Hide and seek: a model of a zombie invasion

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The thought of a disease that can turn intelligent humans into mindless soulless monsters has captivated the public and has inspired several popular movies and series during the recent years. A particular tense point in these movies is a scenario where a group of humans are trapped in a closed room with zombies. We have created a model for such a zombie attack in a closed room, while introducing objects so that the humans can hide. We have illustrated the outcome of the simulation with different number of hiding places and number of humans, to see what time it takes for the zombie to infect all humans. From this, we show that in a zombie attack it will be best if humans stay by themselves at individual hiding places as far away as possible from each other.

I. INTRODUCTION

One of the most popular apocalyptic themes of modern pop culture are zombies. They are portrayed as mindless monsters with open wounds that feed on human flesh. In addition to this, they are considered immortal and do not stop until their brains are destroyed [1]. Ever since George Romero set the template for the modern zombie in his movie from 1968, *Night of the Living Dead*, zombies have been a natural part of the horror genre [2].

In nature we can find various species and situations that show that some types of "zombies" actually can exist in real life, and not just in fictional movies. One of them are the zombie ants [3] who behave like zombies with a random movement. They can adaptively take over and control the behavior of their prey, and eventually kill them. Researchers have also found species such as zombie spiders, and zombie plants [4], [5]. Another scenario that is similar to one zombie infection is rabies, a deadly virus spread to people from the saliva of another infected mammal. The symptoms of rabies can be behavior changes such as aggression and hallucinations, which can spur the mammal to randomly attack humans or other animals [6]. One study has been done on rabies where rivers act as barriers for raccoons, showing that the environment place a large role in creating mathematical models of a disease spread [7].

Other studies that have been done in this field are predator-prey systems with some disease involved. Research shows that in most cases when there is a disease spread among the prey the predators can easily hunt them down, and if there is an infection among the predators the prey population will grow [8]. In the case of the zombies, we can consider zombies as infected predators and humans as healthy prey. In nature this would, as mentioned, mean that the humans will survive. The difference in this scenario is that zombies do not kill the humans, they just turn them into new zombies, which makes the zombie population more powerful for each infection.

Consequently, previous studies on zombies have mostly focused on the epidemiological view and not the hunting part. One of the first models on zombies was an article by Munz et al. [9], that is based on the classical disease model SIR. Another interesting paper is one by Hällgren and Buchanan [10]. They look into how zombies can represent a doomsday scenario and how we can use fiction as a research tool.

It might also be an interest from both movie directors, writers and hobbyists to see a simulation of different scenarios with zombies. From which one can draw conclusions about how an infection will spread. In movies such as *World War Z* and *28 Days Later* we can see scenes including a zombie infection in a closed room. Typically they show how the protagonists have to hide from the zombies. This scenario is often particularly tense and a high point of the movie or the series.

Similar events happen when prey have to escape from one predator, and choose to find a safe place instead of trying to outrun the predator. Examples of animals with this strategy includes ungulate calves that hide in long grass, and flatfish settled on the sea bottom [11]. This strategy increase the chance of surviving just because it lets the predator pass by without noticing the prey. The prey will simply just flee if it knows that it is detected by the predator. With the same approach we will let the humans be hunted by zombies and hide as long as they are not detected by the zombie.

The aim of this study will be to investigate how long it will take for one zombie to infect all humans in a closed room. The time will be calculated depending on the number of hiding places, humans, and sight ranges.

II. MODEL

An agent based model is used to simulate the attack [12]. The model consists of a room with different sizes of random obstacles, zombies and humans. The room is implemented as a matrix that creates a grid where each tile can either be free, an obstacle, a zombie or a human.
The agents of the model are the humans and the zombies. The humans can move in different specified speeds and will use obstacles to hide from the zombies. This strategy is chosen as zombies will target the human if and only if the human is within the zombies line of sight, and if the human manage to get out of the line of sight of the zombie, the zombie will interrupt the chase of that human. The zombie will always target the closest human in it's sight. If it gets to a neighbouring tile to the human, the human is infected and will immediately turn into a zombie. In our model, the humans can neither fight back nor escape from the room, which is why we have made it so that their strategy is to hide behind obstacles.

