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Emergence of autocatalytic reaction in a meme propagation model based on particle motion

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Abstract: Meme refers to a unit of human cultural transmission, analogous to gene in biological evolution. Meme propagation has an autocatalytic property in the sense that it increases its reproductive rate by duplicating the source of propagation. The purpose of this study is to gain general knowledge about dynamics of meme propagation. This paper presents a minimal model based on physical movement of particles for investigating the relationship between the behavior of the hosts (velocity of particles) and the autocatalytic property of the meme. It is demonstrated that two extreme memes, the fastest and the slowest ones, have a strong tendency to survive by autocatalytic properties at individual and aggregate levels, respectively, although all memes seem neutral in terms of fitness in the model definition.

Keywords: Agent-based model, Artificial life, Autocatalytic reaction, Meme

1 INTRODUCTION

Meme [1] refers to a unit of human cultural transmission, analogous to gene in biological evolution. A meme parasitizes a human brain and propagates from one brain to another mainly by imitation. For a meme to be successful, it has to have "fecundity", "longevity" and "accuracy of replication", which are recognized as the main components of the fitness of memes.

In principle, meme propagation has an autocatalytic property in the sense that it increases its reproductive rate by duplicating the source of propagation. When comparing it with chemical autocatalytic reactions, we see a big difference arising from the difference between duplication of materials and information. This autocatalytic property of memes will be more strengthened if the meme has a greater fecundity, in other words, a greater tendency to make the host behave for propagating the meme. Bura [2] successfully demonstrated that this type of autocatalytic process could evolve memes which are detrimental to their hosts. In his model MINIMEME, the interaction between the memes and the host animals are modeled, and the following autocatalytic phenomenon was found: memes provoked the gathering of their hosts, which led to a situation in which they reinforced each other and their replication was made easier. Thus, memes that kill their hosts by overcrowding could survive and even become dominant.

The purpose of this study is to gain general knowledge about dynamics of meme propagation. Specifically, this paper presents a minimal model based on physical movement of particles for investigating the relationship between the behavior of the hosts (velocity of particles) and the autocatalytic property of the meme. It is demonstrated that two extreme memes, the fastest and the slowest ones, have a strong tendency to survive by autocatalytic properties at individual and aggregate levels, respectively, although all memes seem neutral in terms of fitness in the model definition.

2 MODEL

Particles move around on a two-dimensional square field with boundaries in the model. Memes inhabit the particles and decide the velocity of the hosts. There are seven kinds of memes, each corresponding to a different velocity: "meme0", "meme1", ..., "meme6" in ascending order of velocity. Fig. 1 shows the relationship between an agent and memes. A meme is represented as an arrow of which length corresponds to its velocity. Each particle has four memes (allowing duplication of kinds), and moves forward with the velocity specified by one of these memes at each step. In-use meme is represented as a solid arrow and the others are represented as a dashed arrow in this figure. The velocity of each particle is switched according to a randomly selected meme from these four memes with a fixed probability at each time step. Each particle keeps its moving direction unless it switches its in-use meme or collides with other particles or boundaries.

Fig. 2 shows an example of meme transmission. Each particle has an interaction area represented as a circle (all particles have the same radius in this paper). While two interaction areas overlap, both particles send their in-use meme to the other at the same time at each step. When receiving a meme, a randomly chosen meme is replaced by the received meme. The thick and solid arrows represent the transmitted

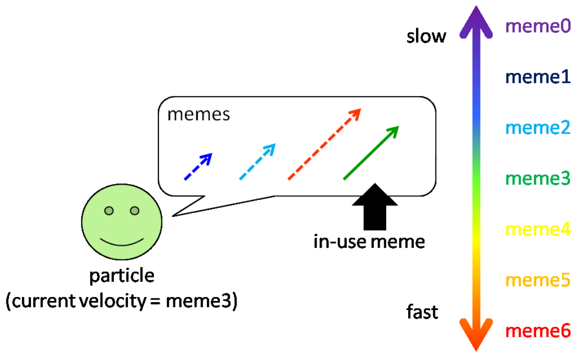


Fig. 1. Relationship between a particle and memes.

