

Towards Representing Disasters in Computational Social Simulations

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Abstract. The modeling of disasters will be a very important topic for computational social science. An approach to modeling disasters is presented using a point source and exponential decay of the intensity of the disaster with space and time from the disaster's origin. The representation is demonstrated using the modification of a well-known NetLogo model as well as its application to modeling a flooding disaster in East Africa.

Keywords: Disaster Representation, Disaster Modeling, Agent-Based Modeling (ABM).

1 Introduction

In a speech in 2010, Elizabeth Ferris, of the Brookings Institute and the Co-Director, Brookings-Bern Project on Internal Displacement stated flatly: “The frequency and severity of sudden-onset natural disasters is increasing. Presently there are about 400 natural disasters per year, affecting 200 million people. This is double the number reported 20 years ago.”[1] This indicates that the modeling of sudden disasters is an important topic for computational social science.

The topic is part of a large multi-year project studying disasters and humanitarian relief in East Africa. Our team has developed a large agent-based model of households and their subsistence behaviors on a daily basis in a 1,000 by 1,000 mile area around Lake Victoria (see Figure 1). Most of our efforts have been focused on the modeling of the environment and the subsistence activities of the approximately 120 million people in the region (see [2][3][4][5]). This paper discusses a recent effort to address disasters that arise not from challenges to subsistence activities, relatively slowly developing situations, but from faster events such as floods or armed conflict. We discuss the modeling methods and demonstrate disaster modeling using a modified NetLogo model. We also discuss the application of disaster modeling to the RiftLand model.

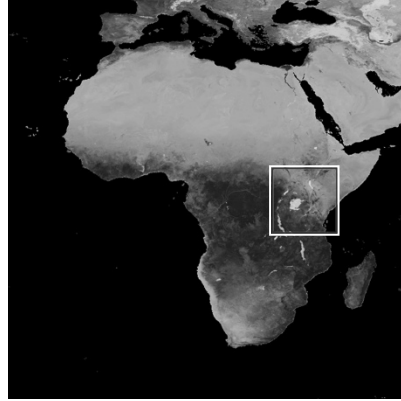


Fig. 1. The RiftLand model area within Africa. Sources: NASA image, box by the authors.

2 Disaster Representation

Recognizing that “all models are wrong, but some are useful” (quote attributed to George Box [6]), we developed a representation and model intended to be useful while recognizing that it would be an abstraction of actual mechanisms, missing details, and therefore “wrong”. We wanted our model to represent the strength of the disaster calculable for any specific location and time and we wanted the representation to be human-readable. Three main factors of a disaster are represented: the location of the disaster in time and space, the initial intensity of the disaster, and how the intensity of the disaster changes over space and time. Our approach reduces the intensity exponentially with time and distance from a disaster origin.

2.1 *Intensity of the disaster*

The definition of a disaster is the result of a hazard, either natural or man-made, that is a “serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources”. A hazard is a “[n]atural processes or phenomena or human activities that can cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.” These definitions come from the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) [7].

We are not modeling the cause of the disaster, but its effect. We do that by using a real number as the intensity of a disaster at a point in space and time. The value can be used to represent the percentage of agents at a location that are affected in some fixed way or the value could be as input to a calculation of the affects on agents. A calculated disaster intensity of 1.00 for an area at some time could mean everyone in that area would be impacted by the disaster in a particular way. Alternatively, it could also be used to determine how agents are affected, such as above 0.8 agents die, between 0.4 and 0.8 agents move away quickly, and below 0.4 agents move away slowly.

We do not limit the intensity value to be less than or equal to one. That way the calculated value can be greater than one over a large area, which may be necessary for some purposes. If the effects of the intensity vary with a lower threshold for the worst effect, values above that threshold can be useful over a large area. For example, if a typical tree could be blown over by any wind over 100 mph, then an impact representing winds greater than 100 mph have the same effect and all trees would be blown over in a region but then only some blown over outside that region. If the intensity were to be reduced with time and distance and we used the intensity compared to a threshold, then only those above the threshold would feel the effect. To spread the intensity, we need a disaster location concept.

