GISTAM 2017
GIS Theory
Applications and
Management

Using Constraint Cellular Automata To Simulate Urban Development in a Cross-Border Area

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Context

Urban development simulation in a cross-border area

Cross-border spatial planning issues

- **Open border areas experience particular growth dynamics**
  - New cross-border scenarios reflecting a border residential growth (debordering) can be planned and need to be simulated
- **Application on a French-German cross-border territory**
  - A pilot European territory promoting the development of cross-border projects (Strasbourg-Ortenau Eurodistrict project)

CA: an adapted tool for modelling urban development

- Allows the implementation of spatial rules based on empirical knowledge
- Shows the role of different neighbourhoods on urban growth processes
- Simulates scenarios of future urban development

Materials and data

Cross-border data collection

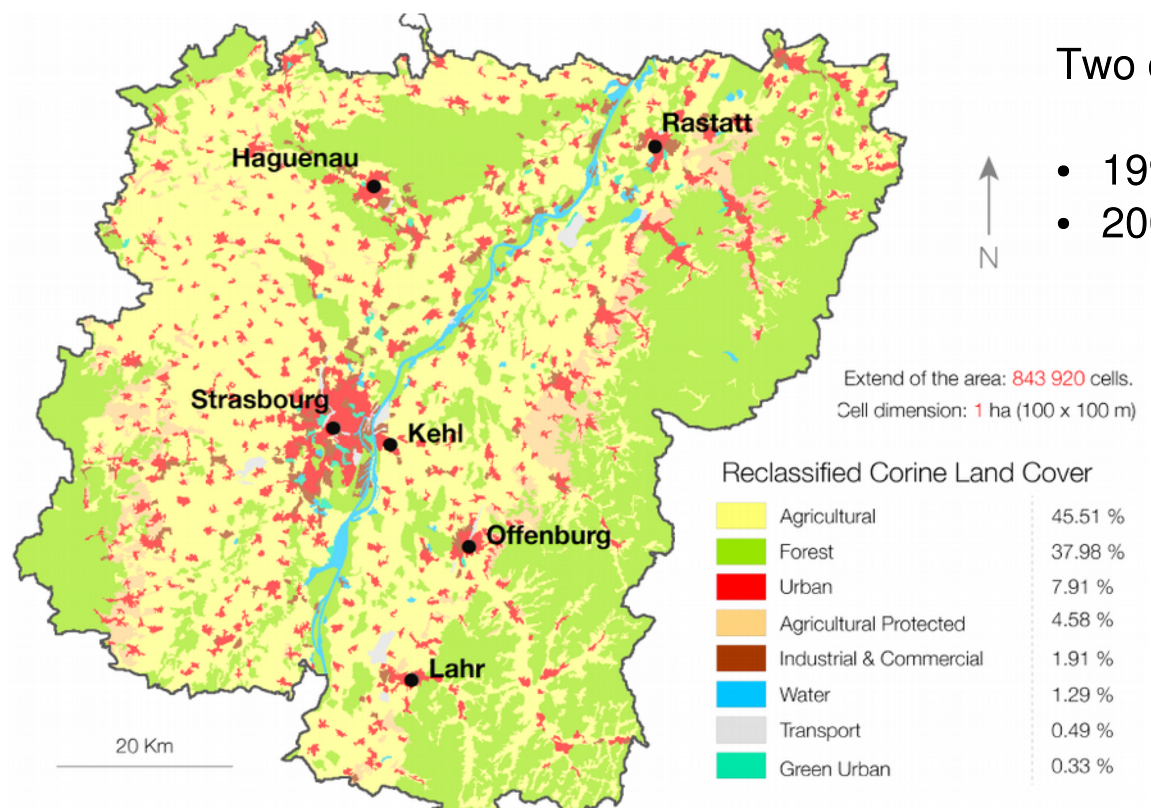
Needs: cross-border land-use

Corine Land Cover (CLC) : European biophysical land cover database

For the analysis of land use and its evolution

For the measure of the soil artificialization

A reclassification of the initial CLC database from 44 to 9 classes

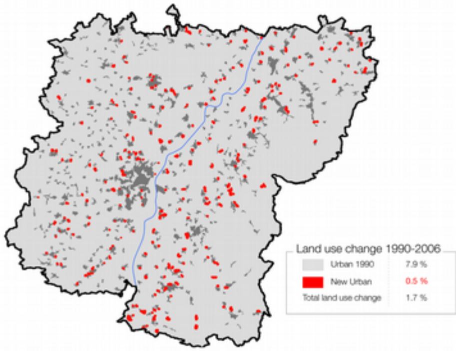


Two dates available :

- 1990
- 2006

Methodology

Quantification of future changes



Land use analysis

Past land-use vectors

	Urban	Industrial	Transport	Equipment	Fields	Vine	Forest	Water	Sum
1990 (nb)	*42143*	*10163*	*2628*	*1747*	*242397*	*24410*	*202321*	*6850*	490516
1990 (%)	*8,59*	*2,07*	*0,54*	*0,36*	*49,42*	*4,98*	*41,25*	*1,40*	**100**
2006 (nb)	*44612*	*11977*	*2634*	*2078*	*238826*	*23556*	*202237*	*6739*	488047
2006 (%)	*9,14*	*2,45*	*0,54*	*0,43*	*48,94*	*4,83*	*41,44*	*1,38*	**100**

