

# Documentation for the Toolbox to Simulate and Mitigate COVID-19 Propagation

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## 1. Description of the functions

The MatLab-based toolbox is mainly composed of six functions, which are explained in detailed next.

### 1.1. Construction of the continents data

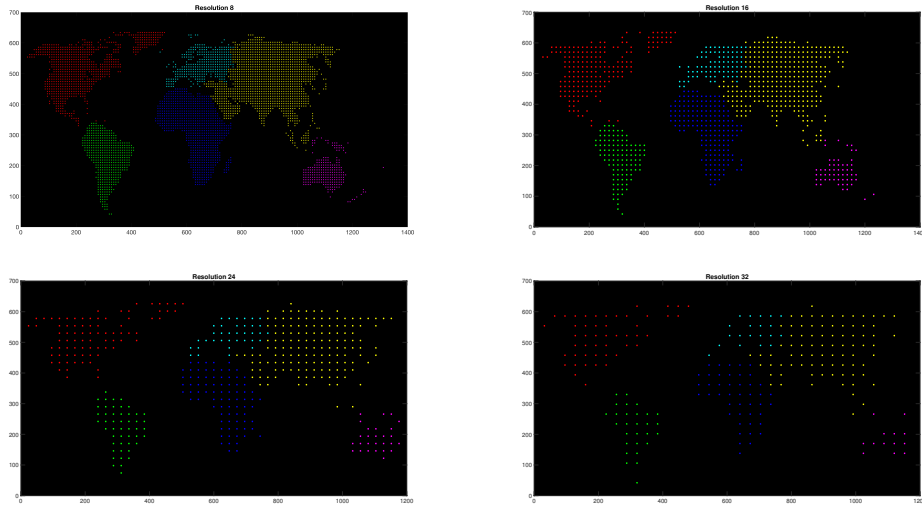
The function `construct_continents` is in charge of generating the required data for each one of the regions in the world map. There are six main regions as follows:

- North America
- South America
- Africa
- Europe
- Asia
- Australia

#### 1.1.1. Inputs

The function `construct_continents` (`I,resolution_grid`) has two main inputs as follows:

- `I`: this input corresponds to the image *continents.png* that is attached in the toolbox. This picture classifies the different regions by means of different colors.



**Figure 1:** Different resolutions selected in the function `resolution_grid`.

- `resolution_grid`: this input determines the resolution of the discretization of the map, i.e., it is associated to the number of nodes considered in the map. Figure 1 shows the world map for four different resolutions.

### 1.1.2. Outputs

The function

`[Datos_NorthAmerica, ..., Datos_Oceania]`

`=construct_continents` returns six outputs, each one of them corresponding to a region in the map. These outputs are the following:

- `Datos_NorthAmerica`
- `Datos_SouthAmerica`
- `Datos_Africa`
- `Datos_Europe`
- `Datos_Asia`
- `Datos_Oceania`.

Each output is a cluster composed of three components as follows:

- `Datos_NorthAmerica{1}`: this element returns the total number of nodes corresponding to the region North America. Similarly, the elements `Datos_SouthAmerica{1}`... `Datos_Oceania{1}` return the number of nodes in the continents South America ... Australia, respectively. Notice that this number directly depends on the resolution selected in `resolution_grid`.
- `Datos_NorthAmerica{2}`: this element of the cluster returns a matrix of the x-y coordinates for each one of the nodes introduced in `Datos_NorthAmerica{1}` for the region North America. Similarly, coordinates for the nodes of other regions are obtained from `Datos_SouthAmerica{2}`... `Datos_Oceania{2}`
- `Datos_NorthAmerica{3}`: this element of the cluster returns the corresponding filtered region from the image `I` (see Figure 2). The filtered regions South America ... Australia can be obtained using the functions `Datos_SouthAmerica{3}` ... `Datos_Oceania{3}`, respectively.

## 1.2. Publication of the sets $\mathcal{S}$ , $\mathcal{I}$ , $\mathcal{R}$ , and $\mathcal{D}$ for the regions

The function `show_map` plots the discretized map by using the nodes constructed in the function `construct_continents`.

### 1.2.1. Inputs

The function `show_map(S,I,R,D,C,color)` has six inputs as follows:

- `S`: this input corresponds to the set of susceptible nodes for any selected region, e.g., `S_NorthAmerica`. These nodes are plotted with a desired color selected by the user and introduced in the last input of this function `color`
- `I`: this input corresponds to the set of infected nodes for any selected region, e.g., `I_NorthAmerica`. These nodes are always plotted with orange color.
- `R`: this input corresponds to the set of recovered nodes for any selected region, e.g., `R_NorthAmerica`. These nodes are always plotted with yellow color.
- `D`: this input corresponds to the set of dead nodes for any selected region, e.g., `D_NorthAmerica`. These nodes are always plotted with red color.

- **C**: this input corresponds to the coordinates of the nodes for the whole world map, e.g., `C= [Datos_NorthAmerica{2}, ..., Datos_Oceania{2}]`
- **color**: this input determines the color for the susceptible nodes, e.g., `[0,0,1]` plots the nodes with blue color.

### 1.2.2. Outputs

The function `show_map` does not have any numerical output. Instead, this function generates the plot of the map with the characteristic selected in the inputs. Figure 5 shows an example.

## 1.3. Computation of a neighborhood set around a node

This function allows computing a set around a certain node. This function is fundamental in order to compute the set of susceptible nodes around a sick node to propagate the virus.

### 1.3.1. Inputs

The function `neighbor(agent, radius, xpos, ypos)` has four inputs as follows:

- **agent**: this input is given by any node from the discretization of the map. This node can belong to any of the six regions.
- **radius**: this scalar value allows determining the size of the neighborhood. This parameter allows configuring either the local or long-distance propagation of the virus.
- **xpos**: this entry corresponds to the x coordinates for the whole world map, i.e., `xpos=C(:,1)`
- **ypos**: this entry corresponds to the y coordinates for the whole world map, i.e., `ypos=C(:,2)`

### 1.3.2. Outputs

The function `N = neighbor` has a unique output. This output `N` is a set of nodes corresponding to the neighborhood set of `agent`. See Figure 5.

## 1.4. Generation of the age distribution

The function `show_age` publishes the world map showing the distribution of three age ranges defined by `age1`, `age2`, and `age3`.

#### 1.4.1. Inputs

The function `show_age(C, age1, age2, age3)` has four inputs described as follows:

- **C**: this input corresponds to the matrix of coordinates for all the nodes in the world map as in the function `show_map(S, I, R, D, C, color)`, i.e., `C= [Datos_NorthAmerica{2}, ..., Datos_Oceania{2}]`
- **age1**: set of nodes with age in the range  $[0, 39]$
- **age2**: set of nodes with age in the range  $[40, 69]$
- **age3**: set of nodes with age greater than 70

#### 1.4.2. Outputs

The function `show_age` does not have any numerical output. Instead, this function generates the plot of the map with the age distribution for the three age ranges. Figure 6 shows the distribution of ages for the six regions and Figure 7 shows the distribution of the ages in the map for the whole world.

