Individual-based Epidemic Simulator and Its Visualization as Generative Art

Prof. T. Unemi, BEng, MEng, DEng.
Department of Information Systems Science, Soka University, Hachioji, Japan
www.intlab.soka.ac.jp/~unemi/
e-mail: unemi@soka.ac.jp

Abstract

The author developed an individual-based epidemic simulator in the spring of 2020 mainly targeting COVID-19. It is useful not only as a tool to help governmental decision making for both people's health and social activities, but also as an artwork to express fragility of human societies and individual lives. As the spread dynamics of infectious disease is a type of generative process, it would be possible to recognize the visualization showing the events in the simulator's virtual world to be viewed as a kind of generative art.

1. Introduction

Since late of 2019, infection of new Corona virus, SARS-CoV-2, has spread around the world with deadly disease, COVID-19. Facing those facts of the long incubation period and the easy spread by airborne, many of the experts tried to contribute any points to avoid tragic damage on individual health and social activities. The author also started his own experimental project in March 2020, to develop a simulator under expectation to provide a tool for both education and prediction. Among the possible variations of modelling methods, the simulator is based on a multi-agent model but not on differential equations with continuous parameters.

One of the well-known methods for generative art is to use a model of collective behaviour of animals, such as birds, fish, and insects. The author's past experiences to create several artworks utilizing such models [1-5] were very helpful for development of the individual-based simulator. The basic model employed BOIDS algorithm [6] for collective behaviour for local contacts with probabilistic events of gatherings. It also models a long distance move within the simulated area. The rest of this paper describes a very short summary of the simulation mechanism, visualization, typical scenario, and then remarks from a viewpoint of generative art.

2. Simulation Mechanism

The model includes a lot of features that we assume to take important roles of the aspect of infection spread, such as, people's behavior under restriction of transport and gatherings, pathogenesis from infection to recovery or death, development of medicines and vaccines, schedule of vaccination, appearance of new virus variants, and so on. This simulator has been used as one of challenges for scenario analysis to assist the decision making by national and local government in Japan, together with the other types of models of differential equations, machine learning, human network models, and so on [7].

The population in the virtual world is placed in 2D square plane where each individual moves around and contacts each other. The model of pathogenesis is applied to each individual when it is infected from the other via contact. The virus infects from one to another probabilistically when they meet each other in a short distance. The probability depends on the distance, the type of virus variant, immunity of susceptible individual, and so on. The test is conducted for an individual who has a symptom. When the test result is positive, the patient moves to the hospital as quarantine. The tests are also applied for those who have close contacts with the patient. After the patient is recovered, it returns to the home position. If the recovery was too late, the patient moves to the cemetery.

The simulation process runs along a scenario given in request for invasion of a new variant, vaccination schedule, restriction of travels and gatherings, obedience by people, and so on. It is useful for both inspection of the past and prediction for the future to evaluate the strategies.

It is possible to handle some millions of individuals as a population utilizing a parallel algorithm if the hardware has enough capacity, but sixteen thousand is an appropriate number for smooth animation by an ordinary personal computer, MacBook Pro M2 for example. More details from scientific and technical viewpoint are described in the author's other literatures [8,9].

3. Visualization

An important feature of individual-based simulation is that it is relatively easy to make a graphical visualization to show what occurs in the virtual world in a micro level movement of individuals, which is helpful to understand the nature of spread dynamics. The population is shown as a distribution of dots on the screen that move for gatherings and travel. The time evolutions and the histograms of sampled indexes are also displayed dynamically. Figure 1 is an example display on the screen of full HD 1920x1080 resolution; that contains four charts and two histograms of statistics in the left side, and the population distribution in the rest part.

3.1 Population

Each individual is drawn as a small dot with the color that indicates the health state; susceptible, asymptomatic, symptomatic, recovered, and vaccinated. The population is animated as it moves. A thin triangle is attached when it travels in distance, moves to and from the hospital, and is buried in cemetery. These features enable the viewers to notify how spread happens when people have close contacts in gatherings. It is also clearly recognizable how travel makes the spread widely.

3.2 Trends

Some of the indexes measured in the real world on epidemic are useful to catch the current situation and trend as several governmental organizations for health and private companies servicing big data have been providing those data online. In addition to these observable data, hidden indexes, such as the number of infected patients missing the tests are also measured in the simulated world.

In the left side of the screen shown in Figure 1 includes the ratio of the number of people of each health state, the number of asymptomatic and symptomatic patients newly reported per day, the number of patients for each rank of severity, and the number of patients infected by each virus variant. The scales of both horizontal and vertical axes are dynamically adjusted as the simulation process progresses.

3.3 Histograms

Some of the statistical frequency distributions are also helpful to understand the characteristics of current spread, such as incubation period, recovery period, period to death, and the number of patients infected by a single contagious person. The left bottom area shown in Figure 1 displays the histograms of these indexes.

