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Modelling Socio-Economic Processes with Minimalistic Agents

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Schedule

1. Complex vs. Minimalistic Agents
2. Communication Field
3. Model of Economic Aggregation
4. Computer Simulations
5. Conclusions

Complex System

"By complex system, it is meant a system comprised of a (usually large) number of (usually strongly) interacting entities, processes, or agents, the understanding of which requires the development, or the use of, new scientific tools, nonlinear models, out-of equilibrium descriptions and computer simulations."

Journal "Advances in Complex Systems"

Multi-Agent Systems (MAS)

agent:

◇ subunit with "intermediate" complexity

⇒ may represent local processes, individuals, species, agglomerates, components, ...

multi-agent system:

◇ *large number* / *different types* of agents

◇ interactions between agents:

- on *different spatial and temporal scales*
- local / direct interaction
- global / indirect interactions (coupling via resources)

Complex Agent

- autonomous; knowledge based / behavior based rules
- performs complex actions: BDI, rational choices, ...
- specialization, learning, genetic evolution, ...

1. Problem: information flow

"rational agent" (economics):

- ◇ complete knowledge of all possible actions and their outcomes (or known probability distribution over outcomes)
- ◇ common knowledge assumtion

2. Problem: combinatoric explosion of the state space

- ◇ 1000 Agents with 10 rules ⇒ 10^{13} possibilities
- ◇ *Solution:*
  restrict interactions ⇒ control of information flow
  personally addressed interaction instead of "broadcasting"
- ◇ *freedom:* define rules *and* interactions ⇒ *pitfall*

Minimalistic Agent

- ◇ possible simplest set of rules ⇒ "sufficient" complexity (depends on the system considered)
- ◇ *functional information:* simple *algorithm*, which is steadily repeated
- ◇ *structural information:* external information (*data*) received by the agent
- ◇ *pragmatic information:* ⇒ effective information
  - emerges from the processing of the data by the algorithm
  - specific for each agent ⇒ enables actions, decisions

Characteristics:

- *internal degree of freedom:* θ_i (e.g. -1, $+1$)
  $\Rightarrow$ enables different actions
- mobility (active walker, active Brownian particle)
- deterministic and stochastic influences (Langevin equation):

$$\frac{dr_i}{dt} = \alpha_i \left. \frac{\partial h^e(r,t)}{\partial r} \right|_{r_i} + \sqrt{2\,\varepsilon_i}\;\xi(t)$$

  - local response of agent i to *structural information*
  - α_i: weights the importance of the information received
  - ε_i: individual sensitivity
  - $h_e(r,t)$: effective communication field $\Rightarrow$ components:

$$\nabla_i h^e(r,t) = \nabla_i h^e\left(..., h_\theta(r,t), h_\theta(r,t), ...\right)$$

