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Modelling Spatial Urban and Economic Aggregation Bottum Up

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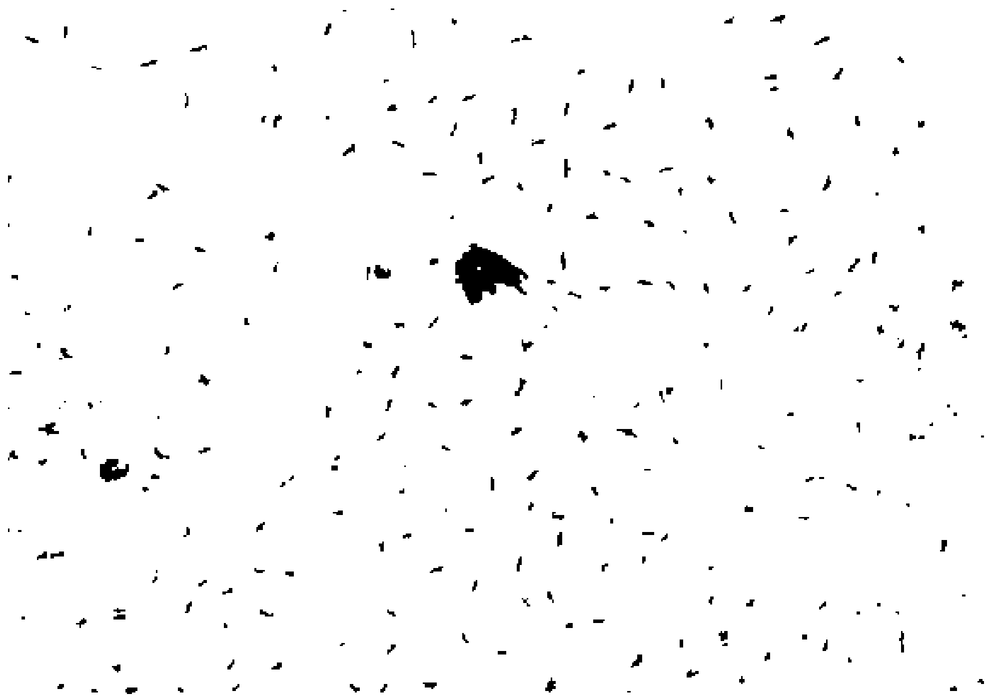
Schedule

1. Modelling Urban Cluster Distribution
2. Spatial Information Field
3. Example: Aggregation by positive Feedback
4. Example: Urban Growth
5. Example: Economic Agglomeration
6. Conclusions

