Wai-Ki CHING

Executive and Research Summary (2019)

Wai-Ki Ching is a Professor in the Department of Mathematics, the University of Hong Kong. He obtained his B. Sci. (Hons) and M. Phil. degrees from the University of Hong Kong. He then received his Ph.D. degree from the Chinese University of Hong Kong. He was a visiting post-doc Fellow at the Cambridge University and a lecturer in the Faculty of Mathematical Studies at the University of Southampton before taking up the lectureship at his Alma Mater.

He was awarded the Best Student Paper Prize (2nd Prize) in the Copper Mountain Conference (Colorado University and SIAM) U.S.A. (1998), the Outstanding Ph.D. Thesis Prize in the Engineering Faculty, the Chinese University of Hong Kong, Hong Kong (1998), the Certificate of Merit in the IEEE (Hong Kong Section) Postgraduate Student Paper Contest, Hong Kong (1998), the Croucher Foundation Fellowship, Hong Kong (1999), Doris Zimmern HKU-Cambridge Hughes Hall Fellowship, HKU (2011), University Knowledge Exchange Award for Faculty of Science, HKU (2012), HKU Overseas Fellowship Award, HKU (2013), 2013 Higher Education Outstanding Scientific Research Output (Team Member) Awards (Second Prize), Ministry of Education (MoE) of China (2014), visiting professor of Beijing University of Chemical Technology (2016), Distinguished Alumni Award, Faculty of Engineering, The Chinese University of Hong Kong (2017), Long Service award (15-year), The University of Hong Kong, (2017), Outstanding Reviewer for International Journal of Production Economics (2017) Journal of Economics Dynamics and Control (2018).

Ching's research interests are stochastic modeling and matrix computations. In particular, the applications of stochastic models and numerical algorithms in solving problems related to Markov chain and its applications, bioinformatics, image processing, management sciences and quantitative finance. He is an author/editor of more than 300 publications including 6 books, 5 edited journal special issues, over 200 refereed journal papers, over 40 refereed book chapters and over 70 conference proceeding papers. Ching has reviewed papers for more than 100 different international journals. He has obtained a number of research grants, as the principal investigator, including GRF Competitive Earmarked Research Grants, External Consultancy Grants, Hung Hing Ying Physical Research Grants and Learnet Grant. He is also a co-investigator of several NSF grants in China.

Apart from academic research, he also committed in training high quality postgraduate students and currently he is supervising 3 Ph.D. students. Under his supervision, 11 M. Phil. students and 18 Ph.D. students have been graduated. His Ph.D. graduates got lectureships from world-renown universities such as Fudan University, Renmin University, and Hong Kong Baptist University and post-doc fellowships at Oxford University, Harvard University and Max Planck Institute. His students also won the following awards: Outstanding Research Postgraduate Student Award, HKU (3 times), DAAD Summer School Travel Award, China, (2007), University Postgraduate Fellowships, HKU (5 times), Hong Kong Ph.D. fellowship (2015), Excellent Student Paper Award in the 36th C& IE conference, Taiwan, (2006), Excellent Student Paper Award in the World Congress on Engineering, U.K., (2009); the 5th APBC Conference Travel Award, India, (2010); IMS workshop Travel Award, Columbia University, U.S., (2011); Hung Hing Ying Scholarship, HKU, (2011,2018); IEOR Faculty Fellowship (2011) and Marshall-Oliver-Rosenberger Fellowship (2012), UC Berkeley. The joint papers with his students were also awarded the Best Paper Award in CSO2011, Kunming, China (2011); CSO2012, Harbin, China (2012); BIFE2012, Lanzhou, China (2012); IEEE ISB2012, Xian, China (2012); and CSO2014, Beijing, China (2014); PIMS Student Travel Award (2016), SIAM Student Travel Award (2016,2017), and Research Foundation Flanders (FWO) Travel Award (2018).

He has organized and served as a program committee member in more than 50 conferences and workshops. He has presented over 65 talks. He also provided consultancy services for the HKSAR government and also a number of local companies and the including PCCW, China Light and Power, Hong Kong Government Environmental Protection Department, Hong Kong Hospital Authority, ExchangeRepublic.com, Education Bureau and ETI Consulting Limited. He is currently a member of the Curriculum Development Council Committee on Mathematics Education, Education Bureau, HKSAR.

