[1] D. Alderson and K. S. Hoo. The role of economic incentives in securing cyberspace. Technical report, CISAC, Stanford University, November 2004. [bib | .pdf]

In the last eight years, every significant public policy initiative to address the safety and security of U.S. national information infrastructure has recommended a significant, largely voluntary, role for the private sector, owing in large part to the dominant ownership stake of private entities in the infrastructure. Notably absent from much of the policy discourse and underlying research has been a careful examination of the stakeholder incentives to adopt and to spur the development of security technologies and processes. We believe that the lack of progress to date in achieving a secure and robust cyber infrastructure is in large part the direct result of a failure by public policy to recognize and to address those incentives and the technological, economic, social and legal factors underlying them.

We advocate a new approach for the analysis and development of coherent policy in which the interaction of economic incentives among stakeholders is explicitly considered. By economic incentives, we mean the full array of economic and technological factors that shape infrastructure decision-making, not merely government subsidies or tax credits. We provide an initial framework for understanding the technology dependencies and economic incentives associated with cyber security, along with illustrative examples of the key players and their motivations. We argue that the successful development of a secure cyber infrastructure will require more than improved technology and that it could be accelerated by careful consideration of the evolving economic and legal issues that shape stakeholder incentives.

[2] W. B. Arthur. *Increasing Returns and Path Dependence in the Economy*. Univ. of Michigan Press, 1994. [bib]

[3] W. B. Arthur. *Handbook of Computational Economics: Agent-Based Computational Economics*, volume 2, chapter Out-of-equilibrium Economics and Agent-Based Modeling. ELSEVIER/North-Holland, forthcoming 2005. [bib | .pdf]

[4] D. Braess. über ein Paradoxen aus der Verkehrsplanung. *Unternehmensforschung*, 12:258-268, 1968. [bib]

[5] R. I. Brafman and M. Tennenholtz. Efficient learning equilibrium. *Artificial Intelligence*, 159(1-2):27-47, November 2004. [bib | DOI]

We introduce *efficient learning equilibrium* (ELE), a normative approach to learning in non-cooperative settings. In ELE, the learning algorithms themselves are required to be in equilibrium. In addition, the learning algorithms must arrive at a desired value after polynomial time, and a deviation from the prescribed ELE becomes irrational after polynomial time. We prove the existence of an ELE (where the desired value is the expected payoff in a Nash equilibrium) and of a Pareto-ELE (where the objective is the maximization of social surplus) in repeated games with perfect monitoring. We also show that an ELE does not always exist in the imperfect monitoring case. Finally, we discuss the extension of these results to general-sum stochastic games.

[6] C. Bruun. Introduction to agent-based computational economics, September 2004. [bib | .pdf]

[7] L. Camp and S. Lewis, editors. *Economics of Information Security*. Kluwer Academic Publishers, Boston, 2004. [bib]

[8] J. Dessalles and D. Phan. Emergence in multi-agent systems: cognitive hierarchy, detection, and complexity reduction part i: methodological issues. In *Proceedings of the Symposium in Agent-based Computational Methods in Finance, Game Theory and their applications*, volume 564 of *Lecture Notes in Economics and Mathematical Systems*. Springer, September 2005. [bib | .pdf]

[9] H. Gintis, E. Smith, and S. Bowles. Costly signaling and cooperation. *Journal of Theoretical Biology*, 213(1):103-119, November 2001. [bib | DOI | .pdf]

We propose an explanation of cooperation among unrelated members of a social group in which cooperation evolves because it constitutes an honest signal of the member's quality as a mate, coalition partner or competitor, and therefore results in advantageous alliances for those signaling in

this manner. Our model is framed as a multi-player public goods game that involves no repeated or assortative interactions, so that non-cooperation would be a dominant strategy if there were no signaling benefits. We show that honest signaling of underlying quality by providing a public good to group members can be evolutionarily stable, and can proliferate in a population in which it is initially rare, provided that certain plausible conditions hold, including a link between group-beneficial signaling and underlying qualities of the signaler that would be of benefit to a potential mate or alliance partner. Our model applies to a range of cooperative interactions, including unconditionally sharing individually consumable resources, participating in group raiding or defense, and punishing free-riding or other violations of social norms.