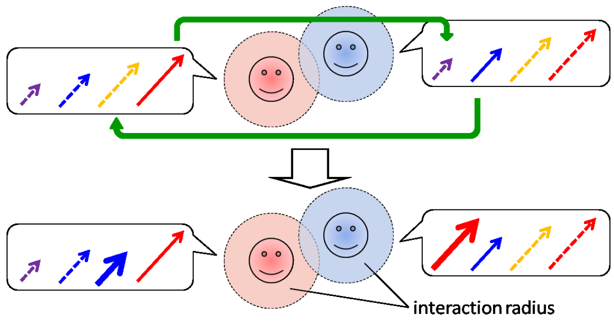


Fig. 2. Meme transmission.

Table 1. Parameters.

Size of field	510 × 510
Number of particles	100
Velocity of meme0	3
Velocity of meme1	6
Velocity of meme2	12
Velocity of meme3	24
Velocity of meme4	48
Velocity of meme5	96
Velocity of meme6	192
Particle radius	5.0
Interaction radius	[5.0, 7.0]

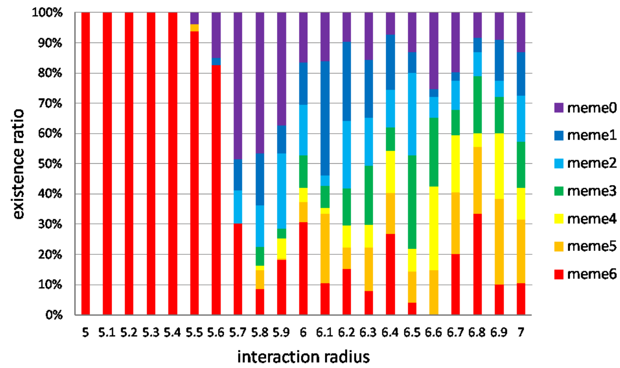


Fig. 3. Existence ratio after convergence.

memes in this figure. Therefore, through each meme transmission, the number of the in-use memes is increased by one unless they are replaced by the meme transmitted by the other particle or they replace the same meme of the other particle.

3 EXPERIMENTS

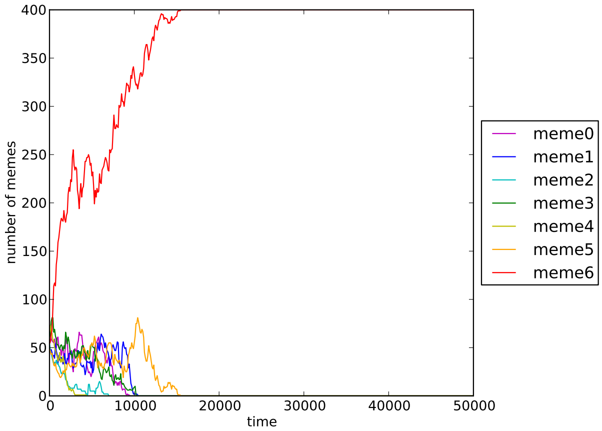
In the initial population of memes, we put particles at random in the field and allocated memes to each particle randomly. We ran the model until the time step reached 50,000. Table 1 shows the parameters to be used. We conducted experiments by changing the value of the interaction radius from 5.0 to 7.0.

Fig. 3 shows the existence ratio of each meme in the population during the last 100 time steps in the different cases of the interaction radius. Each value is the average over 10 trials.

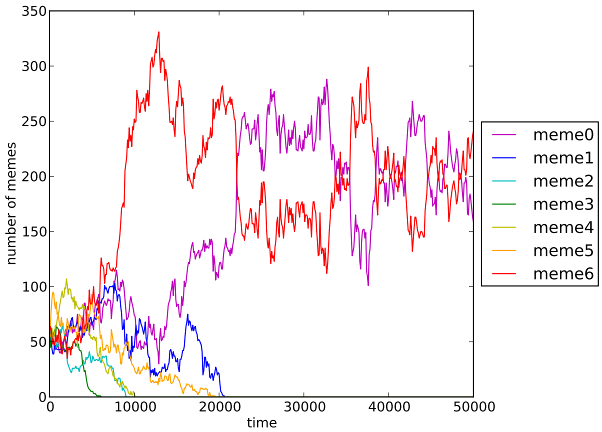
We see that the behavior of the population is strongly dependent on the interaction radius. When the interaction radius was small, 5.4 or less, the population converged to the fastest meme (meme6) in all trials. As the interaction radius increased until around 5.7, the existence ratio of the slowest meme (meme0) increased, and thus the fastest and the slowest memes tended to coexist. As the interaction radius got larger, we observe that memes with intermediate velocity survived and tended to coexist but their ratio fluctuated significantly.