Probabilities calculation

1990-2006 transition matrix

	Urban	Industrial	Transport	Equipment	Fields	Vine	Forest	Water	Sum
Urban	***0,9893***	*0,0063*	*0,0001*		*0,0038*	*0,0003*		*0,0001*	**1**
Industrial	*0,0093*	***0,9539***	*0,0006*	*0,0076*	*0,0120*		*0,0100*	*0,0066*	**1**
Transport		*0,0030*	***0,9844***	*0,0118*	*0,0008*				**1**
	0,0074	*0,0137*		***0,9788***					**1**
Fields	*0,0104*	*0,0069*	*0,0001*	*0,0011*	***0,9794***	*0,0005*	*0,0010*	*0,0006*	**1**
Vine	*0,0106*	*0,0016*			*0,0274*	***0,9593***	*0,0011*		**1**
Forest	*0,0001*	*0,0013*			*0,0018*	*0,0001*	***0,9962***	*0,0005*	**1**
Water		*0,0028*	*0,0001*		*0,0159*		*0,0441*	***0,9371***	**1**

Markov chain (iteration)

Expected future land-use vectors

	Urban	Industrial	Transport	Equipment	Fields	Vine	Forest	Water	Sum
2022 (nb)	*47027*	*13700*	*2640*	*2411*	*235334*	*22735*	*202162*	*6644*	485626
2022 (%)	*9,68*	*2,82*	*0,54*	*0,50*	*48,46*	*4,68*	*41,63*	*1,37*	**100**
2038 (nb)	*49391*	*15339*	*2648*	*2748*	*231921*	*21948*	*202096*	*6566*	483266
2038 (%)	*10,22*	*3,17*	*0,55*	*0,57*	*47,99*	*4,54*	*41,82*	*1,36*	**100**

8811 cells

Methodology

Location of future changes

CA formalization

E : Set of cells that can undergo a transition (non locked)
S_i : Land use of the cell i
N_i : Neighborhood of the cell i within a radius r (at time t)
C_n^r : Number of cells with a land use S within a radius r at time t

