Zombie Apocalypse Simulations using C and Gnuplot

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Projects

- SZR Model (Susceptible, Zombies, Removed)
- SIZR Model (Susceptible, Infected, Zombies, Removed)
- SIZRQ model (Susceptible, Infected, Zombies, Removed, Quarantine)
- SIZRC model (Susceptible, Infected, Zombies, Removed)
- SIZGR Model (Susceptible, Infected, Zombies, Ghouls, Removed)

Introduction

In the paper called 'WHEN ZOMBIES ATTACK!: MATHEMATICAL MODELLING OF AN OUTBREAK OF ZOMBIE INFECTION' by Philip Munz and Ioan Hudea. There are models zombie apocalypse. The were The Basic Model(SZR), The Model with Latent Infection(SIZR), The Model with Quarantine(SIZRQ), The Model with a Treatment(SIZRT), I will be showing the C programs of these models and show my resulting Gnuplots. Also I will be doing the same with my custom model that adds adiffrent type of zombie in the the basic model The Zombie and Ghoul model(SZGR)

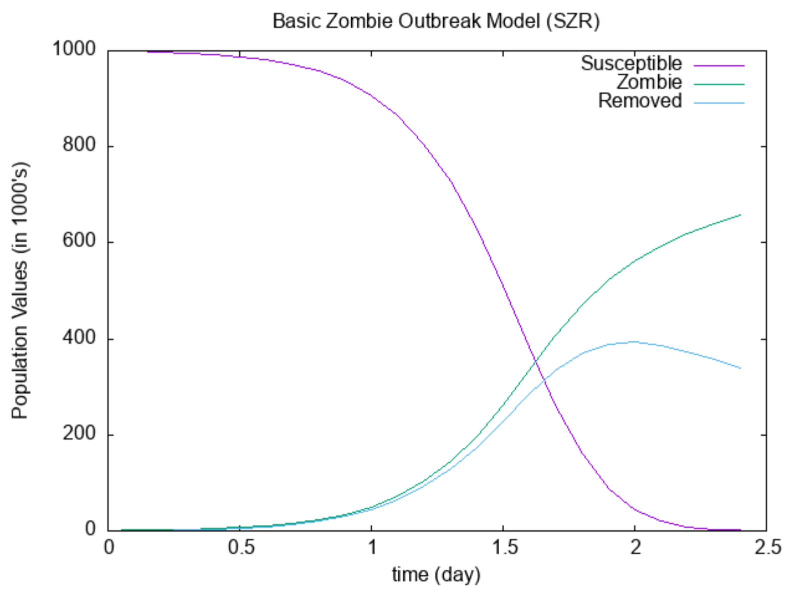
The SZR Model

For the The first model there are 3 groups. (S) Is the number of people who are not zombies yet. (Z) Is the Number of zombies, (R) Is the number of dead people and zombies. The parameters for equations are (pi) Which is the human birth rate. (alpha) Which is the rate zombies are defeated. (beta) Which is the rate humans are infected. (delta) Which is rate humans die to non zombie related events. (zeta) Which is the rate zombies come back from the dead. Below are the equations in c code that were in the SZR simulation.

SZR model equations coded in C

```c
#include <stdio.h>
#include <stdlib.h>
int main (int argc, char **argv){
        if(argc != 9){
                fprintf(stderr,"Usage %s S Z R pi alpha beta delta zeta\n", argv[0]);
                printf("Example: ./a.out 1000 1 0 0 0.005 0.0095 0.0001 0.5 > szr.dat\n");
                return 1;
        }
        float s,z,r,t=0,dt = 0.1;
        float S = atof(argv[1]);
        float Z = atof(argv[2]);
        float R = atof(argv[3]);
        float pi = atof(argv[4]);
        float alpha = atof(argv[5]);
        float beta = atof(argv[6]);
        float delta = atof(argv[7]);
        float zeta = atof(argv[8]);
        while(S > 1){
                printf("%f\t%f\t%f\t%f\n",t,S,Z,R);
                s = S;
                z = Z;
                r = R;
                t += dt;
                S = s + (pi - beta*s*z - delta*s)*dt;
    Z = z + (beta*s*z + zeta*r - alpha*s*z)*dt;
                R = r + (delta*s + alpha*s*z - zeta*r)*dt;
        }
        return 0;
}
```

For the Simulation I made S=1000, Z=1, R=0, pi=0,
alpha=0.005, beta=0.0095, delta=0.0001, and zeta=0.5. The birth rate pi I made zero for this model and the other models because the simulations ended up hapening in a such a short time frame that this parameters has no noticeable effect on the model unless the number is set unrealistically high.



