Simulating the Outbreak of a Zombie-Virus

Alice Forehand Robert Pienta Eric Reed

Computer Science and Software Engineering Department

Rose-Hulman Institute of Technology

Terre Haute, IN 47803

Abstract

A model of the spread of a zombie virus among a human population using swarm intelligence. Agent behavior is modeled using social forces to achieve desired flocking behavior. Humans are able to retaliate against zombies.

## Introduction

The spread of infectious disease among a populace is at least as difficult to model as it is important to understand. Groups like the Center for Disease Control (CDC) actively study and attempt to better understand the spread of pathogens through the populace. The need for data, whether real or simulated, is tremendous.

As it is entirely unethical to stage a trial infectious disease, much of our disease data comes from collected data or models simulating different scenarios. Most infectious disease models make very particular assumptions about the agents of the populace and how they interact. Few models have been proposed that consider non-standard disease conditions. A robust modeling method is required to model the complexities of human contact within a particular environment to model more unusual types of diseases.

Little research has been done to analyze and model the effects of a zombifying-disease. That is, a disease in which infected individuals actively seek healthy individuals in the populace. Given the outward assumption that the disease is not airborne, but transferred through bodily contact, a model that accounts for human contact is necessary.

## Previous Work

While there are different theoretical models for the spread of a zombie-virus, we are considering a virus that is transmitted through bodily fluid via direct contact. Therefore, direct contact with the undead will likely result in some form of inoculation. We will likely use a timer to determine the time from bite to zombification, this could be determined based on the severity of the contact, including the possibility of delayed onset or instantaneous transformation. Research into the transfer of a zombie-like virus has been modeled with potentially disastrous implications for humans. However, with no ground truth, it's very difficult to determine the accuracy of the aforementioned model. By modeling zombie outbreak scenarios with an adapted swarm intelligence approach, a secondary analysis of the dangers can be studied.

## Modeling Human Behavior

Modeling the dynamics of a zombie-virus outbreak requires a significant amount of swarm intelligence. Initially both the human agents as well as the zombies will require a plethora of steering behavior including agent-flocking. Craig Reynolds work on agent steering, *Steering Behavior For Autonomous Characters*, is immediately applicable to modeling a zombie-outbreak (1). Reynolds work is mainly concerned with the development and implementation of steering behaviors via a simple point-mass representation. He shows that many complex activities, especially those of flocking can be easily reduced to much more basic steering behavior. This is needed to formulate the basics of our zombie-virus outbreak simulation.

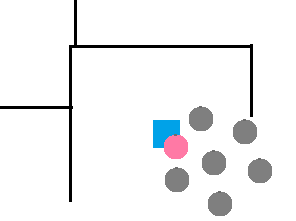
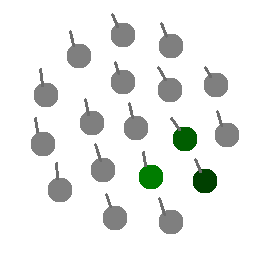
Each agent will need to be able to move and react to its environment. In the case of humans, they will need some form of evasive behavior to avoid zombies. At the same time, the human agents will need to be able to flock with other humans, forming survivor groups trying to escape the zombies. This means that we will need to utilize some form of flocking behavior. This could be achieved with Reynolds' approach to flocking through separation, cohesion, and alignment. A secondary approach to flocking will be addressed later in the proposal.

Humans will also need the basic ability to navigate through their environment. They will need some obstacle avoidance abilities so that they proceed similarly to real humans through their environment. Again, this seems to be covered in Reynolds work, although it seems like there may be a better way of doing some of the necessary calculations to avoid objects. Again we will address this potentially faster and more robust approach to obstacle avoidance and path planning later.

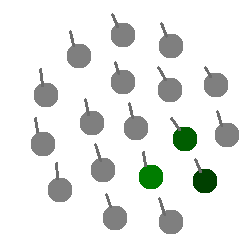
### Modeling Infected Human Behavior

The zombies will need to be able to detect and seek humans in order to sate their endless hunger for brains. Fundamentally speaking the zombies will require basic wandering faculties until they detect a human through their senses. We plan to model both auditory and visual detection in both types of agents.

