Token Economy for Online Exchange Systems

(Extended Abstract)

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ABSTRACT

This paper studies the design of online exchange systems that are operated based on the exchange of tokens, a simple internal currency which provides indirect reciprocity among agents for cooperation. The emphasis is on how the protocol designer should choose a protocol - a supply of tokens and suggested strategies - to maximize service provision, taking into account that impatient agents will comply with the protocol if and only if it is in their interests to do so. The protocol is designed in such a way that it is robust to (small) errors in the designer's knowledge of the system parameters. We prove that robust protocols have a simple pure threshold structure and there is a unique optimal supply of tokens that balances the token distribution in the population and achieves the optimal efficiency. In the meanwhile, we also emphasize that choosing the wrong token supply can result in an enormous efficiency loss.[1]

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*intelligent agents, multiagent system, cooperation*

General Terms

Design, Economics, Theory

Keywords

Game theory, Agent cooperation, Formal model

1. INTRODUCTION

Content, knowledge and resource sharing services are currently proliferating in many online systems, e.g. BitTorrent, Yahoo Answers and crowdsourcing markets such as Amazon Mechanical Turk. The expansion of such sharing and exchange services will depend on their participating members (herein referred to as agents) to contribute and share resources with each other. However, these systems are vulnerable to "free-riding" problems since the participating agents are self-interested. To compel the self-interested agents to cooperate, incentive schemes can be designed which rely on the information that individual agents have. Such incentives schemes can be classified into two categories: personal reciprocation (direct reciprocation) [1] and social reciprocation (indirect reciprocation)[4]. Reputation is often used as a way to achieve cooperation among self-interested users but has limitations in fully anonymous and decentralized systems. Moreover, they are also vulnerable to collusion attacks.

In this paper, we design a new framework for providing incentives in social communities, using tokens. Agents exchange tokens for services: the client who receives service from a server pays for that service with a token which the server will later use to obtain service when it becomes a client. Here we ask what the designer can achieve by imposing a system that relies solely on the exchange of intrinsically worthless *tokens* or *fiat money*. Our emphasis is on the *design* of such a system; in particular, how the designer should choose a protocol - a supply of tokens and suggested strategies - to maximize the system efficiency. Because it seems impossible for the designer to have exact knowledge of the system parameters, we insist that the chosen protocol must be consistent with (small) perturbations in these parameters. Thus, the chosen protocol must induce a *robust equilibrium*. Among all such choices/recommendations, the designer should select one that maximizes the social welfare/system efficiency - or at least approaches this maximum. We characterize the robust equilibria (in terms of the system parameters), show that they have a particularly simple form, and determine the achievable system efficiency. When agents are patient, it is possible to design robust equilibria to nearly optimal efficiency; however, the correct design is important: the "wrong" design do not achieve nearly the optimum, even when agents are arbitrarily patient.

This work connects to a number of literatures. The most related ones include macro-economic literature on money as a medium of exchange [3][6] and computer science and engineering literature on token-like system design [2][5].

2. PROBLEM FORMULATION

We consider a continuum (mass 1) of agents each possess a unique resource that can be duplicated and provided to others. The benefit of receiving this resource is b and the cost of producing it is c; we assume $b > c > 0$. Agents discount future benefits/costs at the constant rate $\beta \in (0, 1)$. Agents are risk neutral so seek to maximize the discounted present value of a stream of benefits and costs. Time is discrete. In

[1]Full version of this paper can be found online at http://www.ee.ucla.edu/∼jiexu/documents/aamas12_long.pdf

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each time period, a fraction $\rho \leq 1/2$ of the population is randomly chosen to be a client and matched with randomly chosen server; the fraction $1 - 2\rho$ is unmatched. When a client and a server are matched, the client chooses whether or not to request service, the server chooses whether or not provide service if requested. The parameters b, c, β, ρ completely describe the environment. Write the benefit/cost ratio $r = b/c$. Each agent can hold an arbitrary non-negative finite number of tokens, but cannot hold a negative number of tokens and cannot borrow. The protocol designer creates incentives for the agents to provide or share resources by providing a supply of tokens and recommending strategies for agents when they are clients and servers. The recommended strategy is a pair $(\sigma, \tau) : \mathbb{N}_+ \to (0,1)$; τ is the client strategy and σ is the server strategy. For each token holding k, $\sigma(k)$ is the recommended probability to provide service when the agent becomes a server; $\tau(k)$ is the recommended probability to request service when it is a client. In other words, the protocol designer recommends a mixed strategy for the agents.

