Complexity and geographical intelligence

S4: Spatial Simulation for Social Sciences

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ABM-S4-ESHIA Lalonde, septembre 2007
Complex System Society roadmap

Territorial intelligence and sustainable development

Innovation, learning and co-evolution
A suggestion about complexity

A measure of complexity for societal systems:
• not computational: combination of signs is a too elementary definition
• not mathematical: the unpredictability of evolution in non-linear systems with many interactions are a necessary but not sufficient condition for a relevant description
• social sciences are « historical », « evolutionary »
  ➔ contexts matters (in space, time…)
  ➔ the number of disciplines which is necessary for approaching intelligibility is a good proxy for measuring complexity
Considering complexity in social systems

The observer is part of the system ➔
Even if models are never used, they contribute to build societal representations

Scientist ethics
Citizen responsibility

But: self-fulfilling prophecies…
Geographical questions

From the planet to the world: ➔ how to explain the differences in the way societies organise the space they live in?

Two parallel sources of explanation:
• Vertical interactions (human ecology)
• Horizontal (spatial) interactions (spatial analysis)

The complexity arises from the diversity of spatio-temporal scales that are to consider for building an explanation from these interactions
Three entrances in geography

An encyclopedia of geographical concepts:
http://hypergeo.free.fr

- Spatiality of societies
- Relationships societies / environnement
- Regions and territories
The complexity paradigm

1 Systems analysis, MIT, Jay Forrester
General systems theory Bertalanffy 1967

- System’s autonomy / its environment
  Models: difference equations

2 Self-organisation theory: Prigogine, Haken (1970-80)

- Open systems, dissipative structures, unpredictable effects of non linear micro-interactions on system’s macro structure and dynamics, path dependence (irreversibility)
  Models: differential equations

3 Santa Fe Institute, ISI, ECSS (1990-2000)

- Emerging properties
  Models: MAS
Agent based approach in geography

What are the relevant geographical entities?

Individuals? Homo geographicus (still to define)?
Households? Firms? Parcels of land?
Neighbourhoods? Villages? Towns, cities?
Regions (« natural », historical, political)?
States?
Cultures?
Networks?

⇒ Roots of geographical ontology are to be found in structure and evolution of geographical space
Question of model validation in MAS

Is validation only an ex-post problem?
Games of imagination

Retro-ductive methods: the model as a substitute to experimentation of theories

- Starting point: stylised facts (not factoïds!)
- Use of existing knowledge and social surveys for fixing parameters values and rules, and even for choosing the agents!
Geographical ontologies

Which are the agents?

MAS for going beyond two fetichisms:
Fetichism of space
Fetichism of actors

How to build geographical objects?
role of scale
Geography and scale: continuity (but non linearity)

Over a variation domain, some processes, slightly non linear, are repeated at all scales with similar effects.

Continuity, self-similarity \(\Rightarrow\) fractal structures, scale free networks.

Example: central place theory.
Central places: a fractal spatial structure

Christaller, 1933
Scale free networks of urban settlements

How to cut in large networks?

In continuous geographical space, it is very difficult to identify relevant sub-systems (for instance, to delineate systems of interacting cities, even national boundaries are not a significant limits for the largest metropolises).

The processes which built this hierarchical differentiation across geographical scales are non-linear.
Example of scaling laws

**Source:** ISCOM: Theoretical reference to scaling laws (G. West) + paper in *Cybergeo* (Paulus, Vacchiani-Marcuzzo, 2007)

Experiments:

- Adjustment between number of employees in economic sectors and urban population size (France, USA and South Africa) on log-log graphs

\[ \log N_{ij} = \beta \log P_{ij} + \alpha \]

According to observations, there are three types of urban activities:

- \( \beta > 1 \)
- \( \beta = 1 \)
- \( \beta < 1 \)
French survey: data

- 276 cities defined as urban areas ("aires urbaines")
  Urban agglomeration (core) and its periphery defined according to the intensity of commuting links

- Population and employment data from 1999 census

- 32 economic sectors (NES)

- 31 occupational groups (PCS)

(Source: Paulus et al. 2007)
US survey: data

- 276 cities defined as Metropolitan Areas (258 MSA and 19 CMSA, without Porto Rico – definitions used for the Census 2000)
  Densely urbanized area (core) and outlying counties defined according to the intensity of commuting links
  Population and employment data from census 2000