Highlights of Some Projects and Contributions

Numerical Algorithms for Queueing and Manufacturing Systems: Continuous time Markov chains are popular models for modeling and analyzing queueing and manufacturing systems. For the purpose of performance analysis, one requires the solution of the steady-state probability distribution of a large and complex Markov chain. Typical examples can be found in Flexible Manufacturing Systems (FMSs) and queueing systems with batch arrivals. Classical iterative methods such as Gauss-Seidel (GS) and Successive Over-Relaxation (SOR) method are common solvers for these problems. However, their convergence rates are slow in general when the problem size is getting large. To speed up the computations, we consider Preconditioned Conjugate Gradient (PCG) methods. Preconditioners are designed by exploiting the near-Toeplitz and block structure of the underlying generator matrices. The idea can be extended to Stochastic Automata Networks (SANs), a general class of stochastic networks. We proved that the preconditioned systems have singular values clustered around one and therefore CG type methods will converge very fast when apply to solving the preconditioned systems. Numerical examples of practical problems are also given to demonstrate the efficiency of our proposed methods.

• R. Chan and **W. Ching**, *Toeplitz-circulant Preconditioners for Toeplitz Systems and Their Applications to Queueing Networks with Batch Arrivals*, SIAM Journal on Scientific Computing, 17 (1996) 762–772.
• **W. Ching**, R. Chan and X. Zhou, *Circulant Preconditioners for Markov Modulated Poisson Processes and Their Applications to Manufacturing Systems*, SIAM Journal on Matrix Analysis and Applications, 18 (1997) 464–481.
• R. Chan and **W. Ching**, *Circulant Preconditioners for Stochastic Automata Networks*, Numerische Mathematik, 87 (2000) 35–57.
• **W. Ching**, *Iterative Methods for Queuing and Manufacturing Systems.* Springer Monographs in Mathematics, Springer, London, 2001.
• **W. Ching**, *Iterative Methods for Queuing Systems with Batch Arrivals and Negative Customers*, BIT, 43 (2003) 285–296.

High-dimensional Markov Chains with Applications in Management Sciences: High-dimensional Markov chains are popular stochastic models for many practical problems in management sciences such as inventory systems, categorical time series and financial credit risk. Given an aperiodic and irreducible Markov chain, it is well-known that the Perron-Frobenius theorem is important for studying the existence of the system stationary distribution. In many applications, one has to employ a multivariate Markov chain so as to capture the positive correlations among different chains. In a conventional multivariate Markov chain model of s chains and each chain has m states, the total number of states is of $O(m^s)$, therefore it grows exponentially with respect to s. We proposed an approximate first-order model ($O(m^2s^2)$ parameters) for this problem. To capture the long-range dependence of a categorical data time series, one has to employ a Markov chain of order n. The number of model parameters grows exponentially with respect to the order n. We proposed a parsimonious model ($O(nm^2)$ parameters) for this problem. We then extended the above models to the case of high-order multivariate Markov chains. We generalized the classical Perron-Frobenius theorem to all the above high-dimensional Markov chain models. Based on the theorems, efficient algorithms are then developed for solving the parameters of the proposed models. Finally the models are also extended to the case of negative correlations and they have been applied successfully in the captured real world problems.

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• T. Siu, **W. Ching**, M. Ng and E. Fung, *On a Multivariate Markov Chain Model for Credit Risk Measurement*, Quantitative Finance, 5 (2005) 543–556.
• **W. Ching**, M. Ng and E. Fung, *Higher-order Multivariate Markov Chains and their Applications*, Linear Algebra and Its Applications, 428 (2-3) (2008) 492–507.
• **W. Ching**, T. Siu, L. Li, H. Jiang, T. Li and W. Li, *An Improved Parsimonious Multivariate Markov Chain Model for Credit Risk*, The Journal of Credit Risk, 5 (2009) 1–25.
• **W. Ching**, X. Huang, M. Ng and T. Siu, *Markov Chains : Models, Algorithms and Applications*, International Series on Operations Research and Management Science, (2nd Edition) Springer, New York, 2013.

