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AUTOMATIC RANDOMIZED TEST GENERATION STRATEGY FOR ASPECT-ORIENTED SOFTWARE

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By

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

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DEDICATION

Dedicated to my dearest mother and to my father, God rest his soul, who taught me how to follow my quest for faith and knowledge.

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

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Chair: Abdul Azim Abdul Ghani, PhD

Faculty: Computer Science and Information Technology

Software systems, nowadays, are used across the world to facilitate our daily life in different ways. Testing and verification of these software systems are very crucial with respect to safety, acceptance, and sidestepping failure damages.

Aspect-oriented programming (AOP), as one of the prominent modularization techniques is gaining popularity as a methodology for contemporary software systems development. To realize the benefits of aspect-oriented programming and to produce validated and high quality aspect-oriented (AO) software, the programs developed by this programming paradigm should be effectively

tested with attention to all of its characteristics, i.e. extension of new constructs and programming means for separation of concerns. The reason to emphasize is that, the AOP-specific defects stemmed from the unique characteristics of AOP can affect the quality of these programs in unusual ways and consequently diminish their general benefits, i.e. enhanced modularity and maintainability. In addition, these unique characteristics have made testing of AOP more sophisticated and challenging, though testing programs with simple functions is already hard and costly.

To reduce the human effort and costs in assuring the correctness and general quality of aspect-oriented programs, it is desirable to automate testing of aspect-oriented programs. In fact, automated testing has been a significant area of interest in current software testing research and has evolved greatly in recent years. However, it has to be said that there is comparatively little work on testing of AOP in the literature and very few and limited studies on automated testing of AOP. From a technical point of view, the existing studies on automated testing of AOP are not adequately effective in their underlying strategies used as the test generation has less AOP-specific focus and it is more founded on the knowledge of base code. In addition, lack of practical tools, lack of reliability and statistical evaluation from testing results with regard to the approach, difficulty in implementation of the strategy, and providing no automated test code generation are major issues associated with the existing

studies. This obviously indicates an insufficiency of automated testing approaches, particularly automatic test generation, for the aspect-oriented programs at the current time and provides a primary motivation for leveraging the current techniques and/or developing new techniques for testing these programs.

It is conjectured that applying recent techniques on testing and verification to AO-based systems is crucially important for making aspect-oriented software development (AOSD) success. As in the sequel, there is much advancement on testing and verification, like automated test generation using random-based and search-based techniques, coverage analysis, fault models, mutation analysis, and so forth. Many of those techniques are not yet applied or at least not properly investigated for AOP. Some would be trivial, but some would need some efforts to make them possible and leverage to testing of AOP.

Random testing (RT) is an active and important research in software testing, which is a niche in practical settings due to its merits, e.g. fault-detection capacities at low cost, ease of implementation, reliability estimation of the software using the test results, and most importantly facility for automation. It can be said that RT is one of the most intuitive techniques for automatic test generation that has been widely studied and applied to test various programs for decades and has formed the core parts of many useful testing approaches.

On this regard, the idea behind random testing can be worthwhile and attractive to offer much promise in regard to AOP test automation problems since current research on testing of AOP, especially automated has not been adequately performed and is still in its infancy.

So far, there is no mature testing approach in the context of AOP, considering the random testing techniques for automatic test generation of aspect-oriented programs, which can make this study as first in this sense. Therefore, to apply the random testing concept on AOP and to improve the degree of automation and the maturity of the automated AOP testing, in this thesis a rigorous automated test generation strategy, called *RAMBUTANS*, and its tool support based on the AspectJ programs were proposed. Furthermore, a thorough empirical study of nine AspectJ benchmark programs by means of mutation analysis was performed to compare *RAMBUTANS* and the four existing automated AOP testing approaches (namely Wrasp, Aspectra, Raspect, and EAT) for testing aspects in terms of fault detection effectiveness and test effort efficiency. The results of experiment and statistical tests ($p<0.01$) presented strong evidence of the effectiveness and efficiency of the proposed strategy. Therefore, the study showed that the resulting randomized tests were reasonably good for AOP testing, thus the proposed strategy could be worthy of use as an effective and efficient AOP-specific automatic test generation strategy.

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

STRATEGI PENJANAAN UJIAN TERAWAK AUTOMATIK UNTUK PERISIAN BERORIENTASI-ASPEK

Oleh

REZA MEIMANDI PARIZI

Ogos 2012

Pengerusi: Abdul Azim Abdul Ghani, PhD

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Sistem perisian, pada masa kini, digunakan di seluruh dunia untuk memudahkan kehidupan seharian kita dalam cara yang berbeza. Pengujian dan penentusahan sistem perisian ini adalah sangat penting berkenaan dengan keselamatan, penerimaan, dan mengelak kerosakan kegagalan.

Pengaturcaraan berorientasi-aspek (POA), sebagai satu teknik pemodulan terkemuka semakin popular untuk digunakan sebagai suatu metodologi bagi pembangunan sistem perisian kontemporari. Bagi merealisasikan manfaat pengaturcaraan berorientasi aspek dan untuk menghasilkan perisian berorientasi-aspek (OA) yang disahkan dan berkualiti tinggi, program yang dibangunkan oleh paradigma pengaturcaraan ini seharusnya diuji secara efektif

dengan menumpu perhatian kepada semua ciri, iaitu binaan dan pengaturcaraan baharu tambahan bertujuan untuk pemisahan kepentingan. Sebab ditekankan adalah kecacatan khusus POA berpunca daripada ciri unik POA boleh menjejaskan kualiti program dalam cara yang luar biasa dan seterusnya mengurangkan manafaat umumnya, iaitu meningkatkan kemodulan dan kebolehsenggaraan. Di samping itu, ciri unik ini telah menjadikan pengujian POA lebih canggih dan mencabar, walaupun menguji program dengan fungsi yang mudah pun sudah susah dan mahal.