- 20 economic sectors (NAICS)

- 23 occupational groups (SOC)

(Source: Paulus et al. 2007)
**French survey: leading economic sectors**

**Research & Development**

\[ \beta = 1.86 \]

95% CL: 1.70-2.02

\[ R^2 = 66\% \]

**Financial activities**

\[ \beta = 1.16 \]

95% CL: 1.13-1.19

\[ R^2 = 89\% \]

**Source:** Paulus et al. 2007
US survey: leading economic sectors

Professional; scientific and technical services

$\beta = 1.21$
95% CL : 1.19-1.23
$R^2 = 93\%$

Finance & Insurance

$\beta = 1.14$
95% CL : 1.11-1.17
$R^2 = 91\%$

(Source: Paulus et al. 2007)
French survey: common sectors

**Hotels & Restaurants**

\[ \beta = 1.03 \]

95% CL : 0.99-1.07

\[ R^2 = 90\% \]

\[ y = 0.0085x^{1.0311} \]

\[ R^2 = 0.896 \]

**Health and social work**

\[ \beta = 0.96 \]

95% CL : 0.93-1.00

\[ R^2 = 92\% \]

\[ y = 0.0762x^{0.9648} \]

\[ R^2 = 0.9211 \]

(Source: Paulus et al. 2007)
US survey: common sectors

Construction

$\beta = 1.01$
95% CL : 1.00-1.03
$R^2 = 97\%$

Accommodation & Food services

$\beta = 0.98$
95% CL : 0.96-1.01
$R^2 = 96\%$

(Source: Paulus et al. 2007)
French survey: mature sectors

Manufacturing

$\beta = 0.92$

95% CL : 0.85-0.98

$R^2 = 76\%$

Manufacture of food products, beverages and tobacco

$\beta = 0.90$

95% CL : 0.83-0.97

$R^2 = 70\%$

(Source: Paulus et al. 2007)
Scaling between occupational groups and city size: France

(Source: Paulus et al. 2007)
Scaling between occupational groups and city size: US

* Professional A: Computer and Mathematical; Architecture and Engineering; Life, Physical and Social Sciences; Legal; Arts, Design, Entertainment, Sports, and Media.
  Professional B: Community and Social Services; Education, Training and Library; Healthcare Practitioners and Technical.
Initial stage of knowledge: a few steps

The Swedisch school: Hägerstrand’s theory on the spatial diffusion of innovation (1952)
Richard Morrill’s experimentations using stochastic simulation models

History of innovation spread in urban systems:
Brian Robson, 1973 (UK)
Alan Pred, 1973, 1977 (USA)

Incremental process of change and distributed growth
Denise Pumain (1978 with T. Saint-Julien and 1982)
Socio-economic co-évolution

F. Paulus, 2003
Interpretation of scaling coefficients

According to observations, there are three types of urban activities related to their **stage in the current innovation cycle**:  
A2 (innovative) with $\beta > 1$
A1 (mature) with $\beta = 1$
A0 (obsolete) with $\beta < 1$

As professions are highly depending upon sectors of activity, scaling effects are observed for professions as well, of the type:
- high skill professions: $\beta > 1$
- skilled professions: $\beta = 1$
- low or unskilled: $\beta < 1$
Formalising the linkage between innovation and organisation of urban systems: scaling laws

**Previous knowledge** from central place theory mainly:
- number and diversity of urban functions are increasing with city size, notion of distinct hierarchical levels among cities
- Systematic relationships between city size and:
  - Number of activities (housing, economic establishments, infrastructures)
  - Product of activities (gross product, income, wages)
  - Consumption of resources
  - Traffics (transportation flows, information flows)
  - Inputs and outputs (people, goods, information)
- But the reference is usually a linear relationship (most « social indicators » are per capita indices)
Adaptive geographical systems through space-time contraction

A. Bretagnolle, 2004
Hierarchical selection

Functional specialisation
= two major processes in geographical differentiation

Differential changes (second order interactions) are produced through asymmetries in interaction flows (that are first order interactions)

= second order interactions shape the geographical entities
Geography and scale: discontinuities