$$\forall i \in E, S_{i,t+1} = f(S_{i,t}, \sum_{n}^{N=1} N_i) \tag{1}$$

où

$$N_i = f(C^r_{S=1,t}, C^r_{S=2,t}, ..., C^n_{S=n,t}) \tag{2}$$

et

$$S \in \{1, ..., n\}; C \in \{1, .., m\}; r \in \{0, .., \infty\} \tag{3}$$

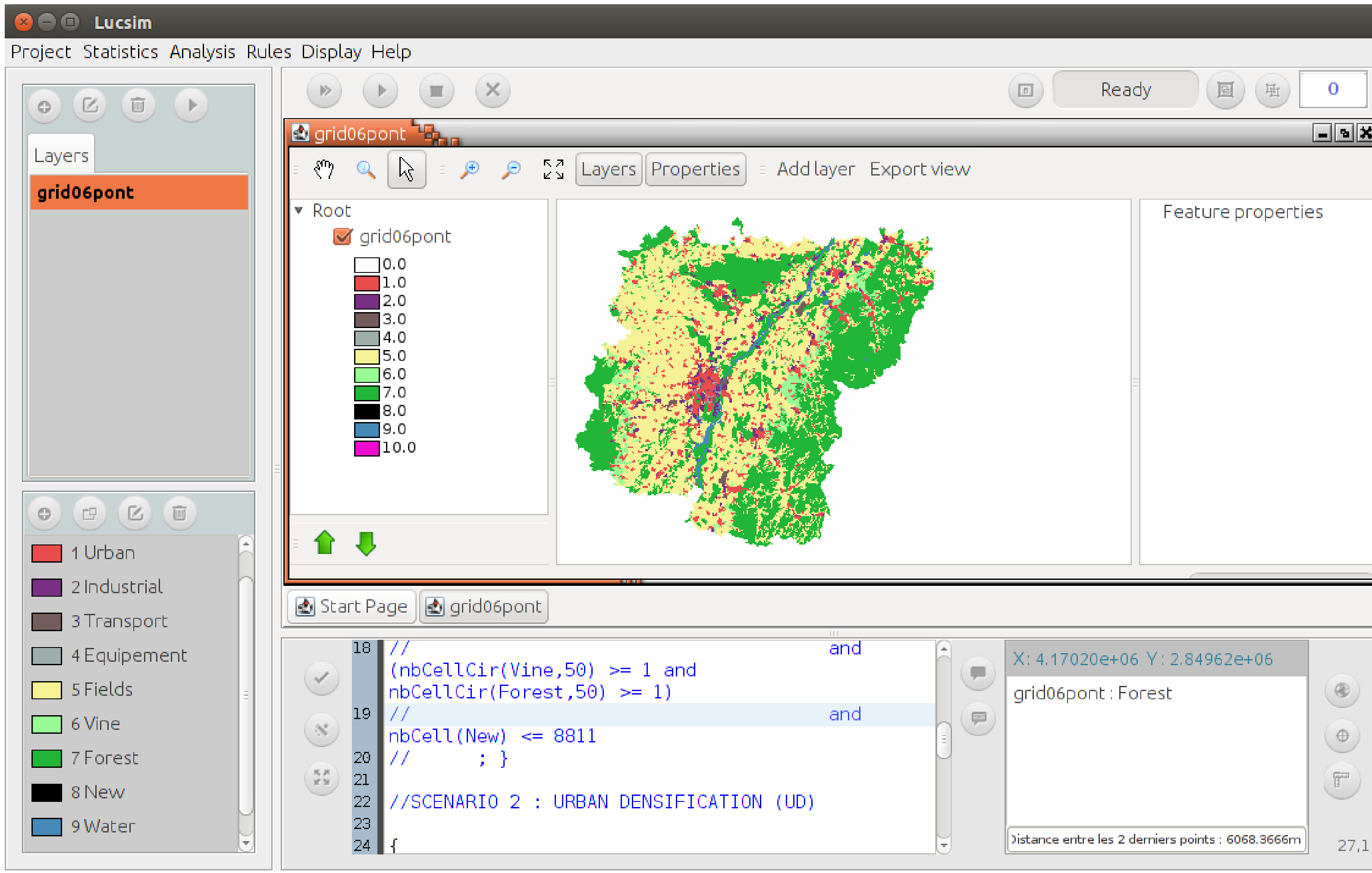
CA tool : LucSim

A cellular automata dedicated to geographical analysis and simulations

Developed from scratch in java by G. Vuidel and authored by J.P. Antoni and G. Vuidel

Methodology

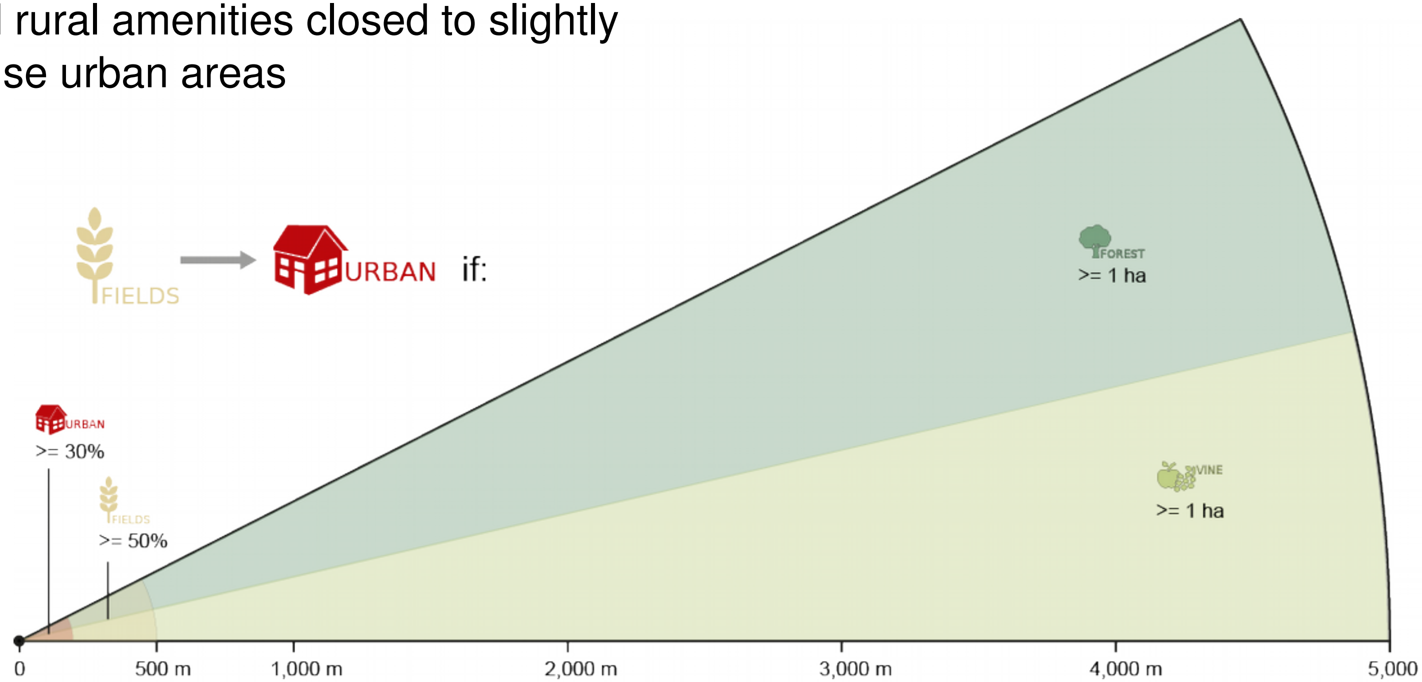
LucSim Software screenshot



Scenarios
Landscape Sprawl (LS)