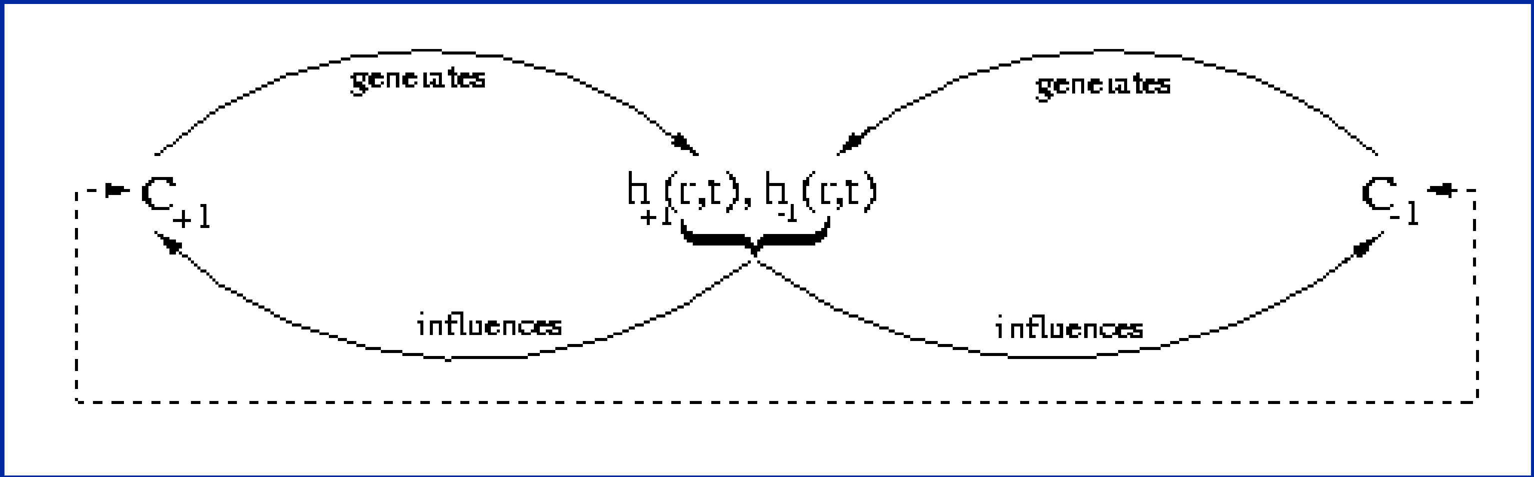
Communication Field

$$\frac{\partial}{\partial t} h_\theta(r,t) = \sum_{i=1}^{N} q_i(\theta_i, t)\; \delta_{\theta,\theta_i}\; \delta(r - r_i) - k_\theta h_\theta(r,t) + D_\theta \Delta h_\theta(r,t)$$

multi-component spatio-temporal field:

- ◇ reflects *spatial* distances between agents (r_i)
- ◇ permanent *local* individual contribution: $q_i(\theta_i, t)$
- ◇ information generated has a certain life time, $1/k_\theta$
  $\Rightarrow$ considers memory effects
- ◇ information can spread throughout the system, D_θ
  $\Rightarrow$ determines how fast information is distributed

Example: Social Interaction



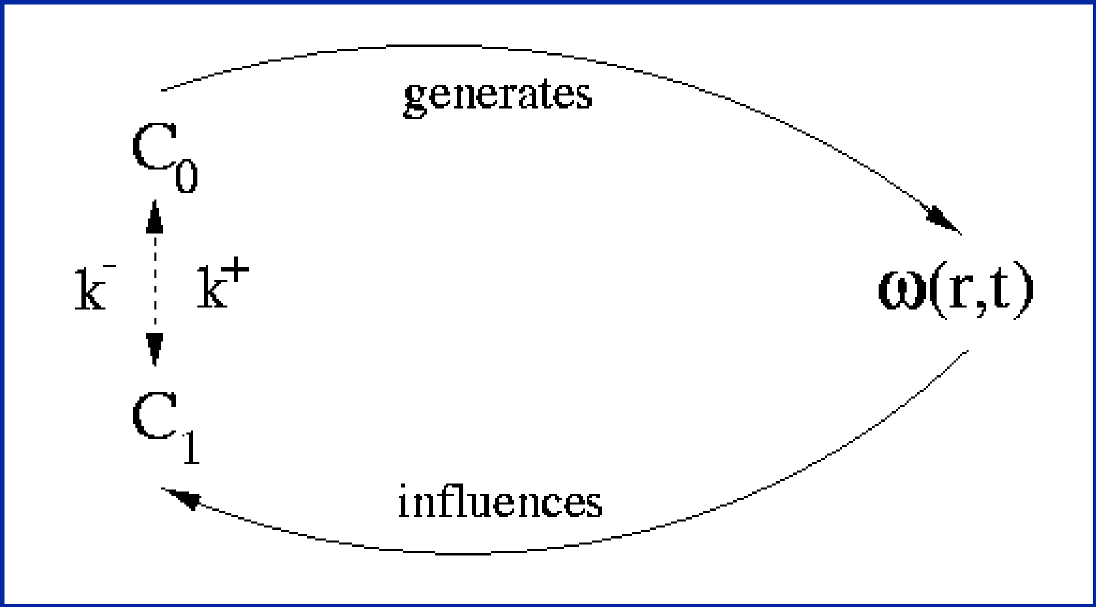
- ◇ agents with two different opinions: $\theta_i \in \{+1, -1\}$
- ◇ two types of strategies:

(1) migration: $h^e(r,t) \Rightarrow$ different types of response

(2) change of opinion

$$w(\theta_i|\theta_i) = \eta \exp\{[h_\theta(r_i,t) - h_\theta(r_i,t)]/\varepsilon_i\}$$

Example: Economic Agglomeration



- $\theta = 0$: *employed agents*, C_0 (immobile) $\Rightarrow l(\boldsymbol{r}, t)$
  $\theta = 1$: *unemployed agents*, C_1 (mobile) $\Rightarrow n(\boldsymbol{r}, t)$
- migration due to spatial wage differences: $\omega(r)$
- “hiring” and “firing”: k^+, k^-

Economic Assumptions

- wage: marginal product of labor:

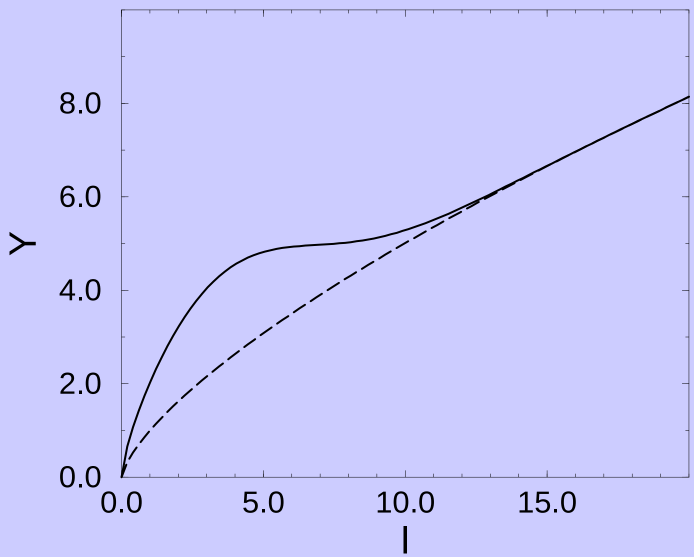
$$w\{l(\boldsymbol{r},t)\} = \frac{\delta Y\{l(\boldsymbol{r},t)\}}{\delta l}$$

- Cobb-Douglas production function

$$Y\{l(r,t)\} = A\, l^{\beta}(r,t), \quad \beta < 1$$

- A: represents level of productivity
  considers *cooperative effects* resulting from interactions among the workers ⇒ non-linear function

$$Y(l) = \frac{\bar{A}}{2}\left[1 + \exp\left(a_1\, l + a_2\, l^2\right)\right]\; l^{\beta}$$



◇ $a_2 < 0$: saturation effects ⇒ advantages of cooperative effects compensated by disadvantages of crowding

"hiring" and "firing" rates:

$\omega^\star$: minimum wage

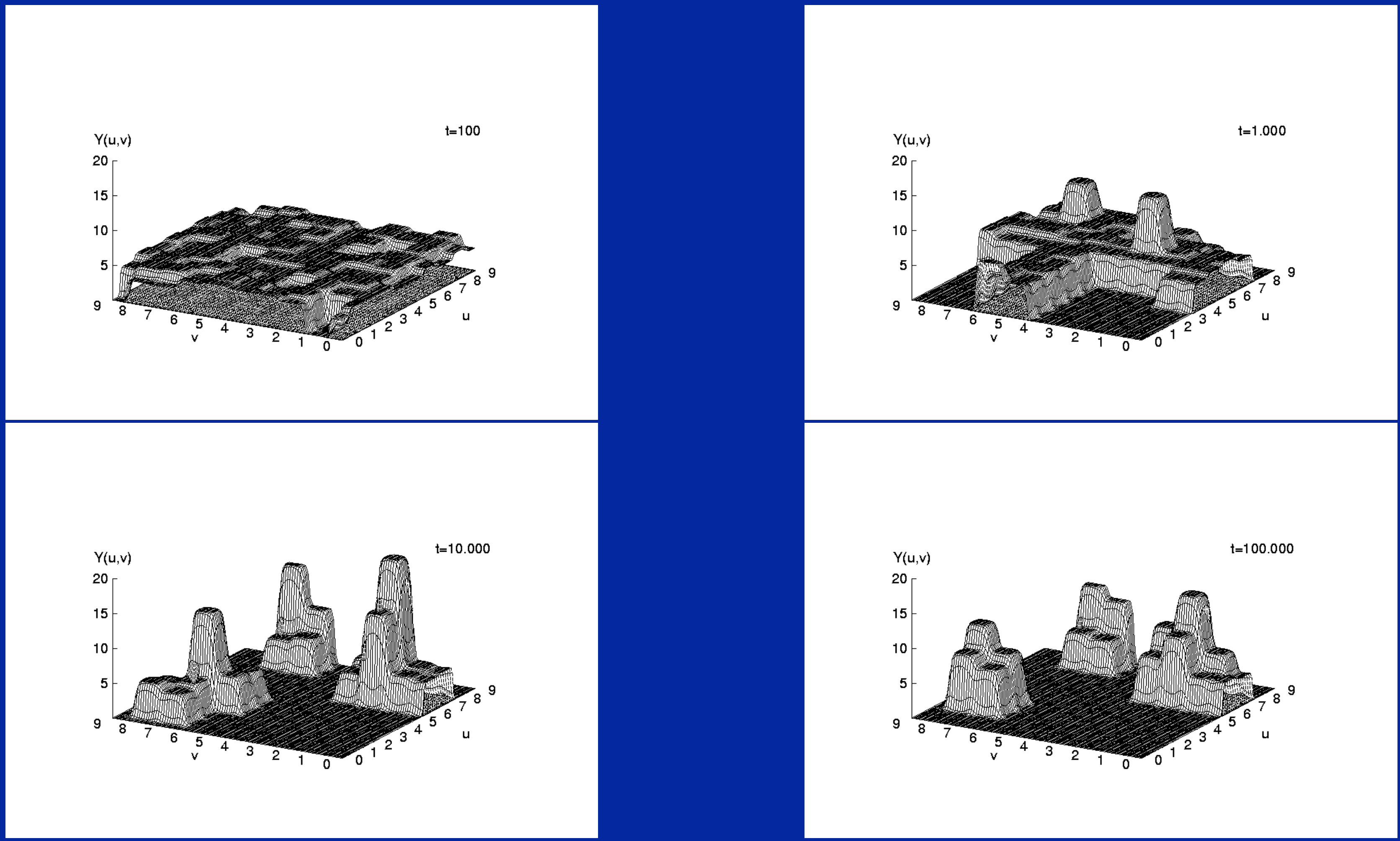
hiring rate k^+: firms hire workers as long as $\dfrac{\delta Y}{\delta l} > \omega^\star$
(maximum profit condition)

$$k^+ = k^+\{l(\boldsymbol{r},t)\} = \eta \, \exp\left\{\frac{\delta Y\,\{l(\boldsymbol{r},t)\}}{\delta l} - \omega^\star\right\}$$

firing rate k^-: external and internal reasons
(i) workers are fired if $\dfrac{\delta Y}{\delta l} < \omega^\star$
(ii) workers can quit their job for better opportunities

$$k^- = k^-\{l(\boldsymbol{r},t)\} = \eta \, \exp\left\{-\left[\frac{\delta Y\,\{l(\boldsymbol{r},t)\}}{\delta l} - \omega^\star\right] + \, c\,\frac{\partial \omega(\boldsymbol{r})}{\partial r}\right\}$$

Spatial distribution of production



Results of Computer Simulations

$t = 0:$ random initial distribution
$t = 100.000:$ distinct *extended major economic regions*

(i) $t < 1.000:$

◇ coexistence of numerous small economic centers
basis: cooperative effects, mutual stimulations

(ii) $t > 1.000:$

◇ some small centers overcome economic bottleneck
$\Rightarrow$ increase of marginal output

◇ competition: *local* attraction of labor force at the expense of the former small economic centers

