Individual-based and pattern-oriented modelling

Volker Grimm

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Introducing myself

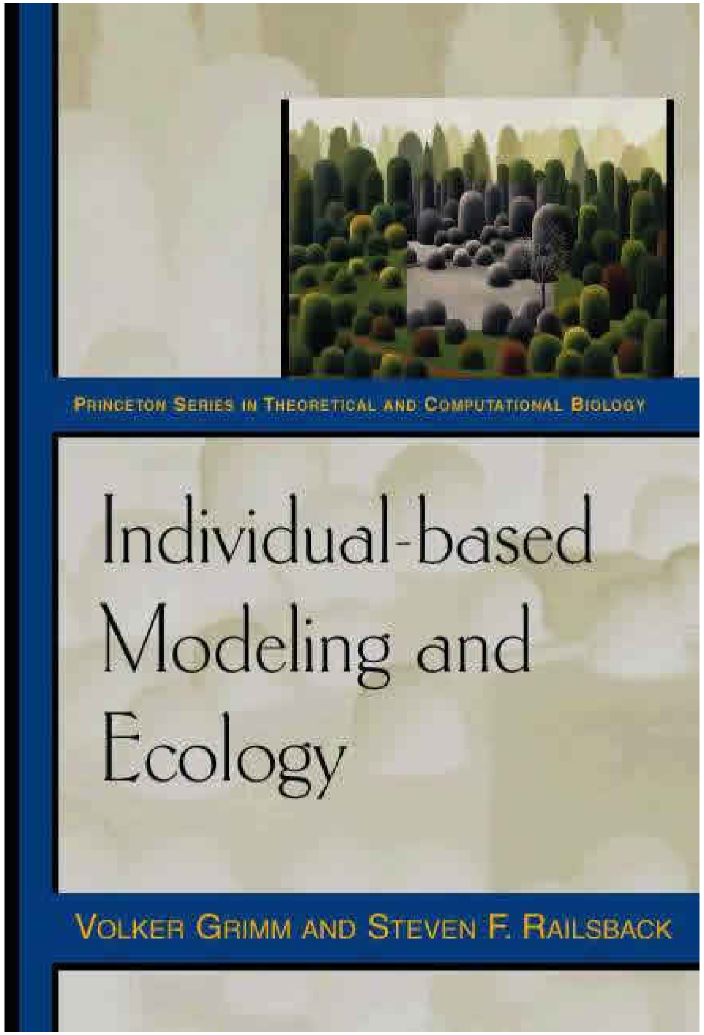
- Biologist and physicist
- Not a „marine“ (only a little bit)
- Individual-based/agent-based modelling
- Pattern-oriented modelling
- Ecological modelling to support environmental decision making
- Theory: emergence of stability properties

What are my lectures about?

- What is a model?
- Individual-based modelling
- The Modelling Cycle
- The ODD protocol
- NetLogo (including a demo tour)

- Pattern-oriented modelling

The real purpose of my lectures..



You all buy and read this book:

Grimm V, Railsback SF (2005) **Individual-based Modeling and Ecology**. Princeton University Press, Princeton, N.J.

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HERO
BY WRANGLER

.. also this one (next year)

You can download 16 (of 24) chapters:

Railsback SF, Grimm V (2011) **A Course in Individual-based and Agent-based Modeling**. Princeton University Press, Princeton, N.J.

http://www.railsback-grimm-abm-book.com

What is a model?

- Before we think about what INDIVIDUAL-BASED models are, we need to agree on what a model is.

Definition

A model is a purposeful (simplified) representation

Modelling is not an activity of some specialists (modellers) but something we do all the time, necessarily, because we never have enough data and time.

Thinking = problem solving = modelling

Modelling: “simplified” representation

- Why do we simplify?
- How do we simplify?
- …

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Modelling: essential or not essential?

- When trying to solve a problem, or answer a question, we continuously are asking ourselves the question:

    Is it likely that this aspect of the real system is essential for the solution of my problem?

- The problem to be solved serves like a kind of **customer**, or **filter**
- But how can we know whether something is essential?
- Answer: **We cannot!** That’s why – in science - we develop the model: To see whether we captured key features of the system!!

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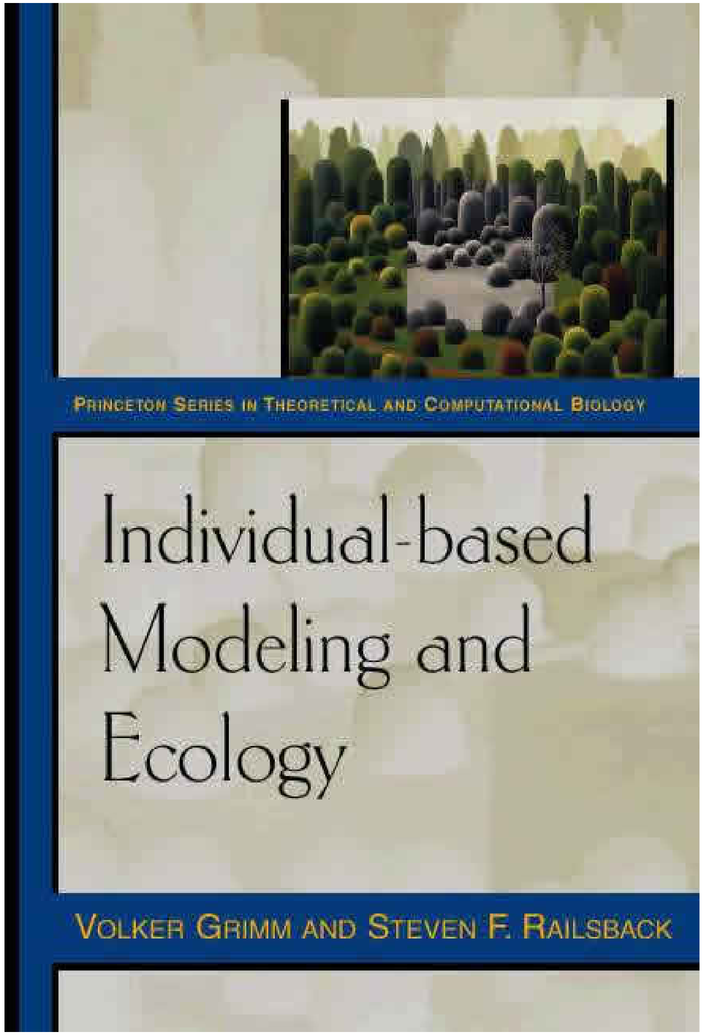

Chapter Two

A Primer to Modeling

Modeling is presented as a discipline that draws (in the first instance) on the perception of the detective rather than the expertise of the mathematician.

—Anthony Starfield and Andrew Bleloch, 1986

2.1 INTRODUCTION

Individual-based modeling is, above all, modeling. If we want to make individual-based modeling effective and coherent, we must understand what modeling really is and how it works. Therefore, in this chapter we introduce general guidelines for developing models, referring readers to other authors (especially Starfield, Smith, and Bleloch 1990; Starfield and Bleloch 1986; and Haefner 1996) for more detailed introduction to the principles of modeling. These guidelines also set the stage for the remainder of the book: subsequent chapters address the modeling tasks introduced here.

Lessons for individual-based modelling

- IBM requires some techniques (programming, mathematics, statistics)
- But “modelling” is independent of this
- In a scientific model, we make all our heuristics and simplifying assumptions **explicit**
- And, we use mathematics and computer logics to **rigorously explore the consequences of these assmputions**

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Why individual-based models?

IBM

Agents/Individuals described as discrete, unique, and autonomous entities

- Individuals ARE discrete entities. Important at low densities.
- Individuals, even of same species and age, can be different. Important e.g. for buffer mechanisms.
- Individuals have a life history.
- Interactions among individuals usually are local, not global.
- Individuals make decisions, which are adaptive, i.e. depend on the individual‘s and its environment‘s state.
- Individuals are no atoms.
- „Ecology“ emerges from individual behavior.

Why individual-based models?

Individuals are represented explicitly

1. **Individuals are unique and different**
2. **Individuals interact locally**
3. **Individuals show adaptive behavior**

ABMs including all **three** of these elements can be dubbed “full-fledged”. Most ABMs focus on only one or two of these elements. (Why?)

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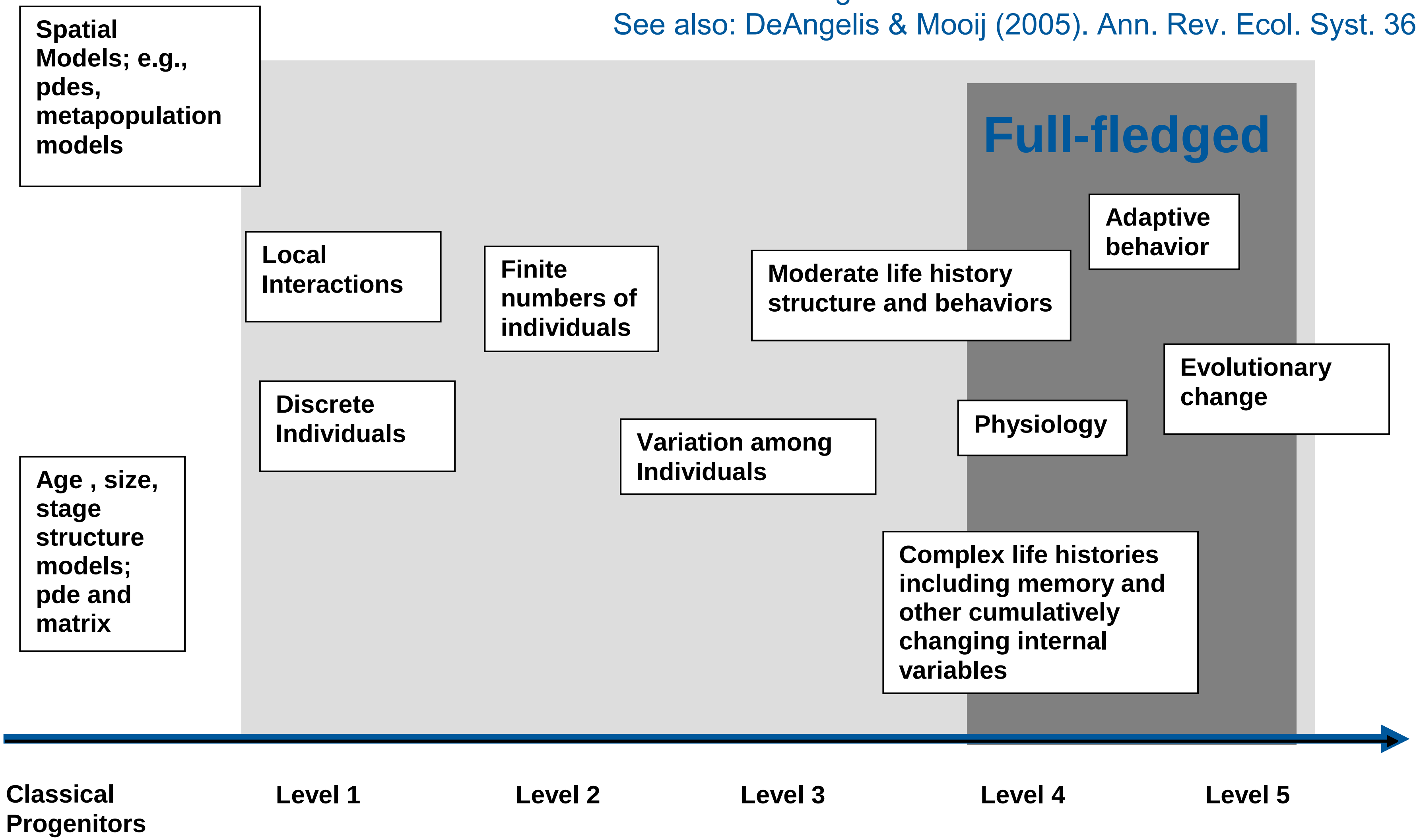
Why NOT individual-based models?