#### 1.5. Computation of the flight connections

The function `flight_connections` computes the set of nodes belonging to the regions to which a node can travel. This function allows computing the long-distance propagation of the virus by means of flights.

##### 1.5.1. Inputs

The function `flight_connections(A, S_NorthAmerica, ..., S_Oceania)` has seven inputs as follows:

- **A**: this input is an adjacency matrix  $A \in \{0, 1\}^{6 \times 6}$  describing the possible intercontinental transmission among the different regions. For example, Figure 8 shows a multi-region connectivity given by the following adjacency matrix

$$A = \begin{pmatrix} 0 & 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \end{pmatrix}$$

and Figure 8 shows an scenario with  $A = \mathbf{0}$ , i.e., without intercontinental connections.

- **S**: this input corresponds to the set of nodes for each region, i.e., `S_NorthAmerica, ..., S_Oceania`

#### 1.5.2. Outputs

The function

`[fc_NorthAmerica, ..., fc_Oceania]`  
`=flight_connections` has six outputs corresponding to each region as follows:

- **fc\_NorthAmerica**: this output is the set of nodes to which an agent belonging to the region North America can move to. In other words, a sick agent belonging to the region North America could infect an agent belonging to the set `fc_NorthAmerica`. This set is determined by using the adjacency matrix  $A$ .
- **fc\_Oceania**: the interpretation of this set is the same as for the set `fc_NorthAmerica` but for the continent Australia.

#### 1.6. Computation of the virus propagation

The function `update` is in charge of updating all the sets  $\mathcal{S}$ ,  $\mathcal{I}$ ,  $\mathcal{R}$ , and  $\mathcal{D}$  for all the regions.

##### 1.6.1. Inputs

The function

`update(S,I,R,D,xpos,ypos,`  
`flight_connections,p,Age)` has nine inputs:

- **S**: this input corresponds to the set of susceptible nodes for any selected region, e.g., `S_NorthAmerica`.
- **I**: this input corresponds to the set of infected nodes for any selected region, e.g., `I_NorthAmerica`.
- **R**: this input corresponds to the set of recovered nodes for any selected region, e.g., `R_NorthAmerica`.
- **D**: this input corresponds to the set of dead nodes for any selected region, e.g., `D_NorthAmerica`.
- **xpos**: this entry corresponds to the x coordinates for the whole world map, i.e., `xpos=C(:,1)`

- `ypos`: this entry corresponds to the y coordinates for the whole world map, i.e., `xpos=C(:,2)`
- `flight_connections`: this is the set of agents that can be infected from other regions because of flights and connectivity of continents, e.g., `fc_NorthAmerica`
- `p`: this input is the set of transition probabilities  $p = [p1, p2, p31, p32, p33, p4, p5]$  in the Markov chain as follows:
  - `p1`: probability that a susceptible agent gets infected
  - `p2`: probability that the sick agent infects an agent from other regions (because of flight connectivity)
  - `p31`: probability of death for a sick agent (age-dependent) [0-39]
  - `p32`: probability of death for a sick agent (age-dependent) [40-69]
  - `p33`: probability of death for a sick agent (age-dependent) [70+]
  - `p4`: probability that a sick agent gets recovered
  - `p5`: probability that a recovered agent gets sick again
- `Age`: this is the vector of ages for each region

#### 1.6.2. Outputs

The function

`[S_dif, I_dif, R_dif, D_dif, S, I, R, D, FSA, Flag] = update` has ten outputs as follows:

- `S_dif`: this output corresponds to the changes that the set of susceptible nodes had
- `I_dif`: this output corresponds to the changes that the set of infected nodes had
- `R_dif`: this output corresponds to the changes that the set of recovered nodes had
- `D_dif`: this output corresponds to the changes that the set of dead nodes had
- `S`: this output corresponds to the updated set of susceptible nodes for any selected region, e.g., `S_NorthAmerica`.

- I: this output corresponds to the updated set of infected nodes for any selected region, e.g., `I_NorthAmerica`.
- R: this output corresponds to the updated set of recovered nodes for any selected region, e.g., `R_NorthAmerica`.
- D: this output corresponds to the updated set of dead nodes for any selected region, e.g., `D_NorthAmerica`.
- FSA: this is a unique agent from the set `flight_connections`, for example `fc_NorthAmerica`, that is in risk of getting infected
- Flag: this value indicates if FSA got infected, i.e., if `Flag=1` then FSA got infected

## 2. Illustrative Examples

Once the main functions of the toolbox have been introduced, we present different examples in order to illustrate how they can be effectively used. The proposed examples show the usage of the functions progressively one by one until the last example presents a simulation of the propagation of the virus in the world divided into six different continents.

### 2.1. Example 1

The main objective of this example is to present the construction of the continents with different resolutions and computation of X-Y coordinates.

```

1 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
3 %%% Authors: J. Barreiro-Gomez, S. E. Choutri, and H. Tembine
4 %%% Learning & Game Theory Laboratory (L&G Lab)
5 %%% Center on Stability, Instability and Turbulence (SITE)
6 %%% NYUAD 2020
7 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
8 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
9 clear all
10 close all
11 clc
12 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
13 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
14 I = imread('continents.png') ; % The reference image is ...
    imported
15 resolution_grid = 8 ; % This defines the resolution

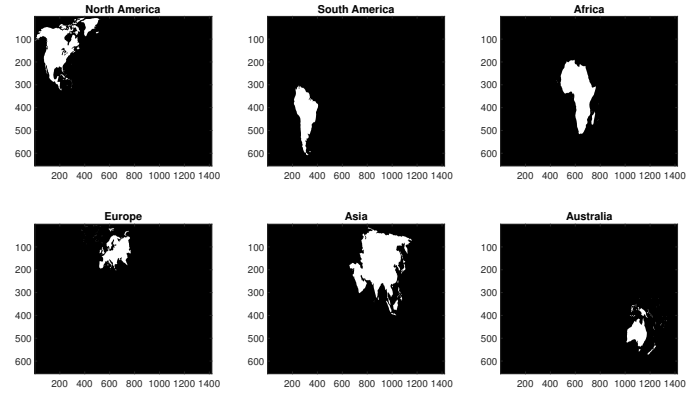
```



```

16 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
17 [Datos_NorthAmerica,Datos_SouthAmerica,...
18 Datos_Africa,Datos_Europe,Datos_Asia,...
19 Datos_Oceania]...
20 = construct_continents(I,resolution_grid) ; % Data per ...
    continent are generated
21 %%% Datos are organized as follows: (1) Number of nodes ...
    in the continent,
22 %%% (2) Coordinates vector, and (3) Map of the continent
23 C = [Datos_NorthAmerica{2};
24 Datos_SouthAmerica{2};
25 Datos_Africa{2};
26 Datos_Europe{2};
27 Datos_Asia{2};
28 Datos_Oceania{2}] ; % This is the vector of coordinates ...
    for the entire world
29 xpos = C(:,1) ; % Position in x axis
30 ypos = C(:,2) ; % Position in y axis
31 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
32 %%% We plot the continents to show how the map was ...
    constructed.
33 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
34 fz = 20 ; %fontsize
35 figure(1)
36 subplot(2,3,1)
37 image(Datos_NorthAmerica{3})
38 colormap(gray)
39 title('North America','fontsize',fz)
40 set(gca,'FontSize',fz)
41 %
42 subplot(2,3,2)
43 image(Datos_SouthAmerica{3})
44 colormap(gray)
45 title('South America','fontsize',fz)
46 set(gca,'FontSize',fz)
47 %
48 subplot(2,3,3)
49 image(Datos_Africa{3})
50 colormap(gray)
51 title('Africa','fontsize',fz)
52 set(gca,'FontSize',fz)
53 %
54 subplot(2,3,4)
55 image(Datos_Europe{3})
56 colormap(gray)
57 title('Europe','fontsize',fz)
58 set(gca,'FontSize',fz)
59 %
60 subplot(2,3,5)

