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Individual-based modeling of spatial population dynamics

In last decades, a variety of mathematical approaches have been explored and they have contributed much to better understand population dynamics in general. Mathematical models have been accumulating. Many of them, however , remain qualitative description of population dynamics focused at "population level" where analytical tractability is prioritized and mechanistic process of individual birth and death are ignored.

$$N_{t+1} = \exp\left[r\left(1 - \frac{N_t}{K}\right)\right] N_t \tag{1}$$

For example, the assumption that per capita growth rate linearly or exponentially decreases with population size as assumed in the Ricker logistic model (1) is completely descriptive one without any mechanistic process explicitly considered at individual level; we just assume it and start from such a descriptive model.
In order to understand population dynamics in general, we think it is necessary to link population dynamics, a phenomenon at population level, with mechanistic processes of birth and death that occur at individual level. In this paper, we aim to reconstruct a population dynamics in terms of individual birth and death and try to derive a dynamical system based on mechanistic interactions between individuals.
We first construct a spatial population dynamics where an individual is a point located in a continuous two dimensional space and a population is represented as a point pattern. Each individual has a territory with radius σ_c and consumes renewable resource to reproduce. Interaction between individuals occurs when territories overlap and overlapped area is handled according to a certain rule each individual adopts. These algorithmic rule constitutes a point process and we have built a flexible framework to implement these rules as individual-based simulation model. We analyze how the point pattern changes temporarily in terms of population size and pair correlation function. And we derive a dynamical system to explain behaviors of the individual-based simulation.

$$N_{t+1} = \left\{\sum_{k=0}^{\infty} {}_{N_t-1}C_k (4\pi\sigma_c^2)^k (1 - 4\pi\sigma_c^2)^{N_t-1-k} e^r \times \mathrm{Max}\left[1 - \frac{\alpha k}{2}, 0\right]\right\} N_t \tag{2}$$

where α is the interaction coefficient.
Our final goal is to understand phenomena at population level based on mechanistic interactions of individual level and how such interactions can be described as a mathematical form. Our individual-based framework also allows to explore evolution of parameters such as territory size and dispersal range. We discuss an individual-based approach to better understand population dynamics as well as evolutionary dynamics.