Untuk mengurangkan kos dan usaha manusia dalam menjamin ketepatan dan kualiti umum program berorientasi-aspek, ia adalah wajar untuk mengautomasikan ujian program berorientasi-aspek. Malah, pengujian automatik telah menjadi domain yang signifikan dalam penyelidikan pengujian perisian semasa dan telah banyak berkembang pada tahun-tahun kebelakangan ini. Walau bagaimanapun, ia boleh dikatakan bahawa secara perbandingan sedikit kerja pengujian POA dalam kesusasteraan dan sangat sedikit dan terhad kajian ke atas pengujian automatik POA. Dari sudut pandangan teknikal, kajian yang sedia ada terhadap pengujian automatik pengaturcaraan berorientasi-aspek tidak cukup efektif dalam strategi dasar mereka yang digunakan kerana penjanaan ujian mempunyai kurang tumpuan khusus kepada POA dan lebih diasaskan kepada pengetahuan kod asas. Di samping itu, kurang alat praktikal, kurang kebolehpercayaan dan penilaian statistik daripada keputusan pengujian

dengan mengambil kira pendekatan tersebut, kesukaran dalam pelaksanaan strategi, dan tidak menyediakan penjanaan kod ujian berautomatik dan penjanaan data ujian adalah isu utama yang berkaitan dengan kajian yang sedia ada. Ini jelas menunjukkan kekurangan pendekatan ujian automatik, terutamanya penjanaan ujian automatik, untuk program berorientasi-aspek pada masa kini dan memberi motivasi utama untuk memanfaatkan teknik semasa dan/atau membangunkan teknik baharu untuk menguji program ini.

Adalah dianggapkan bahawa menggunakan teknik terkini ke atas pengujian dan penentusahan sistem yang berasaskan-OA adalah amat penting untuk membuat pembangunan perisian berorientasi-aspek (PPOA) berjaya. Seperti dalam kesudahan yang baik, terdapat banyak kemajuan ke atas pengujian dan penentusahan, seperti penjanaan ujian automatik menggunakan teknik berasaskan-rawak dan berasaskan-carian, analisis liputan, model kesilapan, analisis mutasi, dan sebagainya. Banyak teknik tersebut masih tidak digunakan atau sekurang-kurangnya tidak disiasat dengan sewajarnya untuk POA. Ada yang remeh, tetapi sesetengah memerlukan sedikit usaha untuk menjadikan mereka tidak mustahil dan dapat dimanfaat untuk pengujian POA.

Pengujian rawak (PR) adalah satu penyelidikan yang aktif dan penting dalam pengujian perisian, yang mempunyai tumpuan dalam persekitaran praktikal kerana meritnya, contohnya kapasiti pengesanan kesilapan dengan kos yang

rendah, memudahkan pelaksanaan, anggaran kebolehpercayaan perisian menggunakan keputusan ujian, dan yang paling penting ialah kemudahan untuk pengautomatikan. Ia boleh dikatakan bahawa PR adalah salah satu teknik yang paling intuitif untuk penjanaan ujian automatik yang telah dikaji secara meluas dan digunakan untuk menguji pelbagai program selama beberapa dekad dan telah membentuk bahagian teras bagi banyak pendekatan pengujian yang berguna. Pada hal ini, idea di sebalik pengujian rawak boleh menjadi berfaedah dan menarik untuk menawarkan banyak janji mengenai masalah pengautomatikan ujian POA kerana penyelidikan semasa pengujian POA, terutamanya secara berautomatik belum secukupnya dilakukan dan masih di peringkat awal.

Setakat ini, tiada pendekatan pengujian yang matang dalam konteks POA, yang mengambil kira teknik pengujian rawak untuk penjanaan ujian automatik program berorientasi-aspek, dalam erti kata ini boleh membuat kajian ini sebagai kajian pertama. Oleh itu, untuk mengguna konsep pengujian rawak terhadap POA dan untuk meningkatkan tahap pengautomatikan dan kematangan pengujian POA automatik, di dalam tesis ini strategi penjanaan ujian automatik yang teliti, dipanggil *RAMBUTANS,* dan alat sokongannya berdasarkan program AspectJ telah dicadangkan. Selain itu, satu kajian empirik yang menyeluruh ke atas sembilan program penanda aras AspectJ melalui analisis mutasi telah dijalankan untuk membandingkan *RAMBUTANS* dan

empat pendekatan pengujian POA automatik yang sedia ada (iaitu Wrasp, Aspectra, Raspect, dan EAT) untuk menguji aspek dari segi keberkesanan pengesanan kesilapan dan kecekapan usaha ujian. Keputusan eksperimen dan ujian statistik membentangkan ($p<0.01$) bukti kukuh tentang keberkesanan dan kecekapan strategi yang dicadangkan. Oleh itu, kajian ini menunjukkan bahawa hasil ujian terawak adalah agak baik untuk pengujian POA, maka strategi yang dicadangkan mungkin layak digunakan sebagai strategi penjanaan ujian automatik khusus POA yang berkesan dan cekap.

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I certify that a Thesis Examination Committee has met on 9 August 2012 to conduct the final examination of Reza Meimandi Parizi on his thesis entitled "Automatic Randomized Test Generation Strategy for Aspect-Oriented Software" 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 degree of Doctor of Philosophy.

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

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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.

REZA MEIMANDI PARIZI

Date: 9 August 2012

TABLE OF CONTENTS