Fig. 4 shows examples of the transition of the number of memes in the population with three typical settings of interaction radius (a: 5.4, b: 5.6 and c: 6.0). In order to analyze the actual behavior of particles in each case, we visualized example snapshots of the model in Fig. 5. Particles are represented as small circles and their color represent their in-use meme.

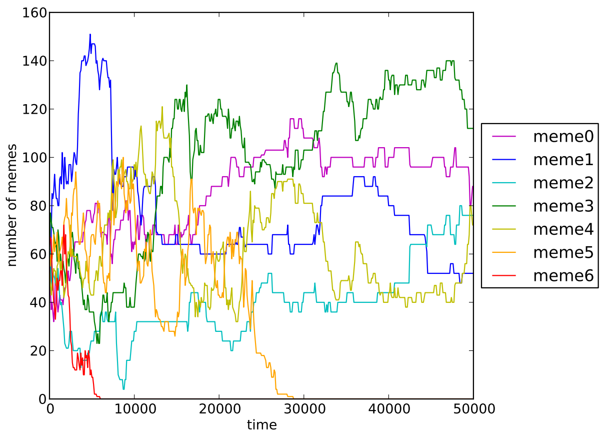
In the case (a), the population was quickly dominated by the meme6, which had the highest velocity. When two particles interact, the in-use meme of a particle is guaranteed to overwrite one of four memes of the other particle. On the other hand, the probability that the in-use meme of a particle is overwritten by the in-use meme of the other particle is 1/4. Therefore, in general, in-use memes can replicate itself in the population by an interaction because of this asymmetric property in probability of meme propagation. In other words, the more a particle interacts, the more frequent opportunities it has to increase the ratio of its in-use meme. Therefore, whether memes increase or not is dependent on the frequency of the propagation of memes. If the interaction radius is small, memes with higher velocity can invade into the population because they enable particles to interact



(a) Interaction radius: 5.4.

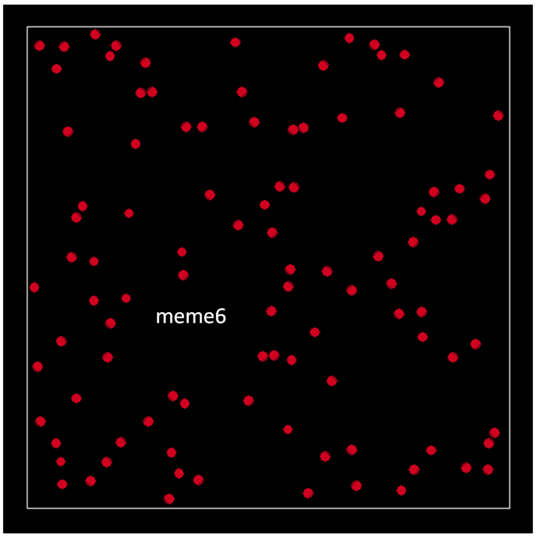


(b) Interaction radius: 5.6.

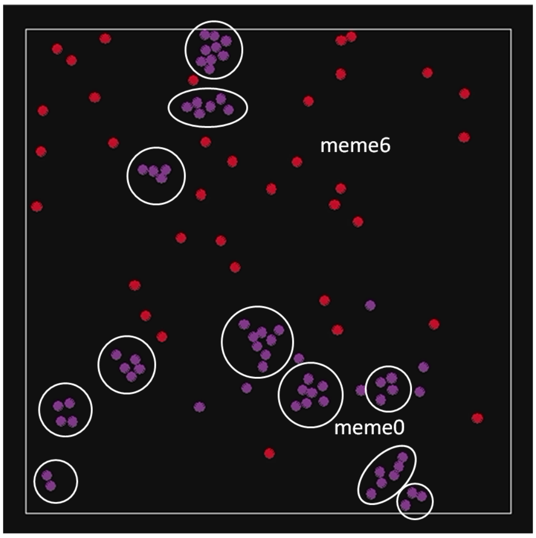


(c) Interaction radius: 6.0.

