

Spatial Divergence & Oscillatory TOCs

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The tragedy of the commons

Garrett Hardin:

*The population problem has no technical solution;
it requires a fundamental extensioin in morality.*

The tragedy of the commons

A tragedy of the commons (TOC) occurs when individuals acting in their own self-interest deplete commonly held resources, leading to a worse outcome than had they cooperated.

Keys to TOC

- Macro-scale:
 - game
 - environment
- Individual level:
 - divergence of incentives & pay-offs

Current frameworks

- Evolutionary dynamics arising from a TOC dilemma can be modeled in terms of changes in the frequencies of individuals from two populations, cooperators and defectors.
- Individuals interact and receive payoffs that depend on their strategy and the strategy of their opponent, where payoff can be modeled by the payoff matrix,

$$A = \begin{Bmatrix} R & S \\ T & P \end{Bmatrix}$$

representing the system's fitness.

- The outcome of TOC is measured by the frequency of co-operators and defectors $(x, 1 - x)$, and the resources.
- This framework is not a zero-sum game.

Current frameworks – equations & conditions

PhysRevLett.122.148102

- fitness

$$\dot{x} = x(1-x)[r_C(x, A) - r_D(x, A)] \quad (1)$$

r_C, r_D : context-dependent fitness payoff to cooperators and defectors, respectively.

- TOC's occurrence condition: $T > R > P > S$.
- To address the reproductive case: resource-dependent payoff matrices

$$A(n) = A_0(1-n) + A_1(n),$$

where $n \in [0, 1]$.

Individual-based coevolutionary game

- Intuitions on the emergent dynamics of social context and resources:
 1. to assess the influence of noise
 2. spatially explicit interactions
- Schemes:

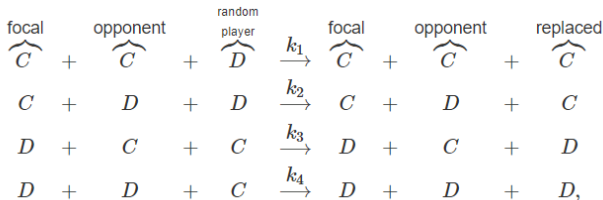


Figure: Transitions of cooperators and defectors.

Individual-based coevolutionary game

- Results
 - Transition rate for #C and #D. Furthermore, the limiting frequency of cooperaters $\lim_{N, n_c \rightarrow \infty} \frac{n_c}{N}$
- Problems: is such frequency convergent or divergent?
 - Recalling a Cauchy distribution, or a Lorenz oscillator.
 - In other words, is the society ending up in tragedy?

Individual-based coevolutionary game

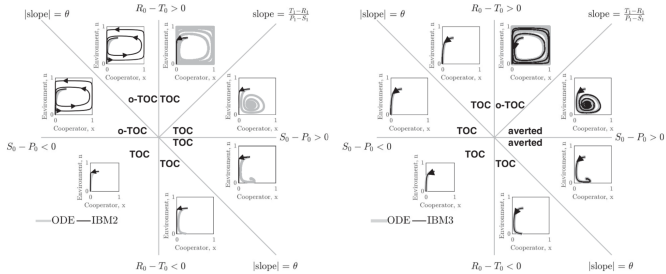


FIG. 1. Coevolutionary dynamics of strategies and resources in replicator and IBM dynamics. (left) The dynamics with “IBM2,” in which offspring of the focal player replace the opponent. (right) The dynamics with “IBM3,” in which offspring of the focal player replaces a random individual. In both panels, parameter space is divided according to the sign of $R_0 - T_0$, $S_0 - P_0$. In each section in the parameter space, a phase diagram with different A_0 is shown, where the abscissa represents x and the ordinate denotes n . Light gray trajectories are mean field solutions and black trajectories denote IBM dynamics where arrows denote the flow of time. Visualized IBM trajectories are the average of 100 replicates with the same parameter set, except for oscillatory dynamics, given phase differences that can arise due to demographic noise. Common parameters for all replicates: $\theta = 2$, $\epsilon = 0.5$, $\Delta x = 1$, and $\Delta t = 0.05$, $A_1 = [3, 0, 5, 1]$; A_0 varies by region. Full parameter list for A_0 in Fig. S1 in the Supplemental Material [7].

Demographic noise and spatial structure

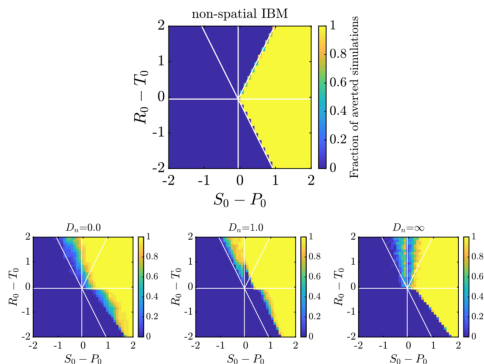


FIG. 2. Strategy-resource dynamics given spatial interactions.

Demographic noise and spatial structure

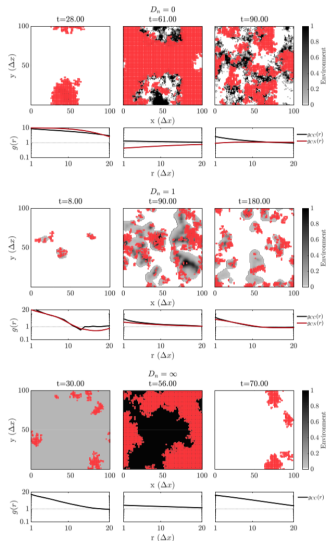


FIG. 3. Spatiotemporal dynamics of resources and cooperators.

Coexistence in cities

- *City* is a concrete of aggregate effect. Such complex is not only the sum of different parts, but also the chemistry through each part.
- The resource of cities?
 - Citizens, which are usually somewhat *evenly* distributed spatially.
 - Firms, diverse in reliance on amongst distances.
- The costs of cities?
 - Dynamics of input and output.

Establishing models

- Task: Predicting the emergence of new firms over a city's space.
0. Collect financial statements of companies and the decay of communication distances, establish the IOs of every trade and the current cross matrix;
 1. Vectorize the factors of different firms by reliance on different trades;
 2. Establish a dynamical matrix of size $kN \times kN$, new companies may emerge at some optimal location to take charge for urban development;
 3. simulate until it ends or a sufficiently long time;
 4. Evaluate the diversity of trades and the fitness of industrial structures.

Expecting

- Some cities' industrial structures may lead to TOC: companies harm their city when pursuing their own benefits.
- Diversity of cities diverges according to the initial conditions since both the specialization and diversification exist.
- Emergence of new companies' spatial and size distribution.

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