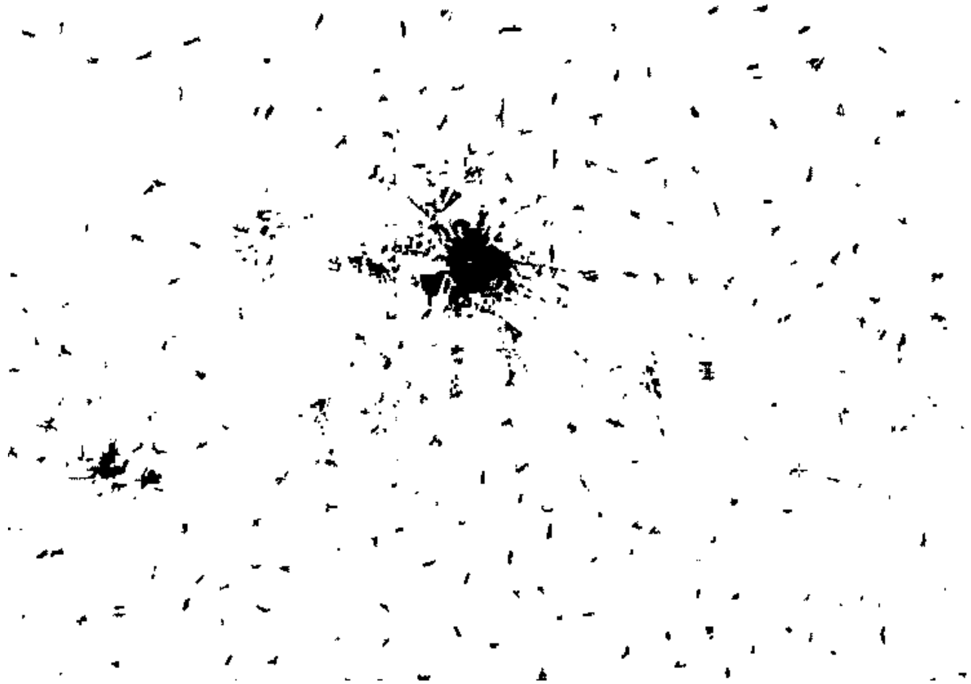
Urban Growth

Example: Berlin 1800 - 1945

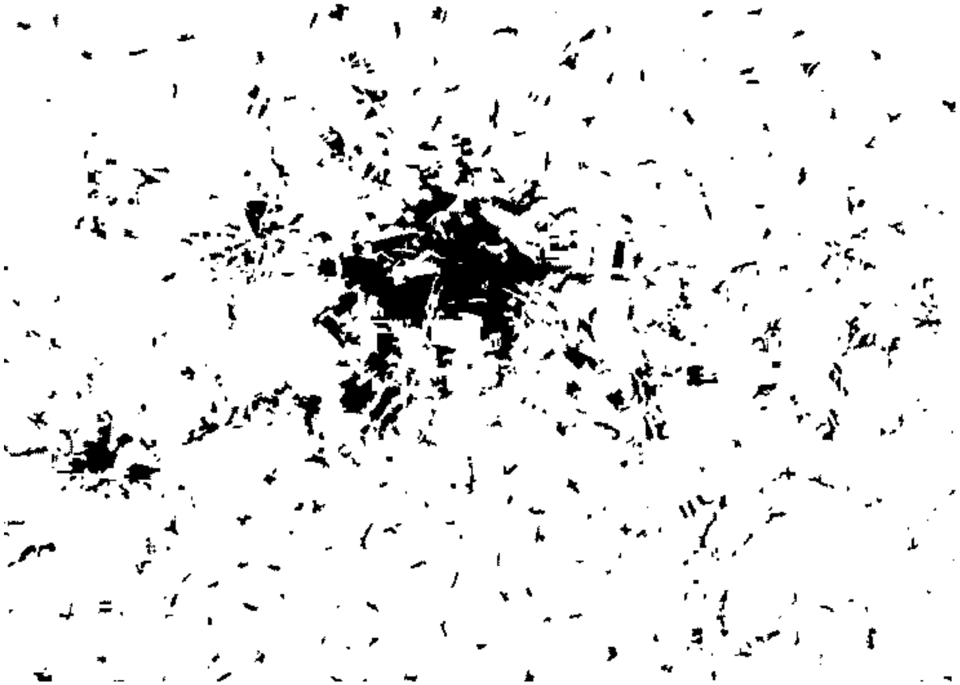
1800



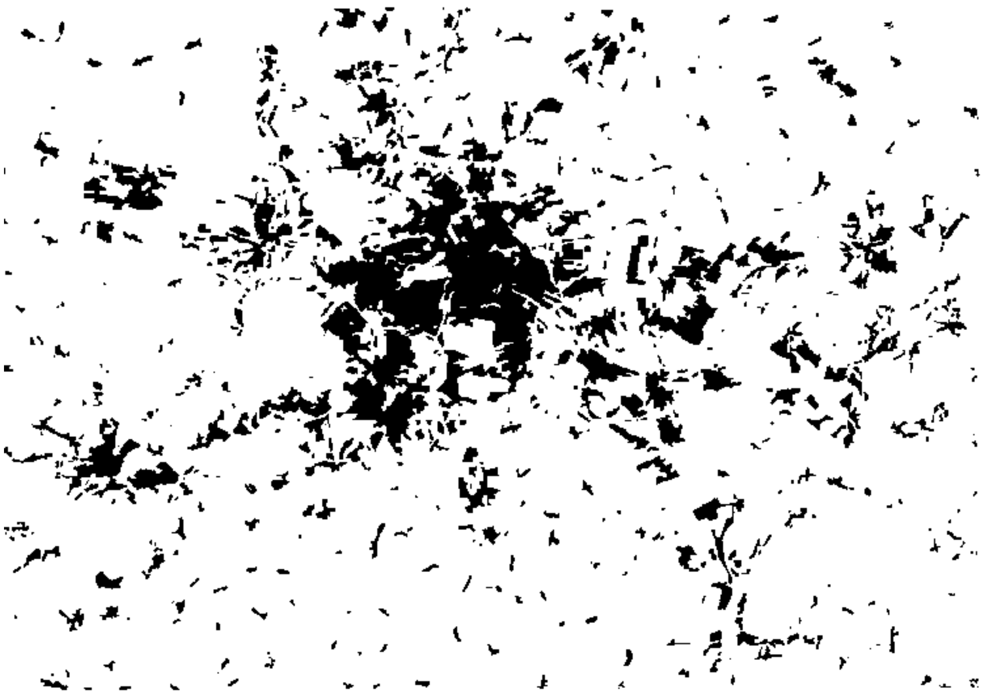
1875



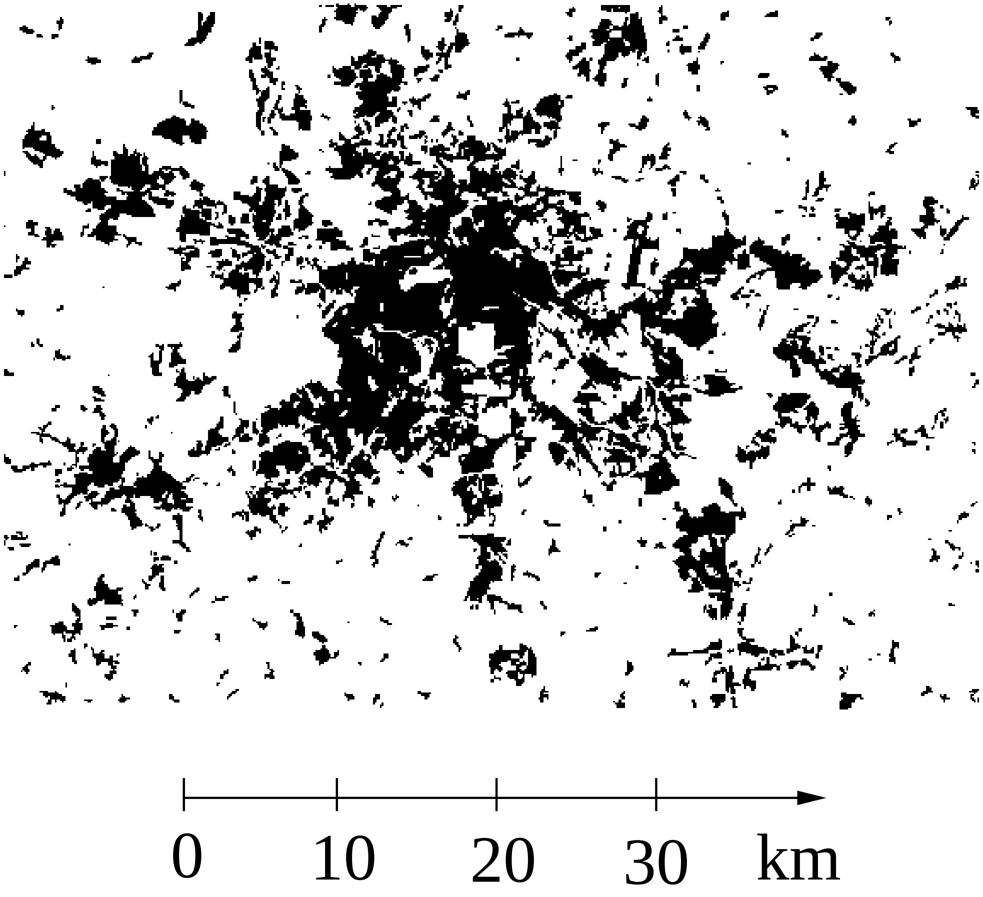
1910



1920



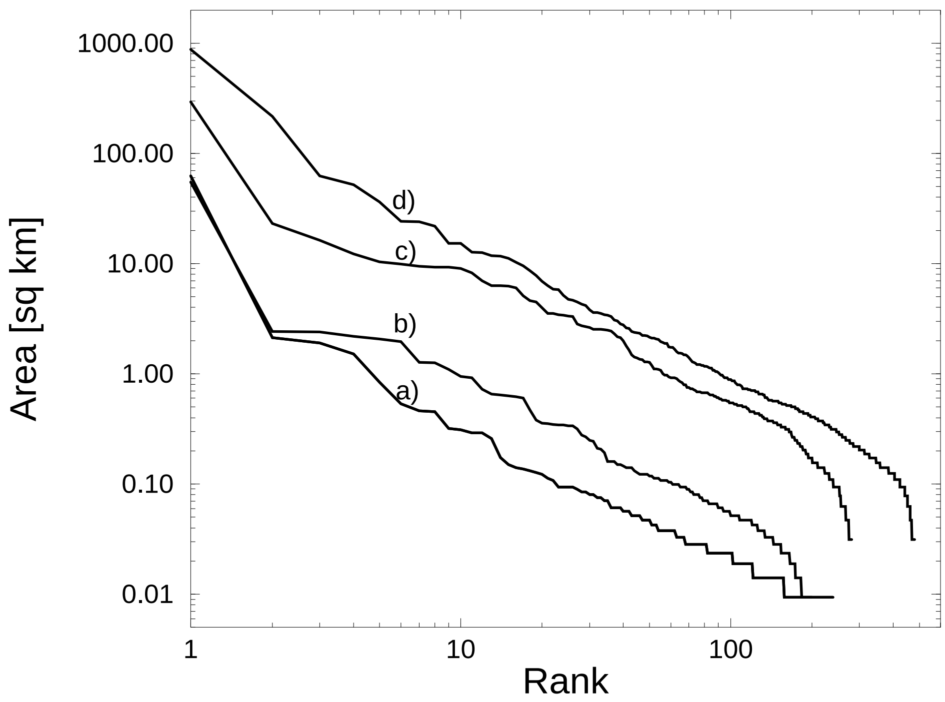
1945



Urban Growth: Common Features

- morphological transition: compact $\Rightarrow$ fractal
  calculation of fractal dimension
- urban aggregate composed of many sub-clusters
  calculation of rank-size distribution

