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ICI: a data-driven individual-based epidemic propagation simulator

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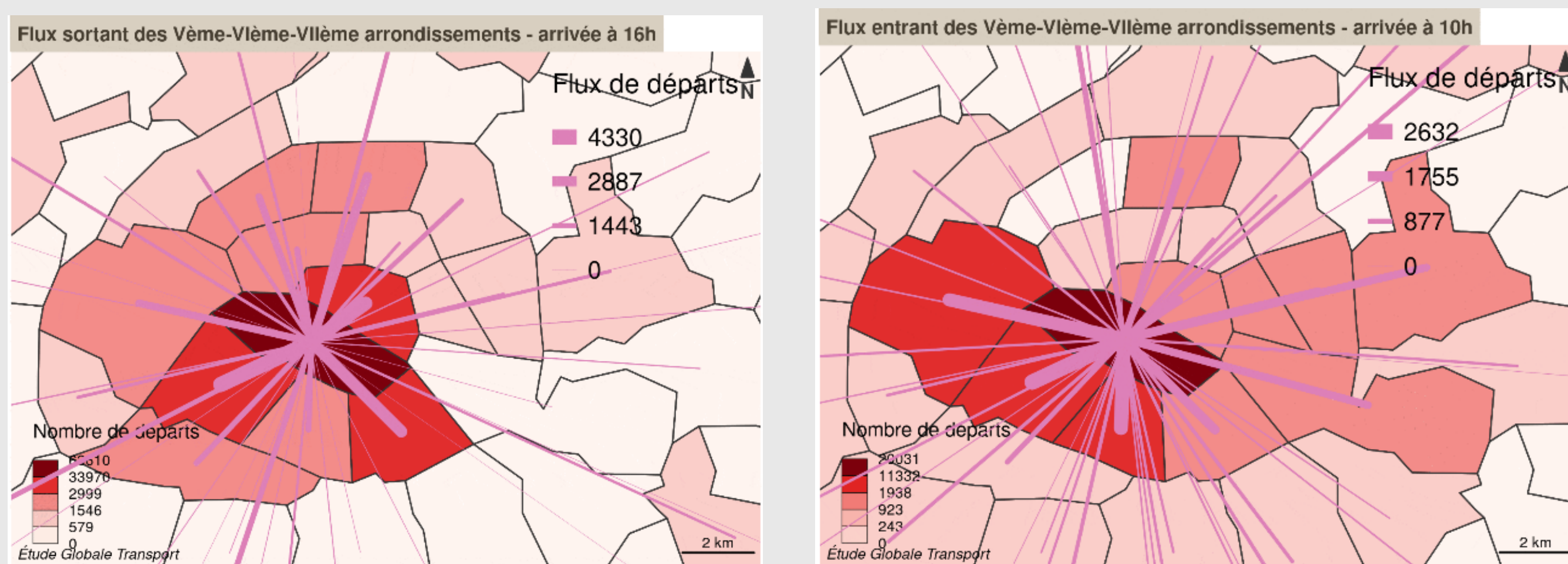
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Context

ICI is a platform for the **data-driven** simulation of **epidemic propagation** in **large urban areas**. It couples a generator of a **digital twin** of the urban area and its population of mobile individuals with an **individual-based** disease contagion model. The **contagion chains** thus simulated resemble those in real life. The aim of the ICI platform is to allow health authorities to test, evaluate, and compare a variety of **custom-designed sanitary** policies in view of their possible implementations.