```



**Figure 2:** Figure 1 generated by the code in Example 1.

```

61 image(Datos_Asia{3})
62 colormap(gray)
63 title('Asia','fontsize',fz)
64 set(gca,'FontSize',fz)
65 %
66 subplot(2,3,6)
67 image(Datos_Oceania{3})
68 colormap(gray)
69 title('Australia','fontsize',fz)
70 set(gca,'FontSize',fz)
71 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
72 figure(2)
73 image(Datos_NorthAmerica{3}+...
74 Datos_SouthAmerica{3}+Datos_Africa{3}+...
75 Datos_Europe{3}+...
76 Datos_Asia{3}+Datos_Oceania{3})
77 colormap(gray)
78 title('World','fontsize',fz)
79 set(gca,'FontSize',fz)
80 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

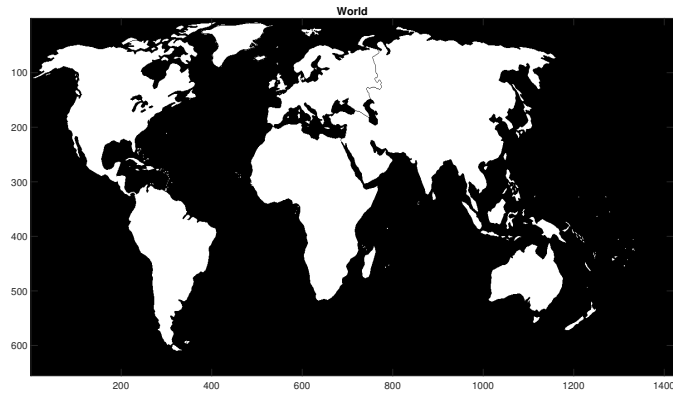
## 2.2. Example 2

The main objective of this example is to present the construction of the following sets per continent: S = susceptible, I = infected, R = recovered, and D = dead, and how to plot the sets with different colors in the map.

```

1 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
3 %%% Authors: J. Barreiro-Gomez, S. E. Choutri, and H. Tembine

```



**Figure 3:** Figure 2 generated by the code in Example 1.

```

4  %%% Learning & Game Theory Laboratory (L&G Lab)
5  %%% Center on Stability, Instability and Turbulence (SITE)
6  %%% NYUAD 2020
7  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
8  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
9  clear all
10 close all
11 clc
12 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
13 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
14 I = imread('continents.png') ; % The reference image is ...
    imported
15 resolution_grid = 8 ; % This defines the resolution
16 [Datos_NorthAmerica,Datos_SouthAmerica,...
17 Datos_Africa,Datos_Europe,Datos_Asia,...
18 Datos_Oceania]...
19 = construct_continents(I,resolution_grid) ; % Data per ...
    continent are generated
20 %%% Datos are organized as follows: (1) Number of nodes ...
    in the continent,
21 %%% (2) Coordinates vector, and (3) Map of the continent
22 C = [Datos_NorthAmerica{2};
23 Datos_SouthAmerica{2};
24 Datos_Africa{2};
25 Datos_Europe{2};
26 Datos_Asia{2};
27 Datos_Oceania{2}] ; % This is the vector of coordinates ...
    for the entire world
28 xpos = C(:,1) ; % Position in x axis
29 ypos = C(:,2) ; % Position in y axis
30 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
31 S_NorthAmerica = 1:Datos_NorthAmerica{1} ;

```

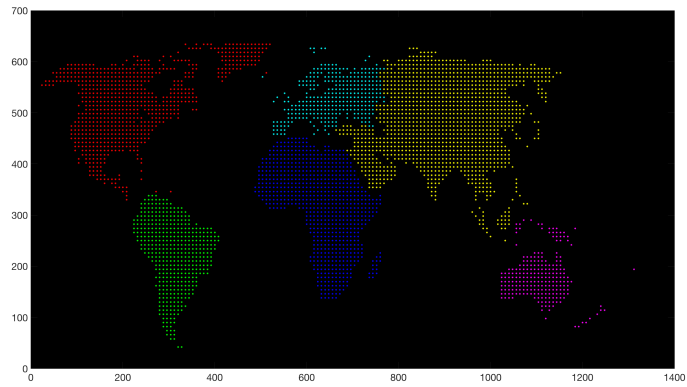
```

32 S_SouthAmerica = Datos_NorthAmerica{1}+...
33 (1:Datos_SouthAmerica{1}) ;
34 S_Africa = (Datos_NorthAmerica{1}+...
35 Datos_SouthAmerica{1})+(1:Datos_Africa{1}) ;
36 S_Europe = (Datos_NorthAmerica{1}+...
37 Datos_SouthAmerica{1}+Datos_Africa{1})+...
38 (1:Datos_Europe{1}) ;
39 S_Asia = (Datos_NorthAmerica{1}+...
40 Datos_SouthAmerica{1}+Datos_Africa{1}+...
41 Datos_Europe{1})+(1:Datos_Asia{1}) ;
42 S_Oceania = (Datos_NorthAmerica{1}+...
43 Datos_SouthAmerica{1}+Datos_Africa{1}+...
44 Datos_Europe{1}+Datos_Asia{1})+...
45 (1:Datos_Oceania{1}) ;
46 fz = 20 ; %fontsize
47 figure(1)
48 show_map(S_NorthAmerica,[],[],[],C,[1,0,0])
49 hold on
50 show_map(S_SouthAmerica,[],[],[],C,[0,1,0])
51 show_map(S_Africa,[],[],[],C,[0,0,1])
52 show_map(S_Europe,[],[],[],C,[0,1,1])
53 show_map(S_Asia,[],[],[],C,[1,1,0])
54 show_map(S_Oceania,[],[],[],C,[1,0,1])
55 set(gca,'color',[0,0,0]);
56 set(gca,'FontSize',fz)
57 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
58 agent_i = 350 ;
59 radius_i = 20 ;
60 agent_d = 520 ;
61 radius_d = 10 ;
62 S_NorthAmerica = 1:Datos_NorthAmerica{1} ;
63 I_NorthAmerica = neighbor(agent_i,radius_i,xpos,ypos) ;
64 R_NorthAmerica = 500 ;
65 D_NorthAmerica = neighbor(agent_d,radius_d,xpos,ypos) ;
66 color = [0,0,1] ;
67 figure(2)
68 show_map(S_NorthAmerica,I_NorthAmerica,...
69 R_NorthAmerica,D_NorthAmerica,C,color)
70 set(gca,'color',[0,0,0]);
71 set(gca,'FontSize',fz)
72 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