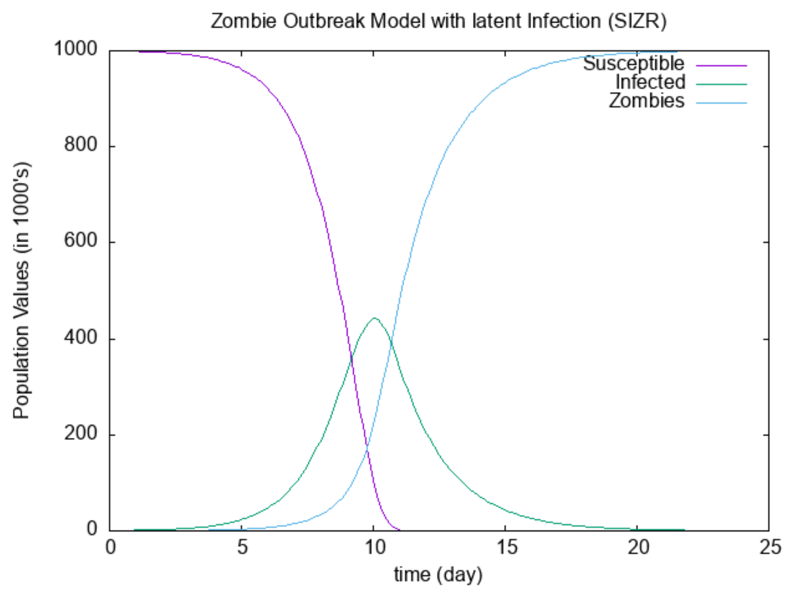
The graph showing the basic model (SZR) you can see that the number of people left drops to almost nothing in the short span of 2.5 days. Also that number of removed people and zombies starts rising at similar rates but as time gose on the zombie line overtakes it. Also after the removed line starts to drop the zombie line keeps growing despite there not being any people left. This is because most of the zombie growth is now coming from the removed group.

SIZR Model

The SIZR Model Was very similar to the SZR model. For this model one more group is added. (I) which is the number of people who have been infected but are not showing symptoms yet. Also those who are infected can sill die before turning into a zombie. Also a new parameter is added. (rho) Which is the rate that the people who are in the (I) group turn in the zombies.

SIZR model equations coded in C

```c
                S = s + (pi - beta*s*z - delta*s)*dt;
                I = i + (beta*s*z - rho*i - delta*i)*dt;
    Z = z + (rho*i + zeta*r - alpha*s*z)*dt;
                R = r + (delta*s + delta*i + alpha*s*z - zeta*r)*dt;
```



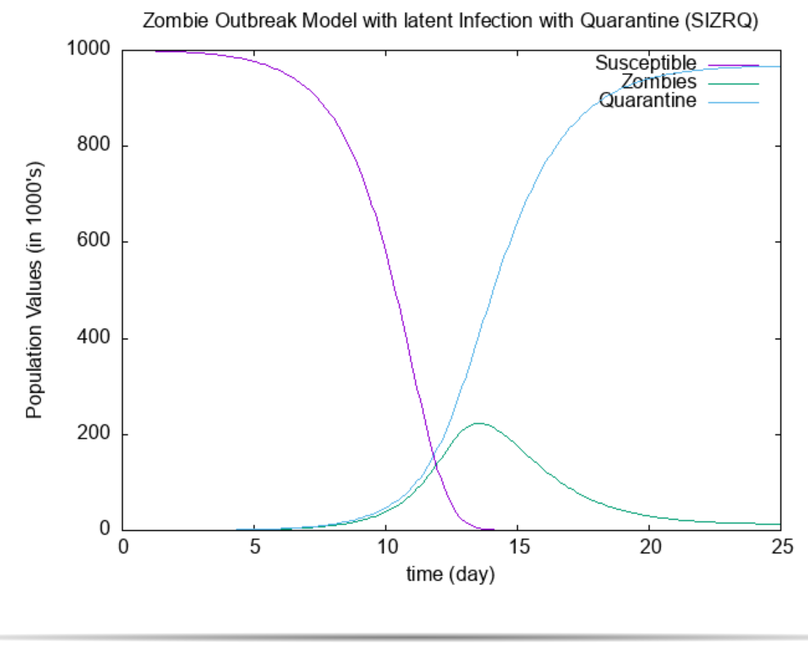
Having rho=0.5, I=1, Z=0 and having the rest of parameters and groups remain the same as the SZR model we get this graph. Compared to SZR it took about 3 times as long for the number of zombies to start to grow but once the 10 day mark was reached the amount of people left started to plummet and amount of zombies started to shoot up.