Digital twin : Locations and movements

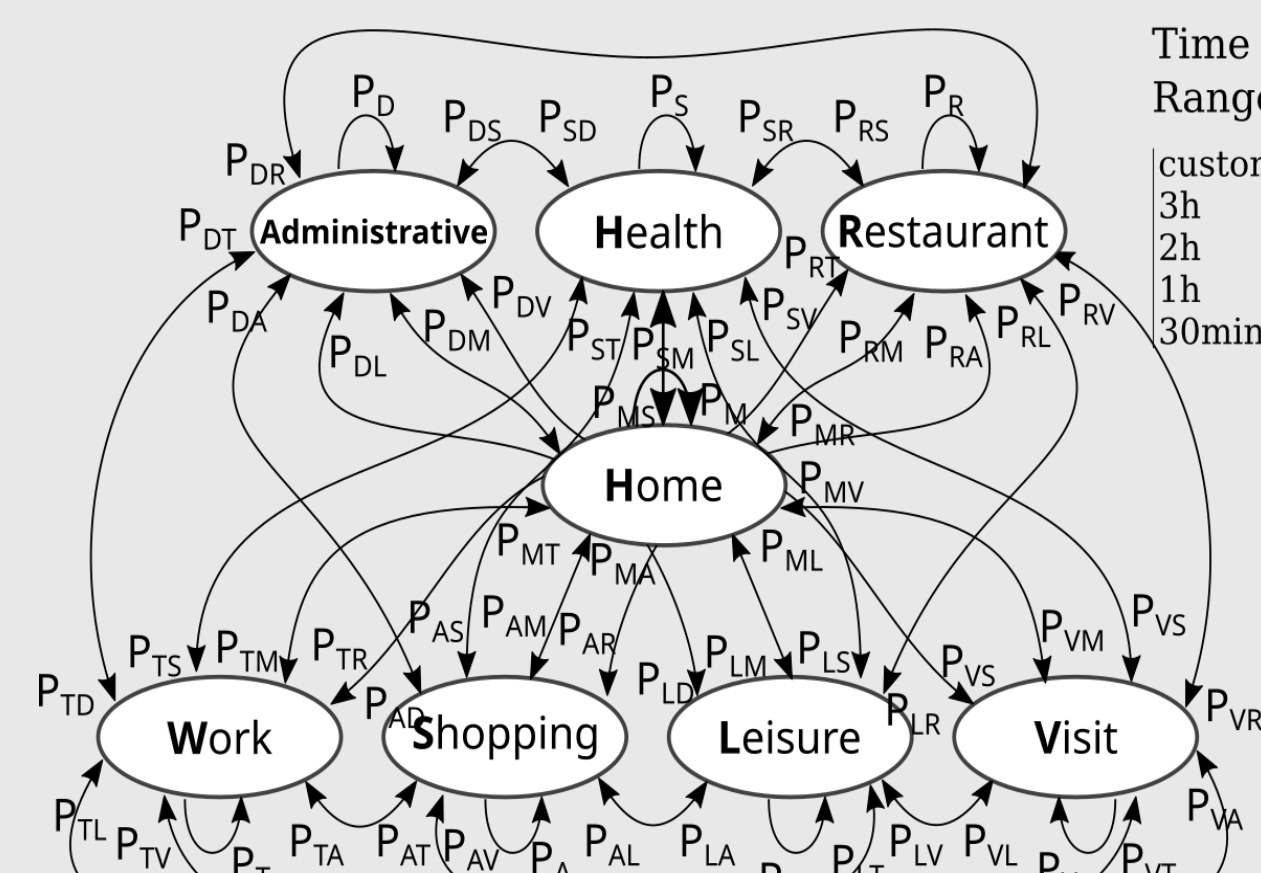
Each **synthetic individual** is allocated a **space for housing or its current activity as needed, initially and after each move**. This uses varied custom methods based notably on large surveys and on transportation and mobile phone data. The flux in and out of the area of individuals furnished with their characteristics is likewise modeled.



The **activity schedule of each individual inside the area is rendered by a Markov Chain**, which is parametrized in terms of the class determined by the individual's characteristics (age, profession, preferred leisure, etc.).

