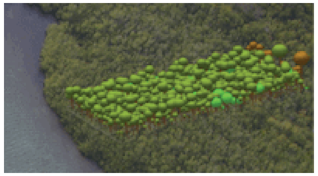


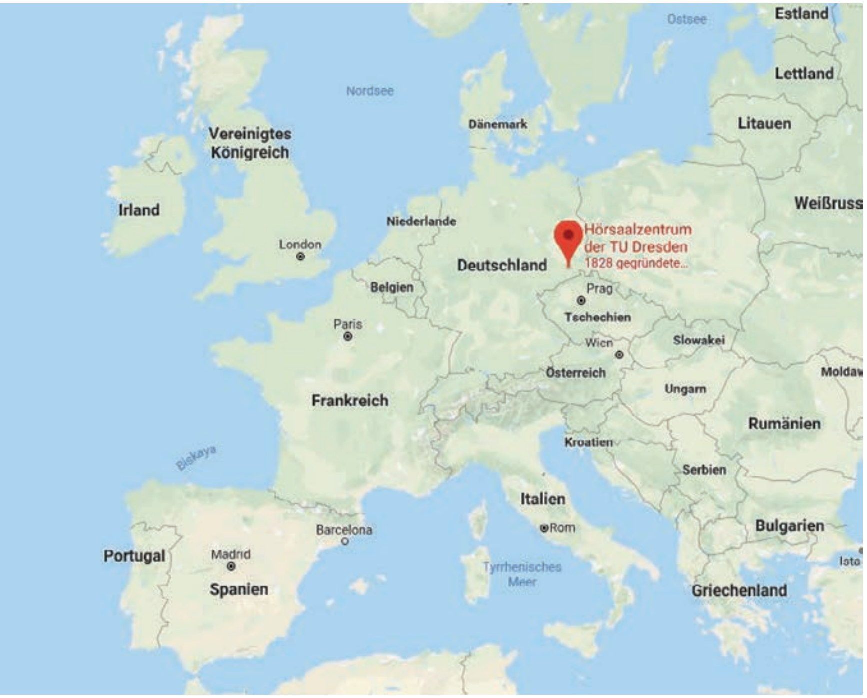
Faculty of Environmental Sciences, Department of Forest Sciences, Institute of Forest Growth and Computer Sciences

Is our world agent-based and can we model it?

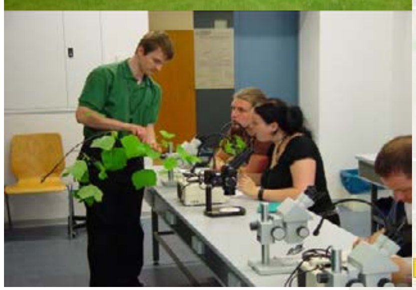
Uta Berger

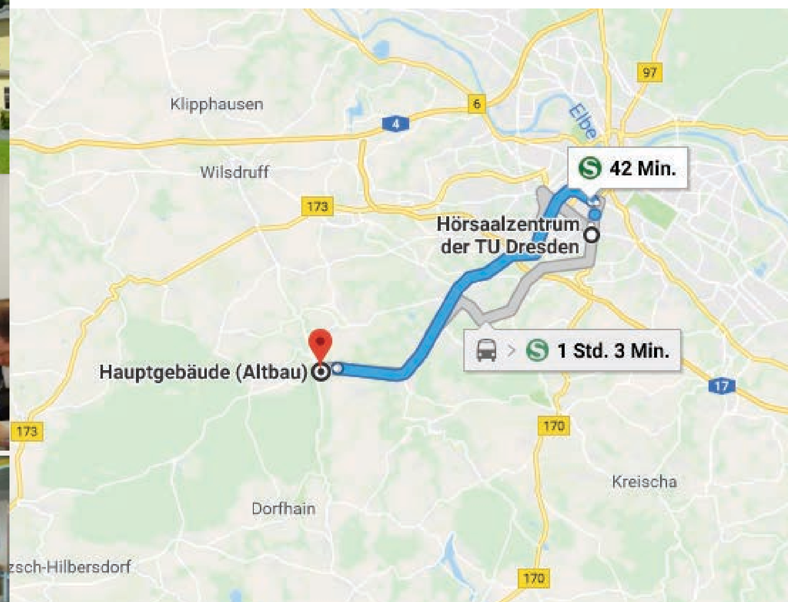
TECHNISCHE UNIVERSITÄT DRESDEN

- Faculty of Environmental Sciences
    - Department of Forest Sciences (Forest Faculty Tharandt)
        - Institute of Forest Growth and Computer Sciences
            - Professorship of Forest Biometry and Systems Analysis

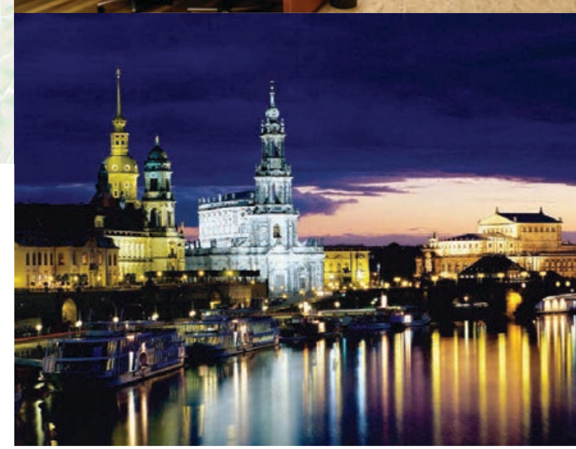


Tharandt





Dresden



Forest Academy Tharandt

- 2nd oldest in the world (est. by Heinrich Cotta 2011)
- Term “sustainability” established

- ~ 700 students (~20.000 TU Dresden)
- Forest Growth And Computer Sciences, Silviculture and Forest Protection, Forest Botany and Forest Zoology, Soil Sciences, Forest Technics, Forest Economy, Plant Chemistry, ..





TECHNISCHE UNIVERSITÄT DRESDEN

Professorship of Forest Biometry and Systems Analysis

Research interest

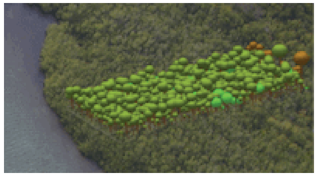
- link between **species adaptations**, **organismic interactions** and long term patterns in **biodiversity** and **systems dynamics**
- **restoration ecology** with a particular focus on **degraded forests**
- concepts of **conservation** under **changing environmental conditions**

Methodologies - Ecological modelling

- individual-based modelling (IBM)
- agent-based modelling (ABM)
- spatial statistics
- …

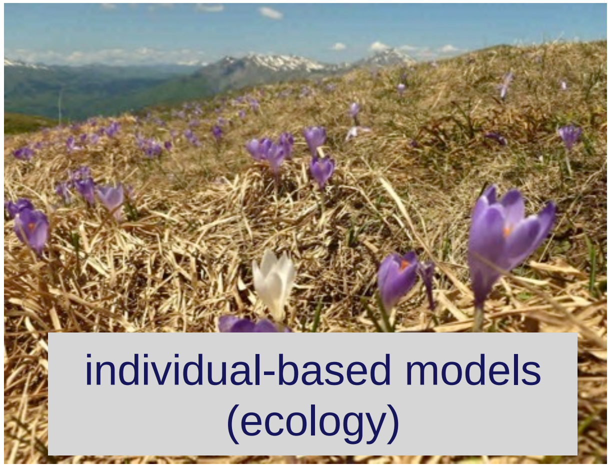
Current systems we are working on

- Mangroves (Brazil, South Africa, Thailand, Vietnam)
- Renaturation of oak trees in pine dominated forests (Germany)
- Peat swamp forests (Indonesia)
- Bark beetle invasions (Germany)
- Pine forests (Syria)
- Farm systems in the Andean region (Peru)
- Antibiotica resistence of microbial communities (freshwater, Germany)
- Spiny lobster fishery (Ecuador)
- Krill (Antarctic Ocean)



Is our world agent-based and can we model it?

1. Basic principles of IBM / ABM (example models: Behavioural Ecology, Plasmid Biology)
2. IBM / ABM meets Machine Learning (example model: plant ecology)
3. IBM merges ABM towards agent-based sciences

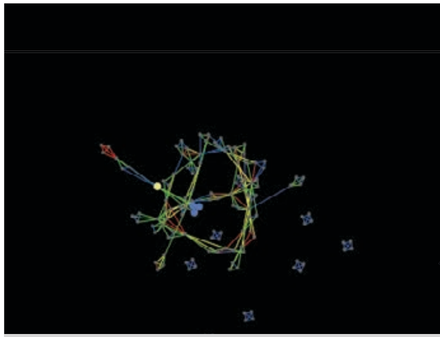


Same objectives

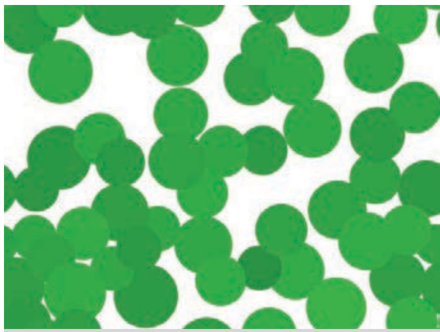
- understanding the functioning of complex systems
- multiple linkages of social-economic-ecological processes
- quantitative forecasts of effects of a changing environment (climate, extreme events, …)

while considering

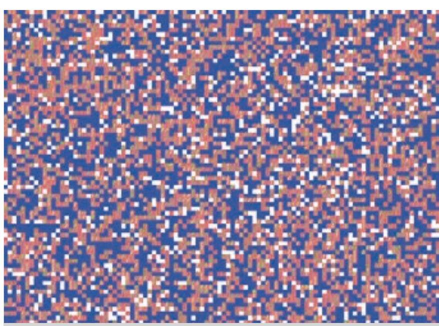
- variability of agents, organisms (plants animals), microbes, .. (entities)
- interactions
- behaviour
- adaptation
- decision making



agent-based models
(social sciences)



stand simulators
(forest sciences)



indiv.-based models
(ecology)

12th Summer School in IBM/
ABM at the TU Dresden

1st Example
Behavioural Ecology

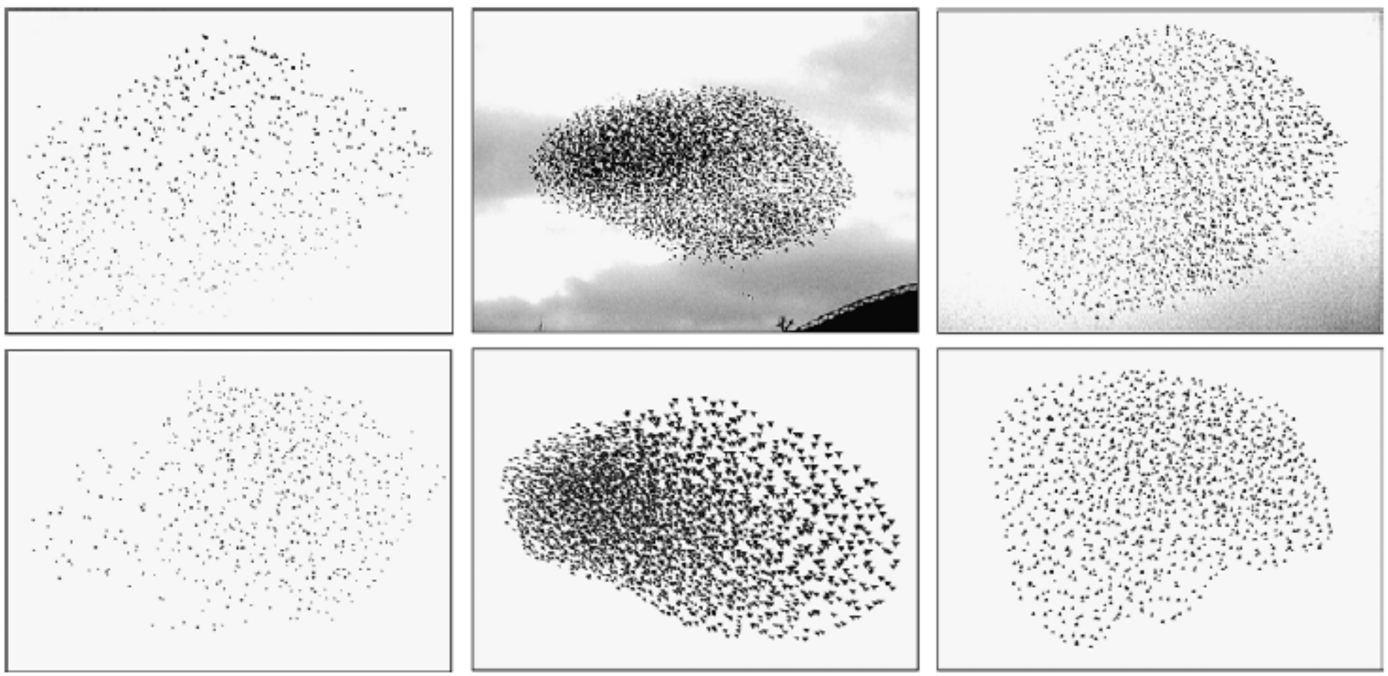
Basic principles of ABM: interactions

Behavioral Ecology
doi:10.1093/beheco/arq149

Self-organized aerial displays of thousands of starlings: a model

H. Hildenbrandt,[a] C. Carere,[b,c] and C.K. Hemelrijk[a]
[a]Theoretical biology; Behavioural Ecology and Self-organisation, Centre for Ecological and Evolutionary Studies, University of Groningen, PO Box 14, 9750 AA, Haren, The Netherlands, [b]CNR–INFM, Dipartimento di Fisica, Universita' di Roma La Sapienza, P.le A. Moro 2, 00185 Roma, Italy, and [c]Dipartimento di Ecologia e Sviluppo Economico Sostenibile Università degli Studi della Tuscia, Viterbo, Italy