Rank-Size Cluster Distribution



(a) Daegu (1988), (b) Munich (1965) (c) Moscow (1980), (d) Philadelphia (1980)

Conclusion

- evolution of urban aggregates towards PARETO distribution
  $\Rightarrow$ aggregate hierarchically composed of clusters of all sizes
- deviations from PARETO distribution:
  $\Rightarrow$ *structural resources for potential development*

Master Equation Approach to Urban Growth

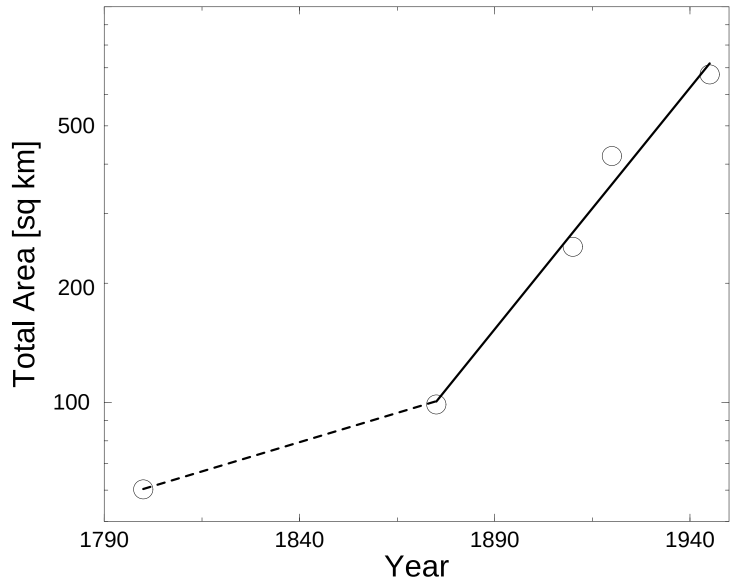
- distribution of clusters of different sizes:

  $n_1, n_2, \ldots, n_k, \ldots, n_A$

  n_k: size (number of pixels) of cluster k (k=1,...,A)

- total mass: $N_{tot}(t) = \sum_{k=1}^{A} n_k$

total growth: almost exponentially

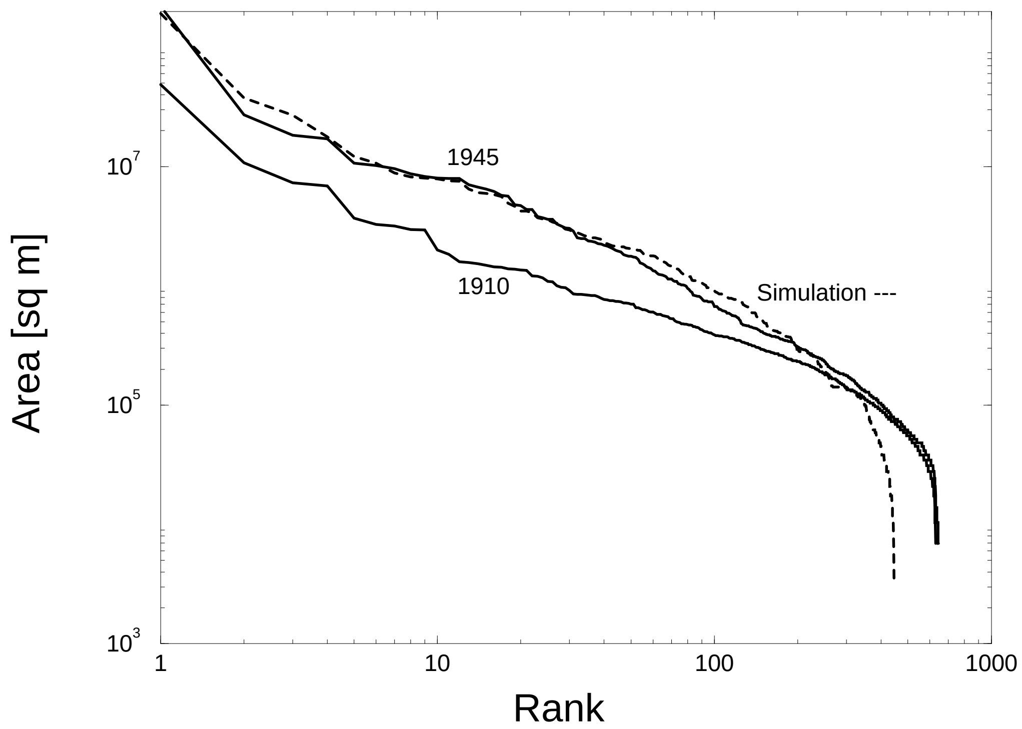


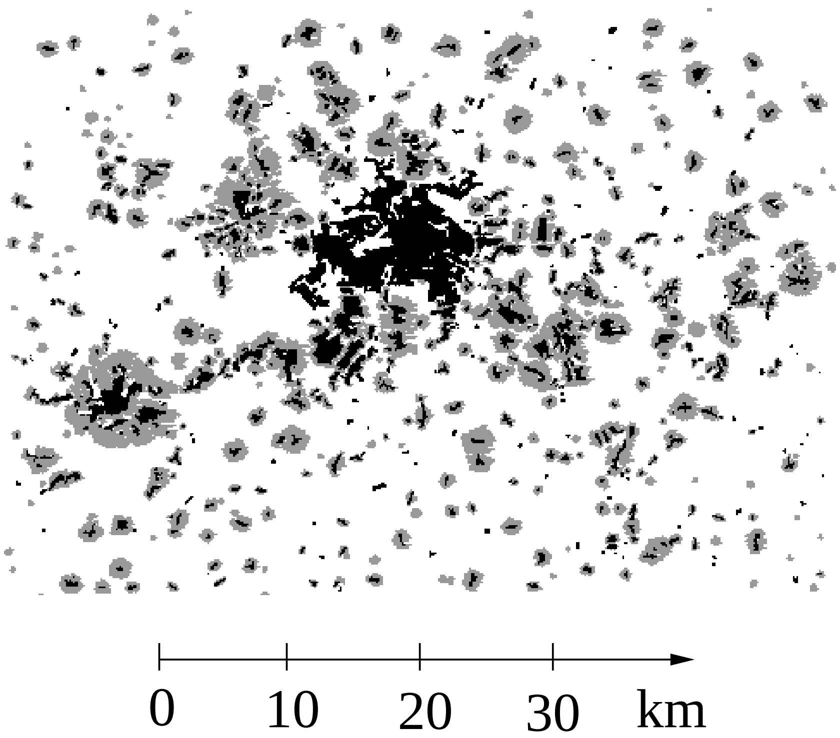
Two elementary processes:

1. *Formation of new clusters*
   $A \xrightarrow{w_1} A+1$
   $w_1 = w(A+1, t+1|A, t) = c(N_{tot})$
   assumption: $c = const.$

2. *Growth of existing clusters*
   $w_k = w(n_k+1, t+1|n_k, t) = \gamma \frac{n_k}{N_{tot}}$
   $\gamma = 1 - c(N_{tot})$

Results of Computer Simulations: Berlin 1910 - 1945




0
10
20
30
km

Conclusion

- sub-cluster of rank 1 grows only by *coagulation*

  reason: *shift of growth zones* towards outer regions

- existence of *spatial correlations*:
  attraction (local growth) $\Longleftrightarrow$ repulsion (stop of growth)

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  How to include spatial correlations ?

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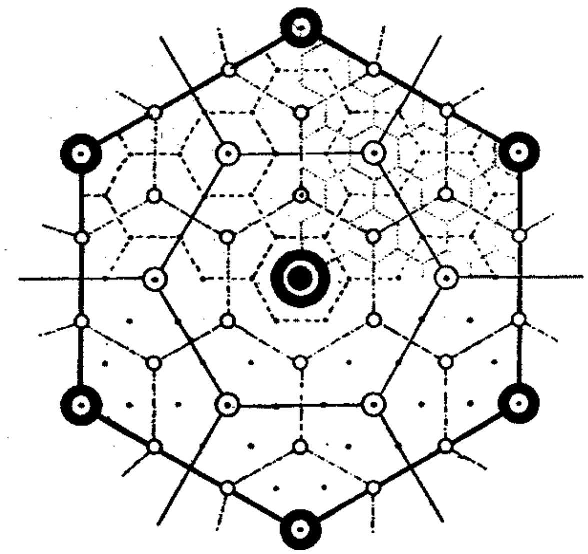
Answer:

Distribution of spatial information !

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

Conclusion

- number and size of locations:
  $\Rightarrow$ hierarchical structure
  $\Rightarrow$ PARETO-like rank-size distribution
- spatial distribution of locations :
  $\Rightarrow$ depends on spatial correlations

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Distribution of spatial information !

Spatial Information 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:

1. production of information:
   permanent *local* individual contribution: $q_i(\theta_i,t)$
2. distribution of information: diffusion-like process, D_θ
   $\Rightarrow$ determines how fast information is distributed
3. memory effects:
   information generated has a certain life time, $1/k_\theta$
4. different kind of information $\Rightarrow \theta$

Who is producing the information ?

Agents (individuals, firms, existing urban aggregations, ...)

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Who is receiving the information ?

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What is the response ?

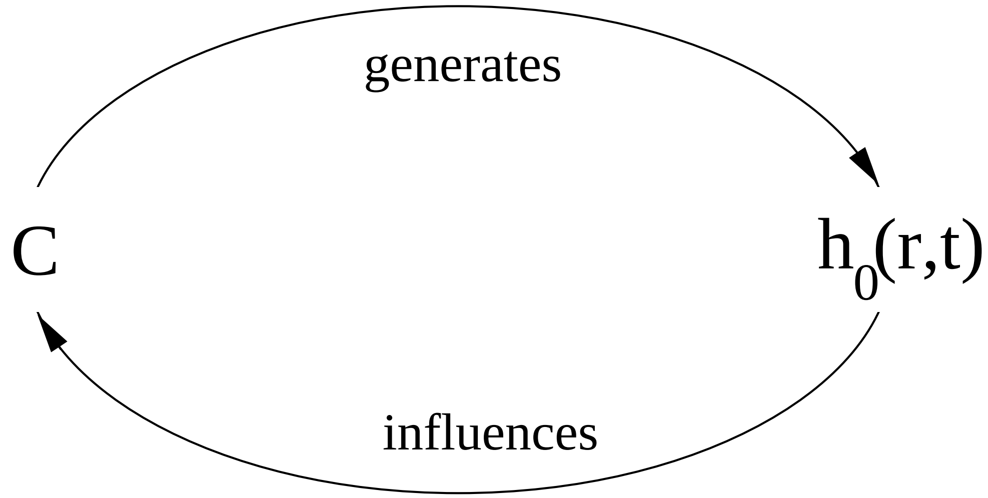
???

Example: Aggregation by Positive Feedback

migration of agents:

$$\frac{d\boldsymbol{r}_i}{dt} = \boldsymbol{f}(\boldsymbol{r}_i) + \sqrt{2D}\,\boldsymbol{\xi}_i(t) \; ; \qquad \boldsymbol{f}(\boldsymbol{r}_i) = \left.\frac{\partial h_0(\boldsymbol{r},t)}{\partial r}\right|_{r_i}$$

$\boldsymbol{f}(\boldsymbol{r}_i)$: guiding force, *local* influence

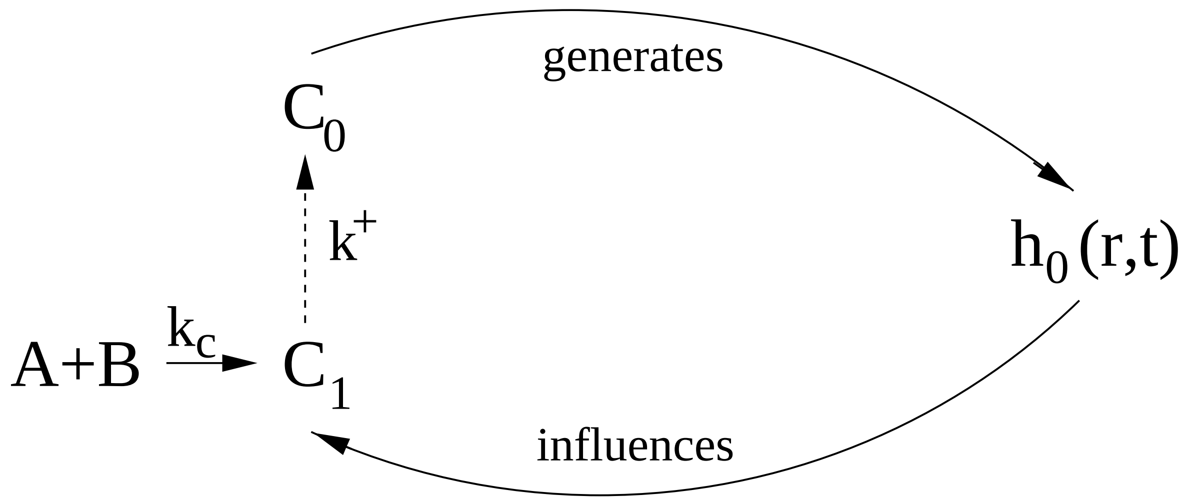


Conclusion:

- positive feedback *only* $\Rightarrow$ occurence of multiple centers
- competition between centers: *ONE* big lump
- What about coexistence between aggregates ?
  Solution: Inclusion of counteractive forces !

