Generative coupled model for urban configuration optimisation

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Outline

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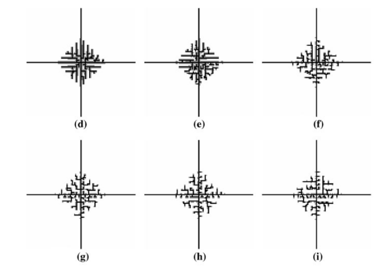
Why use cellular automata in urban planning ?

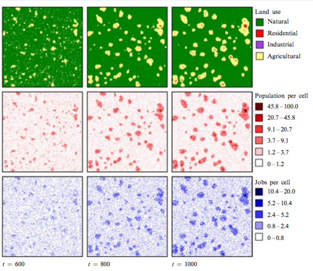
- First introduction in [White and Engelen, 1993] and then [Batty, 1997]: reproduction of fractal urban form and land-use patterns.
- Since then, numerous applications. E. g. coupling with GIS in quantitative geography, calibrations on real land-uses configurations (review in [Iltanen, 2012]).
- Examples: micro-economic model of sprawl [Caruso et al., 2011]; 1D CA to show path-dependance of settlements patterns [Peeters and Rounsevell, 2009]; real-time rules for sustainable development [Wu, 1996].

Examples

Examples of CA models



(a) Microeconomic model of sprawl, [Caruso et al., 2011]



(b) Land use simulations, [van Vliet et al., 2012]

Figure: Different uses of CA models in urban planning

Our framework

- Influence of proximity on urban form: proposition of modeling transportation network coupled with a CA in [Moreno et al., 2007, Moreno et al., 2009].

- Generalisation and extension of the model: from morphological to functionnal properties of the urban environment.

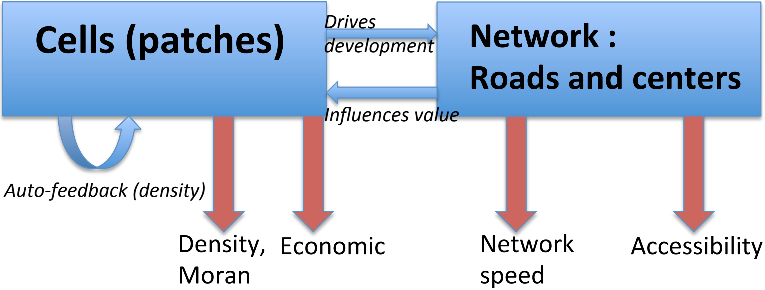
- Objective: apply the model to a real case, by proposing a method for the optimisation of planning on all possible functional configurations.

Outline

Settings and agents

- Fixed agents: cells in a square lattice $(L_{i,j})_{1\leq i,j\leq N}$, occupied or not (function $\delta(i,j,t)$)
- Evolving euclidian network $N(t) = (V(t), E(t))$, including fixed city centers $C_0 \subset V(0)$ for each an activity $a \in \{1, \ldots, a_{max}\}$ is defined (functional properties of the urban scape.
- Heterogeneous explicative variables $(d_k)_{1\leq k\leq K}$ defined on cells, with associated weights $(c_k)_{1\leq k\leq K}$ (main parameters of the model), that are:
  - d_1 the density around the cell (in a fixed radius r)
  - d_2 the distance to the nearest road
  - d_3 the distance to the nearest town center through the network
  - $d_4 = \|(d_A(a))_{1\leq a\leq a_{max}}\|_{p_A}$ with $d_A(a)$ distance to nearest center with activity a through the network: integrated accessibility of activities

Model workflow



Evolution rules

At each time step:

- Sprawling of occupied urban structure. The best N cells according to the value $v(i,j,t) = \frac{1}{\sum_{k=1}^{K} c_k} \cdot \sum_{k=1}^{K} c_k \cdot \frac{(d_k^{max} - d_k)}{(d_k^{max} - d_k^{min})}$ are built.
- Adaptation of the network: when a new cell is built, if $d_2 > d_s$ fixed parameter, the cell is connected to the network with a new perpendicular road.