[10] V. Grimm, E. Revilla, U. Berger, F. Jeltsch, W. M. Mooij, S. F. Railsback, H.-H. Thulke, J. Weiner, T. Wiegand, and D. L. DeAngelis. Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science*, 310(5750):987-991, 2005. [bib]

Agent-based complex systems are dynamic networks of many interacting agents; examples include ecosystems, financial markets, and cities. The search for general principles underlying the internal organization of such systems often uses bottom-up simulation models such as cellular automata and agent-based models. No general framework for designing, testing, and analyzing bottom-up models has yet been established, but recent advances in ecological modeling have come together in a general strategy we call pattern-oriented modeling. This strategy provides a unifying framework for decoding the internal organization of agent-based complex systems and may lead toward unifying algorithmic theories of the relation between adaptive behavior and system complexity.

[11] T. Killingback and M. Doebeli. `Raise the stakes' evolves into a defector. *Nature*, 400(6744):518, August 1999. [bib | DOI]

To understand how cooperation can evolve by reciprocal altruism when individuals can make variable investments, Roberts and Sherratt [17] have introduced a new strategy, `raise the stakes' (RTS), for a continuous version of the iterated `prisoner's dilemma'. An individual investing I bears a cost I, while the recipient gets a benefit kI. For $k>1$, this generalizes the standard prisoner's dilemma,. Over R alternating encounters, RTS is defined as follows: on the first move, invest a, subsequently raise your investment by $2b$ (or b) if your partner's previous investment bettered (or equalled) your last move, otherwise match your partner's last move. This strategy is denoted by $\sigma=(a,b)$. Roberts and Sherratt reported that the strategy $\sigma=(1,1)$ performs well in computer simulations against various alternative strategies but did not consider how a population of RTS strategies with different a and b values evolves. We find that selection within RTS populations always acts to lower the values of a and b, hence RTS cooperation is not a robust phenomenon.

[12] T. Killingback and M. Doebeli. The continuous Prisoner's Dilemma and the evolution of cooperation through reciprocal altruism with variable investment. *The American Naturalist*, 160(4):421-438, October 2002. [bib | DOI]

Understanding the evolutionary origin and persistence of cooperative behavior is a fundamental biological problem. The standard “prisoner's dilemma,” which is the most widely adopted framework for studying the evolution of cooperation through reciprocal altruism between unrelated individuals, does not allow for varying degrees of cooperation. Here we study the continuous iterated prisoner's dilemma, in which cooperative investments can vary continuously in each round. This game has been previously considered for a class of reactive strategies in which current investments are based on the partner's previous investment. In the standard iterated prisoner's dilemma, such strategies are inferior to strategies that take into account both players' previous moves, as is exemplified by the evolutionary dominance of “Pavlov” over “tit for tat.” Consequently, we extend the analysis of the continuous prisoner's dilemma to a class of strategies in which current investments depend on previous payoffs and, hence, on both players' previous investments. We show, both analytically and by simulation, that payoff-based strategies, which embody the intuitively appealing idea that individuals invest more in cooperative interactions when they profit from these interactions, provide a natural explanation for the gradual evolution of cooperation from an initially noncooperative state and for the maintenance of cooperation thereafter.

Keywords: evolution of cooperation, prisoner's dilemma, reciprocal altruism, adaptive dynamics, variable investment

[13] W. Lee, W. Fan, M. Miller, S. Stolfo, and E. Zadok. Toward cost-sensitive modeling for intrusion detection and response. *Journal of Computer Security*, 10(1/2):5-22, 2002. [bib | http]

Intrusion detection systems (IDSs) must maximize the realization of security goals while minimizing costs. In this paper, we study the problem of building cost-sensitive intrusion detection models. We examine the major cost factors associated with an IDS, which include development cost, operational cost, damage cost due to successful intrusions, and the cost of manual and automated response to intrusions. These cost factors can be qualified according to a defined attack taxonomy and site-specific security policies and priorities. We define cost models to formulate the total expected cost of an IDS, and present cost-sensitive machine learning techniques that can produce detection models that are optimized for user-defined cost metrics. Empirical experiments show that our cost-sensitive modeling and deployment techniques are effective in reducing the overall cost of intrusion detection.

[14] A. Namatame, T. Kaizouji, and Y. Aruga, editors. *The Complex Networks of Economic Interactions*, volume 567 of *Lecture Notes in Economics and Mathematical Systems*. Springer, 2006. Not yet published. (Due: Jan 2006). [bib]

This book contains papers which provide a venue for high-quality multi-disciplinary research contributions addressing theoretical and computational aspects of interaction and coordination of economic agents. It focuses on emergent phenomena and collective behavior in economic activities as well as on the development of analytical and computational tools in models with heterogeneous agents. Contributions are not restricted to any particular school of thought, but need to be based on rigorous theoretical models and supported by experimental validation.

