Subject : spread of COVID-19 in a city and control policy

In less than 3 months after its emergence in China, the COVID-19 pandemic has spread to at least 180 countries. In the absence of previous experience with this novel disease, public health authorities have been forced to experiment, in a short period of time and in a largely uninformed way, various combinations of interventions at different scales. These include ban on large gatherings, closure of schools, shops and public places, closure of borders, individual and collective containment, monitoring of population movements, social tracing, social distancing, etc.

However, as the pandemic is progressing, data are collected from various sources, allowing, on one hand, authorities to make informed adjustments to the current and planned interventions, but also revealing, on the other hand, an urgent need of tools and methodologies that enable fast analysis, understanding, comparison and forecasting of the effectiveness of the responses against COVID-19 across different communities and contexts. In this perspective, computational modeling appears as an invaluable leverage as it allows to explore *in silico* a range of intervention strategies before the potential phase of field implementation.

Your goal is to build such a model!

1. Spread of the disease

The model will be designed at the individual scale.
We will use a classical 4-steps SEIR model to represent the epidemiological states of individuals. Each individual is thus in one of the following states:

- S : **Susceptible**, meaning that the individual can be infected,
- E : **Exposed**, meaning that the individual has been infected, but cannot infect other individuals,
- I : **Infectious**, meaning that the individual has been infected and can infect other individuals,
- R : **Recovered**, meaning that the individual has recovered from the disease. We consider it cannot be infected anymore.

A S individual is infected by an I (with a given probability: *probability of transmission*) when they are close enough (in a *transmission distance*) and becomes in the state E. An E will become I after a given duration of time (*incubation period*). An I will become R after a given among of time (*infectious period*).

Model M1.1.

Implement a population of agents of species “Individuals”, with an attribute for its epidemic state. They move randomly in a continuous space (cf. moving skills, wander action). At each step, an I individual infects one of the S individuals agents in its transmission distance (with a given probability). Individuals also execute their own disease dynamics: when they are E, they become I after some steps and from I to R after another duration. These duration are different for each individual. Agents are displayed with a circle, with a colour depending on their epidemic state.
The initialisation creates 500 individuals, and 1 infected in the population.
Display the agents and plot the number of agents in each of the states.

Exploration E1.1. Effect of randomness.

Define a gui experiment, creating 10 experiments (with different seed values) and plot the evolution of the number of I individuals for each simulation.

Exploration E1.2. Impact of the number of individuals.

Define a gui experiment, creating 11 experiments, with the same seed value but with a number of individuals from 200 to 2000 (with a step of 200) and plot the evolution of the number of I individuals.

Exploration E1.3. Impact of the number of individuals.

Define 2 indicators:

- the cycle of the maximum number of infected peoples.
- The duration of the epidemic (when the number of Exposed and Infected is 0).

Define a batch experiment plotting the evolution of these indicators in function of the number of peoples. Save these values in a csv file.

Model M1.2. R0.

The R0 value represents the number of susceptible individuals an infected individual infects.
Modify the model so that each individual computes the number of individuals it has infected.
Define a GUI experiment that plots the min, max and average values of the R0 among the population over time.

2. Spread in a city with a heterogeneous population

The objective of this second part is to implement the disease spread in a realistic city, with a heterogeneous population. The inhabitants will have a daily agenda, that will depend on their age. The simulation will be made with an 1-hour simulation step. A consequence is that we will not model the precise mobility of people on the roads: people will move instantaneously from one building to another one.

Model M2.1. Realistic city

Import a shape file of buildings (you can reuse one of the building shape files used during the various tutorials (evacuation or traffic models), or another one of your choice). Building should have a type among: home, office, school, shops, coffee, restaurant and public park. You can generate them randomly in GAMA at initialisation[1]. Display the buildings with a colour depending on their type.

Model M2.2. Population

People are initialised in a building (their home) and will go work (in the morning) (and school building) in another building (of type industry or office) and come back home (in the afternoon).