The algorithm for a zombies behaviour is as follows:

```
while Uninfected Humans in the room do
  Check if there are any humans in line of sight
  if Humans in sight then
    Take a step towards closest human in sight
    if Human in neighbouring tile then
      Infect human
    end if
  else
    Take a step in a random direction
  end if
end while
```

The algorithm for the human movement is as follows:

```
while Human is not at nearest obstacle do
  Move towards nearest obstacle.
end while
while Human is uninfected and at obstacle do
  Check if there are any zombies in line of sight.
  if Zombies in sight then
    Look for a neighbouring tile that is adjacent to the
    obstacle from which
    no zombie is in line of sight of the human,
    this tile is safe.
    if Found safe neighbouring tile then
      Move to safe neighbouring tile.
    else
      Take a step to a neighbouring tile that is
      adjacent to the obstacle and is furthest away
      from the closest zombie in sight.
    end if
  else
    Stay at current position.
  end if
end while
```

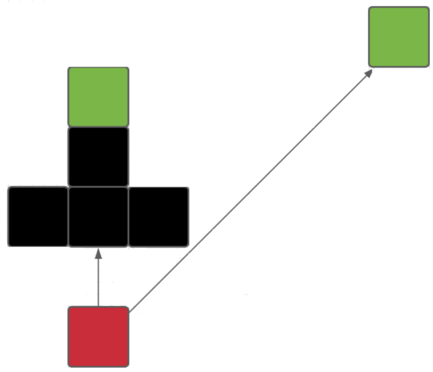


Figure 1. Illustration of the ray casting method. The zombie (red), will first cast a ray towards the closest human (green) that is behind an obstacle (black). Since, it is behind an obstacle the zombie will instead go towards the second closest human as it is not blocked by an obstacle.

In order to determine whether an agent has a clear line of sight towards its enemy, a technique called *Ray casting* will be used. Ray casting is a method which casts a ray from an obstacle in a given direction to find out whether the ray will collide with another obstacle in its path [13]. The ray is drawn using the Bresenham's line algorithm. Bresenham's algorithm determines the set of points of an n-dimensional raster which most closely approximate a line between two points. It calculates the error, that is the distance of the calculated line from the ideal line and rounds it to neighbouring pixels [14]. In the case of a zombie invasion we can simply cast a ray from a given zombie directly towards a human within its sight radius. If the ray would happen to collide with an obstacle along its path towards the targeted human, it means that its sight is blocked by the obstacle. Figure 1 illustrates one case where one zombie has two humans within the sight range, one behind an obstacle and one visible. When a human sees a zombie it will instead try to hide from the zombie behind an obstacle, this is visualized in Figure 2.

The obstacles play a crucial role as it allows the humans to hide from the zombies and thus giving them a chance to avoid getting infected. By varying the shape of the obstacles, the number of them and lastly the distance between them we may be able to change the outcome for the human, making it harder for the zombies to spot the humans as their vision is more likely blocked if there is a larger number of obstacles within the room. The obstacles are randomly generated, both their sizes and shapes in order to make it easier to explore different layouts of the room and how it affects the outcome of the zombie invasion.

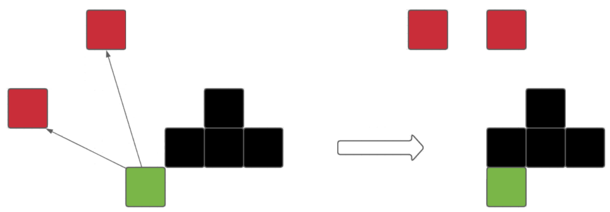


Figure 2. Illustration of the hiding process for the humans. The human (green) is able to see the zombies (red) and thus it moves behind the obstacle (black) such that the zombies is no longer in its vision.

III. RESULTS

As is illustrated in Figure 3, the simulation starts with one zombie and it becomes increasingly difficult for the humans to hide when the infection spreads.

The simulation result after a few time steps, with different obstacle distances, is shown in Figure 4. We can see that the humans gather around the obstacles and that the initial zombie have infected their nearest humans. In Figure 5 we can see that the time it takes for all humans to turn into zombies varies with the distance between the obstacles and the number of initial humans. Figure 5(a) shows the result for a sight range of 30, which is the same size as the grid size, and Figure 5(b) shows the result for a smaller sight range of 10. This result is from an average of ten runs. We can see that for a smaller number of humans, the zombies need more time to infect all of them because humans can hide better behind obstacles and the zombie population increases at a lower rate. For a larger number of humans it becomes more difficult to hide as they often form large clusters around the obstacles and thus find it difficult to be outside the zombie sight range.

Regarding the obstacles, initially when the distance between them increases the time decreases, as the denser distributed obstacles create better hiding places for the humans. But there is a distance where the time is at its minimum, after which an increase in distance leads to an increase of the time to infect all humans. This is because in that case the obstacles become fewer in number as shown in Figure 4, due to the fixed size of the grid. The zombies will move around randomly until they reach an object where humans hide, and then they have to find one of the other obstacles that are now further away to infect even more.

