Description of Eden Cluster Simulation

Husain Hubail

1. Introduction

The Eden model is a classical stochastic process used to simulate cluster growth on a lattice, originally proposed by Murray Eden in 1961. Unlike Diffusion-Limited Aggregation (DLA), where particles perform a random walk before sticking, the Eden model grows clusters by randomly adding new sites adjacent to the existing cluster. This results in compact, approximately circular clusters with rough, non-fractal boundaries. Eden growth is commonly used to model biological colony expansion, tumor growth, and other surface-limited aggregation processes.

Eden clusters are not just computational simulations—they appear in several real-world systems where growth occurs primarily at the boundary of a cluster. Examples include:

1. **Bacterial Colony Growth:** Certain bacteria, such as *Escherichia coli* or *Bacillus subtilis*, grow outward on a Petri dish. Growth occurs at the colony edge, creating roughly circular, compact colonies with rough boundaries.

2. **Tumor Growth:** Tumor cells often proliferate at the periphery of a mass while interior cells remain largely inactive. The resulting shape is compact with irregular boundaries, similar to an Eden cluster.

3. **Crystal Growth (Surface-Limited Deposition):** Thin-film crystals or ice crystals can grow by adding material at the surface. The edges are rough while the interior remains compact, resembling Eden cluster morphology.

4. **Fungal or Vegetation Colonies:** Fungi, mosses, or slime molds (e.g., *Physarum polycephalum*) spread outward from an initial seed, growing primarily at the colony edge and producing rough circular patterns.

System	**Eden-like Feature**
Bacterial colonies	Surface-limited cell division → compact, rough circular clusters
Tumors	Edge proliferation dominates → irregular yet compact growth
Crystals	Surface deposition → uneven edges, compact core
Fungi/Plants	Peripheral growth → rough circular patterns

The simulation presented here implements a two-dimensional Eden cluster using a square lattice and random site selection.

2. Algorithm Overview

The Eden cluster growth algorithm proceeds as follows:

1. **Initialization:**
    - A two-dimensional lattice is defined with coordinates ranging from $(-1000, 1000)$ along both x and y axes.
    - The origin $(0, 0)$ is initialized as the first occupied site of the cluster.
    - The four nearest neighbors of the origin are identified as potential growth sites (the 'rto' list) and removed from the available grid of empty sites.
2. **Cluster Growth Loop:**
    - For each iteration (e.g., 100 iterations in this implementation), a new site is randomly chosen from the list of potential growth sites ('rto').
    - The chosen site is added to the cluster and written to an output file ('eden.txt') for later visualization.
    - After a site is added, its unoccupied nearest neighbors are appended to the list of potential growth sites, and these sites are removed from the available grid.
    - The growth continues until the desired number of particles (cluster size) is reached.
3. **Output:**
    - The coordinates of each newly occupied site are written to a file for visualization or further analysis.

3. Data Structures

The simulation uses the following data structures:

- **grid**: a list of all unoccupied lattice sites.
- **oc**: a list of occupied sites (starts with the origin).
- **rto**: a list of nearest-neighbor sites adjacent to the cluster that are candidates for growth.

These structures ensure that the algorithm only adds valid, unoccupied sites to the cluster and maintains efficient random selection of growth sites.

4. Simulation Characteristics

The Eden model produces clusters that are:

- Compact and approximately circular in shape.
- Non-fractal but with rough boundaries due to stochastic growth.
- Growth-limited to nearest-neighbor sites of the existing cluster.

The randomness in site selection simulates surface-limited growth processes such as bacterial colony expansion, crystal surface deposition, or tumor growth, where each new element attaches directly to the perimeter of the existing structure.

5. Summary of the Simulation Process

1. Initialize an empty lattice and occupy the origin.
2. Identify nearest-neighbor sites as potential growth candidates.
3. Randomly select a candidate site, add it to the cluster, and update the candidate list with its unoccupied neighbors.
4. Repeat until the desired cluster size is achieved.
5. Save all occupied site coordinates to a data file for visualization.

6. Possible Extensions

- Increase the lattice size or number of particles for larger clusters.
- Implement periodic or reflecting boundary conditions to study finite-size effects.
- Analyze the cluster roughness or growth rate using statistical measures.
- Extend to three dimensions for volumetric growth modeling.