But: there are also good arguments to avoid the IBM approach and prefer more aggregated modelling techniques (calculus, matrix models, statistical (empirical) models, etc.)

- Too complex to be understood.
- Impossible to include everything in a model.
- Too data hungry.
- Too many parameters unknown.
- Too much uncertainty in model structure.
- Hard to test.
- Require too much man and computer power.
- Problem of model communication is limiting scientific value.

State-of-the-Art

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

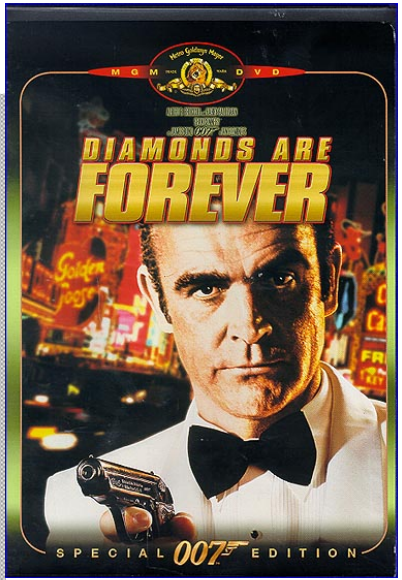


Terminology

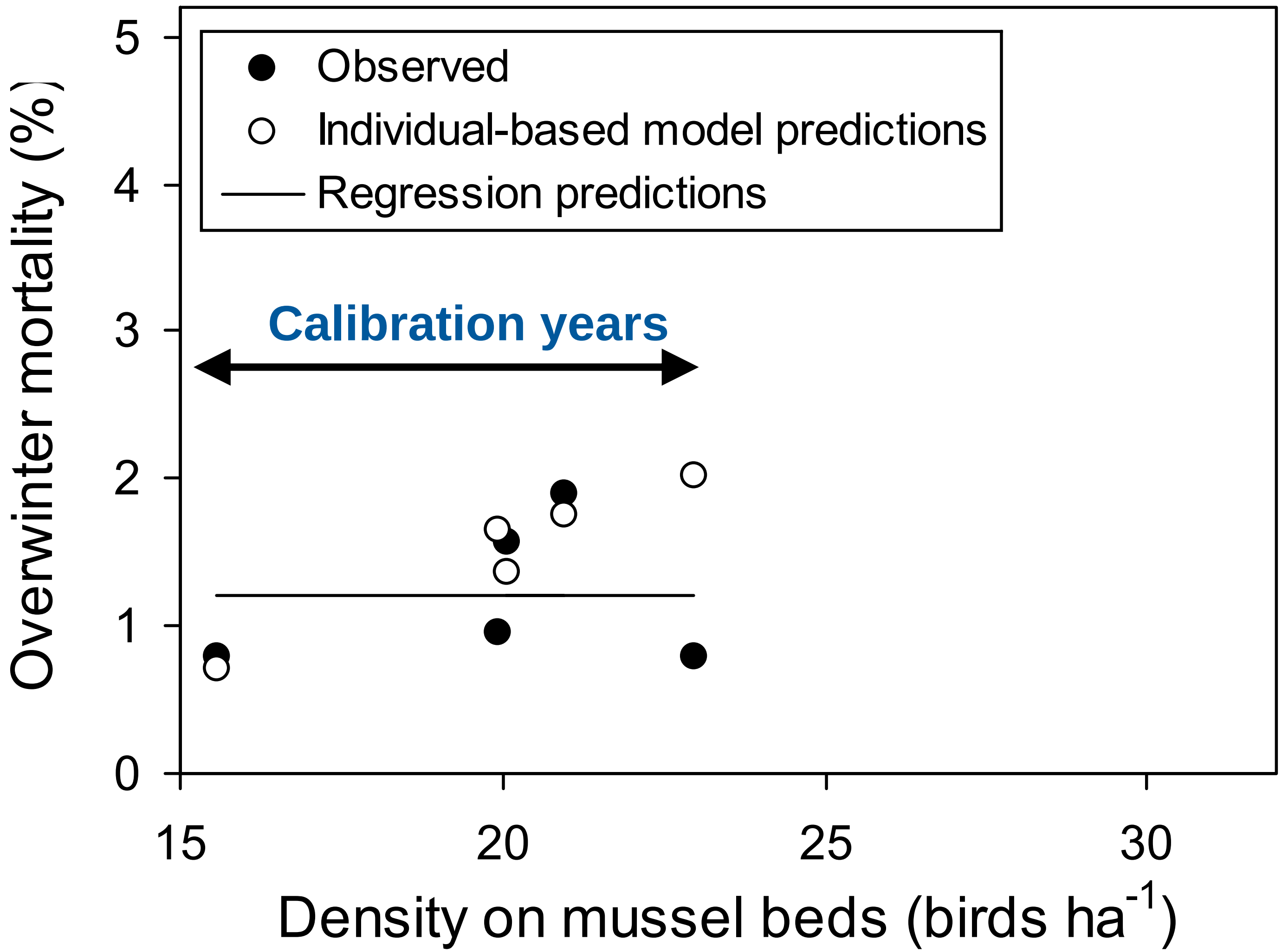
In **individual-based models (IBM)**, agents used to be quite simple- or even zero-minded (plants, animals), whereas **agent-based models (ABM)** have a strong focus on decision making and mental processes.

But these historical differences are fading away, which is good. I will use ABM and IBM interchangably.

Multi-agent systems (MAS) are similar, but have their background in artificial intelligence and computer science (and are often not useful for non-computer scientists)

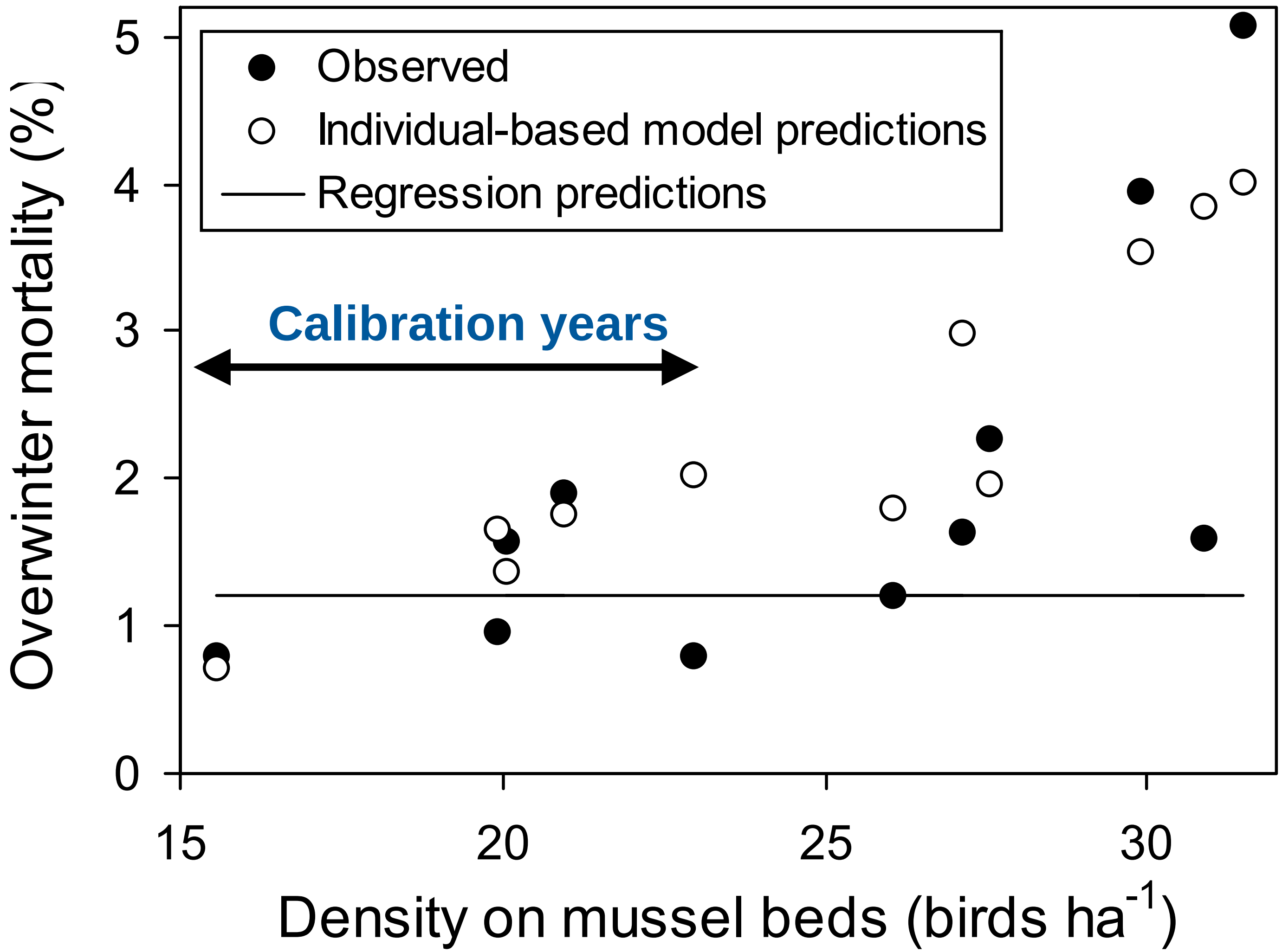


Example: Oystercatcher mortality (1976-1981)



Data collected by John Goss-Custard from Exe estuary, UK
Data from Stillman *et al*. (2000) Journal of Applied Ecology, 37, 564-588

Example: Oystercatcher mortality (1976-1991)



Data collected by John Goss-Custard from Exe estuary, UK
Data from Stillman *et al*. (2000) Journal of Applied Ecology, 37, 564-588

Example: flocks of starlings

Individuals are represented explicitly

- **Individuals are unique and different**
- **Individuals interact locally**
- **Individuals show adaptive behavior**

Behavioral Ecology
doi:10.1093/beheco/arq149

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

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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

Example: flocks of starlings

Main new features of Hildenbrandt et al. 2010:

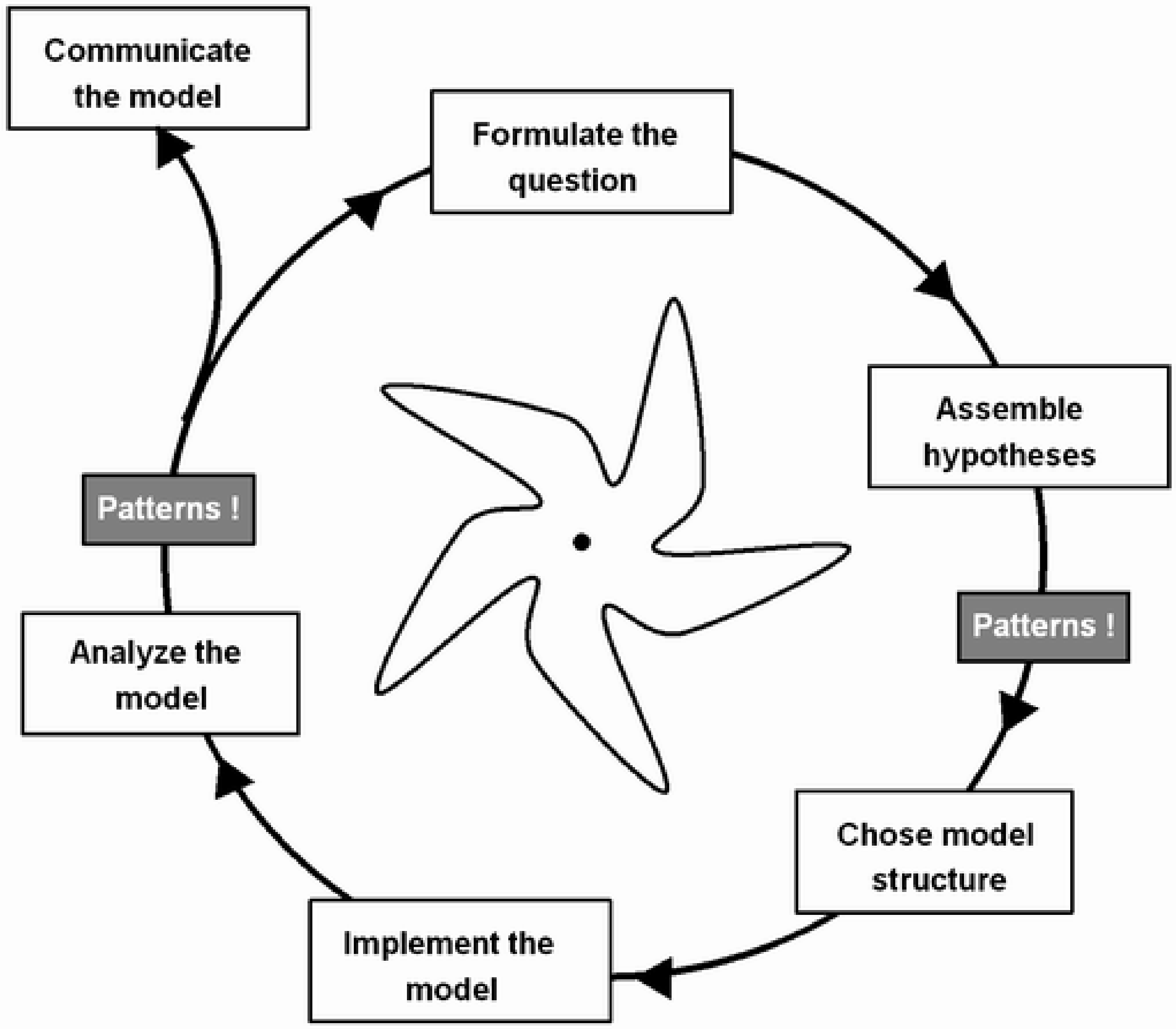
- **Flight physics (banking, lift, drag, …)**
- **No fixed neighborhood radius: birds try to take into account 6-8 neighbors**
- **Invisible (soft) wall of preferred roosting area**

Movie…

Modelling: iterative process

- We need to have a clearly formulated research question
- We need to simplify to simplify **TO SIMPLIFY**
- Simplify to the threshold of pain, and beyond – and see how it works!
- Modelling is an **iterative process**: formulating the question, the simplified representation, implementing the model as a program, testing the program, analyzing the model output, throwing everything in the trash can, starting with a modified (question/model/program) etc. etc.
- The **Modelling Cycle**

The Modelling Cycle



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Tasks of the cycle

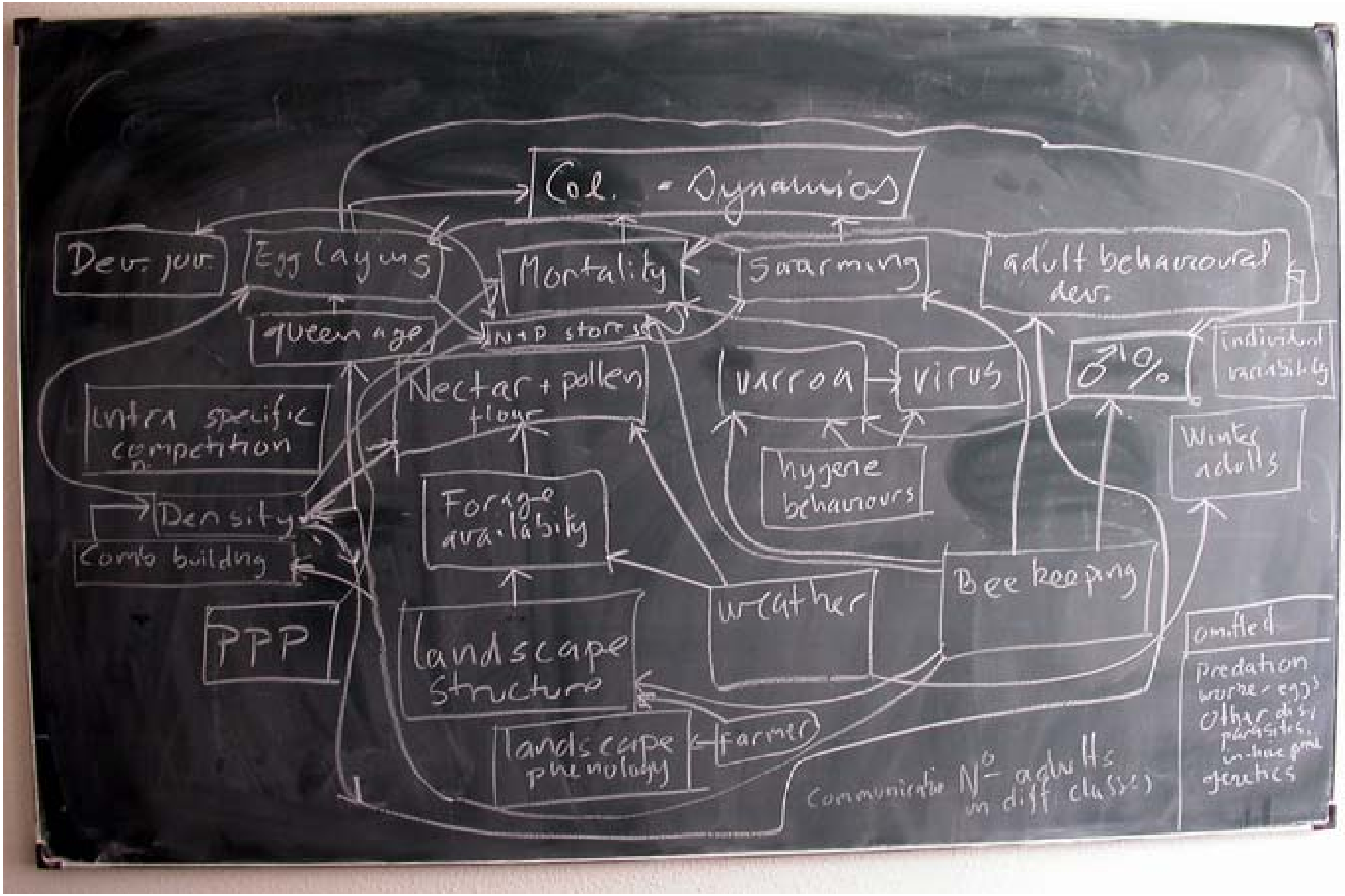
Formulate the question

- The question or problem serves as a filter for those aspects of the real system that are included in the model.
- First modelling the system, then specifying the question does not work!

Assemble hypothesis

- We need a conceptual (often: verbal, graphical) model of how the system works and what the answer is.
- This conceptual model can be based on: empirical experience; theory; intuition … .
- Discuss and revise the conceptual model thoroughly, but not forever. It can‘t be tested in your head!

Example: „Influence diagram“



Tasks of the cycle

Choose model structure ODD

- What are the model's entities, by what sets of state variables are they characterized. How to represent the abiotic environment? What are temporal and spatial resolutions and extents?
- Which processes do we include in the model (interactions, disturbances, management, growth, etc.)?
- How do we schedule the processes?
- How do we represent (=model) these processes?

Implement the model

- Write down the equations and/or implement the model as a computer programm (if-then rules, loops)
- Chose an appropriate software platform (e.g. for prototyping, NetLogo).

Tasks of the cycle

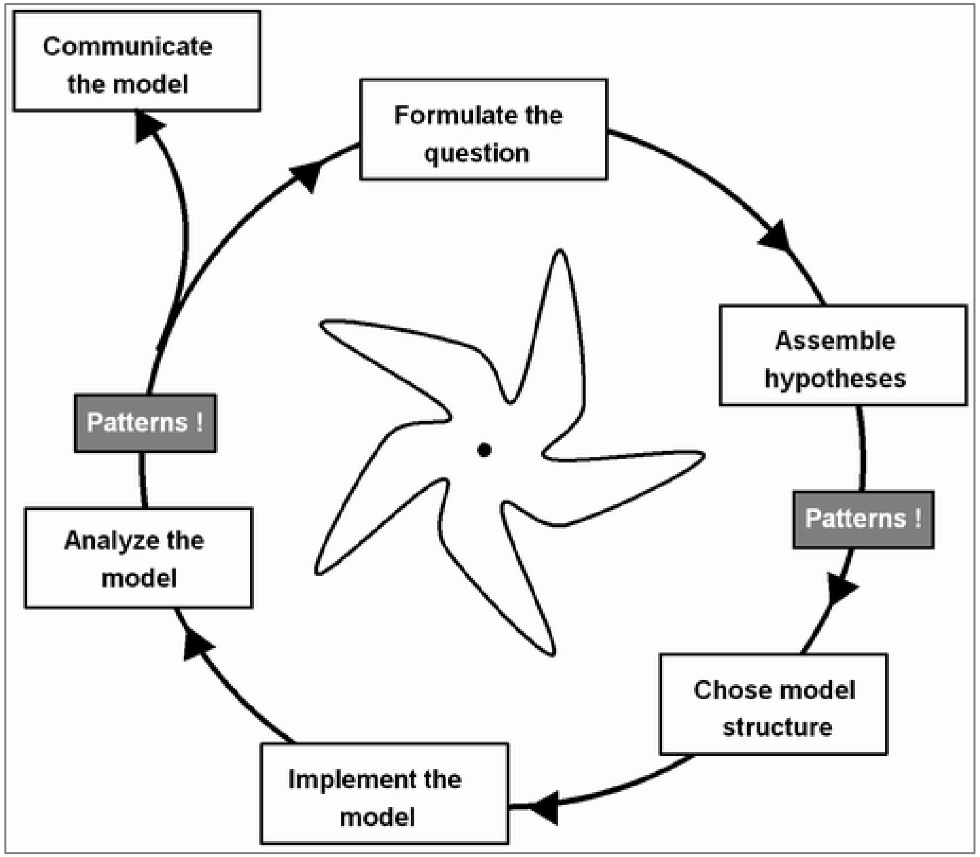
Analyze the model

- Usually, we do not **understand** immediately why a simulation model does what it does. So, we need to perform **controlled simulation experiments** to understand what is going on („What if I make the environment homogeneous, or double carrying capacity?“)
- Simulation experiments are designed and analyzed just as real experiments.
- This is the „hard“ science part of the cycle, which usually requires 95% of our time.

