Introduction to Multi-Agent Systems (MAS)

- *Part 1*: MAS versus other modelling approaches in spatial analysis;
formalization of space; interactions, emergence, diversity

– *Part 2*: how to formalize an agent-based model
choice of a modelling level; simulation; validation;

- *Part 3* : Multi-Agent Simulation Activities with NetLogo
(MAS platform)

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ISA Summer School, 28 June 2007

Spatial Analysis : different definitions

- "whole cluster of techniques and models which apply formal, usually quantitative, structures to systems in which the prime variables of interest vary significantly across space" (Longley, Batty, 1996)

- "Searching, within the features of spatial entities, what is relevant to their geographic positions, particularly their *relative* geographic positions, making it necessary to model the spatial structure" (Charre, 1995)

- « Formalized analysis of the configuration and properties of the geographic space, as it is produced and experienced by human societies" (Pumain, Saint-Julien, 1997)

« Space matters »

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Place of space in different modelling frameworks ....

Formalization framework	Representation of space
Statistics Trends/singularities Exploratory/explanatory	**Variables / ”individuals”,** distance, accessibility, connection, neighborhood descriptor, X, Y
Differential equations Attractors, bifurcation	**Variables** distance
Cellular automata (CA) Emergence	**Grid, neighborhood**
Multi-agent system (MAS) Emergence, multi-level	Grid, mobile or non mobile **agents in an environment**

The framework of statistics

Traditionnaly: Focus on variables, example of questions:

- Is there a correlation between settlements hierarchical level and the quality of soil?

- Does the distance to neighboring settlement « explain » the differences in duration?

attributes / settlements	hierarchy	soil	altitude	duration	dist. neighb.	……..
Nîmes						
Sommières						
Maguelone						
Lattes						
.						
.						

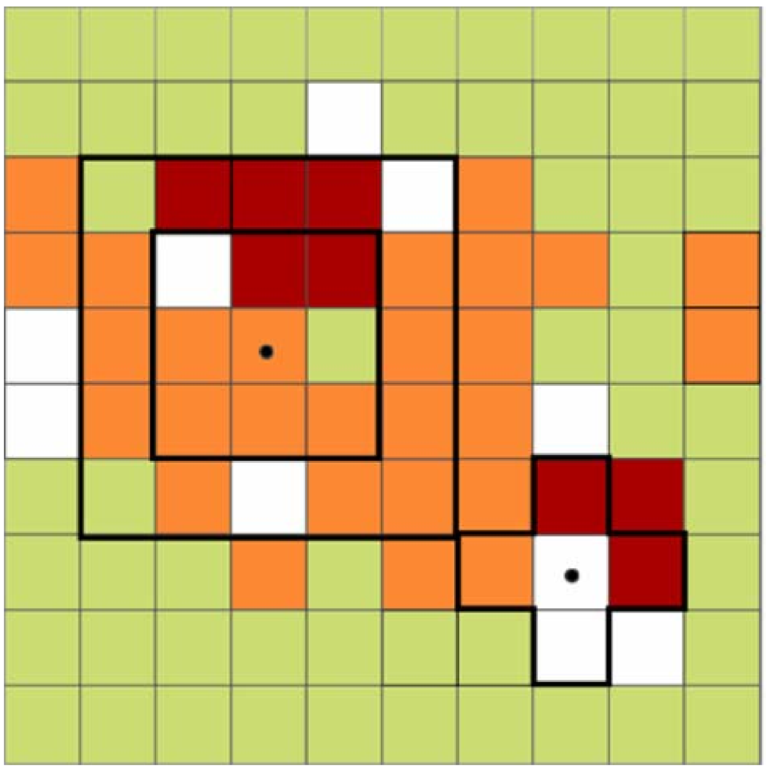
Quantitative geography: enlargement of the interest to the « individuals » (spatial entities)

Place of space in different modelling frameworks ….

➢ Formalization framework	➢ Representation of space
➢ **Statistics** Trends/singularities Exploratory/explanatory	➢ **Variables/"individuals",** distance, accessibility, connection, neighborhood descriptor, X, Y
➢ **Differential equations** Attractors, bifurcation	
➢ **Cellular automata (CA)** Emergence	➢ **Grid, neighborhood**
➢ **Multi-agent system (MAS)** Emergence, multi-level	➢ Grid, mobile or non mobile agents in an environment

The framework of Cellular automata

change depends on the neighbourhood



t ⟶ t+1

A transition rule detemines the change of state of each cell according to the state of its neighbourhood

An early interest in geography: - Tobler, 1979, “Cellular geography”

- Couclelis, H. 1985. “Cellular worlds: a framework for modeling micro-macro dynamics”

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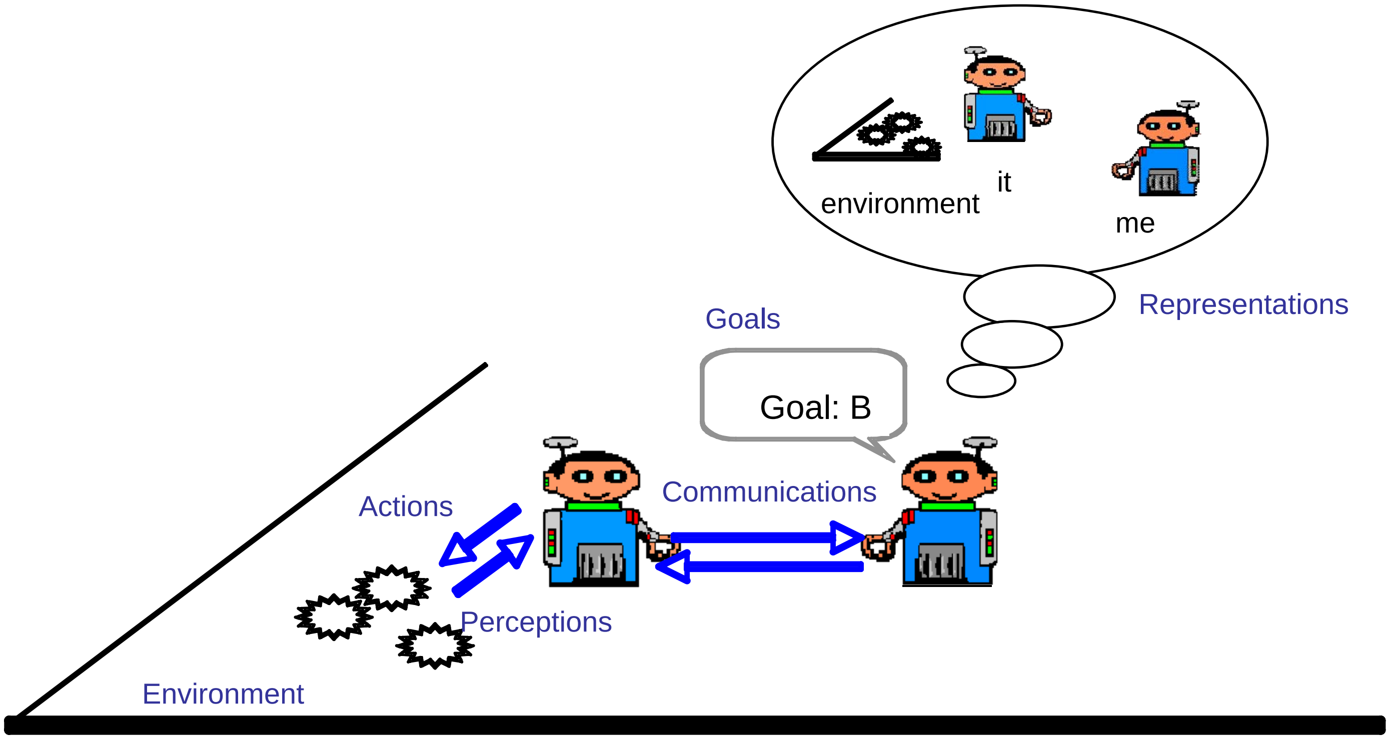
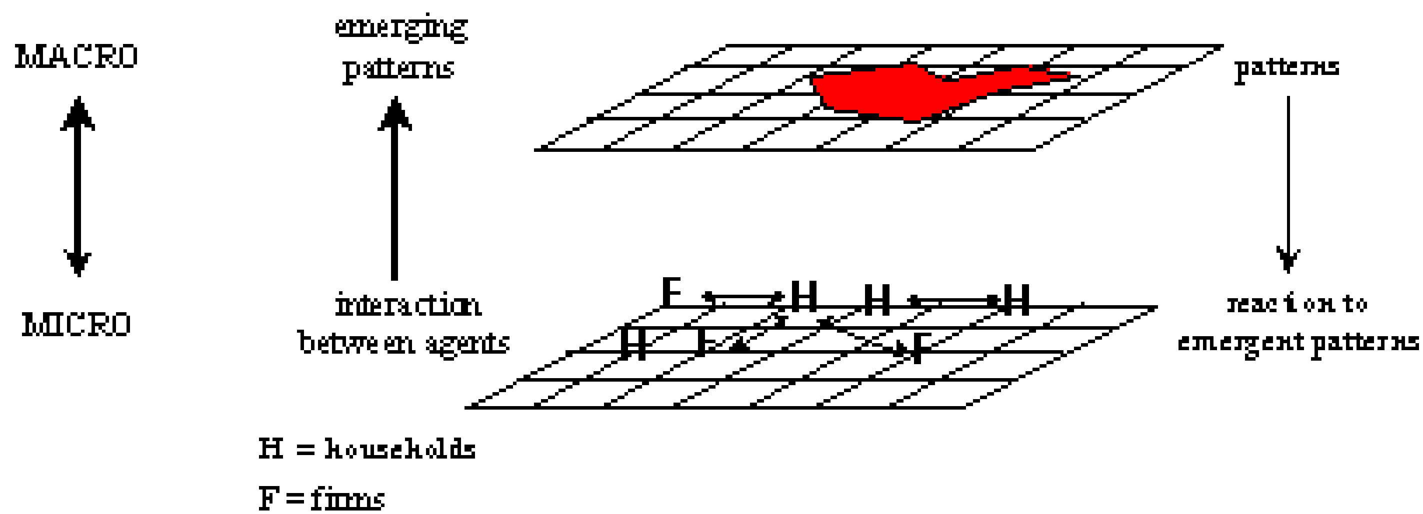
The framework of multi-agent systems



Source: Ferber (1995, 2007)

The concept of emergence

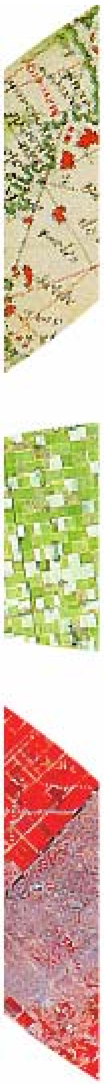


Source: Otter et al., 2001, in JASSS

Main fields of application in spatial analysis:

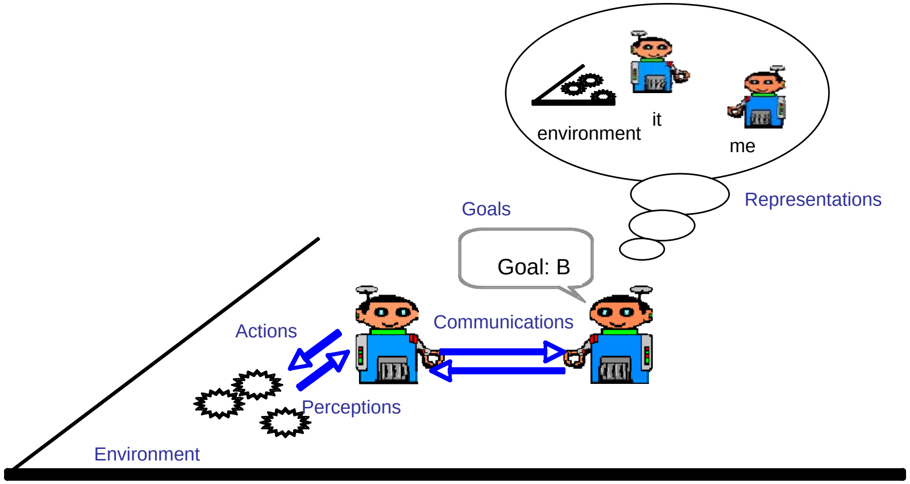
. Segregation

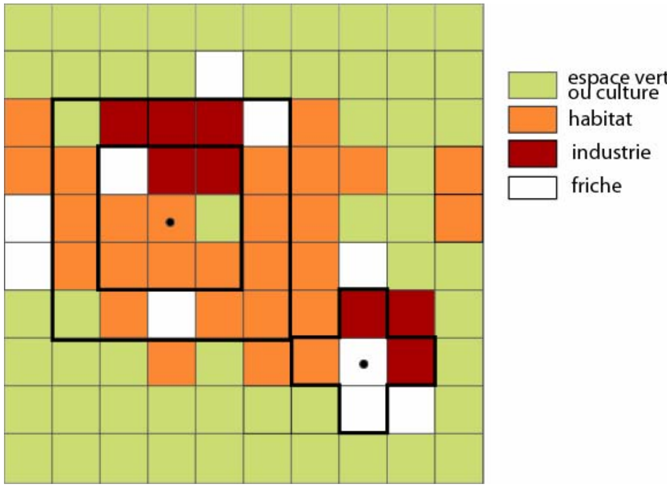
. Competition for resources



settlements \ attributeS	hierarchy	soil	altitude	duration	dist. neighb.
Nîmes	. . . .				
Sommières					
Maguelone					
Lattes					
.					
.					

Different formalisms for modelling in spatial analysis





complementarities

- Some applications in order to discuss:

  . Stylized fact / observed phenomena

  . Agent representing :
  a human being / a spatial entity

  . The driving role of diversity

Simulating spatial dynamics: two approaches

Stylized fact ⟷ observed phenomena

Ex: Model of Shelling

- segregation
- *emergence* of a spatial pattern

Ex: model of White-Engelen

- land-use
- *reproduce* observed change

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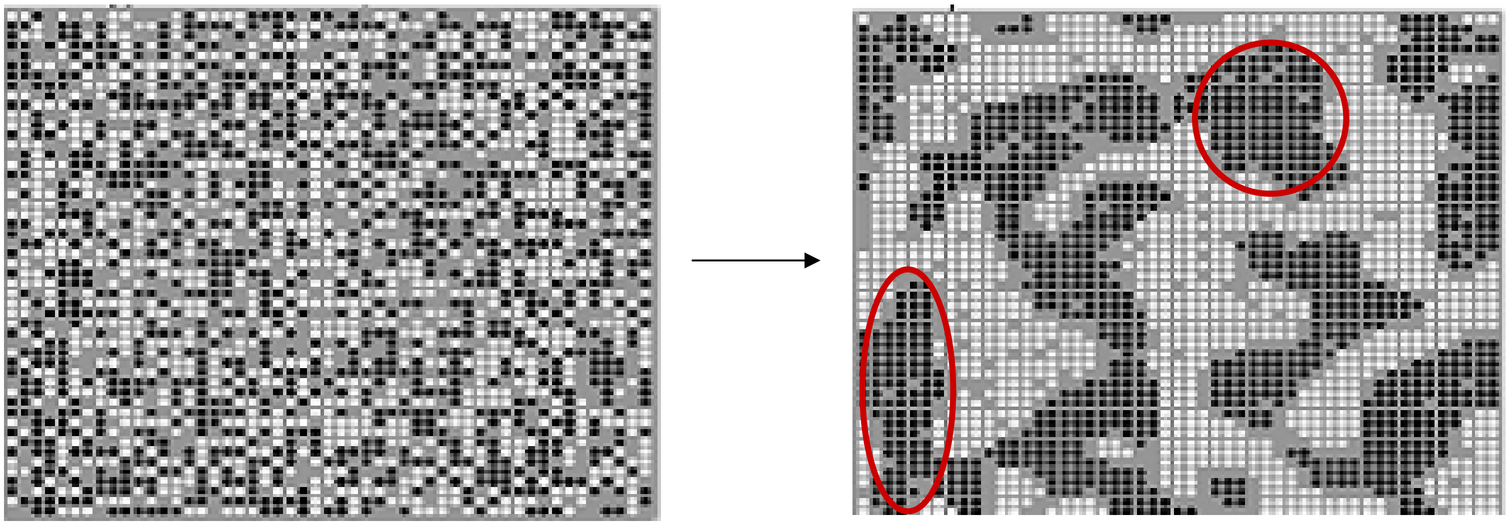
emergence of a segregation in a residential space (Shelling model)



Source: Batty, Barros, Alves Junior 2004, CASA

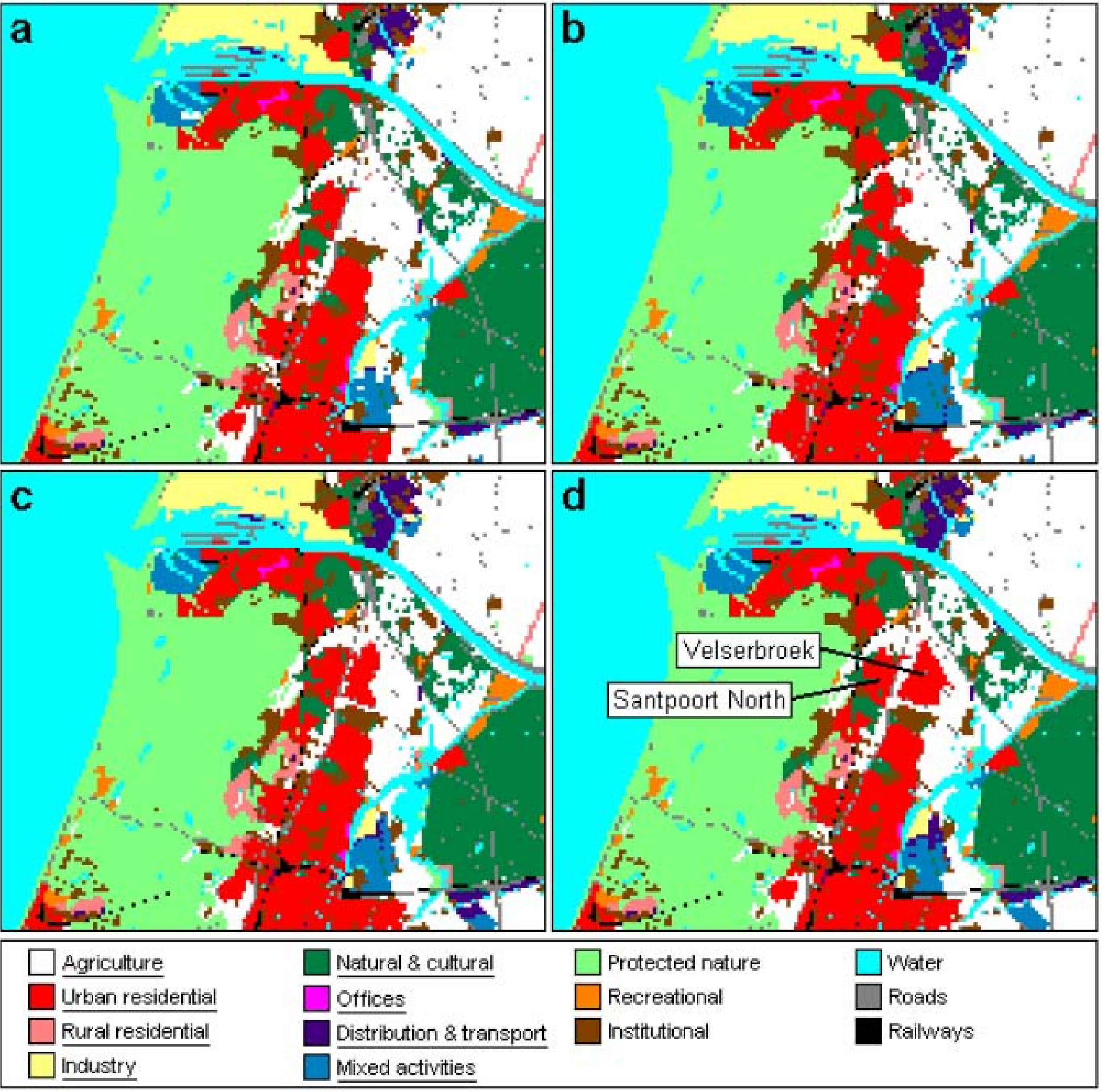
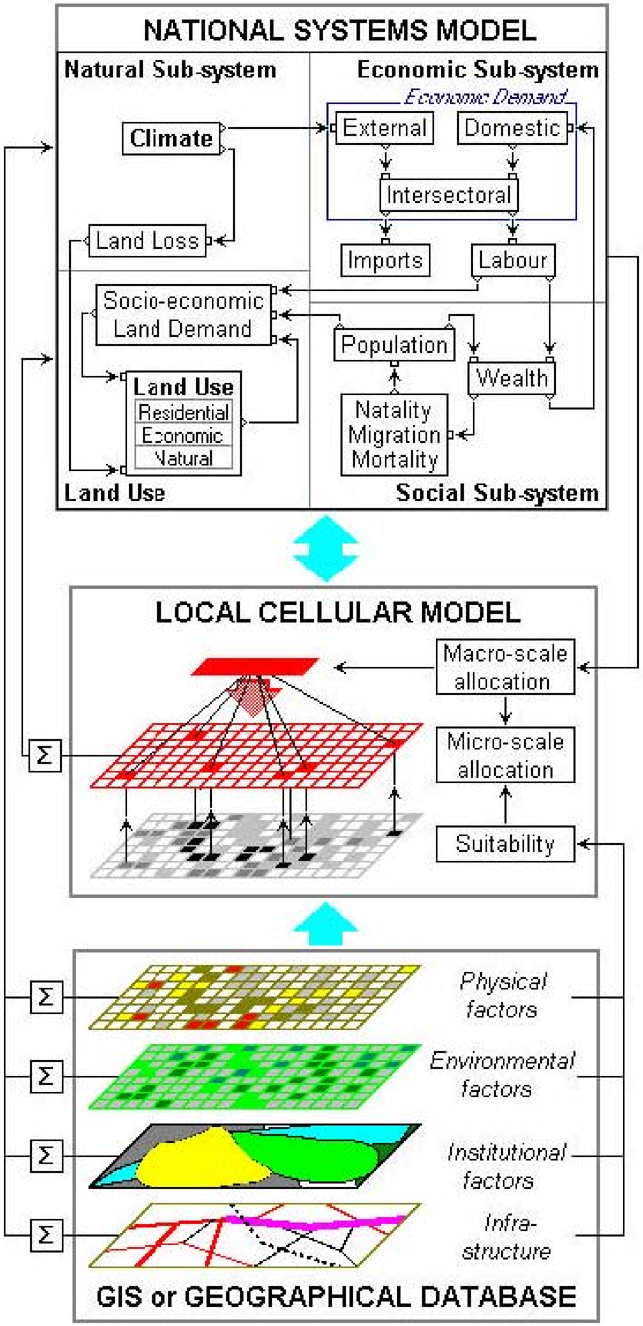