Markov Chain

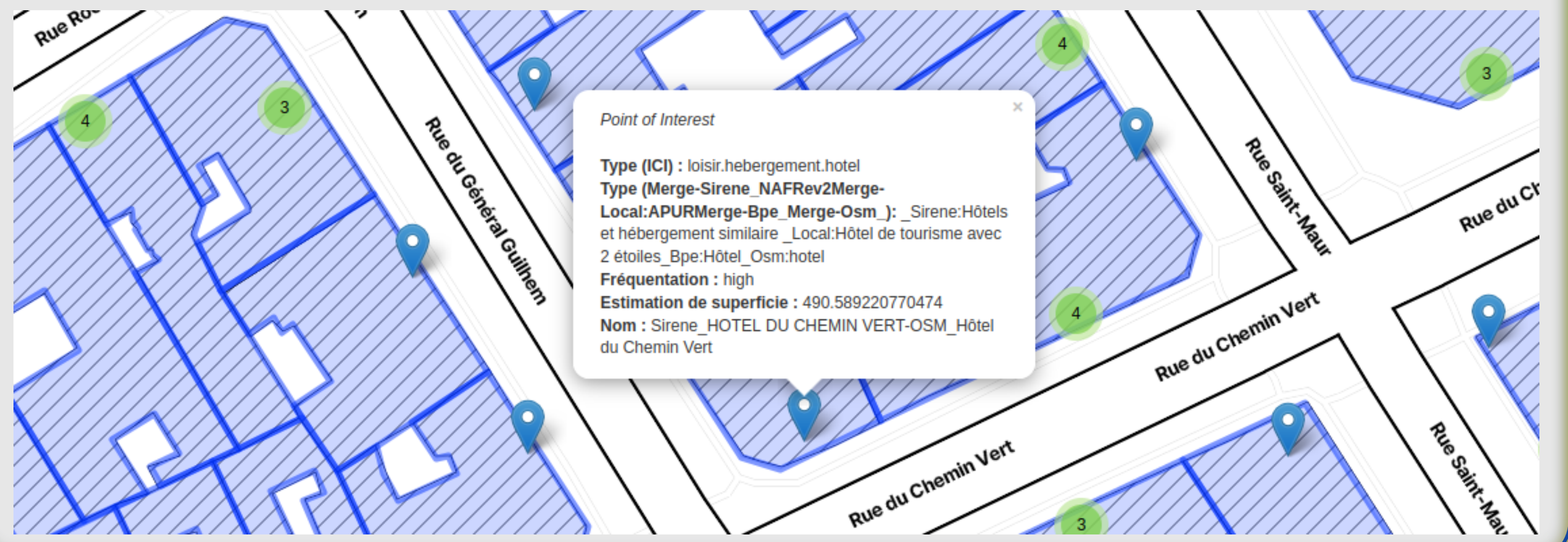
Parameterization for population categories



Time	Age	Occupation	Social Status	Loc	Day
Range	0-2	Agriculteur	Libéral	Paris	type
custom	3-5	Libéral	Libéral	Paris	Semaine
3h	6-10	Étudiant	Intellectuel	1 ^{ère} Couronne	Samedi
2h	11-17	Actif	Intermédiaire	2 nd Couronne	Dimanche
1h	18-24	Actif	Employé	1 ^{ère} Couronne	
30min	25-39	Mitemps	Ouvrier	2 nd Couronne	
	40-54	Chômeur	Retraité		
	55-64	Retraité	Autre		
	65-79				
	80+				

