Initial spatial conditions in simulation models: the missing leg of sensitivity analyses?

GeoComp 2017

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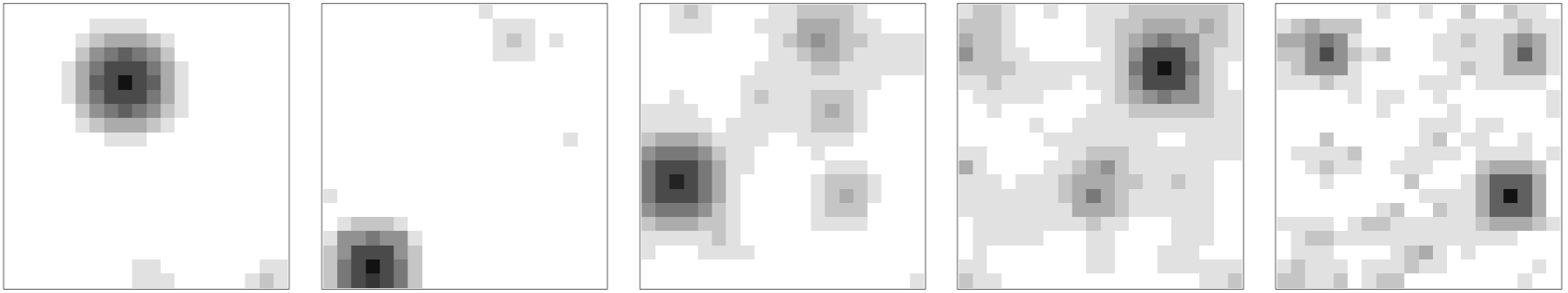


Geocomputation2017 | Leeds, UK | Wednesday 6th September 2017

Spatial biases | context

- **Empirical evidence** | Modifiable Areal Unit Problem
  [Openshaw, 1984; Fotheringham & Wong, 1991]

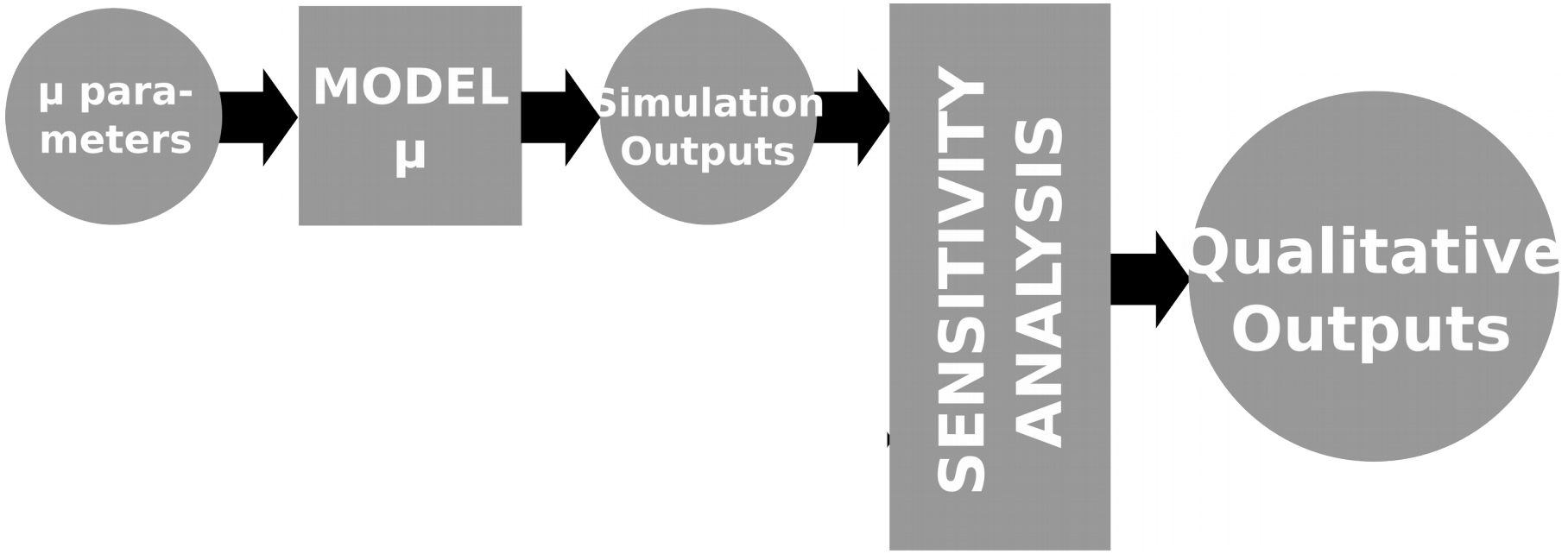
  Effect of city form on society (ex. inequality)
  [Jargowsky, 2002; Wheeler, 2006]

- **In simulation** | Accuracy of spatial input data
  [Hagen-Zanker & Jin, 2012; Thomas et al., 2017]

