Introduction
000

The model
00
000
0

Contagions
0
000
0

Exploring cases
0
00
0
000000

New use cases of the model
0

A new model
000

Final remarks
00

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# An Agent-Based Model to simulate the Covid-19 epidemic diffusion, with the use of Genetic Algorithms to optimize vaccinations

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## Outline

## Objectives of the model

- We propose an agent-based model to simulate the Covid-19 epidemic diffusion, with Susceptible, Infected, symptomatic, asymptomatic, and Recovered people: hence the name S.I.s.a.R. The scheme comes from S.I.R. models, with (i) infected agents categorized as symptomatic and asymptomatic and (ii) the places of contagion specified in a detailed way, thanks to agent-based modeling capabilities.

- The infection transmission is related to three factors: the infected person's characteristics and those of the susceptible one, plus those of the space in which contact occurs.

- The model includes the structural data of Piedmont, but it can be readily calibrated for other areas. The model manages a realistic calendar (e.g., national or local government decisions), via a script interpreter.

### Tool and links

- We use NetLogo, at https://ccl.northwestern.edu/netlogo/.
- S.I.s.a.R. is at https://terna.to.it/simul/SIsaR.html with information on model construction, the draft of a paper also reporting results, and an online executable version of the simulation program, built using NetLogo.
- A short paper is published at https://rofasss.org/2020/10/20/sisar/ G. Pescarmona, P. Terna, A. Acquadro, P. Pescarmona, G. Russo, and S. Terna. How Can ABM Models Become Part of the Policy-Making Process in Times of Emergencies—The SISAR Epidemic Model. *RofASSS*, 2020.

## The scale and the items

- 1 : 1000.

- Houses.
- Schools.
- Hospitals.
- Nursing homes,
- Factories.

# The interface and the information sheet



Figure 1: The interface

# The interface and the information sheet

### WHY THE NAME?

```
S - Susceptible
I - Infected
s - symptomatic
a - asymptomatic
R - Recovered
```

with capital letters referring the *classic* S.I.R. model, also in Wikipedia.

**Website**

The model has a website.

### PRELIMINARY NOTE

This is a simulation with random events, please do not take it as a sure forecasting machine: it is a reasoning machine, a sort of very complex "what if" mental experiment.

The New York Times offers us an analysis on the The Covid-19 Riddle: Why Does the Virus Wallop Some Places and Spare Others? (open link). At the end of the article, we read: *Roll of the Dice - Finally, most experts agree that there may be no single reason for some countries to be hit and others missed. The answer is likely to be some combination of the above factors, as well as one other mentioned by researchers: sheer luck.*

In the same way, in the simulations run with this model we can have very different outcomes as we change the initial seed of the random numbers. Those values are determining mainly the movements at a tiny scale and so the interactions-infections chains.

We can use the model in a comparative way, observing different range of results with different initial conditions (parameters).

Finally, to have a reference at an actual situation, the model is related to the Piedmont scale, with 4,350 agents vs. 4.35 millions of inhabitants. The scale 1 to 1000 is over-represented in the case of schools, with their classrooms with a realistic number of students, apartments with a realistic quantity of inhabitants, and likewise workspaces, hospitals, nursing homes.

We look also to the time series of the total infected people in Piedmont.

### VIEWING THE MODEL

In the desk version, we can use both the *continuous* view, observing all the agents' movements and the "on tick" one, faster but updating the screen only at the end of each tick. To set the view, we use a chooser in the top part of the screen.

In the web version we have uniquely the *on tick* feature.

The desk version also allows 3D view: right click on the map of the world and choose *Switch to 3D View*.

### HOW IT WORKS

#### Scripting capability

The code can manage a script to set the parameter modifications occurring while the simulation is running. Explanations in the right side of the interface.

The simulation starts at tick 1, but we can already set the initial values at tick 0.

**A trick:** (i) via **setup** set all the default values for the experiments at tick 0 and then (ii) modify those that we want change before hitting **go**.

