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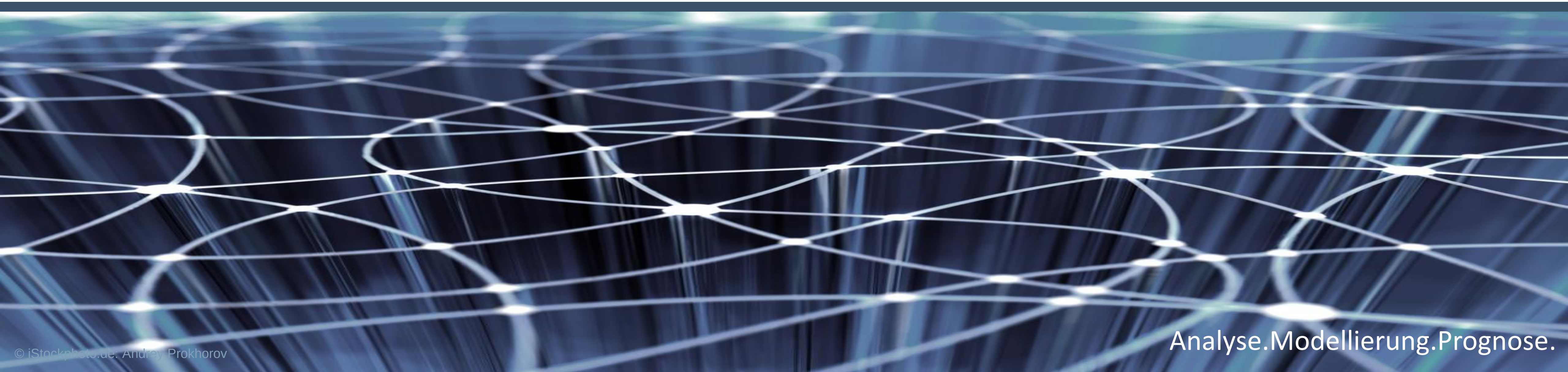
Systemanalyse GmbH

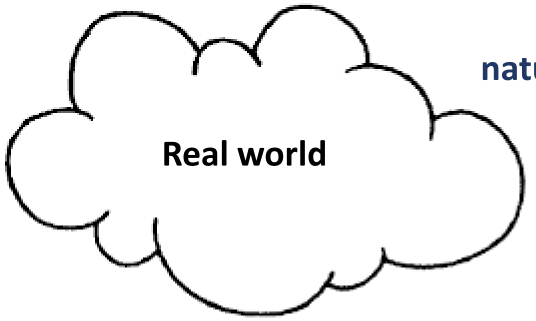
Universität Stuttgart
II. Institut für Theoretische Physik

Individual Decisions, Innovations and Sustainable Economics

Günter Haag



One fundamental stimulus of human research



natural system

“Dass ich nicht mehr mit saurem Schweiß
rede von dem was ich nicht weiß

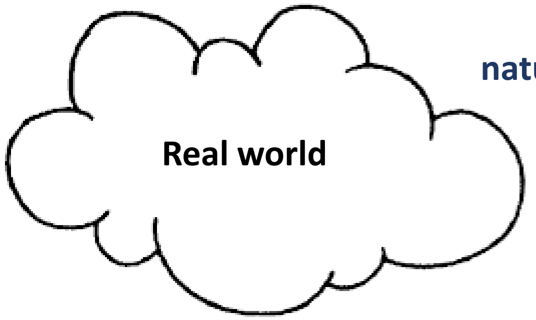
(sondern)

Dass ich erkenne, was die Welt
im Innersten zusammenhält” (Goethe, Faust I)

“What holds the world together at its core”

Douglas Adams (1979) formulated in his famous book “The Ultimate Hitchhiker´s Guide to the Galaxy” in a simple but realistic way, …where do we come from, where do we go and where do we get the best Wiener Schnitzel?

What is a model?



natural system

Models are based on rules
Rules are based on experience
John L. Casti

Models can be formulated and built in different languages

country sayings and weather proverbs
in a field report

models e.g. for weather forecasting in the language of
physics and mathematics

The model should be kept as simple as possible but not too simple
Albert Einstein

Picturing the world in mathematics

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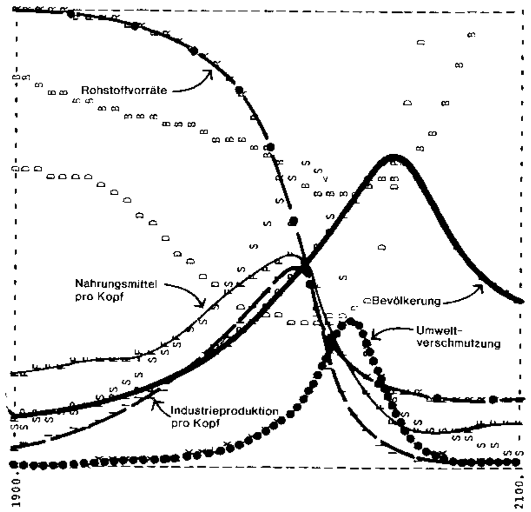
Real world

Deterministic Models

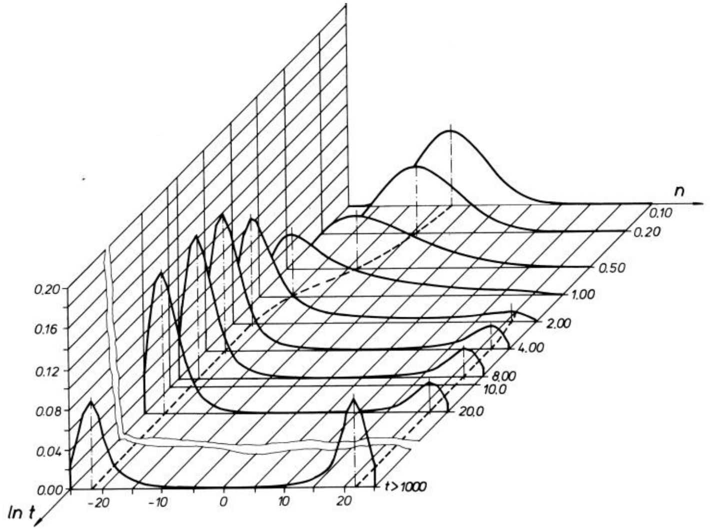


Club of Rome (1972)
System Dynamics (Jay Forrester)

MIT Boston (1990)
World model (about 160.000 equations,
95% of the world economy)

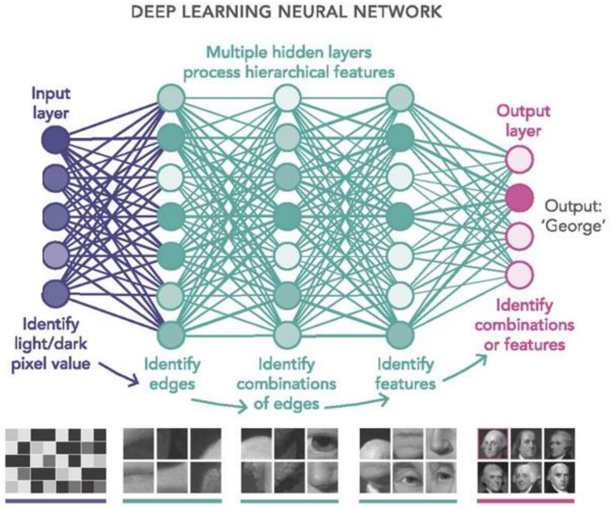
Statistical Models

models with uncertainties

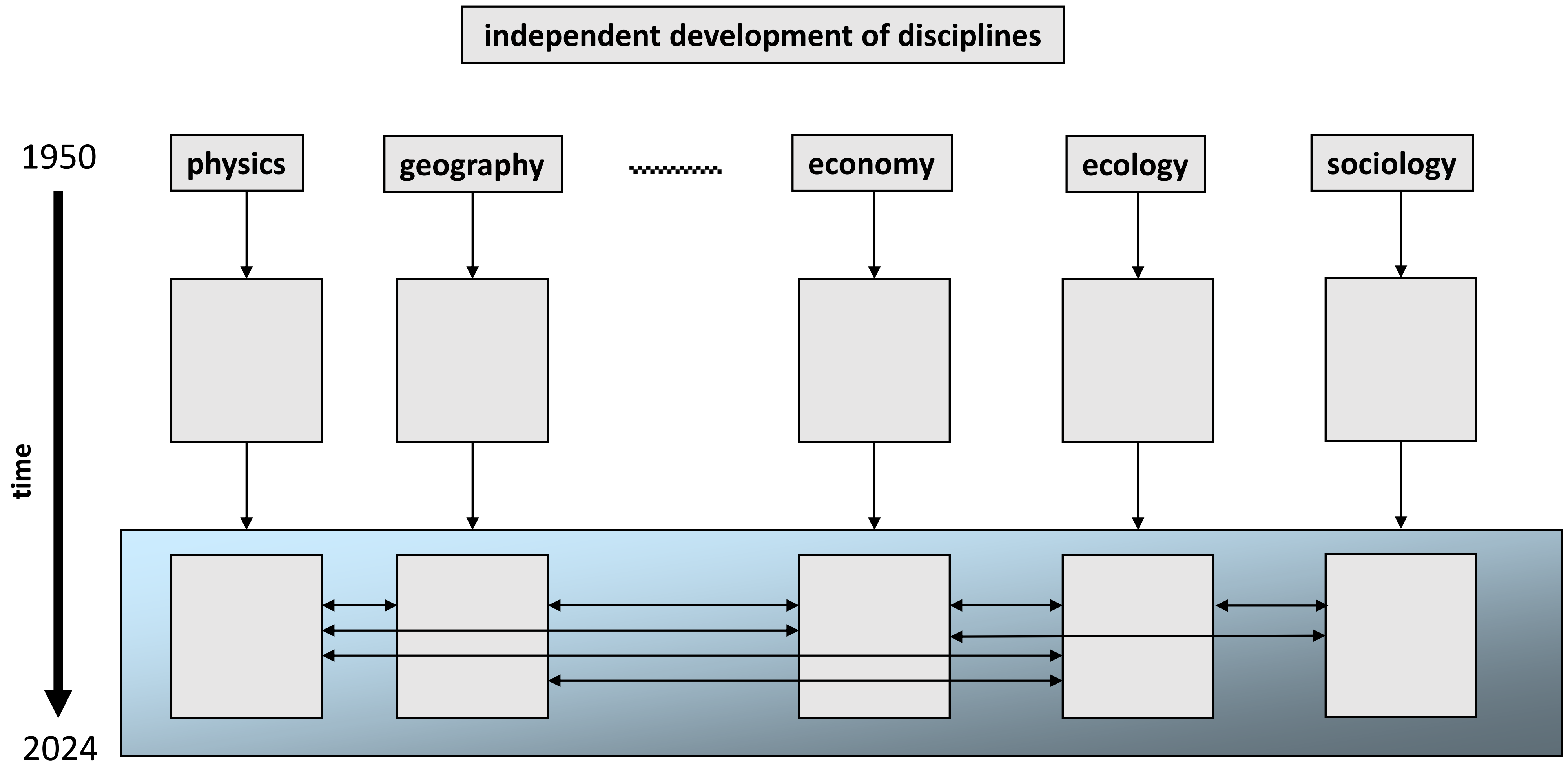


Neural Networks (AI)

data driven modelling



Towards Interdisciplinarity 50's onwards



Integration of disciplines, transfer of methods, ideas by pioneers like H.v.Foerster, Haken, Weidlich, Prigogine, Haag,…