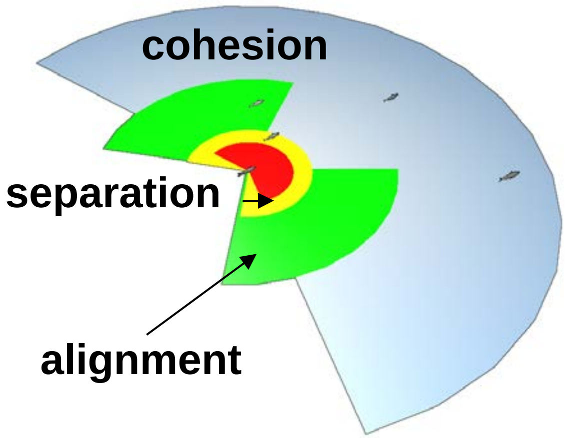
Through combining theoretical models and empirical data, complexity science has increased our understanding of social behavior of animals, in particular of social insects, primates, and fish. What are missing are studies of collective behavior of huge swarms of birds. Recently detailed empirical data have been collected of the swarming maneuvers of large flocks of thousands of starlings (*Sturnus vulgaris*) at their communal sleeping site (roost). Their flocking maneuvers are of dazzling



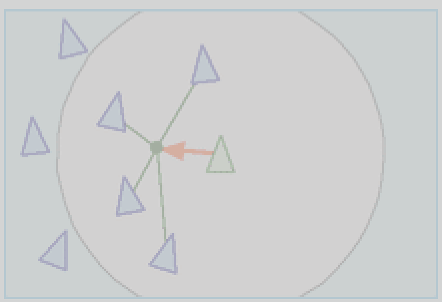
Basic principles:

interactions of organisms

a starling flocks at the sky of Termini (Italy)

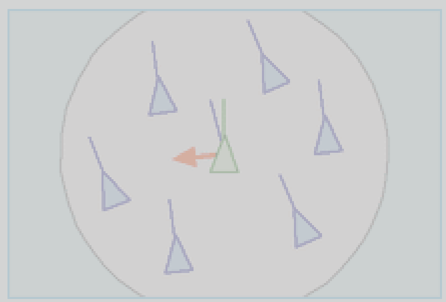


cohesion



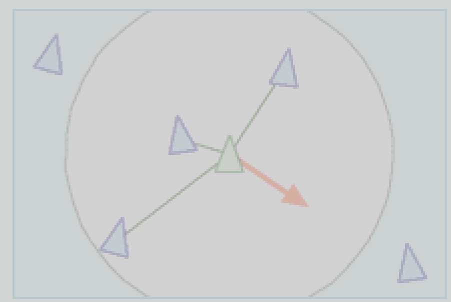
$$\vec{F}_{cohesion} - \left(\frac{1}{n} \sum_n \vec{p}_n \right) - \vec{p}$$

alignment



$$\vec{F}_{align} - \left(\frac{1}{n} \sum_n \vec{f}_n \right) - \vec{f}$$

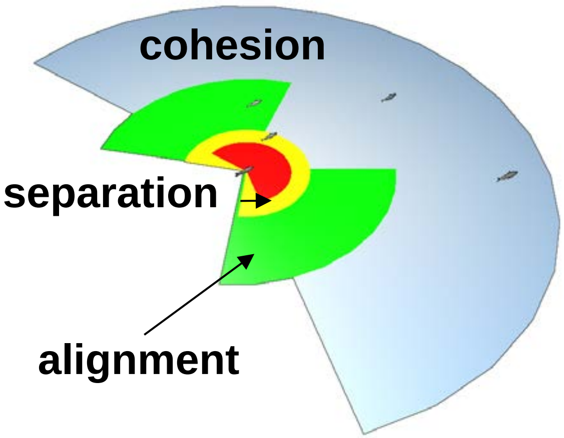
separation



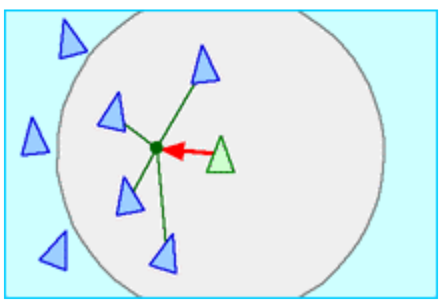
$$\vec{F}_{separation} - \left(\frac{1}{n} \sum_n \frac{-(\vec{p}_n - \vec{p})}{\left\| \vec{p}_n - \vec{p} \right\|^2} \right)$$

pictures: Hanno Hildenbrandt

steering rules according Craig Reynolds (1987, boids)
http://www.red3d.com/cwr/boids/

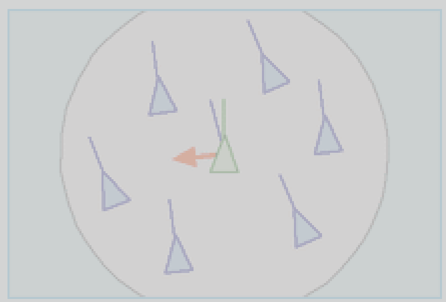


cohesion



$$\vec{F}_{cohesion} = \left(\frac{1}{n}\sum_{n}\vec{p}_n\right) - \vec{p}$$

alignment



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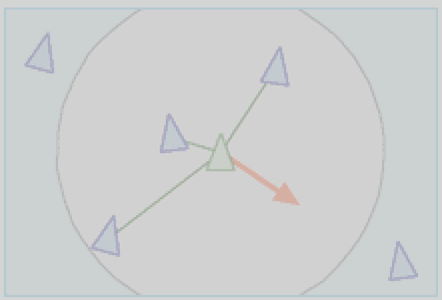
separation



$$\vec{F}_{separation} = \left(\frac{1}{n}\sum_{n}\frac{-(\vec{p}_n - \vec{p})}{\left\|\vec{p}_n - \vec{p}\right\|^2}\right)$$

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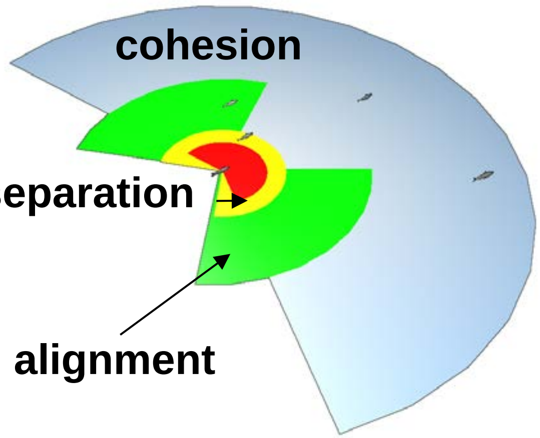
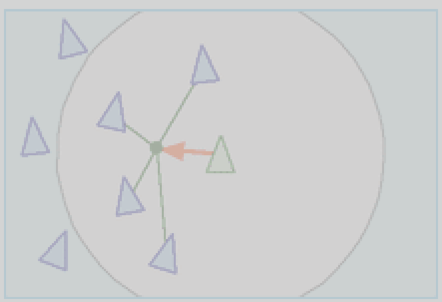


cohesion



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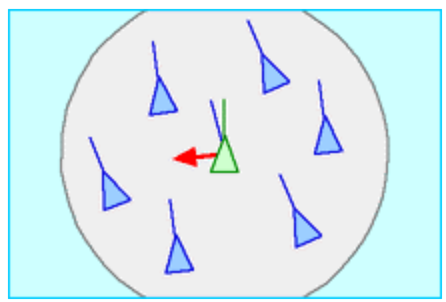
alignment



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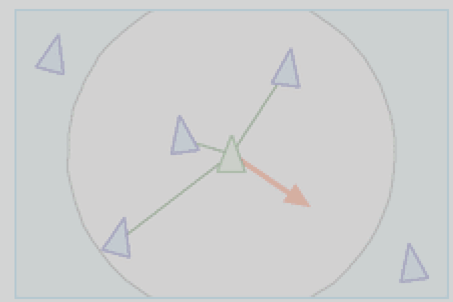
separation



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steering rules according Craig Reynolds (1987, boids)
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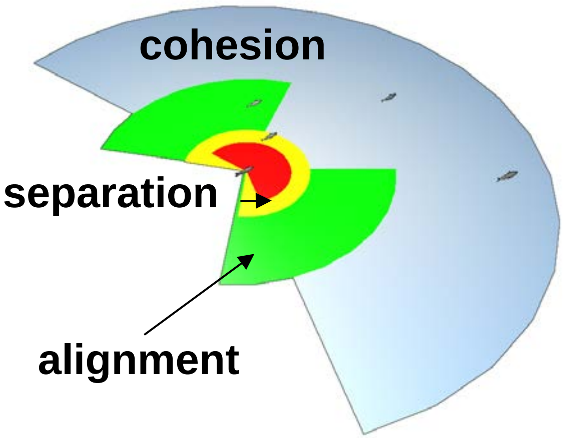
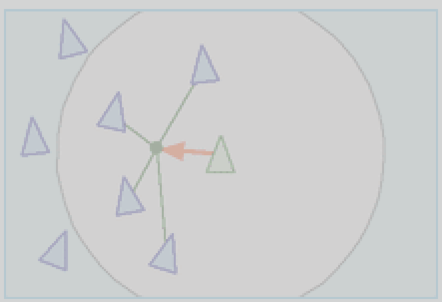
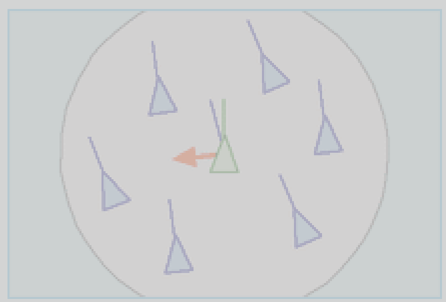


cohesion



$$\vec{F}_{cohesion} = \left(\frac{1}{n}\sum_n \vec{p}_n\right) - \vec{p}$$

alignment



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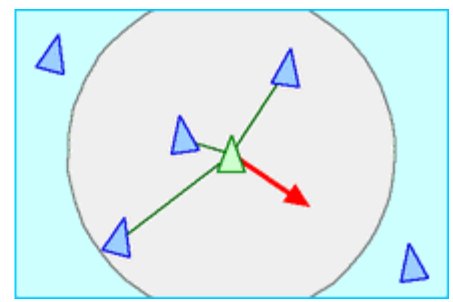
separation



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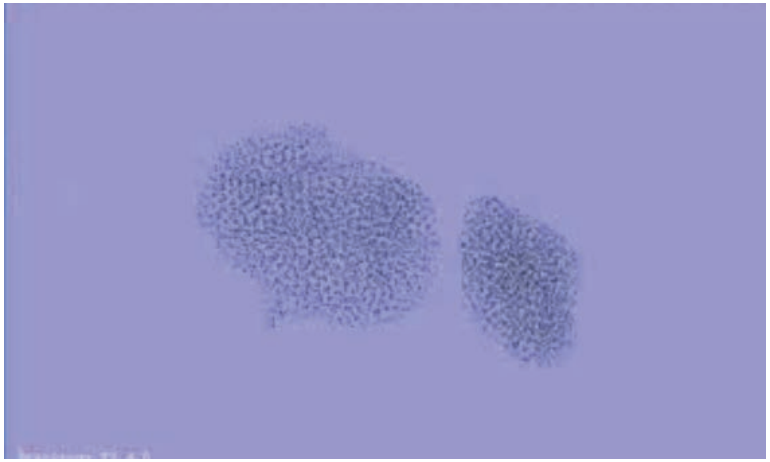

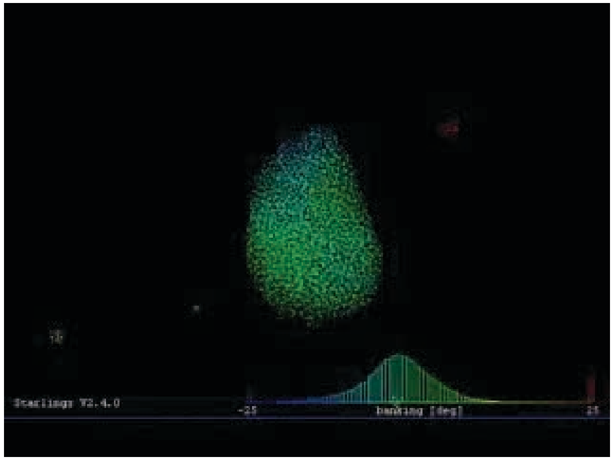

screenshots of an ABM developed by Hanno Hildenbrandt

(Uni Groningen, Netherlands)

Locust Swarms - Subsahara

http://news.nationalgeographic.com/news/2009/01/photogalleries/locust-swarm-theory-serotonin/photo5.html

Ecological Modelling 361 (2017) 26–40

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Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Self-organized spatial structures of locust groups emerging from local interaction

CrossMark

Jamila Dkhili[a,b,c,*], Uta Berger[d], Lalla Mina Idrissi Hassani[a], Saïd Ghaout[c], Ronny Peters[d], Cyril Piou[a,b,c]

[a] *Faculté des sciences, Université Ibn Zohr, Agadir, Morocco*
[b] *CIRAD, UMR CBGP, 34398 Montpellier Cedex 5, France*
[c] *CNLAA, BP15, 86343 Inezgane, Morocco*
[d] *TU Dresden, Faculty Of Environmental Sciences, Germany*

F1000Prime RECOMMENDED

DeAngelis D and Zhang B: F1000Prime Recommendation of [Dkhili J et al., Ecol Modell 2017, 361:26-40].

