSeCF approach.....	199

# ABSTRACT

E-Government is becoming ever more active in terms of improving the provision of services to citizens from a citizen-centred perspective, in which online services and information are delivered to citizens on a personalised basis. Some developed governments have started to offer personalised services through their official portals. However, the personalised services that are offered are mostly limited to static customisation and are therefore far from achieving effective citizen-centred e-Government services. Furthermore, delivering personalised online services that match the different needs and interests of government users is a challenge for e-Government, specifically in connection with the increasing information and services that are offered through the medium of government portals. Therefore, more advanced and intelligent e-Government systems are desirable.

Personalisation techniques, particularly in the form of recommender systems, are promising to provide better solutions to support the development of personalisation in e-Government services. Furthermore, semantic enhanced recommender systems can better support citizen-centred e-Government services and enhance recommendation accuracy. The success of semantic enhanced hybrid recommendation approaches and the citizen-centric initiative of e-Government have fostered the idea of developing personalised e-Government recommendation service systems using semantic enhanced hybrid recommender systems. Accordingly, the effectiveness of utilising the semantic knowledge of e-Government services to enhance the recommendation quality of offered services is addressed in this thesis.

This thesis makes five significant contributions to the area of e-Government personalised recommendation services. These contributions are summarised as follows: (i) the thesis first proposes a general framework for offering personalised e-Government services from a citizen-centred perspective based on the available user profiles information and semantic knowledge of a specific e-Government domain of interest; (ii) based on this general framework, a personalised e-Government tourism service recommendation framework is also proposed and considered as a target domain in this research study; (iii) new semantic enhanced hybrid recommendation approaches are

developed to support the implementation of the recommendation generator engines of the proposed e-Government frameworks. The recommendation generator engines represent the core components of the proposed frameworks; (iv) new semantic similarity measures based on semantic knowledge of a target domain ontology are proposed to effectively evaluate the similarity between e-Government service items. The new semantic similarity measures are incorporated within the proposed hybrid approaches to improve the quality and accuracy of recommendations and to overcome the limitations of existing hybrid recommendation approaches; and (v) a switching semantic enhanced hybrid recommendation system is further proposed to enhance the overall quality of recommendation, address the sparsity, the cold-start user and item problems.

Experimental evaluations of the proposed semantic enhanced hybrid recommendation approaches and switching system, on a real world tourism dataset, show promising results against state-of-the-art recommendation approaches in terms of the quality of recommendations, capacity to alleviate the sparsity, cold-start item and user problems.