Diffusion-Limited Aggregation (DLA) Simulation in Fortran90

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1. Introduction

Diffusion-Limited Aggregation (DLA) is a stochastic growth model that describes how particles undergoing Brownian motion cluster together to form complex fractal structures. The model was originally introduced by Witten and Sander in 1981 and has since been used to explain numerous physical phenomena, including dielectric breakdown, electrodeposition, and mineral crystallization.

The process begins with a single seed particle at the origin. Randomly moving particles (random walkers) are released from a circular boundary and move randomly until they contact the growing cluster, where they permanently attach. Over many iterations, this results in the formation of a highly branched, self-similar fractal.

2. Algorithm Overview

The DLA simulation follows these main stages:

1. **Initialization:**
   - Define a square lattice from $-n$ to n in both x and y directions.
   - Initialize all grid sites with zeros, representing unoccupied points.
   - Set the origin $(0, 0)$ as the seed of the cluster (occupied site).
   - Mark the four nearest neighbors as potential aggregation sites.
2. **Particle Release:** Each particle starts at a random position on a circular boundary with radius $r_{\max}$. The random launch angle θ is chosen uniformly from 0 to 2π:

$$\theta = 2\pi \times \text{rand}()$$

The initial position of the walker is:

$$(x_{\text{walk}}, y_{\text{walk}}) = (\text{nint}(r_{\text{max}} \cos\theta), \text{nint}(r_{\text{max}} \sin\theta))$$

3. **Random Walk:** Each particle performs a discrete random walk on the lattice. Random direction steps are generated as:

$$dx = \text{sign}(1, 2\text{rand}() - 1), \quad dy = \text{sign}(1, 2\text{rand}() - 1)$$

   If a random variable $a \geq 0$, the step occurs along the y-axis; otherwise, it occurs along the x-axis. Boundary checks ensure the particle remains within the simulation grid. If it exits the boundary, it is reinitialized.

4. **Aggregation:** When a particle visits a site adjacent to an occupied one, it attaches and becomes part of the cluster. The site is marked as occupied, and its four neighboring sites are marked as available for future attachment.

5. **Cluster Growth Update:** The cluster radius r is updated after each aggregation event:

$$r_{\text{temp}} = \sqrt{x_{\text{walk}}^2 + y_{\text{walk}}^2}$$

   If $r_{\text{temp}} > r$, then:

$$r = r_{\text{temp}}, \quad r_{\text{max}} = r + 5$$

6. **Data Output:** The coordinates of each new particle are saved to a file (`DLA.txt`) for later visualization or analysis.

3. Simulation Characteristics

The resulting pattern exhibits the fractal nature typical of DLA growth, with a characteristic fractal dimension $D \approx 1.65$ in two dimensions. The model reproduces the dendritic and self-similar structures seen in natural diffusion-controlled processes.

Adjustable parameters include:

- `n` — grid half-size (defines the simulation space)
- `np` — number of released particles
- `rmax` — initial launching radius for walkers

4. Compilation and Execution Steps

To compile and run the Fortran90 program on your computer, follow these steps:

1. Save your program as `dla.f90`.
2. Open a terminal (or command prompt) in the same directory as the file.
3. Compile the program using the GNU Fortran compiler:

   ```
   gfortran dla.f90
   ```

4. Run the compiled program:

   ```
   a.exe
   ```

5. The program will produce an output file named `DLA.txt` containing the (x, y) coordinates of aggregated particles.
6. You can visualize the results using Python, MATLAB, or any plotting software. For example, in Python:

   ```
   import numpy as np
   import matplotlib.pyplot as plt

   data = np.loadtxt('DLA.txt')
   x, y = data[:,0], data[:,1]
   plt.scatter(x, y, s=1)
   plt.axis('equal')
   plt.show()
   ```

5. Conclusion

The Fortran90 DLA simulation successfully models diffusion-controlled growth processes that exhibit fractal properties. The simulation produces realistic branching structures using simple random walk and aggregation rules. By adjusting the grid size and number of particles, one can explore how stochastic diffusion processes lead to emergent complexity and fractal geometries observed in nature.