UNIVERSITI PUTRA MALAYSIA

VOTING ALGORITHMS FOR LARGE SCALE FAULT-TOLERANT SYSTEMS

ABBAS KARIMI

FK 2011 105

VOTING ALGORITHMS FOR LARGE SCALE FAULT-TOLERANT SYSTEMS

By

ABBAS KARIMI

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

August 2011

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To My Dear Parents,

For Their Unconditional and Everlasting Love and Support

And

To My Wife, Faraneh

In All Love, Humility and Gratitude

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

VOTING ALGORITHMS FOR LARGE SCALE FAULT-TOLERANT SYSTEMS

By

ABBAS KARIMI

August 2011

Chair: Adznan b. Jantan, PhD

Faculty: Engineering

Fault tolerance is the feature of computing systems which can continue their normal operation in the presence of fault(s). In line with this, various methods have been proposed in the last three decades. Redundancy is one of the methods in building fault-tolerant systems which is implementable at both hardware and software levels. In these systems, voting algorithms are extensively employed to arbitrate among the results of N redundant hardware modules or software versions. They have a wide range of application in which the goal is to decrease the probability of the system hazardous behavior. So far, various voting methods are proposed which are mostly proper for small-scale systems. In this research, we proposed optimal algorithms using Divide and Conquer, Brent's theorem and parallel algorithms, appropriate for today's large scale systems such as satellite processing systems, traffic control, weather forecasting which all face a large quantity of processing input data. To do so, we have introduced a new

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sequential m-out-of-n algorithm with prediction ability which is known as enhanced m-out-of-n voter. Using a proper test-bed, after 10000 run times, we compared our newly proposed algorithm with the basic algorithm in terms of reliability and availability. By extracting various plots from different aspects, we demonstrated that, compared to the basic algorithm, our algorithm has higher reliability and availability as the quantity of the input data increases. Then, we introduced an appropriate system suitable for analytical modeling. It is called Predictive Hybrid m-out-of-n redundancy (PHmn) which is applicable for such systems as X-by-wire. To investigate the reliability and availability of this structure, discrete Markov models were obtained for reliability and availability analysis. The results of analytical modeling, based on different values of N, M, λ (failure rate), and μ (repair rate) demonstrated that the availability and reliability of the analytical modeling verify simulation result.

Among basic voting algorithms, average voter and weighted average voter have higher availability but unfortunately they have higher time and calculation complexity in large scale systems. To solve this problem and gain benefits of this algorithm, we employed parallel algorithm technique and by using optimal number of processors, we could propose optimal algorithms known as Parallel Average Voting and Parallel Weighted Average Voting which both have optimal time complexity and less calculation cost.

Since Plurality voting, among the popular and widely applied algorithms, has more correct responses even more than the most known and practical voting algorithm like majority and by relying on the benefit of parallel algorithms, we

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proposed parallel plurality voting with the minimum number of processors in an optimal time compared to its sequential type. In addition to having all the features of sequential algorithm, this algorithm has far less time complexity and has higher processing speed in voting process in large scale systems. In a nut shell, we tried to introduce voting algorithms and structures suitable for large scale fault-tolerant systems which have optimal and proper time complexity (in parallel voting algorithms) and more reliability and availability (in enhanced m-out-of-n voting algorithm) compared to the basic types.

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

ALGORITMA PENGUNDIAN UNTUK SISTEM TOLERANSI KEGAGALAN SKALA BESAR

Oleh

ABBAS KARIMI

Ogos 2011

Pengerusi: Adznan b. Jantan, PhD

Fakulti: Kejuruteraan

Toleransi kegagalan adalah satu ciri sistem pengkomputeran yang perlu meneruskan operasi normalnya atas kehadiran kesalahan. Seiring dengan ini, pelbagai kaedah telah dicadangkan dalam tiga dekad terakhir ini. Lebihan adalah salah satu kaedah dalam membina sistem toleransi kegagalan yang dilaksanakan di kedua-dua peringkat peranti keras and perisian. Dalam sistem ini, algoritma pengundian dipakai secara meluas untuk menjadi perantaraan antara hasil modul N peranti keras berlebihan atau versi perisian. Mereka mempunyai pelbagai jenis aplikasi dimana tujuannya adalah untuk mengurangkan kemungkinan perilaku berbahaya sistem. Setakat ini, pelbagai kaedah pengundian dicadangkan dimana sebahagian besarnya adalah sesuai untuk sistem skala kecil. Dalam kajian ini, kami telah mencadangkan algoritma optimum dengan menggunakan Bahagi dan Kuasai, teorem Brent dan algoritma selari yang sesuai untuk sistem skala besar hari ini seperti sistem pemprosesan satelit, kawalan lalu lintas, peramalan cuaca yang semuanya menghadapi sejumlah besar masukkan