Discontinuities in geographical space define geographical objects

Examples:
- Administrative or political boundaries (fixed but not always stationary)
- Evolutionary, adaptive systems: fuzzy and evolutionary limits: example of the urban field
A view of urban space

Built-up areas in Europe from the sky (1990)

CORINE Land Cover

Source: European Environment Agency (1996)
The urban local interaction field

The urban field:
an example around Lyon (France)

a) grid for analysis

b) a double linear gradient

c) two fractal dimensions

Marianne Guérois,
2003
Space filling parameter: two fractal dimensions

Two different values of fractal dimension according to the distance from the urban centre

M. Guérois, 2003
A general model for European urban areas

<table>
<thead>
<tr>
<th>Cities</th>
<th>Spatial range (in km)</th>
<th>Shape</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td>Core</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>50</td>
<td>1.91</td>
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<tr>
<td>Barcelona</td>
<td>60</td>
<td>1.70</td>
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<tr>
<td>Frankfurt</td>
<td>50</td>
<td>1.90</td>
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<tr>
<td>Hamburg</td>
<td>60</td>
<td>1.96</td>
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<tr>
<td>Hannover</td>
<td>40</td>
<td>1.90</td>
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<tr>
<td>London</td>
<td>100</td>
<td>2.04</td>
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<tr>
<td>Lyon</td>
<td>50</td>
<td>2.05</td>
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<td>Madrid</td>
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<td>Napoli</td>
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<td>Roma</td>
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<td>Sevilla</td>
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<td>Torino</td>
<td>50</td>
<td>1.77</td>
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<tr>
<td>Valencia</td>
<td>50</td>
<td>1.48</td>
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</table>
One model for urban densities?

Bertaud
2005
Continental (cultural?) inequalities of urban densities

Figure 1: Average population density in the built-up area of 49 cities

Bertaud
2005
Hierarchical organisation of geographical levels

### Scale and urban systems

**Emerging structural properties**

<table>
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<tr>
<th>Spatio-temporal scales</th>
<th>Emerging properties</th>
<th>Organization levels</th>
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</thead>
</table>
| 1day                   | Hierarchy  
                          Functional diversity  
                          Spatial pattern              | Macro: System of cities  
                          (urban networks)            |
| 1 hour                 | Centrality  
                          Function  
                          Morphology  
                          “Ambiance urbaine”            | Meso: City  
                          (urban areas)                |

**Descriptors**

| Life cycle  
                          Profession  
                          Power                  | Micro: Actors  
                          (households, firms,  
                          institutions)          |
Scale and urban systems
Constructive interactions

- space filling service networking territorial adaptation
- recurrent politico-administrative decisions (ex: centralization)
- competition for sociospatial influence (territories, networks) with co-evolution (innovations, growth)
- specialization selection incentive to change
- external trade globalization
- networks representation
- "ambiance urbaine" economic externalities site constraints governance
- competition for space institutional co-operation division of labour learning processus
- Main one-level interactions
- interlevel interactions or constraints

Pumain, 2004

ACI Systèmes Complexes en SHS, Cerisy-la-Salle, 1er juin 2007
Classical mistakes when neglecting scale effects

Ecological fallacy

Atomistic fallacy
Classical but less often recognised as misleading linear methods of analysis

The computation of ratios is based upon linear relationships
- Comparison to the surface (density) ➔ bad reference for urban densities
- Comparison to population size (GDP/inhab) ➔ bad reference if scaling effects
- Exponential or logistic growth converted in linear projections…
Stylised facts in spatial interaction

• Gravity model
• Concept of interaction field (Hägerstrand)
• Corridors, barriers, frontiers, discontinuities
• Communications speed and historical time-space convergence
• Non euclidian geographical spaces
• Micro-geographical basis (emotions, values, representations, cost/time constraints, politico/functional/economic asymmetries)
• …
MAS modelling for testing urban theories

Starting point: Comparative observations on urban changes (growth in urbanised area, population size and economic product, evolution of the portfolio of urban activities, qualitative changes…) ➔ systematic similarities and differences in urban evolutions

Hypothesis: changes are produced through interactions at system level (interurban networks) and at local level (urban governance)

There is very little information about urban interactions (trade flows and exchanges, goods, people, information…) ➔ Reconstruction of urban exchange networks through simulation in order to reproduce observed urban changes
Emergence of geographical organisation from spatial interactions