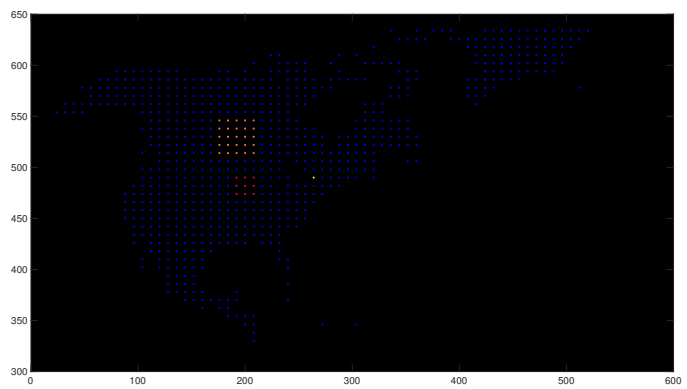
```

### 2.3. Example 3

The main goal of this example is to show how do we generate age for nodes representing the world. For illustration, we use a set of normal distributions to model the age in each continent. However, one can use any other



**Figure 4:** Figure 1 generated by the code in Example 2.



**Figure 5:** Figure 2 generated by the code in Example 2.

distributions such as the exponential distribution. We made the choice of the distribution as part of the parameter that the user can change.

```

1  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
2  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
3  %%% Authors: J. Barreiro-Gomez, S. E. Choutri, and H. Tembine
4  %%% Learning & Game Theory Laboratory (L&G Lab)
5  %%% Center on Stability, Instability and Turbulence (SITE)
6  %%% NYUAD 2020
7  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
8  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
9  clear all
10 close all
11 clc
12 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
13 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
14 I = imread('continents.png') ; % The reference image is ...
    imported
15 resolution_grid = 8 ; % This defines the resolution
16 [Datos_NorthAmerica,Datos_SouthAmerica,...
17 Datos_Africa,Datos_Europe,Datos_Asia,...
18 Datos_Oceania]...
19 = construct_continents(I,resolution_grid) ; % Data per ...
    continent are generated
20 %%% Datos are organized as follows: (1) Number of nodes ...
    in the continent,
21 %%% (2) Coordinates vector, and (3) Map of the continent
22 C = [Datos_NorthAmerica{2};
23 Datos_SouthAmerica{2};
24 Datos_Africa{2};
25 Datos_Europe{2};
26 Datos_Asia{2};
27 Datos_Oceania{2}] ; % This is the vector of coordinates ...
    for the entire world
28 xpos = C(:,1) ; % Position in x axis
29 ypos = C(:,2) ; % Position in y axis
30 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
31 S_NorthAmerica = 1:Datos_NorthAmerica{1} ;
32 S_SouthAmerica = Datos_NorthAmerica{1}+...
    (1:Datos_SouthAmerica{1}) ;
33 S_Africa = (Datos_NorthAmerica{1}+...
    Datos_SouthAmerica{1})+(1:Datos_Africa{1}) ;
34 S_Europe = (Datos_NorthAmerica{1}+...
    Datos_SouthAmerica{1}+Datos_Africa{1})+...
    (1:Datos_Europe{1}) ;
35 S_Asia = (Datos_NorthAmerica{1}+...
    Datos_SouthAmerica{1}+Datos_Africa{1}+...
    Datos_Europe{1})+(1:Datos_Asia{1}) ;

```

```

42 S_Oceania = (Datos_NorthAmerica{1}+...
43 Datos_SouthAmerica{1}+Datos_Africa{1}+...
44 Datos_Europe{1}+Datos_Asia{1}))+...
45 (1:Datos_Oceania{1}) ;
46 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
47 %%% Here we use an arbitrary numerical example to explain ...
48 %%% the use of the
49 %%% tool. Nevertheless, real mean and variance age for ...
50 %%% the different
51 %%% regions should be introduced
52 age_mu_NA = 40; % mean age in NorthAmerica
53 age_sigma_NA = 20; % variance age in NorthAmerica
54 age_NA = max(0,normrnd(age_mu_NA,...
55 age_sigma_NA,1,Datos_NorthAmerica{1})); % vector age in ...
56 NorthAmerica
57 %
58 age_mu_SA = 38; % mean age in SouthAmerica
59 age_sigma_SA = 30; % variance age in SouthAmerica
60 age_SA = max(0,normrnd(age_mu_SA,...
61 age_sigma_SA,1,Datos_SouthAmerica{1})); % vector age in ...
62 SouthAmerica
63 %
64 age_mu_A = 35; % mean age in Africa
65 age_sigma_A = 22; % variance age in Africa
66 age_A = max(0,normrnd(age_mu_A,...
67 age_sigma_A,1,Datos_Africa{1})); % vector age in Africa
68 %
69 age_mu_E = 29; % mean age in Europe
70 age_sigma_E = 30; % variance age in Europe
71 age_E = max(0,normrnd(age_mu_E,...
72 age_sigma_E,1,Datos_Europe{1})); % vector age in Europe
73 %
74 age_mu_As = 42; % mean age in Asia
75 age_sigma_As = 30; % variance age in Asia
76 age_As = max(0,normrnd(age_mu_As,...
77 age_sigma_As,1,Datos_Asia{1})); % vector age in Asia
78 %
79 age_mu_O = 33; % mean age in Australia
80 age_sigma_O = 23; % variance age in Australia
81 age_O = max(0,normrnd(age_mu_O,...
82 age_sigma_O,1,Datos_Oceania{1})); % vector age in Australia
83 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
84 %%% Histograms corresponding to the ages per region
85 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
86 fz = 20 ; %fontsize
87 figure(1)
88 subplot(2,3,1)
89 histogram(age_NA)
90 title('North America','fontsize',fz)

```