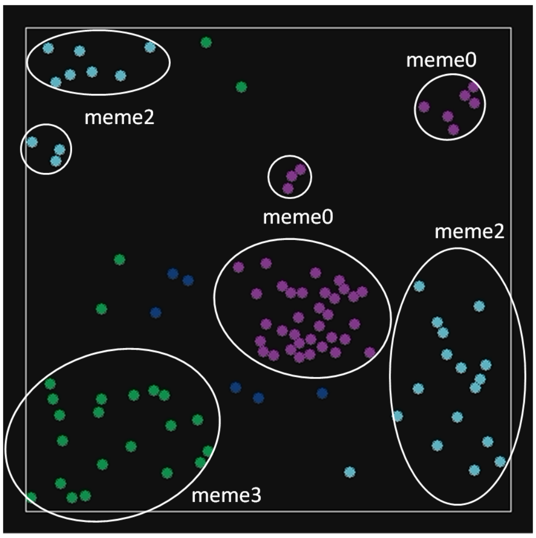
Fig. 4. Examples of the transition of the population.



(a) Every particle has four meme6 (interaction radius: 5.4).



(b) Particles with meme0 gather in the moving particles with meme6 (interaction radius: 5.6).



(c) Particles with each kind of meme gather (interaction radius: 6.0).

Fig. 5. Example snapshots of the population (almost every particle has one kind of meme).

with many other particles by moving around the field. Thus, we can say that meme6 is dominant due to this autocatalytic property at individual level.

In the case (b), the population converged to the state with meme0 and meme6. We can observe the clusters of the meme0 in Fig. 5(b). Note that the white and open circles in Fig. 5 represent the clusters of each meme. The detailed analyses of the behaviors of particles showed that the particles with the meme0 maintained their clusters by trapping incoming particles with the meme6, while they were scattering very slowly. Fig. 6 shows the transition of the proportion of interaction events when a particle received the same kind of meme as the one it sent to the other particle among events when a particle sent the focal kind of meme (the interaction radius = 5.6). Because the percentage of meme0 is large, we can say that the meme0 replicated and increased their frequency via interactions among particles in their clusters due to the larger interaction radius. This makes incoming particles into the clusters receive the meme0 very frequently, and thus they tend to become a part of the clusters. From these facts, despite meme0 has the lowest autocatalytic property at individual level, we can say that meme0 was dominant because of this autocatalytic property at aggregate level.

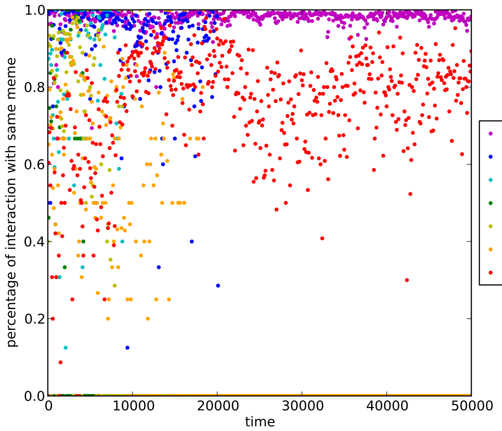


Fig. 6. Transition of the proportion of the interactions between the particles with the same kind of in-use memes.

However, as the interaction radius increased further, such as case (c), the population converged to the state with more kinds of memes as shown in this example. We did not observe dominant memes because of large variations in each trial within the limited number of the time step 50,000. It is expected to be due to the fact that the larger interaction radius makes effects of the difference in the velocity of memes on the behavior of particles less significant, by making interaction events frequent and global. Thus, we did not observe emergence of autocatalytic behaviors at both individual and aggregate level, which are based on the two extreme properties of memes.

4 CONCLUSION

We presented a minimal model based on physical movement of particles for investigating the relationship between the behavior of the hosts and the autocatalytic property of the meme. The simulation results showed that two types of autocatalytic processes could emerge at individual and aggregate levels, which evolve two extreme memes, the fastest and the slowest ones, respectively. It is a noticeable fact that the evolution was not based on the explicit fitness definition. If we consider the model describes religious propagation, the fastest meme and the slowest meme might correspond to a popular religion and a cult, respectively.

Our model assumes a direct relationship between a meme and the movement of its hosts. It would be interesting to associate the assumption with the recent experimental finding by Hommel et al. that religious practice can not only affect spatial and temporal characteristics of stimulus selection but also control processes devoted to action regulation [3].

Sayama is developing the Swarm Chemistry model [4], which is an artificial chemistry framework that can demonstrate self-organization of dynamic patterns of kinetically interacting heterogeneous particles. One of the promising directions would be to enhance our model towards Sayama's model to aim to make our model capable of open-ended evolution while keeping neutrality of memes in terms of fitness in the model definition.

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