Boolean Networks and Probabilistic Boolean Networks: Mathematical and computational models are important for studying genetic regulatory networks. Boolean Networks (BNs) and its extension Probabilistic Boolean Networks (PBNs) are effective mathematical models for studying genetic regulatory interactions. For a BN, finding a control strategy leading to the desired global state is a NP-hard problem in general. We proved that a polynomial time algorithm exists if the network has a tree structure. A PBN is essentially a collection of BNs driven by a Markov chain process and therefore can be studied by using the Markov chain theory. The steady-state distribution of a PBN gives useful information about the desirable states (attractor cycles) of the underlying genetic network where the attractor cycles have important biological interpretations. Controls (interventions) can be applied to a genetic network to avoid undesirable states associated with diseases like cancer. The optimal control problem can be formulated mathematically by using the principle of stochastic dynamic programming. The size of the transition probability matrix of a PBN is 2^n-by-2^n where n is the number of genes in the network and the problem size grows exponentially with respect to n. By employing a matrix approximation technique, we obtain approximations for both the steady-state distribution of a PBN and also a near-optimal policy for the captured control problem. The approximation method can reduce the computational cost significantly and yet still retain the important information of the network. We established some theoretical bounds for the errors by using matrix perturbation theory. Numerical examples and simulation results are given to demonstrate both the efficiency and effectiveness of our proposed methods.

• T. Akutsu, M. Hayasida, **W. Ching** and M. Ng, *Control of Boolean Networks: Hardness Results and Algorithms for Tree Structured Networks*, Journal of Theoretical Biology, 244 (2007) 670–679.
• **W. Ching**, S. Zhang, M. Ng and T. Akutsu, *An Approximation Method for Solving the Steady-state Probability Distribution of Probabilistic Boolean Networks*, Bioinformatics, 23 (2007) 1511–1518.
• S. Zhang, **W. Ching**, M. Ng and T. Akutsu, *Simulation Study in Probabilistic Boolean Network Models for Genetic Regulatory Networks*, International Journal of Data Mining and Bioinformatics, 1 (2007) 217–240.
• **W. Ching**, S. Zhang, Y. Jiao, T. Akutsu, N. Tsing and A. Wong, *Optimal Control Policy for Probabilistic Boolean Networks with Hard Constraints*, IET Systems Biology, 3 (2009) 90–99.
• Y. Cong, **W. Ching**, N. Tsing and H. Leung, *On Finite-Horizon Control of Genetic Regulatory Networks with Multiple Hard-Constraints*, BMC Systems Biology (2010), 4(Suppl 2).

Iterative Solvers for Toeplitz Systems and Imaging Processing Problems: A square matrix is called a Toeplitz matrix if it is constant along its diagonals. Toeplitz and Toeplitz-like matrices appear in many real world applications such as signal processing, image processing and queueing systems etc. Preconidtioned Conjugate Gradient (PCG) method is an efficient iterative solver for solving such as a linear system. Circulant matrix is a classical candidate for preconditioner. We exploited the off-diagonal decay property of the inverse of a Toeplitz matrix and construct a factorized banded inverse preconditioner. Using the constructed preconditioner, we proved that the spectra of the preconditioned matrices clustered around one and PCG method converges very fast in solving a class of image restoration problems. Numerical results indicate that it is even better than the circulant type preconditioner. We also proposed iterative algorithms for solving the image restoration problems. The algorithms are based on the decoupling of deblurring and denoising steps in the restoration process. The algorithms make use of the Fast Fourier Transform (FFT) and take advantage of the Toeplitz-like structure of the concerned matrix. We proved that the algorithms are convergent. Numerical examples show that the proposed algorithms are both efficient and effective for the captured problem.

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• **W. Ching**, M. Ng, K. Sze and C. Yau, *Super-Resolution Image Reconstruction Using Multisensor*, Numerical Linear Algebra with Applications, 12 (2005) 2-3, 271–281.
• **W. Ching**, M. Ng and Y. Wen, *Block Diagonal and Schur Complement Preconditioners for Block-Toeplitz Systems with Small Size Blocks*, SIAM Journal on Matrix Analysis and Applications, 29 (2007) 1101–1119.
• Y. Wen, M. Ng and **W. Ching**, *Iterative Algorithms Based on Decoupling of Deblurring and Denoising for Image Restoration*, SIAM Journal on Scientific Computing, 30 (2008) 2655–2675.
• M. Nikolova, M. Ng, S. Zhang and **W. Ching**, *Efficient Reconstruction of Piecewise Constant Images Using Nonsmooth Nonconvex Minimization*, SIAM Journal on Imaging Sciences, 1 (2008) 2–25.