

USING MICRO GENETIC ALGORITHM FOR SOLVING SCHEDULING
PROBLEMS

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ABSTRACT

Job Shop Scheduling Problem (JSSP) and Timetable scheduling are known to be computationally NP-hard problems. There have been many attempts by many researchers to develop reliable scheduling software, however, many of these software have only been tested or applied on an experimental basis or on a small population with minimal constraints. However in actual model JSSP, the constraints involved are more complicated compared to classical JSSP and feasible schedule must be suggested within a short period of time. In this thesis, an enhanced micro GA, namely micro GA with local search is proposed to solve an actual model JSSP. The scheduler is able to generate an output of a set of feasible production plan not only at a faster rate but which can generate a plan which can reduce the makespan as compare to those using manual. Also, in this thesis, the micro GA is applied to the timetabling problem of Faculty of Electrical Engineering Universiti Teknologi Malaysia which has more than 3,000 students. Apart from having more students, the faculty also offers various different types of specialized courses. Various constraints such as elective subjects, classrooms capacity, multiple sections students, lecturer, etc have to be taken into consideration when designing the solution for this problem. In this thesis, an enhanced micro GA is proposed for timetable scheduling in the Faculty to overcome the problems. The enhanced micro GA algorithm is referred to as distributed micro GA which has local search to speed up the scheduling process. Comparisons are made with simple GA methods such that a more optimal solution can be achieved. The proposed algorithm is successfully implemented at the Faculty meeting a variety of constraints not achievable using manual methods.

ABSTRAK

“Job Shop Scheduling Problem” (JSSP) dan penjadualan jadual waktu adalah masalah pengiraan “NP-hard”. Ramai penyelidik telah melakukan banyak percubaan untuk membangunkan perisian penjadualan yang boleh diharap, namun begitu, banyak daripada perisian ini hanya diuji atau digunakan pada dasar eksperimen atau pada populasi yang kecil dengan kekangan yang minima. Sebagai contoh dalam model JSSP sebenar (*actual model JSSP*), kekangan-kekangan yang terlibat adalah lebih rumit berbanding dengan JSSP klasik dan jadual yang tersaur mesti dicadangkan dalam masa yang singkat. Dalam tesis ini, satu GA mikro yang dipertingkatkan, iaitu GA mikro dengan carian tempatan (*micro GA with local search*) telah dicadangkan untuk menyelesaikan model JSSP sebenar. Penjadual tersebut berupaya mencadangkan satu pelan pengeluaran yang tersaur bukan hanya pada kadar yang lebih laju, malah boleh menjana satu plan yang mengurangkan masa pelaksanaan (*makespan*) berbanding dengan cara manual. Dalam tesis ini juga, GA mikro telah diaplikasikan dalam masalah penjadualan jadual waktu di Fakulti Kejuruteraan Elektrik, Universiti Teknologi Malaysia, Johor, Malaysia yang mempunyai bilangan pelajar melebihi 3,000 orang. Selain daripada bilangan pelajar yang ramai, fakulti tersebut juga menawarkan pelbagai jenis kursus yang khusus. Pelbagai kekangan seperti matapelajaran elektif, kapasiti bilik kuliah, seksyen pelajar yang banyak, pensyarah dan sebagainya perlu diambilkira semasa merekabentuk penyelesaian untuk masalah ini. Dalam tesis ini, satu GA mikro yang dipertingkatkan telah dicadangkan untuk penjadualan jadual waktu di fakulti untuk mengatasi masalah-masalah tersebut. GA mikro yang dipertingkatkan dirujuk sebagai GA mikro yang mempunyai carian tempatan untuk mempercepatkan proses penjadualan. Perbandingan telah dibuat dengan teknik GA mudah (*simple GA*) agar penyelesaian yang lebih optima boleh dicapai. Algoritma yang dicadangkan telah diimplementasikan dengan jayanya di Fakulti dengan memenuhi pelbagai kekangan yang tidak tercapai sewaktu menggunakan cara manual.