Their ability to hear will likely be a set radius, where as their vision will be a predefined angle. Representing vision as a narrow cone in a simulated world has proven fairly effective (2). As previously mentioned, upon detecting a human the zombie will enter an excited state due to its immense hunger and attempt to seek out the human. We would like to model hordes of zombies, so when a zombie enters an excited state, it will alert neighboring zombies who will at the least come investigate the loud zombie, if not join in on the human hunt.

A key element in the danger of zombie outbreaks is the panic induced by the zombies. We will model panic behavior in the human agents, likely proportional to the number of zombies in visual our auditory range. Helbing et al. modeled and simulated the dynamical features of escape panic by analyzing human psychological patterns (3). This work could be essential in modeling the panic of the survivors. We will likely branch out from the work in (3) to be based upon the proximity and number of local threats, in our case zombies. This would form a more natural style of panic, in which the panic ebbs and flows according to the current threat of zombies.

### A Secondary Crowd-Dynamics Methodology

This leads us to a secondary potential means of flocking and agent movement. Helbing et al. used *social forces* to successfully model pedestrian dynamics (2). They used a sum of social forces to determine the acceleration of agents in a simulated environment. This approach has proven successful in modeling and simulating standard crowd dynamics. We could use a similar approach to avoid obstacles, flock to other humans, flock and move under panic, and even flee zombies. As determining the vector for acceleration is a straightforward sum of forces, it is quite easy to add in additional factors on the agents' movement. This is where we could use a function dependent on the number and relative proximity of zombies to generate panic behavior.

## Methodology

Each run of the simulation begins with a large number of unarmed humans and a small number of zombies. They are in an environment filled with a random assortment of predefined walls and randomly placed gun caches. As the simulation progresses, zombies hunt and infect humans, while humans try to avoid zombies, pick up guns, and shoot zombies.

We modeled every object in the simulation—humans, zombies, walls and gun caches—as an agent, each with its own set of social forces that it exerts on others. All of the agents have properties such as mass, visual range—that is, angle, distance and line of sight—and velocity. In addition to these, each agent subclass has unique properties.

### Human Agents

In addition to the common properties of agents, humans have personal space, the ability to possess a gun and shoot zombies with it, health, and the ability to incubate the zombie virus if attacked. If other agents are within the human’s visual range, it exerts social forces on them.

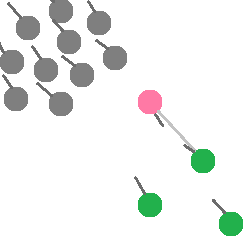
If those agents are walls or gun caches, the forces are simple: humans avoid running into walls and are attracted to gun caches if they are unarmed and the cache is not empty.

Fig: A group of humans encounters a gun cache. When a human acquires a gun, it turns pink.

If the agents are humans or zombies, the social forces are more elaborate. When interacting with other humans, they engage in standard flocking behavior by maintaining cohesion, separation and alignment.

Fig: a flock of humans maintaining separation, cohesion and alignment. Dark green agents are incubating the zombie virus. The lighter the shade, the closer the human is to transformation.

If there are zombies in range, humans behave in one of two ways, depending on whether or not they’re armed. If unarmed, the humans panic and try to escape from the zombies. Humans have a melee attack range, and they can do harm to zombies this way. However, the force to escape is very strong and if a zombie is within this range, the human is probably facing away from it. If humans have guns, their fear is outweighed by a thirst for vengeance. Instead of running, they shoot at them. The accuracy of their shot is sigmoidal and dependent upon their distance from their target. The effect of this is a high chance of killing the zombie outright, a high chance of missing, and a small chance of injuring them. As the zombie gets closer to the human, the chance of a fatal shot goes up and the chance of missing goes down.

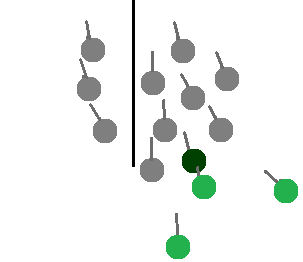
Fig: A flock of humans flees zombies. An armed human shoots a nearby zombie.

If a human is attacked by a zombie, it enters an incubating state. In this state, it continues to appear human to other humans. It loses health until it dies, at which point it becomes a zombie and begins hunting the humans around it.

### Zombie Agents

Zombies are governed by simpler rules than are humans. They have a somewhat larger visual range, but they move much slower. They avoid walls in the same manner, but they ignore gun caches.