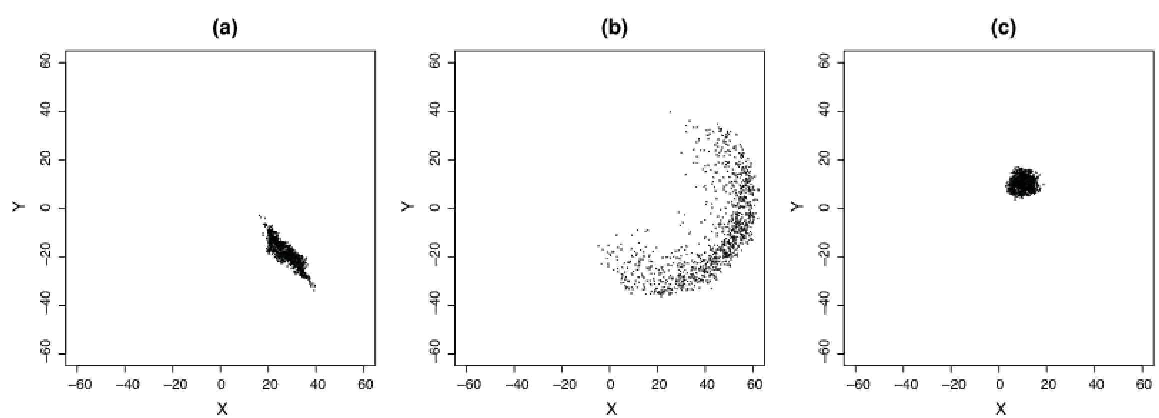
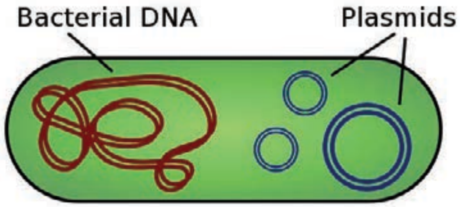


Fig. 2. Example of the three patterns generated by the model: (a) ribbons pattern; (b) band pattern; (c) spot pattern.

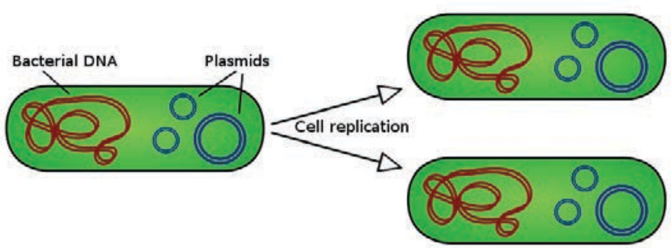
2nd Example
Antibiotica Resistance

(Plasmid Biology)

Basic principles of ABM: interaction & variability



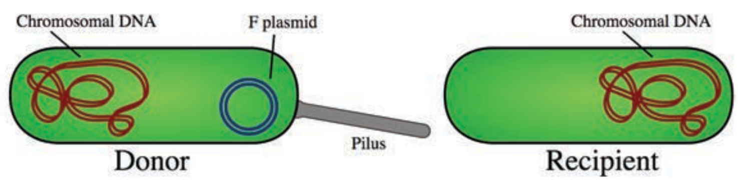
Vertical component (cell fission)
persistence from one generation
to the next



all figures: Wikimedia commons

non transmissible

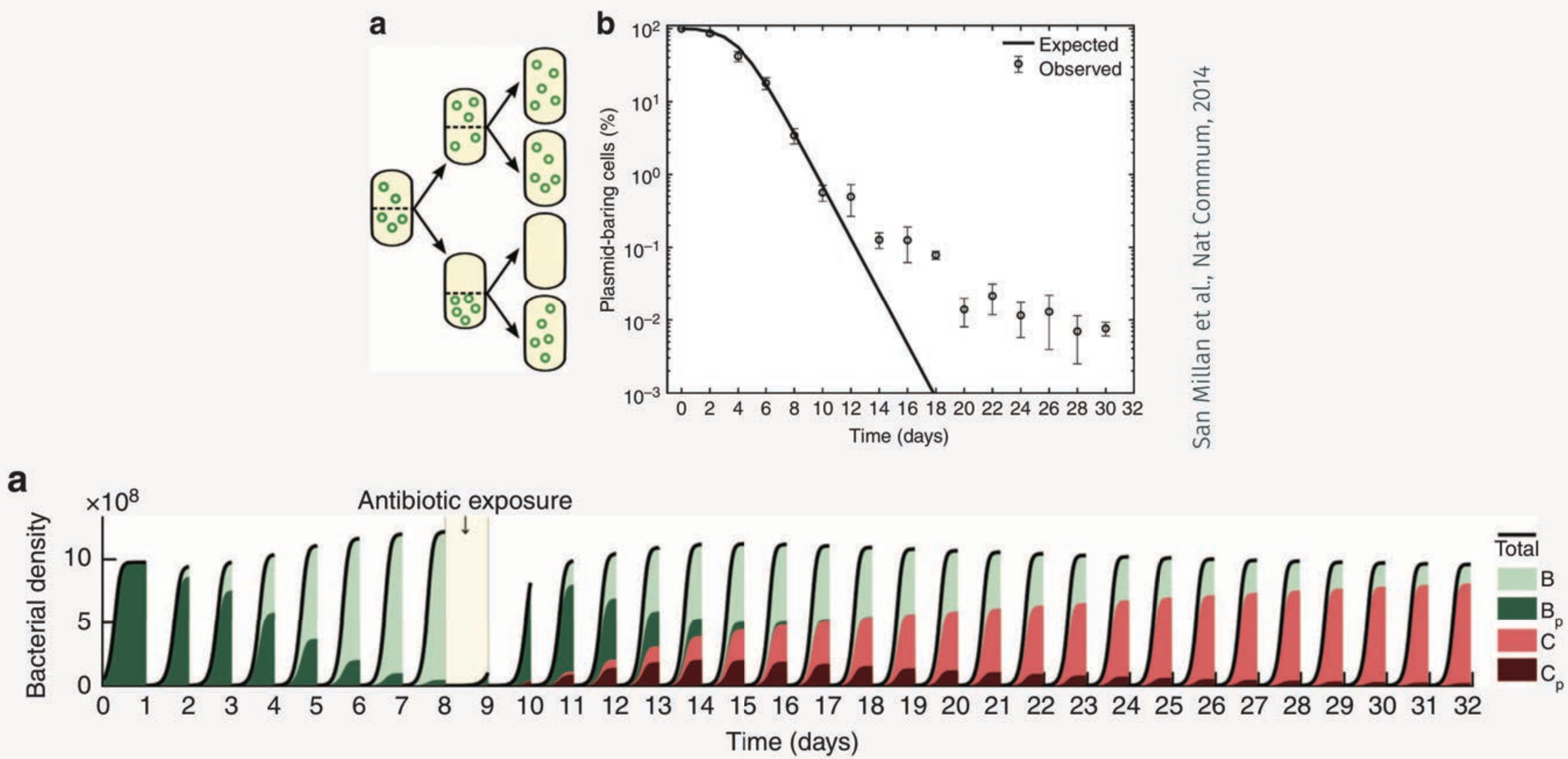
Horizontal component (conjugation)
persistence from one generation to
the next



transmissible

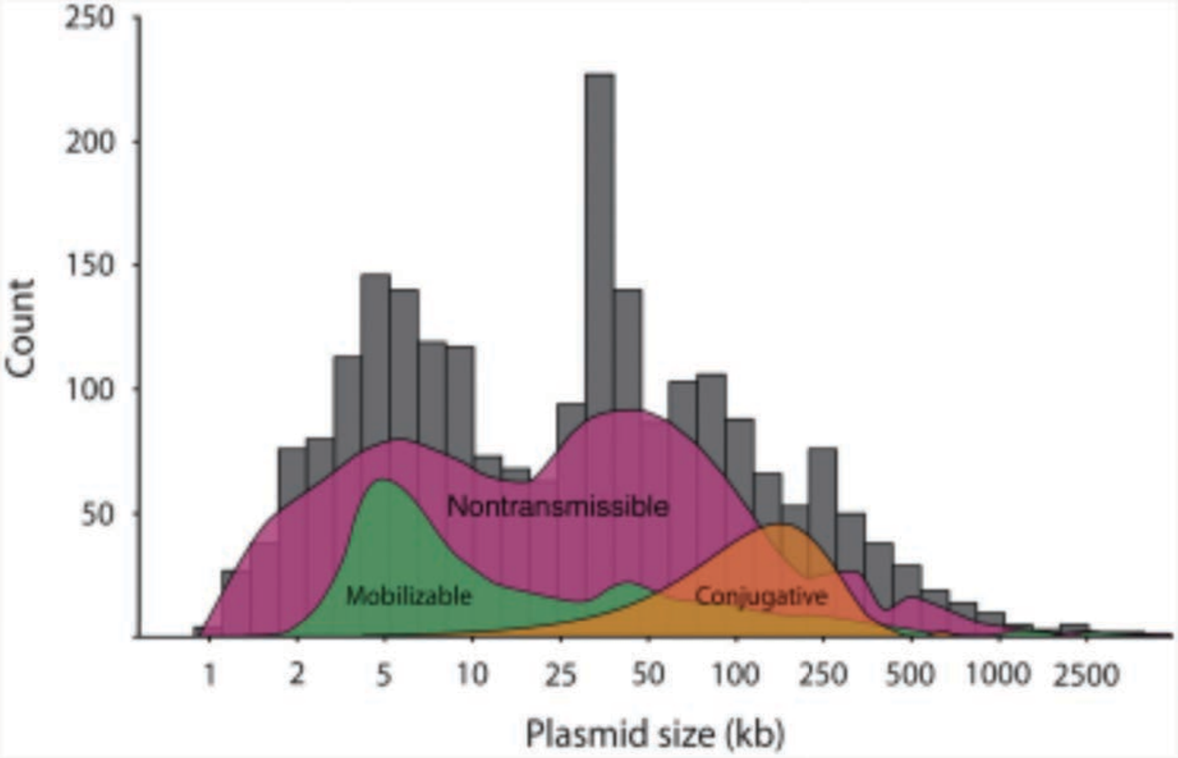
- repressed
- derepressed

Theory: replication and plasmid burden lead to a loss without positive selection.



Reality

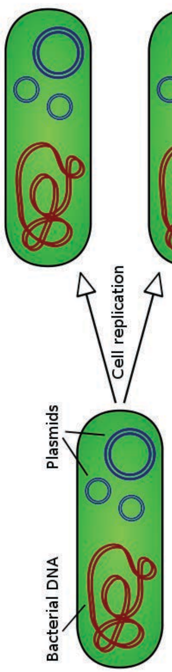
- 50% of the plasmids are non-transmissible



Garcillán-Barcia et al., FEMS Microbiol Rev, 2011

- What is the consequence of a co-occurrence of plasmids differing in mobility?

Concept for the persistence of plasmids without positive selection.