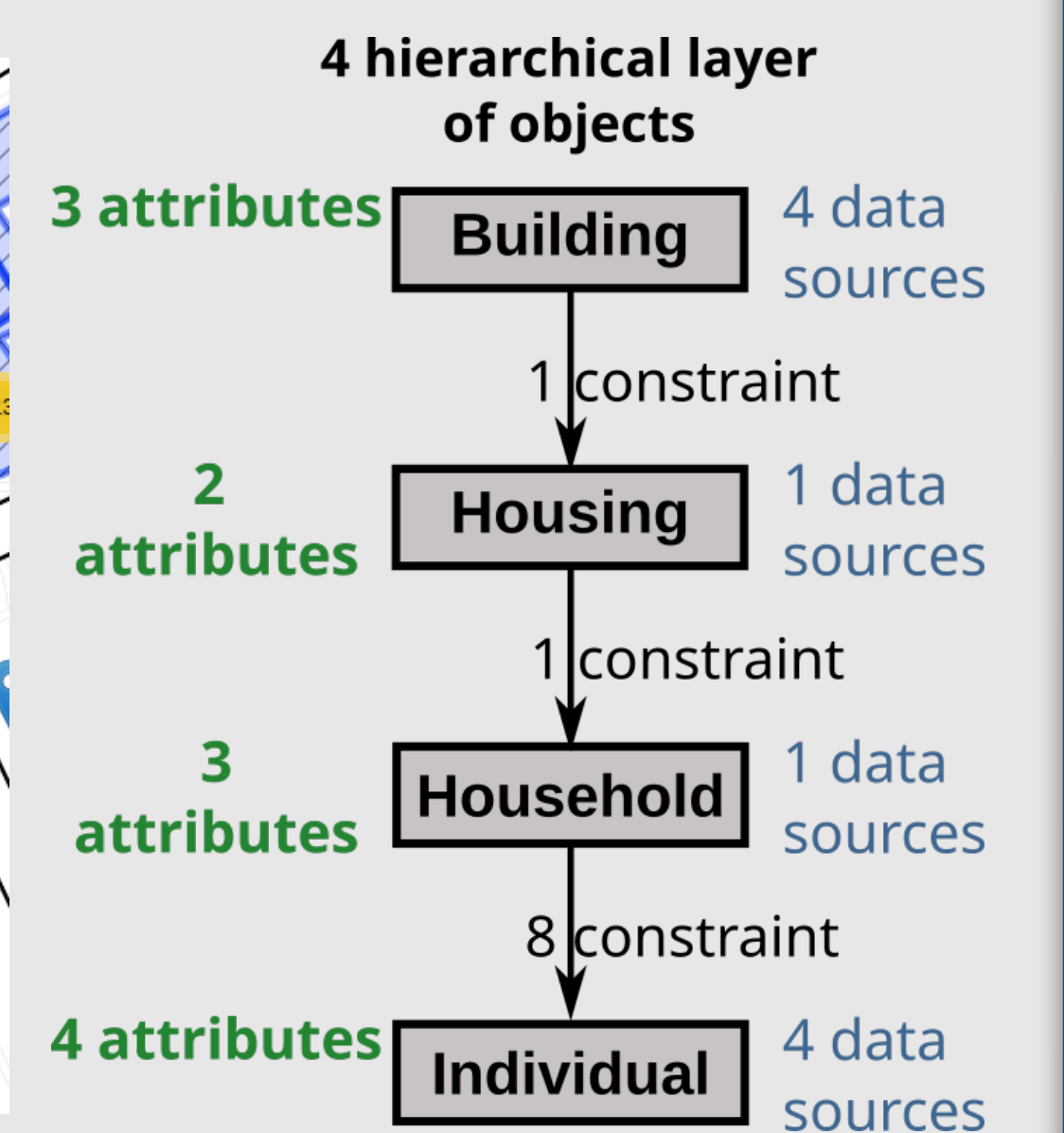