Their primary driving force is to hunt humans. If humans are in a zombie’s visual range, it will chase the closest one until it infects the human or the human escapes its visual range. If a human is in a zombie’s attack range, the zombie deals damage to it, bringing it to 90% health and causing it to enter incubation.

Fig: A group of humans fleeing zombies. One human becomes infected. The flock separates when it encounters a wall.

When interacting with other zombies, they maintain separation: they do not flock, but only avoid collisions.

### Walls and Gun Caches

Walls and gun caches are the simplest agents. They do not interact with the other agents per se. Rather, they make calculations that help the mobile agents interact with them. Both calculate whether another agent is within its bounds. Gun caches also keep track of how many guns they contain. The visual appearance of the gun caches is dependent on the number of weapons inside. More guns represent a visually larger gun cache.

Walls are used to determine which side of it an agent is on, what its closest point to the agent is on the wall, and how far the agent is from this point. Walls utilize an exponential repulsion force based on the inverse of the distance to the wall:

This exponential approach forces agents to go around walls. By using an exponential function the force will dominate the closer they get to the wall and effectively making the wall an impassable obstacle.

The levels are generated procedurally by placing a number of custom-made buildings on the map. This makes the runs of the program significantly different from one run to another. This approach ensures that particular advantageous structures won't persist over a number of trials.

## Experiments

A number of experiments were carried out with the model to determine the effect of the different factors.

* **Mass** – The mass of the agent determines how quickly the forces acting on it will accelerate it. Values between 1 and 10 were most effective.
* **Sight Range** – The distance that an agent can effectively see. Once an agent of any kind is out of this range, it cannot be detected by the agent in question. Distances of 50 to 200 work especially well. The lower the sight range, the less likely the humans are to flock together. Zombies with short sight ranges can easily lose humans during a chase through obstacles. With full vision, wherein every agent can see every other agent, the humans quickly form into an enormous slow moving group. Zombies with unlimited vision are often ineffective due to the number of potential targets from which they can choose.

* **Field of View Angle** – The angle with which the mobile agents, zombies and humans, can detect other mobile agents. In order for an armed human to shoot a zombie the zombie must be within the human's field of view. Narrow fields of view—those below 90**°**—were extremely ineffective as zombies would have trouble tracking and chasing people. Given low fields of view, humans would form very tenuous flocks that would easily split or otherwise dissolve.

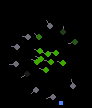
* **Max Speed** – The maximum rate at which mobile agents may progress through the environment. A number of interesting patterns would occur when the humans and zombies were of equivalent speeds. Human-zombie spirals would form under equivalent maximum speed and forces. This is because the surrounding humans each draw the zombies outwards equally, while the zombie center would repel the humans that were otherwise attempting to form a flock.

* **Melee Attack Range** – The distance at which mobile agents could physically attack opposing agents. If the attach range of the humans is larger than that of the zombies, the uptake of the disease within the groups of survivors slows drastically. If the range of the zombies is longer the rate of infection increases drastically.
* **Melee Damage** – The amount of damage dealt to a mobile agent by a physical attack. For zombies a nonfatal attack will spread the disease to the human host, causing them to incubate the disease until their demise, wherein they too rise as a zombie. Often zombies are unable to completely kill a human and merely infect the human, unbeknownst to the rest of the human's flock.
* **Incubating Rate** – The rate at which humans slowly die from the fatal disease. Larger values cause the time from inoculation to death and therefore zombification to decrease. Small values take much longer to kill incubating humans and therefore extend the lifetime of the humans.

**Experiment 1:**

|  |  |  |
| --- | --- | --- |
|  | **Humans**  150 | **Zombies**  25 |
| **Mass** | 5 | 5 |
| **Sight Range** | 100 | 120 |
| **Field of View Angle** | 120**°** | 160**°** |
| **Max Speed** | 1.2 | 0.85 |
| **Melee Attack Range** | 5 | 10 |
| **Melee Damage** | 10 | 10 |
| **Incubating Rate** | 0.1 | - |

The first experiment used values determined from popular media. This experiment utilized the assumption that humans tend to be faster than zombies, while the zombies are extremely keen at detecting fresh meat.

Given the reasonably large sight range and field of view angle, the humans quickly formed into flocks. These flocks were sizable and usually contained at least one human equipped with a gun. The low frequency of gunmen often had disastrous results for the entire pack of humans, sometimes resulting in a violent and explosive surge of new zombies from members of the pack.