Towards Interdisciplinarity 50‘s onwards

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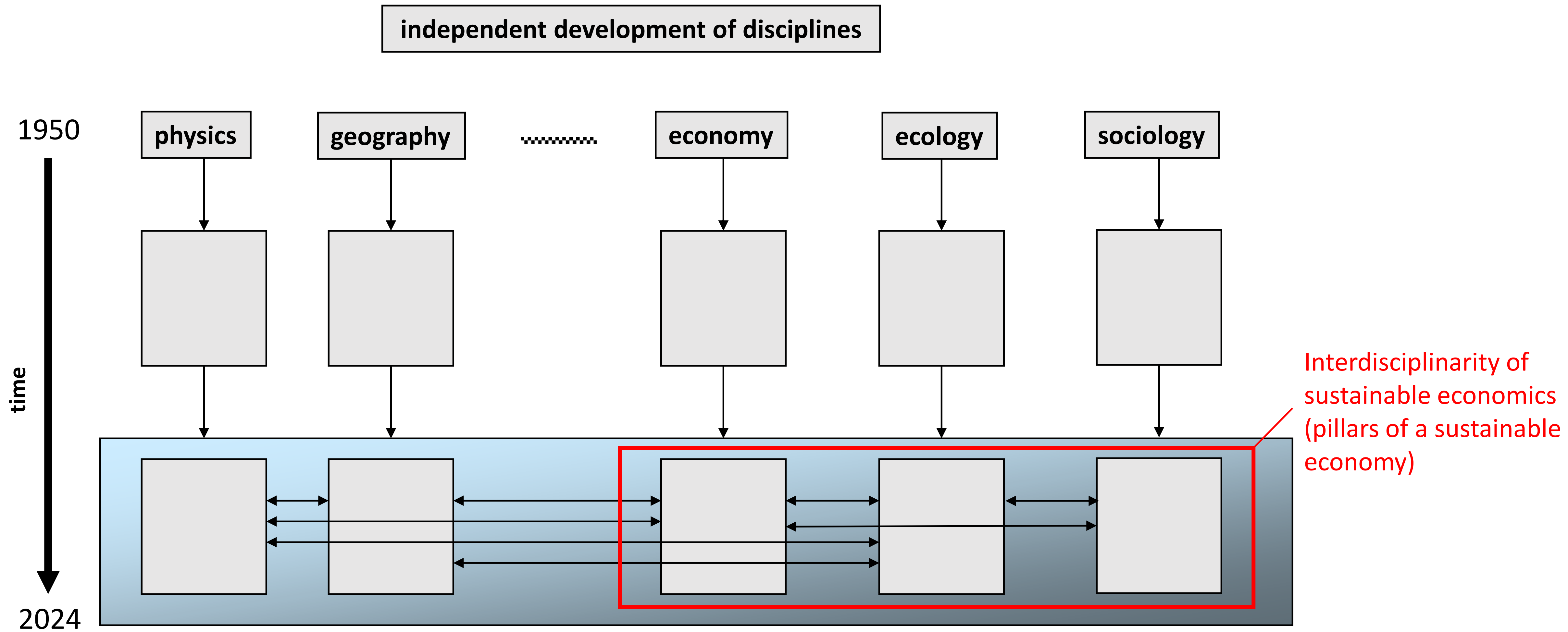
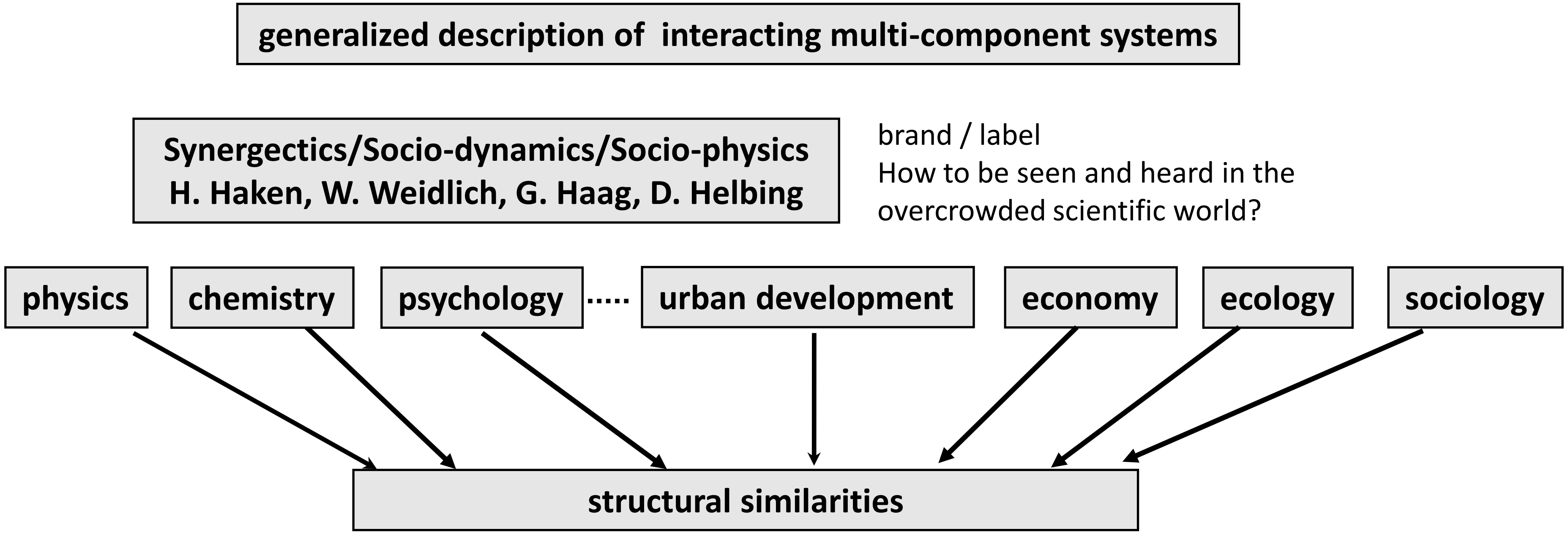


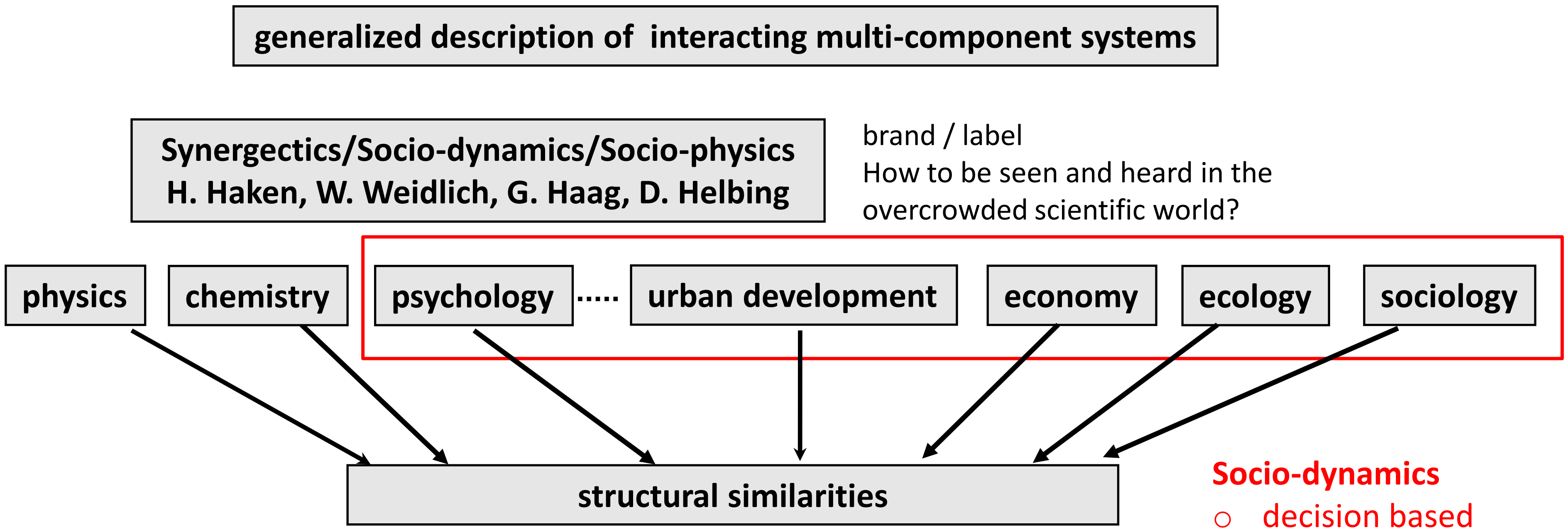
Integration of disciplines, transfer of methods, ideas by pioneers like H.v.Foerster, Haken, Weidlich, Prigogine, Haag,…

Appropriate Modelling: Looking for Structural Similarities



- universality (mathematics of stochastic processes)
- many subsystems
- interactions different on the micro-level beside structural similarities
- non-linearities (self-organisation)
- fluctuations
- space-time features, path dependence, SOC, multiple equilibria, chaos,…
- open or closed systems

Appropriate Modelling: Looking for Structural Similarities



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- open or closed systems

Socio-dynamics

- decision based
- highly nested system
- uncertainties constantly present
- decisions influenced by the society
- political guidelines
- highly dynamical environment
- nonlinear interactions

⇓

sustainable economics

How to model Decision Processes – The Framework

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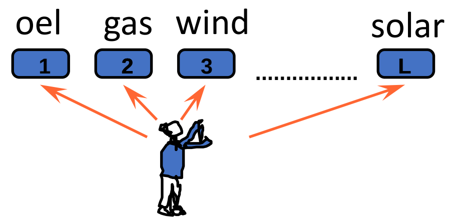
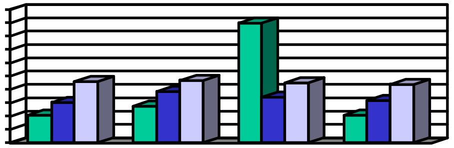
Individual choice
selection of alternative technologies



Individual attitudes
cost
longevity
value for money
regionality
conserving resources

decision process
multi-component system
with nonlinear interactions



number of users of an alternative

micro-level
decisions of individual agents
(household, entrepreneur...)

feedback

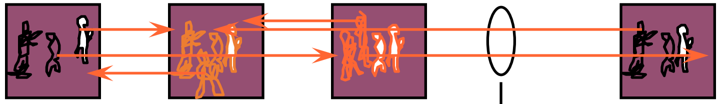
macro-level
behaviour of macro-variables
(fraction of market pentration,
housing stock, population,...)

socio-economic environment
global climate
policy
number of user of
different technologies

Master equation
probability to find a certain
decision pattern

$P(\vec{n})=P(n_1, n_2, \ldots n_L)$

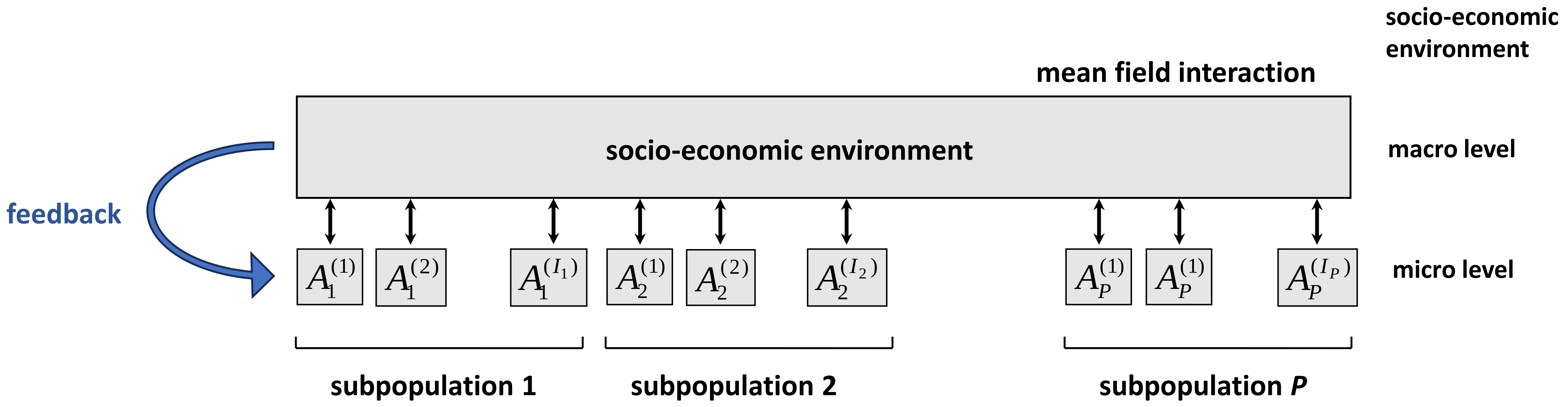
probability



$n_1(t)$ $n_2(t)$ $n_3(t)$ $n_L(t)$ — number of decision maker

$W_{ij}(t)$ — number of changes between alternatives

Interactions between agents in a complex environment



individual decisions

- partially rational expectations
- unobserved characteristics (uncertainties)
- correlated decisions (Haag 1989, Akerlof 2000)
- non-linear effects

Master equation framework

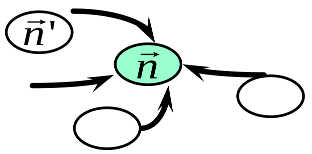
Pauli Master equation

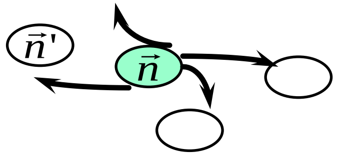
input: transition rates

trend parameter

$$\frac{dP(\vec{n},t)}{dt} = \sum_{\vec{n}'} w_t(\vec{n},\vec{n}';\vec{\kappa})P(\vec{n}',t) - \sum_{\vec{n}'} w_t(\vec{n}',\vec{n};\vec{\kappa})P(\vec{n},t)$$

output: change of probability



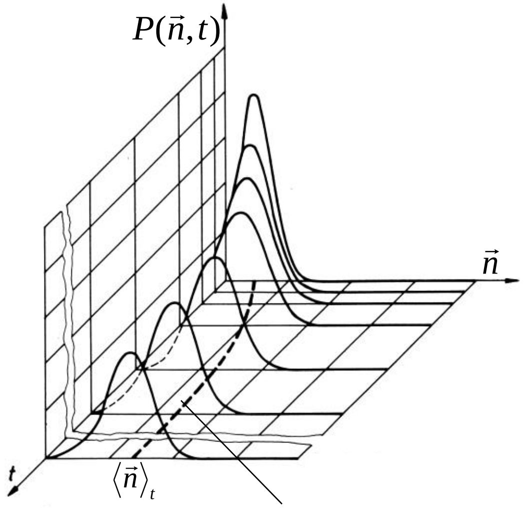


$\vec{n}=(n_1, n_2, \dots n_L)$

different alternatives

Some properties

- The transition rates define the process – all we need
- dynamic equation for probability to find a certain configuration
- → Mean value equation, variance equation
- balance equation for probability fluxes
- irreversable dynamics → unique stationary state
- Markoff assumption → socio-dynamics: system parameters change over time
- Master equation → Agent-Based-Modelling, Fokker-Planck-Equation



