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Cellular automata for the spreading of technologies in socio-economic systems

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Abstract

We introduce an agent-based model for the spreading of technological developments in socio-economic systems where the technology is mainly used for the collaboration/interaction of agents. Agents use products of different technologies to collaborate with each other which induce costs proportional to the difference of technological levels. Additional costs arise when technologies of different providers are used. Agents can adopt technologies and providers of their interacting partners in order to reduce their costs leading to microscopic rearrangements of the system. Analytical calculations and computer simulations revealed that starting from a random configuration of different technological levels a complex time evolution emerges where the spreading of advanced technologies and the overall technological progress of the system are determined by the amount of advantages more advanced technologies provide, and by the structure of the social environment of agents. We show that agents tend to form clusters of identical technological level with a power law size distribution. When technological progress arises, the spreading of technologies in the system can be described by extreme order statistics.

Keywords: Spreading; Technology; Cellular automata; Extreme order statistics

1. Introduction

Recently, the application of statistical physics and of the theory of critical phenomena provided novel insight into the dynamics of socio-economic systems [1–8]. Various types of models have been developed which capture important aspects of the emergence of communities [1], opinion spreading [2–7] or the evolution of financial data [9]. The dynamics of innovation and the spreading of new technological achievements show also interesting analogies to complex physical systems [8,10–12]. The process of innovation has recently been studied by introducing a technology space based on percolation theory [11]. In this model new inventions arise as a result of a random search in the technology space starting from the current best-practice frontier. The model could reproduce the interesting observation that innovations occur in clusters whose sizes are described by the Pareto distribution [11]. Another important aspect of technological development is the spreading of

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new technological achievements. In a socio-economic system different level technologies may coexist and compete as a result of which certain technologies proliferate while others disappear from the system. One of the key components of the spreading of successful technologies is the copying, i.e., members of the system adopt technologies used by other individuals according to certain decision mechanisms. Decision making is usually based on a cost-benefit balance so that a technology gets adopted by a large number of individuals if the upgrading provides enough benefits. The gradual adaptation of high level technologies leads to spreading of technologies and an overall technological progress of the socio-economic system.

In the present paper we consider a simple agent-based model of the spreading of technological achievements in socio-economic systems. Agents of the model may represent individuals or firms which use certain technologies to collaborate with each other. For simplicity, we assume that costs of the cooperation arise solely due to the incompatibility of technologies used by the agents which then have two origins: on the one hand, difference of technological levels incurs cost, the larger the difference is, the higher the cost gets. On the other hand, technologies used by agents may belong to different providers which induce additional costs. Agents interacting with their social neighborhood can decrease their cost by adopting technologies of their interacting partners. The local rejection–adaptation strategy of agents can lead to interesting changes of the system on the meso- and macro-level, namely, agents can form clusters with identical technological levels, which can also be accompanied by an overall technological progress of the system.

We analyze the time evolution of this model socio-economic system starting from a random configuration of technological levels and providers without considering the possibility of innovation. Based on analytic calculations and computer simulations we study how the adaptation of technologies of interacting partners leads to spreading of technological achievements. We characterize the microstructure of communities of agents, and the technological progress of the system on the macro-level.

2. Model

Our model captures some relevant features of the spreading of technological developments when they are mostly used for the cooperation of individuals. In the model we represent the socio-economic system by a set of agents which posses products of different technological levels and use it to cooperate with each other. Thinking in terms of telecommunication technologies, agents are characterized by two variables: the technological level of the product an agent has (the technological level of the device the agent uses for communication) is described by a real variable τ such that a larger value of τ stands for more advanced technologies. New technologies developed by the producers reach the agents through providers. For simplicity, we assume that there are at most two providers active in the system and each agent belongs to one of them. The provider of agents is characterized by an integer variable S which can take two different values $S = \{-1, 1\}$.

The agents are assumed to cooperate with their social partners which is the easiest if the partners have products of the same technological level. Using technologies of different level can induce difficulties which may be realized by additional costs. It is reasonable to assume that the cost C induced by the collaboration of agents i and j is a monotonous function of the difference of the technological levels $|\tau_i - \tau_j|$. For the purpose of the explicit mathematical analysis we consider the simplest functional form and cast the cost of cooperation into the following form:

$$C(i \to j) = a|\tau_i - \tau_j| + \tfrac{1}{2}\Delta(1 - S_i S_j). \tag{1}$$

The equation expresses that being at different technological levels (having different τ values) incurs cost, the higher the difference is in τ the higher the costs are, while being at the same technological level is cost-free. This crude assumption models a socio-economic system which favors the local communities to be at the same technological level. The value of the multiplication factor a has to be chosen to capture the effect that in case of different technological levels it is favorable for agents to be on a higher technological level than their interacting partners. It follows that the value of a should depend on the relative technological level of the