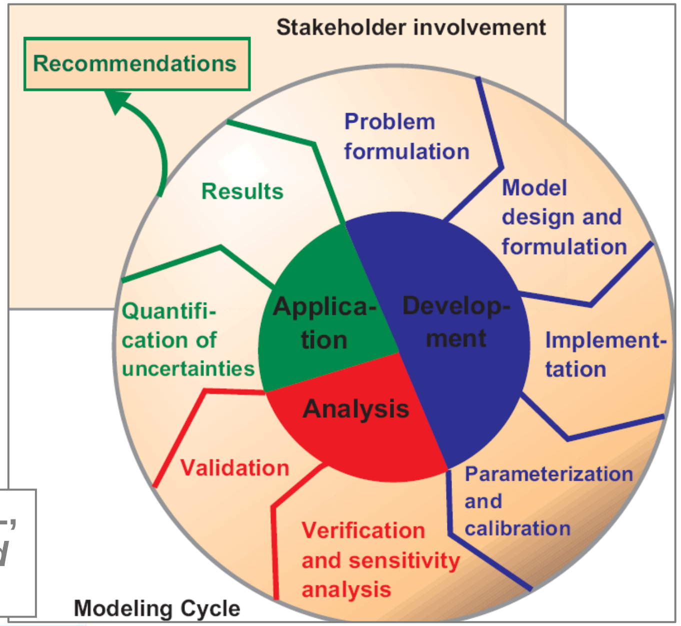
Communicate the model

- Like a lab protocol, model development has to be documented with written formulations.
- The final formulation should enable peers to fully understand and reimplement the model (→ ODD).

The modelling cycle



The role of „patterns“ will be explained later (pattern-oriented modelling, POM)



Schmolke A, Thorbek P, DeAngelis DL, Grimm V. 2010. *Trends in Ecology and Evolution* 25: 479-486

ODD: Overview – Design concepts - Detail

ECOLOGICAL MODELLING 198 (2006) 115–126

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

A standard protocol for describing individual-based and agent-based models

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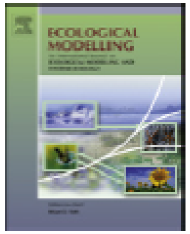

The ODD protocol: A review and first update

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ABSTRACT

The 'ODD' (Overview, Design concepts, and Details) protocol was published in 2006 to standardize the published descriptions of individual-based and agent-based models (ABMs). The primary objectives of ODD are to make model descriptions more understandable and complete, thereby making ABMs less subject to criticism for being irreproducible. We have systematically evaluated existing uses of the ODD protocol and identified, as expected, parts of ODD needing improvement and clarification. Accordingly, we revise the definition of ODD to clarify aspects of the original version and thereby facilitate future

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ODD

	Elements of the original ODD protocol (Grimm et al. 2006)	Elements of the updated ODD protocol
Overview	1. Purpose	**1. Purpose**
	2. State variables and scales	**2. Entities, state variables, and scales**
	3. Process overview and scheduling	**3. Process overview and scheduling**
Design concepts	4. Design concepts • Emergence • Adaptation • Fitness • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation	**4. Design concepts** • Emergence • Adaptation/Adaptive traits? • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation
Details	5. Initilization	**5. Initialization**
	6. Input	**6. Input data**
	7. Submodels	**7. Submodels**

1. Purpose

Question: **What is the purpose of the model?**

2. Entities, state variables, and scales

Questions:

What kinds of entities are in the model?

Agents, collectives, spatial units, global environment

By what state variables, or attributes, are these entities characterized?

Age, sex, wealth, opinion, strategy; soil type, land costs; rainfall, market price, disturbance frequency

What are the temporal and spatial resolutions and extents of the model?

3. Process overview and scheduling

Questions:

Who (i.e., what entity) does what, and in what order?

When are state variables updated?

How is time modeled, as discrete steps or as a continuum over which both continuous processes and discrete events can occur?

Except for very simple schedules, one should use pseudo-code to describe the schedule in every detail, so that the model can be re-implemented from this code. Ideally, the pseudo-code corresponds fully to the actual code used in the program implementing the ABM.

4. Design concepts

Questions:

There are **ten design concepts**. Most of these were discussed extensively by Railsback (2001), Grimm and Railsback (2005; Ch. 5), and in Railsback and Grimm (in press) and are summarized in the following questions:

Emergence

What emerges from the model (rather than being imposed)?

Adaptation

How do the agents adapt to improve their fitness? (Directly and indirectly)

Fitness

What are the goals of the agents? What determines their survival?

Prediction

How do agents predict the consequences of their decisions? Use of learning, memory, environmental cues, embedded assumptions

Sensing

What are agents assumed to know or perceive when making decisions?

Is the sensing process itself explicitly modelled?

Interaction

What forms of interaction among agents are there?

Stochasticity

Justification for any stochasticity in the model

Collectives

Grouping of individuals

Observation

How are data collected from the model for analysis?

5. Initialization

Questions:

What is the initial state of the model world, i.e., at time *t* = 0 of a simulation run?

In detail, how many entities of what type are there initially, and what are the exact values of their state variables (or how were they set stochastically)?

Is initialization always the same, or is it allowed to vary among simulations? Are the initial values chosen arbitrarily or based on data? References to those data should be provided.

6. Input data

Question:

Does the model use input from external sources such as data files or other models to represent processes that change over time?

7. Submodels

Questions:

What, in detail, are the submodels that represent the processes listed in “Process overview and scheduling”?

What are the model parameters, their dimensions, and reference values?

How were submodels designed or chosen, and how were they parameterized and then tested?

Example

2.2.1. Purpose

The model was designed to predict the probability of small re-introduced populations of wild dogs establishing themselves and persisting in the release area under various scenarios, including regular translocation of disperser groups.

Gusset et al. 2009

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Example

2.2.2. State variables and scales

The three entities included in the model were individuals, packs and disperser groups. Individuals were characterized by their state variables sex, age, social status and pack or disperser group membership. A pack was defined as a reproductive unit (either newly formed or established, see below) that contained a dominant pair, potentially also including pups as well as subordinate yearlings and adults of both sexes. Pups were less than one, yearlings between one and two, and adults more than 2 years of age. A disperser group consisted of one or more same-sexed individuals originating from the same pack. Time proceeded in discrete steps of 1 year. The model was not spatially explicit to make it more generally applicable and because disperser groups are highly mobile; however, space was indirectly included in the model by considering the ecological capacity for wild dogs in HiP (see below).

Gusset et al. 2009

Example

2.2.3. Process overview and scheduling

The fate of each individual in the population was traced from birth to death. Within each year, the following processes were simulated in the given (biologically meaningful and computationally practical) order for each of the given entities: ageing (individuals), reproduction (packs), dispersal (individuals), pack formation (disperser groups), mortality (individuals), catastrophes (individuals), management interventions (packs and disperser groups) and dominance (packs). Individuals, packs and disperser groups were processed in a randomized sequence every year. The rules defining the above processes are described in Section 2.2.7 below.

2.2.4. Design concepts

2.2.4.1. Emergence. Wild dog population and pack dynamics emerged from the behaviour of individuals, but individual behaviour was entirely imposed by probabilistic empirical rules. No Allee effects at the pack level were imposed onto the model, as no such effects were observed in the population modelled here (Somers et al., 2008). However, possible Allee effects were allowed to emerge from the model.

2.2.4.2. Interaction. Four types of interaction were modelled implicitly: (i) within each pack, dispersing individuals of the same sex formed a disperser group, (ii) formation of a new pack was

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Example

2.2.5. Initialization

Simulations started with a specified number of packs and individuals per pack, but no disperser groups. One male and female per pack were randomly selected as dominants. Sex and age of individuals in initial packs was random: the probability of being male was 0.50 and age was uniformly distributed from 1 to 6 years.

2.2.6. Input

The model did not include any environmental variables as driving the population, as competitor density, amount of rainfall and prey availability did not significantly influence the population modelled here (Somers et al., 2008). Environmental variation was represented by environmental stochasticity and random catastrophic events.

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Example

2.2.7. Submodels

2.2.7.1. Ageing. The age of all individuals increased by 1 year. All individuals that reached their observed maximum age of 9 years died (Somers et al., 2008).

2.2.7.2. Reproduction. Both males and females could theoretically become dominant and reproduce from 1 to 8 years of age, with only packs that contained a dominant pair potentially reproducing (Somers et al., 2008). The probability of a pack reproducing in a given year was piecewise density-dependent, which best matched the observed linear negative density dependence in population growth rate (Somers et al., 2008). HiP's ecological capacity for wild dogs, based on the availability of the most important prey species, was estimated to be at $N = 62$ (Lindsey et al., 2004), with N being the total number of all adults and yearlings plus half the number of pups. If N was smaller than half of the ecological capacity, a litter was added annually with an observed probability 0.33 to newly formed packs (i.e. in the first breeding season after formation)

ODD Update

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Details	5. Initilization	**5. Initialization**
	6. Input	**6. Input data**
	7. Submodels	**7. Submodels**

Big surprise with ODD

- Originally designed merely for **communication** (in publications)
- Turns out to **change your way of formulating and designing** ABMs in the first place!!
- You start **thinking and speaking – ODD**
- You start **expecting** others to speak ODD, to better understand what they do and mean

Remark: ODD and NetLogo match well

	Elements of the updated ODD protocol	NetLogo elements
Over-view	1. Purpose	Information tab
	2. Entities, state variables, and scales	breeds, turtles-own, patches-own, globals
	3. Process overview and scheduling	“go” procedure
Design concepts	4. Design concepts • Emergence • Adaptation/Adaptive traits? • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation	• Information tab • primitives • plots, monitors, agent monitors, file output
Details	5. Initialization	“setup” procedure
	6. Input data	file input
	7. Submodels	procedures, reporters

How to implement IBMs?

All-purpose programming languages (C++, Delphi, Java, etc.)

- **You can do anything you want (flexibility)**
- You have to implement anything you want yourself. Almost nothing that supports IBMs is provided ready-to-use
- No observer facilities
- Platforms often proprietory

Software libraries designed for IBMs (Swarm, Repast, Mason)