SIZRQ model

The SIZRQ model is very similar to the SIZR model. A another group is added (Q) Which is the number of people that are quarantined. This group has both people that are infected or zombies. This model adds three more new parameters aswell. Those being (kappa) Which is the rate that those who are infected are sent to group (Q). (sigma) Which is the rate that zombies are sent to group (Q). (gamma) Which is the rate of those in quarantine be it people or zombies are put into the removed group. For my new parameters they are set to these values for my simulation kappa=0.005 sigma=0.0001 gamma=0.0001.

SIZRQ model equations coded in C

```c
                S = s + (pi - beta*s*z - delta*s)*dt;
                I = i + (beta*s*z - rho*i - delta*i - kappa*i)*dt;
    Z = z + (rho*i + zeta*r - alpha*s*z - sigma*z)*dt;
                R = r + (delta*s + delta*i + alpha*s*z - zeta*r + gamma*q)*dt;
                Q = q + (kappa*i + sigma*z - gamma*q)*dt;
```



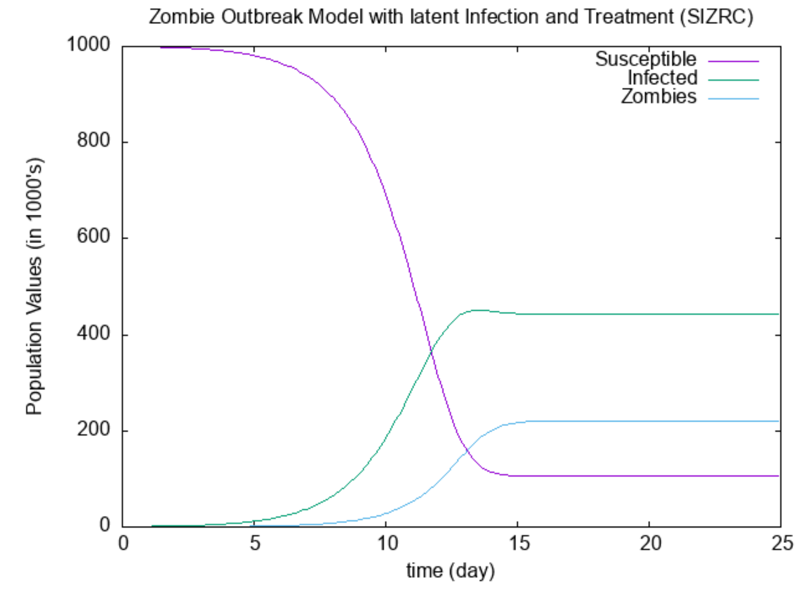
As you can see from the SIZRQ graph adding quarantine to this model did not help to much with stoping the spread with. The sharp decline of people was only held back for a few more compared to the other graph. For qurantine to work in slowing down the spread the rate in which people are quarantine would need to be higher or the infection rate would need to be lower.

The SIZRC model

The SIZRC model also takes the SIZR as a base and just adds one new parameters (c) Which is the rate people are taken cured from being zombies and taken from the the (Z) group and put back into the (S) group.

SIZRC model equations coded in C

```c
                S = s + (pi - beta*s*z - delta*s + c*z)*dt;
                I = i + (beta*s*z - rho*i - delta*i)*dt;
    Z = z + (rho*i + zeta*r - alpha*s*z - c*z)*dt;
                R = r + (delta*s + delta*i + alpha*s*z - zeta*r)*dt;
```



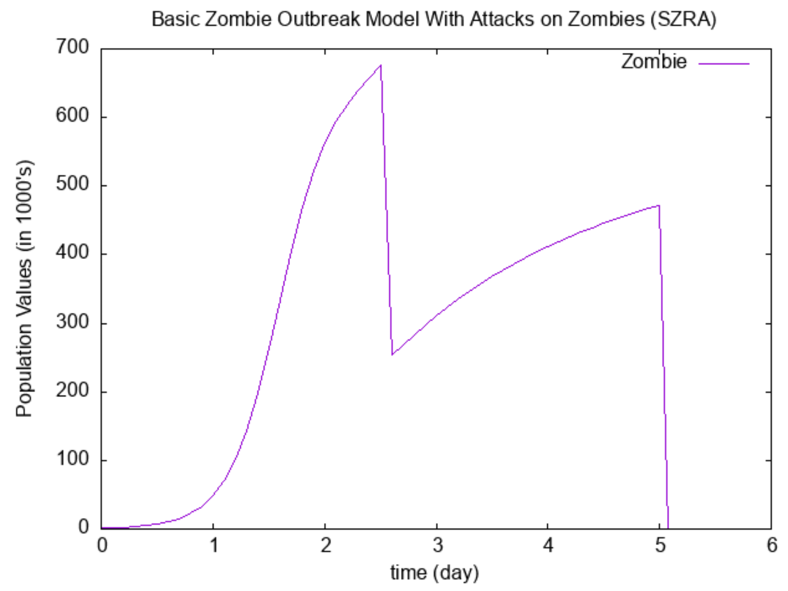
In this model if the cure rate is high enough the all the groups shown will eventually reach an unstable equilibrium with each other. If the cure rate is too low this will not happen the this model will just end up have the susceptible group reach zero.