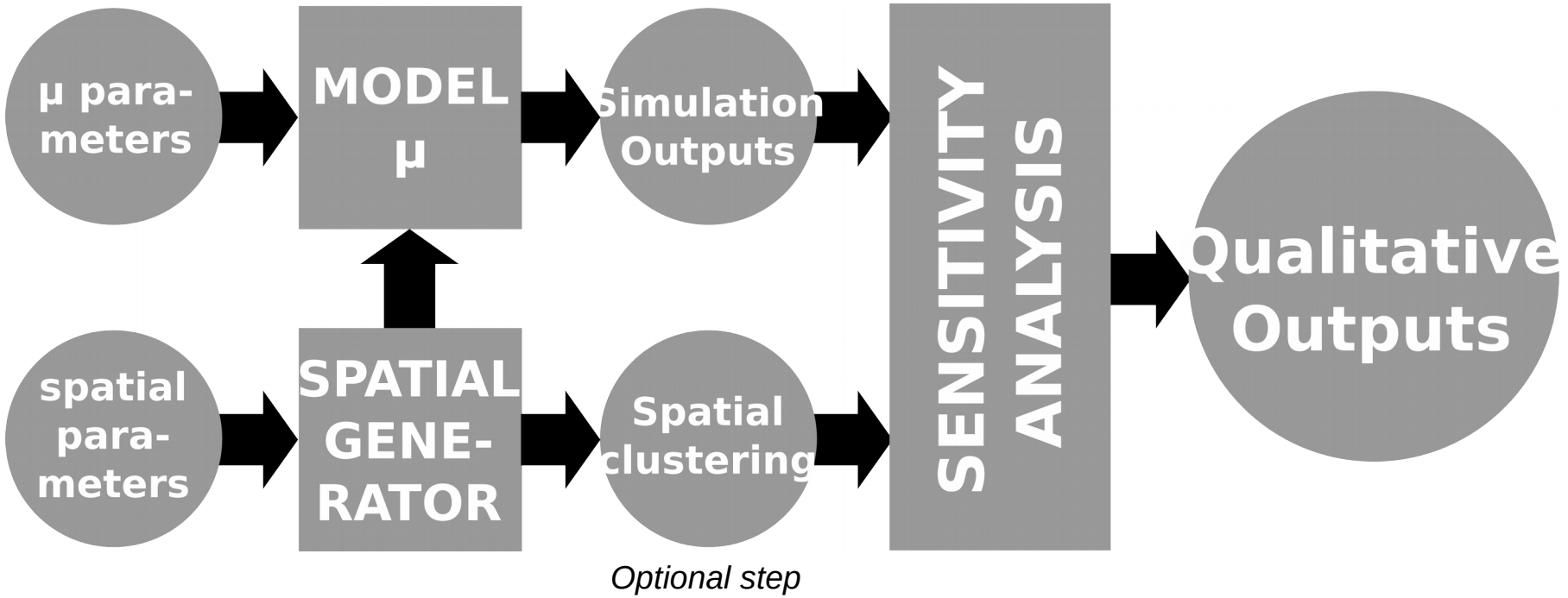
  Shape, size and precision of the spatial system
  [Axtell et al., 1996; Flache & Hegselmann, 2001; Banos, 2012]

  Spatial heterogeneity
  [Stauffer & Solomon, 2007; Hatna & Benenson, 2012; Gauvin et al., 2010]

General simulation approach



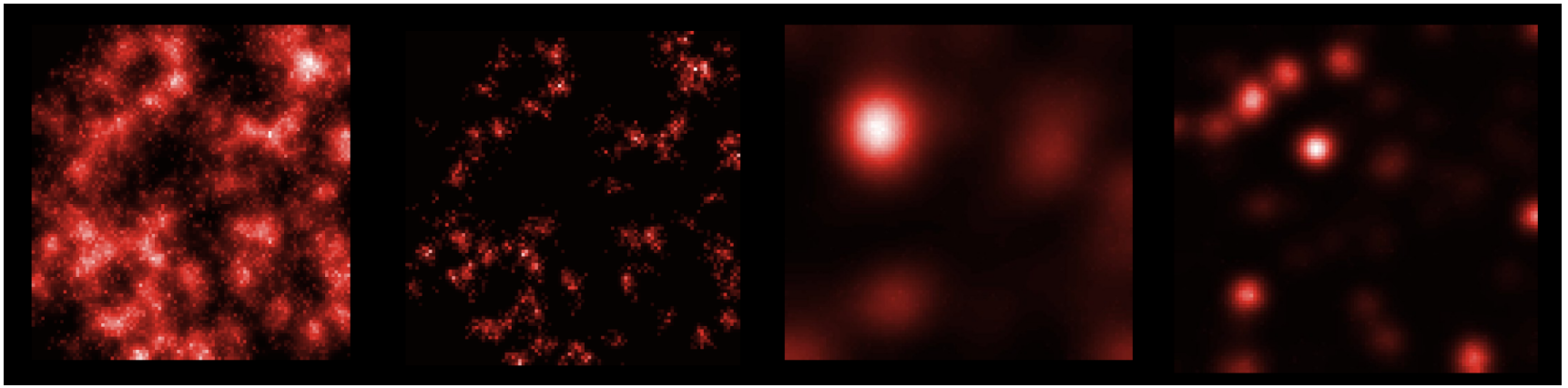
Our simulation approach



Spatial Generator

Urban Morphogenegis Model

[Batty, 2007a; Raimbault et al., 2014]



Meta-parameters:

N : population added at each time step t, from a void grid

α : strength of preferential attachment to existing cluster for each unit of N

β : strength of the diffusion process (share of population of cell I translated to neighbouring cells)

n : number of smoothing iterations for the process of diffusion

Spatial clustering | typo of density grids

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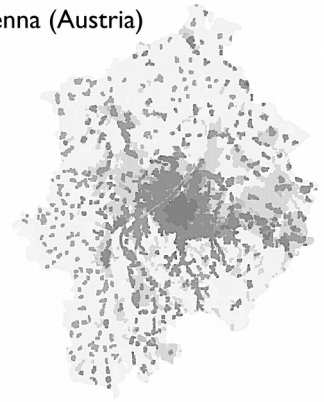
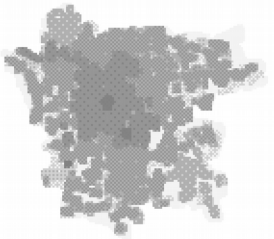
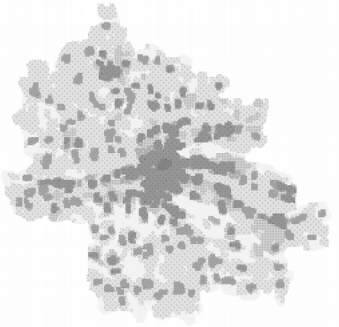
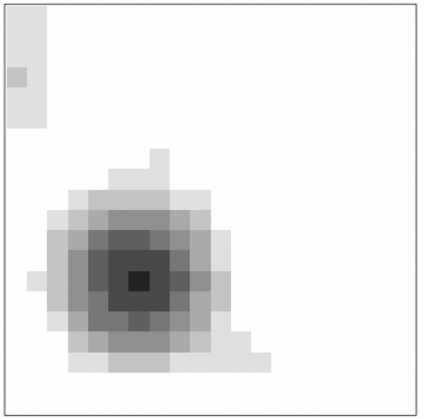
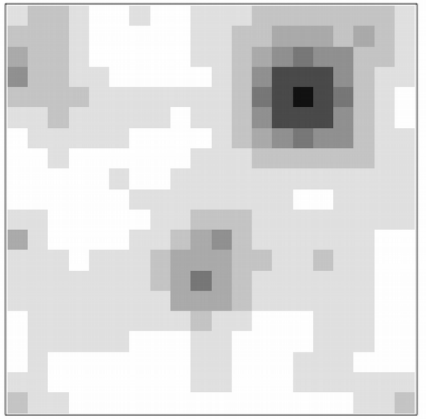
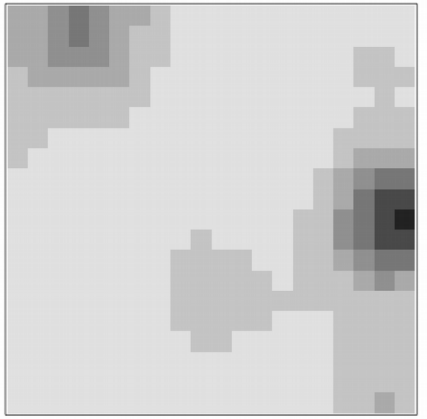
Compact	Polycentric	Discontinuous
European Reference		
Vienna (Austria) 	Liege (Belgium) 	Augburg (Germany) 
Examples of generated grids		
		
Corresponding meta-parameters		
α 1.707024718	1.525077587	1.853205966
β 0.00568899	0.00764774	0.10796615
n 3	2	1
N 1753.09434	4629.16844	12905.6414

x 15
for each type

Application Cases

Schelling

[Schelling, 1971]

Model overview:

- Abstract housing market
- Neighbourhood satisfaction review
- Emerging segregation patterns

Model parameters:

S : Proportion of similar agents required in the neighbourhood to provide individual satisfaction [0,1] ~ intolerance level

V : Vacancy rate of city housing [0,1]

Model Outputs:

Indices of segregation (dissimilarity, entropy, moran's I)

Sugarscape

[Epstein & Axtell, 1996]

Model overview:

- Resource extraction in basic society (sugar)
- Agents endowed with different metabolisms and vision scopes
- Emerging wealth inequality

Model parameters:

P : Population of agents [50, 510]

s- : minimum initial resource [10, 100]

s+ : maximum initial resource [110, 200]

Model Outputs:

Indices of inequality (Gini)

Experiment Design

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Schelling

[Schelling, 1971]

468 parameter combinations
x **100** replications (random seed)
x **45** density grids
= **2,106,000** simulation runs

Emphasis:

> 15 different grids per morphological types

Sugarscape

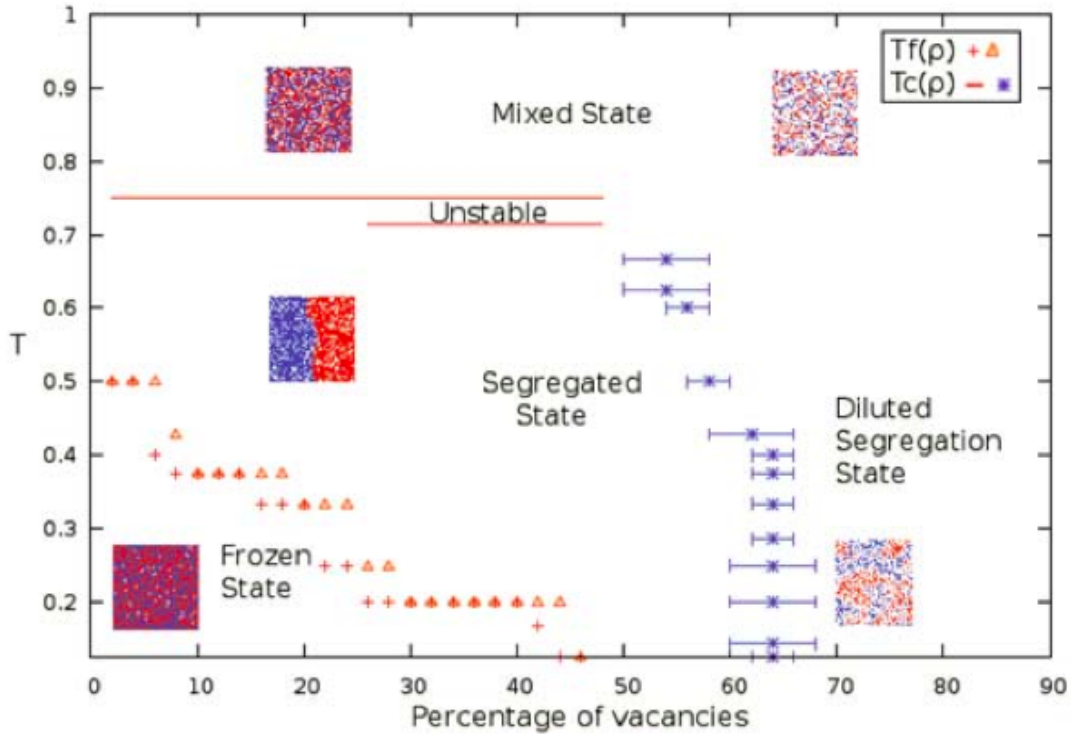
[Epstein & Axtell, 1996]

1000 parameter combinations
x **50** replications (random seed)
x **50** density grids
= **2,500,000** simulation runs

Emphasis:

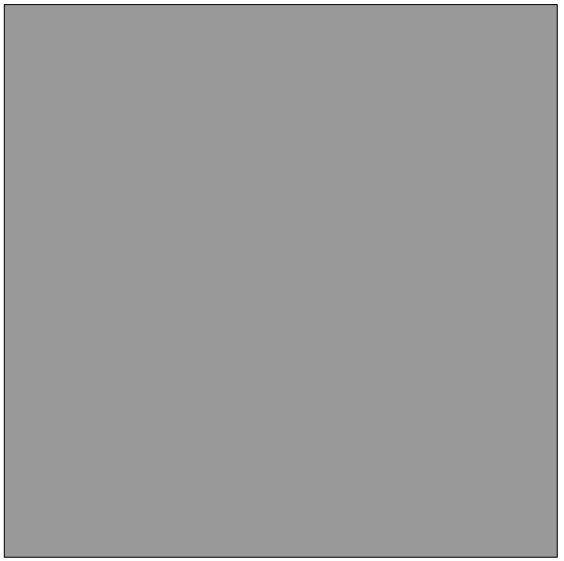
> comparison of phase diagrams

Phase diagrams | ex. Schelling

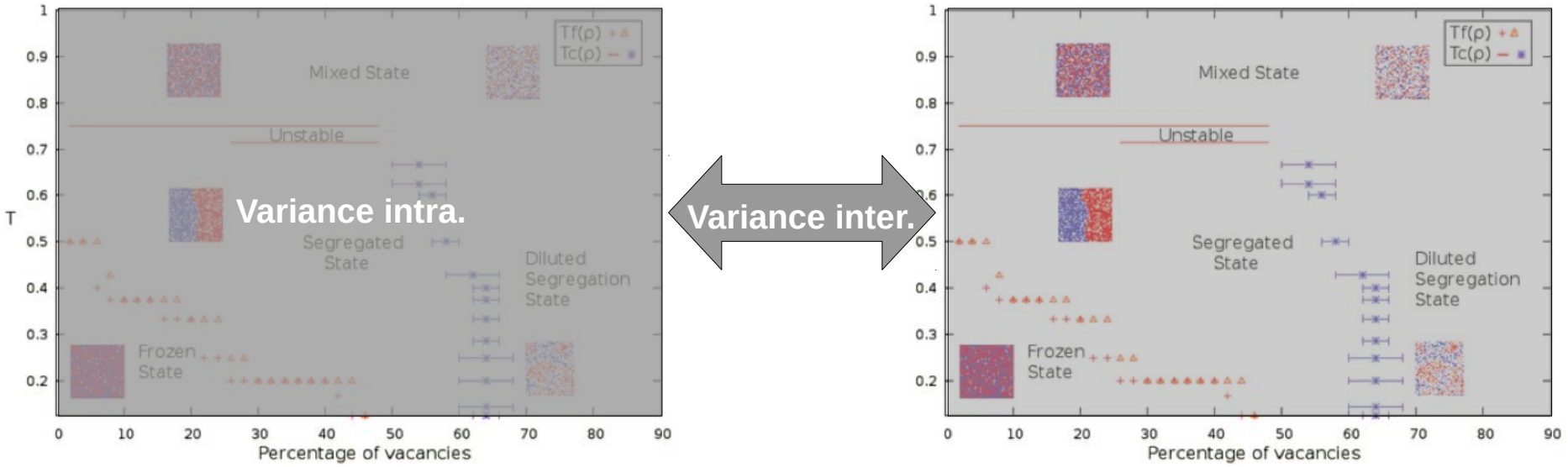


Source: Gauvin et al., 2009

Implicit density grid:

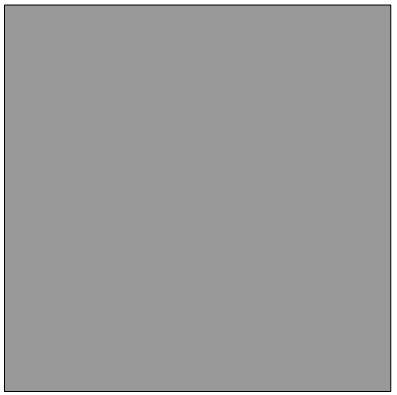


Comparing phase diagrams

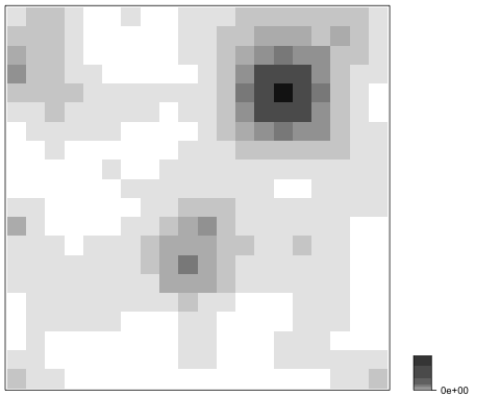


$$d_r(\alpha_1, \alpha_2) = 2 \cdot \frac{d(f_{\vec{\alpha_1}}, f_{\vec{\alpha_2}})^2}{Var[f_{\vec{\alpha_1}}] + Var[f_{\vec{\alpha_2}}]}$$

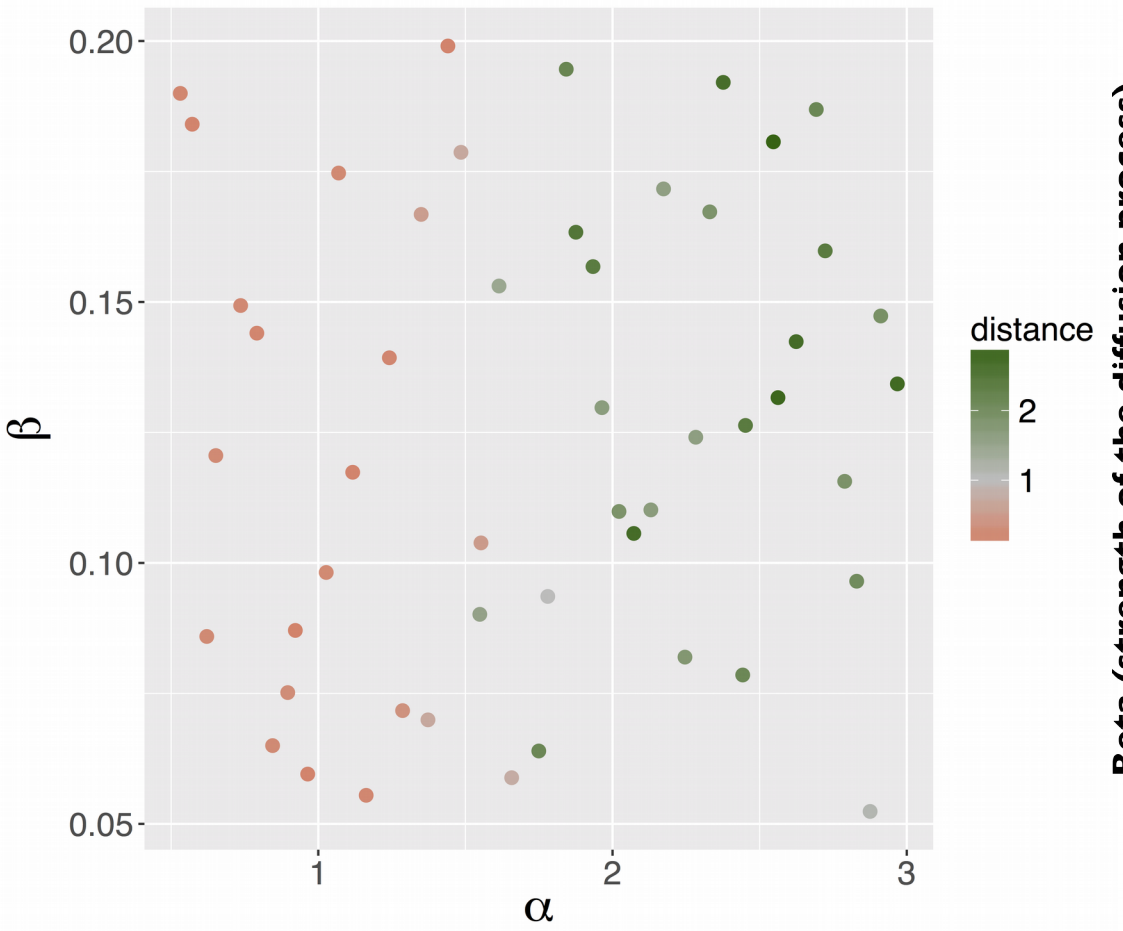
Implicit density grid:

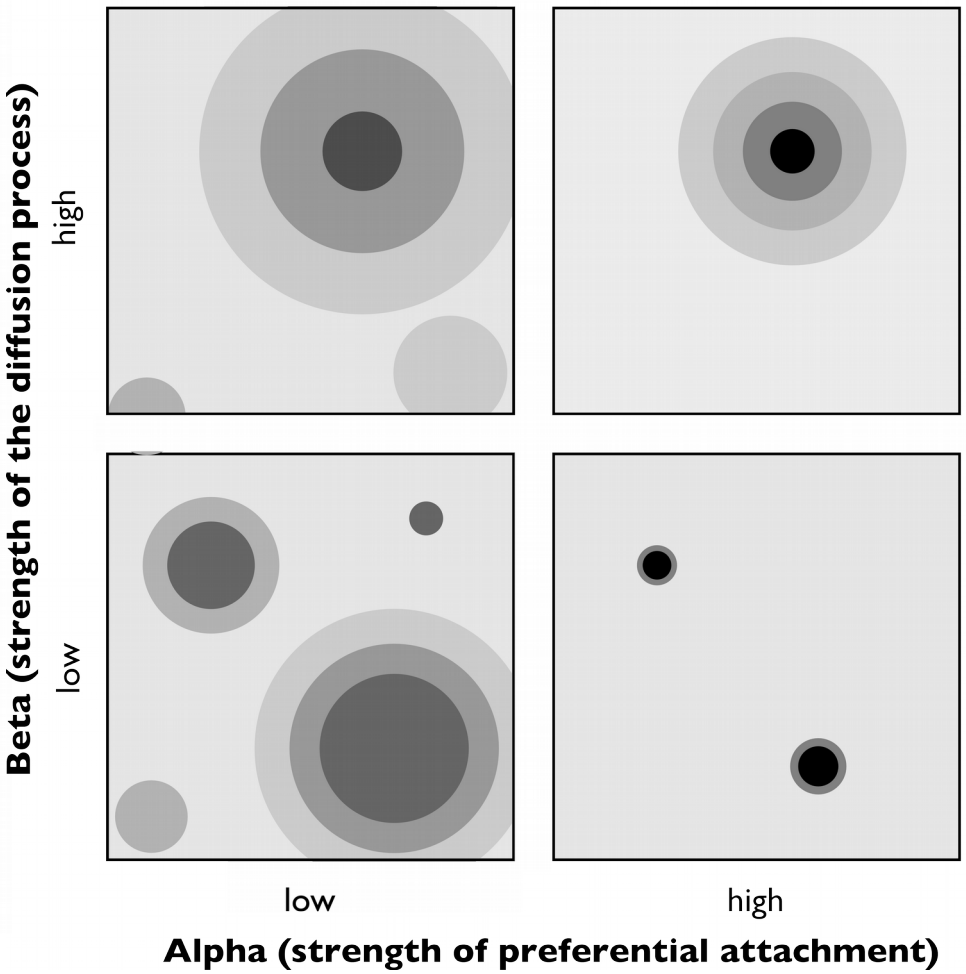


Explicit density grid:



Comparing phase diagrams | Ex. Sugarscape





Comparing phase diagrams | Ex. Sugarscape

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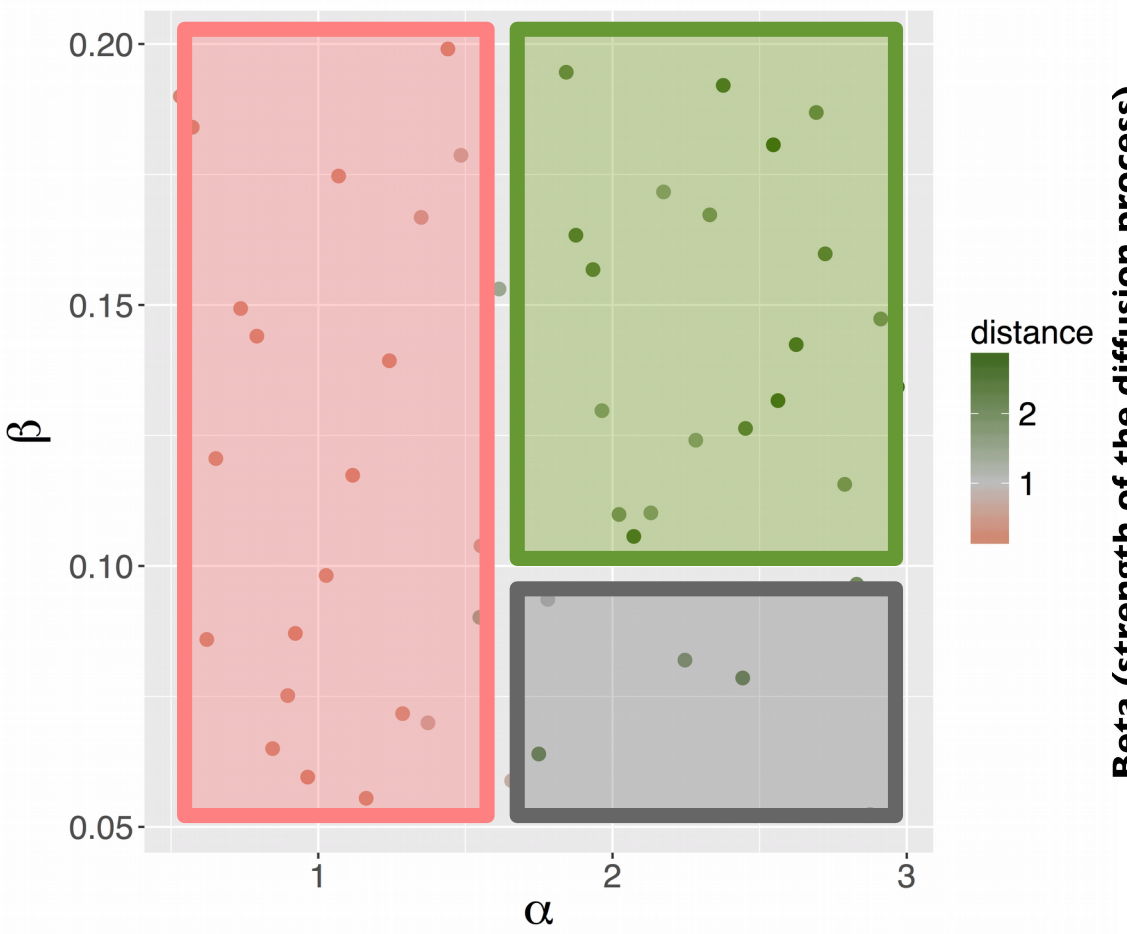

