Geographic Automata Systems

Paul M. Torrens and Itzhak Benenson

International Journal of Geographical Information Science
Vol. 19, No. 4, April 2005, 385–412

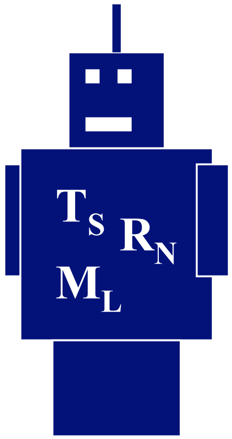
April 8, 2009

Seth Sheldon
Raster GIS

UMass Boston
David Tenenbaum

Introduction

- Automaton
  - A discrete processing unit, characterized by internal states
- Purpose
  - To develop a new framework for characterizing dynamic systems from existing models
- Methods
  - Extensive literature survey
  - Demonstration of method in existing spatial simulation software



Cellular Automata and Multi-Agent Systems as automata systems

- Cellular Automata (CA)
  - Defined by
    - State (S)
    - Transition Rule (T)
    - Neighborhood (N)
  - Fixed location

- Multi-Agent Systems (MAS)
  - Defined by
    - S and T, too
  - Gifted with **mobility**
  - Social Sciences

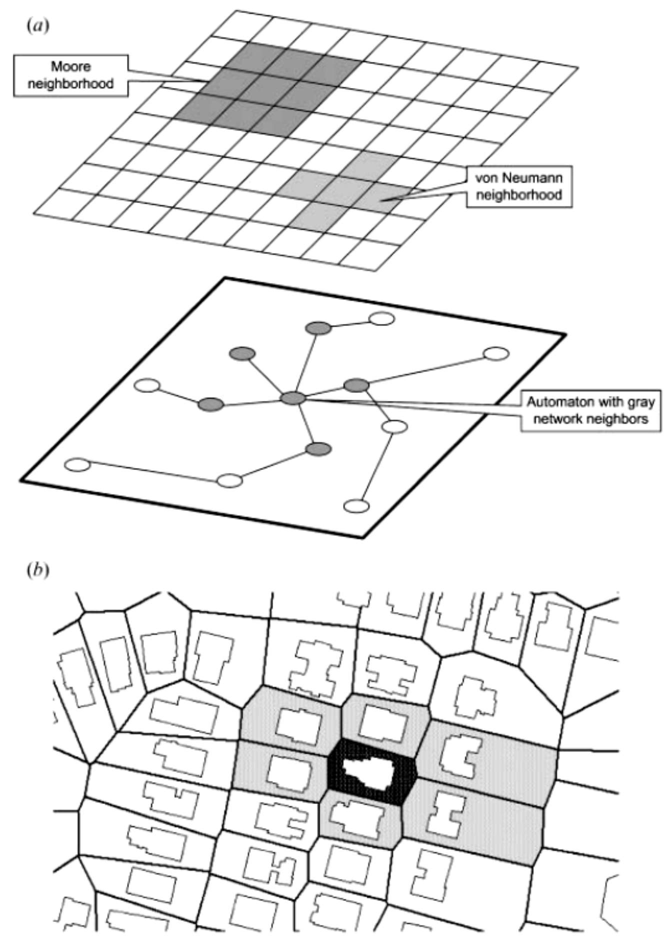


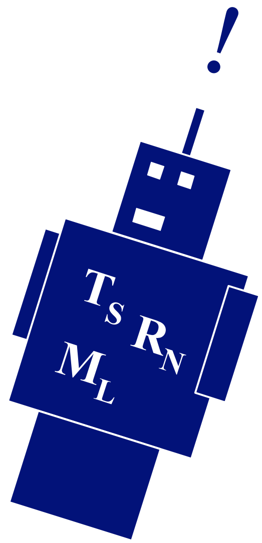
Figure 1. (a) Grid and network neighborhoods. (b) Voronoi neighborhood (gray), based on property coverage.

A rationale for *Geographic* automata systems

- CA and MAS
  - Insufficient in characterizing the moving world
  - The models "misbehave"

- Cellular Automata
  - Only diffuse information
  - Not free to move

- Multi-Agent Systems
  - Often over-general
  - Underestimate importance of spatial behavior



Geographic Automata Systems

- Georeferencing
  - Direct
  - Indirect

- Internal States for Animation:

State Transition

$\mathbf{T_S}: (S_t, L_t, N_t) \rightarrow S_{t+1}$

$\mathbf{M_L}: (S_t, L_t, N_t) \rightarrow L_{t+1}$

$\mathbf{R_N}: (S_t, L_t, N_t) \rightarrow N_{t+1}$

Location Movement

Neighborhood Rules

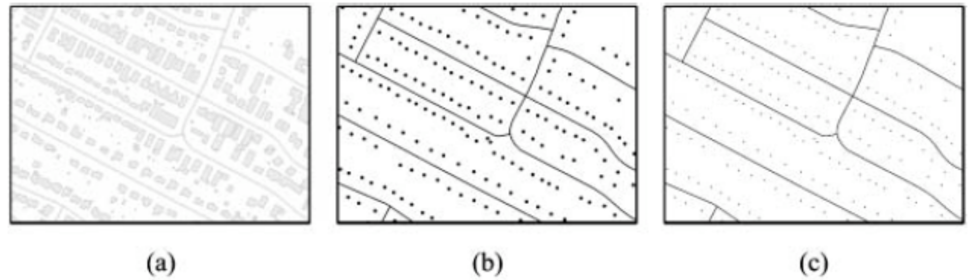


Figure 2. Direct geo-referencing. (a) Buildings are represented by means of foundation contours; road segments by means of road boundaries, (b) Buildings are represented by means of foundation centroids; road segments by means of a road segment centreline, (c) Building centroids and roads are represented by cells.