*Figure 7: Results of the calibration run. **a**: actual land-use in 1989; **b**: simulated land-use in 1997 without zoning maps; **c**: simulated land-use in 1997 with zoning maps; **d**: actual land use in 1997. In the legend the functions categories are underlined.*

Land-use change in the region of Haarlem : calibration of the model from 1989-1997

Source: Engelen, Geertman, Smits, Wessels, 1999



Coupling :

- Global dynamic model
- GIS
- Cellular automata

Source: Engelen, Uljee, White

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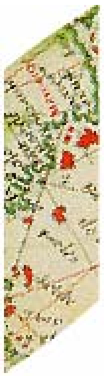
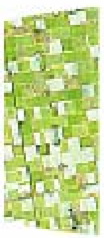
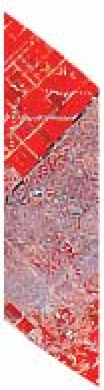
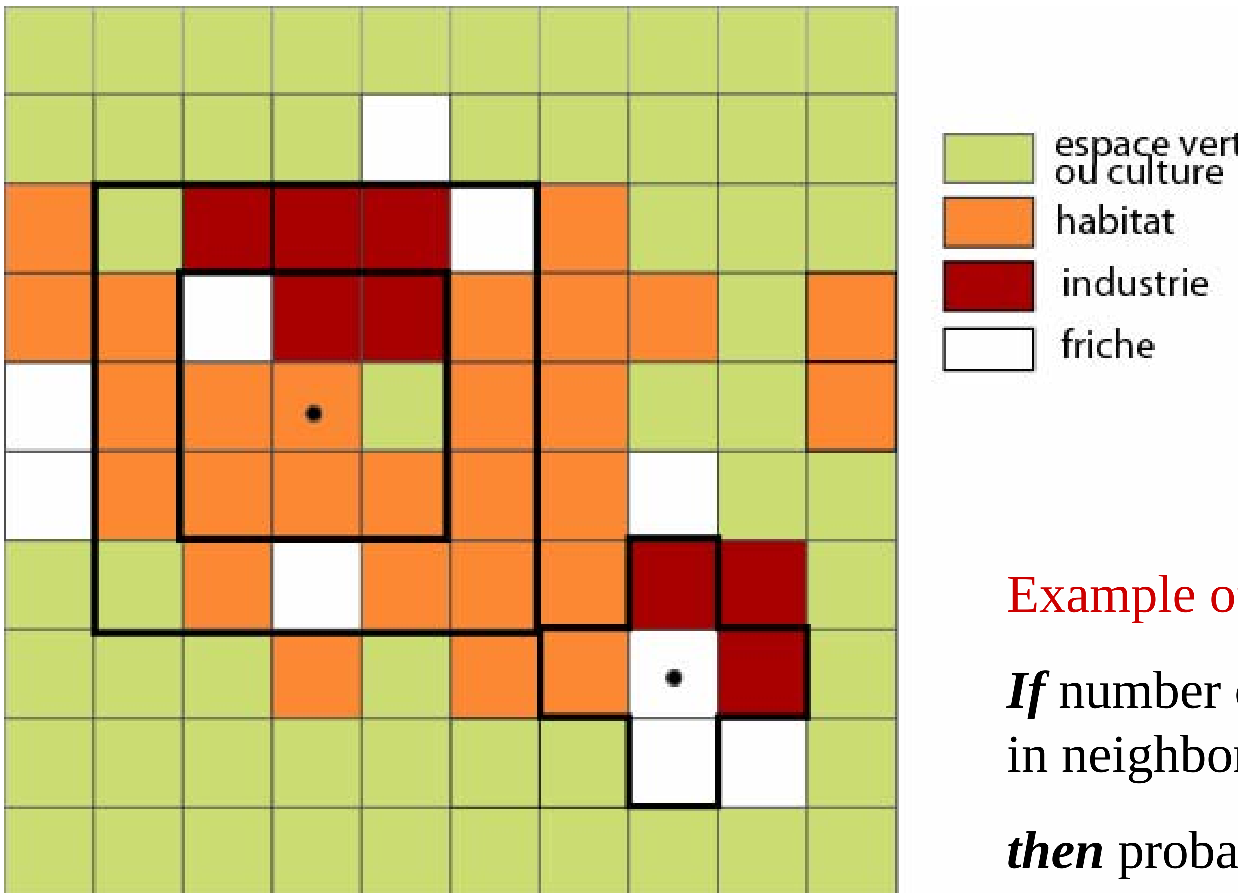
Basic principles of land-use change in a cellular automata model









Example of rule:

If number of residential-cells in neighborhood > **K**

then probability of being residential is **p**

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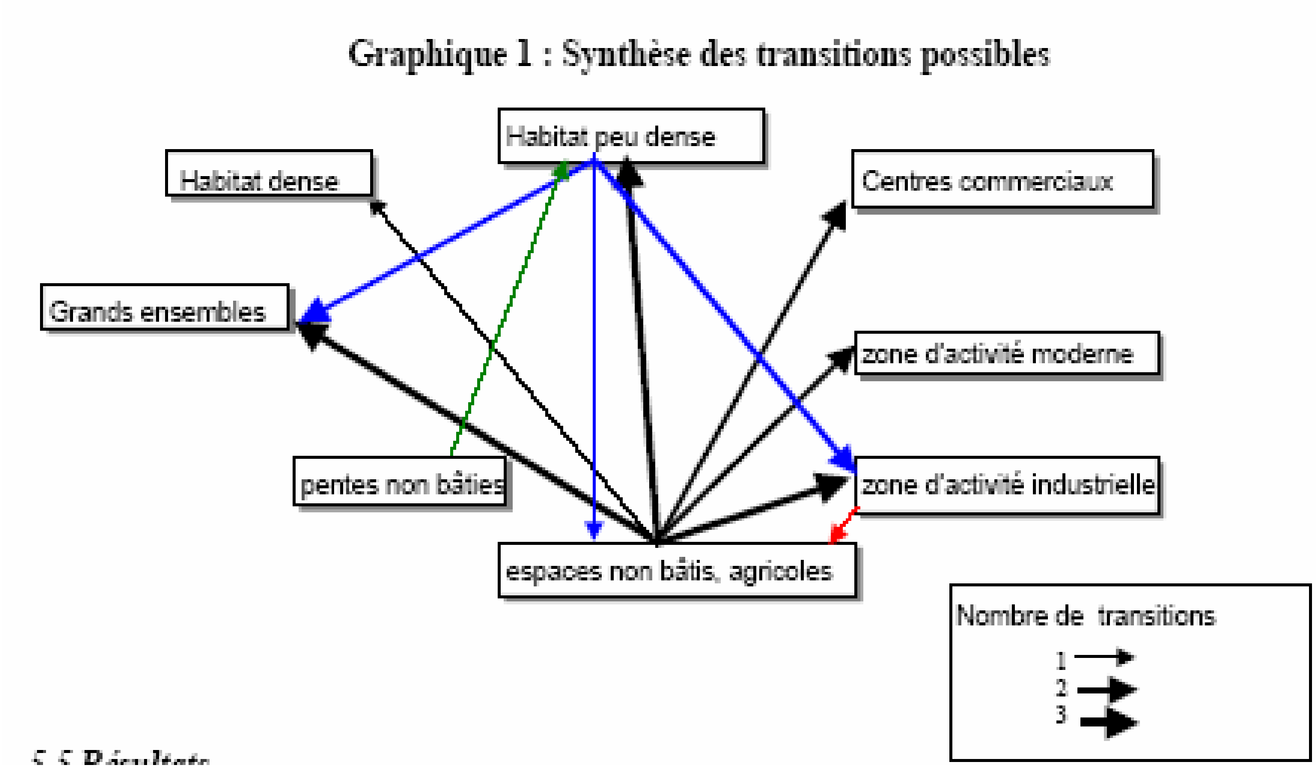
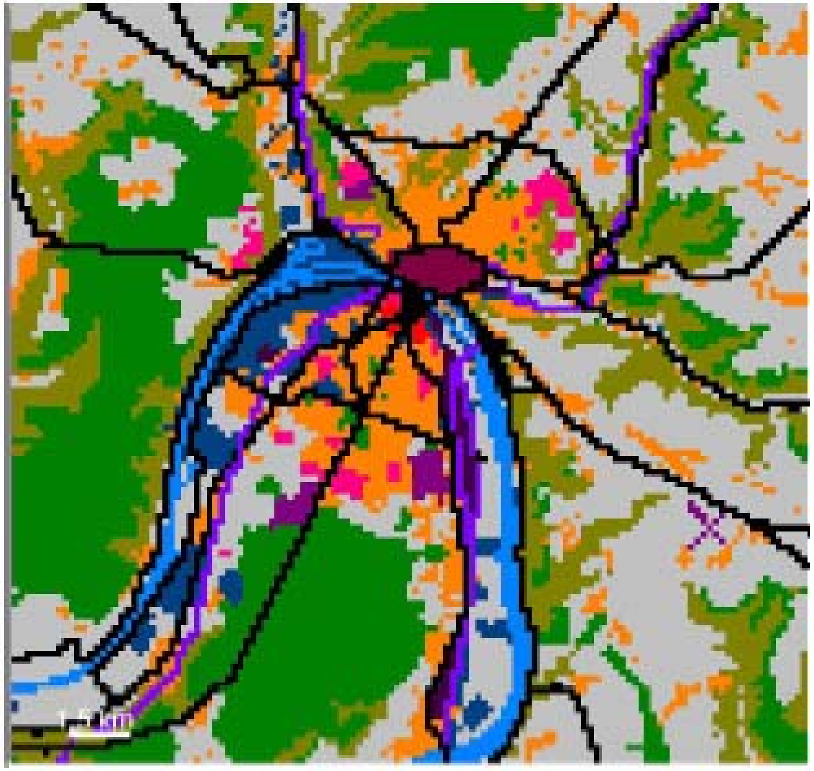
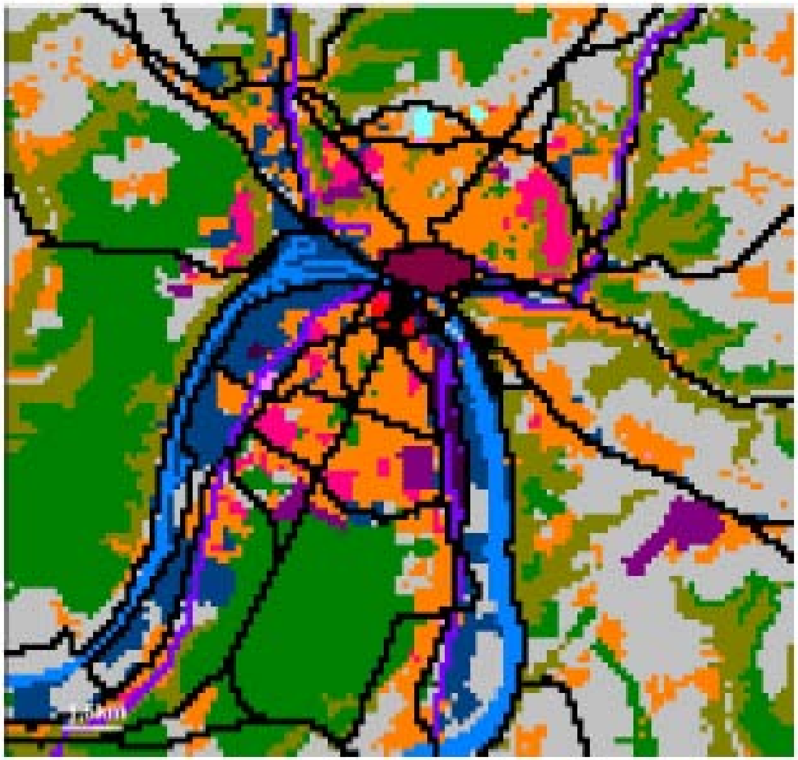
The example of SpaCelle, a model for simulating urban evolution
Dubos-Paillard, Guermond, Langlois, MTG, Rouen