Main idea

- Residential preference around landscape and rural amenities closed to slightly dense urban areas

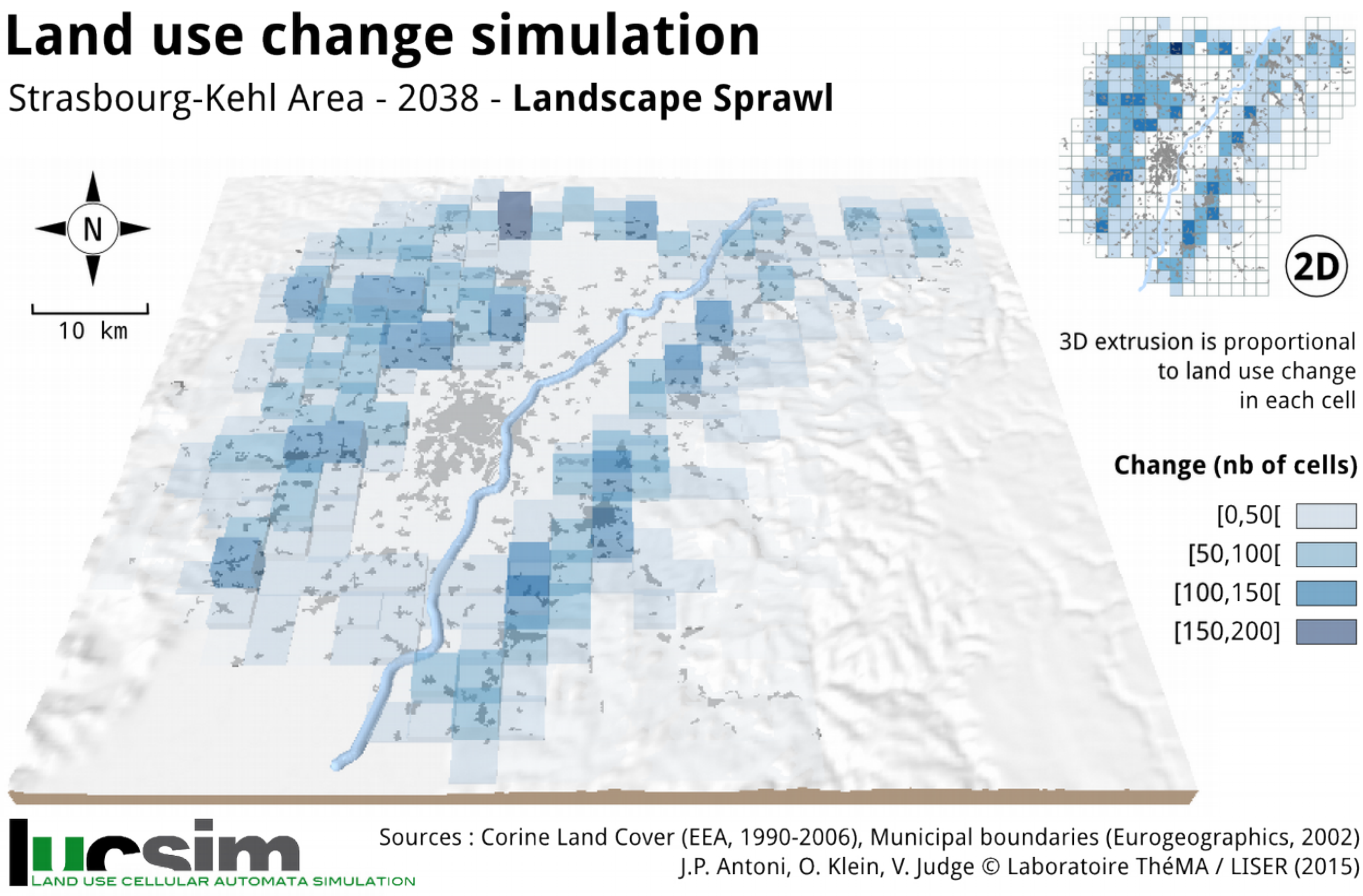


CA rule

```
{
        Fields -> New :         (pCellCir(Urban,2) + pCellCir(New,2)) >= 30%
                                and     pCellCir(Fields,5) >= 50%
                                and     (nbCellCir(Vine,50) >= 1
                                and     nbCellCir(Forest,50) >= 1)
                                and     nbCell(New) <= 8811
; }
```

Scenarios

Landscape Sprawl (LS)