Master equation framework: Parameter Estimation

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Error minimization

$$F[\vec{\kappa}] = \sum_{t} \sum_{\vec{n},\vec{k}} \{w_t^e(\vec{n},\vec{n}') - w_t(\vec{n},\vec{n}';\kappa)\}^2 = \min$$

empirical data   model data

optimal estimation of system parameters

input of parameters

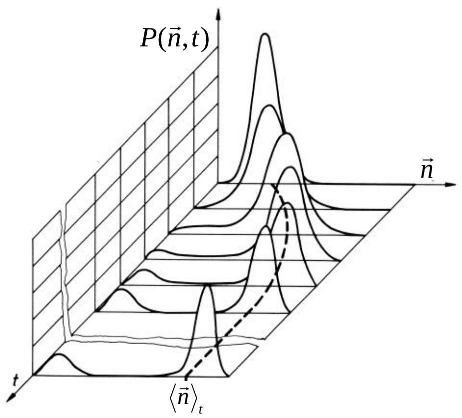
non-linear system of difference equations for the mean values

different scenarious

forecasting of the mean behaviour of the trajectories

Equations of motion

$$\frac{d\overline{n(t)}}{dt} = \sum_{\vec{n}} \vec{n} \frac{dP(\vec{n},t)}{dt} = \frac{d}{dt} \sum_{\vec{n}} \vec{n} P(\vec{n},t)$$



1. Example: Business Cycles – Theory of Investments

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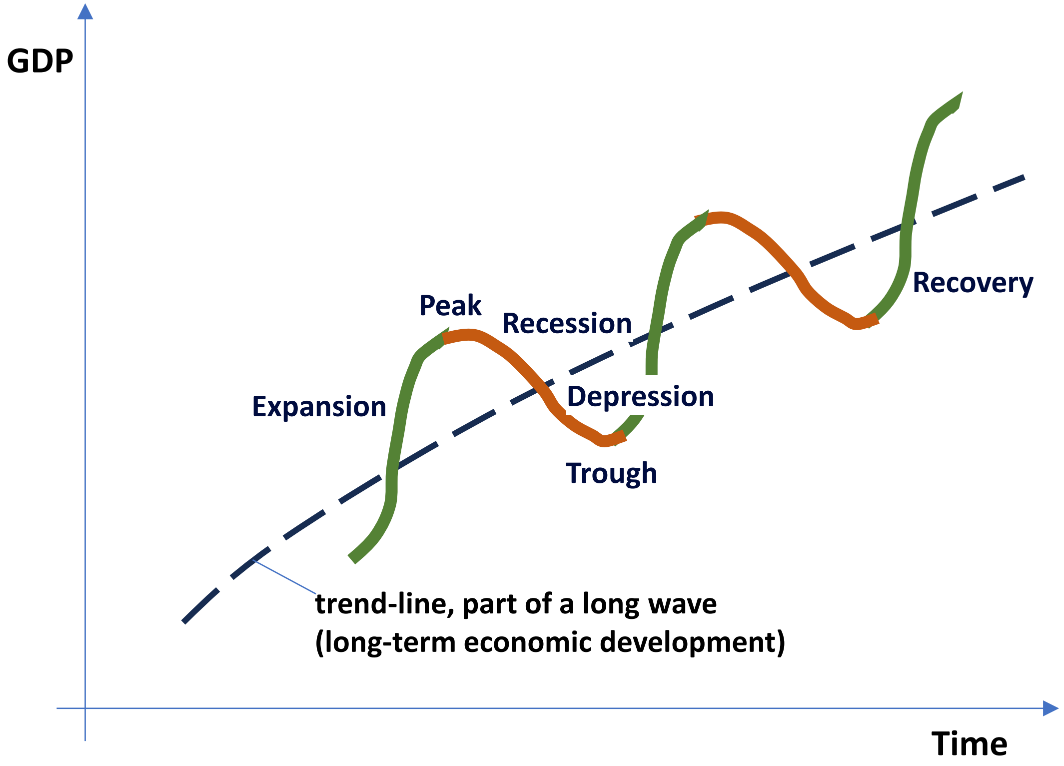


Business cycle (4 to 6 years)
cycle of fluctuations in the Gross Domestic Product (GDP) around its long-term natural development
- Expansion
- Peak
- Recession
- Depression
- Trough
- Recovery

Observation at trade fairs:
years nothing new – years all have new
coordination of firms activities (information exchange)
→ collective behaviour

How can we eliminate business cycles (Tinbergen, 1983)?

Business cycles and fluctuations around the trend line are natural – we have to anticipate its development (Haag)

Schumpeter Clock – Theory of strategic investments

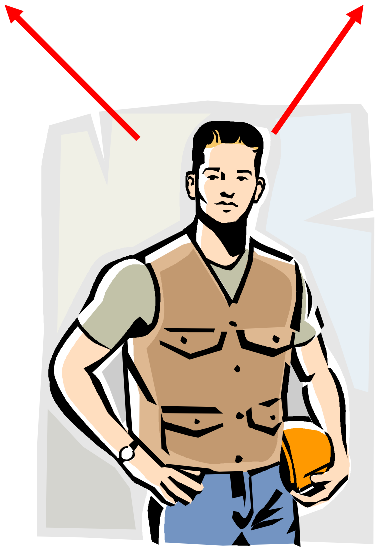
choice process
strategic investment

$I(t) = E(t) + R(t)$

$E(t)$ $R(t)$

expansionary
investment

rationalizing
investment



**Investor
entrepreneur**

Sectoral restrictions
„Schumpeter goods sector“ – parts of industry and public sector operating similar to industrial organisations

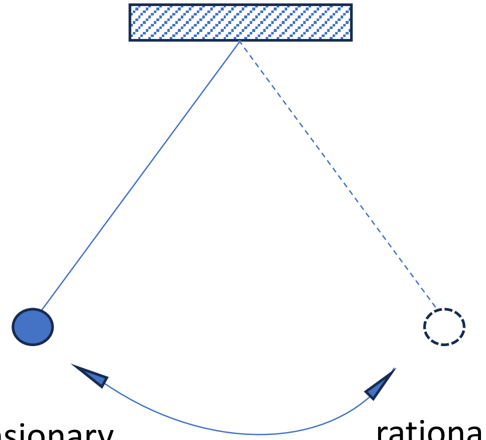
Spatial restrictions
Fokus on statistical units such as whole nations, states or regions

Functional restrictions
Fokus on industrial investor and his strategic behaviour under rivalry

Focus on supply side
Demand side neglected, induced investment neglected
(taken into account by Reiner Koblo, 1991)

Schumpeter Clock (Mensch, Weidlich, Haag, 1981)

strategic investment
searching of profits
$I(t) = E(t) + R(t)$



expansionary
investment E(t)

rationalizing
investment R(t)

How much do I want to invest (next period)

How much did I invest (last period)

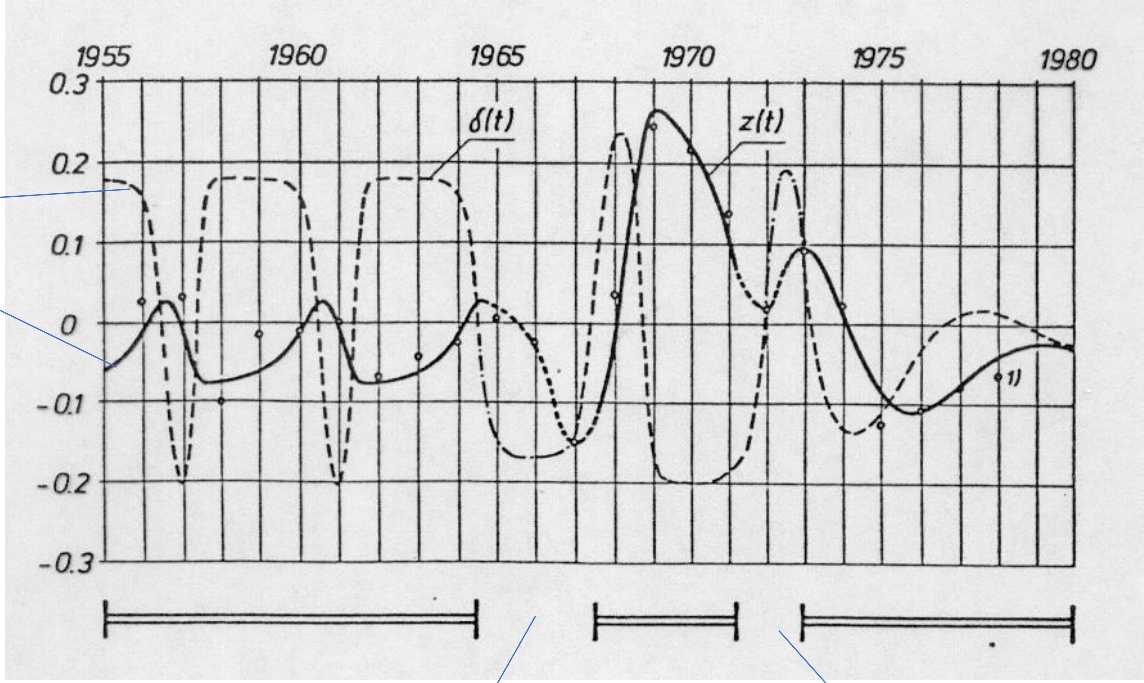
Data Base: IfO-Data about firms investment
of about 6.000 firms

expansionary investments

alternator dynamics

investment structure index
Z=(E-R)/(E+R)

rationalizing investments



hyperboom
„Schiller“ effect
Keynesian economist
Grand coalition
CDU+SPD

two oil shocks caused
slumpflation
(M. Freedman)

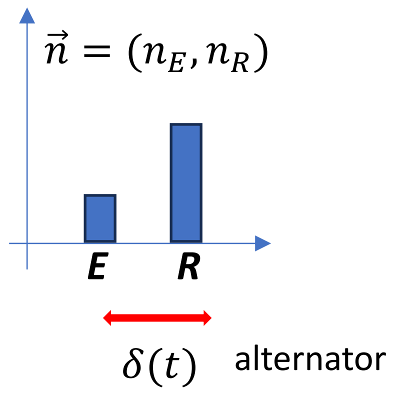
Schumpeter Clock – The transition rates

Suppose number of investors is categorized in *R*-type investor $n_R\,(t)$ and *E*-type investors $n_E\,(t)$
Total number of investors is 2N (constant)

$n_E + n_R = 2N$ constant $\qquad n_E = N + n$

$n_E - n_R = 2n$ relevant variable $\qquad n_R = N - n$

decision configuration



transitions between decision configurations

$$\{n_E, n_R\} \longrightarrow \{n_E + 1, n_R - 1\} \qquad n \longrightarrow n + 1$$

$$\{n_E, n_R\} \longrightarrow \{n_E - 1, n_R + 1\} \qquad n \longrightarrow n - 1$$

number of transitions per time unit between configurations

$$w_\uparrow(n) = w(n \to n+1) = n_R p_{RE}(n) = (N - n)\nu \exp(\,u(n_E) - u(n_R))$$

$$w_\downarrow(n) = w(n \to n-1) = n_E p_{ER}(n) = (N + n)\nu \exp[\,-(u(n_E) - u(n_R))]$$