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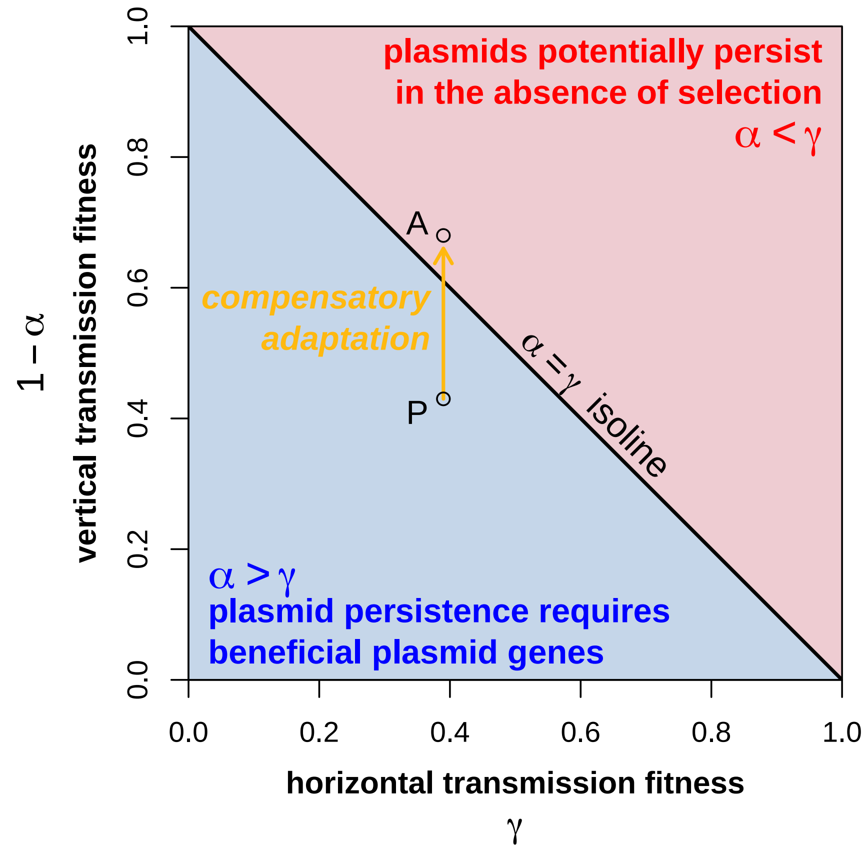
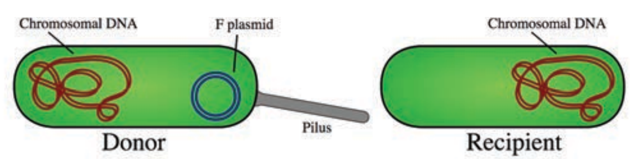
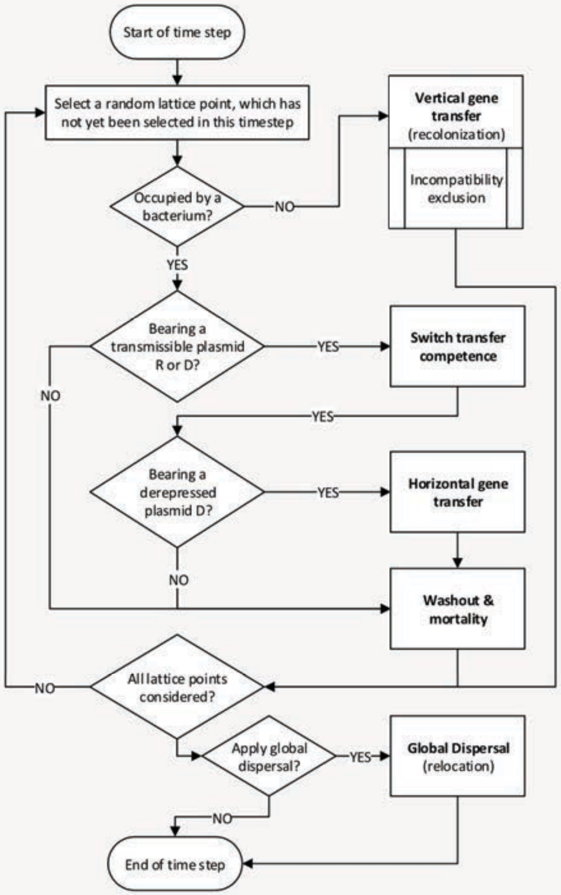




Wikimedia commons

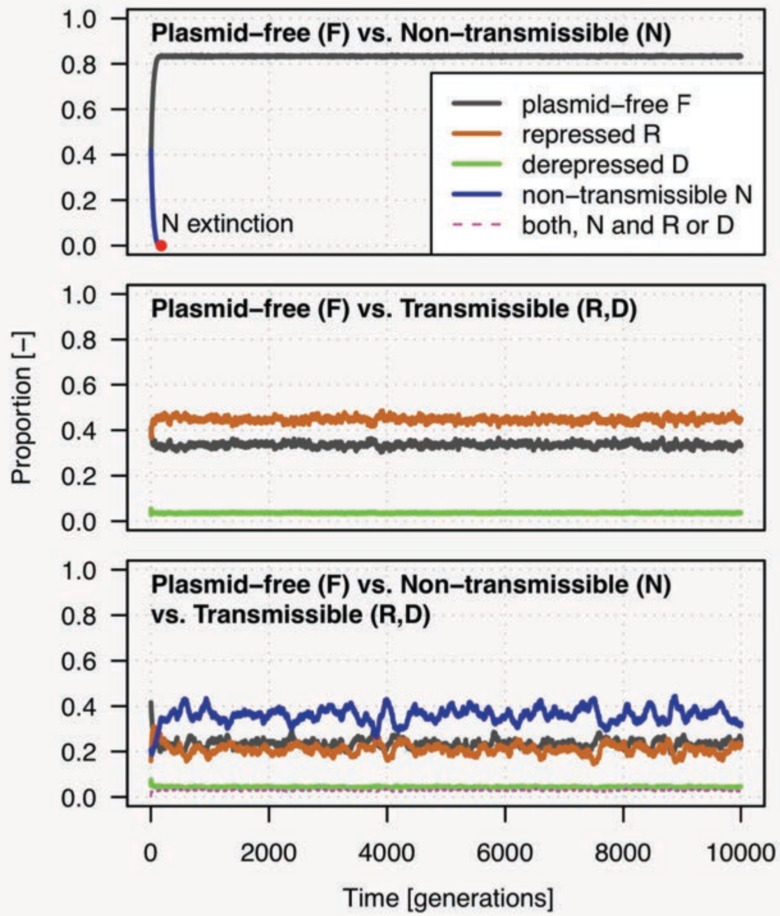
Zwanzig et al. in prep.



Werisch et al., Plasmid, 2017

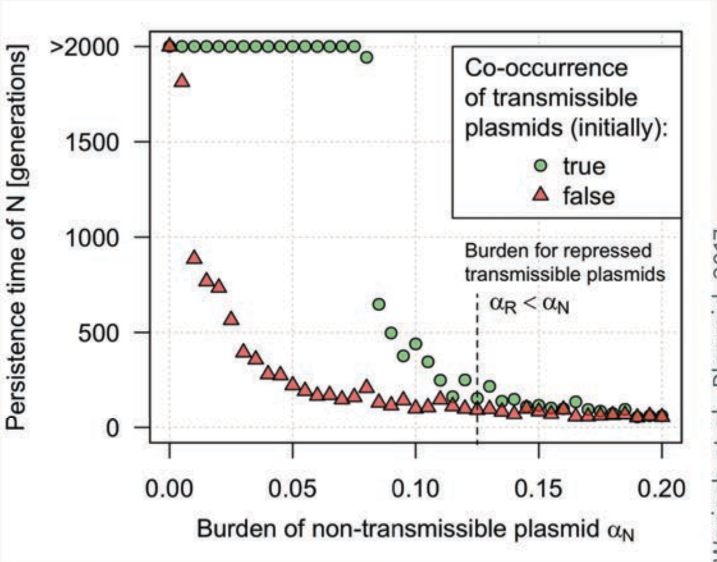
- **ENTITIES:** BACTERIA and *PLASMIDS*
  - *non-transmissible N*
  - *conjugative (repressed R or derepressed D)*
- **PARAMETERS:**
  - Plasmid burden α_N, α_R, α_D
  - Incompatibility-exclusion probability κ_N, $\kappa_R D$
  - Density dependency ρ_R, ρ_D for switch of transfer competence
  - Transfer attempt success probability γ
  - Death or washout probability ω

Werisch et al. (2017)



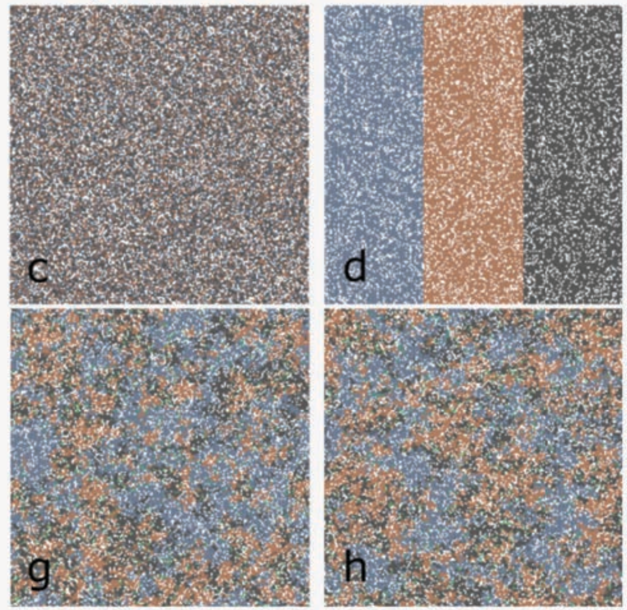
Werisch et al., Plasmid, 2017

► non-transmissible plasmids can be maintained indefinitely in the presence of an incompatible and more costly conjugative plasmid type

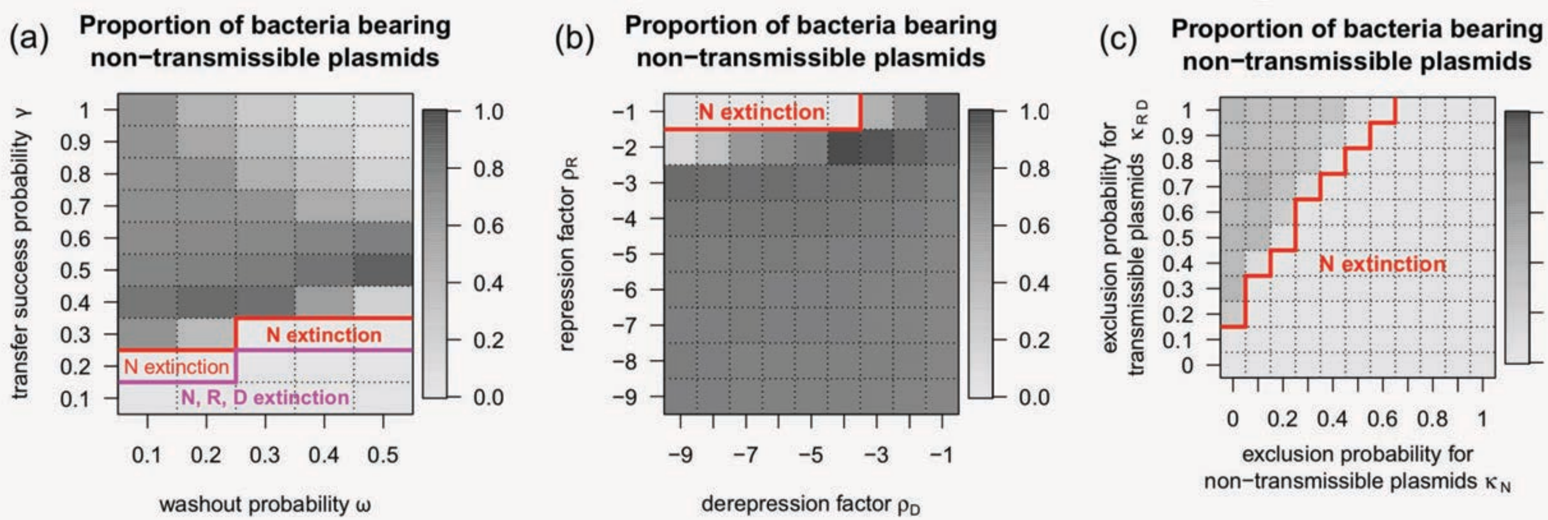


Werisch et al., Plasmid, 2017

► initial plasmid distribution

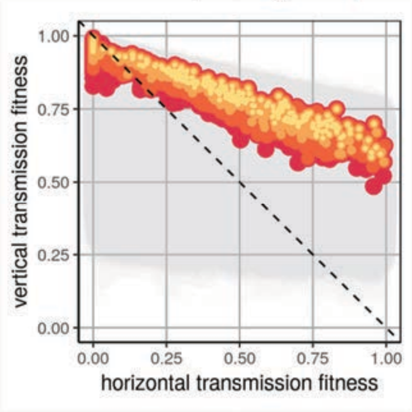


► model parameter settings

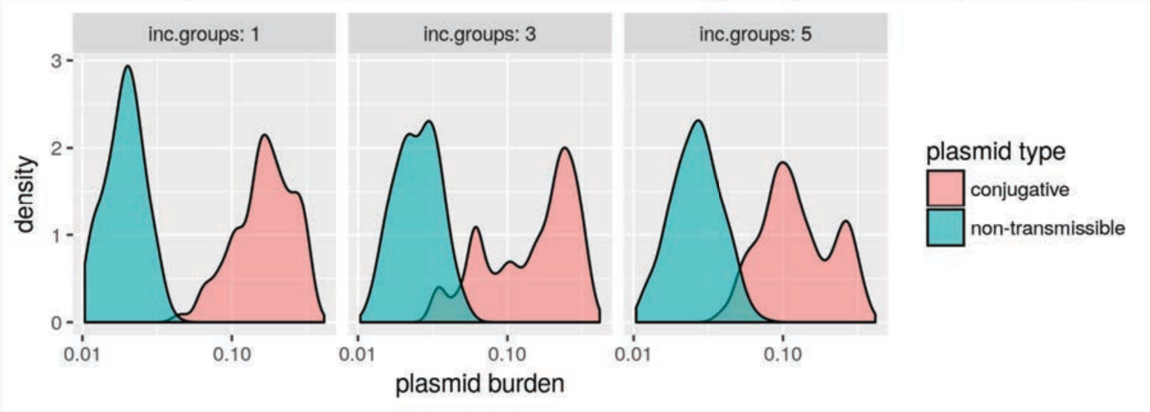


Werisch et al. 2017

selected plasmid types in 100 simulations (inc. groups: 1)

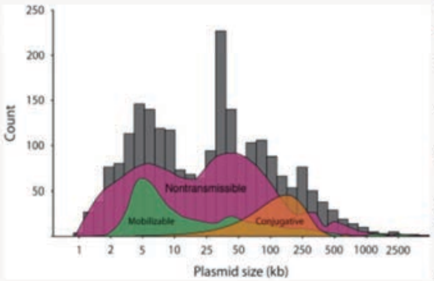


distribution of plasmid burden of evolved community (100 simulations for each inc. group number)



► Inventory of artificial system fits basic features of natural systems

(no selection for accessory-genes of plasmids considered!)