Final stage: distinct extended economic regions

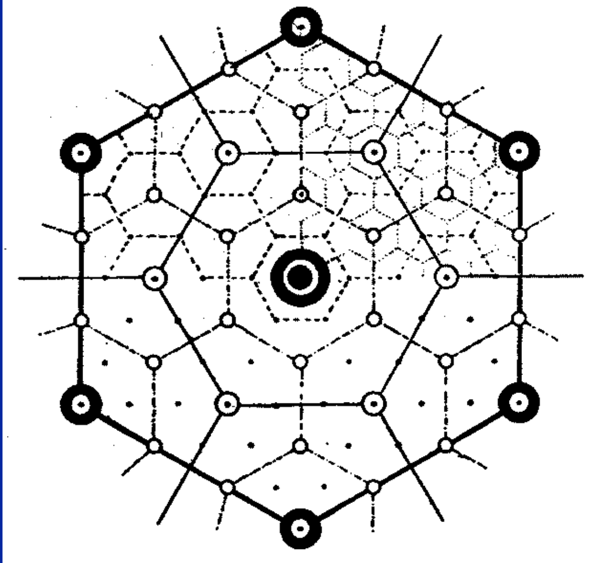
(i) *stable coexistence* of the major economic regions
reason: *critical distance*

◇ each economic center has its own attraction/supply area
$\Rightarrow$ prediction of the *central place theory*

(ii) *quasi-stationary non-equilibrium* within the major economic regions

◇ each economic region consists of some *subregions*
centers do not have same number of employed agents
$\Rightarrow$ still follow a stochastic eigendynamics