$n_E p_{ER}(n)$: rate of change preference from *E* → *R*

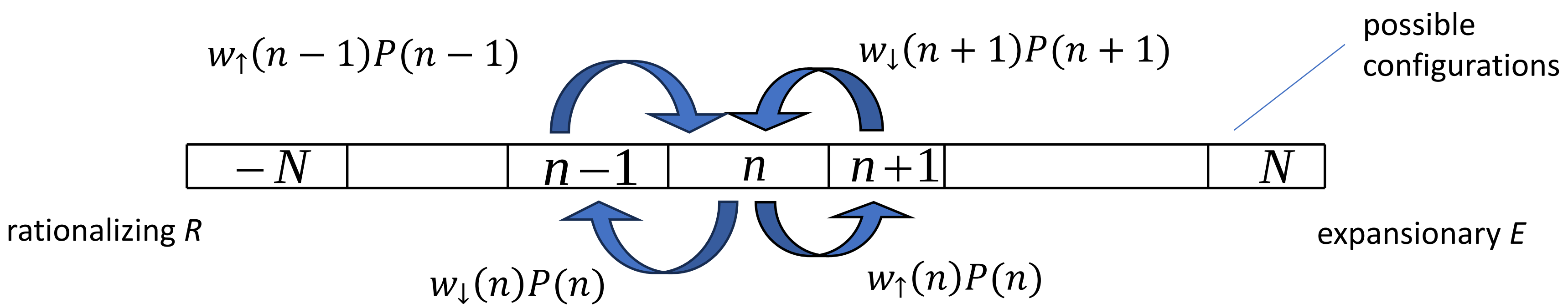
ν: frequency of switch

$u(n_E) - u(n_R)$: utility difference $= \kappa n + \delta(t)$

κn: coordinator

$\delta(t)$: alternator

Schumpeter Clock – The master equation



master equation

$$\frac{dP(n,t)}{dt} = w_\downarrow(n+1)P(n+1,t) + w_\uparrow(n-1)P(n-1,t) - (w_\uparrow(n) + w_\downarrow(n))P(n,t)$$

stationary solution (exact)

detailed balance always fulfilled

$$w_\downarrow(n+1)P_{st}(n+1) = w_\uparrow(n)P_{st}(n) \quad \Rightarrow \quad P_{st}(n) = P_{st}(0)\prod_{m=1}^{n}\frac{w_\uparrow(m-1)}{w_\downarrow(m)} \quad \xrightarrow{x=n/N} \quad x_s = \tanh(\delta + \kappa x_s)$$

x_s: lhs; $\tanh(\delta + \kappa x_s)$: rhs

Schumpeter Clock – Equations of motion

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calculation of mean value

$$\overline{n}(t) = \sum_{n=-N}^{N} nP(n,t) \qquad \text{with} \qquad \bar{x}(t) = \overline{n}(t)/N$$

equations of motion

investors configuration

$$\frac{d\bar{x}(t)}{dt} = 2\nu[\sinh(\delta(t) + \kappa\bar{x}(t)) - \bar{x}(t)\cosh\delta(t) + \kappa\bar{x}(t))] \quad \Longrightarrow \quad x_s = \tanh(\delta + \kappa x_s)$$

alternator dynamics

$$\frac{d\delta\,(t)}{dt} = -2\mu[\delta_0\sinh(\beta\bar{x}(t)) + (\delta(t) - \delta_1)\cosh(\beta\bar{x}(t))]$$

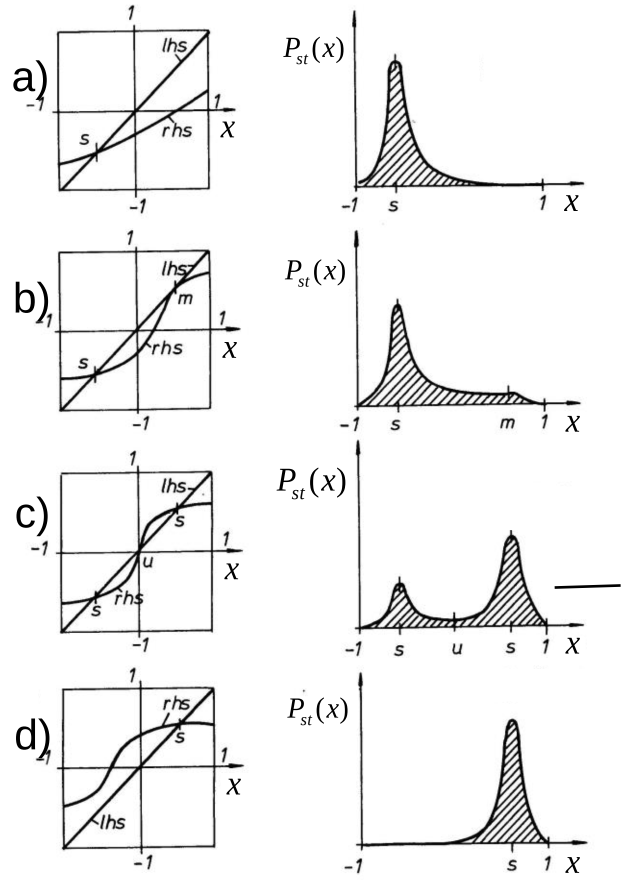
⟹ **Static solutions, limit cycles**

Schumpeter Clock – German Data

$$x_s = \tanh(\delta(t) + \kappa x_s)$$

lhs

rhs



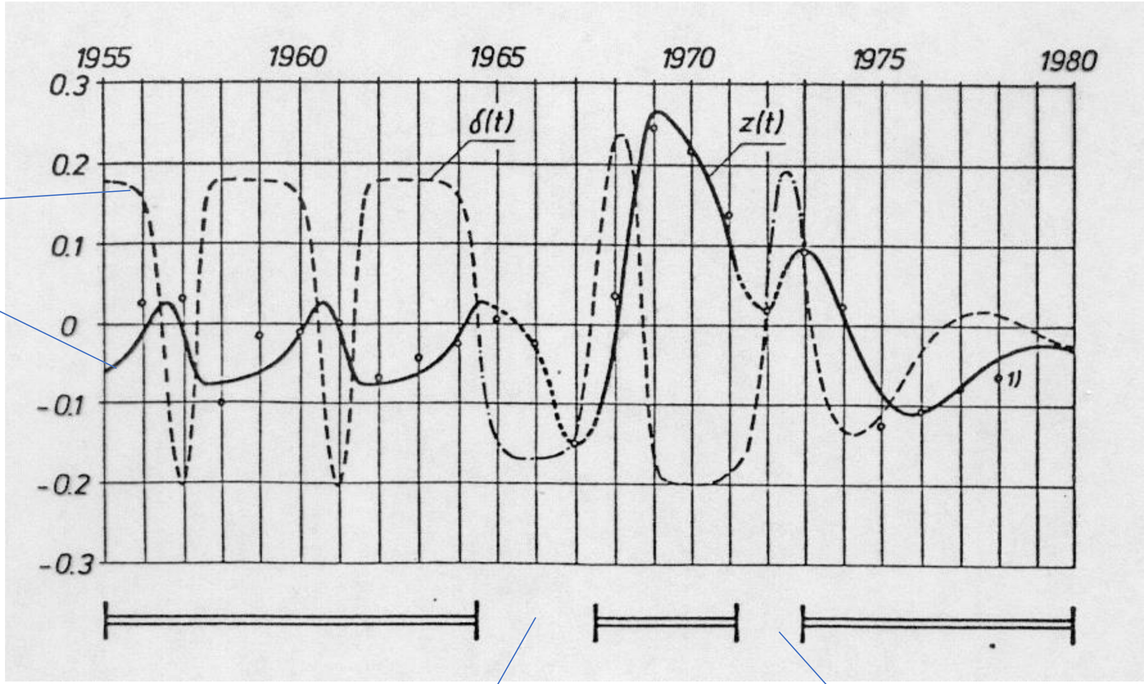
bistability, hysteresis

expansionary investments

alternator dynamics

investment structure index
Z=(E-R)/(E+R)

rationalizing investments



hyperboom
„Schiller“ effect
Keynesian economist
Grand coalition
CDU+SPD

Two oil shocks caused slumpflation
(M. Freedman)

A few limitations

Uncertainties

uncertainties and outliners in the data
uncertainties in the initial conditions
uncertainties in the parameter estimation

Complexity

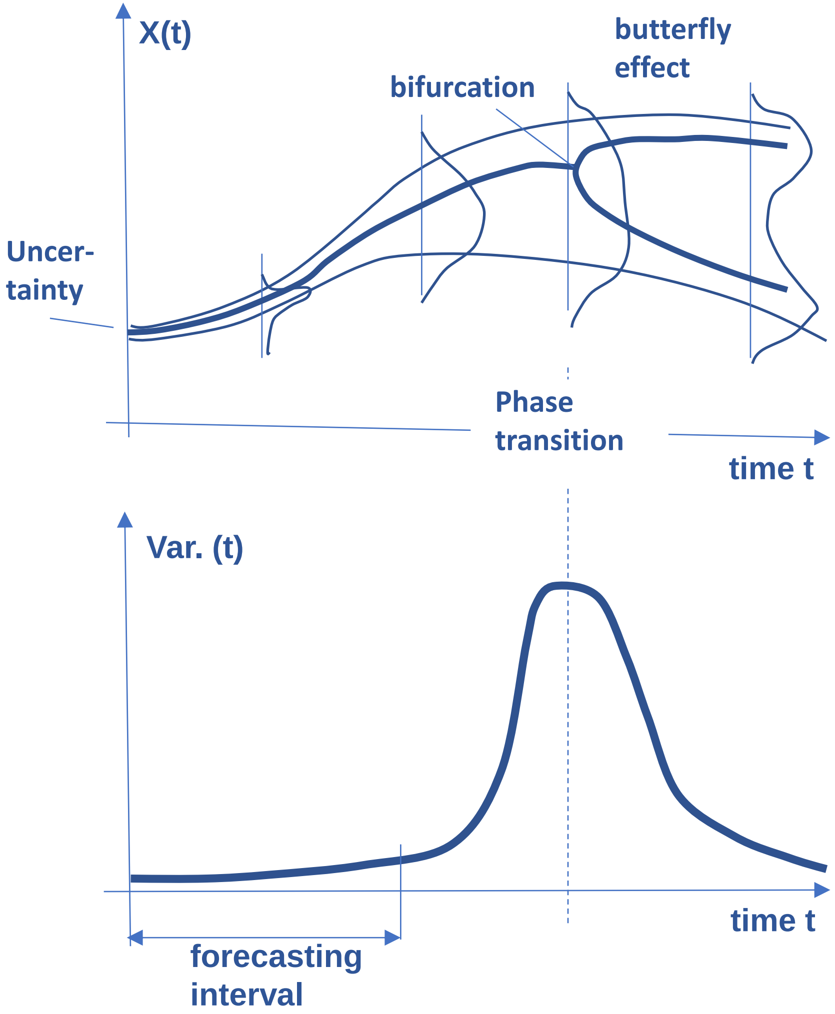
non linearities in the system may create phase transitions
new up to now unknown variables may appear (P. Allen)
social systems are capable of learning
unexpected events (Ukraine war)

What can we do?

scenarios technology - simulation of different possible events
(best, expected, worst)
simulation of uncertenties (Monte Carlo procedure, agent based modelling)

Conclusion

not only one trajectory but a bundle of trajectories
length of forecasting periode is limited



Schumpeter Clock (extended)

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Extended equations of motion, supply side dynamics included
Lecture Notes in Economics and Mathematical systems 369, Reiner Koblo, 1991

investors configuration index

$$\frac{d\bar{x}(t)}{dt} = 2\nu[\sinh(\delta(t) + \kappa\bar{x}(t) + c_3 w(t)) - \bar{x}(t)\cosh\delta(t) + \kappa\bar{x}(t) + c_3 w(t))]$$

alternator dynamics

$$\frac{d\delta(t)}{dt} = -2\mu[\sinh(\beta\bar{x}(t) + c_4 w(t) - \delta(t)Q) - \delta(t)\cosh(\beta\bar{x}(t) + c_4 w(t) - \delta(t)Qt))]$$

supply side

consumers configuration index

$$\frac{dw(t)}{dt} = -2\gamma[\sinh(c_1\delta(t)Q + \bar{c_2} w(t)) - q\cosh(c_1 Q + \bar{c_2} w(t))]$$

demand side

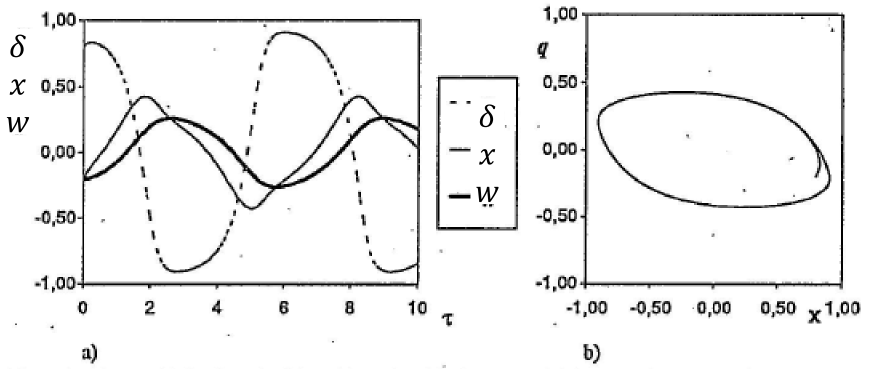
strategic production
propensity to consume

higher production level,
→ higher income

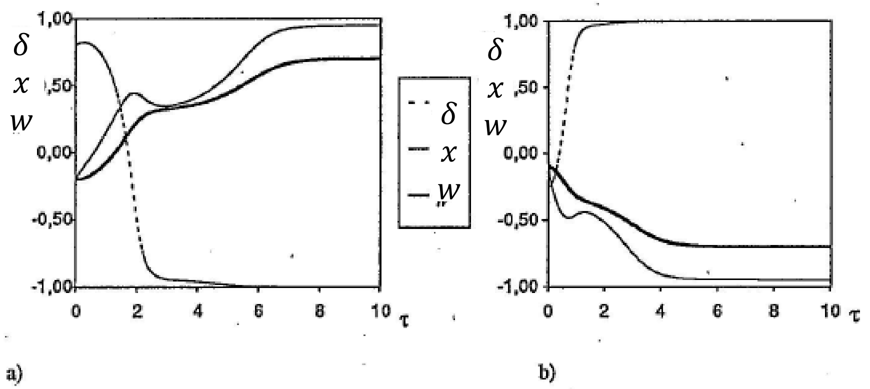
→ **Static solutions, limit cycles, caotic solutions (strange attractor)**

