A residential land use model for the periphery of Rome

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Postcards from the outskirts

Rome, 1959

Rome East end

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The failure of planning

• Arcology experiment gone wrong (late 70s)

• pop. 8000 ca.

• Length ~ 1 km, 9 stories high
A “new” master plan

- Last plan dates back to 1962
- Long and hard process for the new plan: started in 1994, approved this year
- However: “planning-by-doing”
Why modeling?

• Basically a long list of laws and zoning maps

• Projections from census data: population not growing, but number of households is.

• Where is the new residential offer going to be located?
A coupled system ...
Here is a need for an improved understanding of how human actions affect natural processes of the terrestrial biosphere and of the prime societal drivers and dynamics of these actions. There is an even greater need to evaluate the consequences of these changes across different land systems. Very point on Earth can be defined along a continuum of states from wilderness to megacities resulting from the interactions between societal and natural dynamics. Figure 2 shows the dynamic of this continuum generally but not always moves towards increasing human occupation and impact. Abandoned farmland may return to forest, and clear-felled forests may regrow, however, once an area carries human structures it seldom reverts to open land. Timescales of movement along this continuum vary; human development may occur in years, even months as economic and social opportunities arise, but return to a wilderness landscape may take centuries. This continuum needs to be depicted more explicitly to quantify the rates of landscape change and to explain the underlying causalities and decisions involved.

In the development of this science plan, it is hoped that improved understanding of how human actions affect natural processes of the terrestrial biosphere will help to assess the risks faced by societies and their environments and the ways in which societies deal with these risks. In the past few decades, it has become apparent that growth in human well-being, if measured simplistically by gross global economic product, shows no sign of slowing (however, economic and social development is dependent on the services that the Earth provides, e.g., freshwater, clean air, atmospheric temperature control, primary production, and system resilience due to genetic diversity). It is unlikely that economic growth can draw down and substitute for these services indefinitely. There is likely a threshold at which the Earth system, including all its economic, technological, and other societal responses, can no longer function.

GLP (2005) Science Plan and Implementation Strategy. ... with complex interactions
Complexity!

• Are cities complex adaptive systems?

• Is a “science” of cities now possible?

Growth, innovation, scaling, and the pace of life in cities

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The increasing concentration of people in cities presents both opportunities and challenges (9) toward future scenarios of sustainable development. On the one hand, cities make possible economics of scale in infrastructure (9) and facilitate the opti-
Agent-based modeling

• Model the interacting entities
• Specify rules of interaction
• Run many simulations
  • Is the average case representative?
Caveats

• ABM for the social sciences

• Josh Epstein: “If you can’t grow it you can’t explain it”

• Good for formulating new hypothesis, finding new scenarios, hoarding knowledge

• Less good for making new predictive theories
Outline

• Definitions of the model
• Dynamical features of the model
• The Gillespie algorithm
• Calibration & “results”
Area of study

~ 15 km
The city

- A cellular decomposition $\Gamma$
- Irregular neighborhood
- Census system
- Real multidimensional state space $c \in \Gamma$

$$v(c, t) \in \mathbb{R}^p$$
Dynamic var. /endogenous proc.

$$w(c, t) \in \mathbb{R}^q$$
Fixed var. /exogenous proc.
The state space

1. Population (# of abitants) 13. Farming & wildlife surface area (ha.)
2. Available housing (# of flats/dwellings) 14. Empty & undeveloped surface area (ha.)
3. Occupied housing (# of flats/dwellings) 15. Parks and green areas (ha.)
4. Distance* from shopping centre (m.) 16. Trading (retail/wholesale) sector (# of
5. Distance* from school/university (m.) workers)
6. Distance* from hospital (m.) 17. Transportation & communications sector (# of
7. Distance* from cultural/entertainment workers)
   centre (m.) 18. Manufacturing & Energy sector (# of
8. Distance* from transportation network workers)
10. Productive surface area (ha.) 20. Banking, insurances, business (# workers)
11. Surface area of city-level services (ha.) 21. Office/Factory buildings (cu. m.)
12. Surface area for district-level services (ha.) 22. Trading/Services building (cu. m.)

\[ p = 16 \quad \quad q = 6 \]

* nearest!
Agents

- A set of kinds of events $\mathcal{A}$
- A population of agents for a kind of events
- Indirect interactions between populations
  - unlike classic ABM
Rules

1. Move in a house (purchase or rental)
2. Move out of a house
3. Construction of a new residential building
4. Construction of a mall
5. Zoning change from farming to empty
6. Creation of a small shop
7. Creation of a service company
How to build a house

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Update rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>Total number of free available flats in the cell</td>
<td>$N + \Delta n$</td>
</tr>
<tr>
<td>$S_u$</td>
<td>Total undeveloped surface in the cell</td>
<td>$S_u - (\Delta s_1 + \Delta s_2)$</td>
</tr>
<tr>
<td>$S_b$</td>
<td>Total built surface due to residential use</td>
<td>$S_b + \Delta s_1$</td>
</tr>
<tr>
<td>$S_p$</td>
<td>Total built surface due to parkings and paved use</td>
<td>$S_p + \Delta s_2$</td>
</tr>
</tbody>
</table>

Table 1: Update rule of the state of a cell due to the construction of an apartment building

- **Update rules**
  \[
  \pi = (\pi_2, \pi_9, \pi_{10}, \pi_{14}) = (\Delta n, \Delta s_1, \Delta s_2, -(\Delta s_1 + \Delta s_2))
  \]

- **Sampled from a distribution** $\beta_\alpha(c, \pi, t)$
Stochastic dynamic

• Incremental dynamics

\[ v_k(c, t + \Delta t) = v_k(c, t) + \pi_k(\omega, c, t) \]

• How many events occur during a long time step? Sparsity assumptions. Poisson process

\[ \Pr \{ N(t, t + \Delta t) = k \} = \exp(-\lambda\Delta t) \frac{(\lambda\Delta t)^k}{k!} \]

• Time-dependent intensity

\[ \lambda_\alpha(c, t; B) = \int_B \lambda_\alpha(c, \pi, t) d\pi \quad B \subseteq \mathbb{R}^{n(\alpha)} \]
How to simulate?