- Hågerstrand: spatial diffusion theory 1952

- Morrill: migration simulation models 1965 and 1972

- Systematic changes in social interaction space (transportation speed and space-time contraction, E. Reclus 1895, D. Janelle 1969, E. Juillard 1973)

- Empirical analysis of innovation diffusion in urban systems (A. Pred, B. Robson, B. Lepetit….)
Simulating differentiated geographical evolution

• Dynamic models (differential equations)
P. Allen, A. Wilson, M. Clark, W. Weidlich, G. Haag, L. Diappi, R. Camagni, D. Dendrinos…

• Cellular automata and dynamic models
R. White, G. Engelen, M. Batty, S. Lombardo, G. Rabino, J. Portugali…

• Multi-agents models (for a better representation of spatial interaction)
SIMPOP: a multi-agents system

first application of MAS in geography!

Bura, Guérin-Pace, Mathian, Pumain, Sanders

Main results:

- No emergence if no spatial interactions
- Emergence of a polycentric hierarchised system of cities even if homogeneous initial conditions
- A renewed innovation flow is necessary for maintaining structural properties of the system of cities

But: 400 settlements only
two levels only (meso-macro)
Simpop2 (2002-2007)

http://www.simpop.parisgeo.cnrs.fr

Helène Mathian
Thomas Louail
Lena Sanders
Anne Bretagnolle
A model for simulating the geographical differentiation of urban systems

Anne Bretagnolle
Benoît Glisse, Lena Sanders, Hélène Mathian, Céline Vacchiani-Marcuzzo, Thomas Louail, Denise Pumain
Jean-Marc Favaro, Fabien Paulus
The SIMPOP2 Model (multi-agents system)

**Scale**: national or continental integrated urban systems, long term

**Cities are agents**: collective, immobile, heterogenous, evolving entities

**Main attributes**: location, resources (labour force, capital), functions (10 types)

**Three levels**: individual (firm or mayor, for scenarios), cities (local governance), national or multinational (global governance)

**Rules**: stylised facts from comparative study of the observed evolution of integrated urban systems
Aim of the model

- To improve our evolutionary theory of urban systems
  ➔ by designing a spatio-temporal reconstruction of the second order exchange networks (asymmetrical evolutionary interdependencies) that generate urban dynamics (i.e. differential growth and functional speciation)

- To analyse the role of geographical features and processes (location, access to resources, situation in information networks, mobility speed, range and intensity, innovation adoption, selection) in shaping urban dynamics
  ➔ through comparisons (between different types of urban systems, or between simulations starting from a theoretical or an observed initial configuration of the same system)
Endogenous dynamics in SIMPOP2

At city level: two time scales

- short term interaction: trade networks between cities according to three kinds of spatial interaction (depending on functional type)

- long term competition for attracting innovation (adopting new functions) according to successful results in short term trade
Exogenous dynamics in SIMPOP2

- Innovation cycles (new urban functions)
  - Long distance trade (1300-1800)
  - First industrial revolution (1800-1900)
  - Electricity and car manufacturing (1900-1950)
  - Information technologies (1950-2000)

- Adoption of new functions
  - General rules (hierarchical diffusion, from large cities to smaller towns) and strategic local governance (specialisation)

- Increase in interaction speed and frequency
  - Hierarchical selection: short-circuiting of smaller towns
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<th>coordinators</th>
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<td>Sophie de Ruffray</td>
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<td><strong>Advanced training in spatial analysis</strong></td>
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<td><strong>COMET</strong></td>
<td>Giovanni Rabino and Thierry Joliveau</td>
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<td><strong>Collaborative Methods in Territorial Studies</strong></td>
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<td><strong>ENVISA</strong></td>
<td>Silvana Lombardo, Mikhail Kanevski and Christiane Weber</td>
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<td>Céline Rozenblat</td>
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<td><strong>HyperGeo</strong></td>
<td>Bernard Elissalde</td>
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<td><strong>Electronic encyclopedia of geographical concepts</strong></td>
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<td><strong>Geovisualization</strong></td>
<td>Alain L’Hostis and Gilles Palsky</td>
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<td>(Fusion of Libercarto and Cartomouv)</td>
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<td><strong>MODUS</strong></td>
<td>P. Frankhauser, C. Tannier and I. Thomas</td>
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