[15] D. Phan. Agent-based computational economics and cognitive economics, December 2004. Published in Bourgine P., Nadal J.P. eds. (2004) Cognitive Economics; Springer Verlag, p. 371-398. [bib | .pdf]

[16] G. Roberts and J. S. Renwick. The development of cooperative relationships: An experiment. *Proceedings of the Royal Society of London Series B: Biological Sciences*, 270(1530):2279-2283, November 2003. [bib | DOI]

Pairs of individuals frequently face situations in which they could do well if they cooperated, but each risks being exploited. The Prisoner's Dilemma is widely used for investigating such scenarios, but it is framed in terms of cooperating and defecting, whereas in reality cooperation is rarely “all or nothing.” Recent models allowing for variable investment in cooperation indicated the success of a strategy of “raising-the-stakes” (RTS), which invests minimally at first and then increases its investment if its partner matches it. We tested whether this strategy was adopted by subjects participating in an experiment in which they could choose how much money to give to a partner, reciprocity being encouraged by doubling donations. Subjects did increase their donations over successive rounds, both when playing against a stooge who reciprocated with the same investment, and when playing with a partner who was free to choose their investment. Subjects showed a strong tendency to match variations in their partner's investments. Cooperation was therefore achieved through a combination of initial escalation (RTS strategy) and quantitative responsiveness (“give-as-good-as-you-get” strategy). Although initial offers were higher than predicted, our results were broadly consistent with theoretical expectations.

[17] G. Roberts and T. N. Sherratt. Development of cooperative relationships through increasing investment. *Nature*, 394(6689):175-179, July 1998. [bib | DOI]

Reciprocal altruism can become established among selfish, unrelated individuals if they use responsive strategies such as `tit-for-tat.' This result raises the fundamental question: how altruistic should one be? The problem is difficult to solve using current `prisoner's dilemma' based models because they allow only the discrete choice of cooperating or defecting. In reality, however, cooperation is rarely all-or-nothing. Furthermore, if cooperative investment is variable, a new and more subtle kind of cheating becomes possible: individuals may invest slightly less than their partner. A concern is that this `short-changing' will erode cooperative ventures. Here we show that cooperation can thrive despite variable investment through the new strategy of `raise-the-stakes'. This strategy offers a small amount on first meeting and then, if matched, raises its investment, something that no strategy in the discrete model can do. We show that such behaviour can readily invade a population

of non-altruists and cannot be effectively exploited. The practice of `testing the water' rather than making sudden cooperative `leaps of faith' powerfully reinforces the stability and effectiveness of reciprocity.

[18] F. Santos and J. Pacheco. A new route to the evolution of cooperation. *Journal of Evolutionary Biology*, 19(3):726-733, 2006. [bib | DOI]

The Prisoner's Dilemma (PD) constitutes a widely used metaphor to investigate problems related to the evolution of cooperation. Whenever evolution takes place in well-mixed populations engaged in single rounds of the PD, cooperators cannot resist invasion by defectors, a feature, which is somewhat alleviated whenever populations are spatially distributed. In both cases the populations are characterized by a homogeneous pattern of connectivity, in which every individual is equivalent, sharing the same number of neighbours. Recently, compelling evidence has been accumulated on the strong heterogeneous nature of the network of contacts between individuals in populations. Here we describe the networks of contacts in terms of graphs and show that heterogeneity provides a new mechanism for cooperation to survive. Specifically, we show that cooperators are capable of exploring the heterogeneity of the population structure to become evolutionary competitive. As a result, cooperation becomes the dominating trait in scale-free networks of contacts in which the few highly connected individuals are directly inter-connected, in this way contributing to self-sustain cooperation.

[19] T. Shishido and H. Shishido. Alternating continuous Prisoner's Dilemma. In *Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics*, volume 2, pages 1276-1281, October 2001. [bib | DOI]

We study the alternating continuous Prisoner's Dilemma in which the player's next move is a linear function of a player and the opponent's previous moves. The condition of existence of stable equilibrium points is obtained when a player plays a game against the other player with the same type of strategies. We simulate the case where the players may occasionally make mistakes with a wide range of strategies playing against each other.

Keywords: Prisoner Dilemma, equilibrium points, game theory, necessary conditions, sufficient conditions, tit-for-tat player

[20] E. Tardos. Network games. In *Proceedings of the thirty-sixth annual ACM symposium on Theory of computing (STOC)*, pages 341-342, New York, NY, USA, 2004. ACM Press. [bib | DOI]

Network games approach some of the traditional algorithmic questions in networks from the perspective of game theory, which gives rise of a wide range of interesting issues. In this talk we will give an overview of recent progress in many of these areas, and show strong ties to certain algorithmic techniques.
