A Doubly Structural Network Model and Agent-Based Simulation on Emergence of Money

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This paper describes simulation studies in order to examine the validity of our previous predictions of the emergence of money using Doubly Structural Network Model (DSN Model). DSN Model consists of two levels of networks: the one of inner agent-model to represent their beliefs or knowledge about the world and the other of inter agent-model to represent a social network among agents. Using DSN model, we have explained how the concepts of money as a exchangeable media emerges through agent interaction. DSN Model is congenial to agent-based simulation. In this paper, using large scale intensive computer experiments, we investigate the bifurcation analysis derived from dynamics of DSN model. We also show new emergent phenomena on various types of social networks.

We proposed the Doubly Structural Network Model [1] that handles the propagation of knowledge and recognition between agents in society. The structure of this model is defined by formula 1.

$$\begin{array}{ll} G^S \equiv (V^S, E^S), V^S \equiv \{v_i^S | i = 1 \ldots N\}, E^S \subseteq V^S \times V^S & \text{(a)} \\ G_i^I \equiv (V^I, E_i^I), V^I \equiv \{v_\alpha^I | \alpha = 1 \ldots M\}, E_i^I \subseteq V^I \times V^I & \text{(b)} \\ G^D \equiv \{\{v_i^S, G_i^I | i = 1 \ldots N\}, E^S\} & \text{(c)} \\ G_{t+dt}^D \equiv F(t, G_t^D) & \text{(d)} \end{array} \tag{1}$$

- In formula (1a), "social (inter-agent) network" G^S represents the social structure composed of N agents. The node (vertex) v_i^S represents the i-th agent. The edge set E^S represents connection or disconnection between these agents.
- In formula (1b), "internal (recognition) network" G_i^I represents the internal landscape or recognition of the i-th agent on certain objects $(\alpha, \beta, \ldots)$. The node (vertex) v_α^I represents the object α. The edge set E_i^I represents connection or disconnection between those objects in the i-th agent's recognition.
  (Whichever directed/undirected graph is available for social or internal network.)
- Formula (1c) shows that "doubly structural network" G^D is created by attaching (/ mounting) each internal / recognition network $G_i^I (i = 1, 2, \ldots, N)$ onto the corresponding node i (i-th agent) of the social network G^S.
- Formula (1d) shows that a propagation / learning model of the doubly structural network is defined through providing change of state (edges connect / disconnect) in the internal network via interaction of social network nodes (agents) for this network.

We derived some mean-field dynamics and analyze behavior of the doubly structural network model of the emergence of money by the mean-field approximation [2]. By using mean-field approximation, how the social network degree affects the emergence of money was found.

- No-emergence if the connecting degree k is small.
- Only a single emergence occurs if the degree k grows large.
- Multiple emergences occur if degree k grows even larger.

In this paper, we implement a specific mechanism to describe the emergence of money in our model [1]. On the implementation, the social (inter-agents) network reflects the topology of economical/social relationship between agents. The agents' inner networks show their own recognition on the exchangeability between commodities.
Agents in our model interact each other by the following manners in each time step.

1. Exchange: In the social (inter-agent) network, neighboring agents i and j exchange commodities.
2. Learning: Learning process of agents consists of the following four ways.
   Imitation, Trimming, Conceiving, Forgetting

To verify the prediction of mathematical analysis, we execute a simulation, using Regular Network as a social network.
Figure 1 is the experimental result that used the regular network as a social network. A horizontal axis expresses the network degree and the vertical axis expresses the ratio of the number of the emerged proto-money. In Figure 1, the ratio of No-emergence → Single emergence → Multiple emergences is increasing. This result is in agreement with the result by the mean-field approximation.

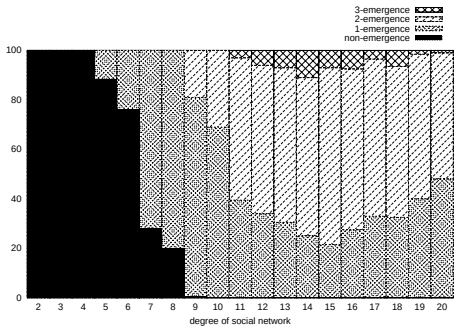

Figure 1: Result of Agent-Based Simulation

Keywords
Social Network, Emergence, Agent-Based Simulation

References
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