Python NetLogo like model group dispersal Matplotlib Animation. Model Overview, Design concepts, Details (ODD)

Overview

This model is an enhanced Python-based implementation of the **first model** described in this article, **Ibrahim, A.M. The conditional defector strategies can violate the most crucial supporting mechanisms of cooperation. Sci Rep 12, 15157 (2022).** **https://doi.org/10.1038/s41598-022-18797-2**.

It builds on the original NetLogo version and introduces key improvements that clarify strategic differences and add new dynamic features.

The central idea is to explore how **conditional selfishness**—agents that usually defect but temporarily cooperate during migration—affects population spread and survival compared to pure cooperation and pure defection.

Strategies in the Model

The improved simulation explicitly distinguishes between **three strategies**:

1. **Cooperators**

    - Always behave cooperatively in resource use.
    - participate in migration or dispersal.
2. **Pure Defectors**
    - Always exploit resources selfishly (never cooperate).
    - Do not engage in cooperative migration, moving only individually when possible.
3. **Conditional Defectors (Newly refined strategy)**
    - Default to selfish exploitation of resources.
    - However, when resources become scarce or migration is needed, they can **temporarily cooperate in collective migration** with other Conditional defectors to share movement costs.
    - After migration, they revert to pure selfish behavior in the new colony.

This refinement—separating **conditional selfishness** from **pure selfishness**—provides a clearer representation of the dynamics and evolutionary success of conditional defectors in migration contexts.

Key Improvements and Added Features

Several new techniques were introduced in the Python implementation to increase realism and analytical clarity:

- **Energy indicator**
  Each agent has an energy value that is displayed during its movement in the resource patches and migration.
- **Prevention of circular moves**
  A rule was added to prevent agents from endlessly moving back and forth between the same locations.

This ensures **smooth directional flow** and avoids getting stuck in redundant cycles.

- **Migration success tracking**
  The model records the proportion of **successful migrants** from each strategy (Cooperators, Pure Defectors, Conditional Defectors). This enables direct comparison of migration effectiveness and long-term evolutionary outcomes.

Simulation Flow

1. **Initialization**
   - The environment is divided into patches containing renewable resources.
   - Agents are randomly distributed, assigned one of the three strategies, and given initial energy.
   - Parameters such as migration cost, dispersal range, resource regeneration, mutation rates, and circular move restrictions are set.
2. **At each time step**
   a. **Resource exploitation**
   - Cooperators share resources, defectors exploit them, conditional defectors defect unless migration is triggered.
   - Agents update energy levels.

   b. **Decision to migrate**

   - If resources are low or energy drops, agents may attempt migration.
   - Conditional defectors can join collective migration groups, temporarily cooperating to split costs.

c. **Movement / Dispersal**

- Agents migrate to random new patches.
- Group migration reduces individual energy costs for participants.

d. **Survival and reproduction**

- Agents survive, reproduce, or die depending on their remaining energy.

e. **Data collection**

- Track population size per strategy, average energy, successful migrations, and prevented circular moves.

Insights and Expected Outcomes

- **Conditional defectors** may outperform both pure cooperators and pure defectors, since they can exploit temporary cooperation to spread efficiently.
- **Circular move prevention** increases realism by eliminating redundant motion, producing smoother migration waves.
- **Migration success rates by strategy** provide a clear comparison of which strategies are best suited for long-term dispersal and survival.
- **Key finding:** The model highlights how agents that would usually overexploit common resources can still form temporary alliances to share the costs of migration, thereby overcoming spatial structure mechanisms and group (multilevel) selection that

would otherwise enhance cooperation, thereby threatening the evolutionary stability of cooperating strategies.