- Application to Rouen, 1950-1994, for simulating the land-use change
- Grid of SpaCelle : 15367 cells (squares of 150 m)



The observed agglomeration of Rouen in 1966 and 1994





Espaces non urbanisés
- Espaces non bâtis, agricoles
- Forêts, espaces verts
- Pentes non urbanisées

Constructions résidentielles
- Habitat peu dense
- Habitat dense
- Centre historique
- Grands ensembles

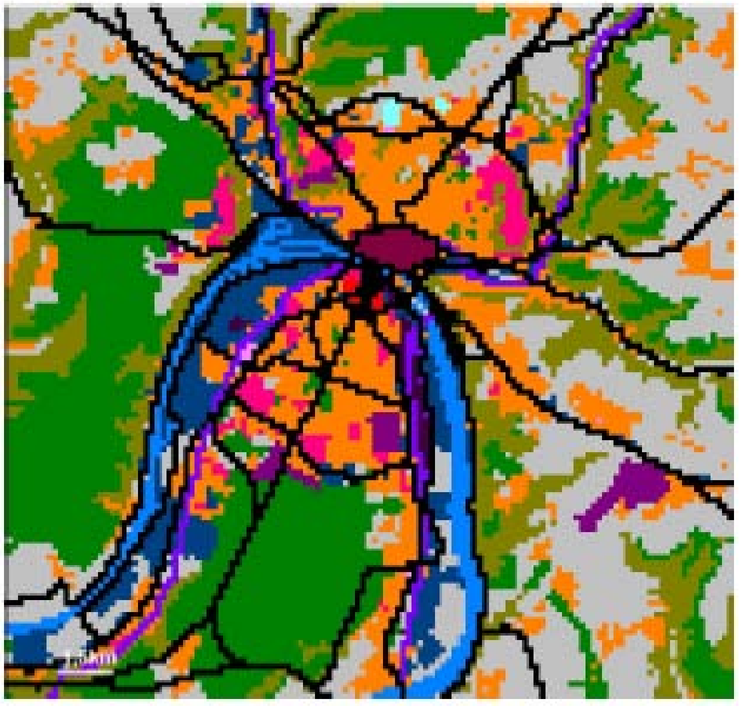
Constructions non résidentielles
- Centres commerciaux
- Equipements publics
- Zones industrielles
- Zones d'activités modernes

infrastructures
- Emprise ferroviaire
- Voies ferrées
- Principaux axes routiers
- Seine

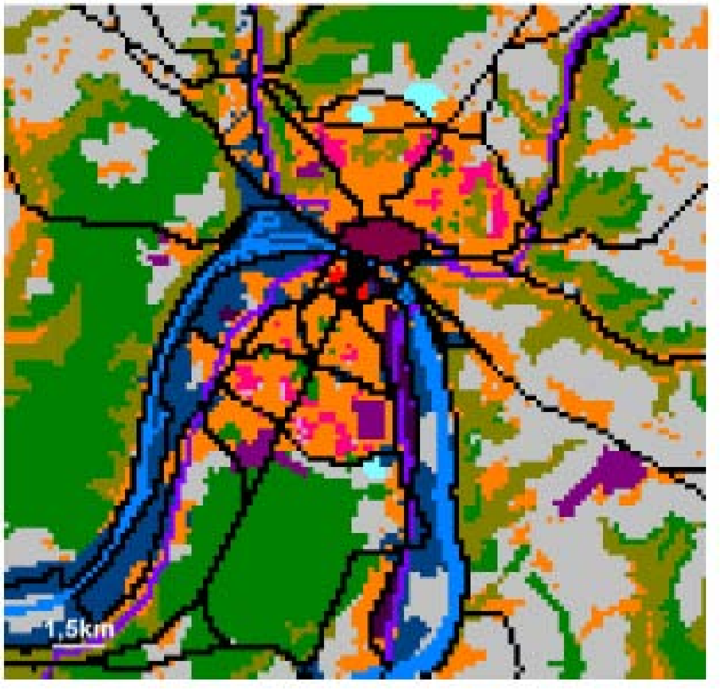
Source: Dubos-Paillard, Guermond, Patrice Langlois, UMR IDEES, laboratoire MTG, university of Rouen

The agglomeration of Rouen in 1994, observed and simulated with SpaCelle

Observed 1994



Simulated 1994



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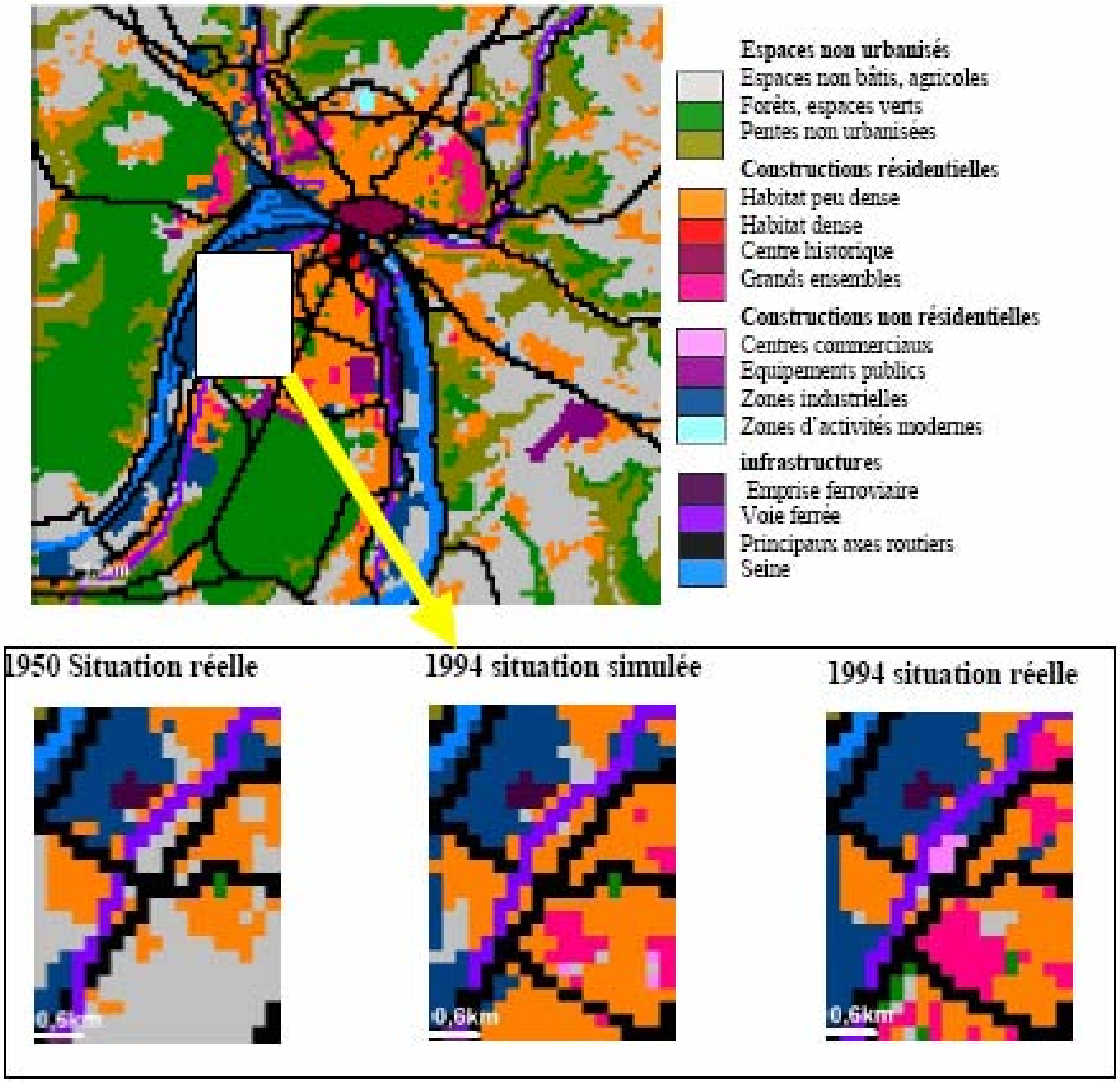
Source: Dubos-Paillard, Guermond Patrice Langlois, UMR IDEES, laboratoire MTG, university of Rouen

Cartes 5: Un exemple détaillé : la rive gauche Ouest



Source: Dubos-Paillard, Guermond Patrice Langlois, UMR IDEES, laboratoire MTG, university of Rouen

- Some applications in order to discuss:

. Stylized fact / observed phenomena

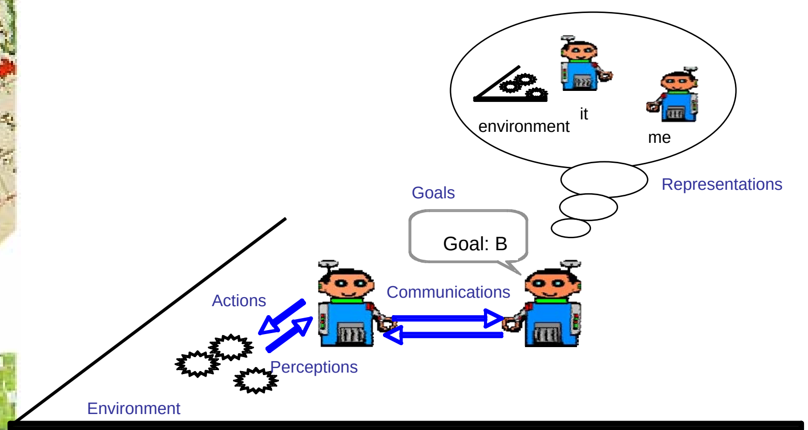
rule driven ⟷ data driven

. Agent representing :

a human being / a spatial entity

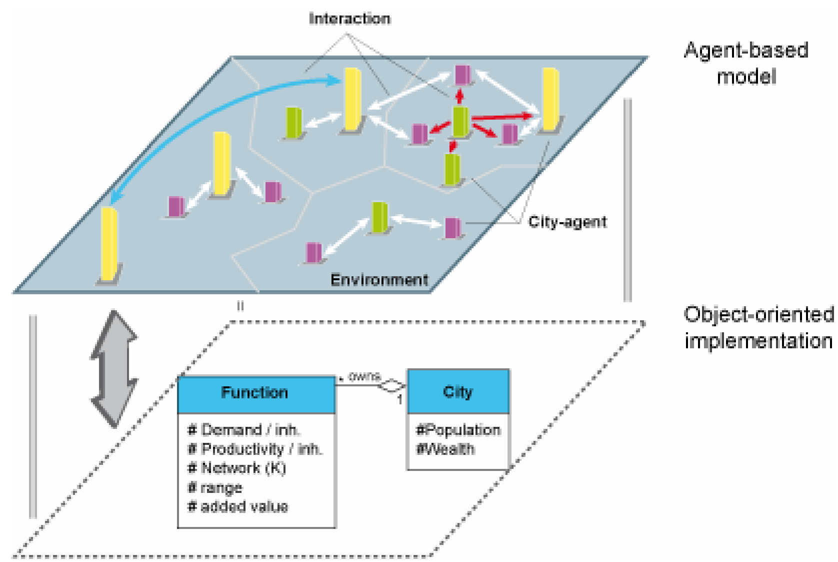
. The driving role of diversity

From human-agent to city-agent



Most applications in social sciences: the agent = an individual (farmer, consumer..) or a household