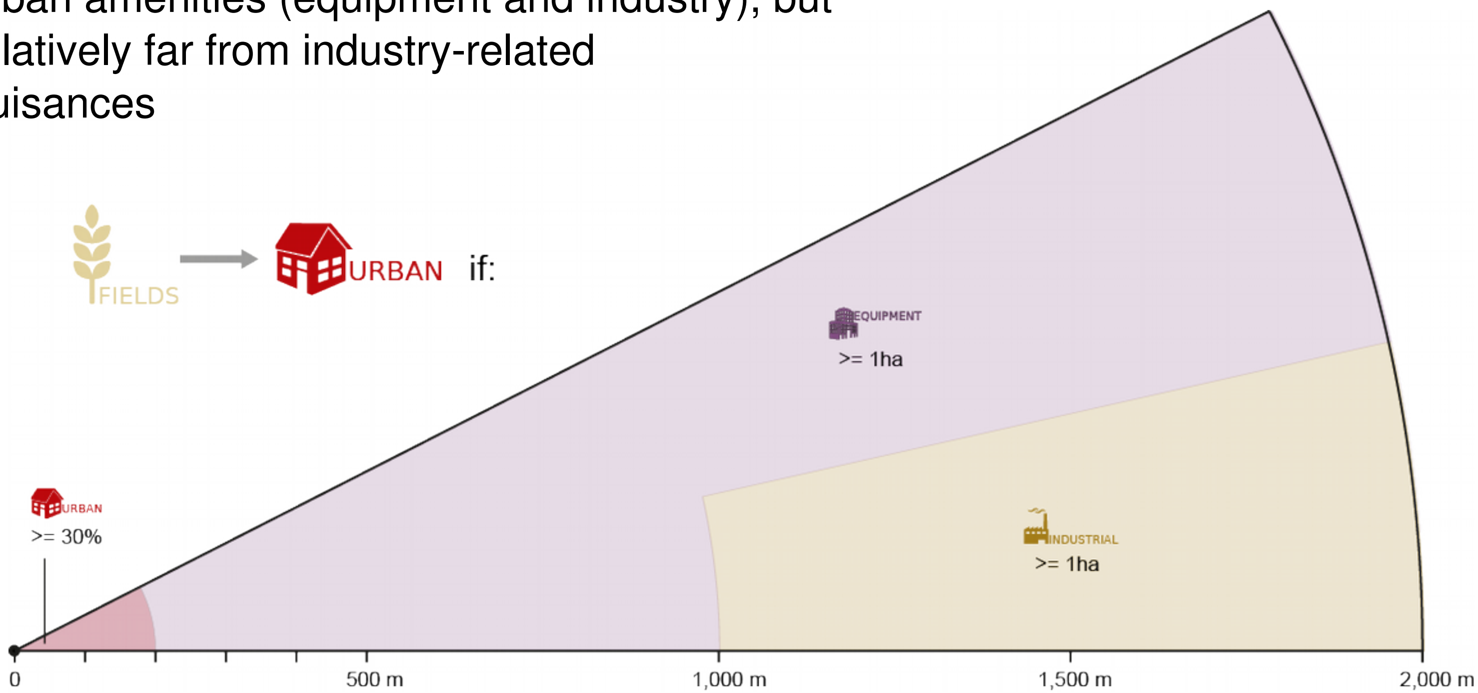


Scenarios

Urban densification (UD)

Main idea

- Residential preference in urban areas, closed to urban amenities (equipment and industry), but relatively far from industry-related nuisances