When comparing the two sight ranges in Figure 5(a) and (b) it shows that for a smaller sight range it generally takes longer time for the zombie to infect all humans while the effect of the other parameters remain the same. The difference is greater for smaller number of humans. However for larger numbers of humans the results are almost the same as a densely populated grid makes it more likely for a human to be in the zombie sight range.

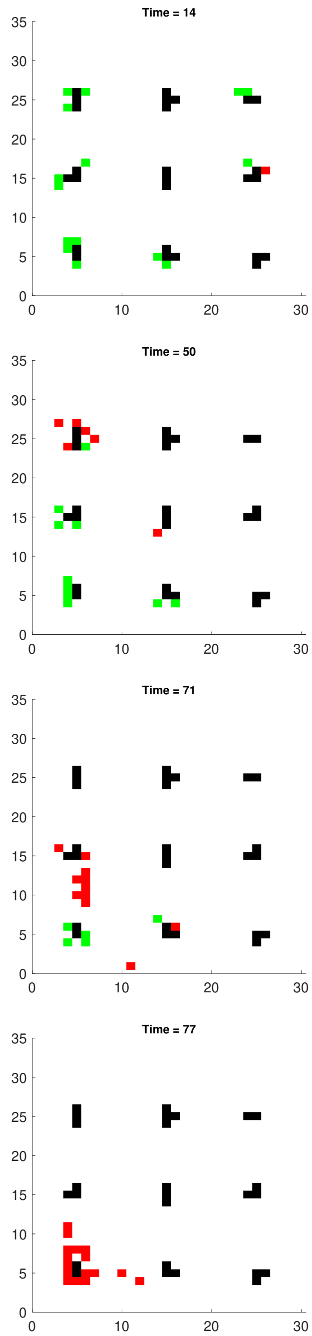


Figure 3. Snapshots of the simulation, the infection spread fast once the zombie (red) found the first human (green).

Furthermore, in Figure 6 we see that a larger room is advantageous for the humans as it prolongs the zombie invasion. A larger room allow the humans to spread across the room, which in turn may prevent large crowds from forming around the obstacles. As a consequence of smaller human crowds the infection rate decreases as the discovery of a human hiding spot becomes less rewarding for the zombie since there are fewer humans to infect at each different hiding spot. In addition a larger room also increase the probability that the humans is out of a given zombie's sight due to its limited sight range and thus increasing the likelihood of survival for the humans as the zombie is not able to target the human.

In order to determine the effectiveness of the human's strategy for survival we compare it with a different scenario where the humans instead move randomly no matter if any zombies are nearby. In Figure 7 we see that a more strategic movement pattern for the humans is advantageous as it yielded a lower infection rate compared to a random movement pattern for different initial human population. By instead utilizing the hiding strategy the humans are able to outsmart the zombies and delay the infection by blocking the vision of nearby zombies. On the contrary when moving randomly the human is less likely to find a safe spot and is thus more likely to be targeted by a nearby zombie.

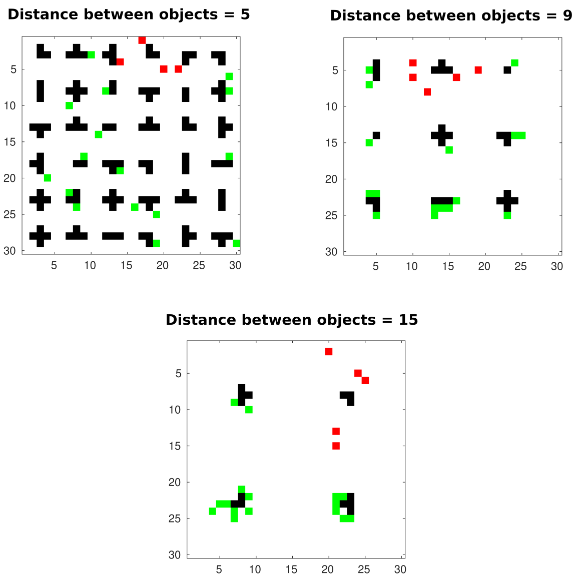
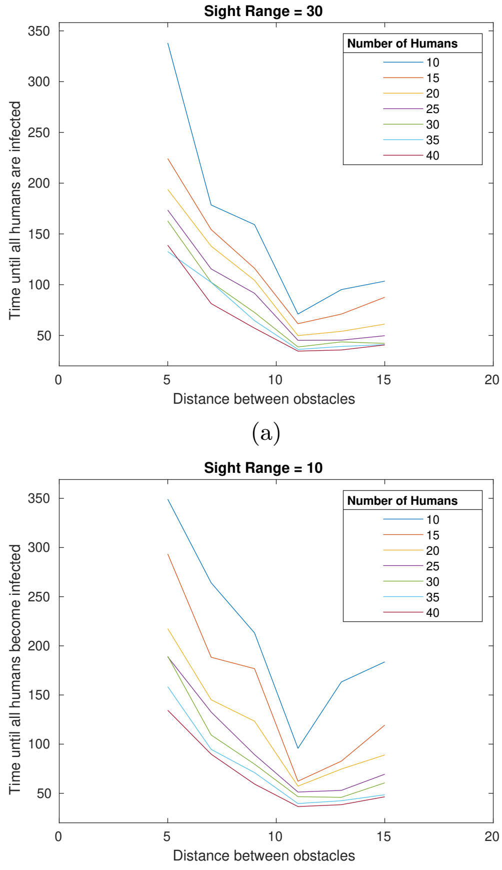


