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## ICI Project: Individual-based epidemic propagation simulator based on a Digital Twin

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# The ICI Project: an individual-based epidemic propagation simulator based on a Digital Twin

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# What is the ICI Project?

ICI couples a generator of **realistic digital twins** of large geographic zones and their **populations** of mobile individuals with an individual-based disease **contagion model**

Given the generated geographic zone and the sampled synthetic population, **large scale Monte Carlo simulations** allow to obtain **precise statistical informations** on, *e.g.*,

- the dynamics of the number of infected individuals within each population class (age, comorbidity, housing area, working place, etc.)
- the future saturation level of given hospitals
- the compared effects of varied sanitary policies

# A modular approach

## Digital twin generation

- Building land-use
- Synthetic population
- Housing of individuals

## Dynamics

- Movement of individuals between their hourly activities

## Epidemic propagation simulations

- Probabilistic epidemiology model, 9 health statuses
- Digital implementation of sanitary policies
- Evaluation and comparison of sanitary policies by Monte Carlo simulations

# Digital twin generation

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# Land-use and building interior model

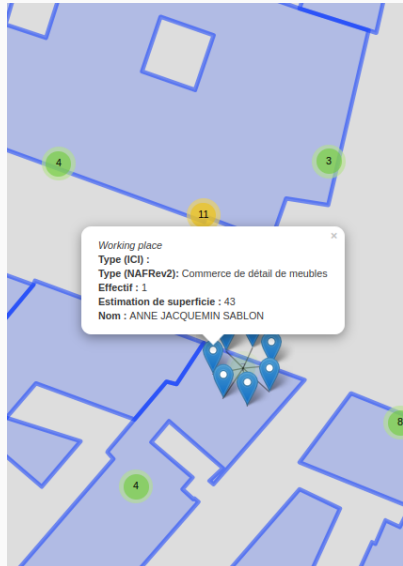
Exhaustive detailed and geolocalized model with building **interiors**.  
Two kinds of spaces:

- **Activities**

- A type
- Open to public
- Frequency indicator
- Number of workers
- Opening hour
- Behaviour during past lockdowns

- **Housing units**

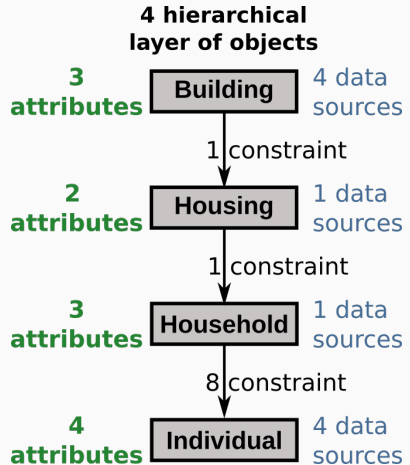
- Area and principal home status
- Linked to the synthetic population



# Four-layered hierarchical synthetic population

## An original generator

- Heavily **geolocalized** and data-driven.
- Plausible and hierarchized configuration, respecting:
  - macro-statistics (general statistics),
  - meso-statistics (statistical aggregates),
  - household and housing constraints.
- Well-described individuals.



# Dynamics

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# Locations of individuals

## In and out fluxes

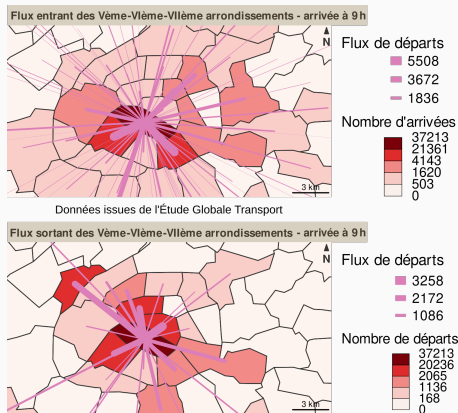
Fluxes based on surveys, mobile phone activity and common transportation counting

## Agenda generation

Based on surveys, relatively to:

- Socio-demographic characteristics, place of living,
- Hour and day of the week

Modelled by a Markov chain between 8 activities.



# Locations of individuals

## In and out fluxes

Fluxes based on surveys, mobile phone activity and common transportation counting

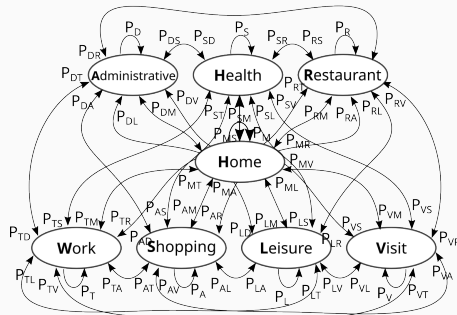
## Agenda generation

Based on surveys, relatively to:

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- Hour and day of the week

Modelled by a Markov chain between 8 activities.