• Use dynamic Monte Carlo
• Trick! simulate separately:

\[ \lambda_\alpha(c, \pi, t) = \lambda_\alpha(c, t) \beta_\alpha(c, \pi, t) \]  
\text{(chain rule)}

• with:

\[ \lambda_\alpha(c, t) = \int_{\mathbb{R}^n(\alpha)} \lambda_\alpha(c, \pi, t) d\pi \]  

conditional density!
“... sampling the number of events?”
Spatial exploration

- Each update rule has a population of agents
- Agents are particles
- Binary state (Active/Passive) + current cell
- Multi-step decision process for one update event
A (urban) space odyssey
A (urban) space odyssey
A (urban) space odyssey

activation -> diffusion -> update

update -> decay

decay
A (urban) space odyssey

activation ➔ diffusion ➔ decay
The exploration model

- Affects how events are sampled!
- A cognitive analogy: two levels of decision making:

<table>
<thead>
<tr>
<th>Information used</th>
<th>Global</th>
<th>Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional context</td>
<td>accessibility</td>
<td>features of the district related to the kind of event e.g. buying a house: “centrality”, average rent</td>
</tr>
<tr>
<td>- Accessibility</td>
<td>- Presence of major infrastructures</td>
<td></td>
</tr>
<tr>
<td>Type of action</td>
<td>activation, diffusion</td>
<td>update</td>
</tr>
</tbody>
</table>
It’s all a matter of gravitation

- Four Poisson sub-processes (activation, diffusion, update, decay). Here activation:

\[ \lambda^{(A)}_{\alpha}(c, t) \]

- Set the total intensity as a parameter

\[ \Lambda^{(A)}_{\alpha}(t) = \sum c \lambda^{(A)}_{\alpha}(c, t) \]

- Define according to a force of attraction:

\[ \lambda^{(A)}_{\alpha}(c, t) := \Lambda^{(A)}_{\alpha}(c, t) \frac{F_{\alpha}(c, t)}{\sum d F_{\alpha}(d, t)} \]
Urban typologies

• Two types of forces of attraction:
  
  \[ F_\alpha(c, t) \quad \text{(global)} \quad G_\alpha(c, t) \quad \text{(local)} \]

• Measure how good a cell is a favorable to update event of a certain kind

• Principal Component Analysis (PCA) of the data matrix used to compute them
PCA & local $G_\alpha$

- Project data over the (first) PCs
- Take the sum of the scores for the variables in the update rule
- Use correlations with the PCs as weights
The regional force

- Less detailed information
- Take into account the context
- Averaging “erases” spatial detail!

\[ F_\alpha(c, t) = \sum_{c'} i(c') h(d_{cc'}) G_\alpha(c', t) \]

integration index

Hill’s decreasing step function of the distance
Putting all together

• Gillespie algorithm:

1. Sample the time to next update
2. Sample kind of update rule \( \alpha \)
3. Sample the decision step (activation, \( \ldots \))
4. Sample the cell
5. If Update: sample the parameters \( \pi \)
6. Update the intensities
Pros & cons

• Asynchronous – fast!
• Need to update the intensities – slow!
• Inherently sequential – “embarrassingly” parallel
• Optimizations may exploit locality (spatial and temporal)
“Results”

- Calibration?
- Intrinsic mechanism hardcoded in the rules:

Zoning → Building → Renting

- farming / green land
- empty / undev. land
- residential surface
- flats

Is the model able to reproduce qualitatively a saturation effect?
The text is not directly translatable into a plain text representation because it contains graphical data that cannot be accurately described in text form. The diagrams illustrate the relationship between time, variables such as population, and the development of residential and undeveloped surfaces over time. Each graph shows different scenarios (indicated by different lines or markers) with varying parameters for time steps and outputs.

For example, Figure 3 (a) shows the housing stock level over time, with multiple curves representing different values of a parameter \( \Lambda \). Each curve represents a different scenario, and the parameter values are indicated on the legend. Similarly, Figure 3 (b) illustrates the developed residential surface, and Figure 3 (c) shows the agriculture and free land. Figure 3 (e) depicts the undeveloped surface over time.

The text mentioned in the image includes discussions on the support system, the assumption of independence, and the dynamical state. It also references the work of Ciampaglia et al., Vancheri et al., and the integration of data at the economic level with the support system.
Residential index

(g) Resident. density vs housing starts  (i) Local services vs housing starts

saturation in residential areas, sprawling growth, but brand new centers need infrastructures!
Summary & future work

★ General framework for dynamic sampling
★ Cognitive model of exploration of the city
★ Interaction based

• It would be fun to do:
  • Put data about rents and housing prices
  • Have data of transportation network
  • Bayesian approach for F and G
  • Use the model!
Questions