```

87 set(gca,'FontSize',fz)
88 subplot(2,3,2)
89 histogram(age_SA)
90 title('South America','fontsize',fz)
91 set(gca,'FontSize',fz)
92 subplot(2,3,3)
93 histogram(age_A)
94 title('Africa','fontsize',fz)
95 set(gca,'FontSize',fz)
96 subplot(2,3,4)
97 histogram(age_E)
98 title('Europe','fontsize',fz)
99 set(gca,'FontSize',fz)
100 subplot(2,3,5)
101 histogram(age_As)
102 title('Asia','fontsize',fz)
103 set(gca,'FontSize',fz)
104 subplot(2,3,6)
105 histogram(age_O)
106 title('Australia','fontsize',fz)
107 set(gca,'FontSize',fz)
108 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
109 %%% Ages in the map
110 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
111 Age = [age_NA,age_SA,age_A,age_E,age_As,age_O] ;
112 age1 = find(Age<40) ;
113 age2 = find((Age≥40)&(Age<70)) ;
114 age3 = find(Age≥70) ;
115 figure(2)
116 show_age(C,age1,age2,age3)
117 title('Ages : 0–39 = Red, 40–69 = Blue, 70+ = ...
    Green','fontsize',fz)
118 set(gca,'color',[0,0,0]);
119 set(gca,'FontSize',fz)
120 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

#### 2.4. Example 4

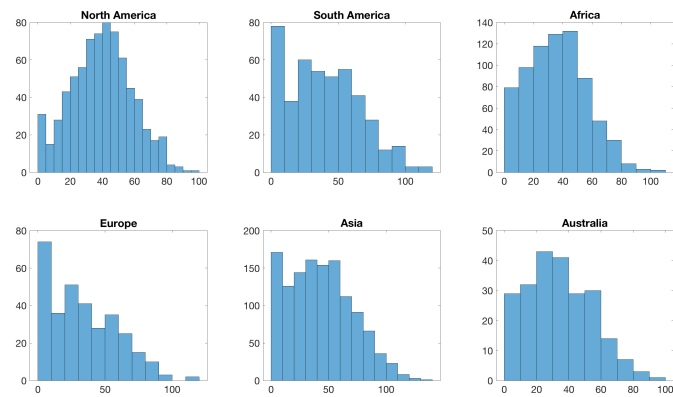
First, we introduce the function named *parameters* in charge of the simulation settings.

```

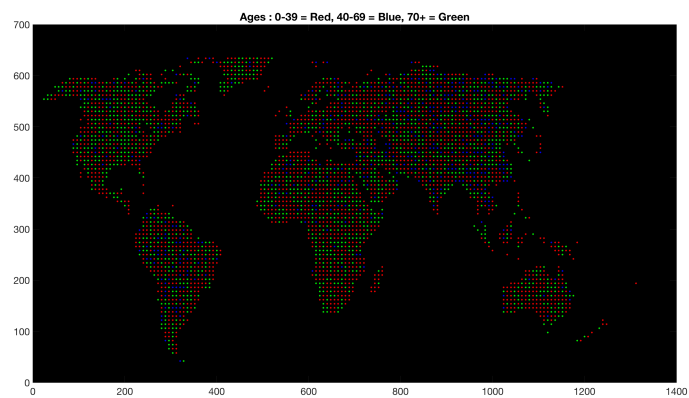
1 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
3 %%% Authors: J. Barreiro-Gomez, S. E. Choutri, and H. Tembine
4 %%% Learning & Game Theory Laboratory (L&G Lab)
5 %%% Center on Stability, Instability and Turbulence (SITE)
6 %%% NYUAD 2020
7 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

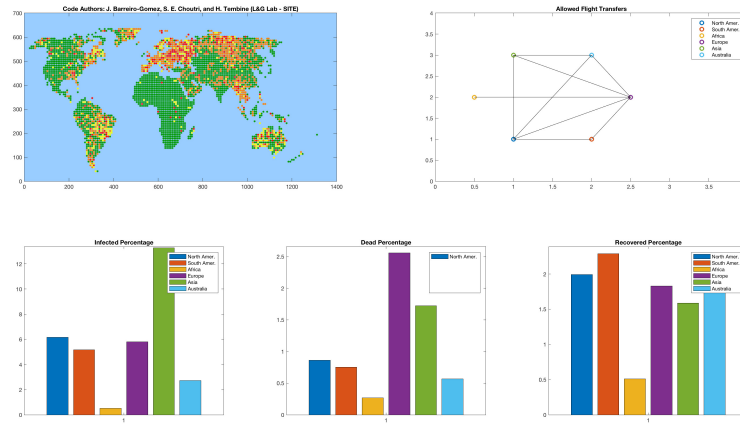




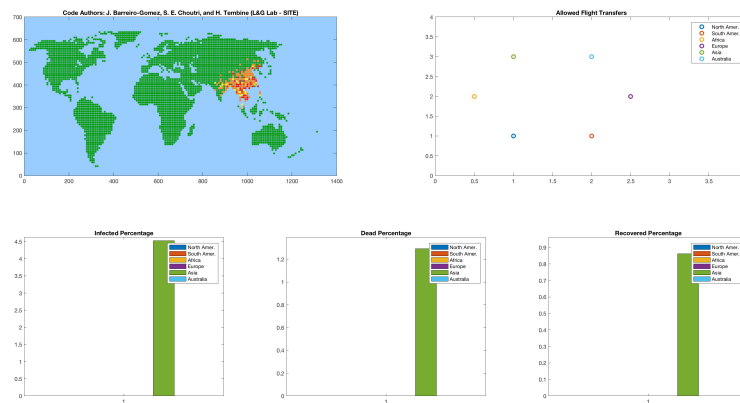
**Figure 6:** Figure 1 generated by the code in Example 3.



**Figure 7:** Figure 2 generated by the code in Example 3.



**Figure 8:** Figure 1 generated by the code in Example 4.



**Figure 9:** Figure 2 generated by the code in Example 4.

```

8 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
9 %%% In this code the parameters are introduced for the ...
   whole simulation
10 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
11 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
12 I = imread('continents.png') ; % The reference image is ...
   imported
13 resolution_grid = 8 ; % This defines the resolution
14 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
15 [Datos_NorthAmerica,Datos_SouthAmerica,...
16 Datos_Africa,Datos_Europe,Datos_Asia,...
17 Datos_Oceania]...
18 = construct_continents(I,resolution_grid) ; % Data per ...
   continent are generated
19 %%% Datos are organized as follows: (1) Number of nodes ...
   in the continent,
20 %%% (2) Coordinates vector, and (3) Map of the continent
21 C = [Datos_NorthAmerica{2};
22      Datos_SouthAmerica{2};
23      Datos_Africa{2};
24      Datos_Europe{2};
25      Datos_Asia{2};
26      Datos_Oceania{2}] ; % This is the vector of coordinates ...
   for the entire world
27 xpos = C(:,1) ; % Position in x axis
28 ypos = C(:,2) ; % Position in y axis
29 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
30 S_NorthAmerica = 1:Datos_NorthAmerica{1} ;
31 S_SouthAmerica = Datos_NorthAmerica{1}+...
   (1:Datos_SouthAmerica{1}) ;
32 S_Africa = (Datos_NorthAmerica{1}+...
   Datos_SouthAmerica{1})+(1:Datos_Africa{1}) ;
33 S_Europe = (Datos_NorthAmerica{1}+...
   Datos_SouthAmerica{1}+Datos_Africa{1})+...
   (1:Datos_Europe{1}) ;
34 S_Asia = (Datos_NorthAmerica{1}+...
   Datos_SouthAmerica{1}+Datos_Africa{1}+...
   Datos_Europe{1})+(1:Datos_Asia{1}) ;
35 S_Oceania = (Datos_NorthAmerica{1}+...
   Datos_SouthAmerica{1}+Datos_Africa{1}+...
   Datos_Europe{1}+...
   Datos_Asia{1})+(1:Datos_Oceania{1}) ;
36 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
37 %%% Here we use an arbitrary numerical example to explain ...
   the use of the
38 %%% tool. Nevertheless, real mean and variance age for ...
   the different
39 %%% regions should be introduced
40 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
41 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