Selected Solutions of the extended Schumpeter Clock

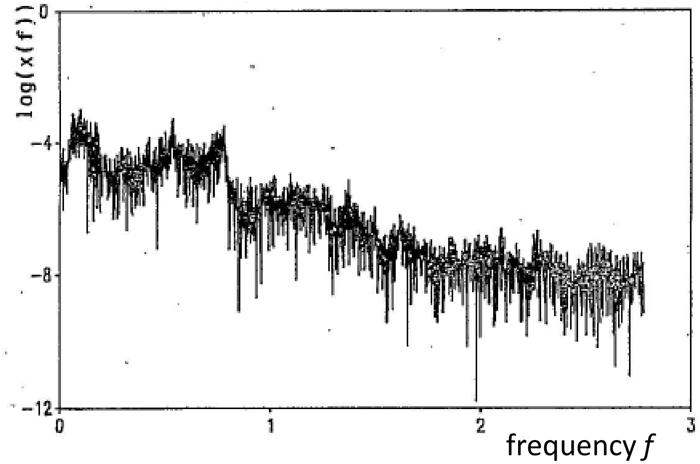
supply side and demand side



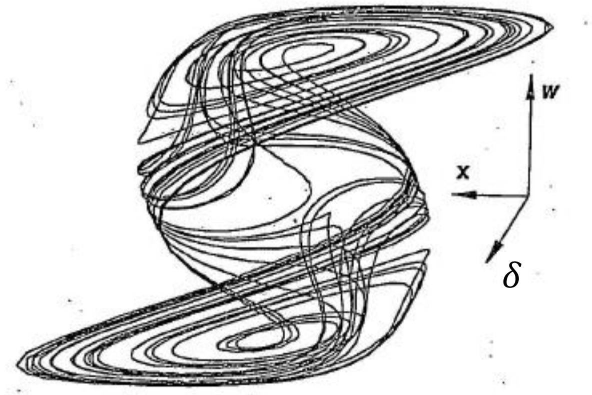
periodic solutions, limit cycle



one of many possible stationary solutions

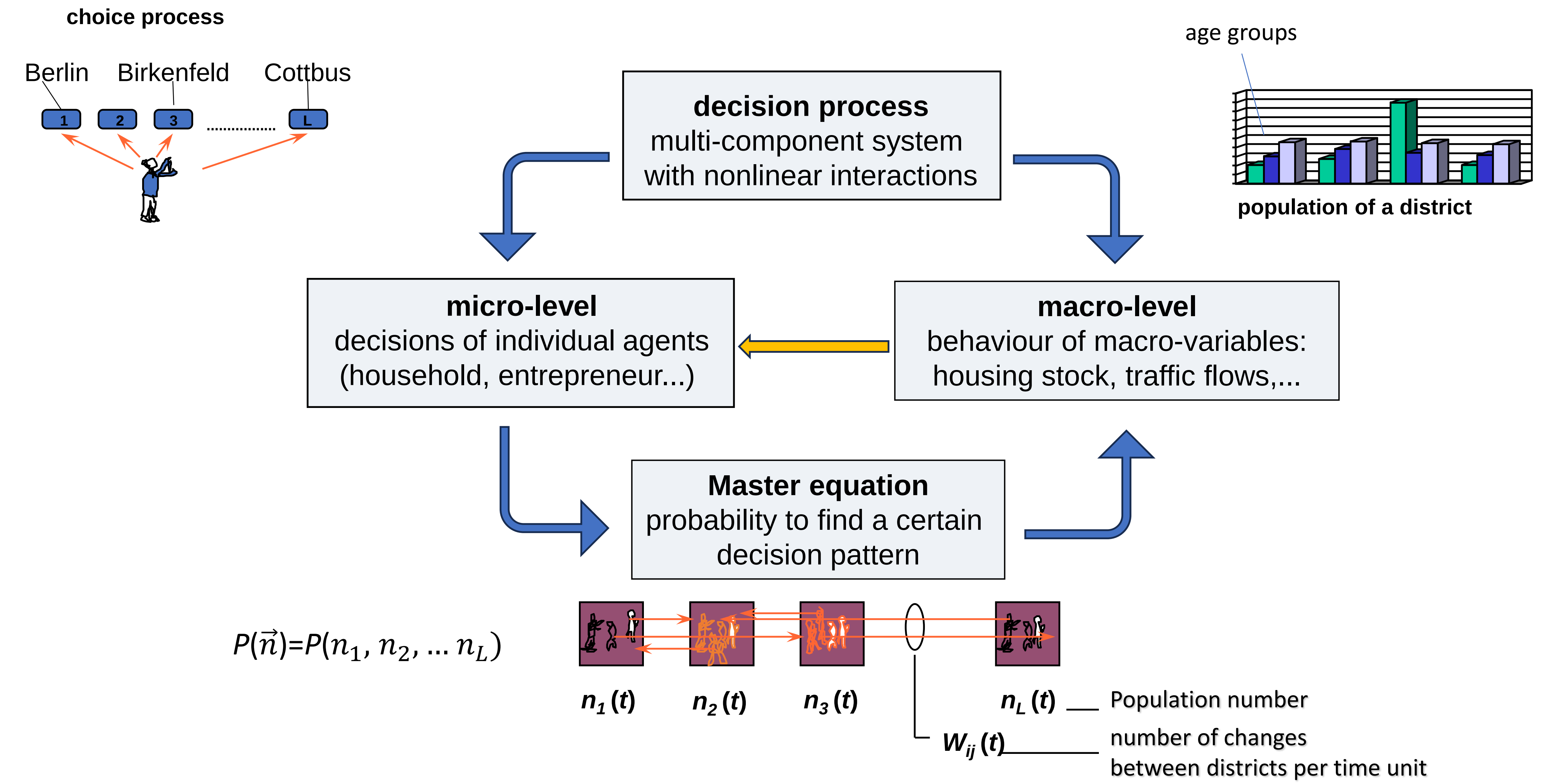


typical chaotic spectrum



phase space of a strange attractor

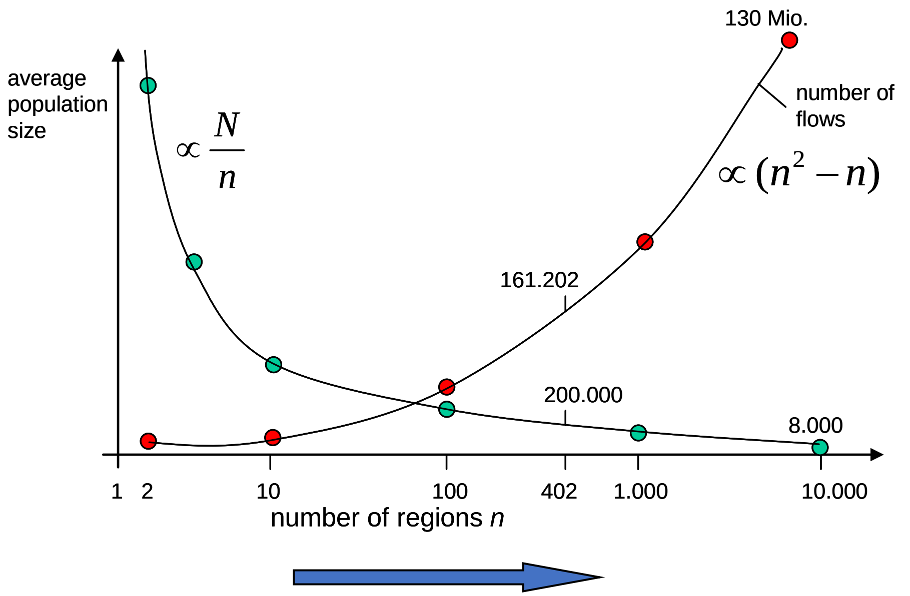
2. Example: Interregional Migration (German districts and communes)



Spatial Disaggregation and Regional Distance

The smaller the spatial units the more interregional migration dominates the population dynamics

In Germany 400 districts and 10.994 communes (2021)



Increase of quality of the measure „distance“
Increase of the number of zero flows

How to construct the transition rates?

transition rate: individual agents

$$w_{ij}(\vec{n},t)=\sum_{\alpha} p_{ij}^{\alpha}(\vec{n},\kappa,t)$$

characteristics

sum over all agents α
performing a transition

transition rate: group specific

group index

$$w_{ij}(\vec{n},t)=n_i^{\gamma}\,p_{ij}^{\gamma}(\vec{n},\kappa,t)$$

number of agents

transition rate

Assumptions concerning individual choice processes
Information from panel data or surveys
Master equation performs the averaging procedure

Master equation procedure

Computer performs the averaging

multi-agent-system (MAS)

Weidlich-Haag Migration model (1981/1988)

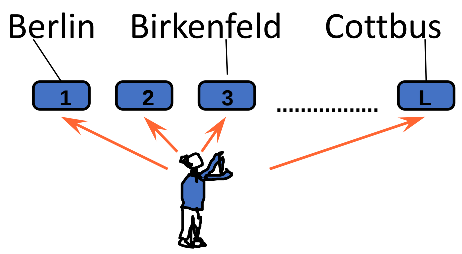
transition rate: changes of residence per year

$$w_{ij}(\vec{n},t) = n_i p_{ij}(\vec{n},\vec{\delta}) = n_i \nu_{ij} \exp(u_j(\vec{n},\vec{\delta}) - u_i(\vec{n},\vec{\delta})) \geq 0$$

- $w_{ij}(\vec{n},t)$: change of residence per time unit *i to j*
- n_i: population living in region *i*
- p_{ij}: "individuel" transition rate from *i* to *j*
- ν_{ij}: effect of „distance" (symmetric matrix) $\nu_{ij} = \nu_{ji}$
- $u_j(\vec{n},\vec{\delta}) - u_i(\vec{n},\vec{\delta})$: difference in spatial attractiveness or utilities

concentration of information

choice process



regional attractiveness and spatial preferences

$$u_i = \kappa n_i + \delta_i(t)$$

- u_i: regional attractive-ness
- κn_i: spatial agglomeration effect
- $\delta_i(t)$: regional preference

$$\delta_i(t) = w_1 XW_i + w_2 XB_i + w_3 XV_i + w_4 XT_i + w_5 XF_i + w_6 XU_i$$

- $\delta_i(t)$: regional preference
- XW_i: housing market indicator
- XB_i: employment indicator
- XV_i: services
- XT_i: accessibility indicator
- XF_i: leisure time Indicator
- XU_i: environment

Exact stationary solution of the decision model master equation:

exact stationary solution of the master equation

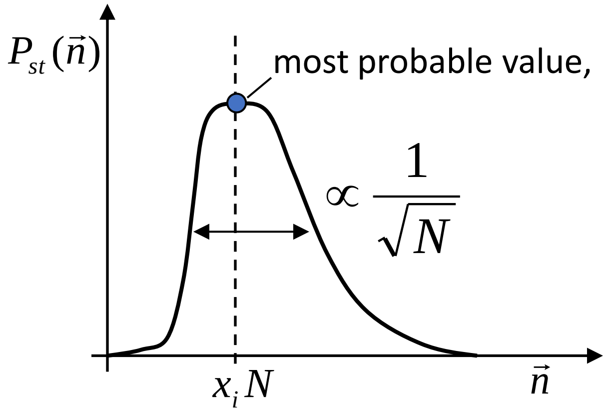
system fulfills detailed balance

$$P_{st}(\vec{n}) = \frac{Z^{-1}\delta\left(\sum_{i=1}^{L} n_i - N\right)}{n_1!n_2!\ldots n_L!}\exp\left(2\sum_{i=1}^{L}\sum_{m=1}^{n_i} u_i(m)\right)$$

Individuals are not distinguishable

most probable value,
Stirling formula

$$\hat{x}_i = \frac{n_i}{N} = \frac{\exp(2u_i(\vec{x}))}{\sum_{j=1}^{L}\exp(2u_j(\vec{x}))}$$

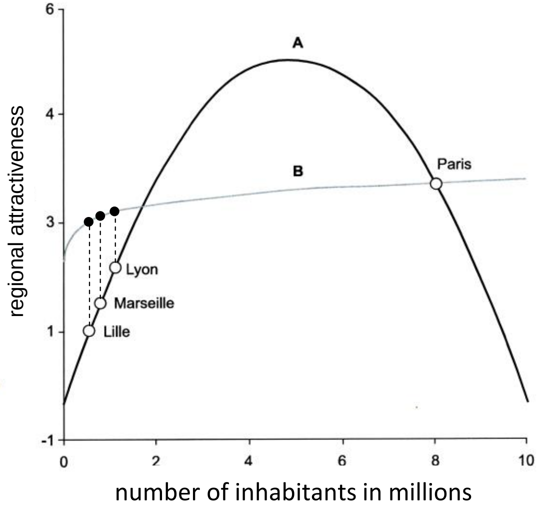


Environment fixed: system moves towards its equilibrium (10 to 20 years)
Policy changes environment: system always behind its equilibrium state

- MNL (multinomial logit model) most probable state for non-interacting individuals
- interactions between individuals (identity economics, Akerlof 1997)
- no memory effects included
- fixed number of alternatives

