Pollution Modeling and Simulation with Multi-Agent and Pretopology

Murat Ahat[1], Sofiane Ben Amor[1], Marc Bui[1], Michel Lamure[2], and Marie-Françoise Courel[1]

[1] Ecole Pratique Des Hates Etudes, 46 rue de Lille, 75007 Paris, France
Murat.Ahat@etu.ephe.sorbonne.fr, {s.benamor,m.bui}@ephe.sorbonne.fr, marie-francoise.courel@cnrs-dir.fr
[2] Université Lyon 1, 43 bd du 11 novembre 1918, 69622 Villeurbanne cedex, France
lamure@mac.com

Abstract. Pollution in metropolitan cities has become a serious problem, resulting in poor living conditions and serious health problems. Pollution being qualified as a complex system, we propose a multi-agent approach to model and simulate it, so that we could study, analyze and predict it better. As in the early stage of the project, we have some successful experiments and attempts to integrate the mathematical theory of Pretopology in the modeling and simulation levels. In addition, these interesting results shades some light on our future direction.

Keywords: Complex System, Pollution, Pretopology, Multi-Agent Simulation, Repast Simphony.

1 Introduction

Pollution, as a by product of development and industrialization, is posing threat to the health of millions of people, environment and ecology. The situation is even worse in the developing metropolitan cities. The case of Ouagadougou [8], a young African city, is the topic of Project Mousson [7]. In this project, scientists and experts from different disciplines (geographers, meteorologists, sociologists, anthropologists, mathematicians and computer scientists) gather to study and analyze the air pollution in Ouagadougou, which is a complex system, in order to build a pollution alarm and alert system.

One of the problem in complex system modeling and simulation is that it is difficult to model and express the qualitative variables and factors. The advantage of multi-agent modeling and simulation is being able to integrate these qualitative information much more easily [9]. Our collaboration with the experts from different domains may yield a better understanding and modeling of the system, in turn results a system that can express the pollution in different levels, and from different angles.

Being in the early stage of modeling, we have conducted some interesting experiments. We have successfully integrated the pretopology method into a classical heat bugs model to simulate the basic pollution diffusion process. Though

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the model is simple, it has shown some interesting results. Thus, in the following sections we will discuss the pollution diffusion model based on the classical heat bugs model, pretopology and pretopology integrated diffusion model.

2 Pollution Diffusion Model and Pretopology

The diffusion process of this simple model is realized according to the heat diffusion in heat bugs model. However, we integrate the pretopological method into this diffusion process to have more insights into the diffusion process. The agents in the model are very primitive, as they just produce pollution into its environment with its pollution strength. Gradual discussion in the following subsections shows how pretopology is used in the model and why.

2.1 Diffusion Process in Heat Bugs Model

Heat bugs model [4] is a famous classical multi-agent model that exists as a example model in various multi-agent simulation toolkits: repast [3], swarm [5], netlogo [6], to name a few. We take its diffusion process and combine it with polluter agents instead of heat bugs. And below is a brief description of how the combination works.

We discretize the space into a two dimensional grid (torus) $G(X, Y)$, as X stands for width, and Y for height. Also, we discretize the time into small time steps t_i, while i is from 0 to n. A location in the grid is denoted by its coordinate $c(x, y)$, at the same time it represents the pollution level at this location. A polluter agent is denoted by pa, whilst its pollution strength is denoted by s. Agent location in the grid is determined from the beginning of the simulation and does not change afterwards. The simulation takes place in the following steps:

1. Simulation preparation: let all $c(i, j)$ in the $G(X, Y)$ be 0; Populate the grid with n polluter agents with pollution strengths s, and randomly scatter them over it.
2. Let every polluter agent pollutes its location.
3. Diffuse the pollution over the grid.
4. Go to step 2.

Now we will introduce the corresponding pseudo code to the step 3.

```
Procedure Diffuse ()
   Constant
     ERate = 0.99; DRate = 1.0;
   Var
     G2(X,Y) as temporary grid;
     c2(x,y) as cells of G2(X,Y);
   Begin
     For (i:=1 to X)
```

```
      For (j:=1 to Y)
        avg := mooreNeighbourAverage();
        c2(i,j) := ERate*(c(i,j)+DRate*(avg-c(i,j)));
      End For; //j
    End For; //i
    copy(G2(X,Y) to G(X,Y));
  End Procedure //Diffuse()
```

In the above code, there are two important constants: evaporation and diffusion rate. Evaporation rate defines how much of the pollution evaporates, while diffusion rate determines the pollution spread speed. They both are in [0..1].