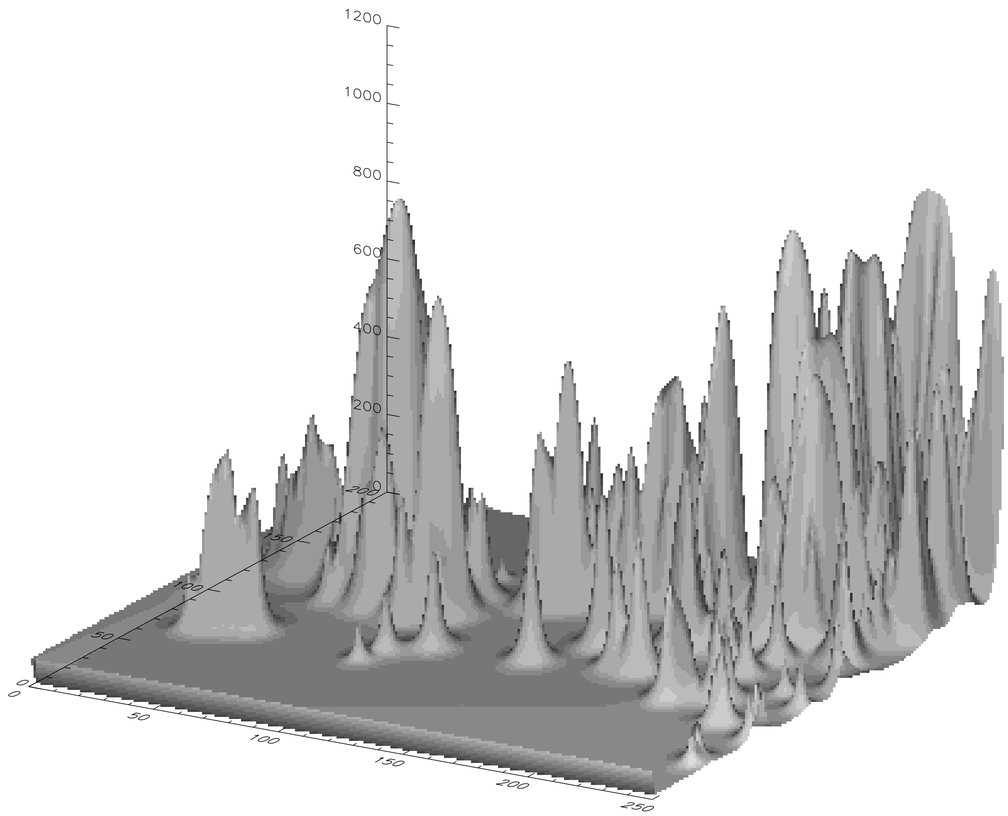
Example: Urban Growth

- non-linear feedback between existing aggregation (C_0) and its further growth
- C_0: generates spatial information "attraction potential" $\Rightarrow h_0(\boldsymbol{r}, t)$
- "growth units" (C_1) respond to attraction potential
- demand for further growth (B) has to match existing free space (A)



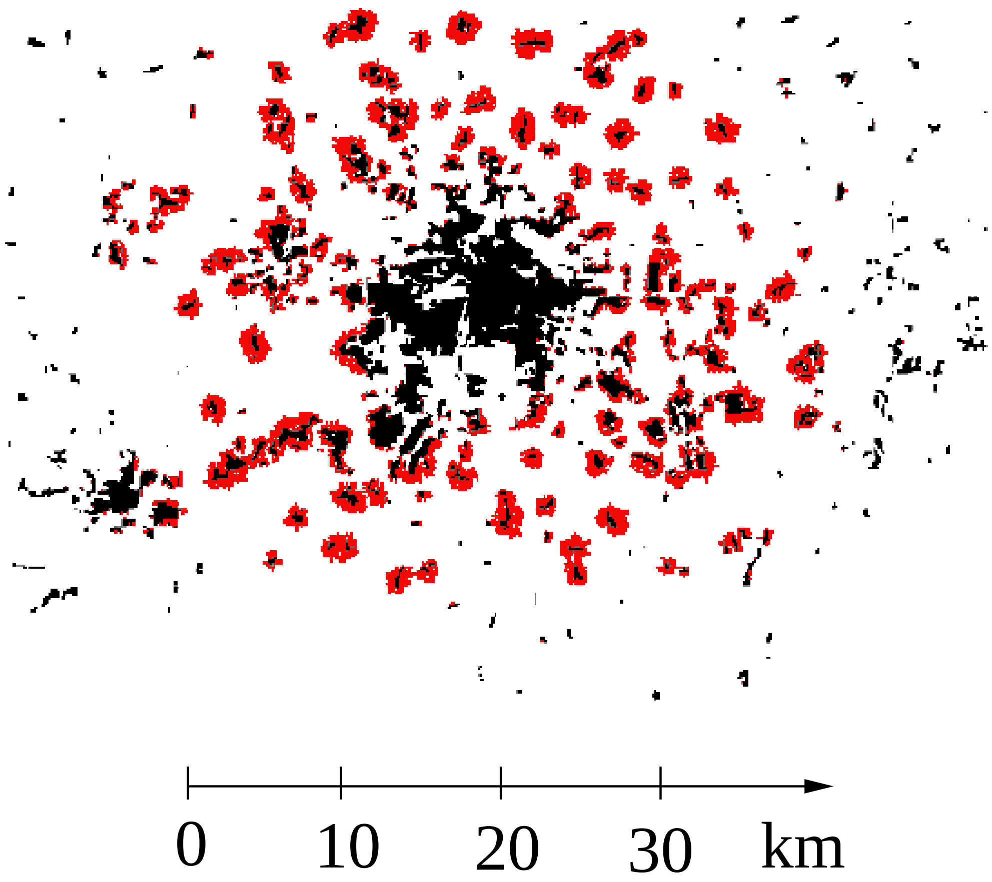
generates
C_0
k^+
$h_0(r,t)$
A+B
k_c
C_1
influences

Urban attraction field (Berlin/Potsdam area 1910)



Result of Computer Simulations (Berlin 1910 - 1920)