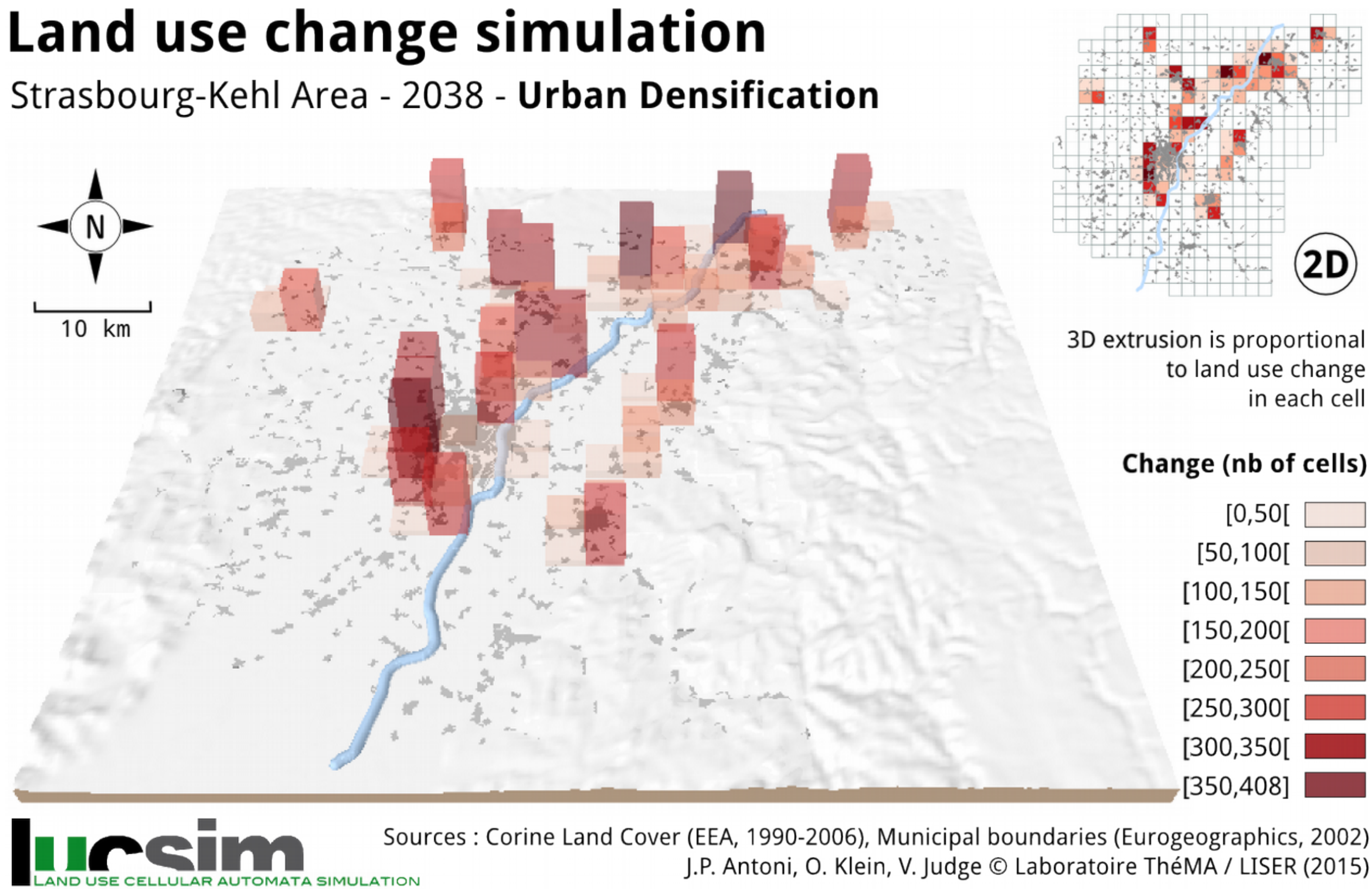


CA rule

```
{
        Fields -> New :         (pCellCir(Urban,2) + pCellCir(New,2)) >= 30%
                                and     nbCellCir(Equipement,20) >= 1
                                and     nbCellCir(Industrial, 10)  = 0
                                and     nbCellCir(Industrial,20) >= 1
                                and     nbCell(New) <= 8811
;}
```

Scenarios

Urban densification (UD)

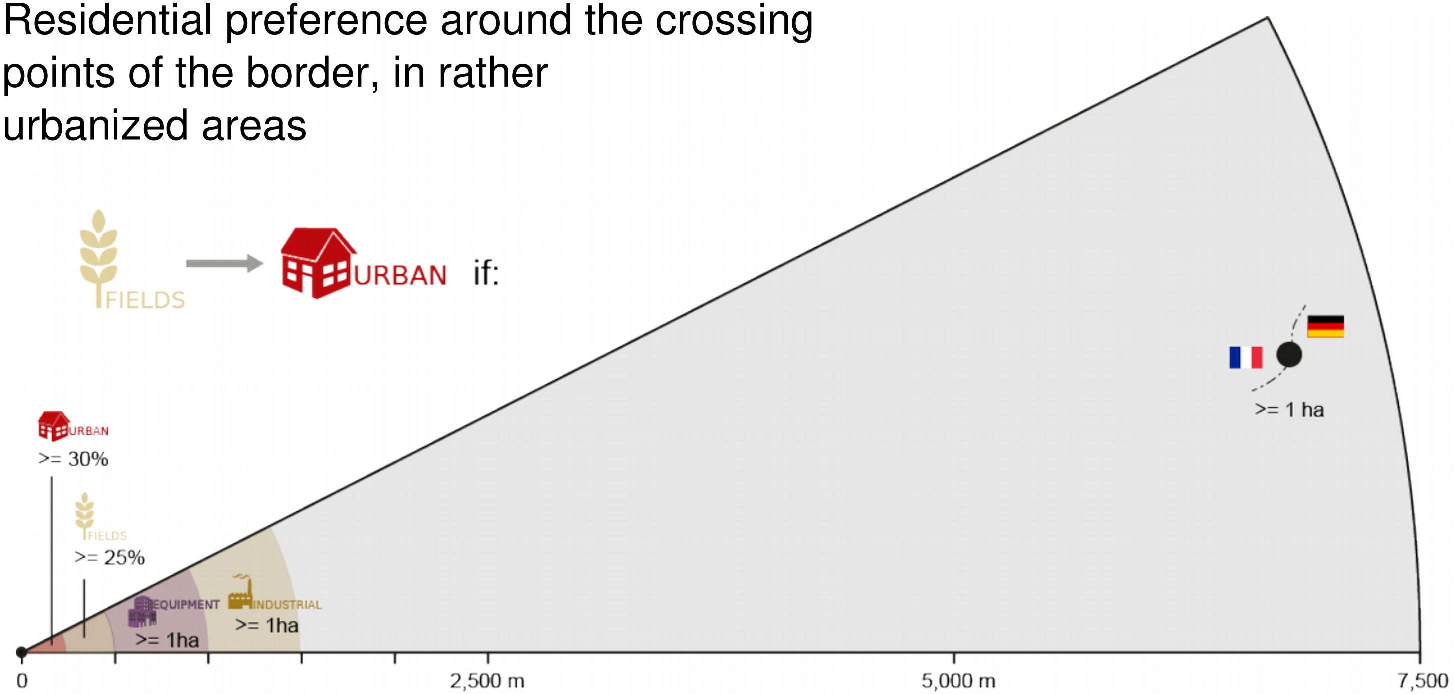


Scenarios

Bridge Transbording (BT)