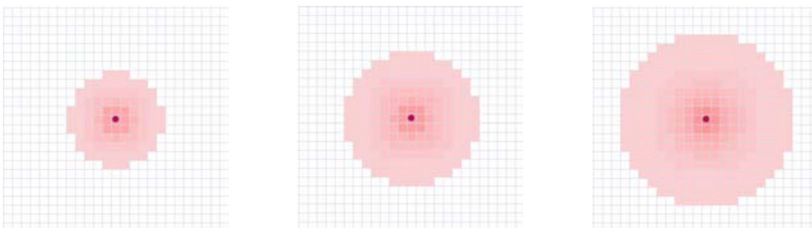

Fig. 1. Pollution diffusion process at different time steps: from left to right at 40, 100 and 250. G(25,25), EvaporationRate = 0.99, Diffusion Rate = 1.0. A polluter agent (red dot) is placed at the center of the grid.

Figure 1 shows diffusion results at different time steps in the simulation. Red color is used to indicate the pollution in the grid. The deeper the color is, the stronger the pollution is. This means around the polluter agent the pollution is stronger. Pollution spreads as time passes.

Besides this fact, experiments with different evaporation and diffusion rates show that by this means different diffusion processes can be achieved.

2.2 The Basic Pretopological Concepts

Developments in hardware technologies facilitate the application of pretopology theory in real-world scenarios. Recently a pretopology library based on java is developed to provide ready to use pretopological data types and algorithms [10]. And there are also attempts and suggestions for using pretopology in the complex system modeling [11] [12] [13]. Our motivation is using pretopological concept of *pseudoclosure* to simulate the pollution diffusion, and meanwhile to observer the evolution of this diffusion process. Here is a brief mathematical introduction to pretopology.

Let E be a non-empty set and let $\mathcal{P}(E)$ designate all of the subsets of E.

Definition 1. *A pseudoclosure $a(.)$ is a mapping from $\mathcal{P}(E)$ to $\mathcal{P}(E)$, which satisfies following two conditions:*

– $a(\emptyset) = \emptyset$ *(P1)*
– $A \subseteq a(A)$ *(P2)*

A pretopological space is a pair (E, a), where E is endowed with a pseudoclosure $a(.)$.

Subset $a(A)$ is called the *pseudoclosure* of A. As $a(a(A))$ is not necessarily equal to $a(A)$, a sequential appliance of pseudoclosure on A can be used to model expansions: $A \subseteq a(A) \subseteq a(a(A))...$, for example,as in pollution diffusion. Figure 2 illustrates the pseudoclosure and its expansion process.

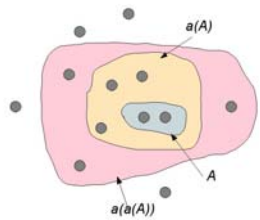

Fig. 2. A and sequential pseudoclosure appliance on A

In our model we will use a type V_D pretopology space, as defined below.

Definition 2. *A V_D pretopology space is a pretopology space that satisfies: $\forall A$, B, $A \subseteq E, B \subseteq E$ $a(A \cup B) = a(A) \cup a(B)$* *(P3)*

The notion of closure is also important in the pretopological space.

Definition 3. *$A \in P(E)$ is a closure only and only if : $A = a(A)$* *(P4)*

2.3 Integration of Pretopology into the Model

From the above discussions, one can easily relate the *pseudoclosure* with expansion of the pollution. Before discussing the *pseudoclosure* integration , we need to introduce the definition of pollution cluster. A pollution cluster is a connected subset of the grid $G(X, Y)$, whose pollution level is above a *threshold*, in our case threshold is 0. This means in the beginning of the simulation, there will be more pollution clusters. With the diffusion process, pollution clusters merge and result bigger ones. Given enough polluters, after certain steps in the simulation, only one pollution cluster will be left in the grid. Now we discuss how we use *pseudoclosure* to simulate the pollution diffusion. Here are the steps:

1. Simulation preparation, let every $c(i, j)$ in the $G(X, Y)$ be 0; Populate the grid with n polluter agents with pollution strength s, and randomly scatter them over it. Create one pollution cluster for every location that has a polluter agent.
2. Let every polluter agent pollutes its location.