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LIST OF SYMBOLS

FKE	-	Faculty of electrical Engineering
GA	-	Genetic algorithm
GOX	-	Generalized order crossover
JSS	-	Job shop scheduling
JSSP	-	Job shop scheduling problems
Micro GA	-	Micro Genetic Algorithm
MT	-	Muth and Thompson
UTM	-	Universiti Teknologi Malaysia

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- Adams, J., Balas, E. and Zawack D. (1987). *The Shifting Bottleneck Procedure for Job Shop Scheduling*, International Journal of Flexible Manufacturing Systems, vol. 34 no. 3, pp. 391-401.
- Bagchi, S. (1991). Exploring Problem Specific Recombination Operators for Job Shop Scheduling. In Belew, R. K. et Booker, L. B., editors, Proceedings of the Fourth International Conference on Genetic Algorithms, pp. 10 – 17. Morgan Kauffmann.
- Baker, K. (1974). *Introduction to Sequencing and Scheduling*, New York: John Wiley & Sons.
- Bierwirth, C. (1995). *A Generalized Permutation Approach to Job Shop Scheduling with Genetic Algorithms*. OR Spektrum, 17:87-92.
- Burke E.K., Elliman D.G. and Weare R.F. (1994) *A Genetic Algorithm for University Timetabling*, AISB Workshop on Evolutionary Computing, Leeds .
- Carlier, J. and Pinson, E. (1989). *An Algorithm for Solving Job-Shop Problem*, Management Science 35, 164-176.
- Cleveland, G. A. and Smith, S. F. (1989). *Using Genetic Algorithms to Schedule FlowShop Releases Proc. 3rd conference on Genetic Algorithms*, D. Schaffer (ed.), Morgan Kaufmann Publ., San Mateo 160-169.

- Coello, C. A. C. and Pulido G. T. (2001). *Multiobjective Optimization using a Micro-Genetic Algorithm*, Proc. of the Genetic and Evolutionary Computation Conference (GECCO'2001), California.
- Corne, D, Ross P. and Fang H.L. (1994). *Fast Practical Evolutionary Timetabling*, Proceedings of the AISB workshop on Evolutionary Computation, Springer Verlag.
- Croce, F D., Tadei, R. and Volta, G. (1995). *A Genetic Algorithm for the Job Shop Problem*, Computers and Operation Research, Vol. 22, No. 1, pp. 15-24.
- David L. C. (1996). *Genetic Algorithms And Optimizing Chemical Oxygen-Iodine Lasers*. Developments in Theoretical and Applied Mechanics, Vol. XVIII, eds. H. Wilson, R. Batra, C. Bert, A. Davis, R. Schapery, D. Stewart, and F. Swinson, School of Engineering, The University of Alabama, pp. 411-424.
- Davis, L. (1985). *Job Shop Scheduling with Genetic Algorithms*. Proceedings of the International Conference on Genetic Algorithms and their Applications, San Mateo Morgan Kaufmann.
- De Werra, D. (1985). *An Introduction to Timetabling*. European Journal of Operation Research, Vol. 19, pp. 151-162.
- Deris, S. and Omatu, S. (1994). *A Knowledge based System for Course Planning and Scheduling*. The 5th JSPS-VCC Seminar on Integrated Engineering, Vol. 2, pp 240-260.
- Dinkel, J.J, Mote, J. and Venkataramanan (1989). *An Efficient Decision Support System for Academic Course Scheduling*. Operations Research, Vol. 3, No.6.
- Dorndorf, U. and Pesch, E. (1995). *Evolution Based Learning in A Job Shop Scheduling Environment*. Computers Ops Res, 22:25-40.