#### Special item "flash"

With the "flash" item, followed by 1 or 2 or 3, we obtain a flash output in the window to the far right, with data at the beginning of the tick for: (1) total infected symptomatic people; (2) total infected asymptomatic people; (3) total infected symptomatic people in NH; (4) total infected asymptomatic people in NH;(5) total deceased.

#### Special item "activate check point"

With the "aCP" (activate checkpoint) item, followed by n with n in [1,6] as closed interval, we collect data at the tick of the aCP command. In BehaviorSpace, we can use the checkpoint data to the table of the results; we have six possible checkpoints, each reporting stocks of infected symptomatic people, infected asymptomatic people, deceased people. The data are at the beginning of the tick.
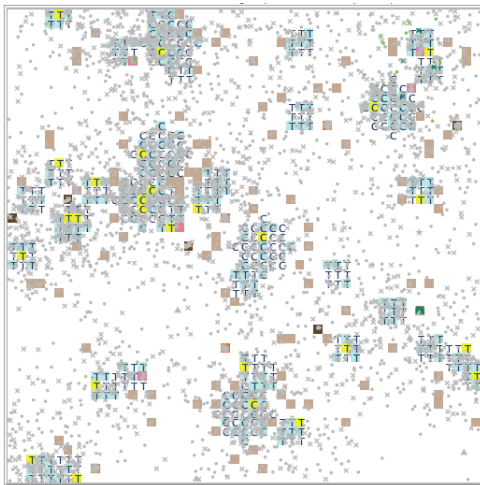
Figure 2: The information sheet, about 20 pages

## The world
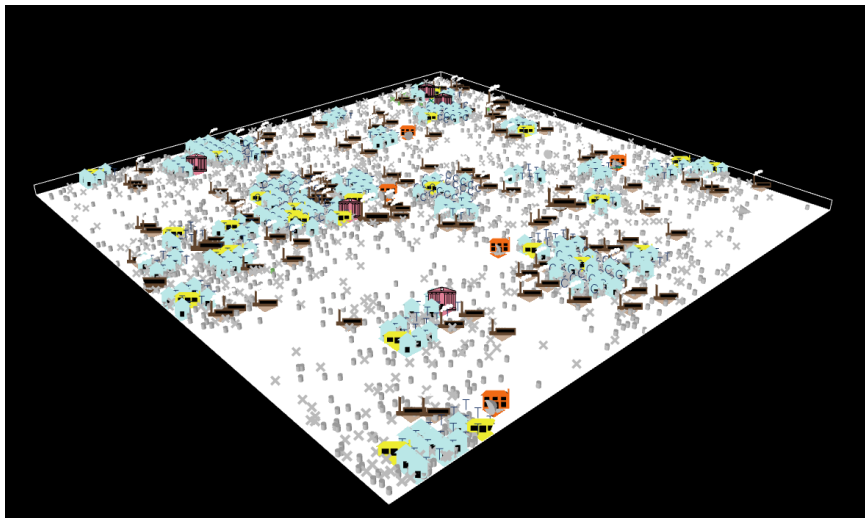


Figure 3: The world

# The world 3D



Figure 4: The world 3D

| Introduction | The model | Contagions | Exploring cases | New use cases of the model | A new model | Final remarks |
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| | oo● | o | o | | | |
| | | o | oooooo | | | |

# The agents



Figure 5: Probes to different agents

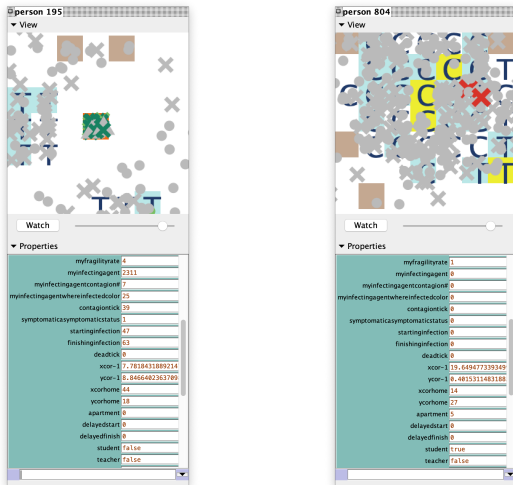| Introduction | The model | Contagions | Exploring cases | New use cases of the model | A new model | Final remarks |
|---|---|---|---|---|---|---|
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| | ooo | ooo | oo | | | |
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| | | | oooooo | | | |