## Markov Chain



# Epidemic propagation simulations

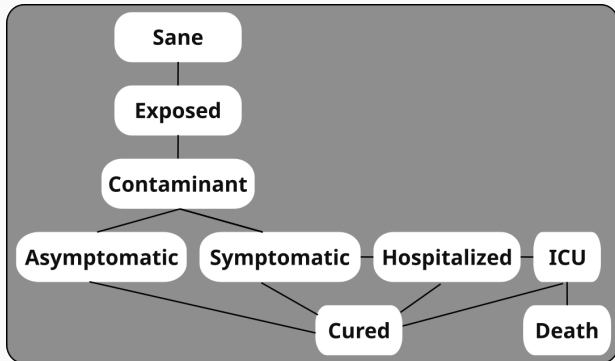
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# Our epidemiology propagation model

**Probabilistic** simulation at an individual scale:

- **Simulate the movements** of the individuals according to their agendas
- **Locate** individuals inside building's activities
- **Sample** the probability distribution of **contamination** between two individuals when they meet in the **same place** at the **same time**
- **Run large scale Monte Carlo replications** for the statistical study of epidemiological spreading

# Epidemiology model with 9 health statutes



**Probabilities** to switch states **depend** on sex and **age** and other **individual** characteristics.

The **fine scale** of the digital twin allows the digital implementation of **various sanitary policies**, for example:

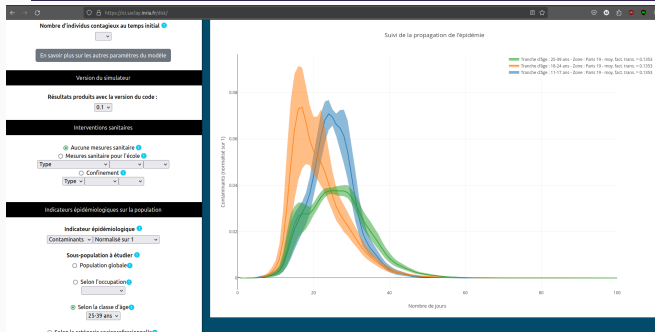
- **School** sanitary protocols
  - Close each class when a detected amount of student is reached.
  - Close every school when incidence rate is reached.
- **Lockdowns**:
  - Total, partial or targeted.
- **Vaccination** campaigns:
  - Random or on targeted population.

## Examples of results

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# Pre-computed simulation results

ICI



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



# Sensitivity analyses, numerical search for optimal decisions

## We use the OpenMOLE platform



1. To explore model behaviours and sensitivities
2. To deploy large scale Monte Carlo simulations over HPC clusters
3. To search **optimal** sanitary policies

Reuillon, R., Leclaire, M. & Rey-Coyrehourcq, S. (2013). OpenMOLE, a workflow engine specifically tailored for the distributed exploration of simulation models, *Future Generation Computer Systems*.

# Sensitivity analyses, numerical search for optimal decisions

## Optimisation parameters:

- **Duration** of the policy.
- **Activation** threshold.

## Optimisation criterion:

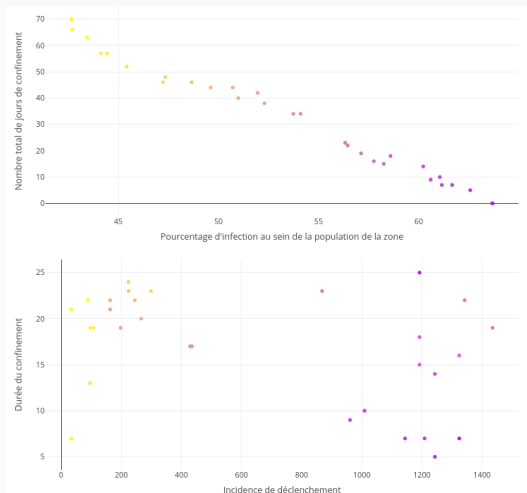
- **Sum** of total **contaminations**.
- Number of lockdown days, total missing days for **students**.



`https://ici.saclay.inria.fr/shiny/multicriterionoptim/schoollockdown/`

# Sensitivity analyses, numerical search for optimal decisions

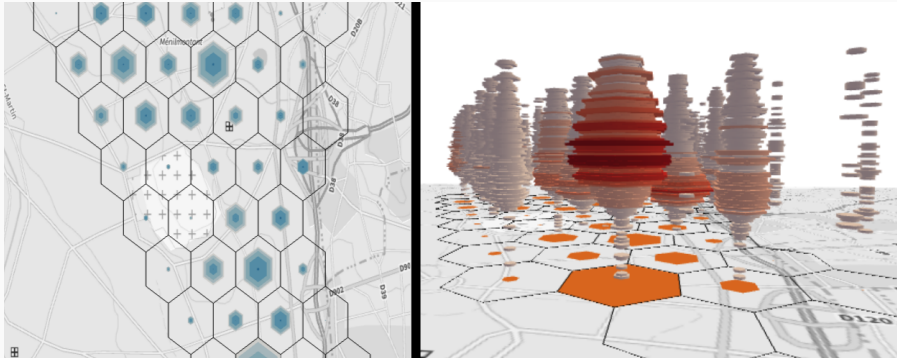
## Illustration: Optimization of **lockdowns** 19th arrondissement of Paris



<https://ici.saclay.inria.fr/shiny/multicriterionoptim/schoollockdown/>

# Advanced geo-visualisation: Geo-epidemiology

Partnership with the LASTIG-**Geovis** team for advanced visualisation of epidemiological dynamics.



Gautier, J., Lobo, M. J., Fau, B., Dugeon, A., Christophe, S., & Touya, G. (2021). COVID-19 geoviz for spatio-temporal structures detection. In *Proceedings of the ICA*.

## Future works and ongoing collaborations

- *With transportation modelling experts::* Modelling of individual behaviours in terms of sanitary constraints
- *With epidemiologists::* Extensions to various diseases and applications to future pandemics prevention
- *Within the Digital Twin of French territories program::* Integration of the ICI modules

Thanks for your attention !

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