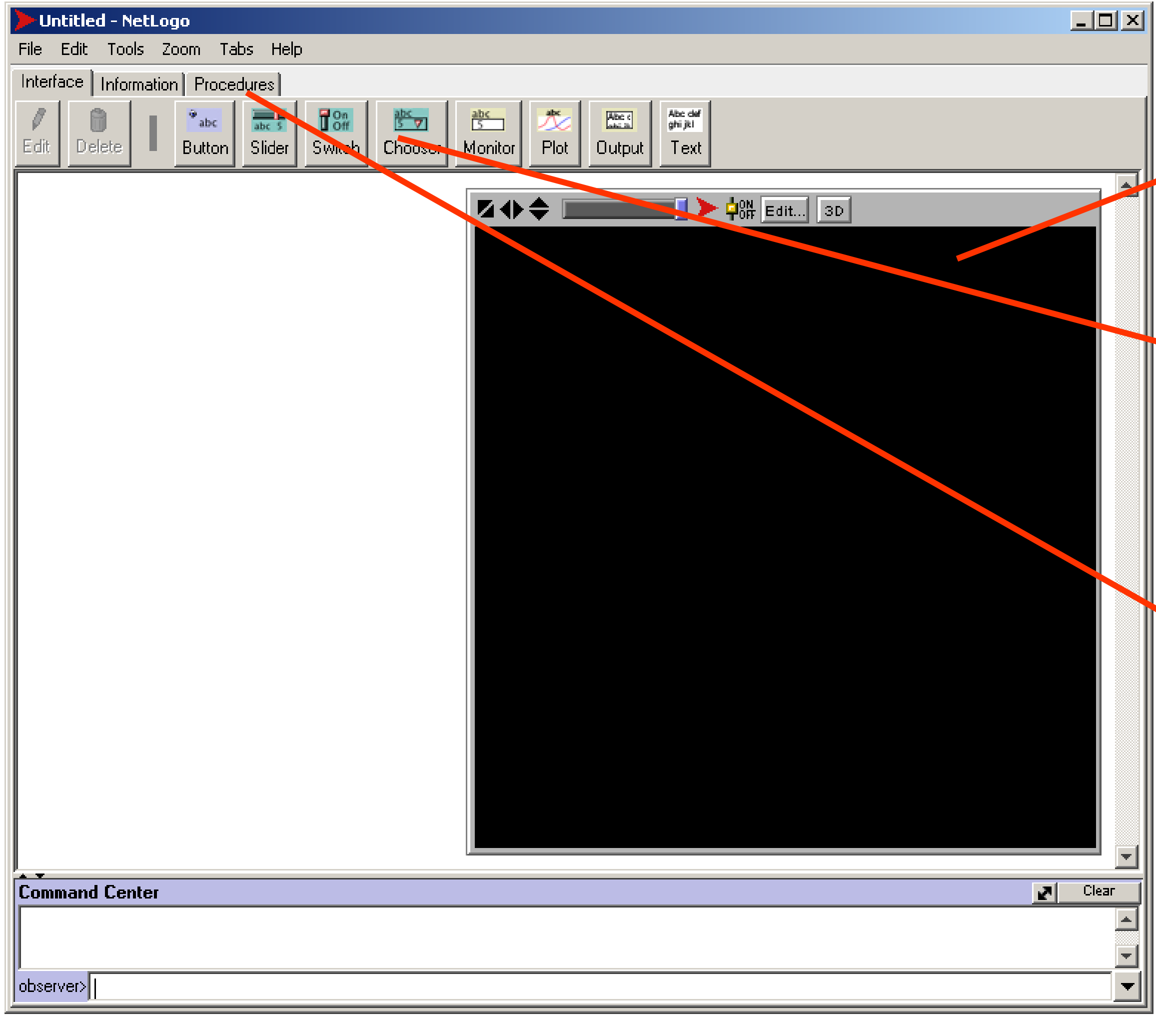
- **You can do anything you want (flexibility)**
- **Many IBM-specific things provided, including observer tools**
- **Free (based on Objective C or Java)**
- **User communities**
- **Easier to share code with others (same design concepts)**
- Steep learning curve (unsuitable for beginners course)

NetLogo

Integrated software platforms (NetLogo)

- **Easy to use for beginners (good for courses)**
- **Powerful concepts (patches, turtles, ask)**
- You can probably do (almost) anything you want, but that might sometimes require work-arounds
- **Very easy to share code**
- **Very good documentation**
- **User community**
- **Maintained by active group (Northwestern University)**
- Look and feel of video games
- Can be too slow (interpreter)
- Model library gives an incomplete idea of NetLogo
- **Inceasingly used for „serious science“**

How it looks like



World, consisting of grid of patches

Elements for user inteface (drag & drop)

Procedures tab to write program

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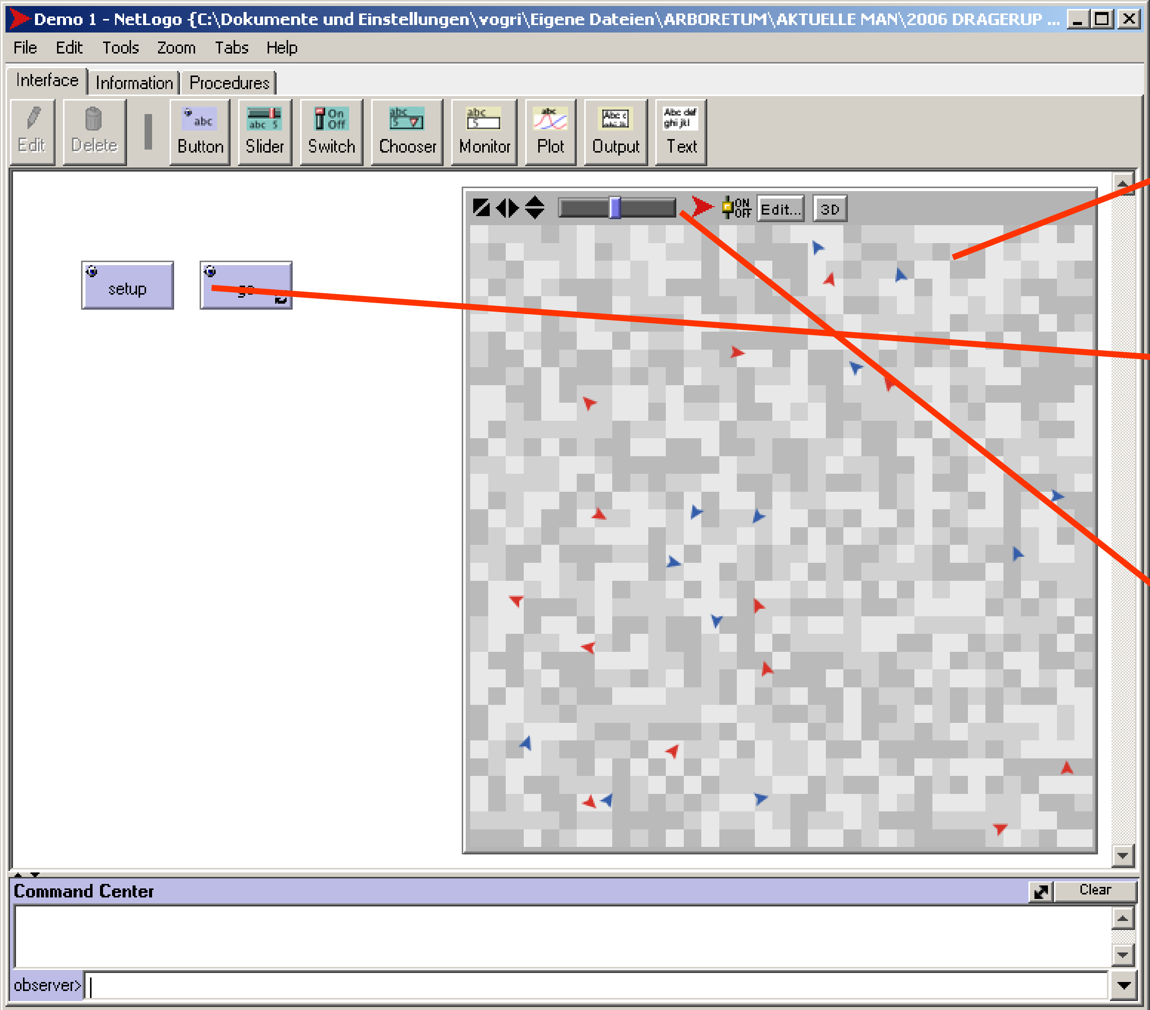
Procedures tab



World, consisting of grid of patches with 25 turtles

Setup and go buttons

Slide to slow down simulation. Edit to change size and geometry of the world

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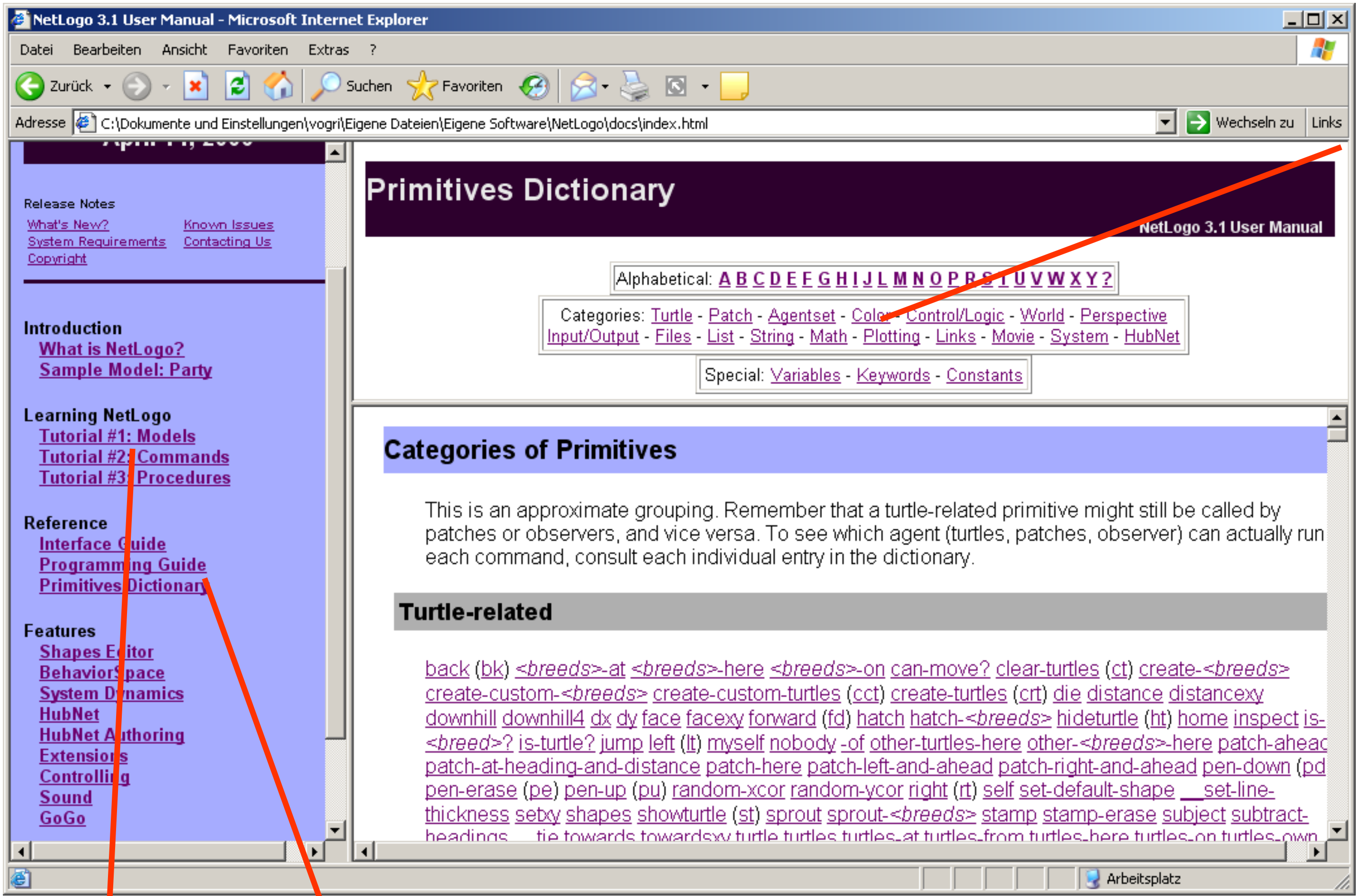
Help