Modify the epidemic dynamic so that an Infected individual can infect all individuals in the same building (and only these ones).

Exploration E2.1. Effect of randomness.

Same question as E1.1.

Model M2.3. Realistic Population

We want to initialise a realistic population: add to each individual a sex and an age attribute (chosen randomly). The buildings home will now contain a household (a set of agents). We make the hypothesis that each building contains only one household. We make the hypotheses on the households (you are free to explore internet to review these hypotheses to have more precise information) contains:

- one male and one female adult individuals (in age of working, so between 23 and 55 years old)
- From 0 to 3 kids (age below 22 years old)
- Possibly grand father and/or grand mother (individuals with age higher than 56 years old, who do not work to office or industry).

[1] Keep a rate of around 80-90% of buildings being homes, and at least 2 schools.

We will define a different agenda (set of activities of the day) for each age category (children, adult and retired people). An agenda will be a map associating to some of the hours fo the day an activity type (an activity is made in a building). As an example:

- children go to schools at 7AM, at 4PM the go the park and at 5PM go back home
- …

(define agenda for adults and retired individuals, to use all the kinds of buildings.)

For each home building, create a household at initialisation.

At each simulation step, agents will find the activity to do (if no activity at that time in the agenda, they do not move), randomly choose a building for this activity and move to it.

Exploration E2.2. Population characteristics.

Define a gui experiment, plotting (with histograms for example) the ratio male-female, the population distribution in terms of age and in terms on number of people.

Exploration E2.3. Epidemic plotting.

Define an experiment to plot epidemic spread (number of individuals in each states).

Model M2.4. Environmental transmission

The virus of the CoVid19 can survive in the environment few days and infect people even when they are not in contact with an infected people.

Modify buildings so that they can contain a virus load, that increases when infected people are in the building and decrease over time.

Exploration E2.4.

Define an experiment comparing the disease spread with and without environmental transmission.

3. Public health policy

Model M3.1. Authorities and policies.

We will now define two new species: the LocalAuthority and the Policy. The LocalAuthority will be in charge of deciding the policy and deciding when it is time to apply it. The trigger of this decision can be (i) time (a policy is applied at the step 0, at step N), (ii) when an infected individual appears in the population, (iii) when tests identify an infected individual… The authority can also chose to drop a policy in some conditions (e.g. stop containment after 15 days, 30 days …). The policies can include: (i) total move freedom, (ii) total lockdown, (iii) containment by ages, (iv) close schools, (v) wear masks…

Define this authority and at least one policy. Modify the model to make this policy impact individuals behaviours.

Exploration E3.1. Impacts of policies.
Implement experiments that are able to show the impact of the defined policy, of their applications and drop conditions.
Define experiments to compare effects with and without the policy.

Deliverables

- **1 zip file** containing all the shape files and 1 model file for each Model MX.Y. question (and related EX.Y.).
  Please zip directly the whole GAMA project containing everything.
- **Report**:
  - Explanation of what has been added that is not explicitly described in the subject (description of agendas …). In particular, describe the implemented policies.
  - For each exploration, screenshots and explanations of the results.

Annex values of epidemiological parameters.

Consider the following parameter values for CoVid19 epidemic dynamics. These are simplifications and adaptation from literature.

- Probability of transmission (between human beings and from buildings to human beings): 17%
- Probability for an Exposed to become Asymptomatic: 30%
- Reduction of the probability transmission for an Asymptomatic: 45%
- Reduction of the transmission probability by masks: 50%
- Incubation period (time in state E): from 3 to 10 days
- Infectious period (time in state I or Asymptomatic): from 10 to 30 days
- Tests: probability of true positive: 89% (i.e. a test as a probability of 89% to return that an individual is infected when it is infected).
- Tests: probability of true negative: 92% (i.e. a test as a probability of 92% to return that an individual is **not** infected when it is **not** infected).