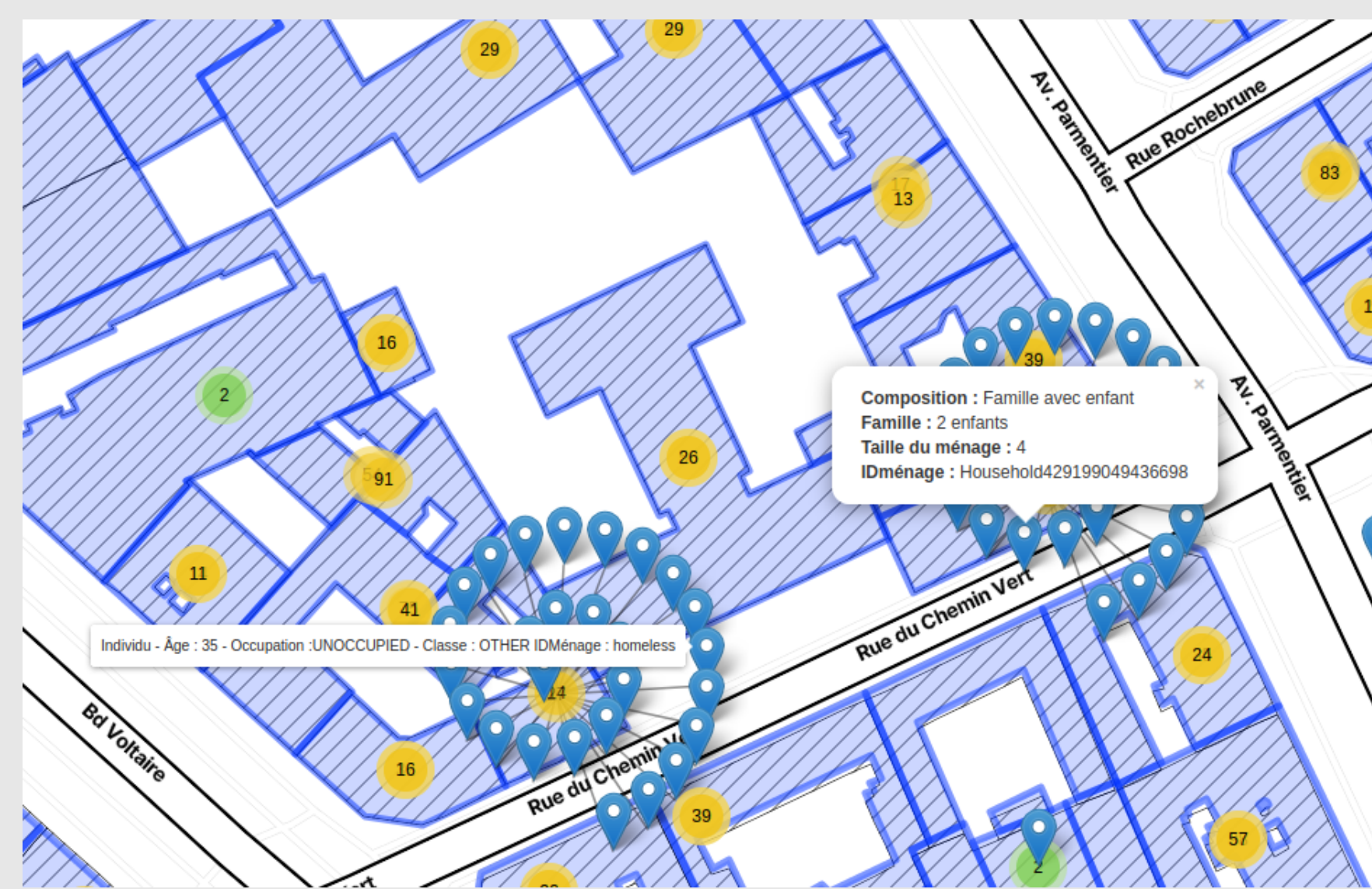
Digital twin : Interiors of buildings