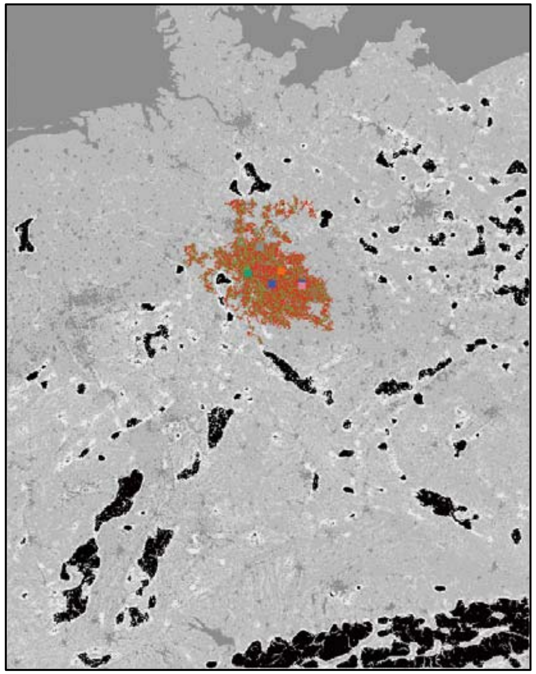


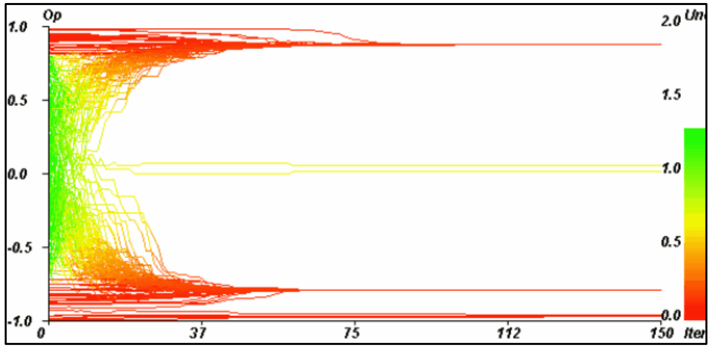
Primitives (=command) grouped and alphabetically

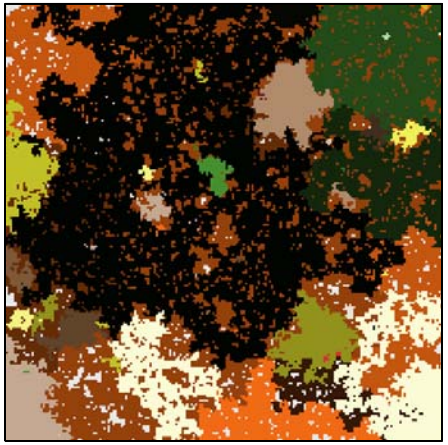
Tutorials

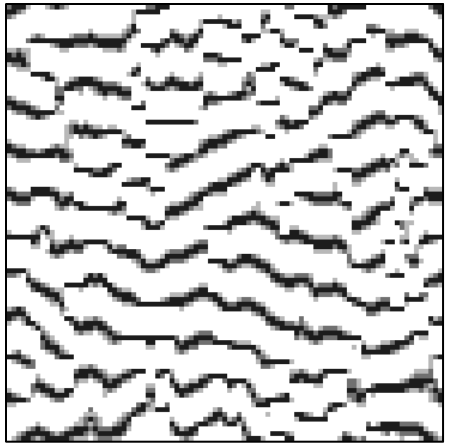
You should always switch between Programming Guide and Primitives Dictionary. Check also: Code Examples and Model Library.

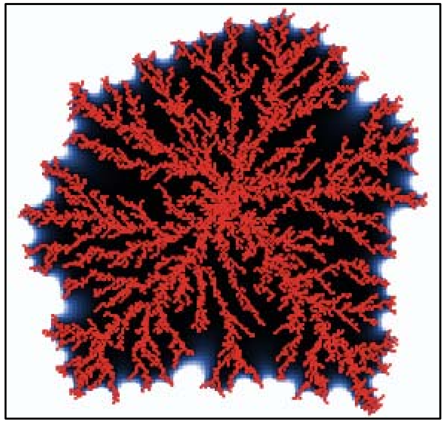
NetLogo











NetLogo

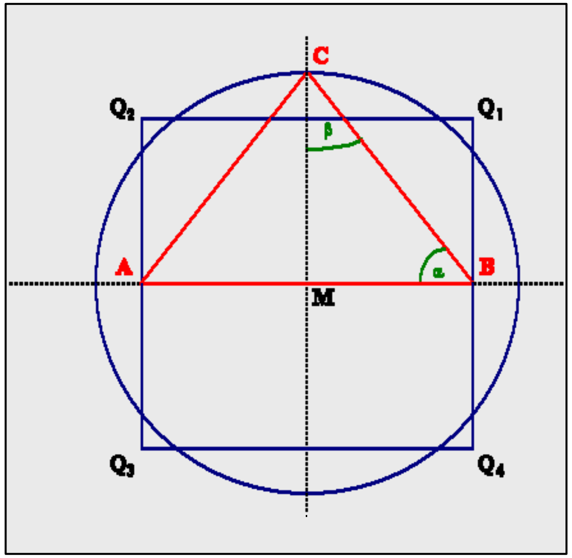
Demonstration tour…

Summary so far

- What is a model?
- Individual-based modelling
- The Modelling Cycle
- The ODD protocol
- NetLogo (including a demo tour)

- Pattern-oriented modelling

Pattern-oriented Modelling



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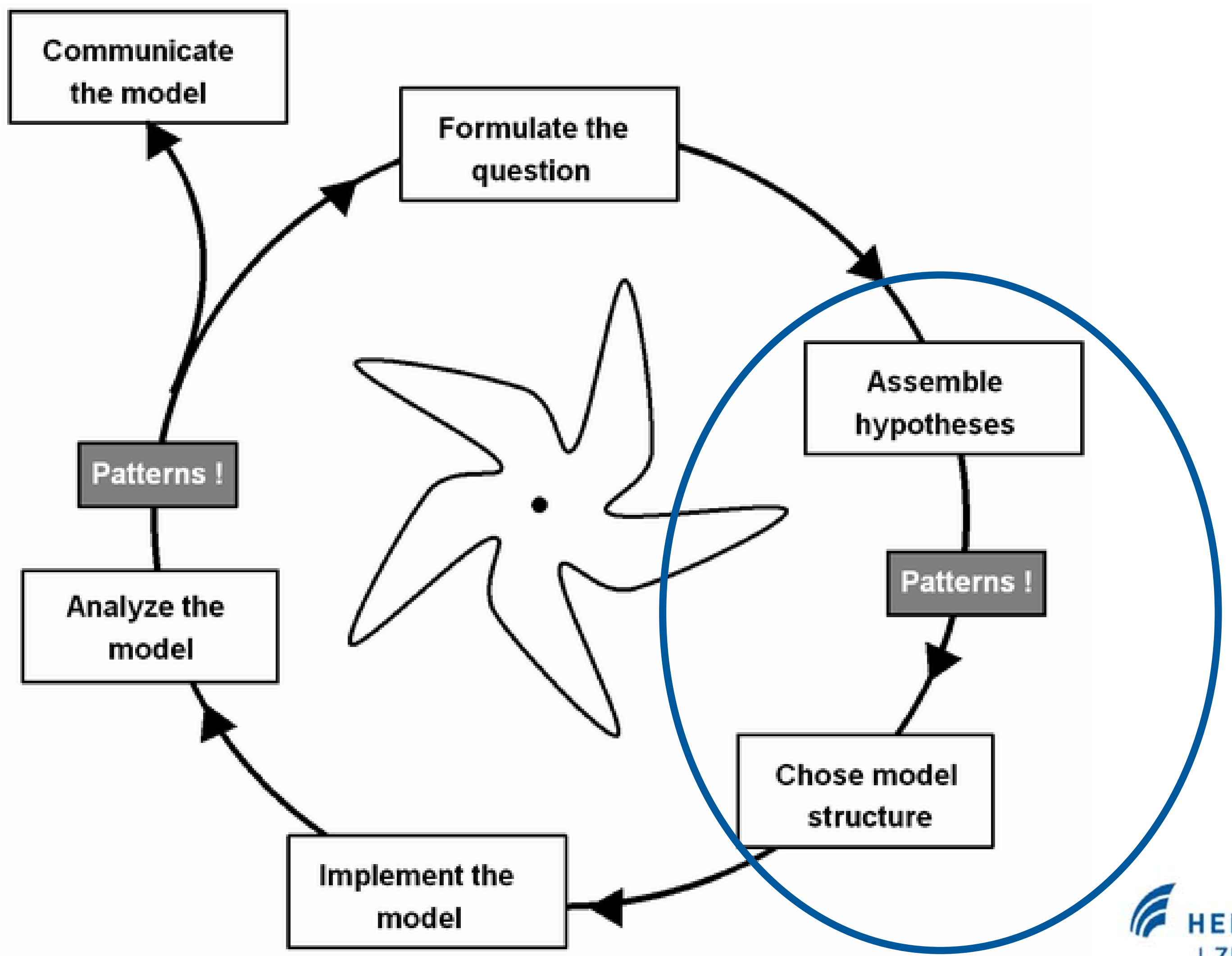
The modelling cycle



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Problem: verification and validation

- **We want to make sure that our models are “sufficiently good” representations of their real counterparts.**
- **We want to learn about the real world**
- **We want to capture essential elements of a real system’s “internal organization”**
- **We want to capture the “generative mechanisms” that generate the structure and behavior of real systems**

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Problem: verification and validation

V1

the model "mimics the real world well enough for its stated purpose (Giere, 1991)" (Rykiel 1996, p. 230).

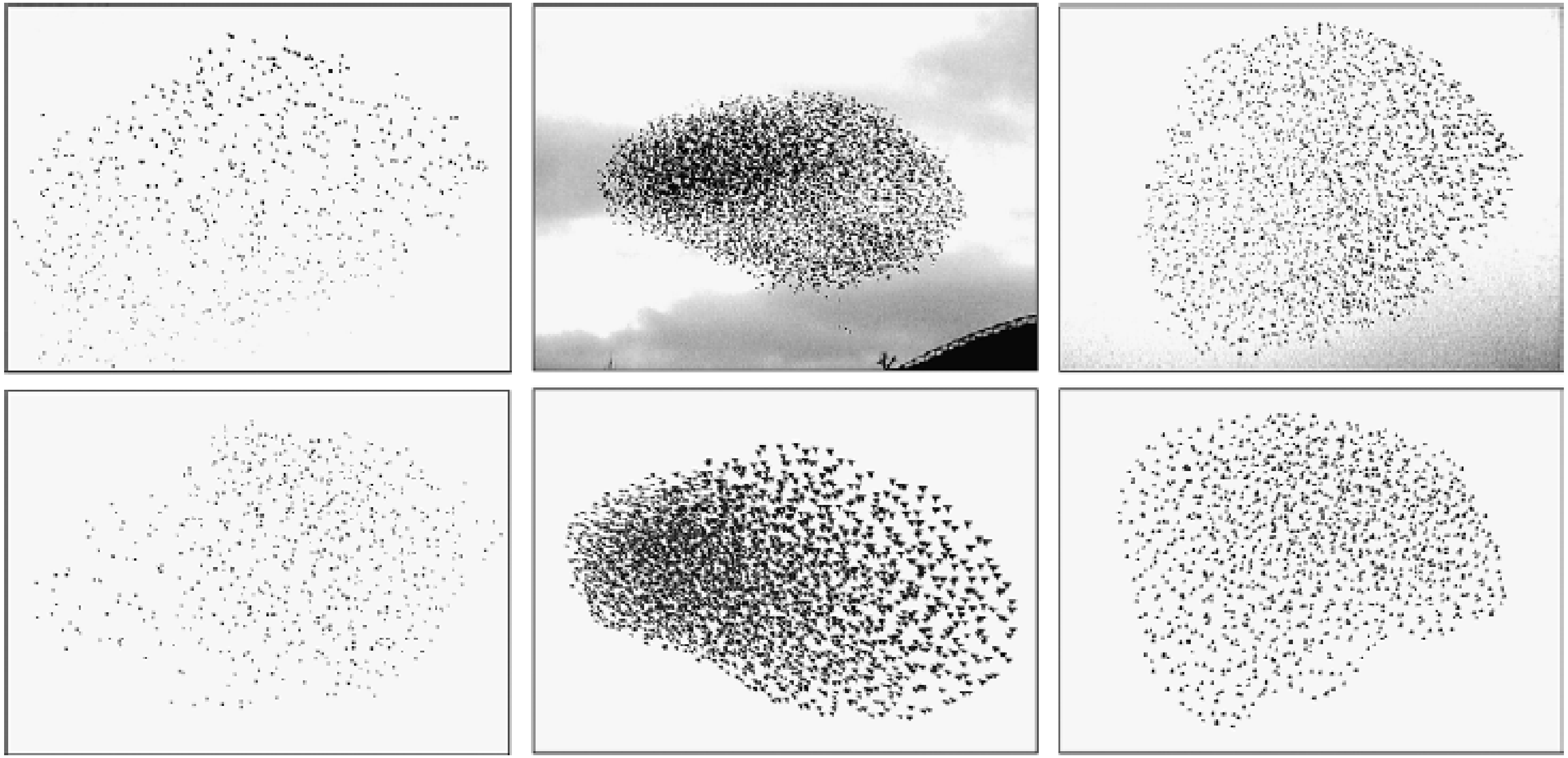
V2

we can place confidence "in inferences about the real system that are based on model results (Curry et al., 1989)" (Rykiel 1996, p. 230)

Note:

Rykiel combines both aspects under one term, validation

Rykiel 1996



Hildenbrandt et al. 2010

Fundamental problem

- Our model might reproduce the right pattern for the wrong reasons
- How can we be sure to capture the real „generative mechanisms“?
- How can we design models so that we „optimize“ model complexity?