Test of Hypotheses: agglomeration/size effects

Test of different size-effects of city attactiveness values
France system of 78 cities



Hypothesis A

$$u_{kt} = \delta_{kt} + \kappa n_{kt} - \sigma n_{kt}^2$$

Hypothesis B

$$u_{kt} = \delta_{kt} + \kappa \log n_{kt}$$

δ_{kt}: regional preference indicator

$$\delta_i = w_1 XW_i + w_2 XB_i + w_3 XV_i + w_4 XT_i + w_5 XF_i + w_6 XU_i$$

- XW_i: housing market indicator
- XB_i: employment indicator
- XV_i: services
- XT_i: accessibility indicator
- XF_i: leisure time indicator
- XU_i: environment

Some fundamental considerations

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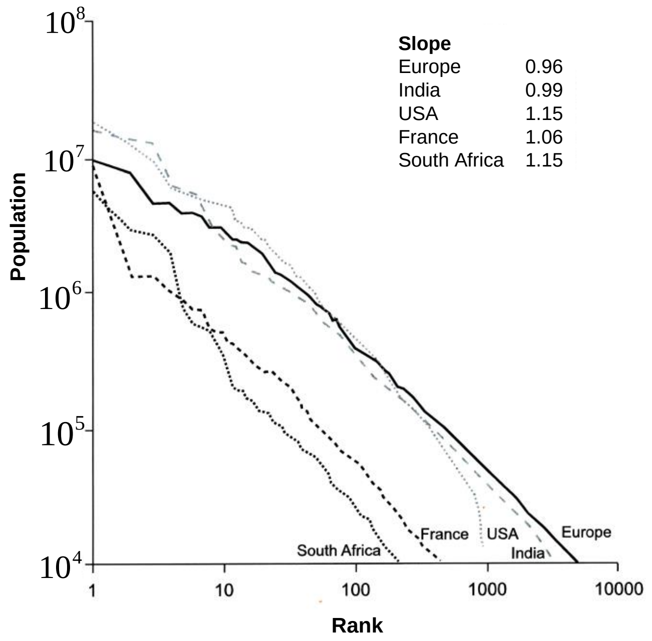
Zipf- distribution dominates in the long run

Scaling relationship, self-similarity: reproduces itself on different scales



Pareto coefficient

population of city k

$$n_k = n_1 k^{-q}$$

population of biggest city *1*

rank of city *k*

In the long run the migration model should produce a Zipf - distribution

$$\frac{d\langle n_j\rangle}{dt} = \sum_{i=1}^{L}\langle n_i\rangle p_{ji}(\langle\vec{n}\rangle) - \sum_{i=1}^{L}\langle n_j\rangle p_{ij}(\langle\vec{n}\rangle) + \langle w_{j+}\rangle - \langle w_{j-}\rangle$$

$$= \sum_{i=1}^{L}\nu_{ji}\langle n_i\rangle \exp(u_j(\langle\vec{n}\rangle) - u_i(\langle\vec{n}\rangle)) - \sum_{i=1}^{L}\nu_{ij}\langle n_j\rangle \exp(u_i(\langle\vec{n}\rangle) - u_j(\langle\vec{n}\rangle)) + \rho_j(t)\langle n_j\rangle$$

Simulation of long-time development (France):

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Hypothesis A

$$u_k = \delta_k + \kappa n_k - \sigma n_k^2$$

attractivity — preference — agglomeration effect

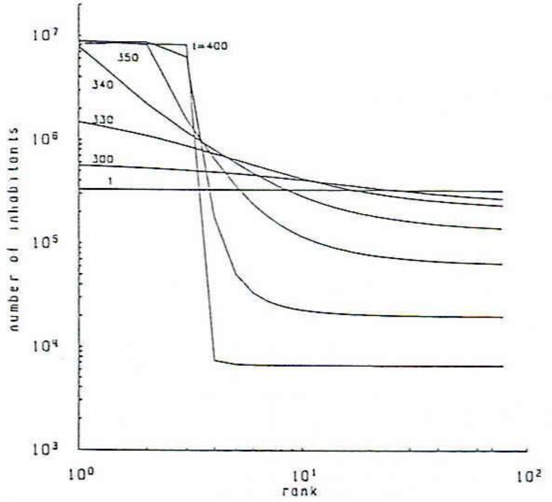

Figure 5 Simulation of an urban system using assumption A

$\kappa = 0.596$; $\sigma = 0.188$; $\nu = 0.001$; $N = 25.6 * 10^6$; $L = 78$.

some big cities, many small cities

critical value $\kappa_c = \frac{1}{2}\frac{L}{N}$

Hypothesis B

$$u_k = \delta_k + \kappa \log n_k$$

preference — agglomeration effect

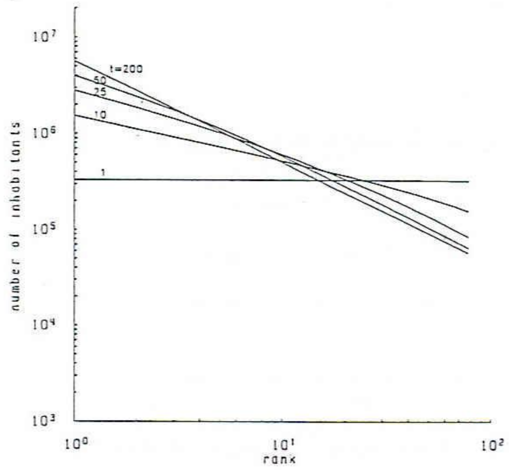

Figure 6 Simulation of an urban system using assumption B

a =0.500; $\nu = 0.001$; $N = 25.6 * 10^6$; $L = 78$.

Zipf-distribution (rank-size distribution)

critical value $\kappa_c = \frac{1}{2}$

Pareto coefficient $q(t) = 2\kappa$

The structure of the migration flow model (hypothesis B)

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Migration model

$$W_{ij} = n_i \nu_0 f_{ij} \exp(a \ln n_j - a \ln n_i + \delta_j - \delta_i)$$

$$W_{ij} = \nu_0 f_{ij} n_i^{(1-a)} n_j^a \exp(\delta_j - \delta_i)$$

regional preferences

for a > ½ destination area prefered
for a < ½ home area prefered

for a = ½ no preference for any region (SOC)

$$W_{ij} = \nu_0 f_{ij} \sqrt{n_i n_j} \exp(\delta_j - \delta_i)$$

mobility

regional interdependencies

population

difference of regional preferences

Mobility and regional interdependencies

$$\nu_0 = \frac{1}{L(L-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{L} \nu_{ij}$$

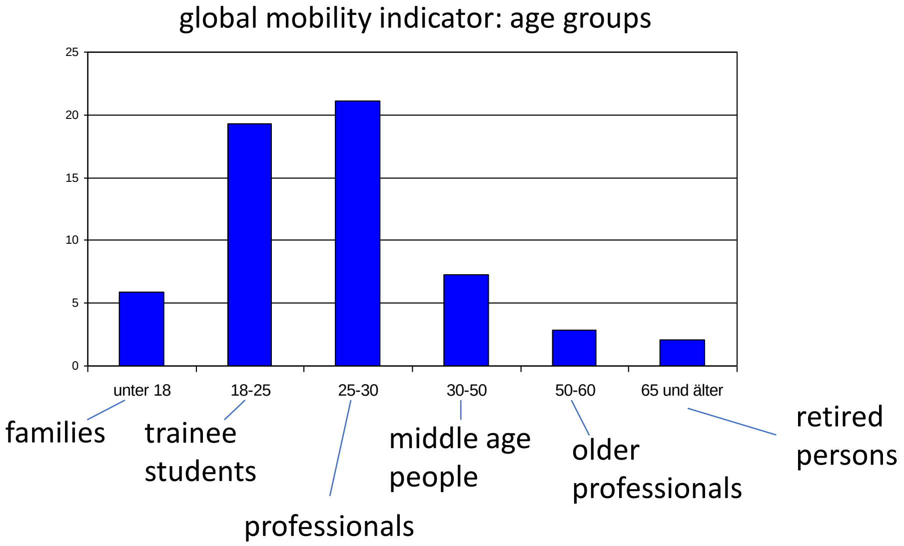
global mobility indicator

$$\nu_{ij} = \nu_0 \; f_{ij}$$

regional interdependencies

$$\frac{1}{L(L-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{L} f_{ij} = 1$$

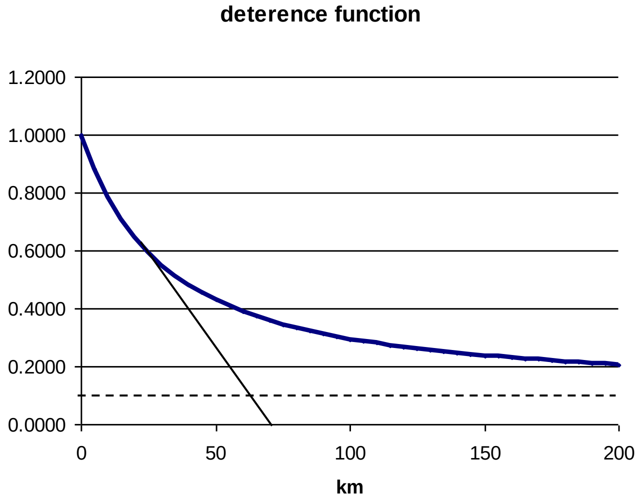
normalization of regional interdependencies



The effect of spatial distance d_{ij}

$$f_{ij}(d_{ij}) = \exp\left(-\frac{\beta \; d_{ij}}{1+\gamma \; d_{ij}}\right)$$

$\beta \; ; \gamma$



Parameter Estimation I

empirical data base

$$(n_i^e(t), w_{ij}^e(t)) \quad \text{for} \quad i, j = 1,2,\ldots,L \quad \text{and} \quad i \neq j$$

parameter estimation via cost function*

$$F[\nu,\vec{u}] = \sum_{i,j} (w_{ij}^e - w_{ij}^m(\nu,\vec{u}))^2 = \sum_{i,j} (w_{ij}^e - n_i \nu_{ij} \exp(u_j - u_i))^2 = \min$$

$L(L$-1)/2
Interaction parameters

(L-1) attractiveness parameters

or $\quad \nu_{ij}(d_{ij}) = \nu_0 \exp(-\frac{\beta\, d_{ij}}{1+\gamma\, d_{ij}})$

(161.202 flows, 80.601 interaction parameters and 401 attractiveness parameters in case of German districts)

Ratio: number of data / number of parameters: **2/1** ??!!

Parameter Estimation II

empirical data base

$(n_i^e(t), w_{ij}^e(t))$ for $i, j = 1,2,...,L$ and $i \neq j$

parameter estimation via cost function

$$F[\nu,\vec{u}] = \sum_{i,j} (w_{ij}^{\mathrm{e}} - w_{ij}^{m}(\nu,\vec{u}))^2 = \sum_{i,j} (w_{ij}^{\mathrm{e}} - n_i \nu_{ij} \exp(u_j - u_i))^2 = \min$$

or

$$\delta F(\underline{\nu},\vec{u}) = \sum_{i=1}^{L} \left[\frac{\partial F}{\partial u_i} + \lambda \right] \delta u_i + \frac{1}{2} \sum_{\substack{i,j \\ i \neq j}}^{L} \left[\frac{\partial F}{\partial \nu_{ij}} + \frac{\partial F}{\partial \nu_{ji}} \right] \delta \nu_{ij} = 0$$

with constraint $\sum_{i=1}^{L} u_i = 0$

This leads to the equations

Lagrange parameter

$$\frac{\partial F}{\partial u_i} + \lambda = 0$$ for $i = 1,2,...,L$

$$\frac{\partial F}{\partial \nu_{ij}} + \frac{\partial F}{\partial \nu_{ji}} = 0$$ for $i, j = 1,2,...,L$ with $i \neq j$

Parameter Estimation III

estimation of attractiveness and regional interdependencies

complete migration matrix available (402 districts in Germany)

principle of minimizing errors

$$F[\vec{u}, v_{ij}] = \sum_{i,j} (w_{ij}^{e} - w_{ij}^{m}(\vec{u}, v_{ij}))^2 = \sum_{i,j} (w_{ij}^{e} - n_i^{e} v_{ij} \exp(u_j - u_i))^2 \overset{!}{=} \min$$

$$\frac{\partial F}{\partial v_{ij}} + \frac{\partial F}{\partial v_{ji}} = 0$$

$$v_{ij} = \frac{n_j^{e} w_{ij}^{e} \exp(u_i - u_j) + n_i^{e} w_{ji}^{e} \exp(u_j - u_i)}{n_j^{2,e} \exp(2(u_i - u_j)) + n_i^{2,e} \exp(2(u_j - u_i))} = v_{ji}$$

attractiveness indicators → **regional interdependencies**

Interaction term completely determined by attractiveness values and empirical data

(L^2-L) migration data, (L-1) attractiveness parameters have to be determined,
(161.202 flows, 401 attractiveness parameters in case of German districts)
Ratio: number of data / number of parameters: **402/1**

