Game Theory in Signal Processing and Communications

Eduard A. Jorswieck, Erik G. Larsson, Marco Luise and H. Vincent Poor

Eduard A. Jorswieck, Erik G. Larsson,
Marco Luise, and H. Vincent Poor

Game Theory in Signal Processing and Communications

Game theory is a branch of mathematics aimed at the modeling and understanding of resource conflict problems. Essentially, the theory splits into two branches: noncooperative and cooperative game theory. The distinction between the two is whether or not the players in the game can make joint decisions regarding the choice of strategy. Noncooperative game theory is closely connected to minimax optimization and typically results in the study of various equilibria, most notably the Nash equilibrium. Cooperative game theory examines how strictly rational (selfish) actors can benefit from voluntary cooperation by reaching bargaining agreements. Another distinction is between static and dynamic game theory, where the latter can be viewed as a combination of game theory and optimal control. In general, the theory provides a structured approach to many important problems arising in signal processing and communications, notably resource allocation and robust transceiver optimization. Recent applications also occur in other emerging fields, such as cognitive radio, spectrum sharing, and in multihop-sensor and adhoc networks.

THE INCREASING INTEREST IN GAME THEORY

This special section's goal is to promote the use of game theory in the signal processing community. The motivation for this is that the successful application of game theory is arising in an increasing number of engineering fields, notably in those related to information and communication technologies. Examples of this are game-theoretic criteria for scheduling processes in multiprocessor computing machines or for distributing bandwidth and transmission power in wireless packet communication networks. There is an increasing interest in the topic of game theory in the signal processing community, as evidenced by the success of recent workshops and special sessions.

In this special section, we bring together eight articles on a variety of topics.

[THE SUCCESSFUL APPLICATION OF GAME THEORY IS ARISING IN AN INCREASING NUMBER OF ENGINEERING FIELDS, NOTABLY IN THOSE RELATED TO INFORMATION AND COMMUNICATION TECHNOLOGIES.]

The first article, "Game Theory and the Flat-Fading Gaussian Interference Channel" by Larsson, Jorswieck, Lindblom, and Mochaourab, introduces basic concepts of noncooperative and cooperative game theory and applies them to spectrum sharing in wireless communications. The cases of single-input, single-output channels; multiple-input, single-output; and multiple-input, multiple-output channels are discussed.

The next article, "Game Theory and the Frequency Selective Interference Channel" by Leshem and Zehavi, provides an overview of game-theoretic models and techniques for communication over frequency-selective interference channels. Both noncooperative (competitive) and cooperative game theoretic models are discussed.

Lasaulce, Debbah, and Altman focus on the fundamental yet challenging issue of finding equilibrium points of cooperative or noncooperative games (i.e., solving the games) in their article, "Methodologies for Analyzing Equilibria in Wireless Games." A number of results concerning the existence, uniqueness, selection, and efficiency of equilibria are presented, and their relevance to problems in wireless communications are discussed.

The fourth article, "Distributed Resource Allocation Schemes," by Schmidt, Shi, Berry, Honig, and Utschick, discusses decentralized, scalable schemes for cooperative resource allocation in wireless networks. The main concept introduced is price of interference, which measures the marginal decrease in utility for a marginal increase in interference.

A classical issue in signal processing, namely, waveform adaptation, is tackled in the next article, "Noncooperative Waveform Adaptation Games in Multiuser Wireless Communications," by Buzzi, Poor, and Saturnino. The authors show that a game-theoretic approach is expedient in the selection of spreading signatures in a code-division multiple-access wireless communications network. They also illustrate the application of the same technique to other signal processing problems, such as beamforming in multiuser communications and signal design in cognitive radio networks.

Cooperation in self-organized decentralized communication systems is analyzed by cooperative game theory in the sixth article, "Coalitional Game Theory for Communication Networks," by Saad, Han, Debbah, Hjørungnes, and Başar.

(continued on page 132)

Digital Object Identifier 10.1109/MSP.2009.933610

component 5), GSTP1, and NFκB. Potential targets for malignant prostate cancer, such as PTN (pleiotrophin), MAP3k3 (mitogen-activated protein kinase) NFκB, and CHUK (conserved helix-loop-helix ubiquitous kinase) are also included in the selected paths. More importantly, it has been reported that PTN in path1 is related to prostate cancer migration and NFkBIA in path3, and path4 is associated with prostate cancer metastasis in the publications. Such collected information indicates that the selected paths are valuable for biomarkers and targets discovery.

Second, by checking the shared GO terms of the proteins in the identified paths, we derived that most proteins in the paths share the same GO terms ($P < 10^{-2}$) [7], which suggests that the proteins on the selected paths may function similarly (Figure 2). The GO molecular function information indicates that most proteins in the identified paths are responsible for the similar tasks related to development of prostate cancer. Many proteins in the identified paths are highly expressed in the prostate tissue. Moreover, the information of cellular localization suggests that the proteins in the path are responsible for the signal transductions between cross-talking of cytoplasm and nucleus (Figure 2).