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data pemprosesan. Untuk melakukannya, kami telah memperkenalkan satu algoritma m-out-of-n dengan kemampuan ramalan. Dengan menggunakan tapak uji yang sesuai, selepas 10000 kali penjalanan, kami membandingkan algoritma cadangan baru kami dengan algoritma dasar dari segi kebolehpercayaan dan ketersediaan. Dengan memetik pelbagai kaedah dari aspek yang berbeza, kami menunjukkan bahawa, berbanding dengan algoritma dasar, algoritma kami mempunyai kebolehpercayaan dan ketersediaan yang lebih tinggi apabila jumlah masukan data meningkat. Kemudian, kami memperkenalkan satu sistem sesuai yang sesuai bagi pemodelan analisa. Ia dikenali sebagai lebiahan m-out-of-n hibrid ramalan (PHmn) yang jenis kecilnya digunakan untuk sistem seperti X-oleh-dawai. Untuk menyiasat kebolehharapan struktur ini, model Markov diskrit diperolehi untuk analisa kebolehpercayaan dan ketersediaan. Keputusan simulasi, berdasarkan nilai yang berbeza bagi N, M, λ (kadar kegagalan), dan μ (kadar perbaikan) menunjukkan bahawa ketersediaan dan kebolehpercayaan model baru ini jauh lebih baik daripada model asasnya.

Di antara algoritma pengundian dasar, pengundi purata memiliki ketersediaan yang lebih tinggi tetapi malangnya ia mempunyai kerumitan masa dan pengiraan yang lebih tinggi dalam sistem skala besar.Untuk mengatasi masalah ini dan mendapatkan manfaat dari algoritma ini, kami memakai teknik algoritma selari dan dengan menggunakan jumlah prosesor yang optimum, kami boleh mencadangkan satu algoritma yang optimum dikenali sebagai Pengundian Purata Selari yang mengandungi kerumitan masa dan penghitungan kos yang optimum. Sejak pengundian berkeadaan banyak, antara algoritma disukai ramai dan banyak digunakan, mempunyai

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gerak balas yang lebih benar bahkan lebih daripada algoritma pengundian yang paling dikenali dan algoritma pengundiana yang praktik seperti kebanyakan dan dengan bergantung kepada manfaat dari algoritma selari, kami mencadangkan pengundian berkeadaan banyak selari dengan jumlah minimum prosesor dalam masa yang optimum berbanding dengan jenis berjujukannya. Selain memiliki semua ciri-ciri algoritma berjujukan, algoritma mulia ini mempunyai kerumitan masa yang jauh lebih sedikit dan mempunyai kelajuan pemprosesan yang lebih tinggi dalam proses pengundian pada sistem skala besar. Ringkasnya, kami cuba memperkenalkan algoritma pengundian dan struktur yang sesuai untuk sistem toleransi kegagalan skala besar yang mempunyai ketersediaan, kebolehpercayaan dan kerumitan masa yang lebih optimum dan tepat dibandingkan dengan jenis asas.

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ACKNOWLEDGEMENTS

Completion of this PhD program would not have been possible without the love, encouragement and inspiration provided by my family and friends. Almost on a daily basis, I was asked of my progress and given well wishes. To you, I am most grateful.

I would like to thank my supervisory committee members. Assoc. Prof. Dr. Adznan Jantan, Assoc. Prof. Dr. Abdul Rahman Ramli, and Assoc. Prof. Dr. M. Iqbal Saripan who joined my committee in my hour of need, are wonderful lecturers and went out of their way to help with all the things needed for the improvement of this study. Your support, guidance, and amazing intuition motivated and inspired me.

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I certify that a Thesis Examination Committee has met on **3 August 2011** to conduct the final examination of **Abbas Karimi** on his thesis entitled "**Voting Algorithms for Large Scale Fault-tolerant Systems**" 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 Thesis Examination Committee were as follows:

Borhanuddin b. Mohd. Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Wan Azizun Binti Wan Adnan, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Khairulmizam b. Samsudin, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Andrew Teoh Beng Jin, PhD
Assistant Professor
Yonsei University
Korea
(External Examiner)

BUJANG BIN KIM HUAT, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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

Adznan b. Jantan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abdul Rahman b. Ramli, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

M. Iqbal b. Saripan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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

Date:

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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, or concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

ABBAS KARIMI

Date: 3 August 2011

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TABLE OF CONTENTS

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