Figure 4. Simulation images for different distances between obstacles. Obstacles are black, humans are green, and zombies are red.



(a)

(b)

Figure 5. The time it takes for all humans to be infected depending on the distance between obstacles and the number of initial humans. (a) have sight range 30, (b) have sight range 10.

IV. DISCUSSION

From the results we can see that if there is many humans in the room, the infection will spread quicker. The reason for this is because when many humans have turned into zombies it becomes increasingly difficult for the humans to hide. More humans also make it harder for one human to hide as it increases the risk that several humans attempt to hide behind the same obstacle, making it easier for a zombie to find them and infect them all. At the same time the humans can neither escape from the room nor fight back in our model and therefore more humans will eventually lead to a bigger zombie population.

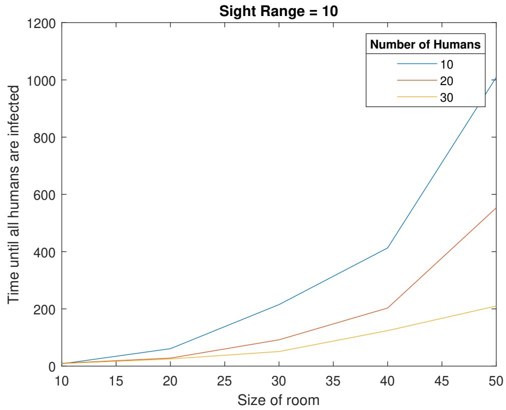


Figure 6. The time it takes for all humans to be infected depending on the size of the room and the number of initial humans.

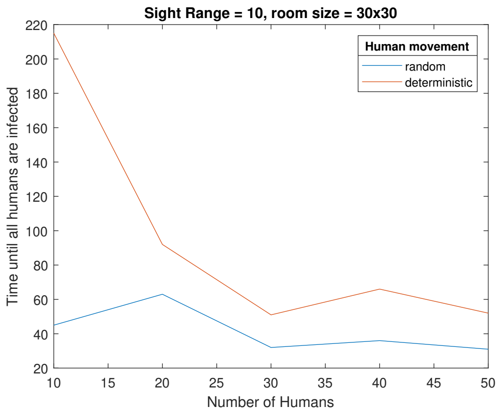


Figure 7. The time it takes for all humans to be infected depending on the movement pattern of the humans and the number of initial humans.

Another, significant factor in this model are the distances between obstacles. We have seen that an increasing obstacle distance will generate a shorter time for the zombie infection to spread. This is because the zombies vision will not be blocked by other obstacles, making them see further. However, we have a threshold when a higher obstacle distance leads to a greater infection time. This could be because with a higher obstacle distance, there will eventually also be fewer obstacles. Which leads to a lesser risk of a chain reaction where the zombies finds the humans behind one obstacle, infects them and then quickly finds another human behind an obstacle that is near. A smaller sight range leads to a more prominent dip than a larger sight range. Just as a smaller sight range makes the zombie more dependant on the mentioned chain reaction phenomenon than if the sight range is larger.

These results can for example be used by writers to give a credible depiction of the spread of a zombie infection in a compromised hideout. The survivors might be those who try to hide outside the sight of both zombies and humans, while those who try to cram into the best hiding spots are the ones to be infected. Additionally, the result can be used to simulate how a predator hunt in nature for prey that hide. For instance it can be the case of a rabies spread where the healthy animals hide from the aggressive infected one.