Empirical flows versus model flows / parameter estimation

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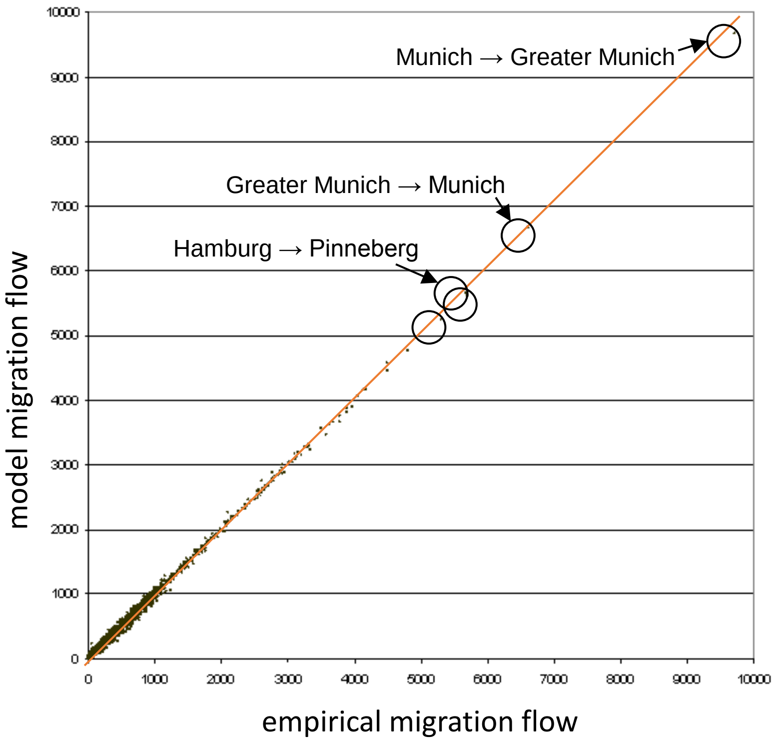
parameter estimation via cost function*

$$F[v,\vec{u}] = \sum_{i,j} (w_{ij}^{\mathrm{e}} - w_{ij}^{m}(v,\vec{u}))^2 \quad = \min$$

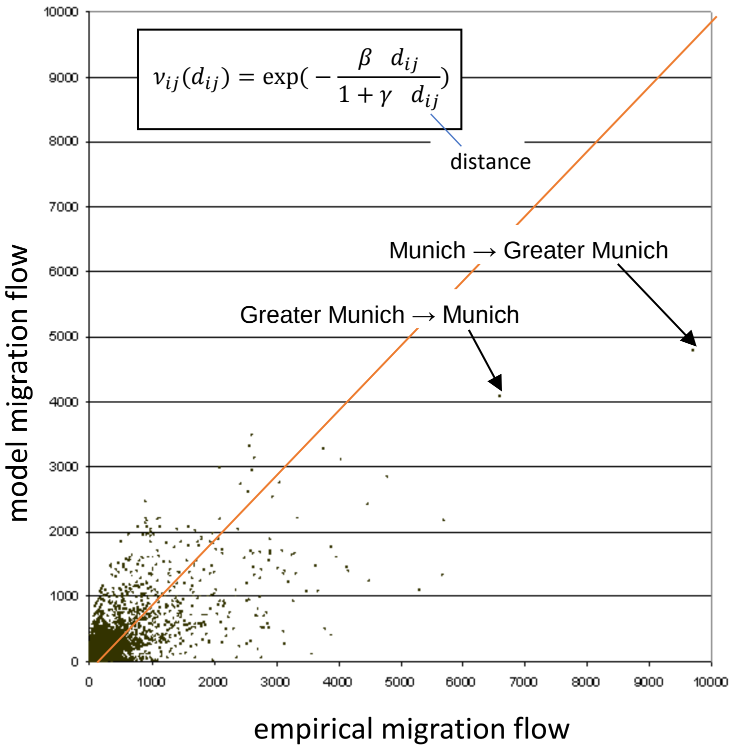
→ all trend parameters

estimated spatial interaction term

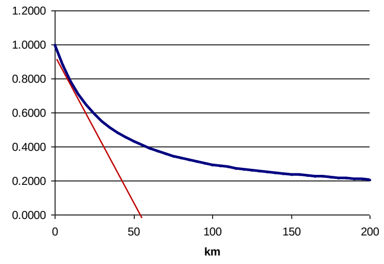


$R^2 = 0{,}98$

assumed distance dependence



distance function



$\beta = 0{,}132$; $\gamma = 0{,}0163$; $R^2 = 0{,}600$

Spatial preferences (total population): districts (400)

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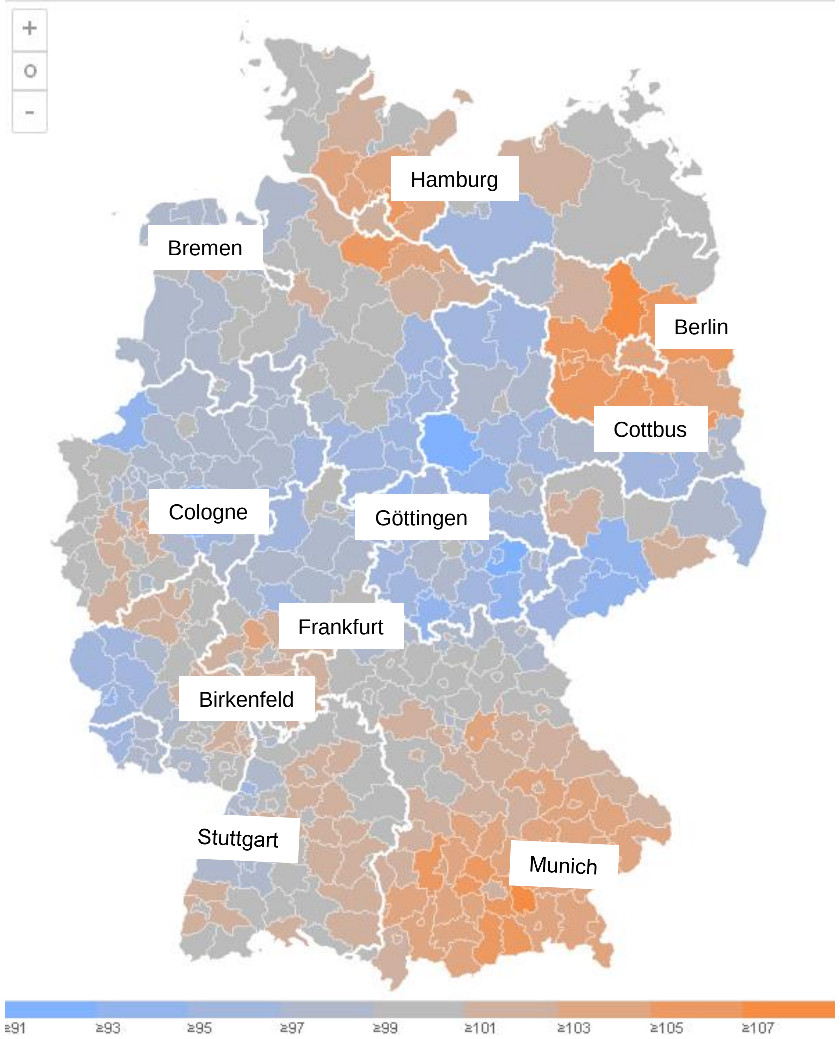

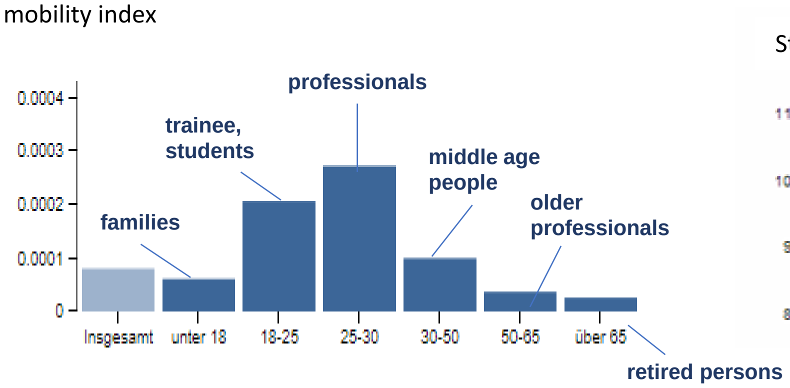

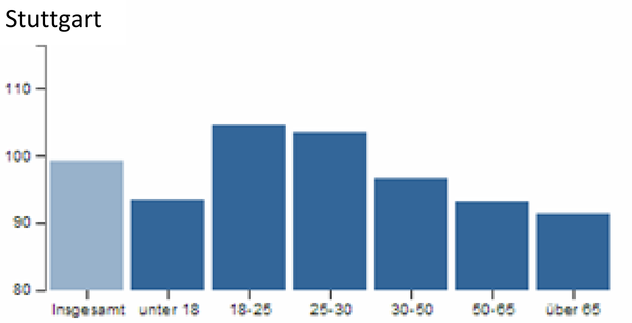

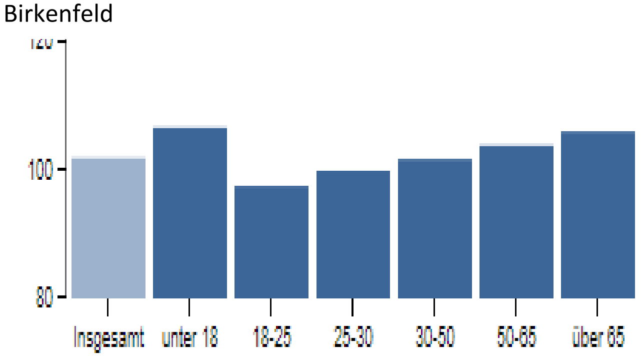

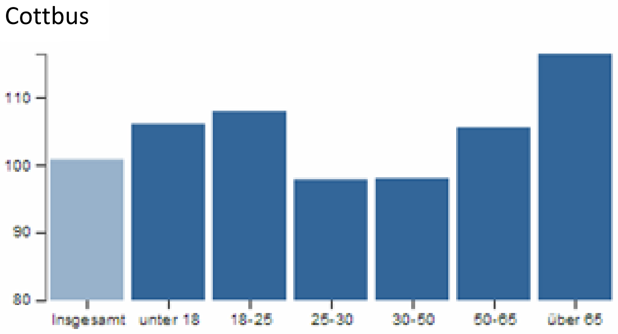

Strength of spatial interaction: City of Birkenfeld (left) and Stuttgart (right) with other districts

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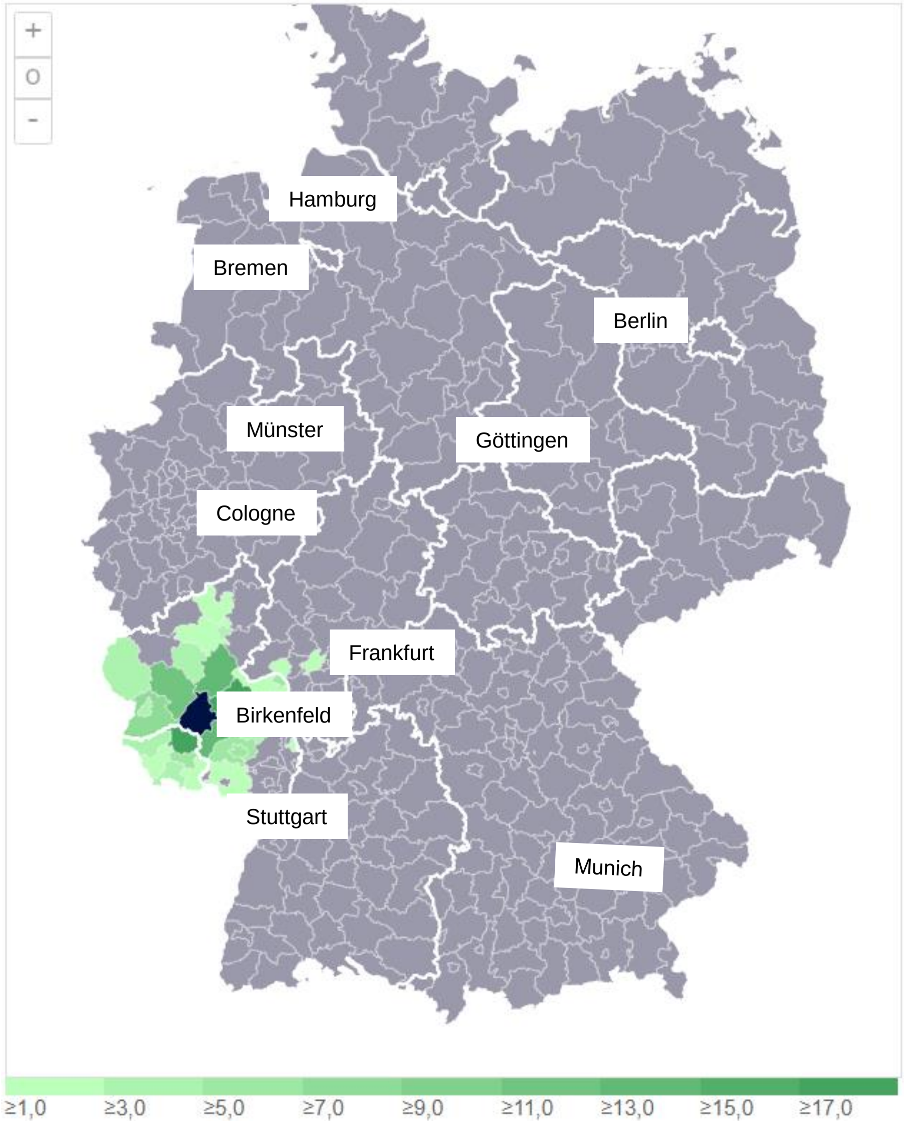