- shift of growth zones towards outer regions prevents urban collapse



Example: Economic Agglomeration

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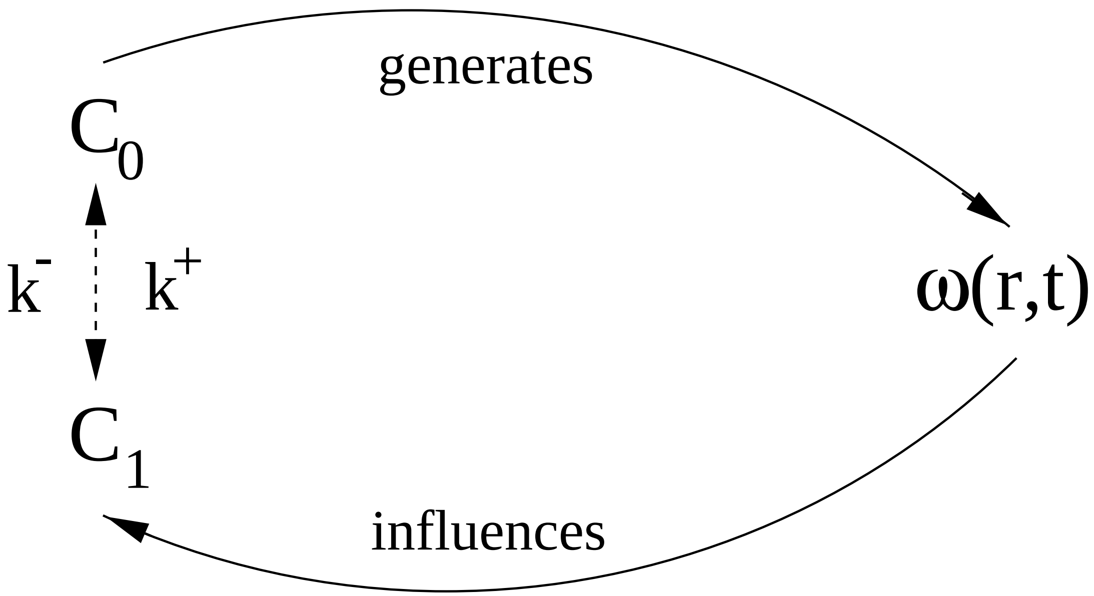


- $\theta = 0$: *employed agents*, C_0 (immobile) $\Rightarrow l(\boldsymbol{r}, t)$
  $\theta = 1$: *unemployed agents*, C_1 (mobile) $\Rightarrow n(\boldsymbol{r}, t)$
- migration due to spatial wage differences: $\omega(r)$
- “hiring” and “firing”: k^+, k^-

Economic Assumptions

- wage: marginal product of labor:

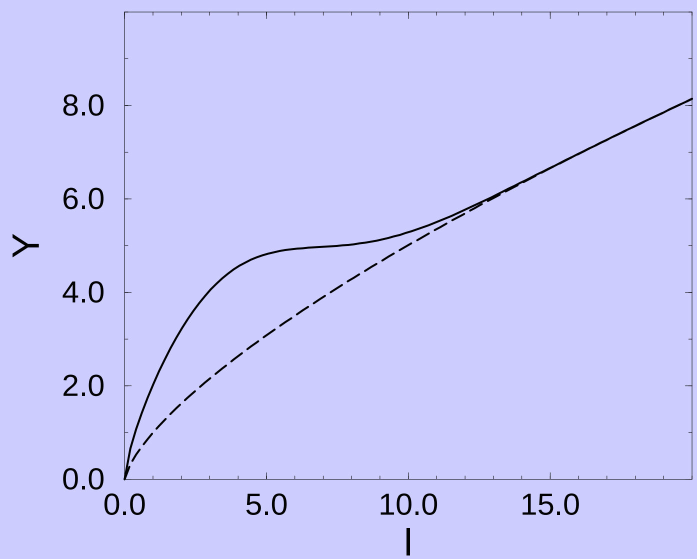
$$w\{l(\boldsymbol{r},t)\} = \frac{\delta Y\{l(\boldsymbol{r},t)\}}{\delta l}$$

- 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 $\Rightarrow$ 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 $\Rightarrow$ 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)

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

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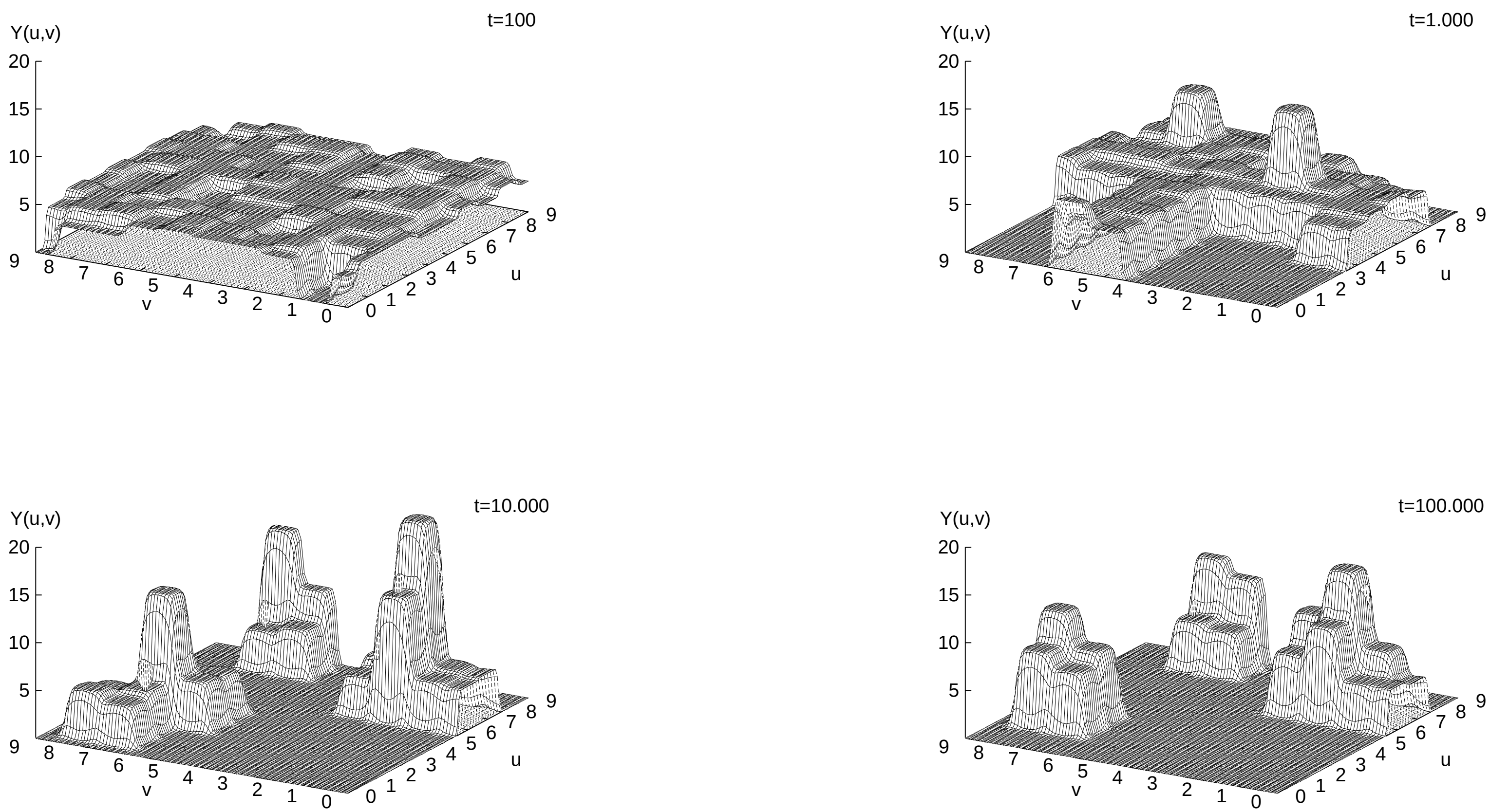
firing rate k^-: external and internal reasons