The SZRA model

The SZRA model which takes the I basic SZR model and adds a twist to it. This model adds that attacks against zombies are being done to get rid of them. A new parameters (k) which is the rate zombies are killed in each attack. The way this model works is an attack against the zombies then after certain intervals if there are still zombies left more attacks will happen. This will happen at each interval until there are no zombies left. For this simulation I set k=0.25.

SZRA model equations coded in C

```c
                printf("%f\t%f\t%f\t%f\n",t,S,Z,R);
                s = S;
                z = Z;
                r = R;
                t += dt;
                S = s + (pi - beta*s*z - delta*s)*dt;
    Z = z + (beta*s*z + zeta*r - alpha*s*z)*dt;
                R = r + (delta*s + alpha*s*z - zeta*r)*dt;
                if(t > n){
                        Z = z - (k*n*z);
                        n=n+n;
                }
```



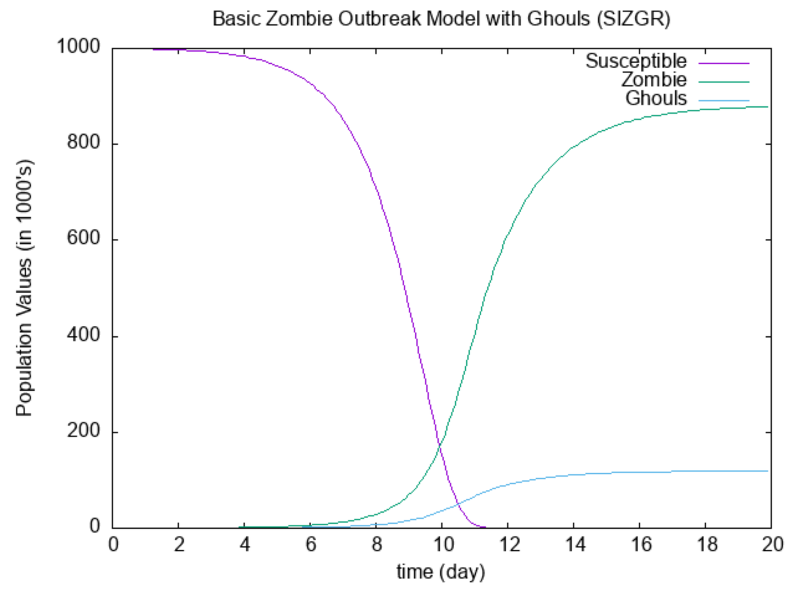
The graph shows that the model is working as it should. However if the kill rate ends up being too low the zombies would just always come back or worse it might just slow down the zombie growth and not stop it at all.

The SIZGR model

This is my custom zombie pandemic called (SIZGR). It is based on the (SIZR) model but it has and added group and two extra parameters. With the group being a different zombie type I am calling Ghouls (G). Ghouls are type of zombies you can become if your Infected. Ghouls do not go after people and like to keep to themselves. But if you kill a ghoul it can come back as a zombie. So it its best to leave them alone. The new new parameters for this model are (mu) the rate the Infected become ghouls and (omega) the rate ghouls die. be it from people or other circumstances.

SIZGR model equations coded in C

```c
                S = s + (pi - beta*s*z - delta*s)*dt;
                I = i + (beta*s*z - rho*i - delta*i - mu*i)*dt;
    Z = z + (rho*i + zeta*r - alpha*s*z)*dt;
    G = g + (mu*i - omega*s*g)*dt;
                R = r + (delta*s + delta*i + alpha*s*z - zeta*r + omega*s*g)*dt;
```



As shown in the graph above the discovery of ghouls does not seem to help the that that much in the long run. If the rate people are turned in to ghouls is higher the rate of susceptible might not drop so fast but it would only delay the inevitable