## Contagion representation

- The model allows analyzing the sequences of contagions in simulated epidemics, reporting the places where the contagion occur.
- We represent each infecting agent as a horizontal segment with a vertical connections to another agent receiving the infection. We represent the infected agents via further segments at an upper layer.
- With colors, line thickness, and styles, we display multiple information.
- This enables understanding at a glance how an epidemic episode is developing. In this way, it is easier to reason about countermeasures and, thus, to develop intervention policies.
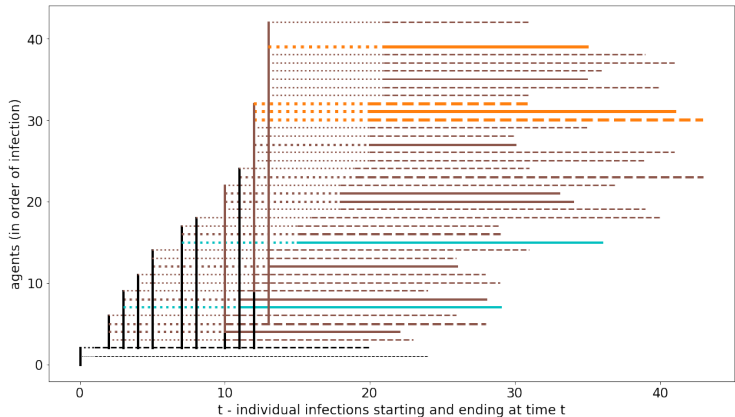
## An example (1/2)



Figure 6: A case with containment measures, first 40 infections: workplaces (brown) and nursing homes (orange) strictly interweaving
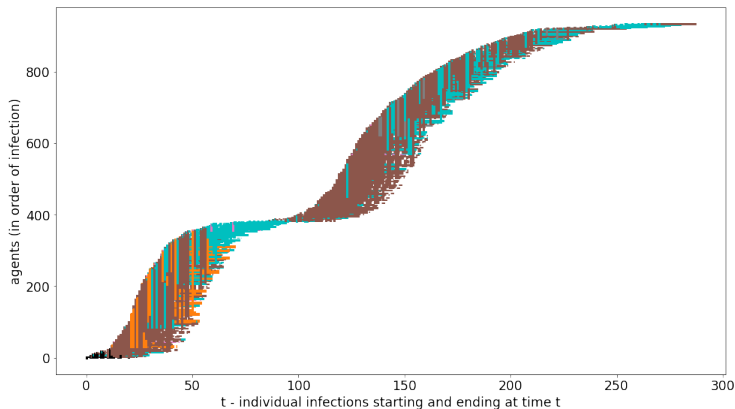
## An example (2/2), more contagions



Figure 7: A Case with containment measures, the whole epidemics: workplaces (brown) and nursing homes (orange) and then houses (cyan), with a bridge connecting two waves

# Other examples (i) on the left, an epidemic without containment measures; (ii) on the right, an epidemic with basic non-pharmaceutical containment measures
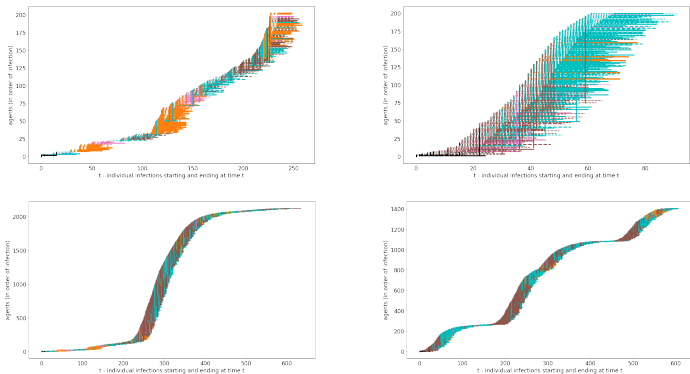