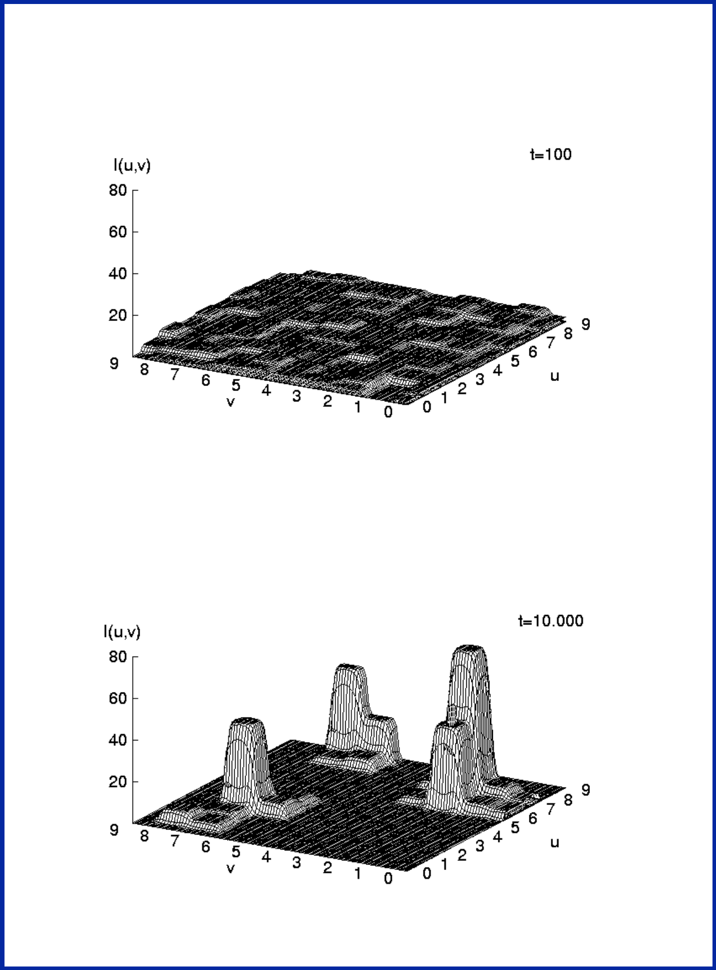
Central Place Theory

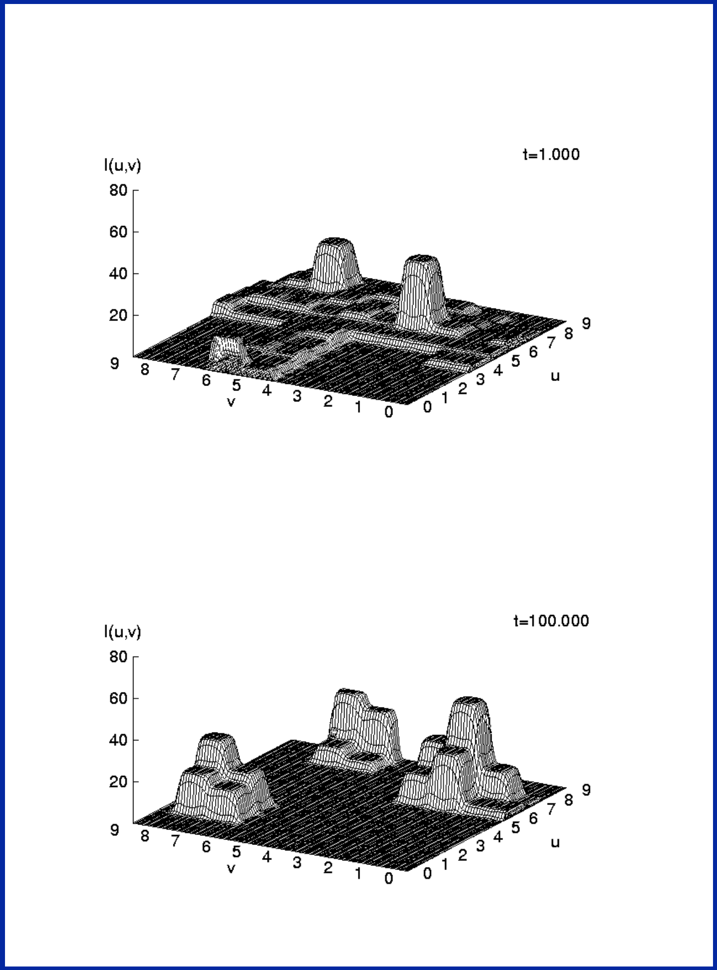


Walter Christaller: *Die zentralen Orte in Süddeutschland.*
Eine ökonomisch-geographische Untersuchung über die Gesetzmäßigkeit der Verbreitung und Entwicklung der Siedlungen mit städtischen Funktionen, Jena: Fischer, 1933
(Reprint: Darmstadt: Wissenschaftliche Buchgesellschaft, 1980)