(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*

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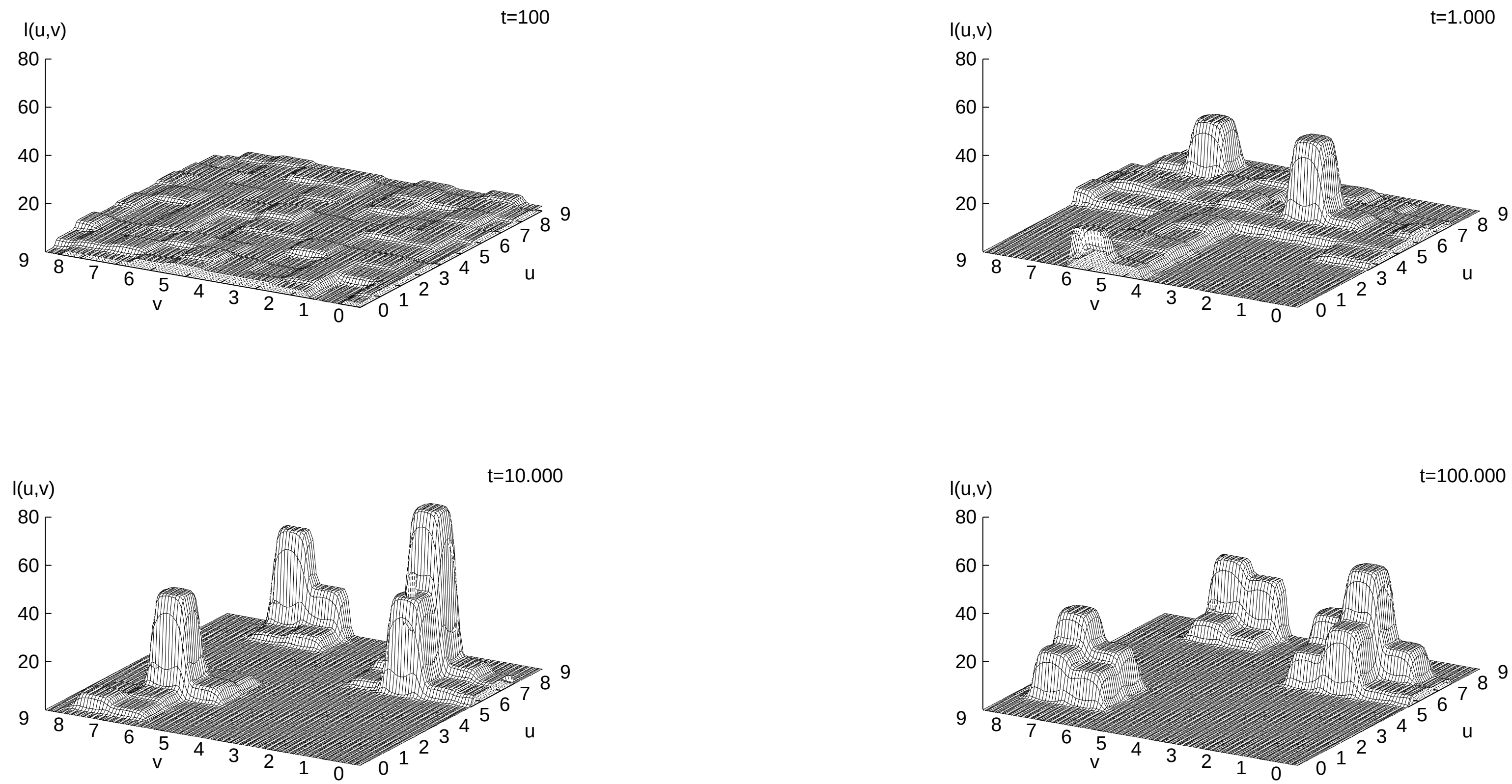
⇒ prediction of the *central place theory*

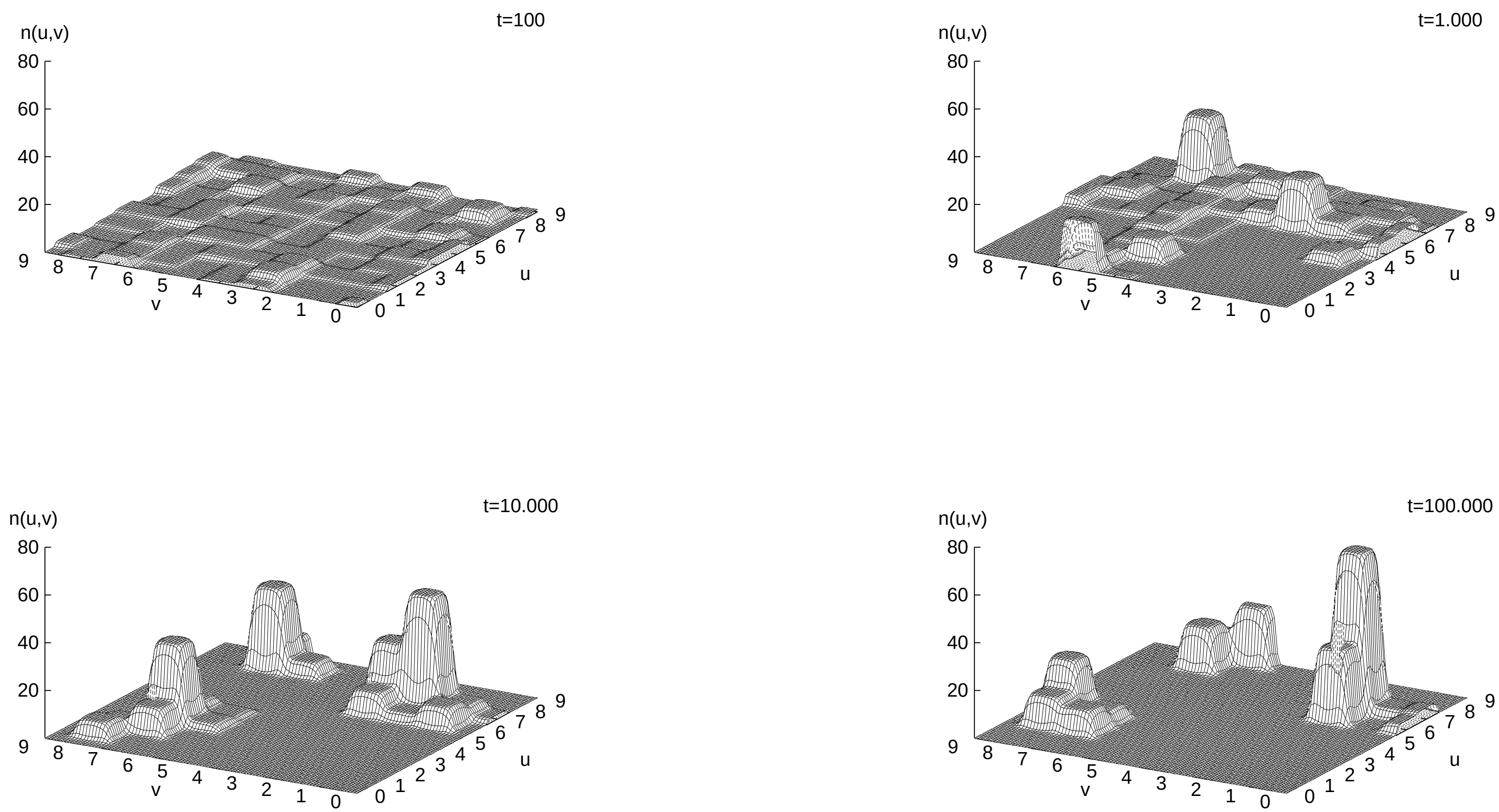
(ii) *quasi-stationary non-equilibrium* within the major economic regions