Figure 8: Two cases with initial and full periods

A contagion sequence suggesting policies: in Fig. 9 we can look both at the places where contagions occur and at the dynamics emerging with different levels of intervention.
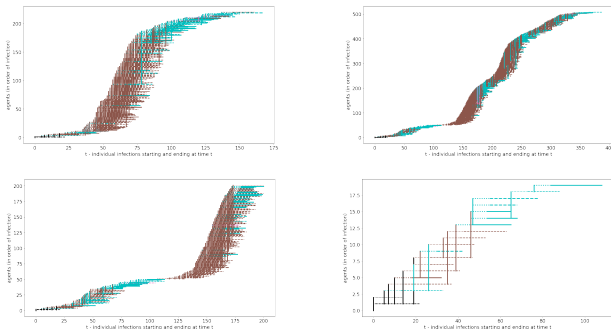


Figure 9: (*top left*) an epidemic with regular containment measures, showing a highly significant effect of workplaces (brown); (*top right*) the effects of stopping fragile workers at day 20, with a positive result, but home contagions (cyan) keep alive the pandemic, exploding again in workplaces (brown); (*bottom left*) the same analyzing the first 200 infections with evidence of the event around day 110 with the new phase due to a unique asymptomatic worker, and (*bottom right*) stopping fragile workers and any case of fragility at day 15, also isolating nursing homes

## Simulation batches

- We explore systematically the introduction of factual, counterfactual, and prospective interventions to control the spread of the contagions.

- Each simulation run—whose length coincides with the disappearance of symptomatic or asymptomatic contagion cases—is a datum in a wide scenario of variability in time and effects.

- Consequently, we need to represent compactly the results emerging from batches of simulation repetitions, to compare the consequences of the basic assumptions adopted for each specific batch.

- We use blocs of ten thousand repetitions. Besides summarizing the results with the usual statistical indicators, we adopt the technique of the heatmaps.

- Each heatmap reports the duration of each simulated epidemic in the *x* axis and the number of the symptomatic, asymptomatic, and deceased agents in the *y* axis. The *z* axis is represented by the colors, in logarithmic scale.

- In our batches we have 10,000 runs.

## Ten thousand epidemics without control in Piedmont

| | symptomatic | totalInfected&Deceased | duration |
|---|---|---|---|
| count | 10000.00 | 10000.00 | 10000.00 |
| mean | 969.46 | 2500.45 | 303.10 |
| std | 308.80 | 802.88 | 93.50 |



Figure 10: Without non-pharmaceutical containment measures

## Ten thousand epidemics with basic control in Piedmont

|  | symptomatic | totalInfected&Deceased | duration |
|---|---|---|---|
| count | 10000.00 | 10000.00 | 10000.00 |
| mean | 344.22 | 851.64 | 277.93 |
| std | 368.49 | 916.41 | 213.48 |



Figure 11: First wave with non-pharmaceutical containment measures

| Introduction | The model | Contagions | Exploring cases | New use cases of the model | A new model | Final remarks |
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| | ooo | ooo | oo | | | |
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| | | | oooooo | | | |