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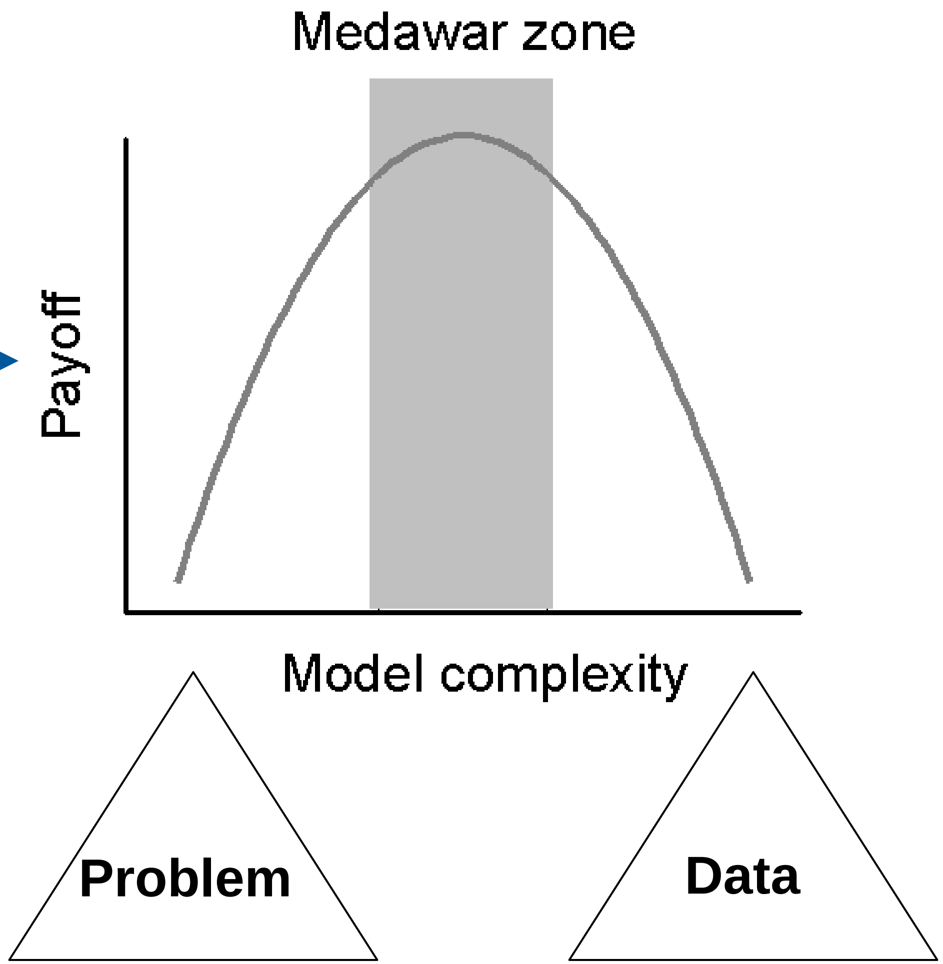
The Medawar zone

Verification

Validation



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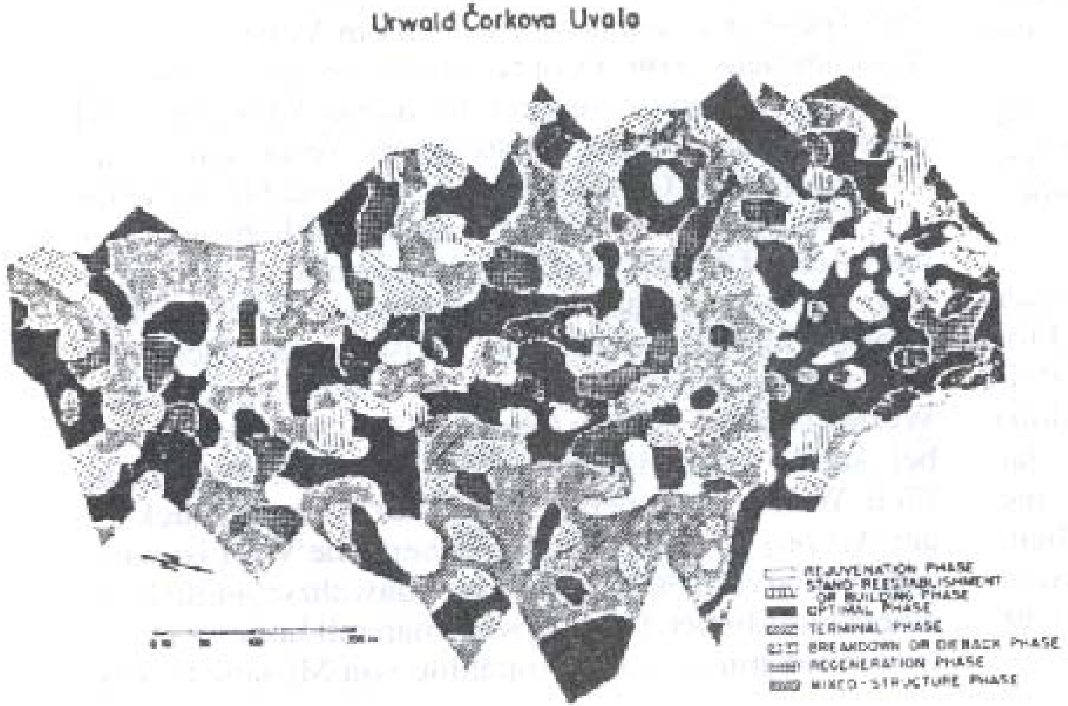
“Mechanisticially rich models”

- If a model is too poor in structure, it will not be able to capture essential mechanisms
- There will be too few means to test (validate) the model
- „Complexity“ of model is not bad per se, but can increase the payoff

DeAngelis and Mooij 2003

Example: Beech forests

Pattern I: Mosaik of developmental stages



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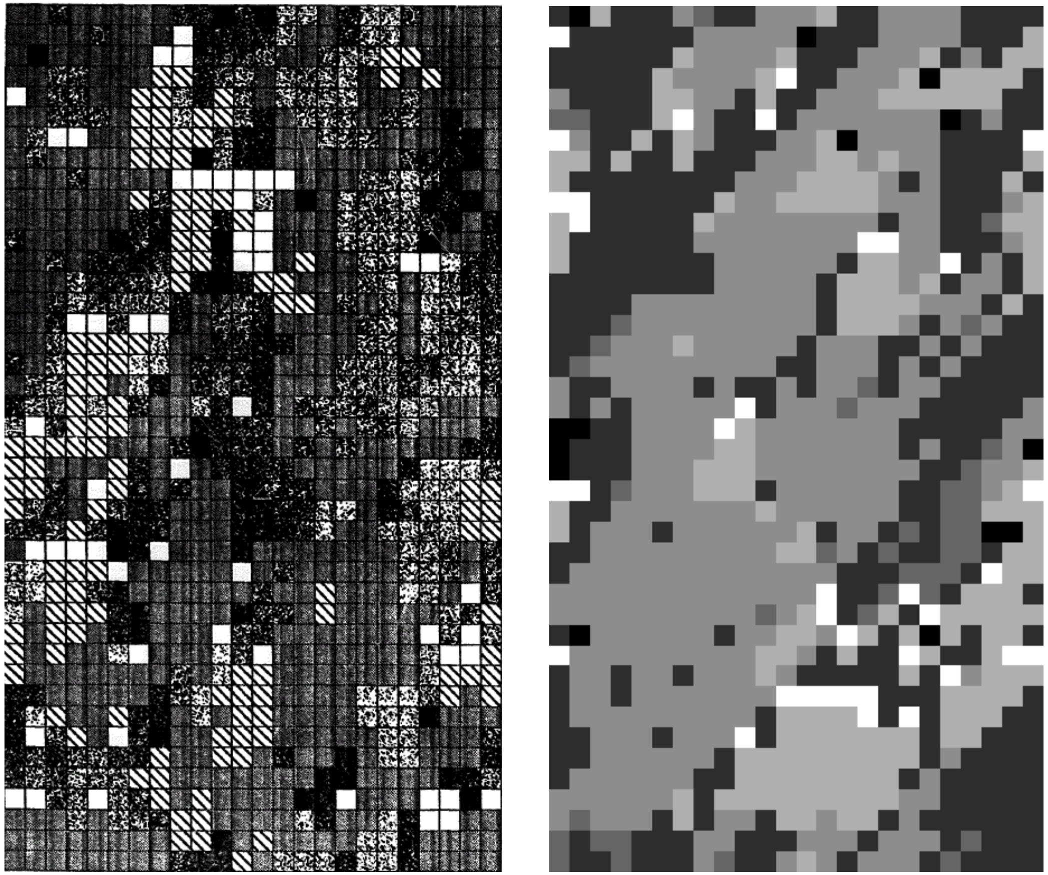
Example: Beech forests

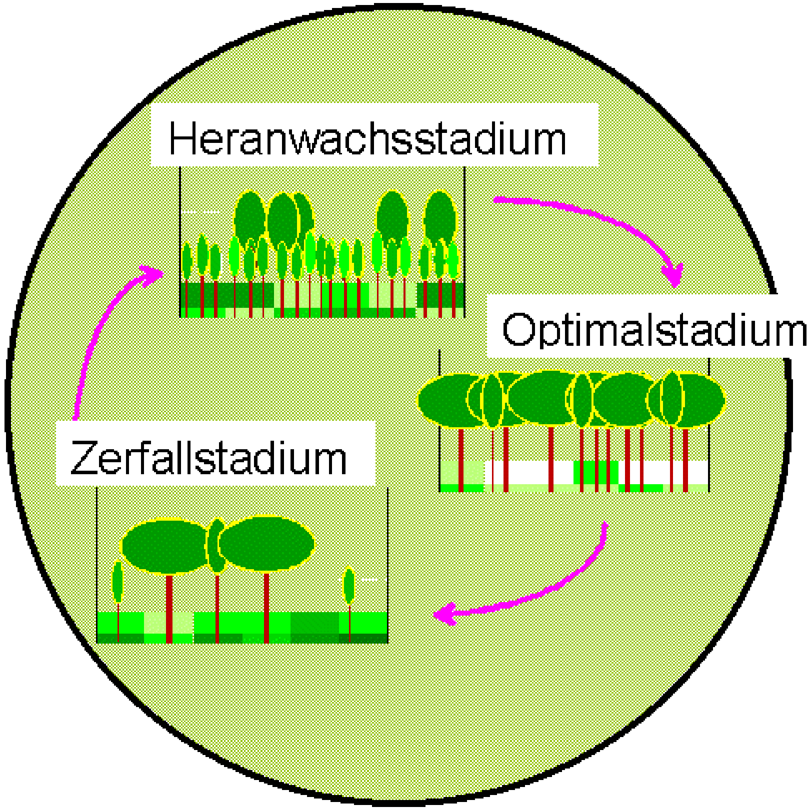
Pattern I: Mosaik of developmental stages