Garcillán-Barcia et al., 2011

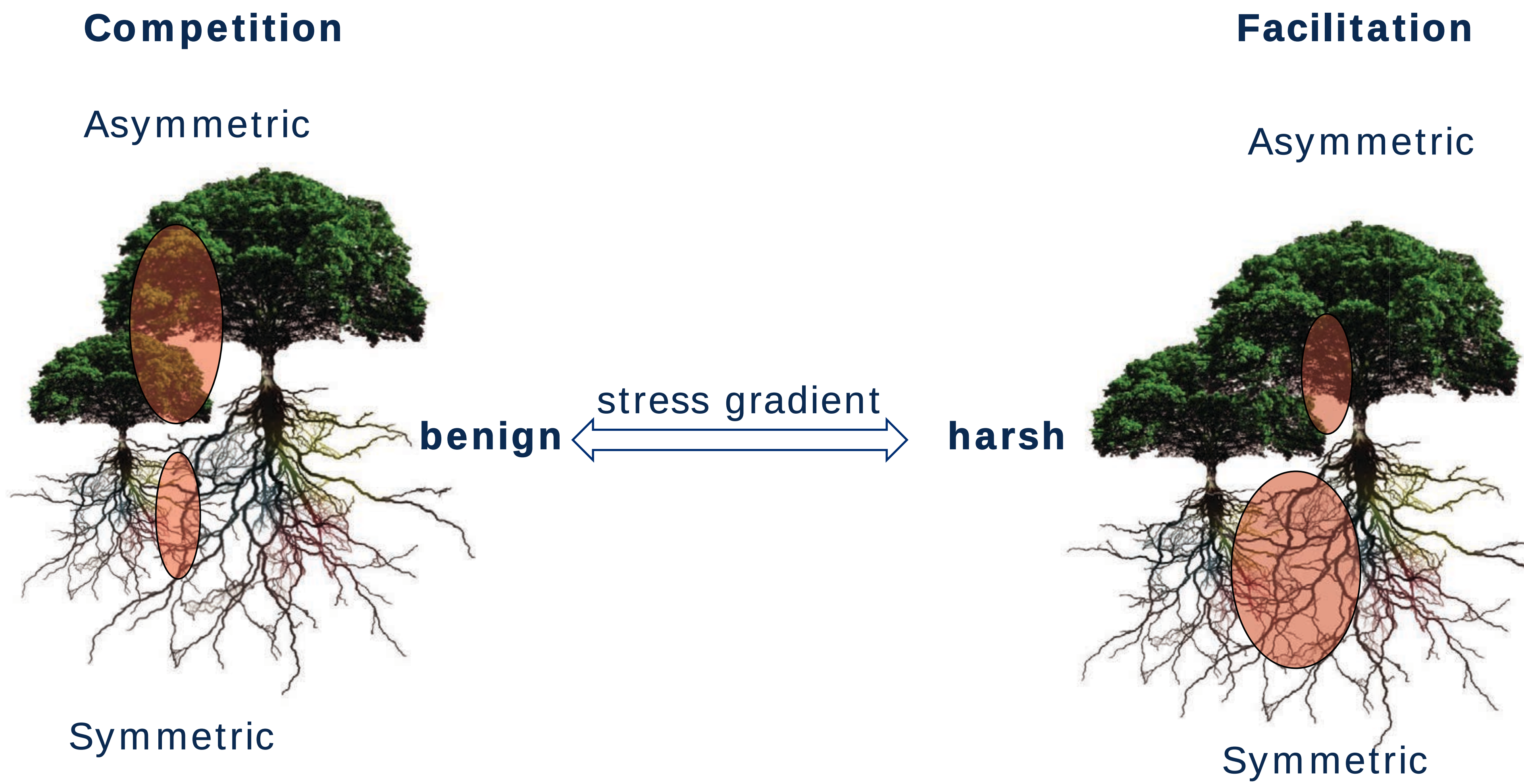
Zwanzig et al. submitted

“WE ARE NOW SEEING A REAL CONVERGENCE OF WHAT EXPERIMENTALISTS WANT AND WHAT THEORISTS CAN DELIVER.”

Genetic Inspiration: Human Genome Project (MIT, early 2000)
Computer Science: Bioinformatics, Data Mining, Simulation Experiments (last decade)
Material Science: currently

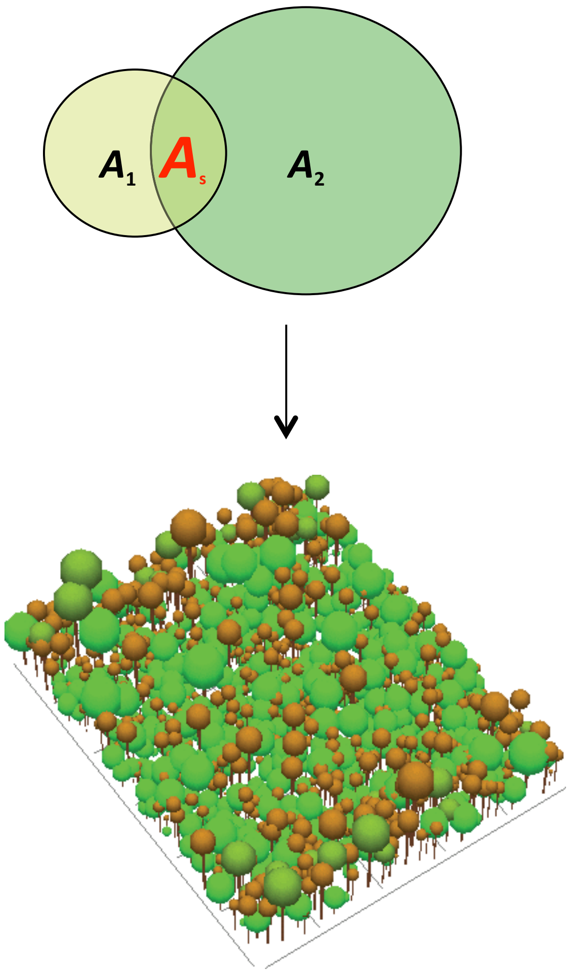
3rd Example
Plant Ecology

ABM meets Machine Learning



Lin et al. 2013

Plant-Interaction (PI) Modell



$dm/dt = f_p f_q cA[\ 1 - (\ m\ /\ M)^{1/4}\ ]$

m .. Current biomass
M .. Maximum biomass
C .. Initial growth rate
A .. Area within the plant exploits resources

f_p .. competition among neighbouring plants

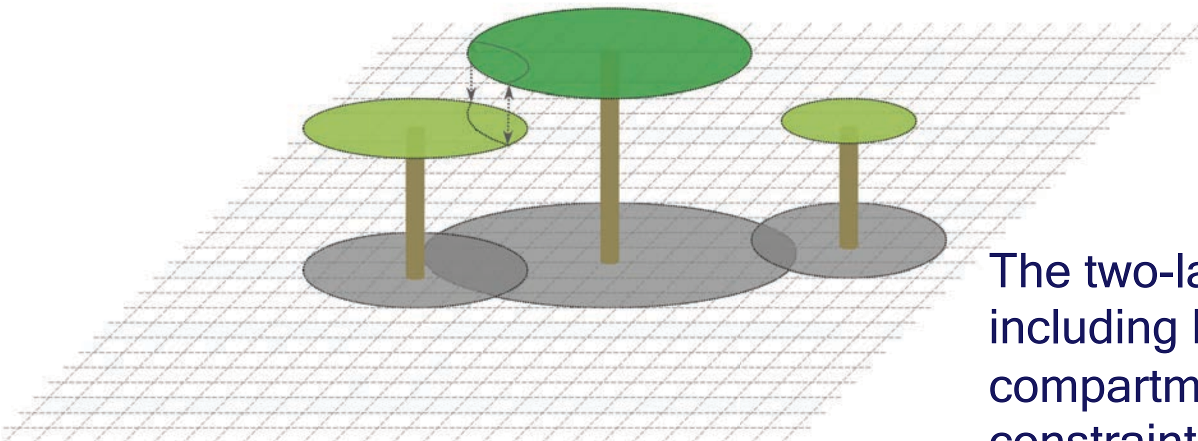
$$f_p = (A_{no} + \sum_{k=1}^{n_o} \frac{v_i m_i^p}{\sum_{j=1}^{n_j} v_j m_j^p} A_{o,k}) / A$$

f_q ... facilitation among neighbouring plants (in case of stress)

$$f_q = 1 - \frac{S}{A_f + 1} = 1 - \frac{S}{\sum_{k=1}^{n_o} (1 - \frac{w_i m_i^q}{\sum_{j=1}^{n_j} w_j m_j^q}) A_{o,k} + 1}$$

A_{no} area of plant i without overlap
$A_{o,k}$ overlapping area with neighbouring plant j
p, q parameter of symmetry – asymmetry
ν, ϖ species-specific weight
S stress level

Schwinning & Weiner 1998, Lin et al. 2012, 2014



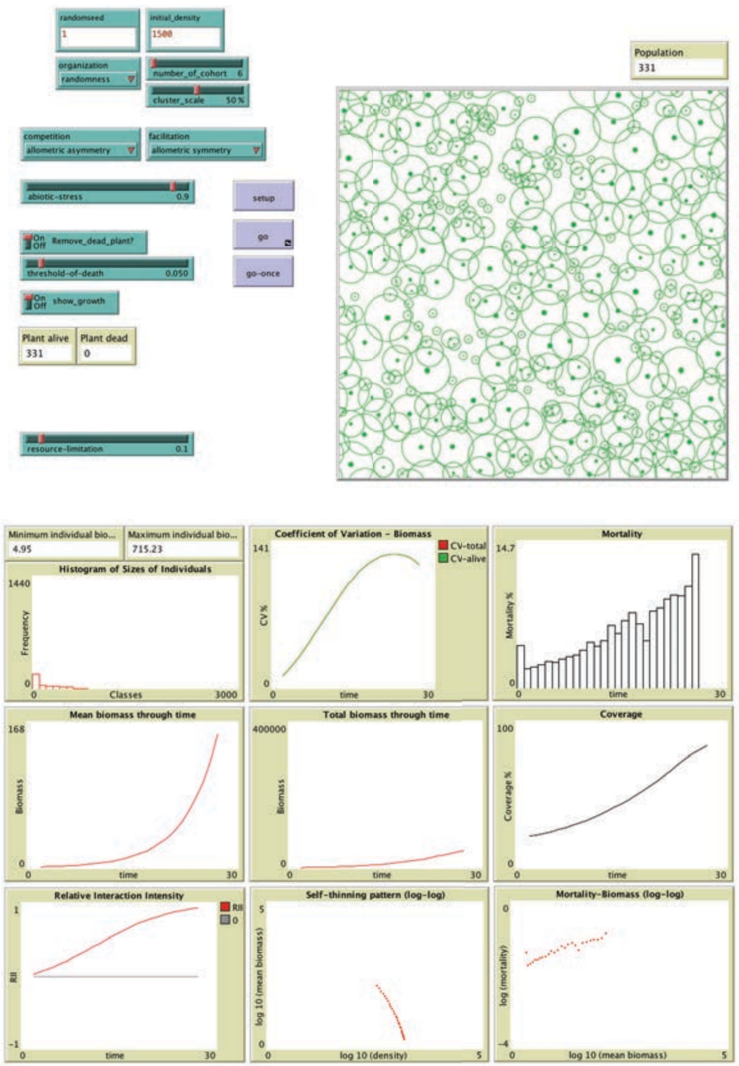
The two-layer version of the PI model including both above- and belowground compartments connected via metabolic constraints.

$$\frac{\Delta m}{\Delta t} = \begin{cases} 2\times \Delta AGR = 2\times f_{R,a} f_{p,a} c_a A_a [1-(m/M_a)^{1/4}], & \Delta AGR < \Delta BGR \\ 2\times \Delta BGR = 2\times f_{R,b} f_{p,b} c_b A_b [1-(m/M_b)^{1/4}], & \Delta AGR > \Delta BGR \\ \Delta AGR + \Delta BGR, & \Delta AGR = \Delta BGR \end{cases}$$

ΔAGR, ΔBGR .. above- and belowground growth rate
a, *b* .. above- and belowground compartment