## Actual data



considering symptomatic and asymptomatic

200.0

considering symptomatic          considering symptomatic

33.3                                      37.5

6.1.20          9.20.20          12.15.20
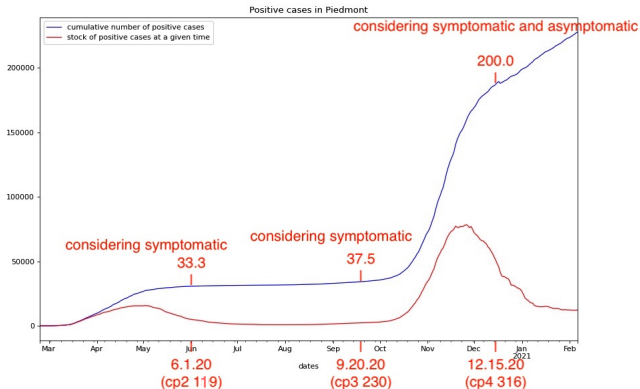(cp2 119)       (cp3 230)        (cp4 316)

Figure 12: Data in Piedmont

## Spontaneous second wave, without specific measures

**170** epidemics stable in Summer 2020 out of 10,000, rule: at Jun 1, 20 select if sym. (10, 70], actual v. 33.3 & at Sep 20, 20 select if sym. (20, 90], actual value 37.5; **140** at Dec 15, 20, rule: sym.+asym.>Sep 20, 20, actual value: 200.0.
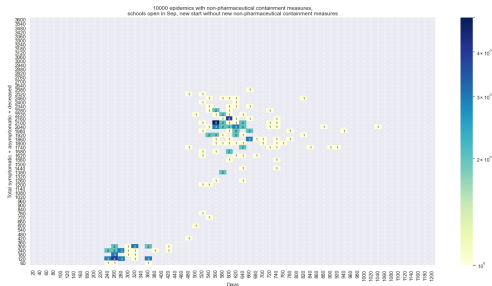


Figure 13: First wave with non-pharmaceutical containment measures, spontaneous second wave, without specific measures

| (1000) | Jun 1, 20 sym. | all | Sep 9, 20 sympt. | totalInf. | Dec 15, 20 sympt. | totalInf. | Feb 1, 21 sympt. | totalInf. | May 1, 21 sympt. | totalInf. | Dec 15, 20 to end sympt. | totalInf. | days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| count | 170.0 | 170.0 | 170.0 | 170.0 | 140.0 | 140.0 | 131.0 | 131.0 | 128.0 | 128.0 | 140.0 | 140.0 | 140.0 |
| mean | 37.9 | 100.2 | 60.4 | 159.3 | **248.4** | **648.7** | **432.2** | **1109.5** | **656.3** | **1655.5** | 701.4 | 1757.9 | 594.2 |
| std | 16.4 | 61.0 | 19.6 | 71.7 | 167.4 | 424.3 | 220.4 | 538.4 | 215.4 | 513.3 | 246.4 | 599.7 | 118.9 |

## Second w., new infections from outside, without specific measures

**1407** epidemics stable in Summer 2020 out of 10,000, rule: at Jun 1, 20 select if sym. (10, 70], actual v. 33.3 & at Sep 20, 20 select if sym. (20, 90], actual value 37.5; **1044** at Dec 15, 20, rule: sym.+asym.>Sep 20, 20, actual value: 200.0.
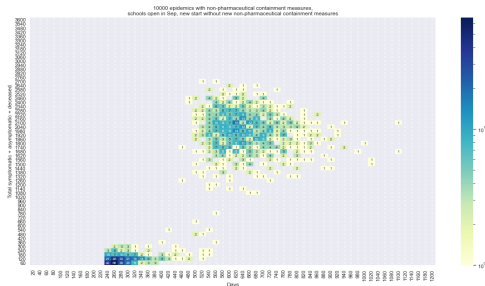


