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Publications

Universality of Nash Equilibria, in *Mathematics of Operations Research*, Vol. 28, No. 3, August 2003, pp. 424–432.

Abstract. Every real algebraic variety is isomorphic to the set of totally mixed Nash equilibria of some three-person game, and also to the set of totally mixed Nash equilibria of an N-person game in which each player has two pure strategies. From the Nash-Tognoli Theorem it follows that every compact differentiable manifold can be encoded as the set of totally mixed Nash equilibria of some game. Moreover, there exist isolated Nash equilibria of arbitrary topological degree.

Using Computer Algebra to Compute Nash Equilibria, in the (refereed) *Proceedings of the 2003 International Symposium on Symbolic and Algebraic Computation*, August 2003, pp. 74–79.

Abstract. A central concern of game theory is the computation of Nash equilibria. These are characterized by systems of polynomial equations and inequalities. We survey the use of currently available software to solve these systems, and conclude that polyhedral homotopy continuation appears to scale best with increasing problem size.

Finding All Nash Equilibria of a Finite Game Using Polynomial Algebra, invited contribution to *Journal of Economic Theory*, to appear, 2007.

Abstract. The set of Nash equilibria of a finite game is the set of nonnegative solutions to a system of polynomial equations. In this survey article we describe how to construct certain special games and explain how to find all the complex roots of the corresponding polynomial systems, including all the Nash equilibria. We then explain how to find all the complex roots of the polynomial systems for arbitrary generic games, by polyhedral homotopy continuation starting from the solutions to the specially constructed games. We describe the use of Gröbner bases to solve these polynomial systems and to learn geometric information about how the solution set varies with the payoff functions. Finally, we review the use of the **Gambit** software package to find all Nash equilibria of a finite game.

Polynomial Graphs With Applications To Graphical Games, Extensive-Form Games, and Games With Emergent Node Tree Structures, `arXiv.org:math.AC/0612463`.

Abstract. We prove a theorem computing the number of solutions to a system of polynomial equations which is generic subject to the sparsity conditions implied by a certain graph. We then apply this theorem to games obeying graphical models and extensive-form games. We define an *emergent-node tree structure* as an additional structure which a particular normal form game may have. We apply our theorem to games having such a structure. We briefly discuss how emergent node tree structures apply to cooperative games.

Comparison of Wireless Token Ring Protocol with IEEE 802.11, in *Journal of Internet Technology*, Vol. 4, No. 4. With Mustafa Ergen, Duke Lee, Jeff Ko, Anuj Puri, Raja Sengupta, and Pravin Varaiya.

Abstract. Wireless Token Ring Protocol (WTRP) is a medium access control (MAC) protocol for wireless networks. The MAC protocol through which mobile stations can share a common broadcast channel is essential in wireless networks. In a IEEE 802.11 network, the contention among stations is not homogeneous due to the existence of hidden terminals, partially connected network topology, and random access. Consequently, quality of service (QoS) is not provided. WTRP supports guaranteed QoS in terms of bounded latency and reserved bandwidth which are crucial realtime constraints of the applications. WTRP is efficient in the sense that it reduces the number of retransmissions due to collisions. It is fair in the sense that each station use the channel for equal amount of time. The stations take turn to transmit and are forced to give up the right to transmit after transmitting for a specified amount of time. It is a distributed protocol that supports many topologies since not all stations need to be connected to each other or to a central station. WTRP is robust against single node failure. WTRP recovers gracefully from multiple simultaneous faults. WTRP has applications to inter-access point coordination in ITS DSRC, safety-critical vehicle-to-vehicle networking, home networking and provides extensions to sensor networks and mobile IP.