The **main location of contagion for airborne diseases are interior spaces**. A fusion of multiple datasets is used to generate realistic interiors for the buildings in the area. Each building hosts a variety of activity or housing spaces having descriptive attributes such as their precise use, floor area, opening schedule, and attendance index.



Digital twin : Synthetic populations

Contagion depends highly on household structures. We build a well geolocalized hierarchical synthetic population, with four levels and multiple individual attributes, using data at various global and local scales. This custom generator is flexible with respect to the input data and the generated attributes.



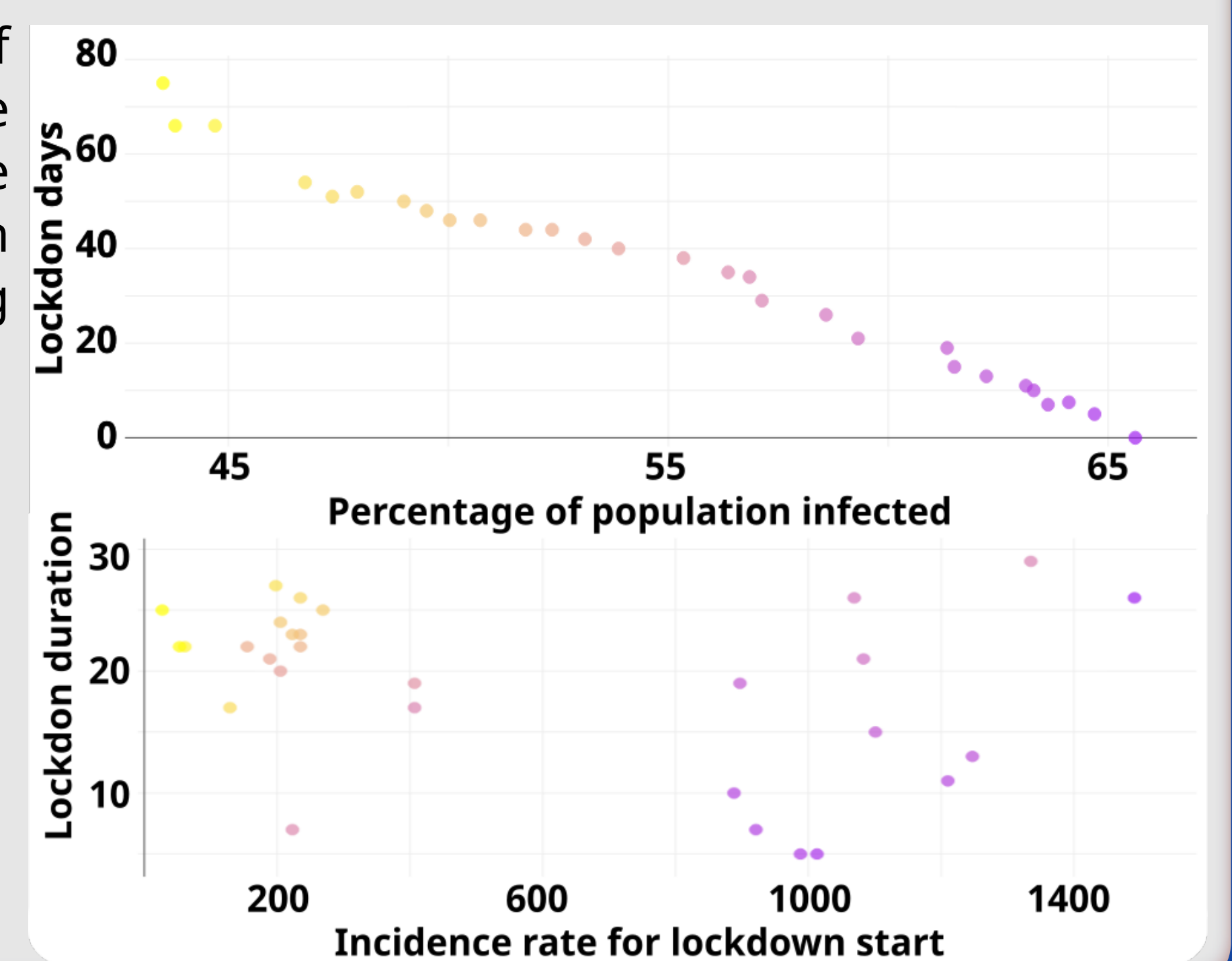
Health policies

The **precision of the description of the urban area and its population allows to evaluate detailed policies**, notably differentiating between geographic areas and population classes.

In a first example, we simulate two kinds of **lockdowns**, similar to the ones in France in March and November 2020, which require to close working places, schools, universities, and other places of interest as well as to work remotely whenever possible.

In a second example, we simulate the propagation dynamics in **schools** with a specific modeling for classes, students, and teachers, in which classes are closed in function of the number of sick students or teachers.

A **systematic optimization of the durations and the incidence rates** of the epidemics for the application of these policies is made using the OpenMOLE[2] platform. For more results, see: <https://lstu.fr/H4KSYdGu>