May et al. (2009), Lin et al. (2013)

Plant-Interaction (PI) Modell



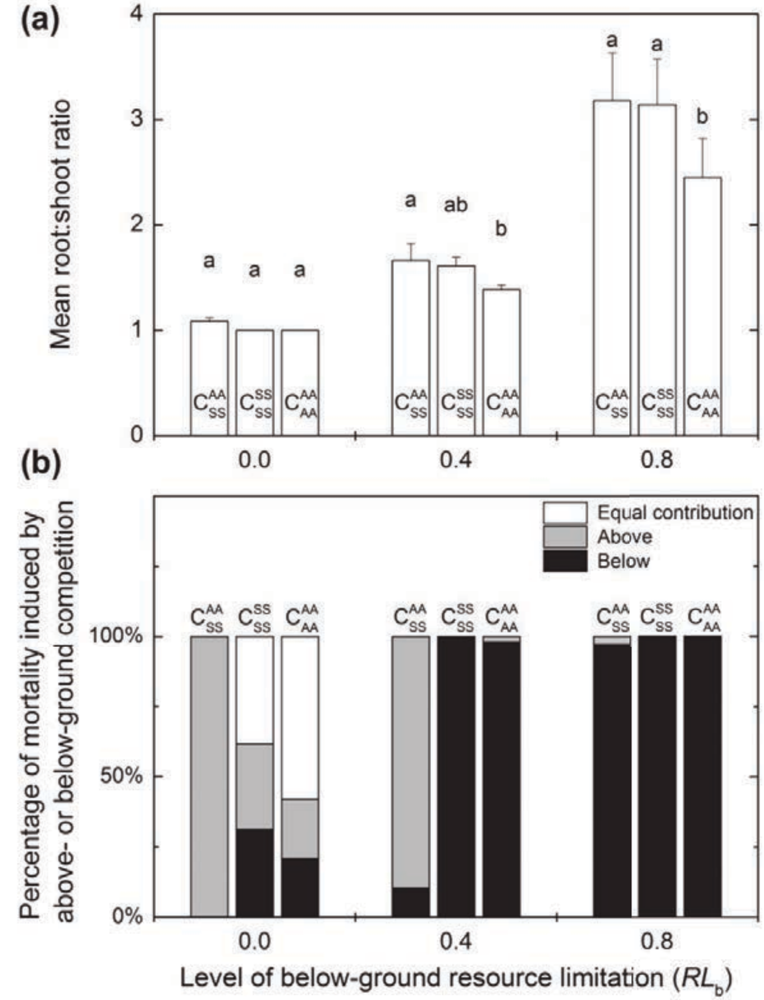
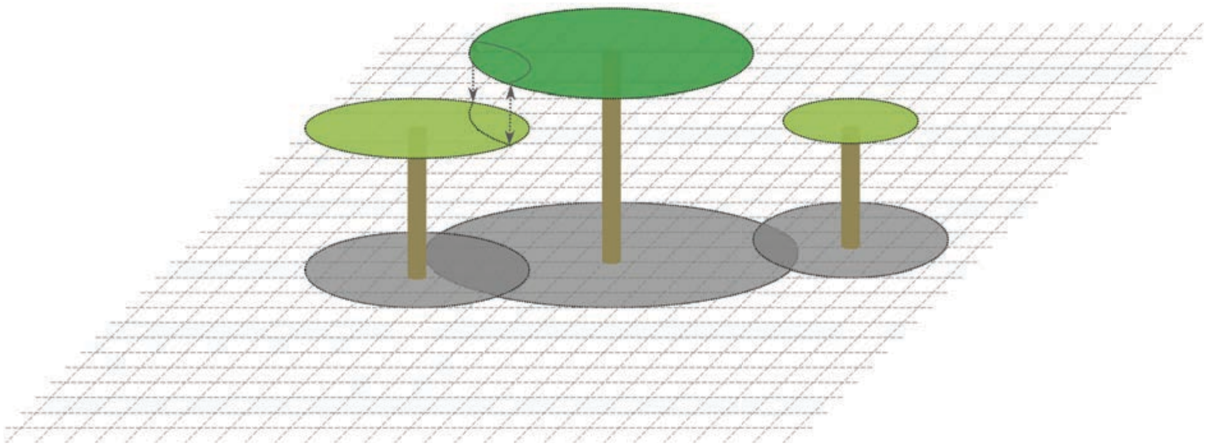


Figure 1. The (a) root:shoot ratio (mean ± 1 SD) and (b) percentage of mortality induced by above- or belowground competition in simulated plant populations at different levels of belowground resource limitation, RL_b, ranging from 0 (no resource limitation) to 1 (maximum resource limitation). C with superscript and subscript indicated the mode of competition for above- and belowground part correspondingly (AA: allometric asymmetry; SS: size symmetry). Bars in the same group that share the same letter do not differ significantly ($p > 0.05$, Holm–Sidak test).

Lin et al. (2013)

”I have a dream …”

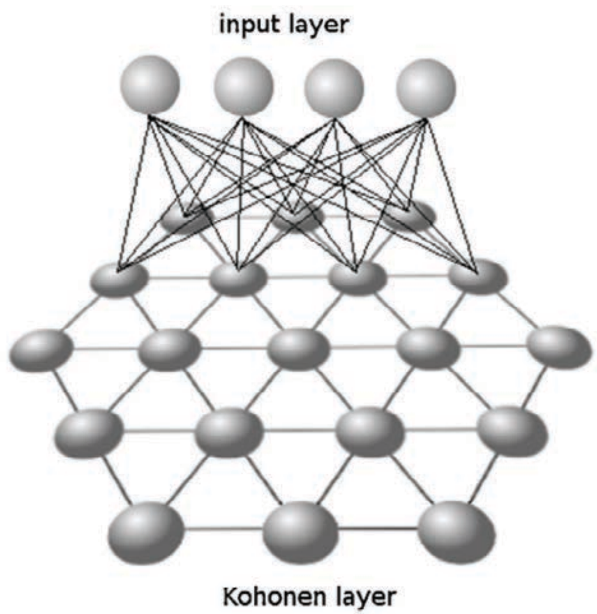
Observations above-ground Dynamic (Mortality, Spatial distribution …)



.. can be used to reveal mechanisms below-ground (competition mode, resource limitation ..)

Dynamic observations at stand level:

- Mortality
- Spatial distribution (Clark Evans Index)



The self-organizing map (SOM = Kohonen layer) links the factors without defining dependencies.

Mechanisms to be detected:

- Below-ground competition mode
- Resource limitation

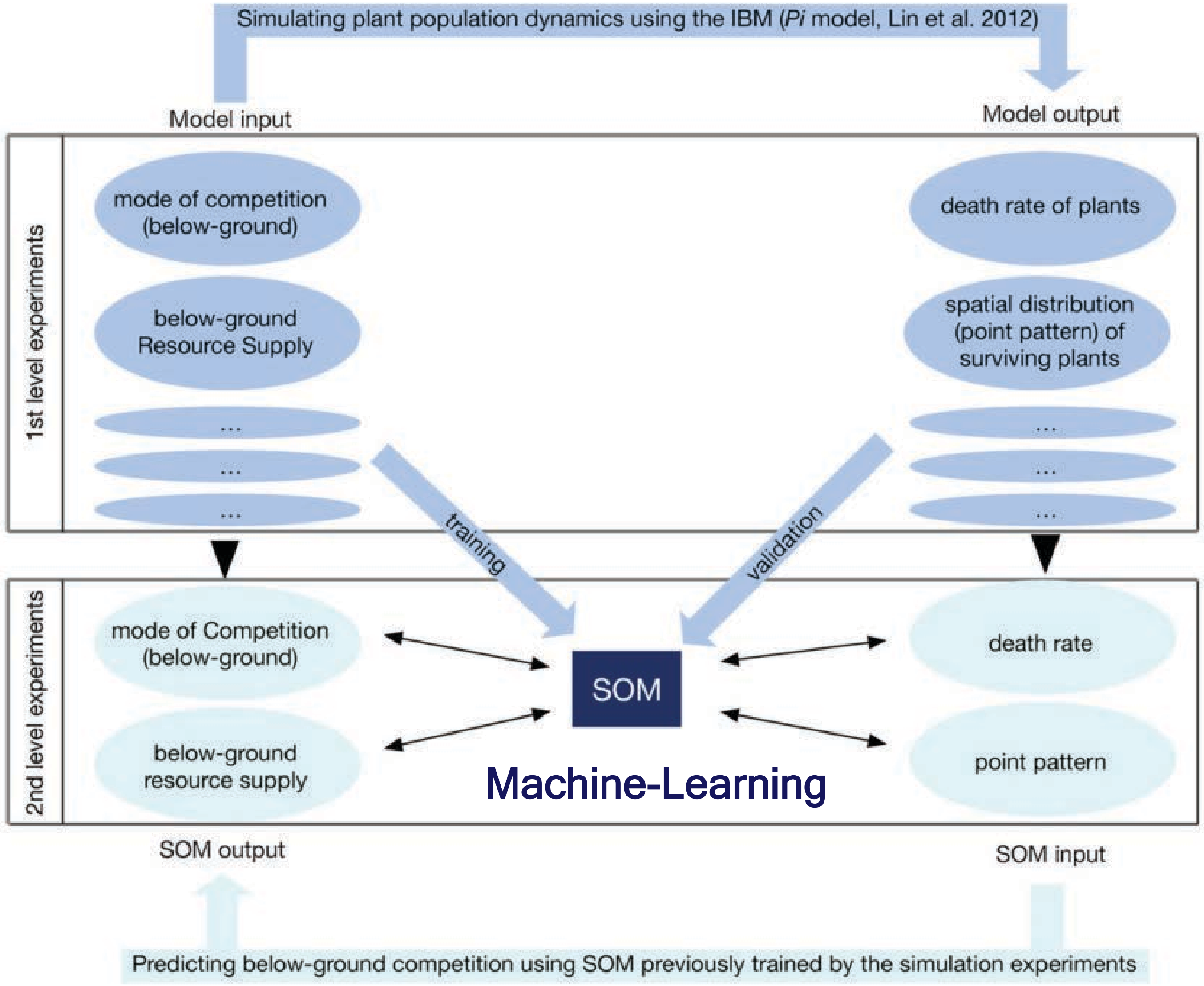


Fig. 1. Strategy of the IBM-ANN approach applied in this study. The figure shows the relationship between the input and output variables of the individual-based simulation model (*Pi* model, above) and their further use by self-organising maps (SOM).

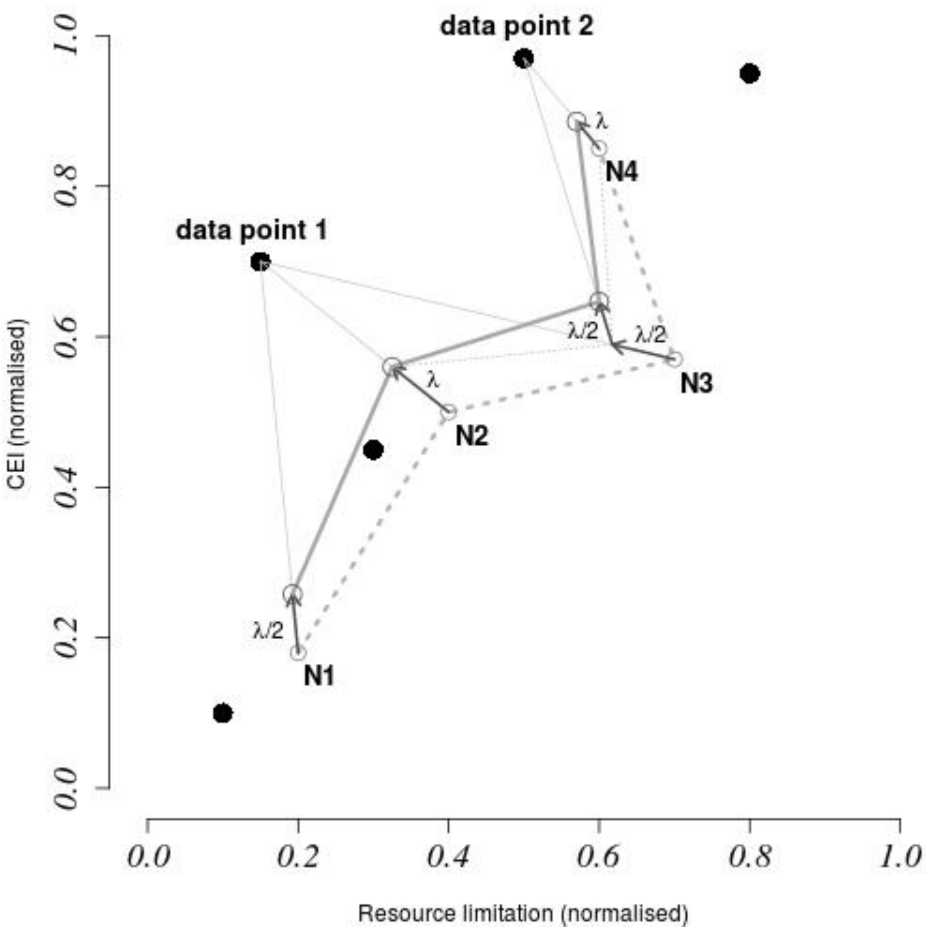
Peters & Berger (2016)

Table 1
The parameter settings used for data generation by means of the individual-based *Pi* model.