2.2 Location of the Disaster

We represent a disaster as starting from a particular point in space and time, i.e., at a specific location at a specific time. We recognize that disasters, such as flooding, may not originate at a point in space and time, such as a specific dam's catastrophic failure, but using a specific point of origin will make calculations of intensity of the disaster much simpler. The origin could be the center of the area initially reported for the disaster, such as a region flooded by heavy rains. We will use the origin of the disaster as a base for spreading the disaster's intensity outward to represent the area impacted by the disaster.

2.2 Size of the Disaster and its Change over Time

We represent a disaster as spreading in a circle around the disaster origin and can vary the size of an encompassing circle with time. With a lot more computational complexity, we could use the elevation of the land around the disaster center or, for more simplicity, a bounding square, but we decided a circle would be sufficient computationally efficient and although "wrong" a reasonable generic shape of a disaster.

We also considered multiple ways to change the size of the circle with time and decided to use an exponential decay of the radius of the disaster circle for its

single parameter representation. We designed this single parameter to be the distance from the center at which the intensity of the disaster is reduced by half. Using the fact that seven times this “half-distance” would mean the disaster intensity is less than a hundredth what it is at the center (mathematically a 128th that of the center), we can establish the size of the area for which we will calculate the impact of the disaster. A disaster half-distance of 10 km is initially calculated for all cells in a 140 by 140 km square around the center point (seven half-distances in both directions).

The mathematical representation of this approach is presented as Equation 1. Let $\lambda-d$ be the half-distance parameter. The independent variable d is the distance from the subject location from the disaster’s origin. Then the dependent intensity, I , is given by:

$$\begin{aligned} I &= (\text{intensity at origin}) * (1/2)^{(\lambda-d / d)} \\ &= (\text{intensity at origin}) * e^{(\log 0.5) * (\lambda-d / d)} \end{aligned} \quad (\text{Eq. 1})$$

The size of the disaster also changes over time. Again, we could have used one of several representations of how the size of a disaster changes over time. We chose to use an exponential decay for two main reasons. First, it is a single parameter effect and second it will combine easily with the distance effect. The single parameter we use is the time for the intensity of the disaster to decrease by half, i.e., a “half-time”, similar to the half-life of radioactive isotopes, which decay exponentially.

The mathematical representation of this approach is presented as Equation 2. Let $\lambda-t$ be the half time parameter. The independent variable t is the number time since the disaster’s origin. Then the dependent intensity, I , is given by:

$$\begin{aligned} I &= (\text{intensity at origin}) * (1/2)^{(\lambda-t / t)} \\ &= (\text{intensity at origin}) * e^{(\log 0.5) * (\lambda-t / t)} \end{aligned} \quad (\text{Eq. 2})$$

2.3 Combining Effects

For each cell within the distance of seven times the half-distance parameter, we calculate a local intensity factor considering both the distance from the center and the time since the start of the disaster.

The mathematical representation of the combined effects of distance and time from the disaster’s origin is presented as equation 3. Let $\lambda-d$ and $\lambda-t$ be the half-distance and half-time parameters and independent variables d and t be the distance and time the current location is from the disaster’s origin. Then the dependent intensity, I , is given by:

$$\begin{aligned}
I &= (\text{intensity at origin}) * e^{(\log 0.5) * (\lambda - d / d)} * e^{(\log 0.5) * (\lambda - t / t)} \\
&= (\text{intensity at origin}) * e^{(\log 0.5) * ((\lambda - d / d) + (\lambda - t / t))} \quad (\text{Eq. 3})
\end{aligned}$$

This completes the description of the mathematical model. We now turn to its demonstration using a NetLogo [7] model.