Figure 14: First wave with non-pharmaceutical containment measures, forcing the second wave, without specific measures

| (1000) | Jun 1, 20 sym. | all | Sep 9, 20 sympt. | totalInf. | Dec 15, 20 sympt. | totalInf. | Feb 1, 21 sympt. | totalInf. | May 1, 21 sympt. | totalInf. | Dec 15, 20 to end sympt. | totalInf. | days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| count | 1407.0 | 1407.0 | 1407.0 | 1407.0 | 1044.0 | 1044.0 | 1005.0 | 1005.0 | 980.0 | 980.0 | 1044.0 | 1044.0 | 1044.0 |
| mean | 35.6 | 72.7 | 40.0 | 84.1 | **180.4** | **462.1** | **354.1** | **900.4** | **623.8** | **1563.3** | 726.6 | 1810.9 | 620.9 |
| std | 14.1 | 42.6 | 16.7 | 52.8 | 134.6 | 354.6 | 213.8 | 535.4 | 217.9 | 527.0 | 221.9 | 544.0 | 110.8 |

## Second w., new infections from outside, with new specific measures

**1407** epidemics stable in Summer 2020 out of 10,000, rule: at Jun 1, 20 select if sym. (10, 70], actual v. 33.3 & at Sep 20, 20 select if sym. (20, 90], actual value 37.5; **874** at Dec 15, 20, rule: sym.+asym.>Sep 20, 20, actual value: 200.0.
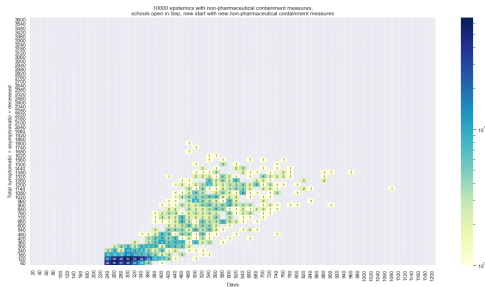


Figure 15: First wave with non-ph.containment measures, forcing the second wave, **with new specific non-ph. containment measures**

| (1000) | Jun 1, 20 sym. | all | Sep 9, 20 sympt. | totalInf. | Dec 15, 20 sympt. | totalInf. | Feb 1, 21 sympt. | totalInf. | May 1, 21 sympt. | totalInf. | Dec 15, 20 to end sympt. | totalInf. | days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| count | 1407.0 | 1407.0 | 1407.0 | 1407.0 | 874.0 | 874.0 | 719.0 | 719.0 | 523.0 | 523.0 | 874.0 | 874.0 | 874.0 |
| mean | 35.6 | 72.7 | 40.0 | 84.1 | **130.0** | 340.6 | **194.4** | **512.8** | **295.7** | **791.2** | 252.7 | 666.4 | 494.1 |
| std | 14.1 | 42.6 | 16.7 | 52.8 | 83.9 | 232.6 | 104.1 | 276.9 | 119.1 | 300.6 | 156.8 | 416.4 | 122.7 |

## Second w., new infect. from outside, with new specific meas. -20 days[1]

**1407** epidemics stable in Summer 2020 out of 10,000, rule: at Jun 1, 20 select if sym. (10, 70], actual v. 33.3 & at Sep 20, 20 select if sym. (20, 90], actual value 37.5; **769** at Dec 15, 20, rule: sym.+asym.>Sep 20, 20, actual value: 200.0.
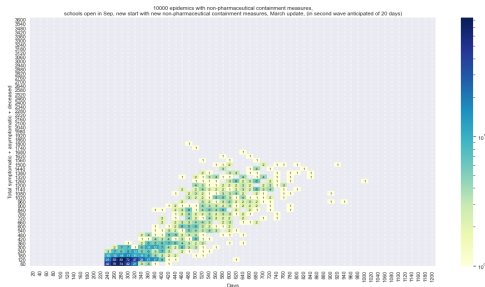