Last, the paths display high accuracies in patient classification (as high as 85%) as shown in Figure 2. The features that are input into a support vector machine (SVM) are the combined path expressions computed by the corresponding gene expressions of composite proteins in the path. After mapping the gene expressions from single proteins to paths, we identified the potential of the paths to serve as the biomarkers for classifying metastasis patients. The results of the patients classification indicate that the selected paths may predict the possibility of prostate cancer migrating to the other tissues. The validations from available biological information indicate that the four selected paths are of high confidence in the central roles of prostate metastasis, and our approach of such biological signal processing is promising to in discovering diagnosis and prognosis biomarkers as well as treatment targets.

ACKNOWLEDGMENTS

This research is funded by NIH R01LM08696, R01LM009161, and R01AG028928.

AUTHORS

Guangxu Jin (Gjin@tmhs.org) is a research fellow in the Center for Biotechnology and Informatics, The Methodist Hospital Research Institute.

Kemi Cui (Kcui@tmhs.org) is a research associate in the Medical Systems Biology Laboratory, the Center for Biotechnology and Informatics, The Methodist Hospital Research Institute.

Xiaobo Zhou (Xzhou@tmhs.org) is an associate professor of radiology, Weill Cornell Medical College, and chief of the Bioinformatics Laboratory, the Center for Biotechnology and Informatics, The Methodist Hospital Research Institute.

Stephen T.C. Wong (STWong@tmhs.org) is the John S. Dunn Distinguished Endowed Chair of Biomedical Engineering, professor of radiology at Cornell University, and director of the Center for Biotechnology and Informatics, The Methodist Hospital Research Institute.

REFERENCES

[1] J. T. Lee, B. D. Lehmann, D. M. Terrian, W. H. Chappell, F. Stivala, M. Libra, A. M. Martelli, L. S. Steelman, and J. A. McCubrey, "Targeting prostate cancer based on signal transduction and cell cycle pathways," *Cell Cycle,* vol. 7, no. 12, pp. 1745–1762, June 2008.

[2] M. Kanehisa, M. Araki, S. Goto, M. Hattori, M. Hirakawa, M. Itoh, T. Katayama, S. Kawashima, S. Okuda, T. Tokimatsu, and Y. Yamanishi, "KEGG for linking genomes to life and the environment," *Nucleic Acids Res.,* vol. 36, pp. D480–D484, Jan. 2008.

[3] R. Milo, S. Shen-Orr, S. Itzkovitz, N. Kashtan, D. Chklovskii, and U. Alon, "Network motifs: Simple building blocks of complex networks," *Science,* vol. 298, no. 5594, pp. 824–827, Oct. 2002.

[4] S. S. Shen-Orr, R. Milo, S. Mangan, and U. Alon, "Network motifs in the transcriptional regulation network of Escherichia coli," *Nat. Genet.,* vol. 31, no. 1, pp. 64–68, May 2002.

[5] D. R. Rhodes, J. Yu, K. Shanker, N. Deshpande, R. Varambally, D. Ghosh, T. Barrette, A. Pandey, and A. M. Chinnaiyan, "ONCOMINE: A cancer microarray database and integrated data-mining platform," *Neoplasia,* vol. 6, no. 1, pp. 1–6, Jan./Feb. 2004.

[6] T. Barrett, T. O. Suzek, D. B. Troup, S. E. Wilhite, W. C. Ngau, P. Ledoux, D. Rudnev, A. E. Lash, W. Fujibuchi, and R. Edgar, "NCBI GEO: Mining millions of expression profiles—Database and tools," *Nucleic Acids Res.,* vol. 33, pp. D562–D566, Jan. 2005.

[7] B. Zhang, S. Kirov, and J. Snoddy, "WebGestalt: An integrated system for exploring gene sets in various biological contexts," *Nucleic Acids Res.,* vol. 33, pp. W741–W748, July 2005. [SP]

from the GUEST EDITORS

continued from page 17

This tutorial provides an overview of coalitional game theory concepts and their applications in communications and wireless networks. The mathematical tools and techniques needed to study coalitional games are presented for three classes of games: canonical coalitional, coalition formation, and coalitional graph games.

The seventh article, "Natural Cooperation in Wireless Networks," by Yang, Klein, and Brown, discusses selfish behavior in networks on different layers using tools from noncooperative game theory. Natural cooperation without extrinsic incentive mechanisms is achieved in a repeated game framework, with credible punishments for defection and under long-term payoffs. The efficiency of this framework is illustrated by several relevant communication scenarios.

Finally, Scutari, Palomar, Pang, and Facchinei introduce a variation inequality (VI) framework for modeling and solving the interaction problems of rational entities in their article "Flexible Design of Cognitive Radio Wireless Systems." This framework integrates and supplements classical game theory and the article reflects the frontier of research in this area. The authors focus in particular on VI techniques for solving problems in the field of resource allocation (power, bit rate) in cognitive radio networks with variable interference constraints.

A NOTE OF THANKS

We received an overwhelming response to the call for this issue. We would like to thank all of the authors for their contributions. We also thank the reviewers for their help in selecting articles, and finally, many thanks go to Associate Editors Doug Williams and Dan Schonfeld for their support. [SP]