3 Demonstration using the NetLogo Flockers Model

This section discusses a demonstration of the use of the disaster modeling in the NetLogo [7] Flockers model. We will provide the code to add to the standard model to implement a disaster affecting the agents in the model. In the Flockers model, the color of the agents is not used in the basic model. We will use it to indicate those agents impacted by the disaster.

3.1 Code added to the Flockers Model

The Flockers code additions are as follows. First, we add the following global variables to specify a disaster:

```

globals [
  start                ;; when disaster starts
  intensity0           ;; initial intensity
  originx              ;; disaster origin (x,y)
  originy
  dist-half            ;; distance to halve intensity
  time-half            ;; ticks to halve intensity
]

```

Second, in the setup procedure, we initialize the disaster:

```

;; initialize disaster
set start 13           ;; disaster starts on step 13
set intensity0 2.00    ;; initial intensity 2.00
set originx 10         ;; disaster origin is (10,20)
set originy 20
set dist-half 5        ;; distance to halve intensity is 5 patches
set time-half 2        ;; ticks to halve intensity is 7 clicks

```

Third, in the go procedure, we add a call to process-disaster immediately after asking the turtles to flock:

```

ask turtles [ process-disaster ]

```

Finally, the core of the code is the disaster-processing procedure that implements Eq. 3:

```

to process-disaster
  ;; test if need to make disaster intensity calculation
  ;; for this this time and this turtle on its patch
  if ticks > start and ticks < start + 7 * time-half
    and (distancexy originx originy) < 7 * dist-half
  [
    ;; calculate and act on intensity for this patch at this step
    let decay exp( ln ( 0.5 )
                  * (( (distancexy originx originy) / dist-half)
                    + (ticks - start) / time-half ) )
    let intensity (intensity0 * decay)
    ;; act on intensity
    if intensity > 0.1
      [ set color green ]
    if intensity > 0.5
      [ set color blue ]
    if intensity > 0.8
      [ set color red ]
  ]
end

```

These changes to the Flockers model can demonstrate the disaster model.

3.2 *Demonstration of Disaster Model*

The disaster represented in the code above occurs at location (10, 20) at time 13 with an initial intensity of 2.0. The distance to halve the intensity is 5.0 units and the time after the disaster start to halve the intensity is 2 ticks. The code uses the calculated intensity to color the agents. Those agents near the origin are colored red. Those somewhat away from the center are colored blue. And those affected slightly are colored green.

Run the model with the number of agents maximized to have the most agents affected by the disaster. When run, at tick 13, some agents may be in range of the disaster and be colored red, blue, or green. At tick 14, the color effects will be recalculated and the red agents may have moved far enough away from the center of the disaster to be re-colored blue and some of the blue agents will become green. There is no code to change those agents back to their original color. So, by the end of the disaster's impact, the originally affected agents will be green and remain so as they disperse throughout the population.

Figure 2 shows a run at tick 15 showing 10 red agents and more blue and green in rings around the red agents with the rest of the 1,000 agents various shades of yellow. Allowed to continue, you can see the mixing of the impacted agents within the population. With the modeling concept introduced and demonstrated, we turn to their application in the large RiftLand model.