Epidemic propagation

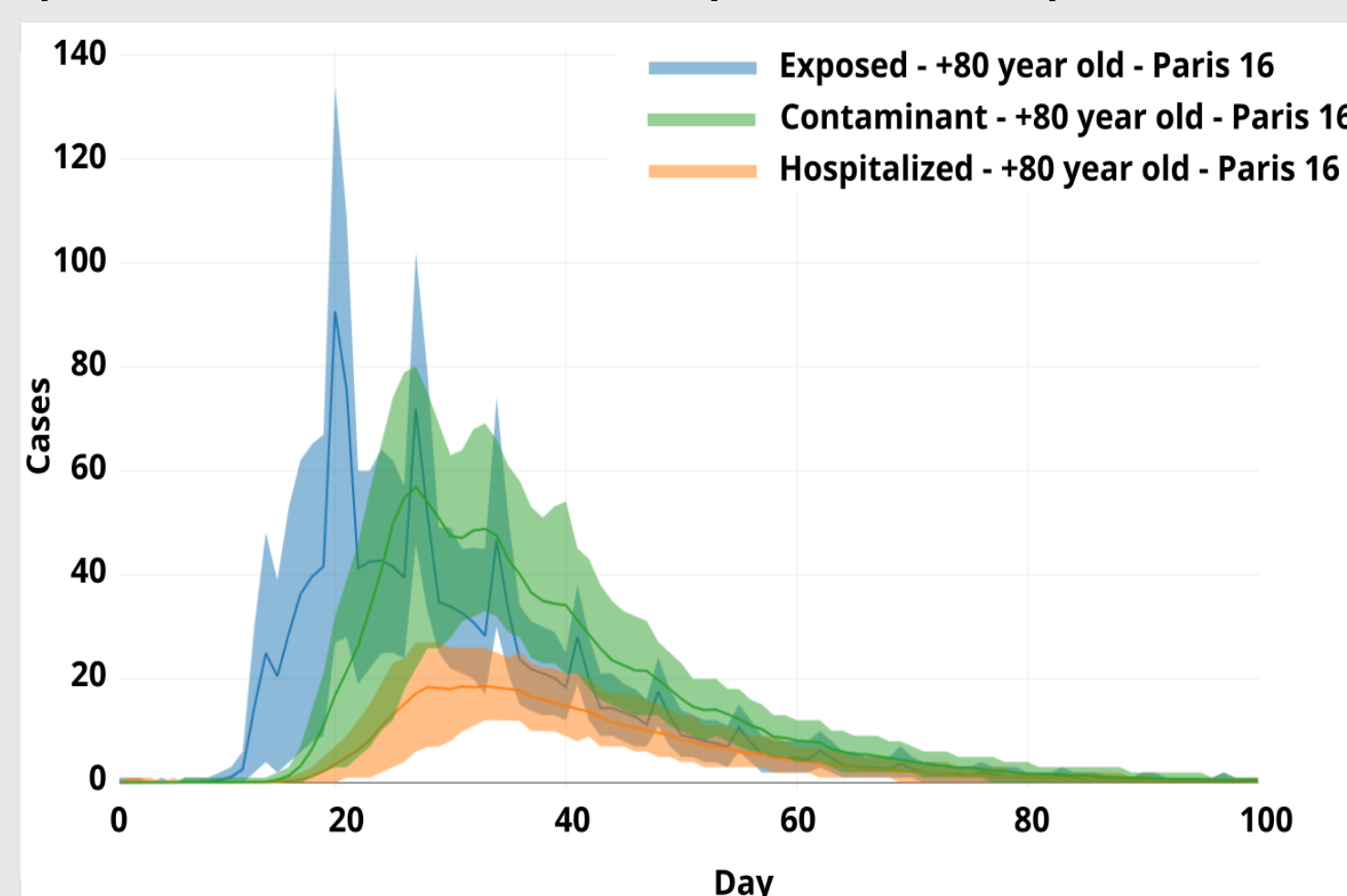
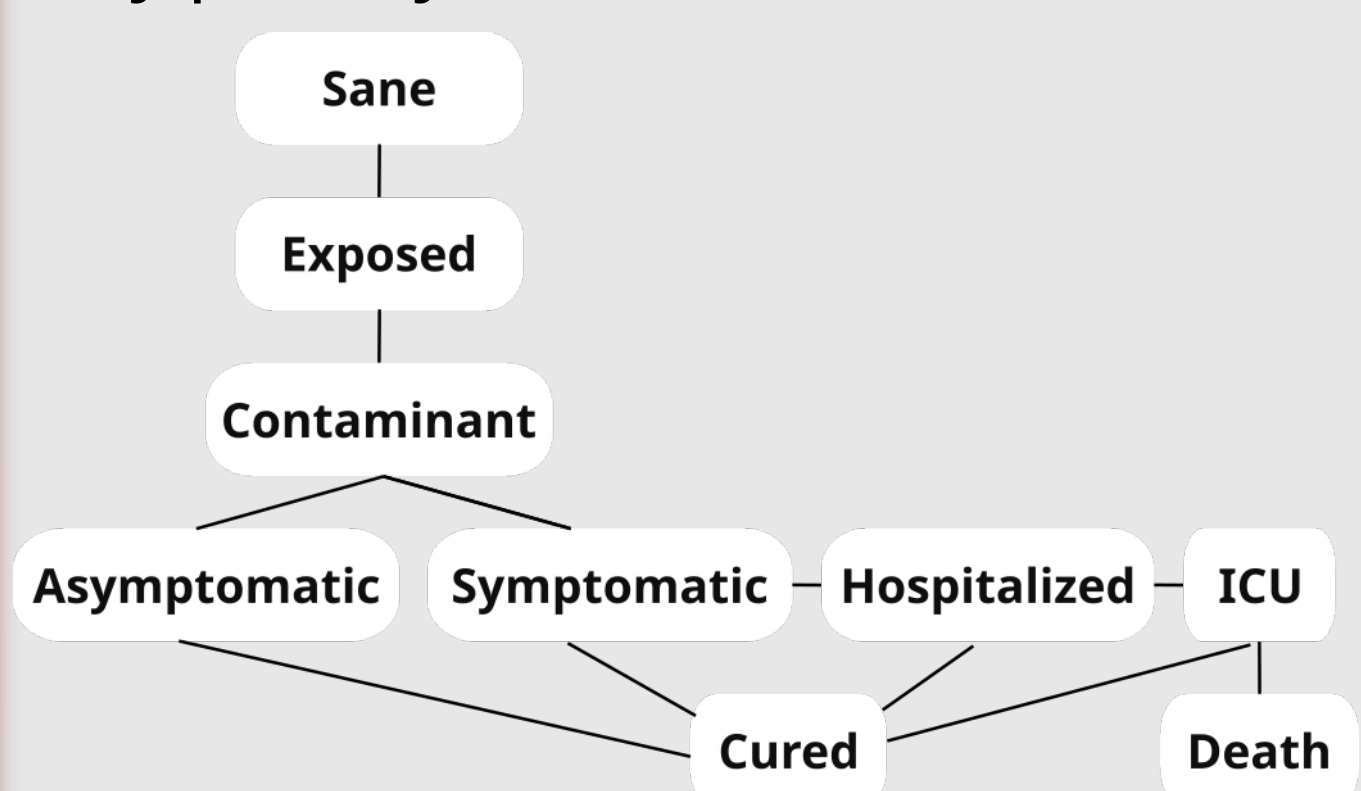
The **simulator allows to propagate epidemics on the digital twin of the urban area**. It has been designed with SARS-CoV-2 in mind but can be readily adapted to other diseases. The simulations are inherently stochastic, and we have developed a fast and optimized implementation allowing multiple Monte Carlo runs in order to obtain pertinent statistics.