50 age_mu_NA = 40; % mean age in NorthAmerica
51 age_sigma_NA = 20; % variance age in NorthAmerica
52 age_NA = max(0,normrnd(age_mu_NA,...
53 age_sigma_NA,1,Datos_NorthAmerica{1})) ; % vector age in ...
    NorthAmerica
54 %
55 age_mu_SA = 38; % mean age in SouthAmerica
56 age_sigma_SA = 30; % variance age in SouthAmerica
57 age_SA = max(0,normrnd(age_mu_SA,...
58 age_sigma_SA,1,Datos_SouthAmerica{1})) ; % vector age in ...
    SouthAmerica
59 %
60 age_mu_A = 35; % mean age in Africa
61 age_sigma_A = 22; % variance age in Africa
62 age_A = max(0,normrnd(age_mu_A,...
63 age_sigma_A,1,Datos_Africa{1})) ; % vector age in Africa
64 %
65 age_mu_E = 29; % mean age in Europe
66 age_sigma_E = 30; % variance age in Europe
67 age_E = max(0,normrnd(age_mu_E,...
68 age_sigma_E,1,Datos_Europe{1})) ; % vector age in Europe
69 %
70 age_mu_As = 42; % mean age in Asia
71 age_sigma_As = 30; % variance age in Asia
72 age_As = max(0,normrnd(age_mu_As,...
73 age_sigma_As,1,Datos_Asia{1})) ; % vector age in Asia
74 %
75 age_mu_O = 33; % mean age in Australia
76 age_sigma_O = 23; % variance age in Australia
77 age_O = max(0,normrnd(age_mu_O,...
78 age_sigma_O,1,Datos_Oceania{1})) ; % vector age in Australia
79 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
80 Age = [age_NA,age_SA,age_A,age_E,...
81 age_As,age_O] ;
82 age1 = find(Age<40) ;
83 age2 = find((Age>=40)&(Age<70)) ;
84 age3 = find(Age>=70) ;
85 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
86 % Parameters to tune
87 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
88 %p = [pv1,pv2,pm31,pm32,pm33,pr4,p5]
89 %pv1 (Virality) probability of getting infected if ...
    neighbor of a sick agent
90 %pv2 (Virality) probability that the virus covers long ...
    distances (airplane)
91 %pm31 (Mortality) probability of death (age-dependent) [0-39]
92 %pm32 (Mortality) probability of death (age-dependent) [40-69]
93 %pm33 (Mortality) probability of death (age-dependent) [70+]
94 %pr4 (Recovery) probability of being recovered

```

```

95 %ps5 (Again Sick) probability of being sick after having ...
    been recovered
96 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
97 S_NorthAmerica = 1:Datos_NorthAmerica{1} ;
98 I_NorthAmerica = [] ;
99 R_NorthAmerica = [] ;
100 D_NorthAmerica = [] ;
101 p_NorthAmerica = [0.3,0.02,0.01,0.08,0.08,0.1,0.01] ;
102 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
103 S_SouthAmerica = Datos_NorthAmerica{1}+...
104 (1:Datos_SouthAmerica{1}) ;
105 I_SouthAmerica = [] ;
106 R_SouthAmerica = [] ;
107 D_SouthAmerica = [] ;
108 p_SouthAmerica = [0.3,0.02,0.01,0.08,0.08,0.1,0.01] ;
109 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
110 S_Africa = (Datos_NorthAmerica{1}+...
111 Datos_SouthAmerica{1})+(1:Datos_Africa{1}) ;
112 I_Africa = [] ;
113 R_Africa = [] ;
114 D_Africa = [] ;
115 p_Africa = [0.05,0.02,0.01,0.08,0.08,0.1,0.01] ;
116 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
117 S_Europe = (Datos_NorthAmerica{1}+...
118 Datos_SouthAmerica{1}+Datos_Africa{1})+...
119 (1:Datos_Europe{1}) ;
120 I_Europe = [] ;
121 R_Europe = [] ;
122 D_Europe = [] ;
123 p_Europe = [1,0.2,0.15,0.02,0.02,0.1,0.03] ;
124 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
125 S_Asia = (Datos_NorthAmerica{1}+...
126 Datos_SouthAmerica{1}+...
127 Datos_Africa{1}+Datos_Europe{1})+...
128 (1:Datos_Asia{1}) ;
129 I_Asia = 3442 ;
130 R_Asia = [] ;
131 D_Asia = [] ;
132 p_Asia = [1,0.2,0.15,0.02,0.02,0.1,0.03] ;
133 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
134 S_Oceania = (Datos_NorthAmerica{1}+...
135 Datos_SouthAmerica{1}+Datos_Africa{1}+...
136 Datos_Europe{1}+Datos_Asia{1})+...
137 (1:Datos_Oceania{1}) ;
138 I_Oceania = [] ;
139 R_Oceania = [] ;
140 D_Oceania = [] ;
141 p_Oceania = [0.1,0.02,0.005,0.08,0.08,0.1,0.01] ;
142 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

143 ite = 1000 ; % number of iterations
144 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
145 %%% Here user decides the posible flight connecvtions%
146 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
147 %%% North_America / South America / Africa / Europe / ...
    Asia / Oceania
148 A = [0 1 0 1 1 1 ;
149 1 0 0 1 0 0 ;
150 0 0 0 1 0 0 ;
151 1 1 1 0 1 1 ;
152 1 0 0 1 0 1 ;
153 1 0 0 1 1 0] ; % adjacency matrix defining possible flight ...
    connections
154 [fc_NorthAmerica,fc_SouthAmerica,...
155 fc_Africa,fc_Europe,fc_Asia,fc_Oceania] = ...
156 flight_connections(A,S_NorthAmerica,...
157 S_SouthAmerica,S_Africa,S_Europe,...
158 S_Asia,S_Oceania) ;
159 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