(economy, sociology, archeology, geography)



BUT, this is not obligatory

Agent = a hamlet, a city, when modelling the dynamics of system of cities

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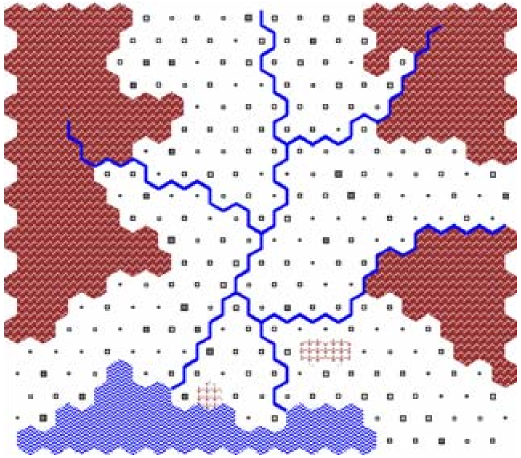
The SIMPOP model



Initial situation :

- regular distribution of the settlements

- a single ressource: farming

Emergence of cities:

- acquisition of new functions

- ability of interacting

Source: Bura, Guérin-Pace, Mathian, Pumain, Sanders, 1996, 1997

www.parisgeo.cnrs.fr/simpop/

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Simplified representation of the functioning of SimPop

t

production and consumption
of each
settlement

↓

exchanges
between the settlements

↓

computation of
the rate of growth
of each settlement

↓

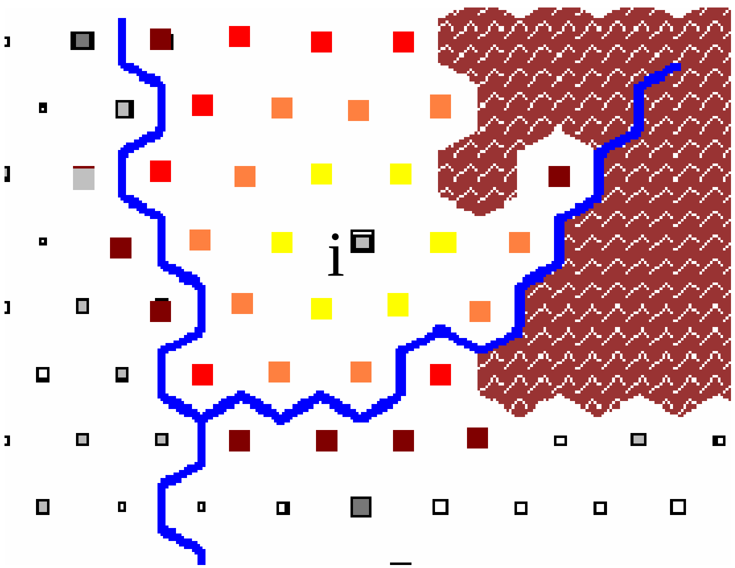
t + 10

Updating, evaluation of change:

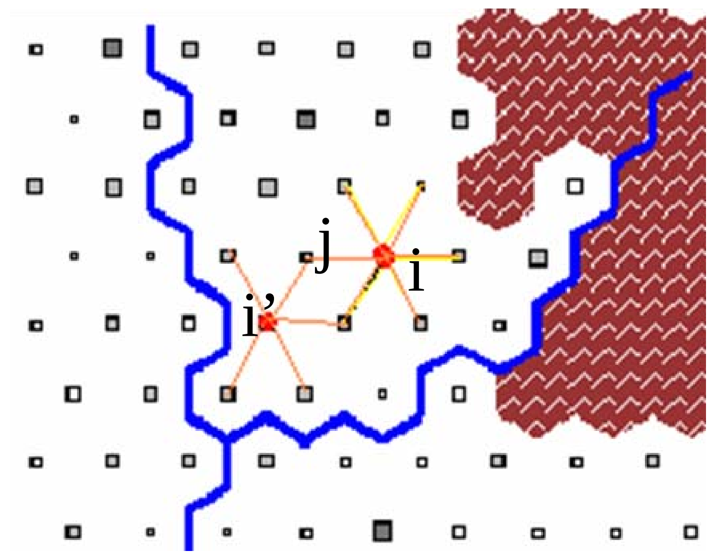
. Quantitative :population, share of workers in different sectors

. Qualitative: level of functions, ranges

SimPop model: range of interactions and interurban competition



Different ranges according to cities functions



Example of overlapping of the influence areas of two cities i and i'

→ **competition**

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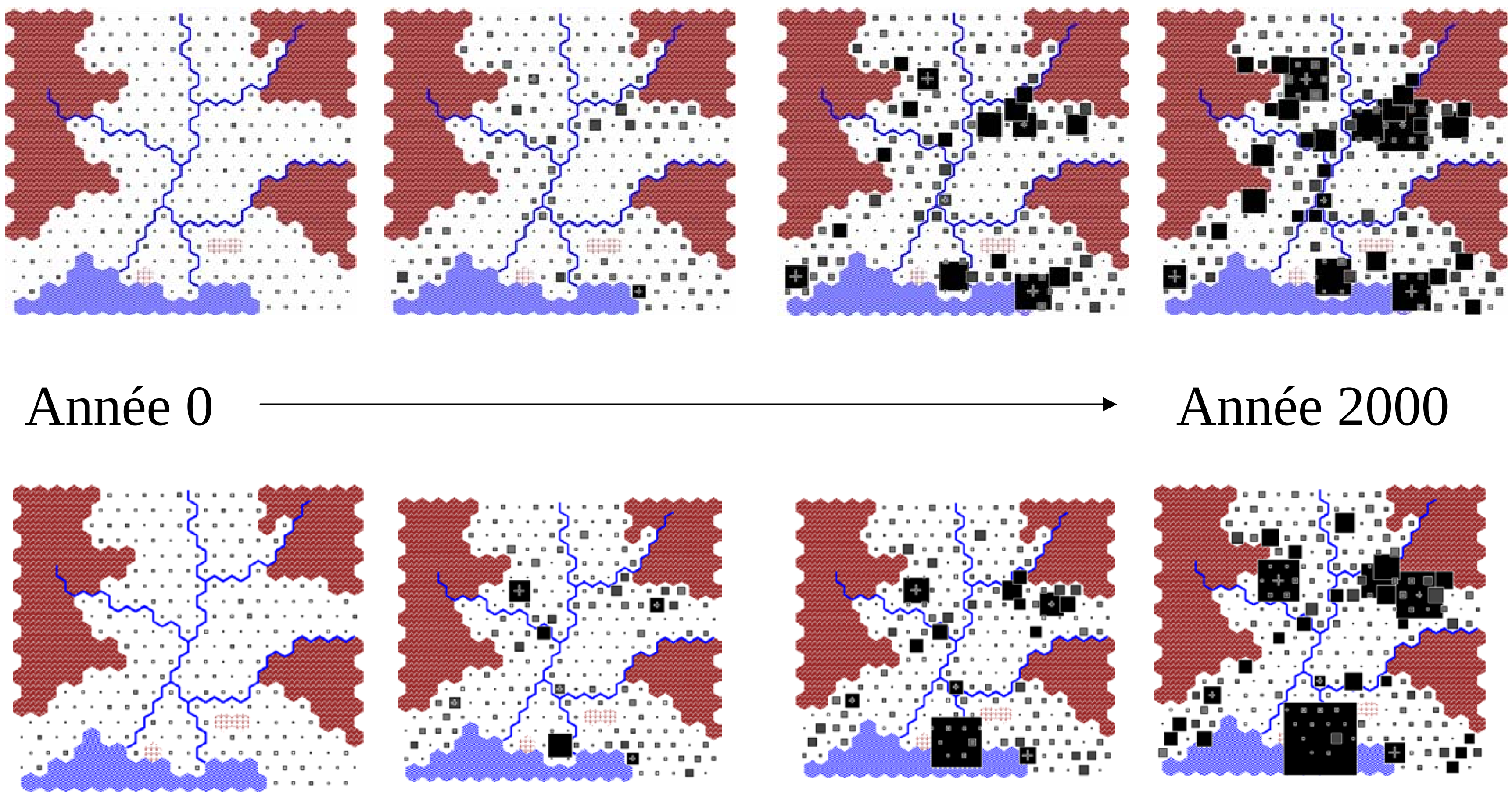
Emergence of polycentric configurations



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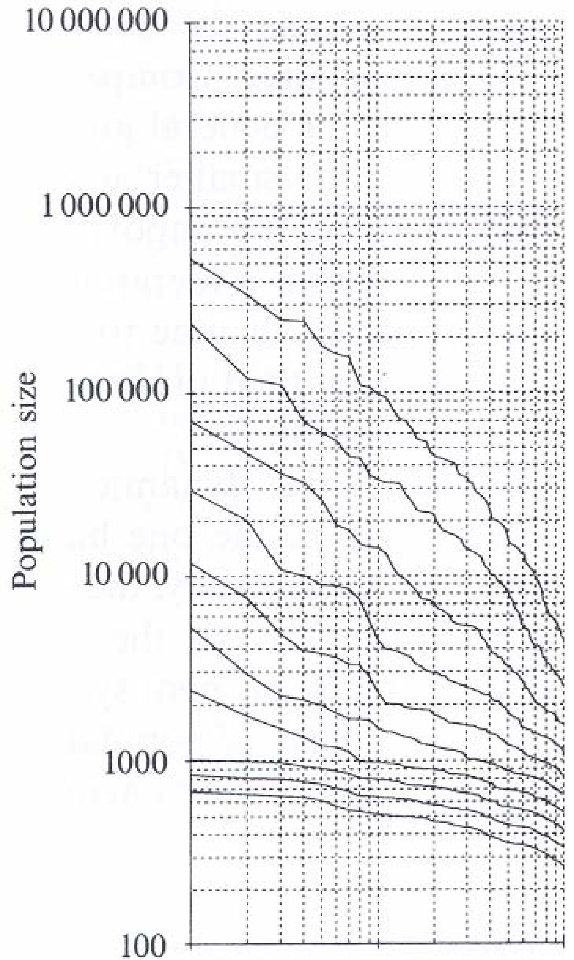
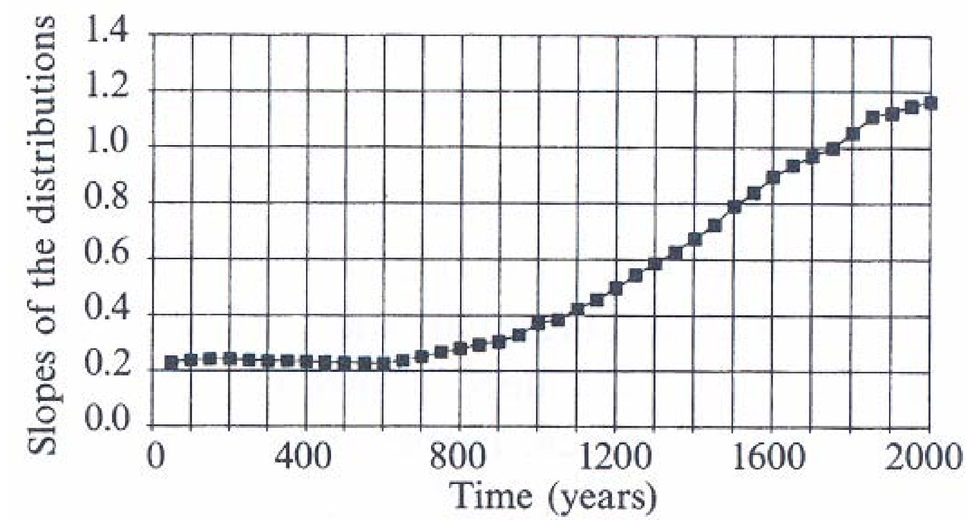
Emergence of a hierarchical organisation of the settlement system (rank-size distribution)