4. Scenario

The setting of scenario depends on the objective of simulation. For providing an appropriate hint for the real strategy taken by the government, it should be realistic and includes possible alternatives on both future strategies and the new variant's unknown features. On the other hand, as an artwork, it would be better to be suitable to inspire the viewers a mixture of their past experiences and possible future events. Figure 1 is one of typical display on the screen after two waves passed using following scenario in JSON format:

```
{{"Lockdown", "symptomatic > 1000"},
 {"gatheringFrequency", 10.0},
 {"Lifting", "symptomatic < 600"},
 {"gatheringFrequency", 50.0},
 {"New variant", "days > 120"},
 {10, 0, "X"},
 {"Vaccination", "days > 140"},
 {"vaccinePerformRate", 7.0},
 {"Lockdown", "symptomatic > 1000"},
 {"gatheringFrequency", 10.0},
 {"Lifting", "symptomatic < 600"},
 {"gatheringFrequency", 50.0}}
```

This scenario means as follows. When the reported number of symptomatic patents reaches more than 1,000, then the frequency of gatherings is set to 10% as a governmental countermeasure. If the number of symptomatic patients becomes less than 600, the frequency of gatherings is set to 50% as the restriction was lifted. When 120 days passed, a new virus variant named X invades and ten people get infected. From 140th day, vaccination starts by 0.7% subjects in the population per day. the second wave of spread happens because the characteristics of variants are as follows.

```
{{variant name:"Original",
  reproductivity:1.0,
  immunity efficacy:{1.0, 0.5}},
 {variant name:"X",
  reproductivity:1.5,
  immunity efficacy:{0.5, 1.0}}}
```

This means the variant X has infectiousness 1.5 times stronger than the original one. The efficacy of immunity by infection is 100% for the same variant, but 50% for different one.

The protocol and efficacy of vaccine are also given by the following settings.

```
{{vaccine name:"PfBNT",
 interval on:true,
```

interval days:21.0,
vaccine efficacy:{1.0, 0.8}}}

This specifies that vaccine named "PfBNT" requires second dose by three weeks of interval. The efficacy against the original variant is 100% but 80% against the new variant X.

Due to the acquired immunity by enough rate of population, the epidemic in the virtual world ends by no patients remaining in the population. For an exhibition setting, the virtual world is reset when the epidemic ends and then a new simulation process starts again. In the initial state of the simulation shown in Figure 1, the population size is 16,000 and 16 people are infected by the original variant.

This scenario was inspired from the phenomena happened from February to September 2021 in Japan. Effective vaccines were just released but the vaccination was not conducted widely yet. Alpha variant invaded to Osaka area and soon it spread rapidly around all other areas. As a response to the severe shortage of medical resources, the government applied a strong restriction on people's activities for both travels and gatherings. The spread gradually shrank as both people's obedience and vaccination. Once it looked hopeful as if the epidemic would end, but Delta variant invaded and some patients suffered severe symptom, typically those who were not vaccinated yet. As the cumulative rate of vaccination reached more than 70%, the spread got rapidly shrunk, and the social activities recovered until Omicron variant comes.

5. Remarks

Spread of infectious disease is a type of complex phenomenon as it includes a generative process. Animated visualization is helpful not only for researchers but also for ordinary citizens and political decision makers. At the same time, such type of visualization has a potential as a type of artwork to provide an occasion for viewers to consider the fragility of human lives and our society.

From a viewpoint of aesthetics, a fine scale of complex movement of massive collection of particles together with dynamic transition of whole visuals is one of the popular techniques to attract human eyes. The animation shown as the population moves includes such feature.

As future works, sonification of visual animation [1,3,5] and speech of narratives on the events in the virtual world [2,4] will be helpful to make this work more impressive for viewers.

The author hopes this work would provide occasions to people both to learn how the countermeasures work and to consider what was the pandemic for both individual and society. The project information is available from the following URL:

http://www.intlab.soka.ac.jp/~unemi/SimEpidemic1/info/

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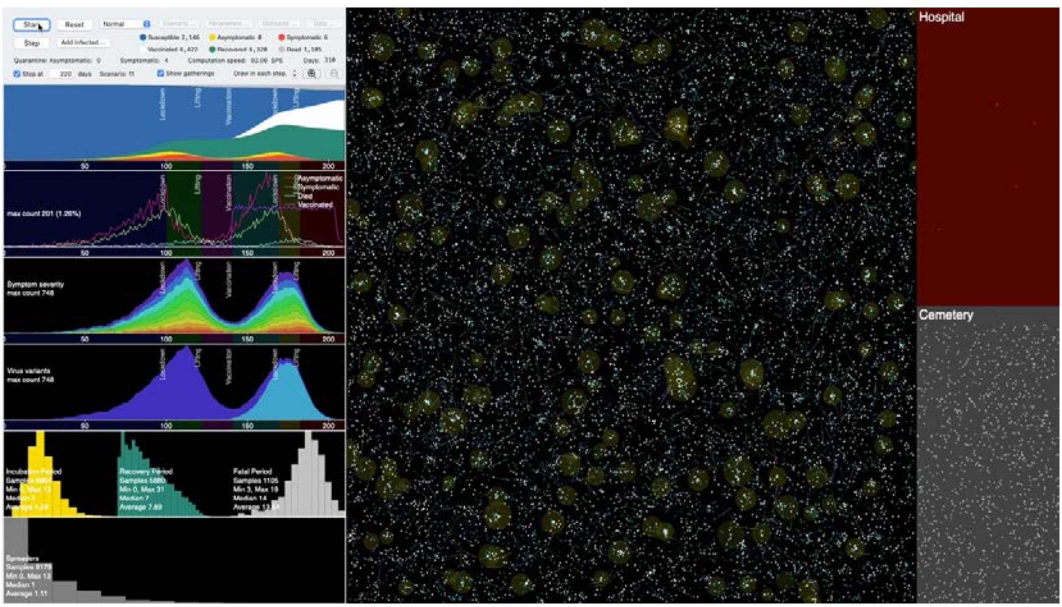

Figure 1. An example display on a full HD screen.
Full duration of video is available
in http://www.intlab.soka.ac.jp/~unemi/SimEpidemic1/movies/SimEpiE001.mov