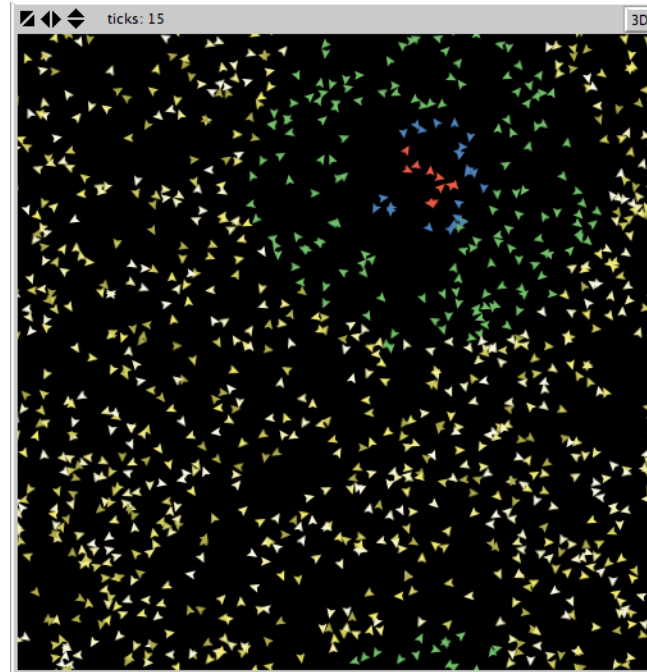


Fig. 2. NetLogo Flockers Demonstration Showing Impact of Disaster. Source: authors

4 Modeling a Flooding Disaster in RiftLand

The RiftLand model focuses on an area 1,000 miles by 1,000 miles in East Africa, home to approximately 120 million people. In the late summer, early fall of 2006, heavy rains resulted in the displacement of approximately 1.8 million people. The heavy rains started in August and continued into December and with flooding reaching the Indian Ocean in late November. Following the drought of the previous year, the ground could not absorb the water fast enough and flooding occurred throughout the area washing away towns and bridges. [9,10]

4.1 Displacing people

From newspaper reports, we identified a series of 10 disaster events through the region moving from the northwest to the southeast. The impact on the local people of each event was modeled using wide circles that persisted over weeks.

Figure 3 shows the 10 disaster events (in red) on a black and white background image of the population density. The flooding generally occurred in the least populated areas of Ethiopia, Kenya, and Somalia and over the months of the rains, displaced 1.8 million people.

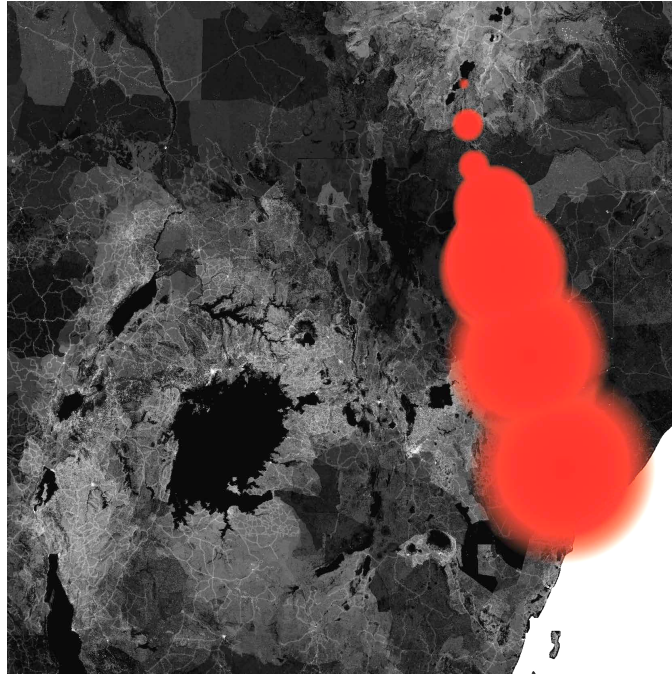


Fig. 3. Modeling the 2006 Flooding Disaster in East Africa. Sources: ORAU population data & the authors.

4.2 Migration of Displaced People

In addition to modeling the numbers of people displaced caused by disasters such as flooding, we also model their migration after they've been displaced. From there, they move through a network of cities. The model, which is described in full in [11], works as follows.

Initially, displaced people relocate to the nearest city and cities are connected in two different networks. The city-interaction network, used when choosing a destination for internally displaced persons (IDPs), has edges based on the strength of the interaction between each pair of cities. This is calculated as the product of the cities' sizes divided by the distance between them raised to some power. This type of spatial interaction model is sometimes referred to as a

“gravity” model because it takes the same form as the equation for the gravitational force between two objects. The outbound links with the highest interaction for each city are kept as edges in the network.