The **probability** that a sane individual is infected by a contagious individual, when both are simultaneously in the same space, is defined by a **law** depending on the space, the two individuals' characteristics, and other factors [1]:

$$1 - \left(1 - \frac{\text{transmission_facteur}}{(\text{distance}/\text{distance_type})^2} \right)^{\text{duration}/\text{duration_type}}$$

• Contact duration and distance between individuals
 • Coefficients for calibration, depending on the type of place where individuals meet

Varied **epidemic states** can be considered, and an individual switches between any pair of states at a rate depending on its characteristics. It is for instance possible to represent in detail the occupancies of wards of specific hospitals on a day per day basis.



References



<https://ici.saclay.inria.fr>

[1] Hoertel, N., Blachier, M., Blanco, C., Olfson, M., Massetti, M., Rico, M. S., Limosin, F. & Leleu, H. (2020). A stochastic agent-based model of the SARS-CoV-2 epidemic in France. Nature medicine.

[2] Romain Reuillon, Mathieu Leclaire, and Sebastien Rey-Coyrehourcq, « OpenMOLE, a workflow engine specifically tailored for the distributed exploration of simulation models », published in Future Generation Computer Systems, 2013.

Conclusion

The **ICI simulator couples a digital twin and an epidemic propagation model**. It is designed with a modular architecture. Each module could be replaced or used in other projects, such as the national catalog of digital twins, and new modules can be added. This simulator can be adapted to various diseases and to diverse geographic areas, which gives it high-potential operational abilities. The aim of our partnership with the CRESS team of INSERM is to develop this simulator so as to contribute to the medical field of interventional epidemiology. **Our website describes more precisely the model. An application allows users to navigate through pre-calculated simulation results and to perform some numerical exploration.**