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THE PRICE OF ANARCHY AND BRAESS PARADOX IN TRANSPORTATION NETWORKS

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Hawoong Jeong
Head of Department of Physics
Chair Professor of KAIST
Korea Advanced Institute of Science and Technology(KAIST), KOREA
e-mail: hjeong@kaist.edu

Abstract

In complex systems, for instance human societies, where self-interested behavior and mutual interactions are common, inefficiency is inevitable unless the systems are centrally coordinated. A lot of emphasis in the studies of complex systems is on optimality control intended to reduce inefficiency. Despite the effort in this respect, it is still often unclear by how much optimal and actual system performance can differ under realistic conditions. There is also still a related open question: what kind of strategy is suitable for improving system performance if directly controlling individual behavior is not an option? In this presentation, I would like to address these issues by analyzing travel times in transportation networks.

In real transportation networks, the delays on the links increase steeply with the total number of users. Therefore, uncoordinated individuals seeking their own quickest paths make strategic decisions depending on other passengers' choices, which may cause undesired delays to others and sometimes ironically even themselves. The "price of anarchy", i.e. the ratio of the Nash equilibrium (the actual travel time) to the social optimum (the possible minimum travel time), is a quantitative measure for this additional delay. In other words, it is the price that individuals have to pay for not being coordinated but being self-interested. According to our results, we face this inefficiency every day on the road: the average travel time in Boston's road network, for instance, can be up to 30% longer than the global minimum, so the traffic flow leaves substantial room for improvement. Surprisingly, we predict that improvement can be achieved by closing any of six streets identified among the total of 246 streets. We also investigate two other cities, London and New York, and find the same counterintuitive phenomenon. This peculiar behavior can be explained in terms of Nash flows that are the consequence of selfish behavior in decentralized systems. By analyzing typical values and statistical properties for various complex networks, we uncover the interplay between the underlying structure and its inherent inefficiency.

Understanding the collective behavior of interacting agents in complex transportation networks is essential for both the design and control of peer-to-peer networks, information packets in the Internet, vehicle routing, job scheduling, and city structure. Our most significant finding is an assessment of the price of anarchy in a real system with important implications for the engineering of networks. Equally important, we observe a potential strategy for guiding the Nash equilibrium to the global optimum without using repressive measures (such as controlling individual behaviors, which is obviously impossible) simply by making structural changes to the network. This result demonstrates a new possibility of solving a social dilemma and will inspire new directions of research for economists, behavioral scientists, and policy makers as well as for pure scientists.

[1] H.-J. Youn, M. Gastner, H. Jeong, "Price of anarchy in transportation networks: Efficiency and optimality control" Phys. Rev. Lett. 101 128701 (2008)