Source: SIMPOP model

➢ Some applications in order to discuss:

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. Agent representing :
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. The driving role of diversity

The role of diversity

Agents not systematically rational, homogenous, independant

diversity plays a driving role for understanding the dynamics of the system

Different ways of introducing diversity:

Microsimulation

Relations

Synthetic population

Diversity through combination of « solitary » attributes and relational properties

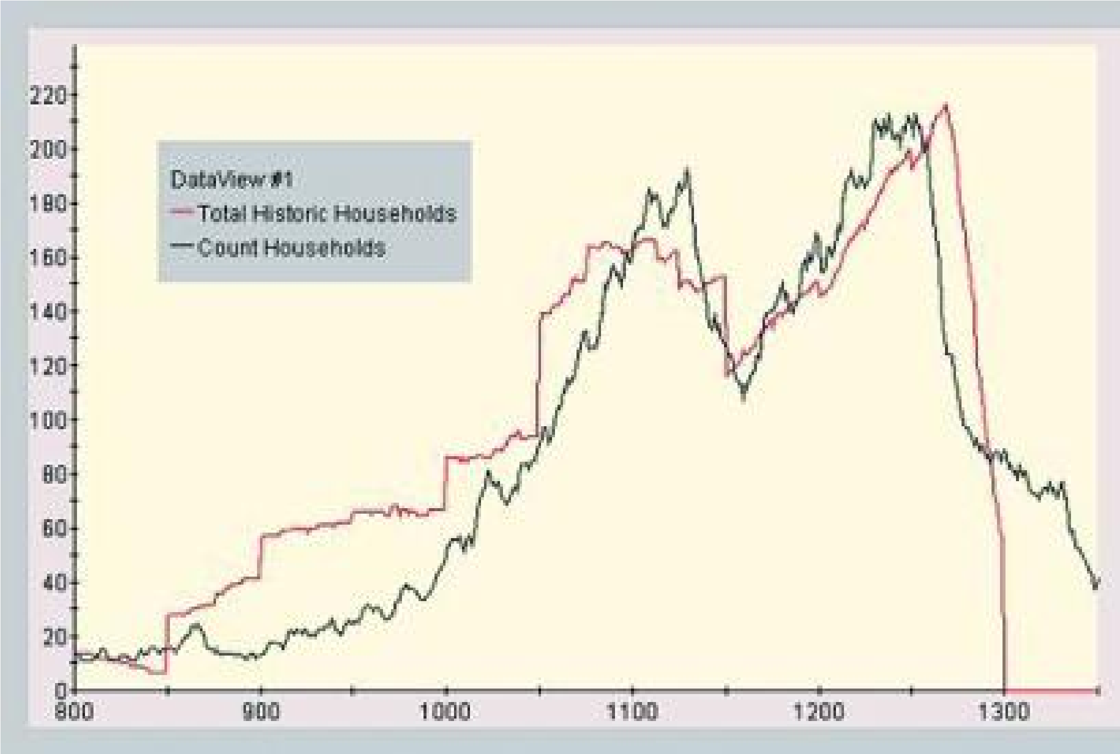
Multi-agent models

Interactions

Artificial world

Diversity through random

The role of *diversity* for simulating the collapse of the Anasazi population



Source: Axtell et al., 2002, Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley

Example 1: A MAS for modelling population dynamics : application to the fall of Anasazi population in Long House Valley

- Aim: . to simulate the evolution of the Anasazi population between 200 and 1300 according to environmental change

  . and to reproduce the abandonment of the region in 1300

- Data: - archeological: human settlement
  - environemental: agricultural potential (reconstituted year by year)
  - anthropological: household composition, nutritional habits..

Source: Axtell et al., 2002, Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley

The Anasazi model

- The agents: - the households : demographical characteristics and nutritional need

- Rules: - household change (16 years old: new household)
  - Migration of the household:
    when storage + expected maize harvest < threshold
  - Choice of a new agricultural place : according to agricultural potential :
    . If several possibilities: the nearest
    . If no possibility: abandonment of the valley
  - Choice of a new residential plot: <1km from the agricultural plot ; if several possibilities: minimizing distance to water

Source: Axtell et al., 2002, Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley

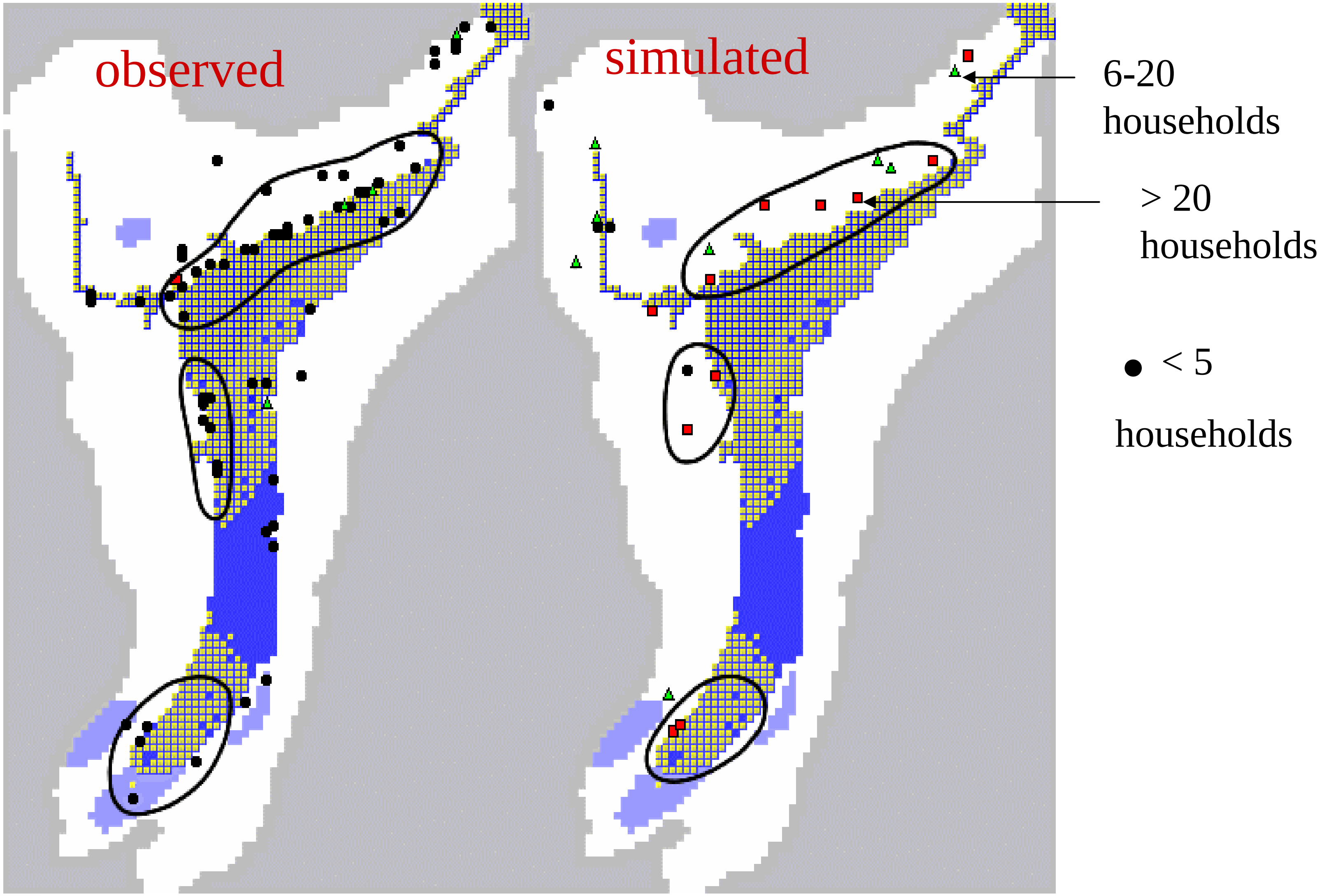
Outputs of the simulation

-Localisation of each household

-Localisation of each cultivated parcel

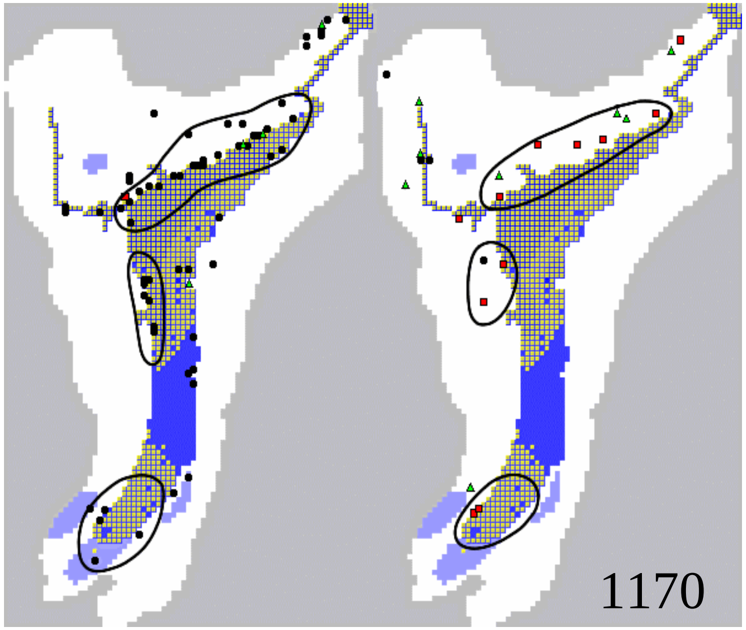
- Size of eachgroup sharing a same site

« Observed » and simulated settlement pattern in Long House Valley in 1170



Source: Gumerman, Swedlund, Dean, Epstein, 2002

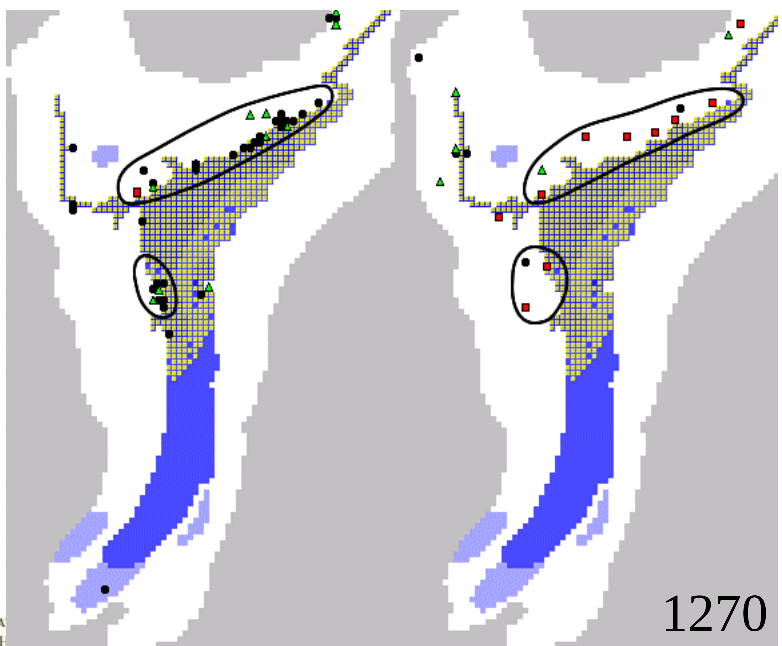
Evolution of the Anasazi settlement pattern on the *recontructed environment*