The results that show us that it is better for the humans to stay by themselves, is similar to the approach of a disease spread or a global pandemic where smaller communities minimize the infection spread. Maybe not for the individuals best, but for the whole populations best. Because, when more humans are infected the infection will have greater risk of spreading further.

What might make the model more accurate, is if the humans could be smarter and outrun the zombies. Either, by making better decisions on which obstacle to hide behind and move more freely or if they could fight back against the zombies for example by picking up weapons. The ability to fight back against the zombie might change the result, making it more advantageous to form up in large clusters to cooperate in the fight against the zombies. Furthermore, one could add some treatment that would allow the zombies to turn into their original human being, or an infection time that would make humans infected some time before becoming zombies. Another thing that would be interesting is to add sub rooms in the current room to more accurately depict a hideout in a zombie apocalypse.

V. CONCLUSION

We can conclude from our simulation, that if it is more humans in the room, the zombie virus will spread faster. The simulation also implies that less obstacles is generally less advantageous for survival in a compromised hideout scenario.

Even if this work is modeling a fictional invasion, hopefully it demonstrates how mathematical models can describe different scenarios. Both for predicting the outcome of some diseases in nature such as the zombie ant or rabies, and for visualising how a zombie invasion would look like that can help movie writers.

[1] Brooks,Max. *The zombie survival guide: Complete protection from the living dead* (Del Rey, 2003).

[2] McIntosh, Shawn, and Leverette,Marc, eds. *Zombie culture: Autopsies of the living dead.* (Scarecrow Press, 2008).

[3] Hughes, David P., et al. *Behavioral mechanisms and morphological symptoms of zombie ants dying from fungal infection* (BMC ecology 11.1, 2011).

[4] Hughes, David P., et al. *From so simple a beginning: the evolution of behavioral manipulation by fungi* (Advances in genetics. Vol.94. Academic Press, 2016).

[5] MacLean, Allyson M., et al. *Phytoplasma effector SAP54 hijacks plant reproduction by degrading MADS-box proteins and promotes insect colonization in a RAD23-dependent manner.* (PLoS Biol 12.4, 2014).

[6] Schnell, Matthias J., et al. *The cell biology of rabies virus: using stealth to reach the brain.* (Nature Reviews Microbiology, 2010).

[7] Smith, David L., et al. *Predicting the spatial dynamics of rabies epidemics on heterogeneous landscapes.* (Proceedings of the National Academy of Sciences 99.6, 2002).

[8] Krishna pada Das. *A mathematical study of a predator-prey dynamics with disease in predator.* (ISRN Applied mathematics, 2011).

[9] Munz, Philip, et al. *When zombies attack!: mathematical modelling of an outbreak of zombie infection.* (Infectious disease modelling research progress 4, 2009).

[10] Hällgren, M. and Buchanan, D.A *The dark side of group behavior: Zombie apocalypse lessons.* (Academy of Management Perspectives 34.4, 2020).

[11] Broom, Mark, and Grame D. Ruxton *You can run—or you can hide: optimal strategies for cryptic prey against pursuit predators.* (Behavioral Ecology 16.3, 2005).

[12] De Marchi, Scott, and Scott E.Page *Agent-based models* (Annual Review of political science 17, 2014).

[13] C.H.Walsh and S.Karaman *CDDT: Fast Approximate 2D Ray Casting for Accelerated Localization* (IEEE International Conference on Robotics and Automation, Brisbane, 2018).

[14] Bresenham, J. E. *Algorithm for computer control of a digital plotter* (IBM Systems Journal, 1965).

Appendix: Contributions

In this project we have worked together with finding the problem formulation and the model description. We have had meetings often to discuss problems regarding the project and scheduling. The remaining work has been divided as follows:

Andreas was responsible for implementing the human movement pattern and the zombie movement pattern as well as the initialization of the zombies and the humans. Furthermore, Andreas contributed to the description of the model in the report as well as the results regarding different movement patterns for the humans and the result for different room sizes.
Niklas have been contributing to the implementation of the targeting functionality and have fixed some bugs in the code. Niklas has also contributed to the Model section of the report.
Josefin have been doing background research regarding both zombies and similar real-world systems. Josefin have written the introduction of the report, and contributed to other sections, mainly the discussion.
Konstantinos has contributed to the targeting function as well as the implementation of the ray casting method. Konstantinos also contributed to the reporting of results for different aspects of the simulation including the effect of different sight ranges and different number of humans on the simulation.