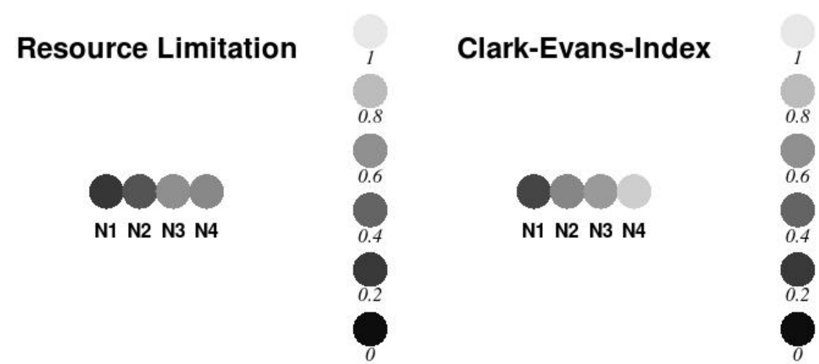
Pi model parameter setting	Training data	Validation data
Above-ground competition mode	Complete asymmetry	Complete asymmetry
Below-ground competition mode	Complete asymmetry Allometric asymmetry Size symmetry Complete symmetry	Complete asymmetry Allometric asymmetry Size symmetry Complete symmetry
Initial individual number	7000 8000 9000	7000 8000 9000
Resource limitation	0.0 0.1 . . . 0.9	0.05 0.15 . . . 0.85
Total number of model runs	120	108

Peters & Berger (2016)

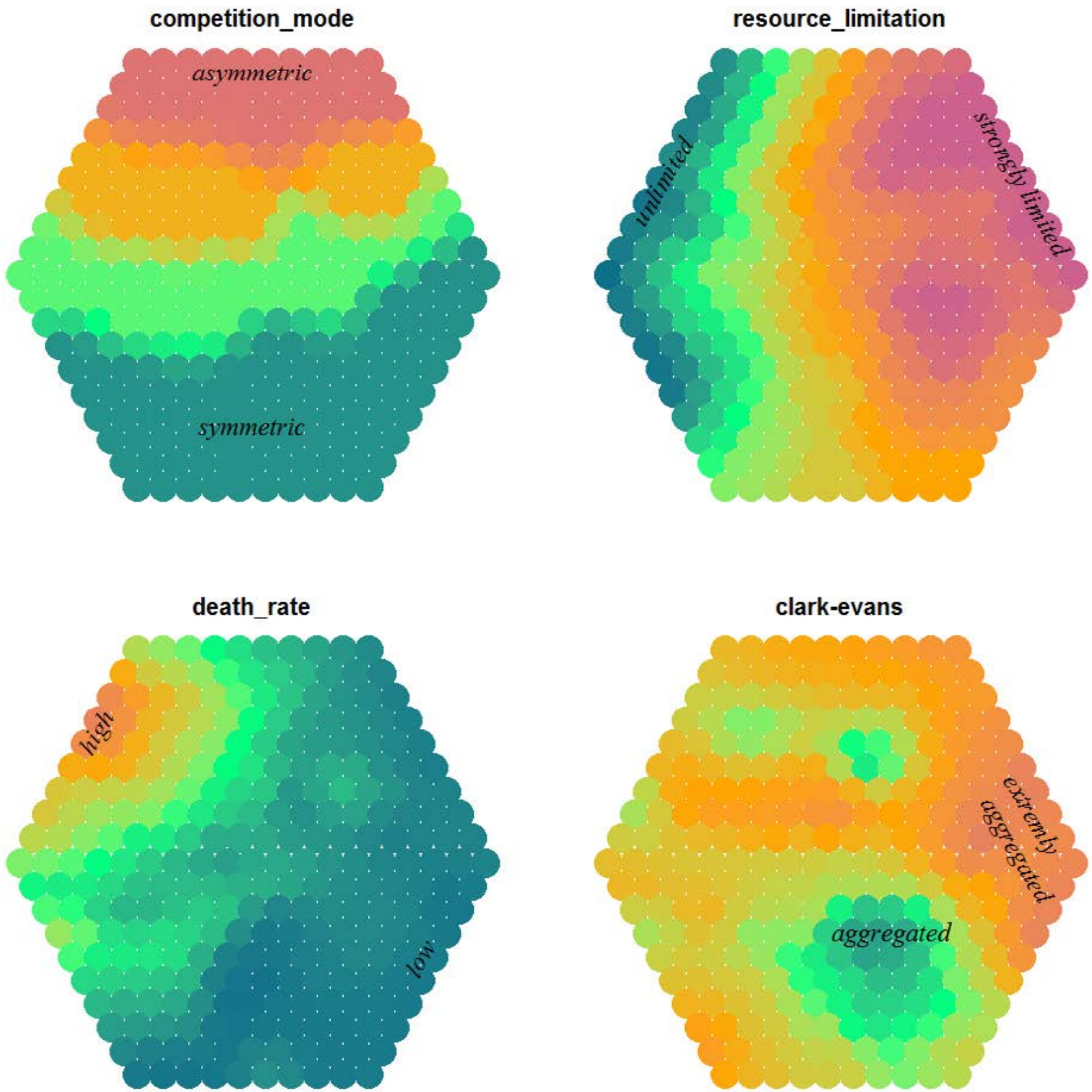
SOM training



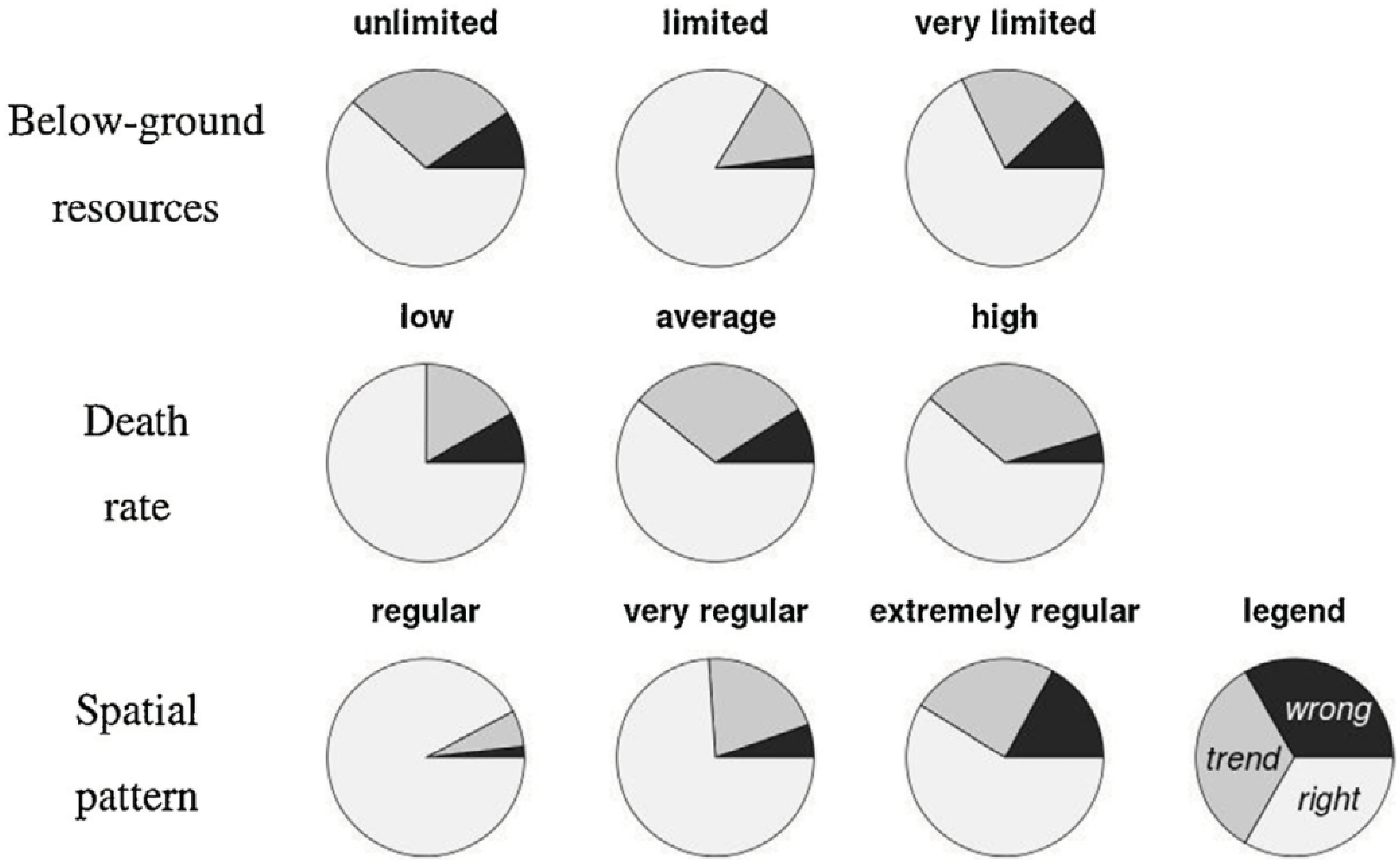
SOM layer after training



Peters & Berger (2016)



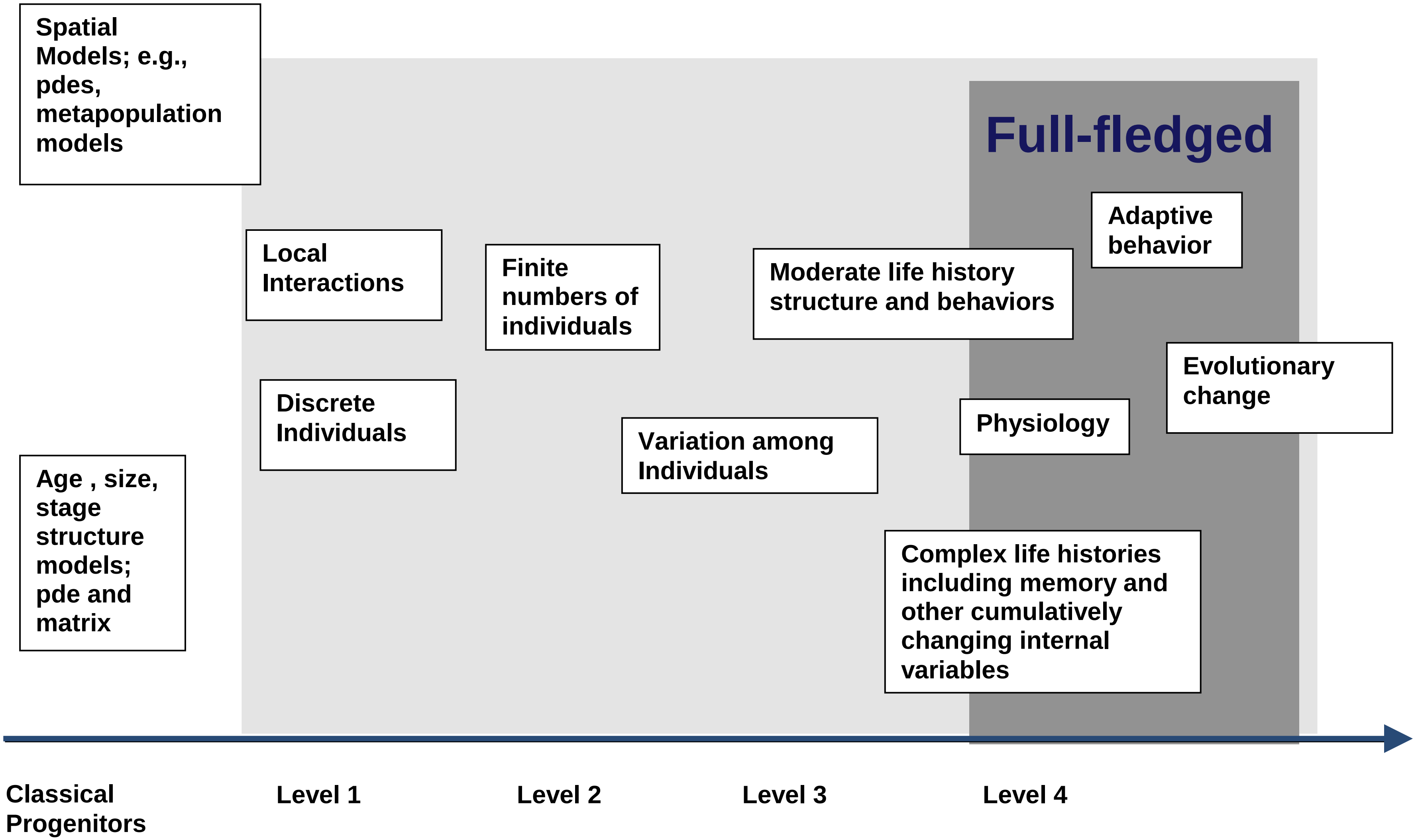
Peters & Berger (2016)



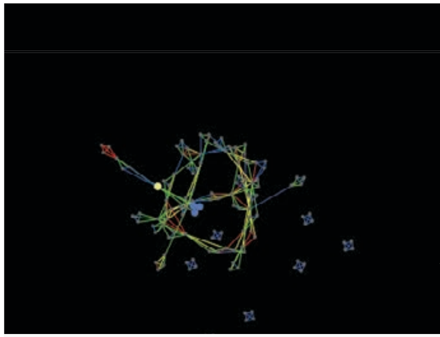
Peters & Berger (2016)

IBM / ABM

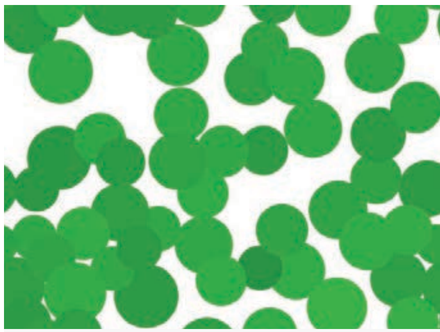
towards agent-based science?