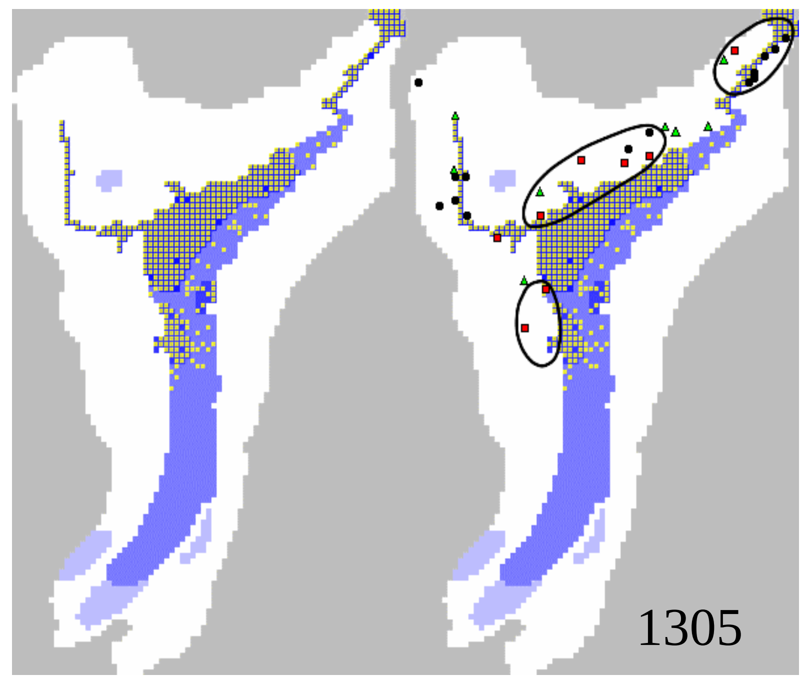


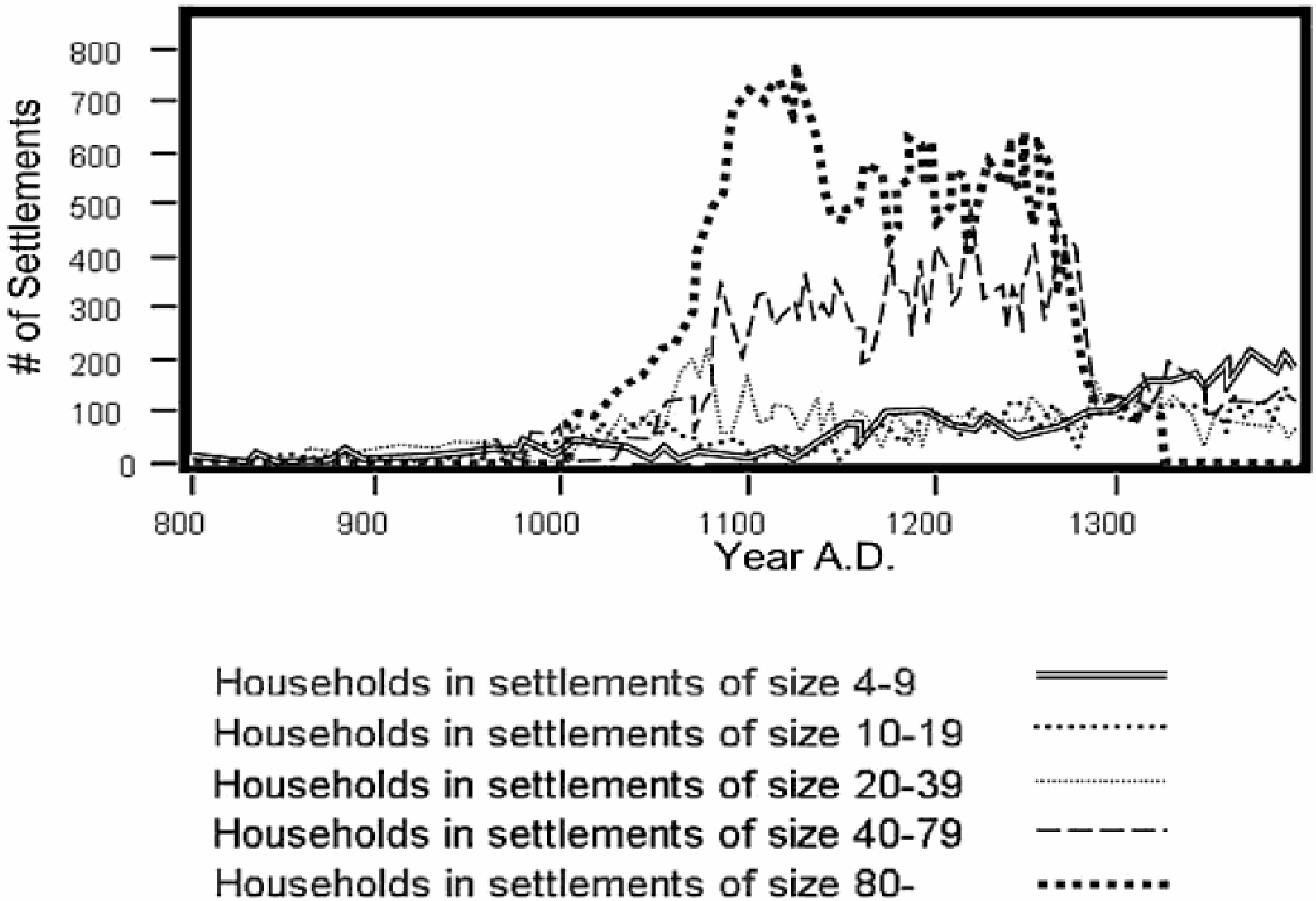
white: unfarmable

grey: water ressources

Source: Gumerman, Swedlund, Dean, Epstein, 2002,





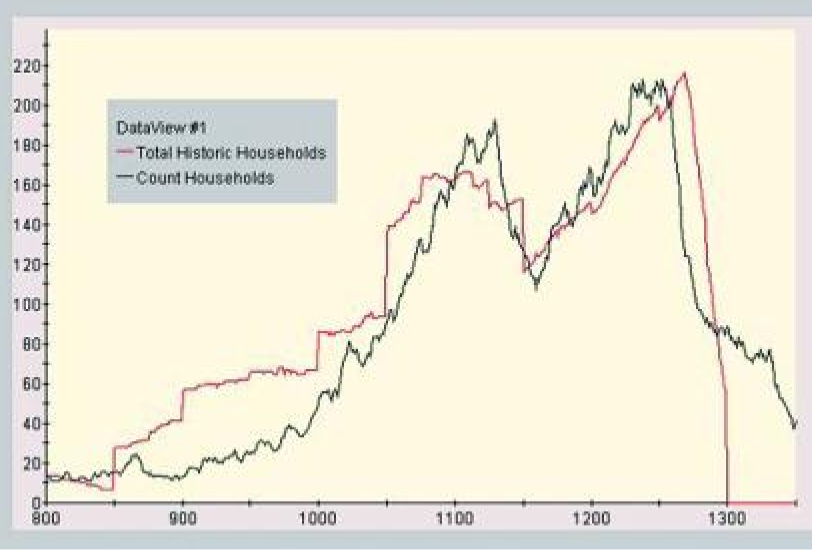


Source: Gumerman, Swedlund, Dean, Epstein, 2002, Santa Fe Institute, Working Paper

What can we learn from the outputs of the model

Model 1: → homogenous agents
Population overestimated *or* too early collapse

Model 2: → diversity (demographic and nutritional)



Conclusion: the model simulates the possibility for a population of reduced size to survive in the area; this does not correspond to observed situation → role of socio-cultural factors

Some references

- Kohler T., Gumerman G. (eds.), 2000, *Dynamics in Human and Primate Societies; agent-based modelling of social and spatial processes*, Santa Fe Institute, Studies in the Sciences of Complexity, Oxford University Press.
- *Amblard F., Phan D. (eds.), 2006, Modélisation et simulation multi-agents; applications pour les Sciences de l'Homme et de la Société,* Hermès-Lavoisier.
- *Amblard F., Phan D. (eds.), 2007, Agent-based modelling and simulation of complex systems for the social sciences: principles and methods of design and use*, ISTE.

Example 2: a MAS for simulating the long term dynamics of a settlement system: empirical and theoretical background

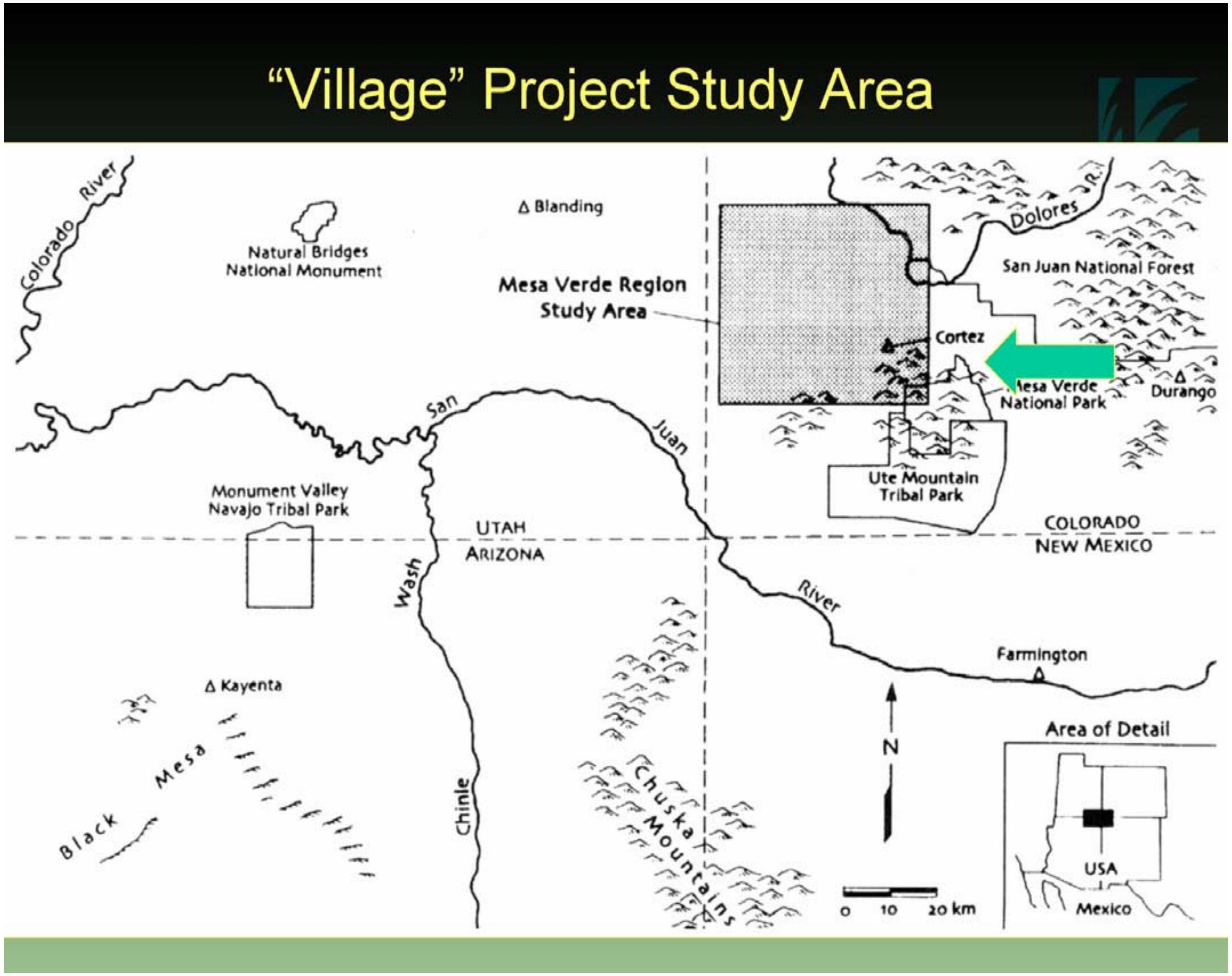
Object of study: settlement dynamics of Pueblo populations of the Mesa Verde Region (900 to 1300)