Evaluation functions

Objective Morphological indicators

- Integrated local density
  $D(t) = \left[\frac{1}{\sum_{i,j}\delta(i,j,t)} \cdot \sum_{\delta(i,j,t)\neq 0} d_1(i,j,t)^{p_d}\right]^{1/p_d}$
- Moran index (spatial auto-correlation, [Tsai, 2005]): world decomposed in a grid of size M ($1 \ll M \ll N$), $(P_i)_{1\leq i\leq M}$ are populations in each part of the grid, then

$$M(t) = \frac{M}{\sum_{i\neq j}\frac{1}{d_{ij}}} \cdot \frac{\sum_{i\neq j}\frac{1}{d_{ij}} \cdot (P_i - \bar{P})(P_j - \bar{P})}{(\sum_{i=1}^{M}(P_i - \bar{P}))^2}$$

Evaluation functions

Performance indicators

- Network speed ([Banos and Genre-Grandpierre, 2012]) $S(t) = \left\| \left(\frac{d_3(i,j,t)}{d(ij,c^{ij}_{min})} \right) \right\|_{p_s}$ with $d(ij, c^{ij}_{min})$ euclidian distance to nearest center density
- Normalized functional accessibility $A(t) = \left\| \left(\frac{d_4(i,j,t)}{max_{i,j} d_4} \right) \right\|_{p_{GA}}$
- Socio-economic segregation potential: run on the generated configuration of an economic residential dynamics ABM ([Schelling, 1969], [Benenson, 1998]), that is strongly sensible to spatial structure according to [Banos, 2012], calculation of the final spatialised segregation index E.

Outline

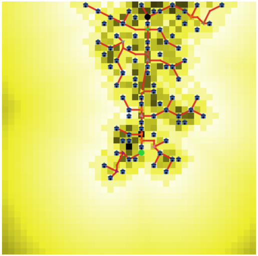
Demonstration

Demonstration of the implementation of the model of simulation in NetLogo

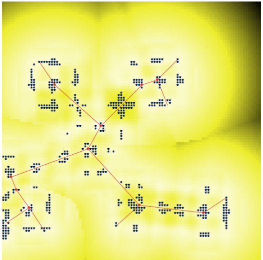
Outline

1. Introduction
2. Model description
3. Demonstration
4. Results

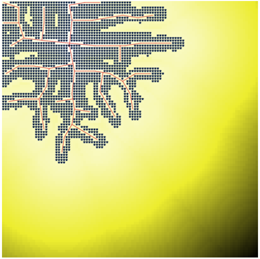
Results: generated shapes



(a) "A city can be a tree", [Alexander, 1964]



(b) Intermediate shape



(c) One center, no density

Figure: Examples of generated shapes

Results: typology of structures

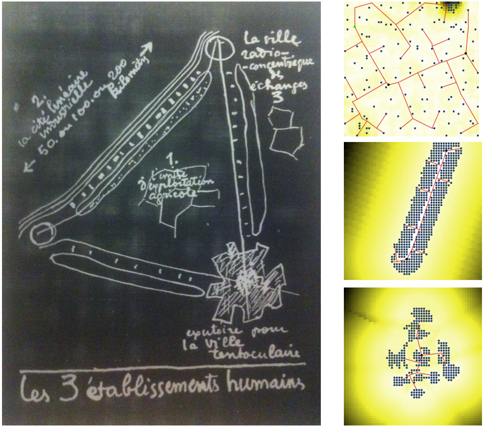


Figure: Parallel between Le Corbusier's typology of "human settlements" and some generated structures