- Even, S., Itai, A. and Shamir, A. (1976). *On the Complexity of Timetable and Multicommodity Flow Problems*. SIAM J. Comput., 5, pp. 691–703.
- Falkenauer, E. and Bouffouix, S., (1991). *A Genetic Algorithm for Job Shop Scheduling*, Proceedings of 1991 IEEE International Conference on Robotics and Automation, pp. 824-829.
- Fang, H.L. (1992), *Investigating Genetic Algorithms for Scheduling*, MSc Dissertation, Department of Artificial Intelligence, University of Edinburgh.
- Fang, H. L. (1994). *Genetic Algorithms in Timetabling and Scheduling*. University of Edinburgh: Ph.D. Thesis.
- Gan, T. H., Marzuki, K. and Rubiyah, Y. (2004). *Generation of An Optimal JSSP Solution Using Genetic Algorithm With Parallel Computing*. Proceedings of the ICAIET Conference, 2004.
- Gan, T.H. (2005). *Parallel Genetic Algorithms With Application To Job-Shop Scheduling Problems*. Thesis for the Msc of Electrical Engineering Honours, Universiti Teknologi Malaysia, Malaysia.
- Giffler, B. and Thompson, G.L. (1960). *Algorithms for Solving Production Scheduling Problems*, Operation Research 8, 487-503.
- Goldberg, D. E. and Deb, K. (1991). *A Comparative Analysis of Selection Schemes Used in Genetic Algorithms*. In G. Rawlins, ed., Foundations of Genetic Algorithms. Morgan Kaufmann.
- Goldberg, D. E. and Lingle, R. (1985). *Alleles, Loci and The Traveling Salesman Problem*. In Proceedings of an International Conference on Genetic Algorithms, pages 10-19. Morgan Kauffman.
- Goldberg, D.E. (1989). *Genetic Algorithms in Search, Optimization & Machine Learning*. New York: Addison Wesley.

- Haruki, I. (2000). *The End Of Supply Chain? And High End Computer*. Japan: ICC.
- Haruki, I. (2002). *Artificial Life*. Japan: ICC.
- Holland, J. H. (1975). *Adaptation in Natural and Artificial Systems: An Introductory Analysis with Applications to Biology, Control, and Artificial Intelligence*. The University of Michigan Press, Ann Arbor, 1975.
- Holsapple, C., Jacob, V., Pakath, R. and Zaveri, J. (1993). *A Genetics-Based Hybrid Scheduler for Generating Static Schedules in Flexible Manufacturing Contexts*. IEEE Transactions on System, Man, and Cybernetics, vol. 23, pp. 953-971.
- Hopfield, J. J. and Tank, D. W. (1985). *Neural Computation of Decisions in Optimization Problems*, Biol. Cybern., vol. 52, pp. 141–152, 1985.
- Horman, S.K (1998), *Using Genetic Algorithms to schedule The University of New South Wales Examination Timetable*, Thesis for the Degree of Computer Science Honours, University of New South Wales, Australia .
- Husbands, P. (1996). *Rectangles, robots, triangles and transients*. Proceedings of International Symposium on Artificial Life and Robotics, Oita, Japan. pp. 252 – 255.
- Krishnakumar, K. (1989). *Micro-Genetic Algorithms for Stationary and Non-Stationary Function Optimization*. SPIE: Intelligent Control and Adaptive Systems, Vol. 1196, Philadelphia, PA.
- Kubota, A. (1995). *Study On Optimal Scheduling for Manufacturing System by Genetic Algorithms*. Ashikaga Institute of Technology : Master Thesis.
- Lenstra, J. K., Rinnooy Kan, A. H. G. and Brucker, P. (1977). *Complexity of Machine Scheduling Problems*, Annals of Discrete Mathematics 1, 343-362.