Main idea

- Mixed residential preference (LS and UD)
- Residential preference around the crossing points of the border, in rather urbanized areas

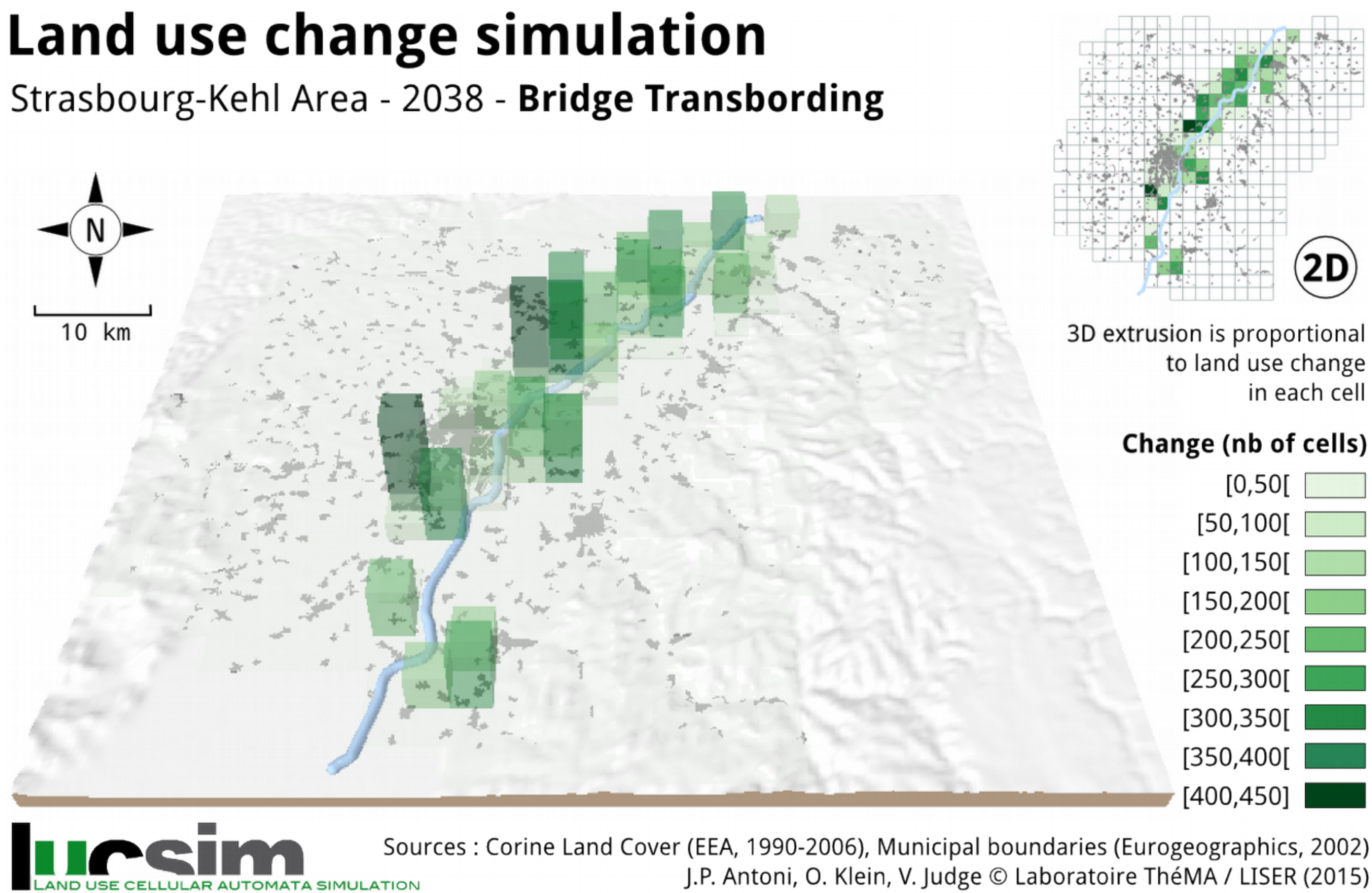


CA rule

```
{
        Fields -> New :         (pCellCir(Urban,2) + pCellCir(New,2)) >= 30%
                                and     pCellCir(Fields,5) >= 25%
                                and     (nbCellCir(Industrial,15) >= 1
                                or      nbCellCir(Equipement,10) >= 1)
                                and     nbCellCir(Bridge,75) >= 1
                                and     nbCell(New) <= 8811
; }
```