Morphological classification

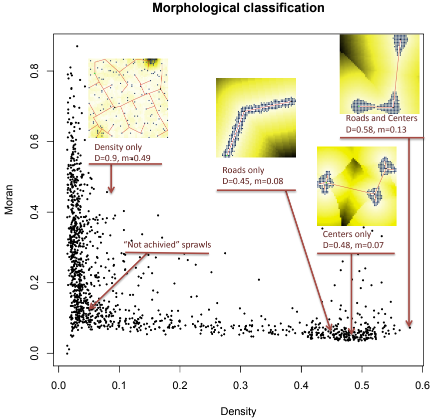
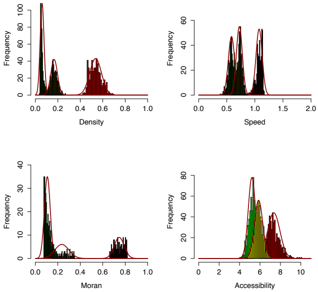
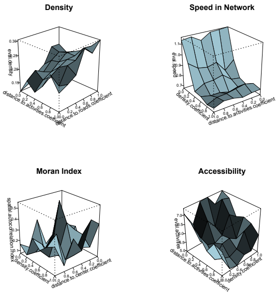


Figure: Projection in the morphological plane of indicators; classification of some structures.

Statistical analysis and exploration of parameter space



(a) Statistical distributions of outputs for different points in the parameter space



(b) Surface of outputs as functions fo two selected parameters

Figure: Exploration

Why are these explorations useful ?

- Statistical study of the behavior of the model: are the output sensible to initial spatial configuration ?
- Demonstration of the robustness of the model and of the possibility to compare runs on different initial configurations (implying to make the calculations on stochastic repetitions), behavior of outputs along moves in the parameter space
- Other necessary points that we explored: influence of update type, size of the grid for Moran index, behavior of the economic ABM.

Economic ABM

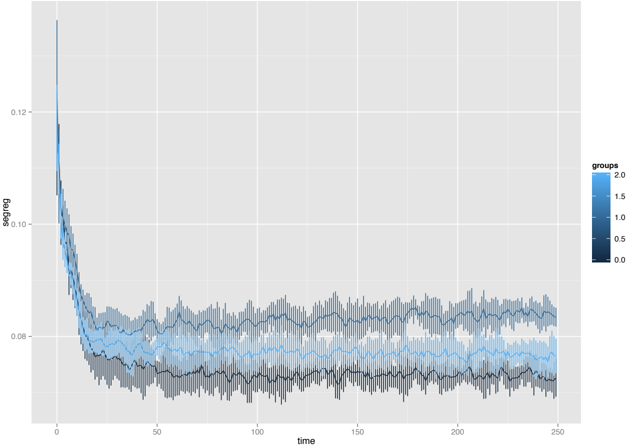


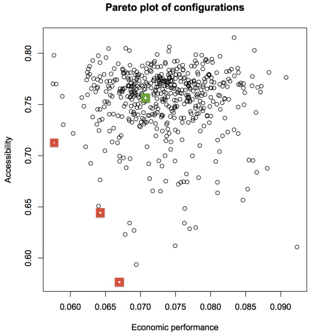
Figure: Time series of segregation index during a run of the economic ABM for different configurations.

Concrete application: method

- Fixing the spatial initial structure and the parameters, optimise on the possible distribution of activities among centers. Choice of parameters is crucial.
- Importation of real GIS data: centers correpond to centroids of zones in a district, initial network to main roads. Some centers have fixed activity (stations), other can be 2 different ones (residential or tertiary).
- Exploration of all possible configurations (possible here, $2^8 = 256$ configurations), Pareto-plot of economic performance/accessibility.

Concrete application: results

(a) Raster map of the evaluated district



(b) Pareto plot for optimisation on economic performance and accessibility

Figure: Concrete application on the district of Massy, Atlantis

Conclusion

- Many questions are still open: do we have the good scale of application ? (although it should be scale-free), do we have isolated the dominant processes ? (cf [Louf and Barthelemy, 2013])
- We have however been able to have qualitative valid results for the generated shapes and a quantitative application of the model to a real case.
- Can be seen as going in the sense of the emergence of a rigourous "evidence-based urbanism", or "quantitative urbanism" ([Portugali, 2012]).

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Questions

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