The system designer chooses a protocol $\Pi = (\alpha, \sigma, \tau)$ where α is the supply of tokens (average number of tokens per capita). Define the system efficiency as the probability that the service provision is successfully carried out when two agents are paired given the system parameters b, c, β. Write μ the fraction of agents who do not request service when they are clients and ν the fraction of agents who do not provide service when they are servers. by the Law of Large Numbers, the efficiency is computed in the straightforward manner,$\texttt{Eff}\,(\Pi|b, c, \beta) = (1-\mu)(1-\nu)$. Taking into account that impatient agents will comply with the protocol if and only if it is in their interests to do so, the protocol need be an equilibrium given the system parameters. Write $\Phi(\Pi)$ the set of $\{(\beta, \gamma)\}$ for which Π is an equilibrium. The design problem are thus to choose the protocol

$$\Pi = \underset{\Pi:(\beta,r)\in\Phi(\Pi)}{\arg\max}\ \texttt{Eff}\,(\Pi|\beta, r)$$

3. MAIN RESULTS

3.1 Structural Property

The knowledge of the protocol designer of the system parameters (b, c, β) may not be accurate. Hence, the strategy must be robust to the small perturbations in the parameters.

THEOREM 1. *If $\Pi = (\alpha, \sigma)$ is a robust equilibrium then σ is a pure threshold strategy.*

Existence of equilibrium is not trivial. It is not obvious that there will be any discount factor β that makes agents be willing to use a certain threshold. The following theorem claims that such β can always be found.

THEOREM 2. *For each pure threshold strategy protocol $\Pi = (\alpha, \sigma_K)$ and benefit/cost ratio $r > 1$, the set $\beta : \Pi_K \in EQ(r, \beta)$ is a non-degenerate interval $[\beta^L, \beta^H]$.*

3.2 Optimal Token Supply

In general it seems hard to determine the efficiency of a given protocol or to compare the efficiency of different protocols. However, for a given threshold strategy, we can find the most efficient protocol and compute its efficiency. Write $\Pi_K = (K/2, \sigma_K)$.

THEOREM 3. *For a given threshold strategy σ_K , Π_K is the most efficient protocol; i.e., $\mathit{Eff}(\alpha, \sigma_K) \leq \mathit{Eff}(\Pi_K)$ for every per capita supply of tokens α. Moreover,*

$$\mathit{Eff}\,(\Pi_K) = 1 - \frac{1}{(K+1)^2}$$

Theorem 3 identifies a sense in which there is an optimal quantity of tokens. This optimal token supply balances the token distribution in the population in the sense that there are not too many agents who do not serve or too many agent who cannot request service. However, these most efficient protocols (for a given threshold) need not be equilibrium protocols; i.e. such combinations of token supply and threshold need not be feasible for all system parameters. For example, given the benefit/cost ratio r, it does not exclude the possibility that for some discount factor β, we cannot find any threshold protocol with the corresponding optimal token supply that is an equilibrium. However, we disclaim this conjecture by showing that the sustainable discount factor intervals overlap between consecutive threshold protocols with optimal token supply. Based on this overlap property, the following theorem describes the equilibrium threshold in the limiting case.

THEOREM 4. *For each fixed benefit-cost ratio $r > 1$*

$$\lim_{\beta\to 1} \inf \{K : (\beta, r) \in \Phi(\Pi_K)\} = \infty$$

Characterizing the equilibrium threshold is important because only with the correct knowledge of sustainable thresholds can the protocol designer choose the right token supply. Otherwise, there may be an enormous efficiency loss. We provide an bound to make the point that choosing the wrong protocol can result in strict efficiency loss.

THEOREM 5. *For each $\alpha \in (0, \infty)$ and each threshold K*

$$\mathit{Eff}\,(\alpha, \sigma_K) \leq 1 - \frac{1}{2\lceil\alpha\rceil + 1}$$

(independently of the parameters of the population)

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