Viral Infection Simulation at Tissue-level Using Compucell3D

Hak Zhang
Advisor: Dr. Sebastian Streichan (Department of Physics), Dr. Eyal Karzbrun (Department of Physics)
Department of Physics, University of California, Santa Barbara (UCSB)

College of Creative Studies

Motivation:

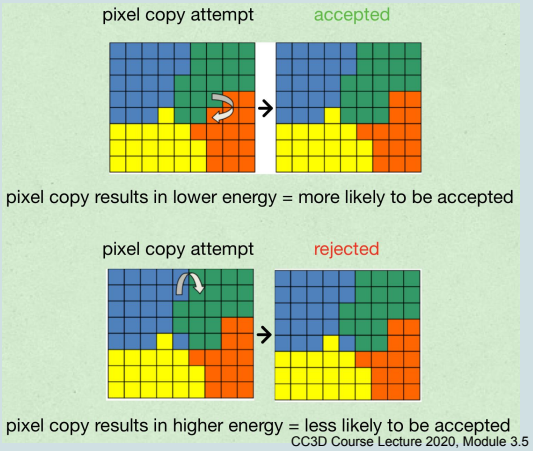
As I write now in the November of 2020, over 53 million people have suffered, and over 1.3 million people have passed away from COVID-19 worldwide. Any understanding of this pandemic, especially those applicable to treatment is of great utility. One way to contribute to this is by implementing a virtual simulation, and study the behavior of the infection.

Method:

Compucell3D

Cellular Potts Model:

- Represent cells as collections of pixels on a lattice (2D or 3D)
- Uses energy to represent the cell properties, cell behavior, and cell to cell interactions
- Each MCS (monte carlo step), border pixels attempts “pixel copy”. Whether the pixel copy succeeds or not is based on the favourability of the total energy of the system by the process.
- The system evolves with each MCS



CC3D Course Lecture 2020, Module 3.5

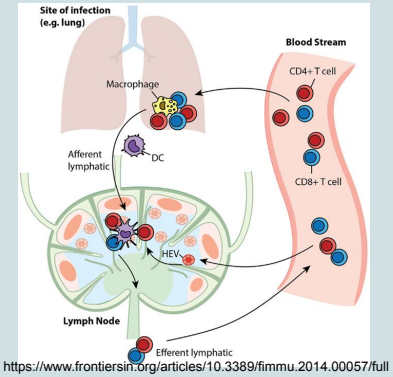
Understanding the viral infection model:

The viral infection process is complicated, and many biological components are involved. We cannot model all of such components, since some details are not understood even today. For a simulation, we need a simple, yet reasonably complicated model to represent the whole process:

1. Virus enters the body and infect cells.
2. Infected cells starts releasing virus (local replication)
3. Infected cells begin to die (Apoptosis) of two causes:
   a. Death caused by the virus
   b. Death caused by the immune response
4. If the immune cells are able to kill the infected cells fast enough, this will stop the infection. If not then cells will die while producing more and more virus, and the infection goes out of control

Immune Response Model:

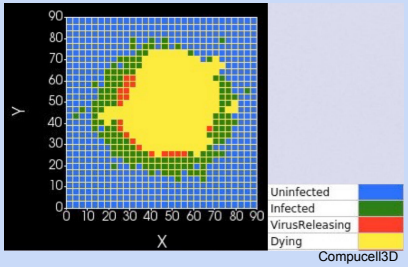
1. Infected cells release cytokines which signals the infection
2. The cytokines is transported to lymph node and triggers production of immune cells
3. Immune cells comes back to the infection cite, and kills infected cells that comes in contact



https://www.frontiersin.org/articles/10.3389/fimmu.2014.00057/full

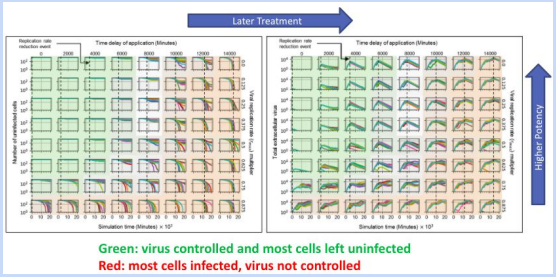
Result:

Here is a typical image of the lattice during simulations:



Compucell3D

By changing the parameters, this model can simulate viruses of varying strength, patient with varying immune strength. By changing parameters mid simulations, it is possible to model a patient receiving treatment certain time after infection.
Since Compucell3D is space and probability based, same initial condition does not always lead to the same conclusion. The Compucell3D team has conducted numerous runs. Here is their result:



CC3D Course Lecture 2020, Module 1.3

One interesting conclusion found is that even weak treatment is better if done early than strong treatment later.

Acknowledgement:

This is work was funded and supported by CCS donors without whom would not have been possible. The software was developed by Compucell3D team, and most work was inspired by the CC3D workshop 2020.