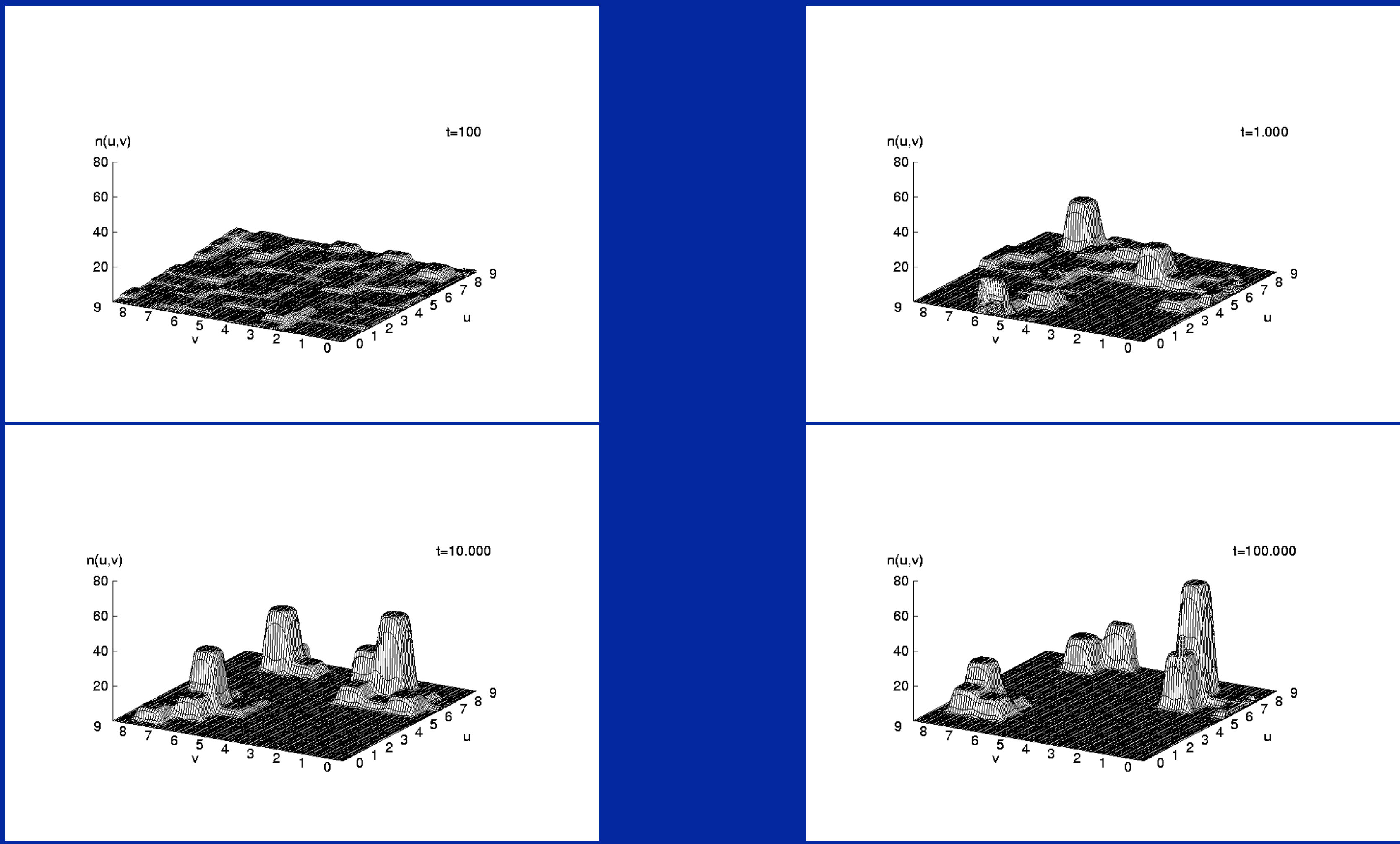
English translation by C.W. Baskin:
Central Places in Southern Germany, London: Prentice Hall, 1966