Ultimately the humans fell to the disease, on average the final human fell at *t =* 2874. This is a relatively fast death for the initial group of 150 humans to 25 zombies.

**Experiment 2:**

|  |  |  |
| --- | --- | --- |
|  | **Humans**  150 | **Zombies**  25 |
| **Mass** | 5 | 5 |
| **Sight Range** | 120 | 120 |
| **Field of View Angle** | 120**°** | 120**°** |
| **Max Speed** | 0.9 | 1.0 |
| **Melee Attack Range** | 10 | 10 |
| **Melee Damage** | 10 | 10 |
| **Incubating Rate** | 0.1 | - |

This experiment utilized what are often referred to as *running zombies*. These are often considered by zombie aficionados to be among the most dangerous types of zombies.

The results of this experiment confirm the danger of running zombies. When the zombies are able to move faster than the humans the result is a massacre. With the final human dying at *t=378* we can see why running zombies are so dangerous.

## Conclusion

Our experiments indicate that the human species would likely be wiped out by zombie infection. The capacity for human infection grows significantly when other infected agents seek to spread the pathogen. This can only be successfully combated if the humans are exceedingly well prepared.

Whether through the use of guns or other aggressive means, an immediate effort to destroy the infected individuals is the best survival strategy. If the zombies are allowed to wander the chances of them infecting individuals from new packs increases greatly.

The inability to detect infected individuals that have no yet turned is a significant weakness that can easily cause human extinction in simulation. The virulence of the zombie virus means that as soon as the infected human does turn into a zombie, many surrounding humans will become infected as well. A single undetected infected human can cause a group of survivors to lose scores of people. To prevent this, survivors need some method of detecting and eliminating infected humans before they turn.

### Impact

The primary impact of this work is on the study of disease spread in populations. While the premise of infected that actively seek uninfected, as zombies do, is unrealistic, the system can easily be adapted because the system only uses the social force model. The force attracting an infected agent to an uninfected agent just needs to be changed to a more realistic force.

This system can be modified to handle multiple diseases, by creating different type of infected agents, that cause different behaviors (consider the behavior of a person infected with rabies versus a person infected with influenza). Uninfected agents with different behaviors can also be created. For example, agents representing medical professionals could be attracted to infected agents whereas other uninfected agents representing ordinary citizens could be repulsed by infected agents.

The system can model both local and global phenomena. Walls can simulate the hallways of a building, the layout of a city, or the travel and trade routes of the world. In short, the system enables simulation of disease spread that is much more flexible than models usually used.

This work can also impact areas outside of disease control. For example, the recruitment aspect of zombies could be used to model the formation of riots in an otherwise peaceful gathering. The adversarial relationship between humans and zombies can model raiders against villagers or guerilla fighters against enemy patrols. Thus, this work has potential applications in social behavior and military domains.

### Future Work

The model could easily be extended in a number of areas:

1. Further implementations of weapons, including more significant variation in the range of melee weaponry

2. The modeling of particular guns, yielding different accuracies, rates of fire, and impact

1. The modeling of limited ammunition
2. Requiring human agents to sleep
3. Requiring human agents to eat

There are a number of potential improvements or extensions that change the focus of the engine. For example the engine could be modified to simulate the transfer of contact viruses in a number of settings. The engine could be used to generate airports, schools, even office buildings.

Another potential use for the system is as a military tactical model. A number of new weapons could be modeled and introduced into a conflict region and the combat of squads could be studied and visualized.

The social forces approach used and demonstrated in our research could be extended to fulfill many scenarios and model a wide variety of complex events.

## References

1. *Steering behaviors for autonomous characters.* **Reynolds, C W.** 1999, Game Developers Conference, pp. 763-782.

2. *Social Force Model for Pedestrian Dynamics.* **Helbing, D and Molnár, P.** 1995, Phys. Rev., pp. 4282-4286.

3. *Simulating Dynamical Features of Escape Panic.* **Helbing, D., Farkas, I. and Vicsek, T.** 2000, Nature, pp. 487-490.

4. *When zombies attack!: Mathematical modelling of an outbreak of.* **Munz, P, et al.** 2009, Infectious Disease Modelling Research Progress, pp. 133-150.