Aim: to understand why, during certain periods, most Pueblo people lived in relatively compact villages, while, at other times, they lived in dispersed hamlets.

Method: - reconstruction of past landscape at a fine spatial (200m x 200m) and temporal (annual) scale

- constructed agents = families, distributed in this reconstructed landscape

Source: Kohler, Kresl, Van West, Wilshusen, 2000



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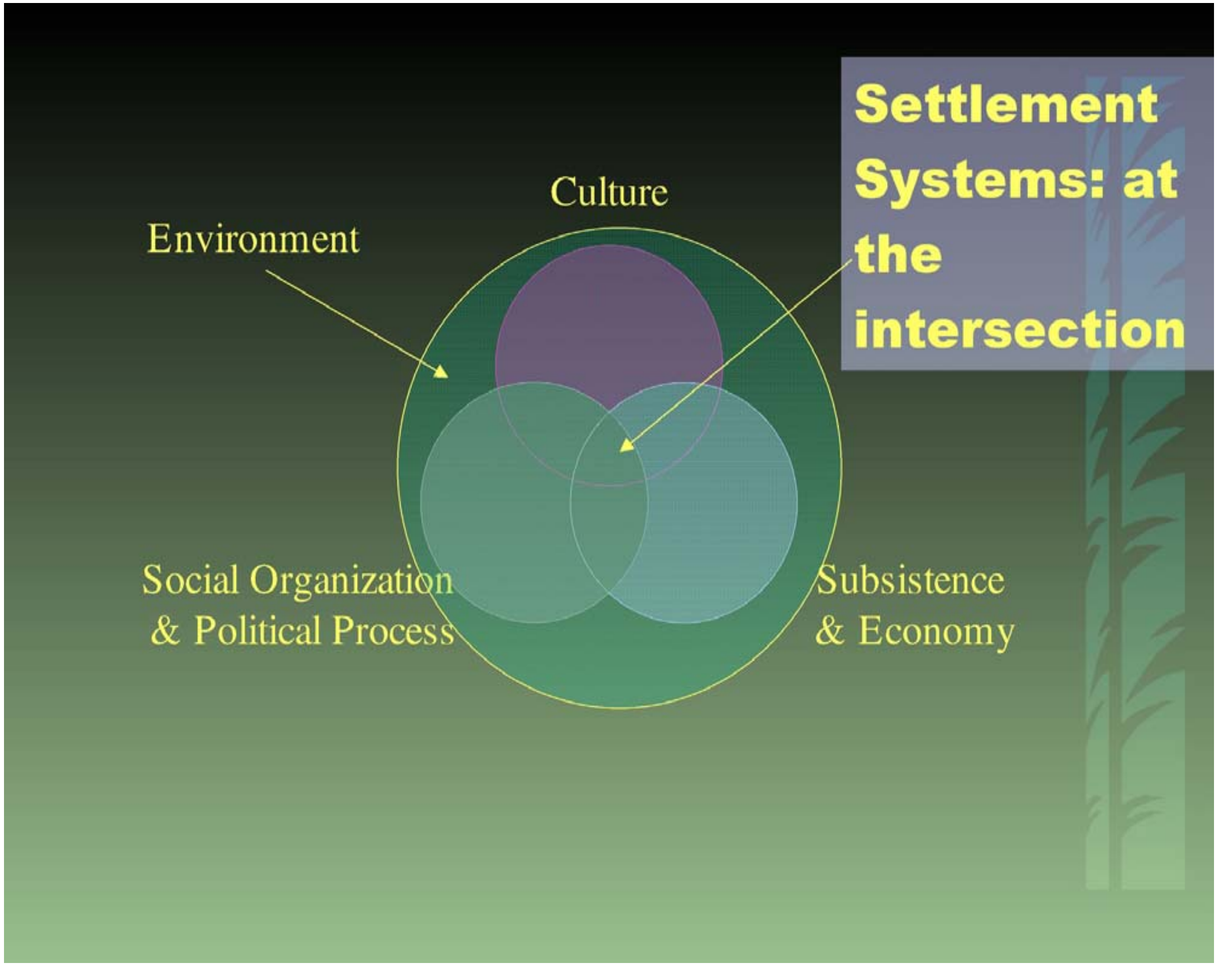

Hyp: the form and dynamics of the settlement system is tied to many interacting factors

Source: Kohler 2003

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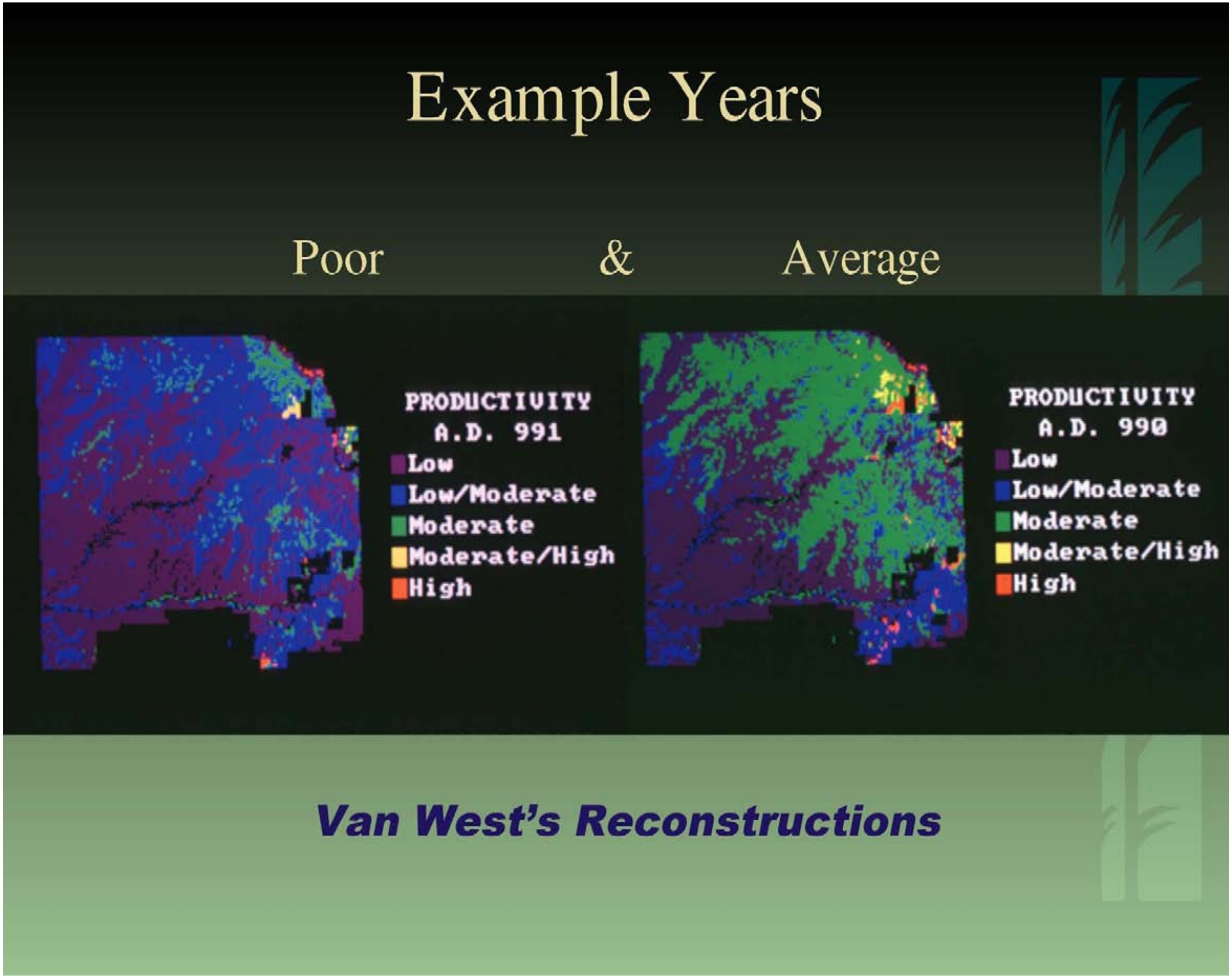

Source: Kohler 2003

Construction of the model

- Different models are tested

  - the role of productivity alone

  - constraint on location according to proximity to water

  - Taking into account degradation due to farming

Source: Kohler, Kresl, Van West, Wilshusen, 2000

Main results

- All models do better than the random model in predicting site locations
- The models for the Pueblo II (910-1139) period perform better than for the Pueblo III (1140-1285) period
- Productivity plays a more determinant role than proximity to water (no role at all for Pueblo III)
- The model taking into account a slight effect of land degradation through farming gives better fit between simulated and « actual » household location patterns

- In this first application the agents are simple, they could not learn, not exchange, not modify their programmed behaviors.

- Following models integrate forms of exchanges between farmers (reciprocal exchange) in order to test effects of exchange behavior on the form of the settlement system

- Source: Kohler 2003

TABLE II: DESCRIPTION OF THE DIFFERENT COOPERATION METHODS AT THE KINSHIP LEVEL.

Cooperation Method	*Description*
0	No cooperation. No exchange of food.
1	When an agent requires food, it is allowed to select and request food from within its kinship network in order to survive.
2	When an agent has excess food, above a determined threshold amount, it is allowed to select an individual(s) from its kinship network and donate some of its excess.
3	Both methods 1 and 2 are enabled together.

TABLE I: CONNECTED NODES IDENTIFIED BY THE KINSHIP SOCIAL NETWORK.

ParentHHTagA	a link to the parent from the mother's side
ParentHHTagB	a link to the parent from the father's side
ChildHHTag	one link to each child that moves away from this household
RelativeHHTag	one link to each extended family member

Source: Kobti, Reynolds, Kohler

Bibliography :

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