生物のサイズスケーリング -代謝の 3/4 乗則を示すモデル-

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The Cellular Automata Model of The Allometric Scaling Law

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The dependence of a metabolic rate E_s on body mass M is typically characterized by an allometric scaling law of the form

$$E_s \sim M^{3/4} \quad \text{or} \quad \frac{E_s}{M} \sim M^{-1/4}. \tag{1}$$

Recently Nakaya, Saito and Motokawa studied the colonial ascidian *Botrylloides simodensis* which grows in a plane and revealed that metabolic rates of two-dimensional organisms also scale as $M^{3/4}$. Although various theoretical hypotheses have been proposed to explain 'the 1/4 power law', none can explain their result when it is extended to two-dimensional systems.

We constructed a general model using d-dimensional totalistic cellular automata (CA) in which the state of each cell took either "active (=1)" or "inactive (=0)". Although our model was quite simple, the 1/4 relation was derived from it. The state of a cell is updated according to the total sum of the activities of itself and the members of Neumann neighborhood (totalistic rule). We premised that the inactive cell does not become active if all the other members in the neighborhood are inactive. We simulated all the possible rules ($2^5 = 32$ for $d = 2$, $2^7 = 128$ for $d = 3$) to investigate the effect of system size L^d on the density of active cells ρ, where L is lattice size.

In two dimensions, only one rule (rule 52 :(0,1,0,1,1)) gives an allometric relation between the system size and ρ with the exponent $-0.250 = -1/4$. This rule gives the lowest positive density of active sites in large systems. In three dimensions, rule 232 (0,0,1,0,1,1,1) also gives the allometric relation with the exponent $-0.246 \approx -1/4$. Thus we could reproduce the 1/4 power scaling by the simplest totalistic CA regardless of the dimension.

Our simulation showed that the behavior of the system could be allometically organized without a centralized or highly-developed control systems, such as circulatory systems with hierarchical branching, but with only local interactions between neighbors. It means that living organisms would be in the self-organized critical state.