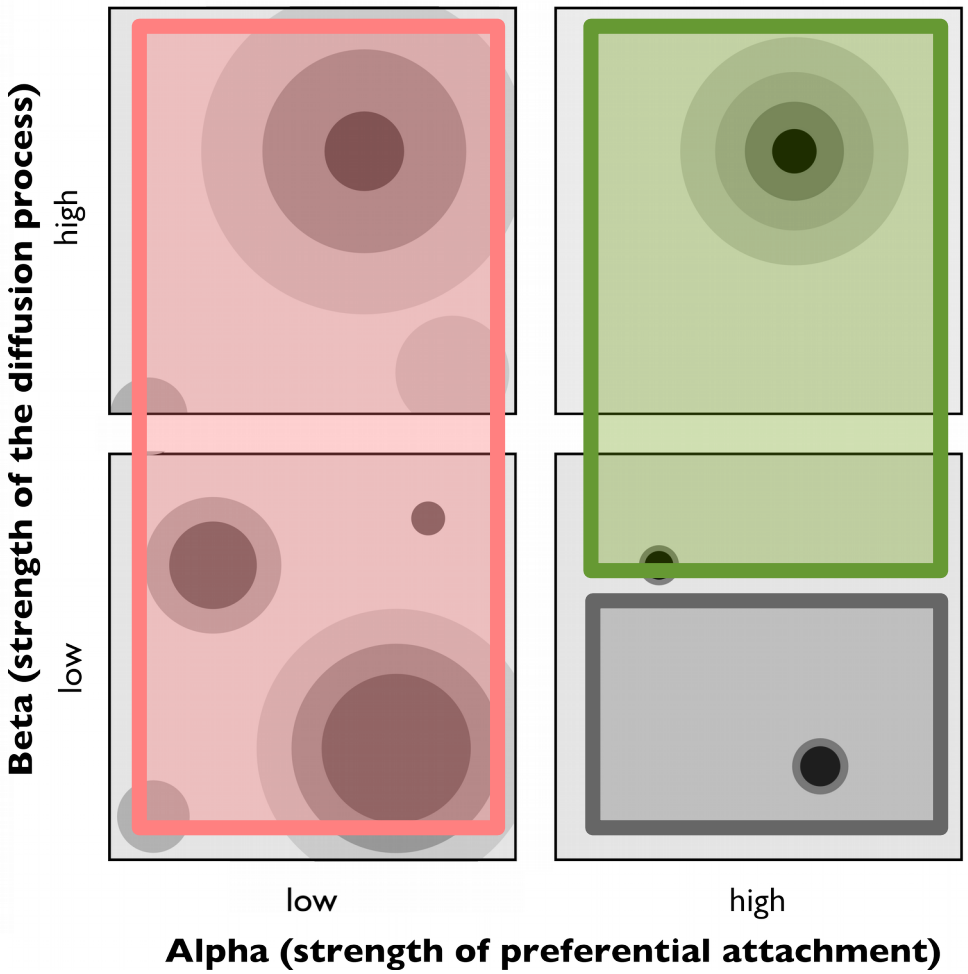

More variation due to **parameter** change in the reference case (intra variance > inter-variance)

Same variation due to **parameter** and to **spatial grids** (intra variance ~ inter-variance)

More variation due to **density grids** as initial spatial conditions (intra variance < inter-variance)

Spatial clustering | Results

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Outputs of Schelling model

Initial Spatial Order Conditions Parameters

Simulation outcome by segregation index:	Dissimilarity		Entropy		Moran's I	
Intercept	-0.212 ***	-0.141 ***	-0.254 ***	-0.208 ***	-0.036 ***	-0.061 ***
Similarity Wanted (S)	1.212 ***	1.212 ***	1.250 ***	1.250 ***	0.550 ***	0.550 ***
quadratic term (S^2)	-0.942 ***	-0.942 ***	-0.963 ***	-0.963 ***	-0.428 ***	-0.438 ***
Vacancy Rate (V)	0.602 ***	0.602 ***	0.453 ***	0.453 ***	-0.027 ***	-0.027 ***
Minority Index (%Maj - %Min)	0.307å ***	0.307 ***	0.130 ***	0.130 ***	-0.067 ***	-0.067 ***
Density Grid = Polycentric		0.087 ***		0.052 ***		0.001 ***
Density Grid = Discontinuous		0.111 ***		0.068 ***		*0.00*
Attraction meta-parameter α		-0.083 ***		-0.053 ***		0.014 ***
Diffusion meta-parameter β		0.323 ***		0.218 ***		0.017 ***
R2 (%)	30.6	34.7	24.1	25.6	23.9	24.0
# of observations (sim. runs)	2,106,000	2,106,000	2,106,000	2,106,000	2,106,000	2,106,000
AIC	-70717.68	-198748.2	208213.8	166048.8	-4385990	-4387816