The second network used in the migration model is used for transportation and represents the roads that a group of displaced people would use when traveling between two cities. This transportation network is a scrubbed and simplified version of the region’s road network.

When the number of displaced people in a city exceeds that city’s capacity, the city expels some of them. Their destination is chosen stochastically from among the neighboring cities in the interaction network with the most spare capacity. Nearer cities are more likely to be chosen than farther ones. Once a destination is chosen, a path is planned through the transportation network and the IDPs are sent on their way. As the IDP group reaches a city along the path to its destination, they may choose a new final destination if one becomes available.

4.3 Modeling the Transportation Impacts of Disasters

In addition to disasters affecting people, they can affect the infrastructure, particularly the transportation networks along which displaced people travel. We used the same disaster impact model to determine the cutting of connections between cities. This was implemented by programming a sequence of line segments that cut transportation links. Figure 4 shows line segments in addition to the disaster displacement impacts on a map of the cities network. These line segments result in impacts on the migration of flooding victims. The impacts can be seen in the time series of the number of IDPs in each city over the duration of the disaster.

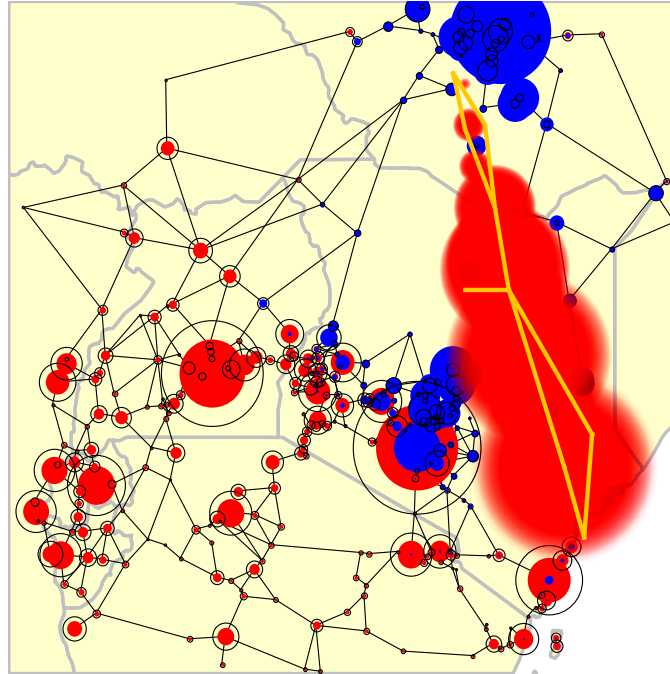


Fig. 4. Flooding Disaster with Transportation Impact. Source: authors.

5 Conclusions and Future Work

We have represented disasters simply and hopefully elegantly by using a point source for the initial intensity and exponentially decaying the intensity based on distance and time from the origin of the disaster event. Our approach supports several disaster events being used to represent the overall disaster. We have developed NetLogo code to demonstrate this representation and provide the code to do so using the Flockers model. In addition to displacing people, we have shown an application of this modeling method on the displacement and migration resulting from a flooding disaster represented in a large social simulation.

Our representation is, of course, a simplification, but we believe its conceptual simplicity and usability overcome its representational inaccuracies. Many other models are possible, such as a Weibull distribution function [12]. Using such a function would provide for the development of the intensity value from no intensity to a maximum before it starts to decay, but its computational and conceptual complication we currently feel, reduces its effectiveness in many

computational simulations. However, we may advance our representation to use such a representation.

We have implemented a multiple disaster capability in our migration model [5] and have replicated the worst flood disaster in the RiftLand area within the past 30 years. Such modeling is able to predict the time series of displaced people in each city over the duration of a disaster, but such actual data is not normally available.

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