Cellular Automaton Simulation for Biological Computation (Maman 11)

Overview

This project is a **cellular automaton simulation** developed as an academic task for the **Biological Computation Course**. It models complex environmental interactions using a particle-based system where each cell interacts with its neighbors based on configurable properties. The project explores emergent behavior and environmental dynamics using cellular automata principles.

Features

- **Educational Focus**: Designed to demonstrate the capabilities of cellular automata for academic study and research.
- **Complete Configuration Control**: Configure properties for every aspect of the simulation, including pollution dynamics, temperature changes, water transfer, and more.
- **Robust Core Logic**: The heart of the simulation lies in the `core` folder, which meticulously implements the cellular automaton behavior.
- **Graphical User Interface**:
  - Real-time visualization of simulation results
- **Logging**:
  - Info-level messages printed to the console
  - Detailed debug logs saved to `simulation.log`

Project Structure

```
.
├── main.py                    # Main entry point for the simulation
├── cli_output.log             # Cli output exapmle
├── config/                    # Configuration management files
│   ├── config_state_handler.py
│   └── conf_presets.py
├── core/                      # Core simulation logic (critical for behavior)
│   ├── Particle.py
│   ├── Simulation.py
│   ├── World.py
│   └── __init__.py
├── display/                   # Visualization modules
│   ├── MatplotlibDisplay.py
│   └── __init__.py
├── screenshots/               # Screenshot of the graphical interface
│   └── _GUI.png
└── utils/                     # Utility functions
    └── helpers.py
```

Configuration Properties

The configuration properties are the foundation of this simulation. Each property can be modified to customize the behavior and environment.

General Simulation Parameters

- `days`: Default Simulation Duration (Days).
- `grid_size`: Default Grid Size `(X, Y, Z)`.
- `initial_ratios`: Proportions of cell types (e.g., `forest`, `city`, etc.).

Baseline Environmental Properties

- `baseline_temperature`: Baseline Temperature (°C).
- `baseline_pollution_level`: Baseline Pollution Levels.

Pollution Transfer Weights

- `cell_type_pollution_transfer_weights`: Pollution Transfer Weights by Cell Type.

Temperature Transfer Weights

- `cell_type_temperature_transfer_weights`: Temperature Transfer Weights by Cell Type.

Water Transfer Weights

- `cell_type_water_transfer_weights`: Water Transfer Weights by Cell Type.

Forest Properties

- `forest_pollution_absorption_rate`: Rate at which forests absorb pollution.
- `forest_cooling_effect`: Cooling effect of forests on the environment.
- `forest_pollution_extinction_point`: Pollution level beyond which forests die.
- `forest_temperature_extinction_point`: Temperature beyond which forests die.

City Properties

- `city_pollution_generation_rate`: Rate of pollution generation by cities.
- `city_warming_effect`: Warming effect caused by cities.
- `city_temperature_extinction_point`: Maximum temperature for city survival.
- `city_pollution_extinction_point`: Pollution level beyond which cities collapse.

Physical Properties

- `freezing_point`: Temperature (°C) at which water freezes.
- `melting_point`: Temperature (°C) at which ice melts.
- `evaporation_point`: Temperature (°C) at which water evaporates.

Water Transfer Dynamics

- `water_transfer_threshold`: Minimum water mass difference for transfer.
- `water_transfer_rate`: Rate of water transfer between cells.
- `ocean_conversion_threshold`: Water mass required to convert a cell to ocean.

Pollution Dynamics

- `pollution_damage_threshold`: Pollution level causing damage to ecosystems.
- `pollution_level_tipping_point`: Pollution level beyond which damage accelerates.
- `natural_pollution_decay_rate`: Rate at which pollution naturally decays.

Temperature Dynamics

- `natural_temperature_decay_rate`: Rate at which temperature equalizes to baseline.

Cloud Properties

- `cloud_saturation_threshold`: Minimum water mass for clouds to precipitate.

Environmental Change Rates

- `melting_rate`: Rate at which ice melts.
- `evaporation_rate`: Rate at which water evaporates.

Conversion Weights

- `cell_type_collision_weights`: Weights governing cell-type collisions.

Base Colors

- `base_colors`: RGBA colors for each cell type.

4. Visualizations

- **Graphs**:
  - Pollution trends over time.
  - Average temperature and water mass.
  - Cell type population counts and standard deviations.
- **3D Visualization**:
  - Displays the grid and cell types with their interactions and transformations.

5. Logs and Results

- Results and metrics are logged in `simulation.log` for further analysis and also are printed in the CLI.
- Metrics include averages, standard deviations, and configuration details.

Code and Logic

Core Components

- **`Particle.py`**: Defines the behavior of individual cells, including pollution absorption, water transfer, and type-specific interactions.
- **`Simulation.py`**: Manages the simulation lifecycle, precomputing states for multiple days and tracking metrics.
- **`World.py`**: Represents the grid and initializes particles using elevation maps.