Figure 16: First wave with non-ph.cont. meas., forcing the second wave, **with new specific non-ph. cont. meas., 20 day anticipation**

| (1000) | Jun 1, 20<br>sym. | all | Sep 9, 20<br>sympt. | totalInf. | Dec 15, 20<br>sympt. | totalInf. | Feb 1, 21<br>sympt. | totalInf. | May 1, 21<br>sympt. | totalInf. | Dec 15, 20 to end<br>sympt. | totalInf. | days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| count | 1407.0 | 1407.0 | 1407.0 | 1407.0 | 769.0 | 769.0 | 637.0 | 637.0 | 471.0 | 471.0 | 769.0 | 769.0 | 769.0 |
| mean | 35.6 | 72.7 | 40.0 | 84.1 | 112.2 | 294.2 | 172.0 | 467.9 | 276.5 | 748.6 | 248.9 | 663.4 | 499.3 |
| std | 14.1 | 42.6 | 16.7 | 52.8 | 66.8 | 188.4 | 91.5 | 251.3 | 112.9 | 286.9 | 158.0 | 417.5 | 124.1 |

[1] Anticipation limit Oct 5.

# Sec. w., new infect. from outs., stop fragile people. 60 days from Oct. 5[2]

**1407** epidemics stable in Summer 2020 out of 10,000, rule: at Jun 1, 20 select if sym. (10, 70], actual v. 33.3 & at Sep 20, 20 select if sym. (20, 90], actual value 37.5; **886** at Dec 15, 20, rule: sym.+asym.>Sep 20, 20, actual value: 200.0.
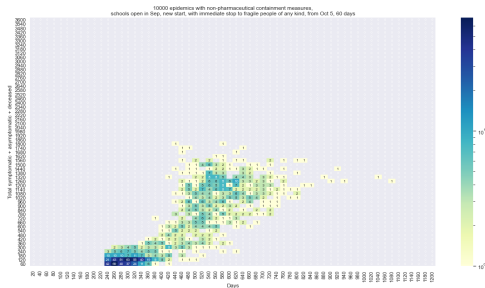


Figure 17: First wave with non-ph, cont, meas.; **in sec. w., uniquely stop fragile people, including fragile workers**

| (1000) | Jun 1, 20<br>sym. | all | Sep 9, 20<br>sympt. | totalInf. | Dec 15, 20<br>sympt. | totalInf. | Feb 1, 21<br>sympt. | totalInf. | May 1, 21<br>sympt. | totalInf. | Dec 15, 20 to end<br>sympt. | totalInf. | days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| count | 1407.0 | 1407.0 | 1407.0 | 1407.0 | 886.0 | 886.0 | 761.0 | 761.0 | 637.0 | 637.0 | 886.0 | 886.0 | 886.0 |
| mean | 35.6 | 72.7 | 40.0 | 84.1 | 128.1 | 326.3 | 211.0 | 555.1 | 323.3 | 862.1 | 301.1 | 792.3 | 515.5 |
| std | 14.1 | 42.6 | 16.7 | 52.8 | 89.6 | 234.2 | 118.1 | 306.7 | 126.4 | 315.9 | 170.7 | 450.2 | 116.9 |

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[2]Schools are always working 100% in this case.

## To recap

| Scenarios | | Dec 15, 20 | | Dec 15, 20 to end | | |
|---|---|---|---|---|---|---|
| | | sympt. | totalInf. | sympt. | totalInf. | days |
| no | | | | | | |
| containments in | count | 140.0 | 140.0 | 140.0 | 140.0 | 140.0 |
| spontaneous | mean | **248.4** | **648.7** | 701.1 | 1757.9 | 594.2 |
| second wave | std | 167.4 | 424.3 | 246.4 | 599.7 | 118.9 |
| no | | | | | | |
| containments in | count | 1044.0 | 1044.0 | 1044.0 | 1044.0 | 1044.0 |
| forced | mean | **180.4** | **462.1** | 726.6 | 1810.9 | 620.9 |
| second wave | std | 134.6 | 354.6 | 221.9 | 544.0 | 110.8 |
| basic | | | | | | |
| containements in | count | 874.0 | 874.0 | 874.0 | 874.0 | 874.0 |
| forced | mean | **130.0** | **340.**6 | 252.7 | 666.4 | 494.1 |
| second wave | std | 83.9 | 232.6 | 156.8 | 416.4 | 122.7 |
| -20 days | | | | | | |
| containments in | count | 769.0 | 769.0 | 769.0 | 769.0 | 769.0 |
| forced | mean | <span style="color:red">112.2</span> | <span style="color:red">294.2</span> | 248.9 | 663.4 | 499.3 |
| second wave | std | 66.8 | 188.4 | 158.0 | 417.5 | 124.1 |
| frag. p. & workers | | | | | | |
| control in | count | 886.0 | 886.0 | 886.0 | 886.0 | 886.0 |
| forced | mean | <span style="color:cyan">128.1</span> | <span style="color:cyan">326.3</span> | 301.1 | 792.3 | 515.5 |
| second wave | std | 89.6 | 234.2 | 170.7 | 450.2 | 116.9 |

