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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, *Economic Theory*, invited survey, 20 February 2009, DOI 10.1007/s00199-009-0447-z.

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.

Published Patent Applications

Query language determination using query terms and interface language. US Patent Application 20070288450. With Fabio Lopiano.

Abstract. Methods, systems, and apparatus, including computer program products, operable to perform operations including receiving from a user through a user interface a search query comprising one or more query terms, the user interface having an interface language, the interface language being a natural language; and determining a query language for the query from the query terms and the interface language, the query language being a natural language.

Augmenting queries with synonyms from synonyms map. US Patent Application 20070288448.

Abstract. Methods, systems, and apparatus, including computer program products, operable to perform operations including receiving through a user interface with an interface language a search query having query terms; using the interface language to select one or more mappings and using the selected mappings to simplify each query term; and applying each simplified query term to a synonyms map to identify possible synonyms with which to augment the search query. In alternative embodiments, the operations include generating a synonyms map from a corpus of documents; where the synonyms map maps each of multiple keys to one or more corresponding variants, where each variant is associated with one or more of document languages. In alternative embodiments, the operations include generating a synonyms map from documents by applying document language-dependent mappings to words in the documents to generate keys for the map.

Augmenting queries with synonyms selected using language statistics. US Patent Application 20070288449. With Fabio Lopiano.

Abstract. Methods, systems, and apparatus, including computer program products, operable to perform operations including receiving from a user through a user interface a search query comprising a query term, the search query having attributed to it a query language; deriving a simplified query term from the query term; and identifying one or more potential synonyms for the query term by looking up the simplified query term in a synonyms map, the synonyms map mapping each of a plurality of keys to one or more corresponding variants, each variant being a word associated with one or more document languages, and each variant being associ-

ated for each associated language with a variant-language score indicating a relative frequency of the variant among all variants for the associated language for the same key.

Simplifying query terms with transliteration. US Patent Application 20070288230.

Abstract. Methods, systems, and apparatus, including computer program products, operable to perform operations including receiving from a user a search query; and receiving an indication of a user preference to apply transliteration in simplifying the query terms of the search query. Alternatively, the operations include receiving from a user a search query of query terms; applying transliteration in simplifying the query terms; and using the simplified query terms to identify synonyms to use in augmenting the search query. Alternatively, the operations include receiving from a user a search query; identifying the user interface language as a small language or not a small language; simplifying each query term to a simplified form; and if the user interface language is a small language, for each original query term that has a simplified form different from the original term, using the original query term as-is and not providing any synonyms for the query term.