Visualization

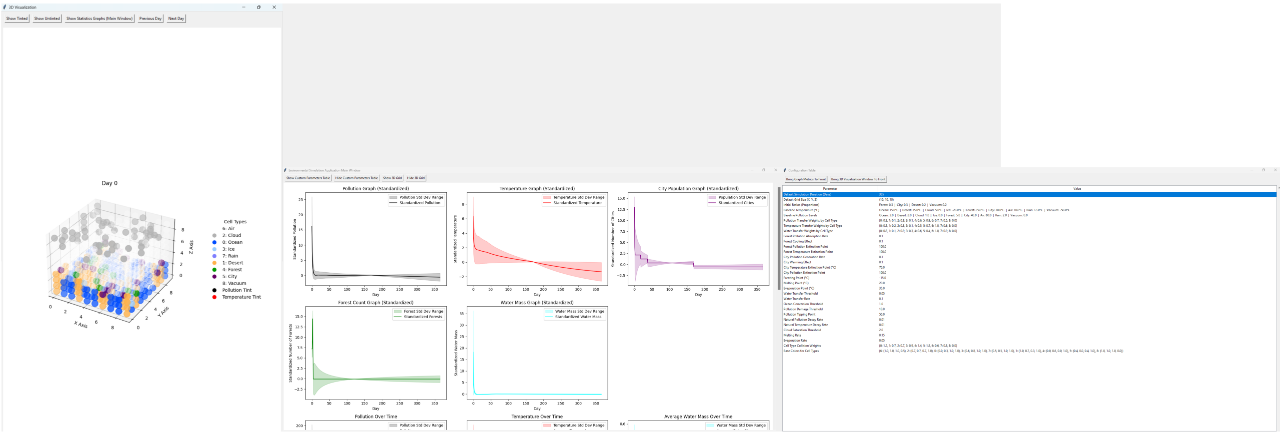
- `MatplotlibDisplay.py`: Generates graphs and 3D visualizations.
- **Real-Time GUI**: Displays metrics and allows interaction during the simulation.

Example Workflow

1. Run the program:

```
python main.py
```

2. Choose a configuration preset or define your custom setup.
3. Observe the simulation progress through the GUI.
4. CLI output example can be found in the `cli_output` file.
5. GUI Screenshot



Requirements

Python Version

- Python 3.11.x

Python Libraries

The program depends on the following Python libraries:

- `numpy==1.24.4`
- `noise==1.2.2`
- `matplotlib==3.9.3`

Installation

Step 1: Clone or Download the Repository

Download the project files to your local machine.

1. Clone this repository or download the ZIP file:

```
git clone https://github.com/v1t3ls0n/Cellular-Automaton
cd Cellular-Automaton
```

Step 2: Install Dependencies

1. Open a terminal (Linux/Bash or Command Prompt on Windows).
2. Navigate to the project directory:

```
cd path/to/project
```

3. Install the required libraries using `pip`:

```
pip install -r requirements.txt
```

Usage Instructions

Running the Program

Running on Windows

1. Navigate to the project directory:

```
cd path\to\project
```

2. Run the program:

```
python main.py
```

Running on Linux/Bash

1. Navigate to the project directory:

```
cd path/to/project
```

2. Run the program:

```
python3 main.py
```

2. Choose Configuration

When prompted, select one of the following options:

1. **Default Configuration Preset**: Uses pre-defined default parameters.
2. **Choose Preset**: Select from a list of predefined presets (e.g., low pollution, high pollution).
3. **Custom Parameters**: Define every property manually.

3. Simulation Execution

- After selecting a configuration, the program validates it and begins the simulation.
- Progress is displayed in real time through a graphical interface.

Compiling to an Executable

Compiling for Windows on Windows

1. Ensure PyInstaller is installed:

   ```
   pip install pyinstaller
   ```

2. Run the following command to bundle the project into a standalone `.exe` file:

   ```
   C:\Users\Studio\AppData\Local\Programs\Python\Python311\Scripts\pyinstaller
   --onefile ^
       --add-data "config/*.py;config" ^
       --add-data "core/*.py;core" ^
       --add-data "display/*.py;display" ^
       --add-data "utils/*.py;utils" ^
       main.py
   ```

3. The executable will be located in the `dist/` folder:

   ```
   dist\main.exe
   ```

Compiling for Windows on Linux/Bash

1. Install **PyInstaller** and the necessary cross-compilation tools:

   ```
   pip install pyinstaller
   sudo apt-get install mingw-w64
   ```

2. Use the `--win` option with `PyInstaller` to specify a Windows target:

```
pyinstaller --onefile \
    --add-data "config/*.py:config" \
    --add-data "core/*.py:core" \
    --add-data "display/*.py:display" \
    --add-data "utils/*.py:utils" \
    --name main.exe \
    main.py
```

3. The compiled `.exe` file will be located in the `dist/` folder:

```
dist/main.exe
```

Troubleshooting

Common Issues

1. **Missing Dependencies**: Ensure all required libraries are installed:

```
pip install -r requirements.txt
```

2. **Executable Closes Immediately**: Run the executable from a terminal or Command Prompt to view error messages:

```
./dist/main.exe
```

3. **FileNotFoundError**: Ensure all `--add-data` paths are correctly specified during compilation.

Logging

- **Console Output**: Info-level messages are printed to the console.
- **File Logging**: Detailed logs are saved to `simulation.log`.

Academic Integrity

This project is an independent academic submission for the **Biological Computation Course**. The implementation, configuration, and logic have been designed solely by **Guy Vitelson**.