The following is the main code generates the whole simulation of the virus propagation.

```

1 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
3 %%% Authors: J. Barreiro-Gomez, S. E. Choutri, and H. Tembine
4 %%% Learning & Game Theory Laboratory (L&G Lab)
5 %%% Center on Stability, Instability and Turbulence (SITE)
6 %%% NYUAD 2020
7 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
8 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
9 clear all
10 close all
11 clc
12 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
13 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
14 %%% Parameters are uploaded
15 parameters
16 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
17 figure(1)
18 subplot(2,2,1)
19 set(gcf,'Position',[0,1000,1400,800])
20 set(gca,'color',[153,204,255]/255);
21 green = [0,153,0]/255 ;
22 show_map(S_NorthAmerica,...
23 I_NorthAmerica,R_NorthAmerica,...
24 D_NorthAmerica,C,green)
25 hold on

```

```

26 show_map(S_SouthAmerica,...
27 I_SouthAmerica,R_SouthAmerica,...
28 D_SouthAmerica,C,green)
29 show_map(S_Africa,...
30 I_Africa,R_Africa,...
31 D_Africa,C,green)
32 show_map(S_Europe,...
33 I_Europe,R_Europe,...
34 D_Europe,C,green)
35 show_map(S_Asia,...
36 I_Asia,R_Asia,...
37 D_Asia,C,green)
38 show_map(S_Oceania,...
39 I_Oceania,R_Oceania,...
40 D_Oceania,C,green)
41 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
42 for t = 1:ite
43 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
44 figure(1)
45 subplot(2,2,2)
46 graph_plot(A)
47 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
48 S = S_NorthAmerica ;
49 I = I_NorthAmerica ;
50 R = R_NorthAmerica ;
51 D = D_NorthAmerica ;
52 p = p_NorthAmerica ;
53 flight_connections = fc_NorthAmerica ;
54 [S_dif_NA,I_dif_NA,R_dif_NA,...
55 D_dif_NA,S_NorthAmerica,...
56 I_NorthAmerica,R_NorthAmerica,...
57 D_NorthAmerica,FSA_NA,Flag_NA] =...
58 update(S,I,R,D,xpos,ypos,...
59 flight_connections,p,Age) ;
60 %
61 S = S_SouthAmerica ;
62 I = I_SouthAmerica ;
63 R = R_SouthAmerica ;
64 D = D_SouthAmerica ;
65 p = p_SouthAmerica ;
66 flight_connections = fc_SouthAmerica ;
67 [S_dif_SA,I_dif_SA,R_dif_SA,...
68 D_dif_SA,S_SouthAmerica,...
69 I_SouthAmerica,R_SouthAmerica,...
70 D_SouthAmerica,...
71 FSA_SA,Flag_SA] =...
72 update(S,I,R,D,xpos,ypos,...
73 flight_connections,p,Age) ;
74 %

```

```

75 S = S_Africa ;
76 I = I_Africa ;
77 R = R_Africa ;
78 D = D_Africa ;
79 p = p_Africa ;
80 flight_connections = fc_Africa ;
81 [S_dif_A,I_dif_A,R_dif_A,...
82 D_dif_A,S_Africa,I_Africa,...
83 R_Africa,D_Africa,FSA_A,Flag_A] =...
84 update(S,I,R,D,xpos,ypos,...
85 flight_connections,p,Age) ;
86 %
87 S = S_Europe ;
88 I = I_Europe ;
89 R = R_Europe ;
90 D = D_Europe ;
91 p = p_Europe ;
92 flight_connections = fc_Europe ;
93 [S_dif_E,I_dif_E,R_dif_E,...
94 D_dif_E,S_Europe,I_Europe,...
95 R_Europe,D_Europe,FSA_E,Flag_E] =...
96 update(S,I,R,D,xpos,ypos,...
97 flight_connections,p,Age) ;
98 %
99 S = S_Asia ;
100 I = I_Asia ;
101 R = R_Asia ;
102 D = D_Asia ;
103 p = p_Asia ;
104 flight_connections = fc_Asia ;
105 [S_dif_As,I_dif_As,R_dif_As,...
106 D_dif_As,S_Asia,I_Asia,R_Asia,...
107 D_Asia,FSA_As,Flag_As] =...
108 update(S,I,R,D,xpos,ypos,...
109 flight_connections,p,Age) ;
110 %
111 S = S_Oceania ;
112 I = I_Oceania ;
113 R = R_Oceania ;
114 D = D_Oceania ;
115 p = p_Oceania ;
116 flight_connections = fc_Oceania ;
117 [S_dif_O,I_dif_O,R_dif_O,D_dif_O,...
118 S_Oceania,I_Oceania,R_Oceania,...
119 D_Oceania,FSA_O,Flag_O] = ...
120 update(S,I,R,D,xpos,ypos,...
121 flight_connections,p,Age) ;
122 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
123 FSA = [FSA_NA,FSA_SA,...

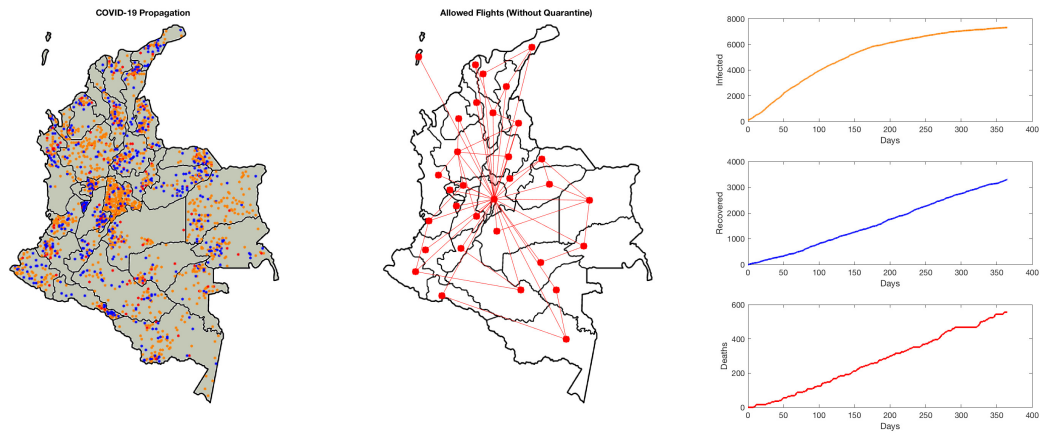
```



```

124 FSA_A,FSA_E,FSA_As,FSA_O] ;
125 %
126 I_dif = I_dif_NA ;
127 S = S_NorthAmerica ;
128 I = I_NorthAmerica ;
129 [I_dif_NA,I_NorthAmerica] =...
130 long_dist_update(FSA,I_dif,S,I) ;
131 %
132 I_dif = I_dif_SA ;
133 S = S_SouthAmerica ;
134 I = I_SouthAmerica ;
135 [I_dif_SA,I_SouthAmerica] =...
136 long_dist_update(FSA,I_dif,S,I) ;
137 %
138 I_dif = I_dif_A ;
139 S = S_Africa ;
140 I = I_Africa ;
141 [I_dif_A,I_Africa] =...
142 long_dist_update(FSA,I_dif,S,I) ;
143 %
144 I_dif = I_dif_E ;
145 S = S_Europe ;
146 I = I_Europe ;
147 [I_dif_E,I_Europe] =...
148 long_dist_update(FSA,I_dif,S,I) ;
149 %
150 I_dif = I_dif_As ;
151 S = S_Asia ;
152 I = I_Asia ;
153 [I_dif_As,I_Asia] =...
154 long_dist_update(FSA,I_dif,S,I) ;
155 %
156 I_dif = I_dif_O ;
157 S = S_Oceania ;
158 I = I_Oceania ;
159 [I_dif_O,I_Oceania] =...
160 long_dist_update(FSA,I_dif,S,I) ;
161 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
162 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
163 figure(1)
164 subplot(2,2,1)
165 set(gcf,'Position',[0,1000,1400,800])
166 set(gca,'color',[153,204,255]/255);
167 show_map([],I_dif_NA,R_dif_NA,...
168 D_dif_NA,C,green)
169 hold on
170 show_map([],I_dif_SA,R_dif_SA,...
171 D_dif_SA,C,green)
172 show_map([],I_dif_A,R_dif_A,...