- Merz, P. and Freisleben, B. (1997). *A Genetic Local Search Approach to the Quadratic Assignment Problem*. Proceedings of the Seventh International Conference on Genetic Algorithms (ICGA97).
- Merz, P. and Freisleben, B. (1997). *Genetic Local Search for the TSP : New Results*. IEEECEP : Proceedings of The IEEE Conference on Evolutionary Computation, IEEE World Congress on Computational Intelligence.
- Michalewicz, Z. (1999). *Genetic Algorithms + Data Structures = Evolution Programs*. Berlin: Springer.
- Muth, J. and Thompson, G. (1963). *Industrial Scheduling*. Englewood Cliffs, New Jersey: Prentice Hall.
- Nakano, R. (1991). *Conventional Genetic Algorithms for Job-Shop Problems*. In Proceedings of the Fourth International Conference on Genetic Algorithms, pp. 474-479.
- Ross, P., Corne, D. and Fang, H. (1994). *Successful Lecture Timetabling Using Genetic Algorithms*. Proceedings of the ECAI'94 Workshop.
- Rubiyah, Y., Tay, C. S., Marzuki, K. and Osamu Ono (2005). *Solving University Timetabling Problems by Distributed Micro-Genetic Algorithm with Local Search*. Twenty-Third IASTED International Multi-Conference on Applied Informatics (IASTED 2005), Vienna, 2005.
- Sakawa, M. and Shibano, T. (1996). *Interactive Fuzzy Programming for Multiobjective 0-1 Programming Problems Through Genetic Algorithms with Double Strings*. In Ruan D. (ed) *Fuzzy Logic Foundations and Industrial Applications*, pp. 113 – 128. Kluwer Academic Press, Boston/London/Dordrecht.

- Shi, K. Q. and Huang Y.P. (1996). *Genetic Algorithms in The Identification of Fuzzy Compensation System*. In Proceedings of the 1996 IEEE International Conference on Systems, Man and Cybernetics, volume 2, pp. 1090-1094, Beijing, China, 14.-17. October 1996. IEEE, Piscataway, NJ.
- Sikora, R. T. (1996). *A Genetic Algorithm for Integrating Lot Sizing and Sequencing in Scheduling a Capacitated Flow Line*. In Computers and Industrial Engineering: Special Issue on Genetic Algorithms, Vol. 30.
- Smith, J. M. (1989). *Evolutionary Genetics*. New York: Oxford University Press.
- Storer, R., Wu, S. and R. Vaccari (1992). *New Search Spaces for Sequencing Problems with Application to Job Shop Scheduling*, Management Science vol 38, no 10, 1495-1510.
- Svetlana R. and Fadil S.(1999). *Application of a Micro-Genetic Algorithm in Optimal Design of a Diffractive Optical Element*. In Proceedings of the 19th IFIP TC7 Conference on System Modelling and Optimization: Methods, Theory and Applications, pp. 251 - 268.
- Tam, V. and Stuckey, P.J. (1998). *An efficient heuristic-based evolutionary algorithm for solving constraint satisfaction problems*. In Proceedings of the Intelligence in Neural and Biological Systems Conference, pp. 75 – 82.
- Tay, C. S., Marzuki, K. and Rubiyah, Y. (2003). *Solving Job-Shop Scheduling Problems by Micro-Genetic Algorithm*. AIAI Seminar, Kuala Lumpur.
- Vaessens, R. J. M., Aarts, E. H. L. and Lenstra, J. K. (1996). *Job Shop Scheduling by Local Search*, INFORMS Journal on Computing 1996;8:302-17.
- Wendt, O. (1994). *COSA: COoperative Simulated Annealing*. University Frankfurt: Ph.D. Thesis.

- Yamada, T. and Nakano, R. (1997). *Genetic Algorithms for Job-Shop-Scheduling Problems*. Proceedings of Modern Heuristic for Decision Support, UNICOM seminar, pp 67-81, 1997 London.
- Yamada, T. and Reeves, C. R. (1997). *Permutation Flowshop Scheduling by Genetic Local Search*. GALESIA'97 Proceedings of the IEE Second International Conference on Genetic Algorithms in Engineering Systems: Innovations and Applications, September 2-4, University of Strathclyde, Glasgow, Scotland, UK, pp. 232-238.
- Yang, X. and Gen, M. (1994). Evolution Program for Bicriteria Transportation Problem. In Gen, M. and Kobayashi, T. editors, 16th Int. Conf. on Computers and Industrial Engineering, pp. 451 – 454, Ashikaga, Japan
- Zervoudakis, K. and Stamatopoulos, P. (2001). *A Generic Object-Oriented Constraint-Based Model for University Course Timetabling*. Lecture Notes in Computer Science, vol 2079, pp. 28 – 48.