Table 1: Report of the key results, with count, mean, and std

## Exploring vaccinations

Exploring vaccination sequences (using *genetic algorithms* or *reinforcement learning*).

## A new model: the map

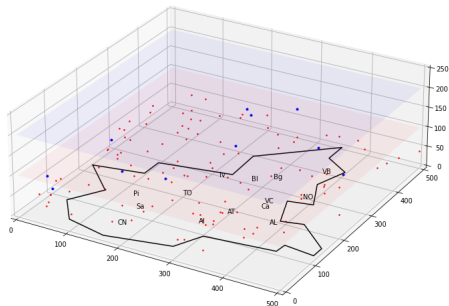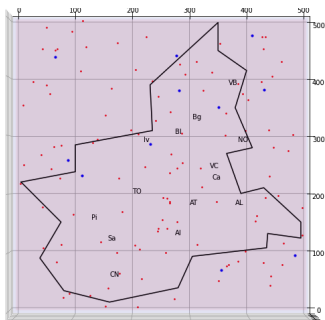

Figure 18: 3D Piedmont

## A new model: the scale and the items

- 1 : 100.
- *Infection engine*, https://terna.to.it/simul/InfectionEngine.pdf.
- Houses.
- Schools.
- Hospitals.
- Nursing homes,
- Factories.
- Transportations.
- Aggregation places: happy hours, night life, sport stadiums, discotheques, . . .

# The tool: S.L.A.P.P.

Scientific advertising: `https://terna.github.io/SLAPP/`



Figure 19: Swarm-Like Agent Protocol in Python

## A few considerations:

- The importance of High Performance Computing.
- From S.I.s.a.R. to a model of the society and of the economy of Piedmont.

- The S.I.s.a.R. model is a tool for comparative analyses, not for forecasting (the enormous standard deviation values are intrinsic to the problem).
- The model is highly parametric and more it will be.
- New crisis calling for immediate simulation could take a substantial advantage from the parametric structure of the model.

The slides are at https://terna.to.it/simul/TernaIRES20210223.pdf.
My homepage https://terna.to.it and my address pietro.terna@unito.it.
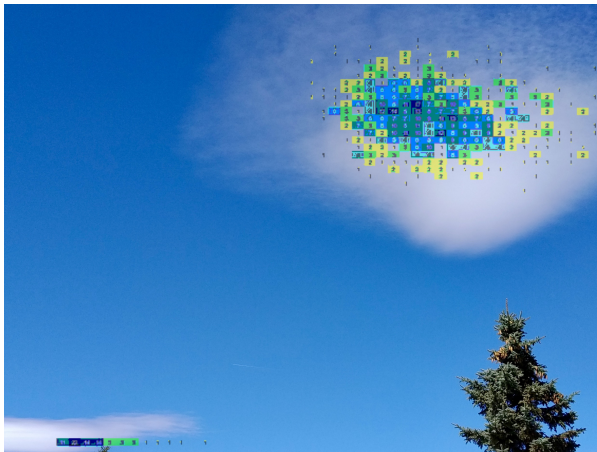
The image, elaborating Fig. **??**, is dedicated to Pietro Greco (Barano d'Ischia, April 20th, 1955—Ischia, December 18th, 2020)