```



**Figure 10:** Propagation of the virus in Colombia with migration constraints among the 32 departments (without quarantine).

```

173 D-dif_A,C,green)
174 show_map([],I-dif_E,R-dif_E,...
175 D-dif_E,C,green)
176 show_map([],I-dif_As,R-dif_As,...
177 D-dif_As,C,green)
178 show_map([],I-dif_O,R-dif_O,...
179 D-dif_O,C,green)
180 title('Code Authors: J. Barreiro-Gomez,...
181       S. E. Choutri, and H. Tembine (L&G Lab - SITE)')
182 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
183 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
184 bar_plots
185 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
186 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
187 %for slow = 1 : 3
188 %    F = getframe(gcf) ;
189 %    writeVideo(v,F) ;
190 %end
191 end
192 %close(v) ;

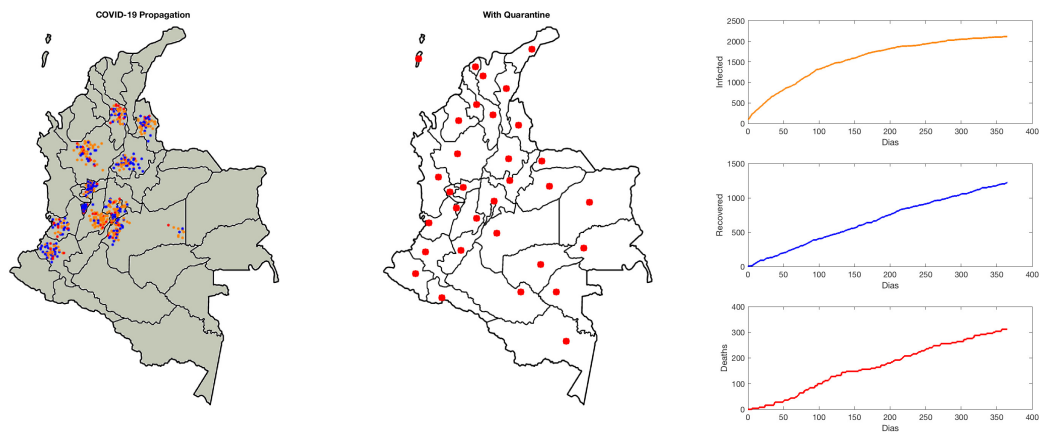
```

The last called function *bar plots* is as follows and it is in charged of the publication of results:

```

1 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
3 %%% Authors: J. Barreiro-Gomez, S. E. Choutri, and H. Tembine
4 %%% Learning & Game Theory Laboratory (L&G Lab)
5 %%% Center on Stability, Instability and Turbulence (SITE)

```



**Figure 11:** Propagation of the virus in Colombia with migration constraints among the 32 departments (with quarantine).

```

6  %%% NYUAD 2020
7  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
8  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
9  figure(1)
10 Total = Datos_NorthAmerica{1}+...
11 Datos_SouthAmerica{1}+Datos_Africa{1}+...
12 Datos_Europe{1}+Datos_Asia{1}+...
13 Datos_Oceania{1} ;
14 subplot(2,3,4)
15 y1 = 100*[(length(I_NorthAmerica)+...
16 length(R_NorthAmerica))/Total,...
17 (length(I_SouthAmerica)+...
18 length(R_SouthAmerica))/Total,...
19 (length(I_Africa)+length(R_Africa))/Total,...
20 (length(I_Europe)+length(R_Europe))/Total,...
21 (length(I_Asia)+length(R_Asia))/Total,...
22 (length(I_Oceania)+length(R_Oceania))/Total;
23 0,0,0,0,0,0];
24 bar(y1)
25 title('Infected Percentage')
26 legend('North Amer.', 'South Amer.',...
27 'Africa' , 'Europe', 'Asia', 'Australia')
28 axis([0.5 1.5 0 max(y1(1,:))+0.1])
29 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
30 subplot(2,3,5)
31 y1 = 100*[(length(D_NorthAmerica))/Total,...
32 (length(D_SouthAmerica))/Total,...
33 (length(D_Africa))/Total,...
34 (length(D_Europe))/Total,...
35 (length(D_Asia))/Total,...

```

```

36 (length(D_Oceania))/Total;
37 0,0,0,0,0,0];
38 bar(y1)
39 title('Dead Percentage')
40 legend('North Amer.', 'South Amer.', ...
41 'Africa' , 'Europe', 'Asia', 'Australia')
42 axis([0.5 1.5 0 max(y1(1,:))+0.1])
43 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
44 subplot(2,3,6)
45 y1 = 100*[(length(R_NorthAmerica))/Total,...
46 (length(R_SouthAmerica))/Total,...
47 (length(R_Africa))/Total,...
48 (length(R_Europe))/Total,...
49 (length(R_Asia))/Total,...
50 (length(R_Oceania))/Total;
51 0,0,0,0,0,0];
52 bar(y1)
53 title('Recovered Percentage')
54 legend('North Amer.', 'South Amer.',...
55 'Africa' , 'Europe', 'Asia', 'Australia')
56 axis([0.5 1.5 0 max(y1(1,:))+0.1])
57 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

### 2.5. Example 5

The presented toolbox can be easily adapted in order to consider any set of regions. To illustrate this, let us consider a unique country divided into several regions. In particular, let us consider Colombia, which is divided into 32 departments. Therefore, we consider not only the different transition rates for the departments, but also the migration constraints among them. Figure 10 shows the propagation of the virus during a year without quarantine whereas Figure 11 shows the propagation of the virus during a year with quarantine and no allowed domestic flights.