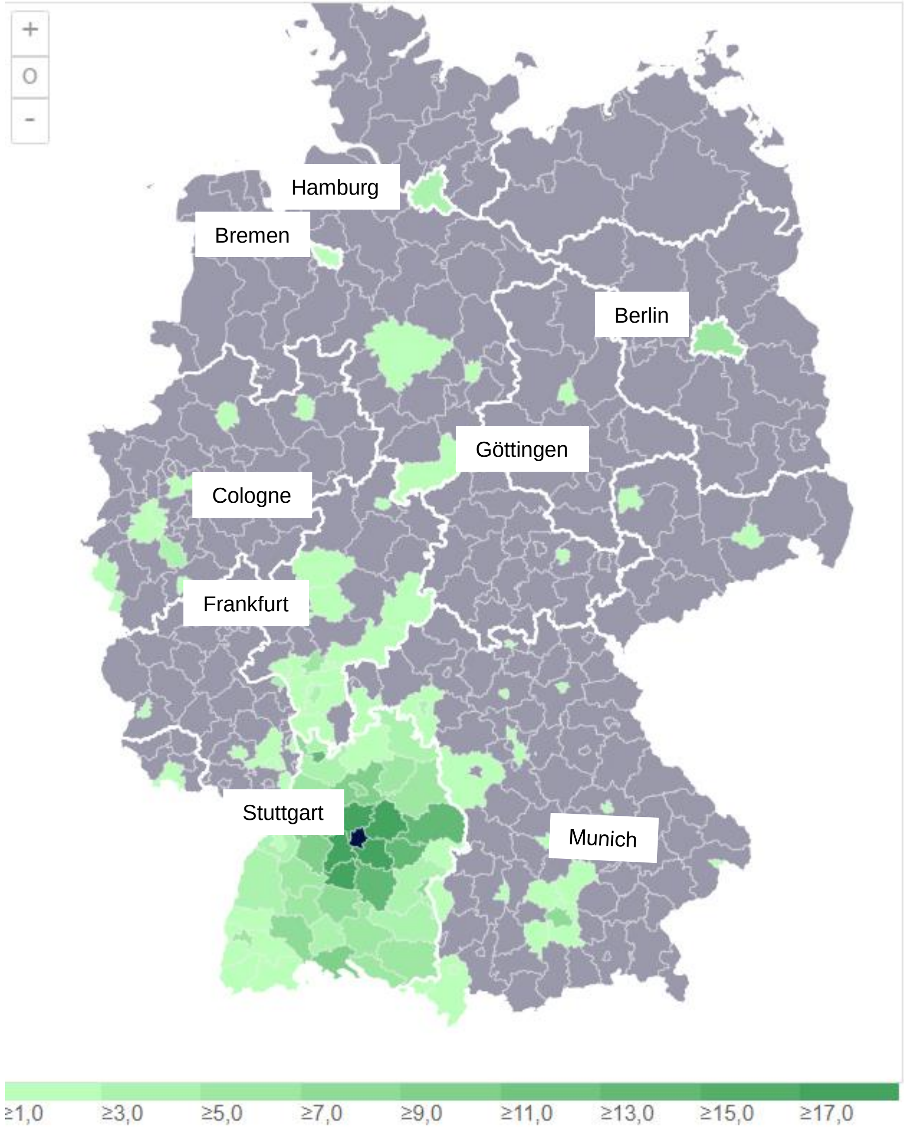

Presentation of German interaction data
Level of districts and communities

Regression analysis of regional preferences

Variables	Model 1	Model 2	Model 3
Const.	-0.680*** (-10.044)	-0.142*** (-2.935)	-0.040 (-0.667)
GfK	2.406E-5*** (8.609)		
NDW	0.009*** (4.955)		
SB	0.014* (1.898)	0.026*** (3.587)	0.036*** (4.644)
ALQ		-0.003 (-1.383)	-0.008*** (-2.649)
BLS		1.784E-6* (1.500)	1.603E-6 (1.132)
CP		0.016*** (8.252)	
PD			0.001*** (3.154)
TCAR			-0.001 (-0.464)
R^2ad	0.346	0.283	0.179

Note: Values in paranthesis are t-values.***, and **, and * indicate the significance levels at the 1, 5, and 10 % using t-statistic. GfK = available income per capita, NDW = new dwellings per 1000 existing dwellings, SB = shop balance: number of business openings and closings per 1000 capita), ALQ = rate of unemployment, BLS = income per capita, CP = construction permit per 1000 existing dwellings, PD = patent density: patents per 1000 capita, TCAR = travel time per car to the next highway

3. Example: Basic Innovations, G. Mensch

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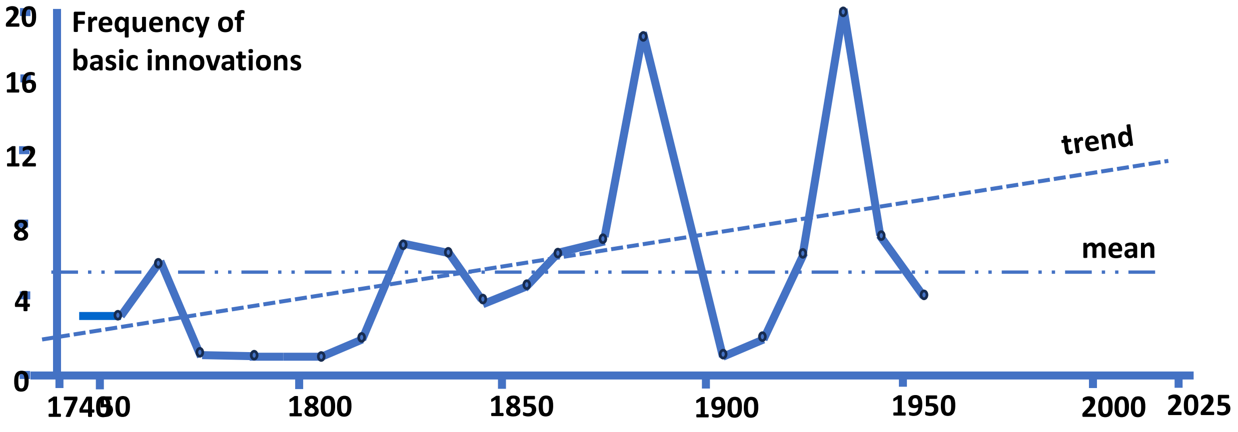
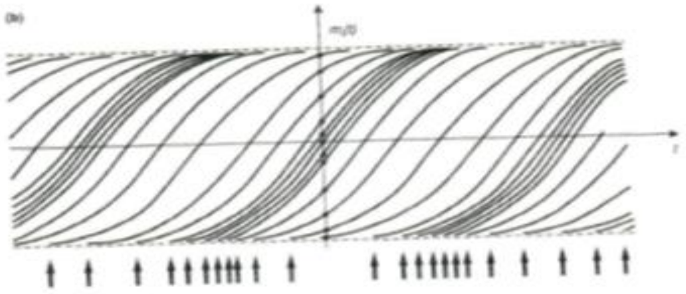


G. Mensch (1979): Stalemate in Technology, Frequency of basic innovations, 1740 – 1960.
The numbers of basic innovtions reported here are given in 10 years bunches.

fraction of
market
penetration



Basic innovtions

- Clustering of Innovations, G. Mensch
- Basic innovations give rise to a new industry

Long-term economic cycles

- Cycle time 40 to 60 years, Cesare Marchetti (54 years, energy sector)
- Logistic growth curve of technologies
- If a technology enters ist peak → chance for a new technological breakthrough (e.g. coal → oil → gas → nuclear → green

Basic Innovations and Long Waves

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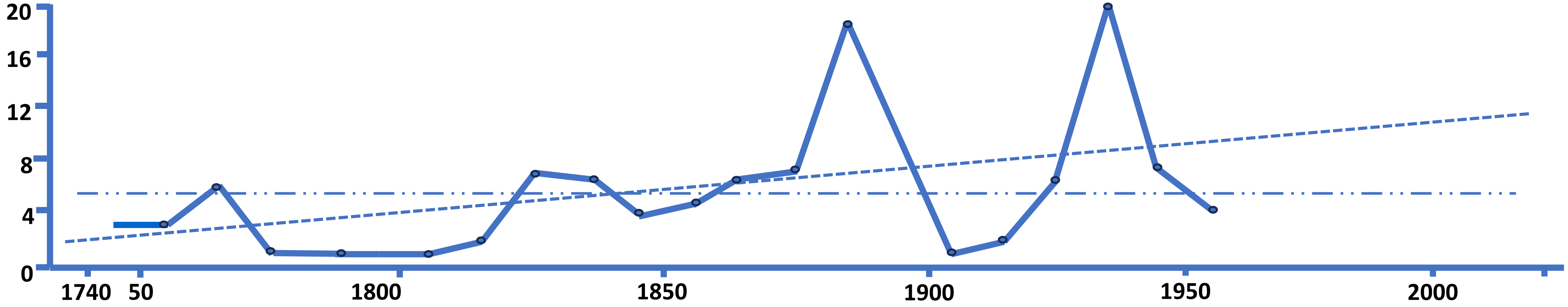

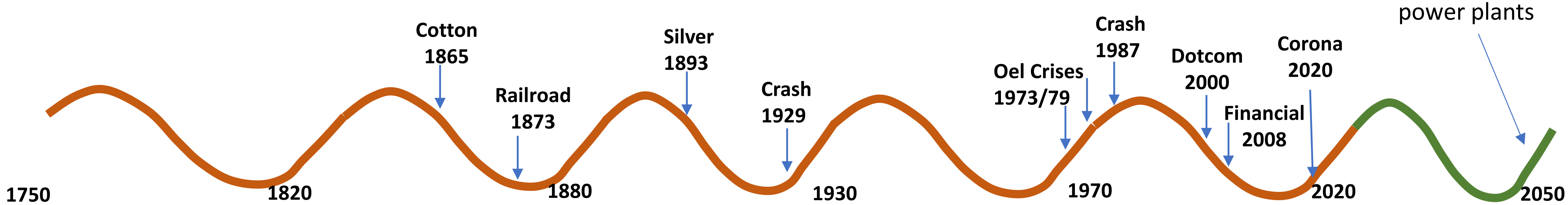

	Kondratieff 1	**Kondratieff 2**	**Kondratieff 3**	**Kondratieff 4**	**Kondratieff 5**	**Kondratieff 6**
	Dampfmaschine, Textilindustrie, Eisenproduktion, Mechanisierung der Produktion	Eisenbahn, Stahl, Schwer-industrie, Dampfschiffe, Brücken- und Bahnhöfe, Vernetzung über die Schiene	Chemie, Elektroindustrie, Elektrizität, Elektrogeräte, Röhrentechnik	Automobil, Petrochemie Kerntechnik, Transistor, Radio, Fernseher, Kühlschrank, PC-Computer, Zuse Z3	Computertechnik, PCs,Informationstech. Halbleitertechnik, Internet, Smartphone, GPS, integrierte Bau-teile,	Grüne Energie, KI, Elektrofahrzeuge, Biotechnologie, vegane Ernährung, Blockchain, ChatGPT, Wasserstoff, Sustainable products
	1. Industrielle Revolution		2. Industrielle Revolution		3. Ind. Revol.	4. Ind. Rev., 5. Rev.

Towards Nested Theories

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Phase I
static concepts
equilibrium
linear theories
investigation of
independent
phenomena

Phase II
dynamic concepts
non-equilibrium
non-linear theories
interactions within
selected processes
fractals, chaos

Phase III
complex modelling
different modelling
concepts integrated
complex spatial modelling
nested systems
GIS-modelling
Bca-algorithm

Phase IV
micro-simulations
fuzzy systems,
network theory,
adaptive systems
SOC

Phase V
Neural networks
Machine learning,
AI artificial intelligence,
Modelling of data networks
Industrial internet of things
Digitalization
Digital twins

until 1970

1970 - 1990
General Systems Theory
(Forrester, Meadows, Zahn)
Synergetics (Haken)
(H-v.Foerster,...)

1980 – 2000
Nonlinear Systems
Chaos theory
Sociodynamics
(Weidlich, Haag,
Nijkamp, Pumain, Pyka)

1990 - 2010
Network Science
(Barabasi, Reggiani, Nijkamp)
Adaptive Systems
(J. Holland,...)
micro-simulations
(R. White,...)

2000- 2020
Deep Learning,...
Self-generating networks
(Ash, Fahlman, Haag)
Data cooperatives
(Lasi, Slama,...)

The ideas of H. v. Foerster, H. Haken, W. Weidlich, Prigogine and other pioneers survive and will foster new developments in the scientific society

The theories and tools currently available make research more effective and support interdisciplinary research

Thank You for your attention