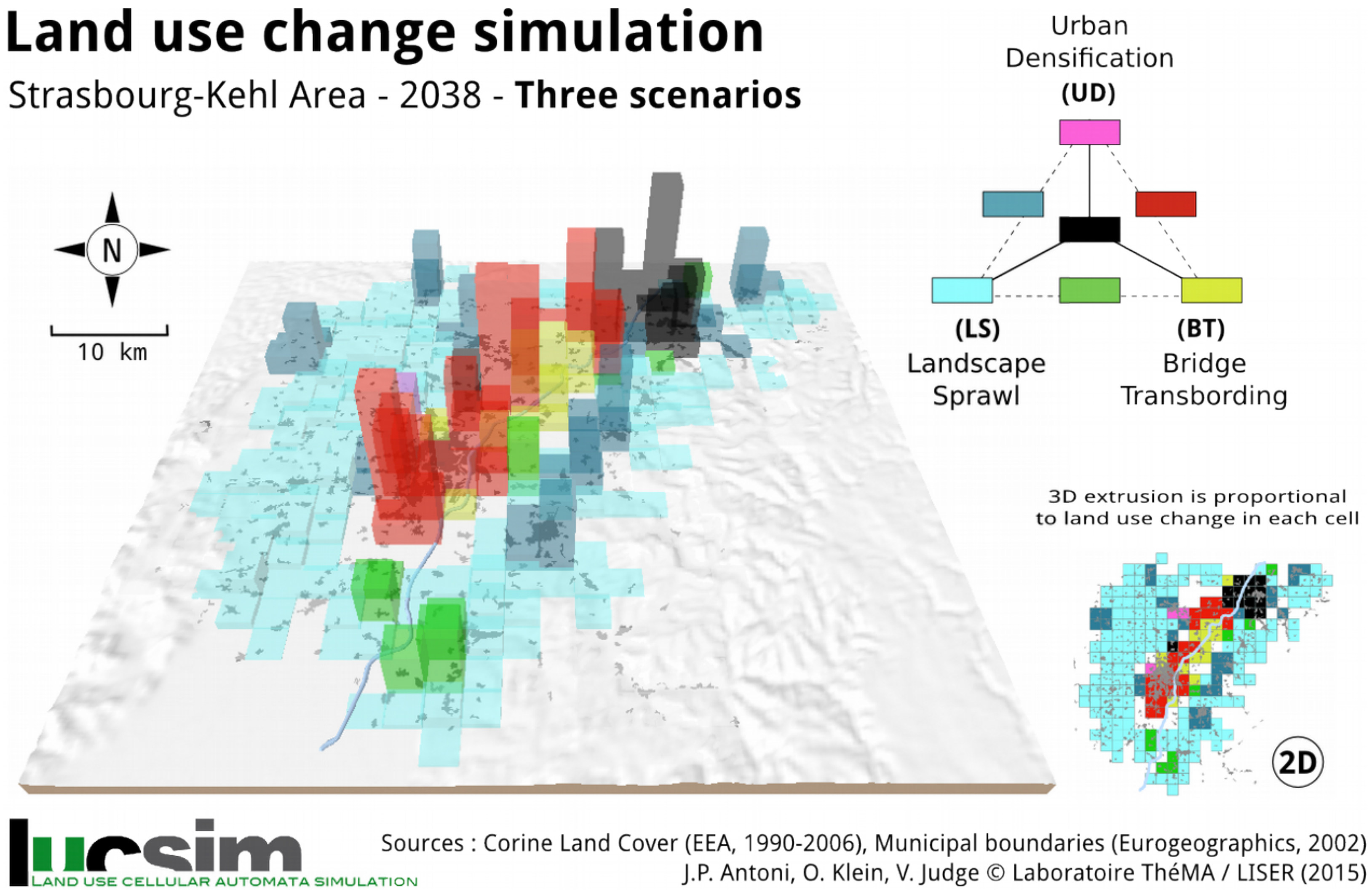
Scenarios

Bridge Transbording (BT)



Discussion

Resulting map



Discussion

Toward automatic calibration and validation?

What about results validation?

- From a scientific point of view, results are not validated
- Moreover, forecasting the future in a complex context is difficult
- Apart from a crystal ball, no techniques allows validating future urban development results at such a fine scale

Images of the future

- But scenarios involve realistic processes and rules
- These rules are based on accurate expert knowledge
- They provide relevant "images of the future" to debate and make decision about desirable residential preferences and land-use changes
- A strong assumption: future transition processes are identical to past transition processes (markovian hypothesis)

Toward automatic CA rules calibration?

- Another way to construct prospective scenarios and CA rules could consist in using Desicion Tree (TD) or Artificial Neural Networks (ANN)
- Artificial intelligence helps to automatically determine transition rules based on the analysis of past processes (e.g. 1990-2000-2016)