➤ each economic region consists of some *subregions*
centers do not have same number of employed agents
⇒ still follow a *stochastic eigendynamics*

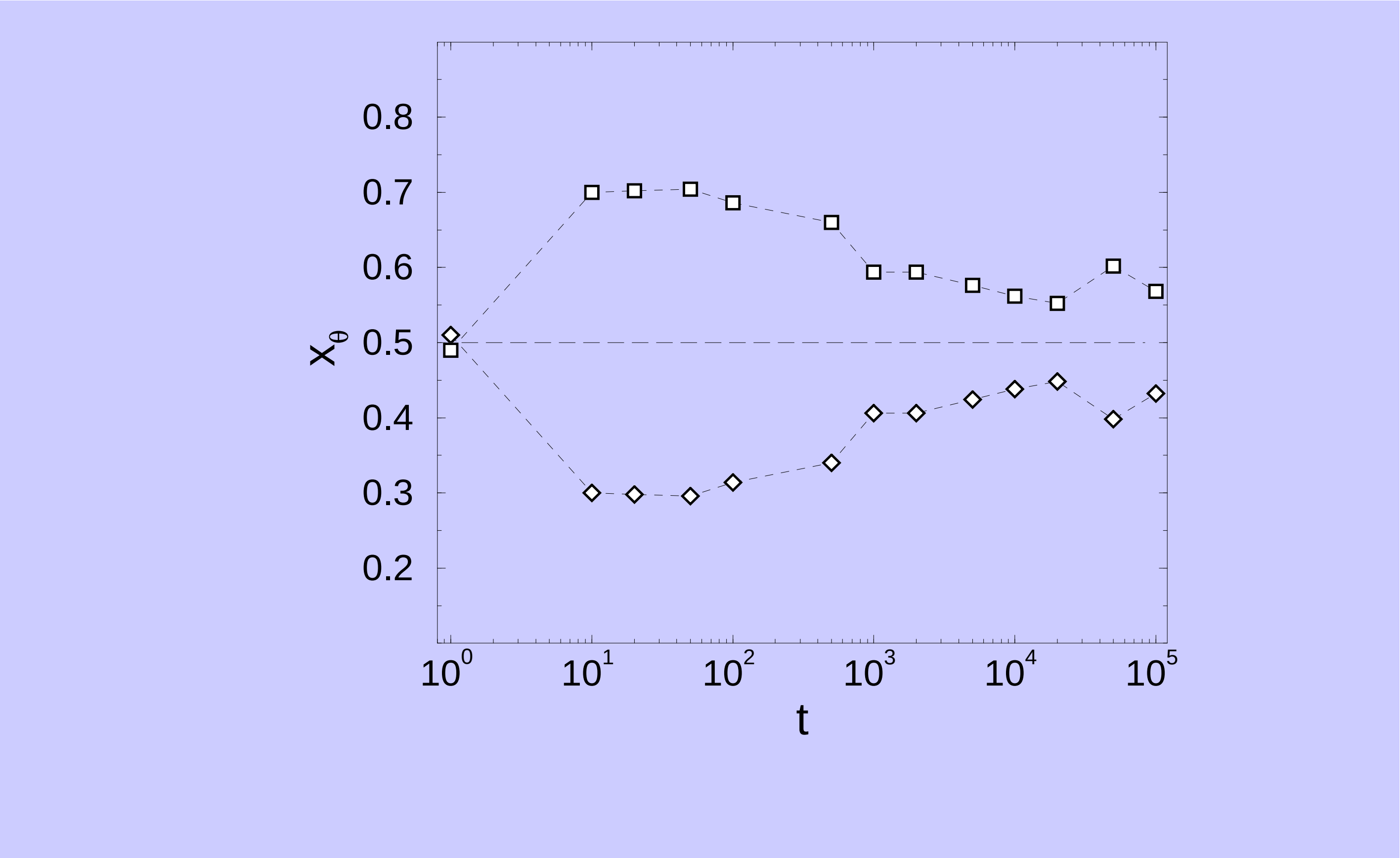
Spatial density of employed agents



Spatial density of unemployed agents



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



employed agents: (□) unemployed agents (◊)

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

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(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

- *Agents* (individuals, firms, urban “growth units”, ...)
- communicating via a *spatial information field*
  local production, distribution of information,
  memory effects

Conclusions

- *Agents* (individuals, firms, urban “growth units”, ...)
- communicating via a *spatial information field*
  local production, distribution of information,
  memory effects
- *minimalistic* multi-agent system:
  - agents: simplex - not complex
  - producing / receiving “information” $h(\boldsymbol{r}, t)$
  - action: local concentration / aggregation
  - path dependence
    further action is “enslaved” by previous history

System's level:

- emergence of complexity
  ⇒ complex spatial patterns
  ⇒ local competition, global coexistence
- adaption to changes in the environment (resources)

  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 ⇒ solutions *emerge* ⇒ *path dependent*
- *bottom-up approach:* create a solution ⇒ self-organization
  top-down approach: design a solution ⇒ 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