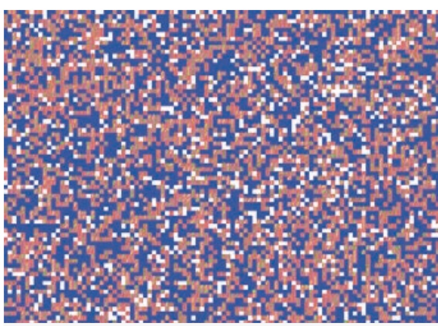
See also: DeAngelis & Mooij (2005). Ann. Rev. Ecol. Syst. 36



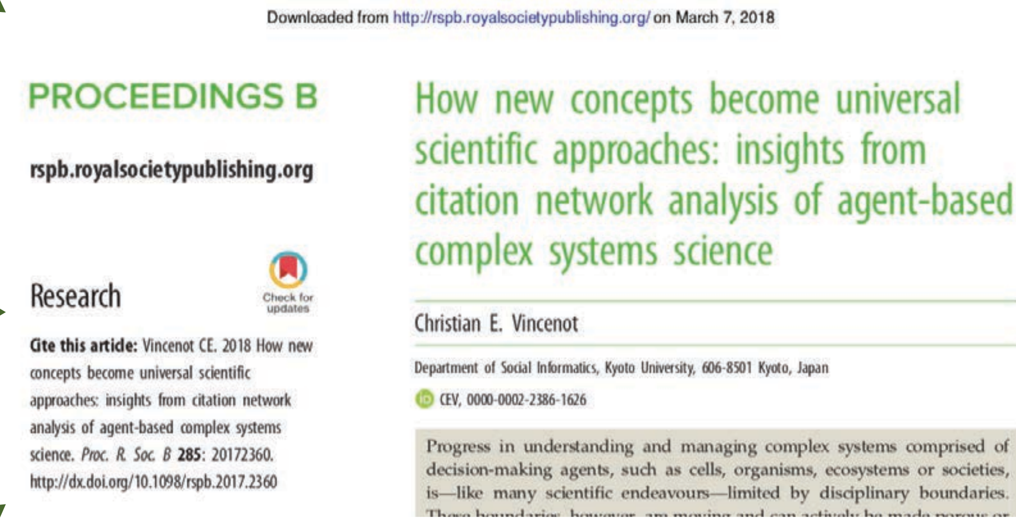
agent-based models
(social sciences)



stand simulators
(forest sciences)



indiv.-based models
(ecology)



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How new concepts become universal scientific approaches: insights from citation network analysis of agent-based complex systems science

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CEV, 0000-0002-2386-1626

Progress in understanding and managing complex systems comprised of decision-making agents, such as cells, organisms, ecosystems or societies, is—like many scientific endeavours—limited by disciplinary boundaries.

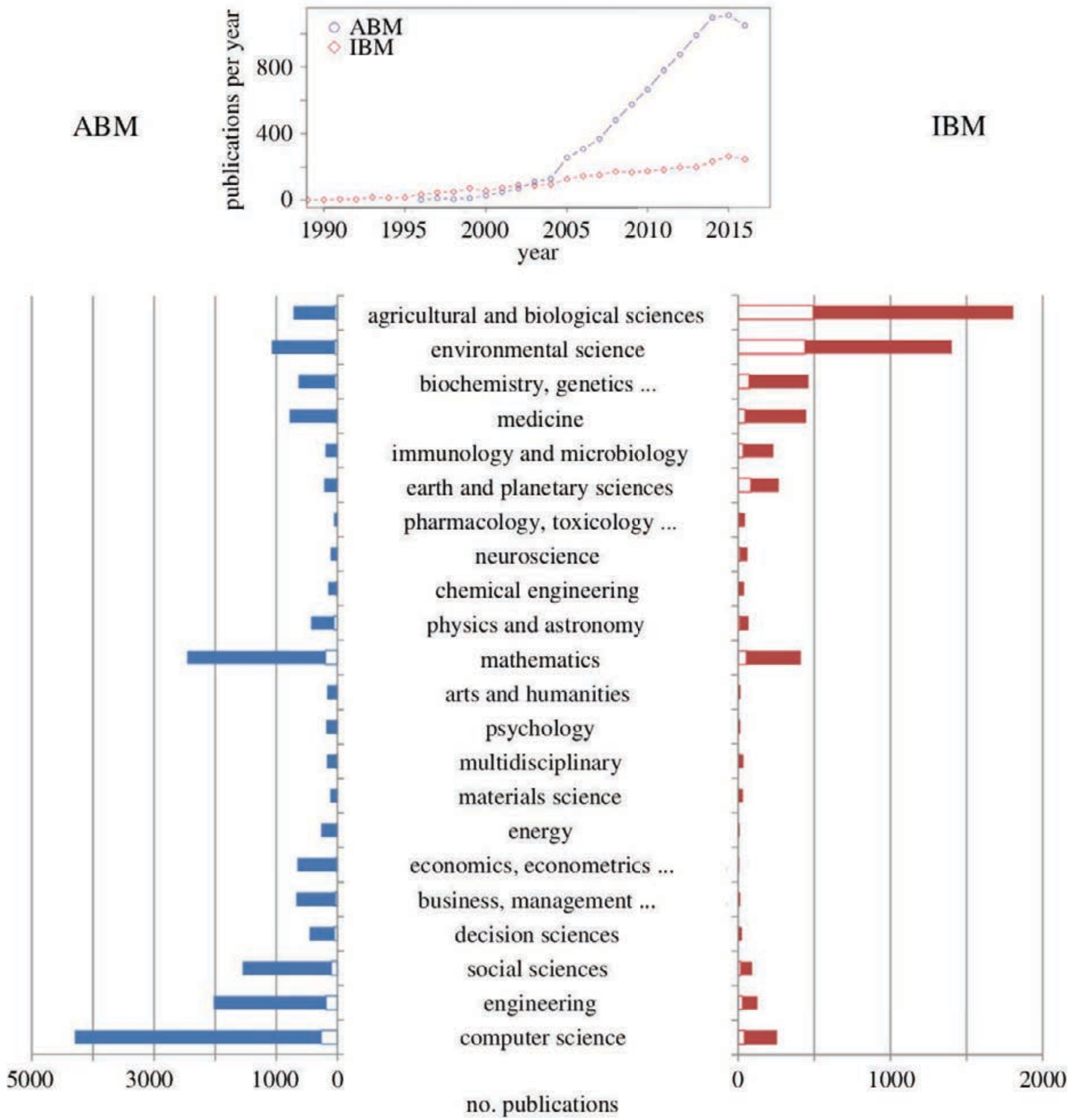

Figure 1. Sciences in which the terms ABM (left) and IBM (right) were dominant until 2005 (empty bars) and post-2005 (solid bars) measured in number of publications referenced on Scopus ($n = 9515$ and 3168, respectively). Publications can belong to more than one scientific domain. The top inset shows the number of publications per year related to ABM and IBM from 1989 to 2016. Publications belonging to both corpora were counted twice. (Online version in colour.)

Vincenot (2018) Proc. R. Soc. B 285: 20172360

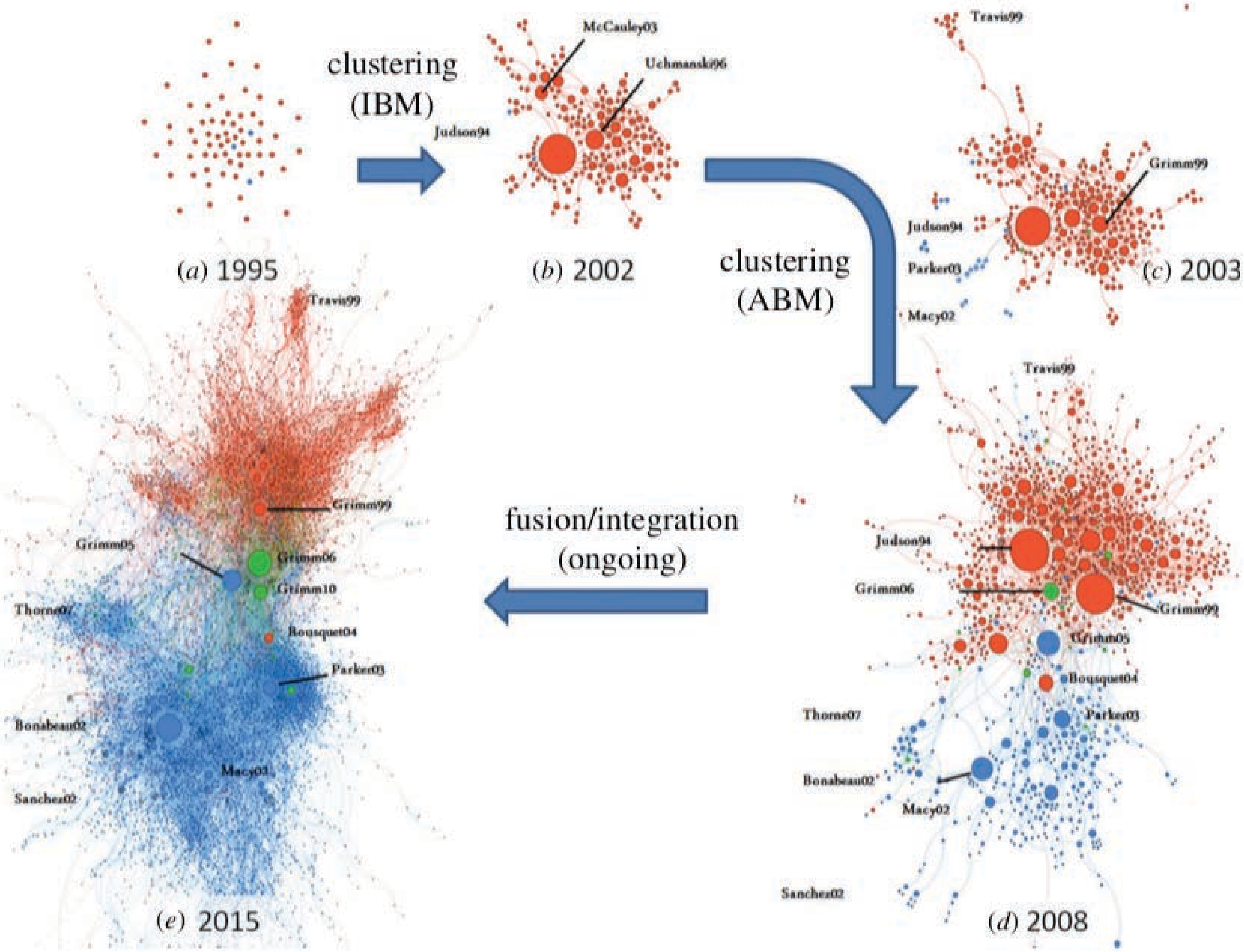

Figure 4. Evolution of the citation graph of ABM/IBM literature over time. Publications are represented by vertices (blue for ABM, red for IBM and green for both), which are attracted to each other proportionally to the number of edges (i.e. citations) linking them. Important publications are labelled with first author name and publication year. For full citations, see references and the electronic supplementary material, table S3. Vertex size is proportional to the number of citations within each time-dependent subgraph, but scaling varies between subgraphs. (*a*) IBM papers appeared first, but had weak interconnections. (*b*) A clustering then took place after the appearance of influential papers. (*c*) ABM papers followed the same pattern with a lag of a decade. (*d*) Clustering of the ABM corpus occurred around central papers. (*e*) Fusion of ABM and IBM emerged under the impulse of key papers. The formation of sub-clusters is also visible; for example, publications centred around Thorne *et al*. [22] focused on cell-scale agent-based models. (Online version in colour.)

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Conclusions

- tendency to full-fledged models (mechanistic, physiology based)
- IBM / ABM toolbox (standardization, ODD, TRACE)
- merging with formerly separated modelling techniques
- ready to go towards agent-based sciences

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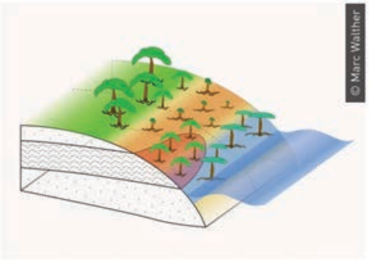

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