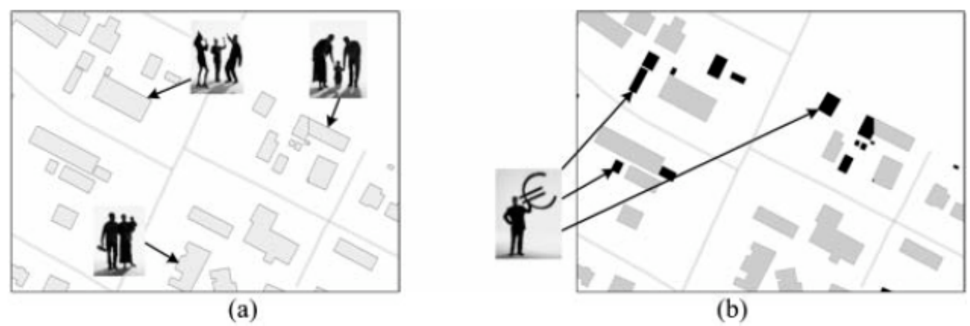


Figure 3. Indirect geo-referencing by pointing. (a) Locating households by pointing to the houses they occupy, (b) Locating a landowner by pointing to its properties.

GAS as a dynamic extension of GIS

- Vector
  - Geographic automata correspond to GIS features
  - Location for fixed automata
  - Relationships easy to evaluate
- Raster
  - Parallel to Cellular Automata
  - (Probably intuitive)

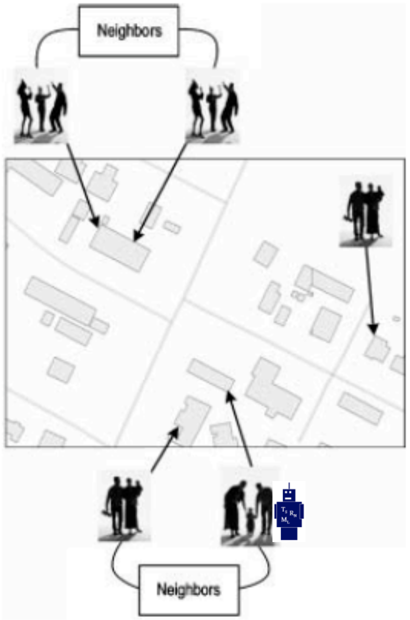
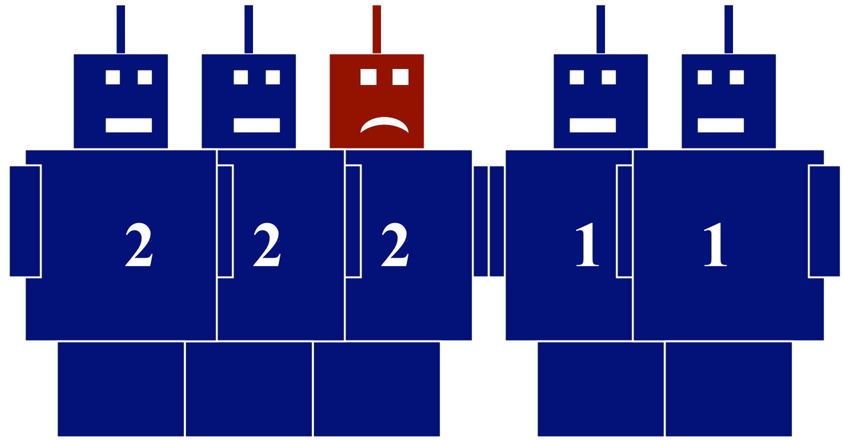


Figure 4. Neighbor relationships for indirectly located geographic automata. Two households are neighbors if they are located in the same property or in neighboring properties.

From GAS to Dynamic Spatial System



- Managing Time
  - Synchronous
  - Asynchronous

- Self-organization
  - *"It is very well known that if system rules are non-linear and the system is open, then the emergence and self-maintenance of entities at above-automata levels become feasible."*
  - Internal States (T_S, M_L, R_N)

Implementing the GAS framework in an urban context

- Schelling model (1969)

(a) (b)

Figure 6. Visual output of the Schelling model, implemented in (a) abstract and (b) real-world spaces.

Conclusions

- From GIS to GAS

Geographic system→Priority of location information and spatial relations between elements→Collective dynamics of geographic automata in space→GAS

- Adapting existing CA and MA to GAS

Source	Form of geographic automata	Characterization of states	Location of objects: Fixed	Location of objects: Non-fixed	Neighborhood rule(s)
(Chapin and Weiss 1962, 1965, 1968, Donnelly *et al.* 1964)	Identical square land cells	Discrete ordinal variable denoting fraction of urban land-use	Rectangular grid	–	3×3 Moore neighborhood
(Engelen *et al.* 1995; White and Engelen 1993, 1994, 1997, White *et al.* 1997)	Identical square land cells	Nominal variable representing four land-uses: vacant, housing, industry, commerce.	Rectangular grid	–	Cells at a distance less than 7 cell-units
…					…

Thanks!