Spatial density of employed agents

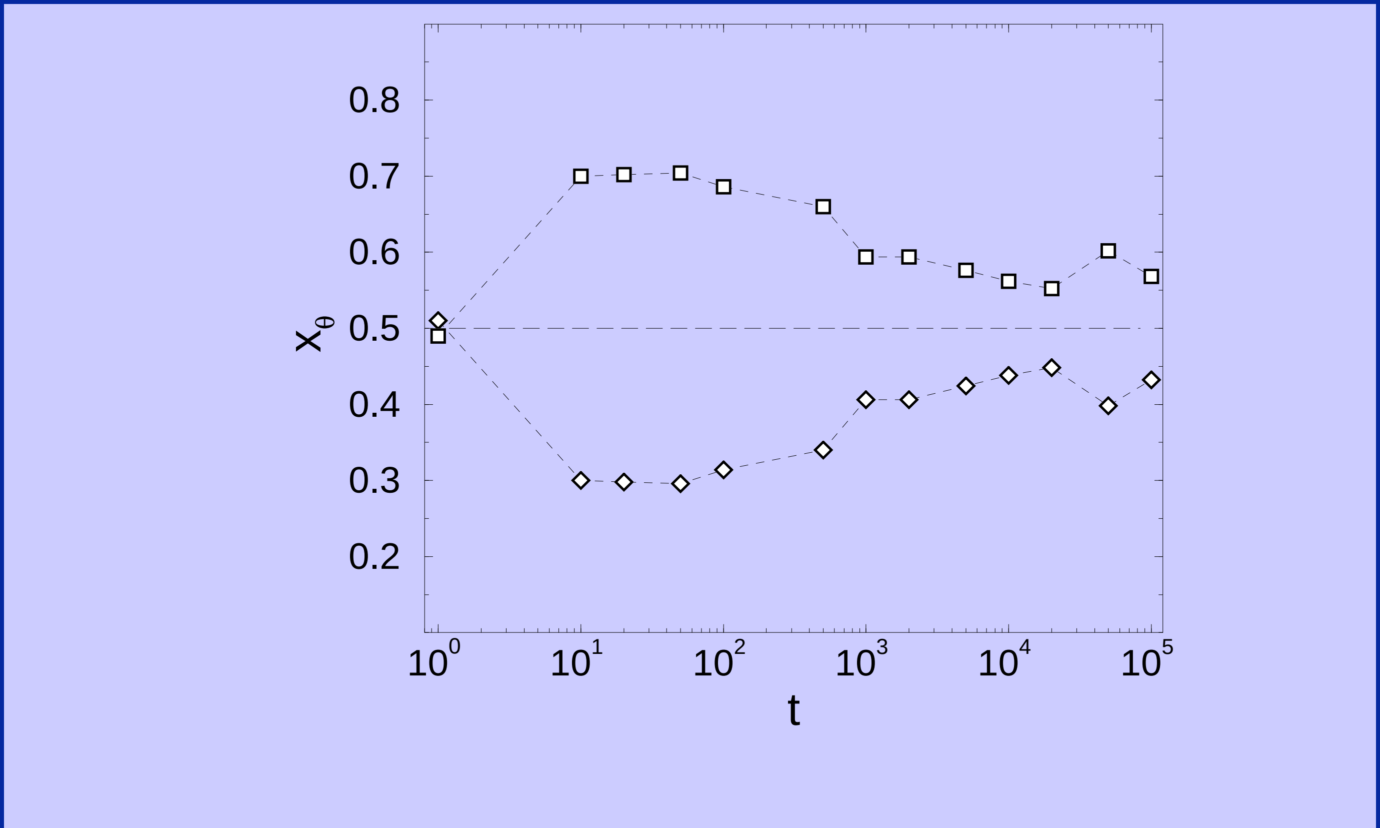




Spatial density of unemployed agents



Total share $x_\theta = N_\theta / N$



employed agents: ($\Box$) unemployed agents ($\Diamond$)

Spatio-Temporal Evolution of Unemployment

(i) **small scale production**

- ◇ significant higher share of employed agents ($\sim$ 70 percent) broadly distributed

(ii) **large scale production**

- ◇ increase of wage $\Rightarrow$ affects migration of unemployed agents concentrate in the productive regions
- ◇ important for the further growth: agents to hire
- ◇ concentration of employed *and* unemployed agents in the *same* regions
- ◇ new (larger) centers employ 60 percent of the agents $\Rightarrow$ *increase of unemployment*

Conclusions

Minimalistic multi-agent system: two levels of description

Agent's level:

- ◇ simplex - not complex ⇒ "intermediate" complexity
- ◇ *local* response/changes of the environment
- ◇ internal degrees of freedom ⇒ variety of responses
- ◇ parallel *independent* actions *coupled* by information flow

System's level:

- ◇ emergence of complexity
- ◇ adaption to changes in the environment
- ◇ failure tolerant (single agents, external pertubations)

$\Rightarrow$ Reason: *Self-Organization*
solutions result from the non-linear interaction
boundary conditions (semi-structured environment)

Characteristics of the approach:

- *non-deterministic*
  random events (fluctuations) play a considerable role
- *non-finalistic*
  final (global) solutions cannot be predicted from local interactions $\Rightarrow$ solutions *emerge* $\Rightarrow$ *path dependent*
- *bottom-up approach:* create a solution $\Rightarrow$ self-organization
  top-down approach: design a solution $\Rightarrow$ planning

Self-Organization

Self-Organization is the process by which individual subunits achieve, through their cooperative interactions, states characterized by new, emergent properties transcending the properties of their constitutive parts.

Biebricher, C. K.; Nicolis, G.; Schuster, P.: Self-Organization in the Physico-Chemical and Life Sciences, EU Report 16546 (1995)

Self-organization is defined as spontaneous formation, evolution and differentiation of complex order structures forming in non-linear dynamic systems by way of feedback mechanisms involving the elements of the systems, when these systems have passed a critical distance from the statical equilibrium as a result of the influx of unspecific energy, matter or information.

SFB 230 “Natural Constructions”, Stuttgart, 1984 - 1995