NB: *** = significative coefficient

Spatial clustering | Results

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# of observations (sim. runs)	2,106,000	2,106,000	2,106,000	2,106,000	2,106,000	2,106,000
AIC						

Polycentric & Discontinuous cities are more segregated than compact cities

NB: *** = significative coefficient

Spatial clustering | Results

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Simulation outcome by segregation index:	Dissimilarity		Entropy		Moran's I	
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AIC						

Grids with high alpha less segregated

Grids with high beta more segregated

NB: *** = significative coefficient

Discussion | next steps

- **Limits** | Phase diagram comparison
  > Next: Using spatial metrics for the comparison

  Meta-regression model of simulation results
  > Next: Finding the most appropriate regression models

  Platform constraints and docking
  > Next: Compare with other implementations

- **Opportunities** | Reproducibility and other applications
  > All grids and workflows on GitHub repo: **ISCPIF/spacematters**

  Relaxing physics hypotheses in geosimulation models
  > homogeneity, isotropy, etc.

Conclusion

- **New method for geosimulation models**
  - > Spatial generator with meta-parameters
  - > Reproducible and easily repurposed
- **New insights on classical models**
  - > Urban morphologies produce more or less segregation
  - > Sugarscape is more sensitive to the spatial distribution of the resource than to the agents parameters

Thank you.

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For more...

> Paper soon on ArXiv.org !

> Repo soon on GitHub !

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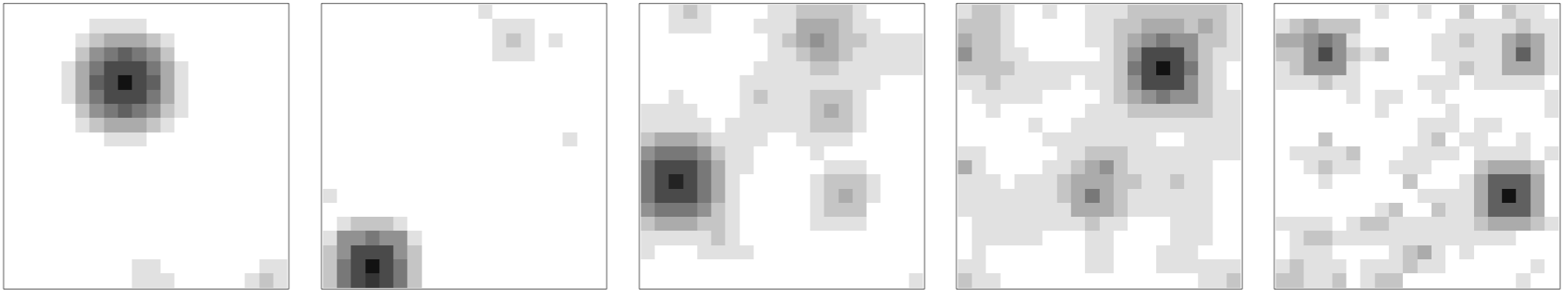
Acknowledgements: OpenMole **(openmole.org) &** European Grid Infrastructure **(www.egi.eu)**



Density grids **Generation**

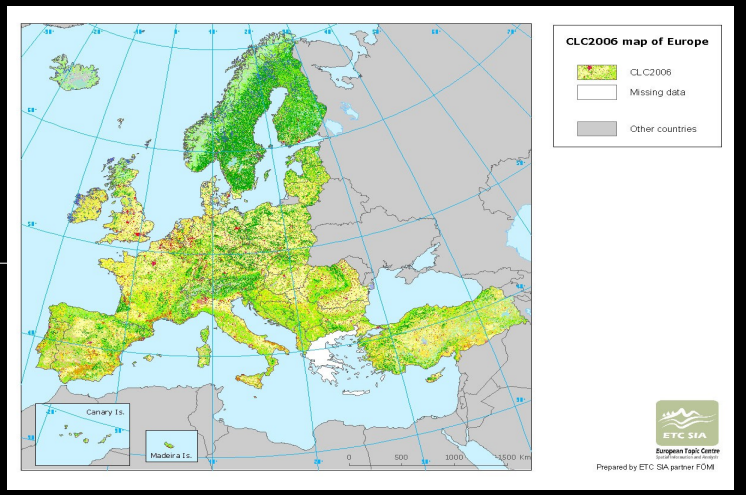
Definition of the grid indicators bounds :

Two fixed indices due to computational burden

- **size** index : 100 000 agents
- **intensity** index : 250 agents/cell on average

Observed values from European 110 metropolitan areas (Corine Land Cover 2006)

- **concentration** index
- **hierarchy** index
- **centrality** index
- **continuity** index



[http://sia.eionet.europa.eu/CLC2006]

Density grids **Generation**

- Stochastic exploration (mean on 50 replicated) of a LHS Sampling (2000 points) of the parameter space (N,n,a,ß) for 50x50 grids 25km grids on all Europe.
  → **170 grids** (closest to real point cloud)