3. Calculate the pseudoclosure of every pollution cluster.
4. Merge clusters if they are mergable.
5. Go to step 2.

The pseudo code of step 3 and 4 are as shown below:

```
Procedure PseudoClosure ()  //Step 3
  Var
    PollutionClusterSet: Set;
    G2(X,Y) as temporary grid;
    c2(x,y) as cells of G2(X,Y);
  Begin
    For (every pollutionCluster in PollutionClusterSet)
        For (every c(i,j) in pollutionCluster) //diffuse
            average:=mooreNeighbourAverage();
            c2(i,j):=ERate*(c(i,j)+DRate*(average-c(i,j)));
        End For;
        For (every c(i,j) neighbour of pollutionCluster)
            avg:=mooreNeighbourAverage();
            c2(i,j):=ERate*(c(i,j)+DRate*(avg-c(i,j)));
            If (c2(i,j)>0) Then
              Add c2(i,j) to pollutionCluster;
        End For;
    End For;
    copy(G2(X,Y) to G(X,Y));
  End Procedure //PseudoClosure()

Procedure MergePollutionClusters ()  //Step 4
   Var
     PollutionClusterSet: Set;
   Begin
     LABEL: DEBUT;
     If (sizeof(PollutionClusterSet) > 1)
       For (every pc1 in PollutionClusterSet)
         For (every  pc2 in PollutionClusterSet)
             If ((pc1<>pc2)and(pc1,pc2 has common area)) Then
                 pc1 = merge(pc1,pc2);
                 remove(pc2, PollutionClusterSet);
                 goto DEBUT;
             End If;
         End For;
   End Procedure //MergePollutionClusters()
```

This pretopology integration gives us the advantage of tracking the evolution of pollution clusters.

3 Simulation Results

In the simulation, evaporation rate is fixed to 0.99, and diffusion rate is to 1.0. Our pollution environment is a 200x200 torus grid. We have populated the grid with 40 to 220 polluter agents in ten runs, adding 20 agents in each subsequent run. The pollution strength of the agent is fixed to 10.

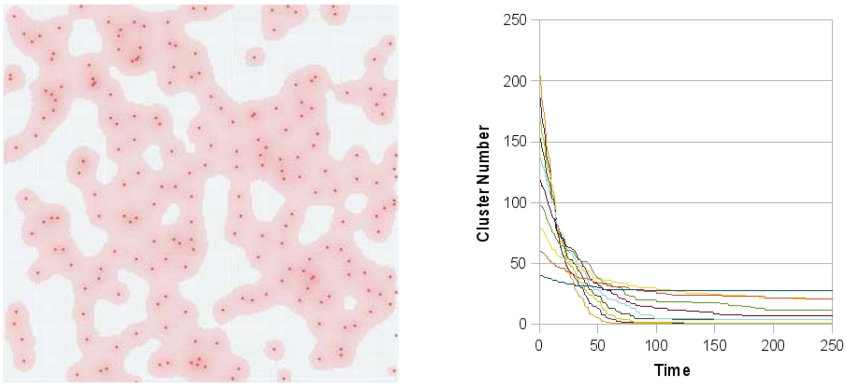

Fig. 3. Left: visualization of pollution diffusion, showing merging of pollution clusters. Right: Pollution cluster number plot in ten run.

Figure 3, illustrates our simulation results. On the left, the pollution clusters are merging to form a single big cluster. So, our question is what kind of conditions trigger the big cluster emergence? The chart on the right answers the question: big cluster emerges when there are more than 180 polluter agents with pollution strength 10, or when the polluter agent density is higher than 0.45%. When pollution strength is set to 5 and 20, the emergence has occurred with 0.9% and 0.25% of polluter agent density. This strongly indicates the emergence occurs when the overall pollution amount given off at every time step reaches a point, in the case this example, roughly around 1800 per time step.

We are now able to observer the diffusion process in the terms of pollution clusters, thanks to pretopology integration. That is why we obtained results that show there is a link between emergence of a single cluster and overall pollution amount. Though at this level, we are not able to validate simulation results, we hope that in the future to validate the results using the data available from the Project Mousson.

The model is developed with Repast Simphony [3], which considerably decreased the development time, eased the visualization [1] and analysis steps [2].

4 Conclusion

Though a simple one, the model paves the road for the more complex and complete pollution simulation system. This also shows a successful pretopology integration into simulation, and its usefulness in the complex system modeling and analysis.

Our work does not stop here. Our goal in the near future is to keep collaborates with other experts from different domains, and complete the model in a gradual manner: integration of GIS, real world agents, complex environment, etc. In the long run, through collaboration and gradual development, we aim a simulation system that is usable in the real world scenarios.

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