Wissel 1992

Example: Beech forests

Pattern II: Vertical structure - Cycles



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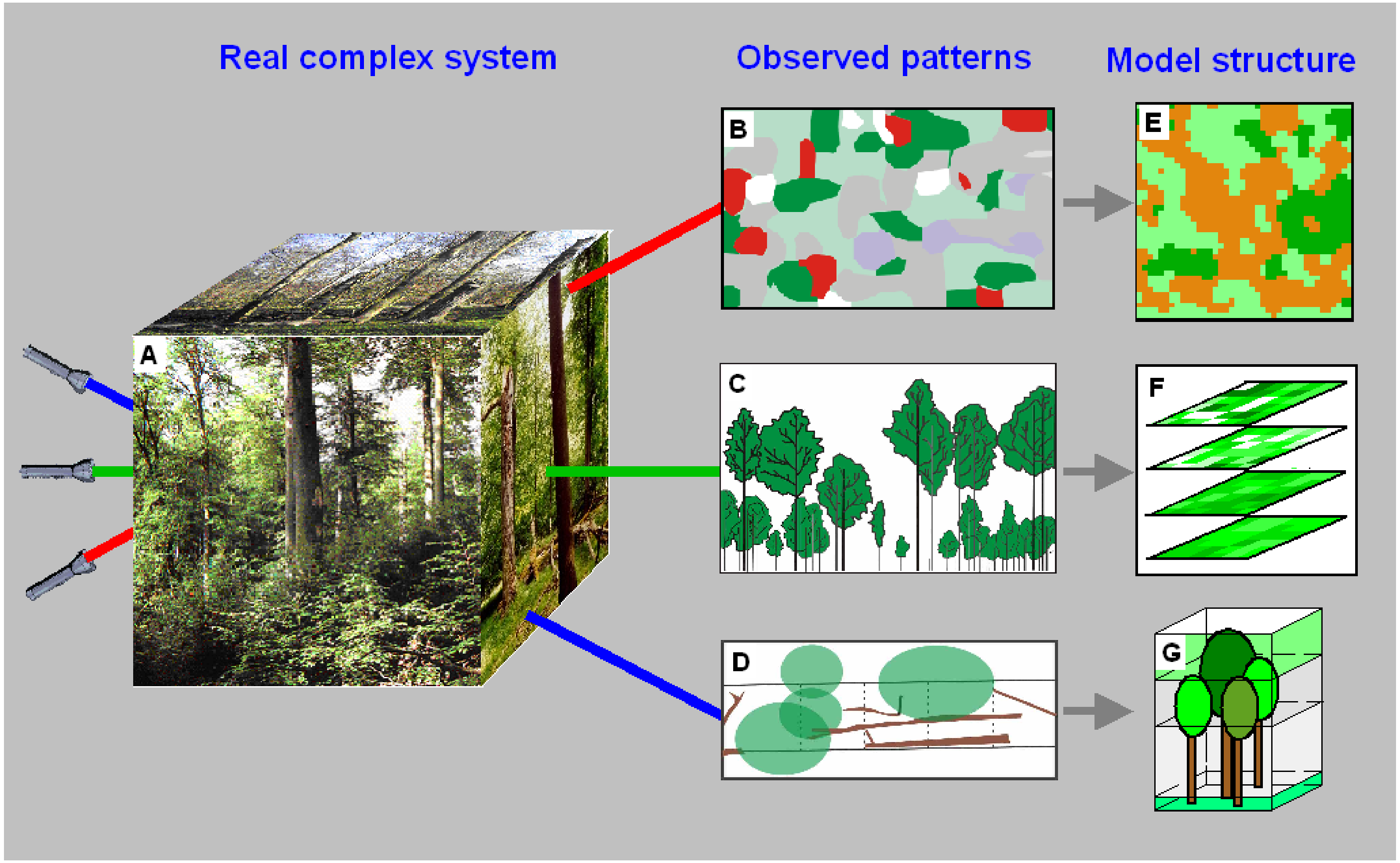
Example: Beech forests



Rademacher et al. 2004, Grimm et al. 2005

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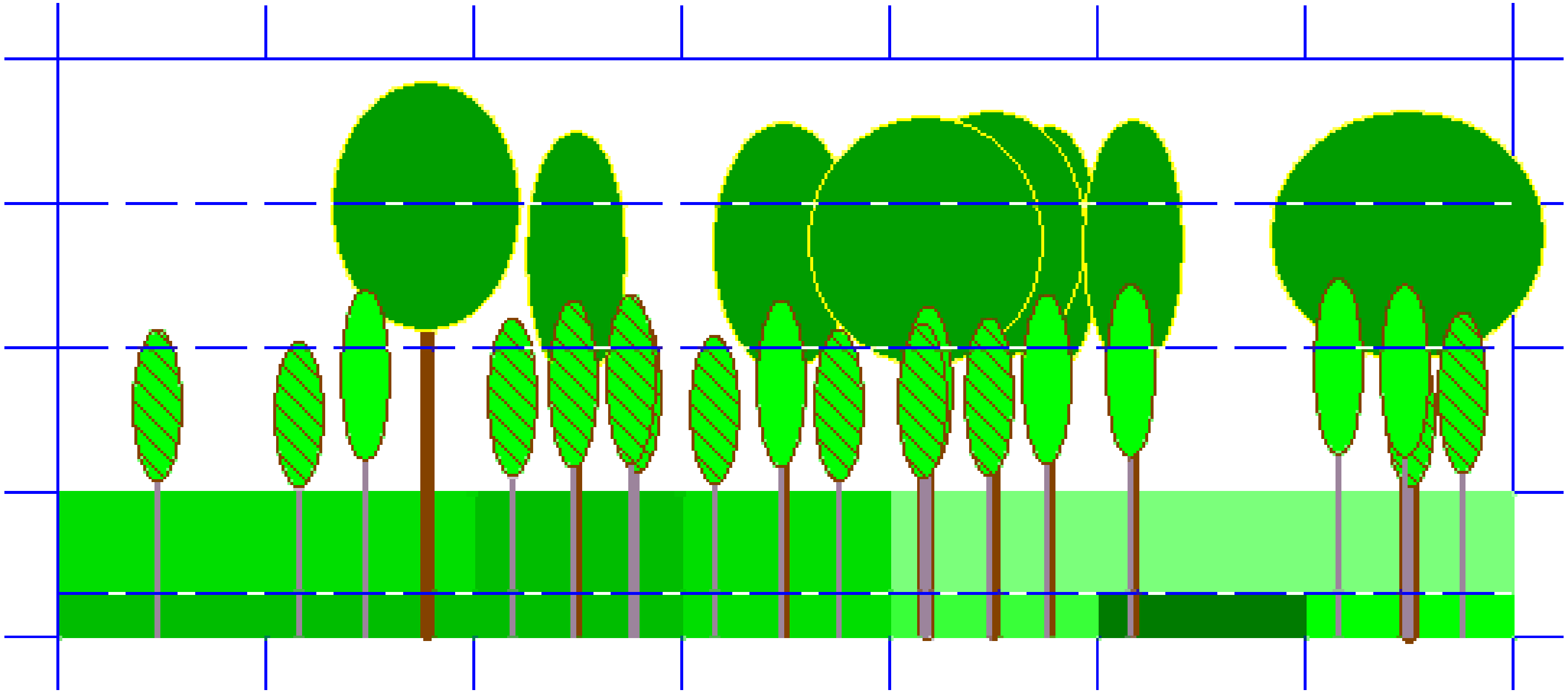

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Verification

Occurrence of mosaic pattern ✓

Size of mosaic patches 0,3 ha (model) / 0,1- 2 ha (Remmert) ✓

Duration of stages ✓

	Modell	(Korpel)
Development	105	85-100
Optimal	45	40-50
Decay	120	95-110

(Percentage total area)

Modell	(Korpel)
35,7 ± 11,9	34 – 43
20,3 ± 9,3	20 – 22
44,1 ± 11,8	42 – 45

Succession of stages: 90% right, only in 3% wrong ✓

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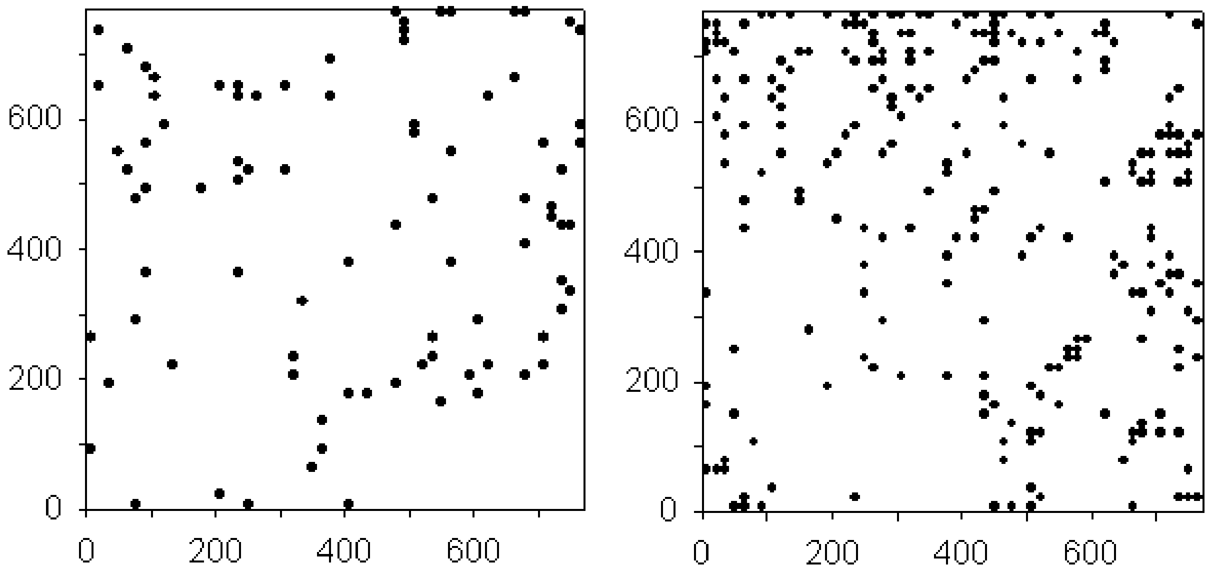
Validation

- **Age structure in the canopy ✓**
- **Spatial distribution of very large (or old) trees („giants“) ✓**
- **Amount and spatial distribution of dead wood**



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Why did it work?

- Model structure oriented towards MULTIPLE patterns.
- This makes model rich in structure and mechanism (but not too rich).
- This richness allows to analyze the model from different perspectives.
- This allows for independent predictions.
- If the predictions are OK, we know that the model is „structurally realistic“ (contains essential key structures and processes).
- If all this is so, the model can easily be adjusted to other questions.

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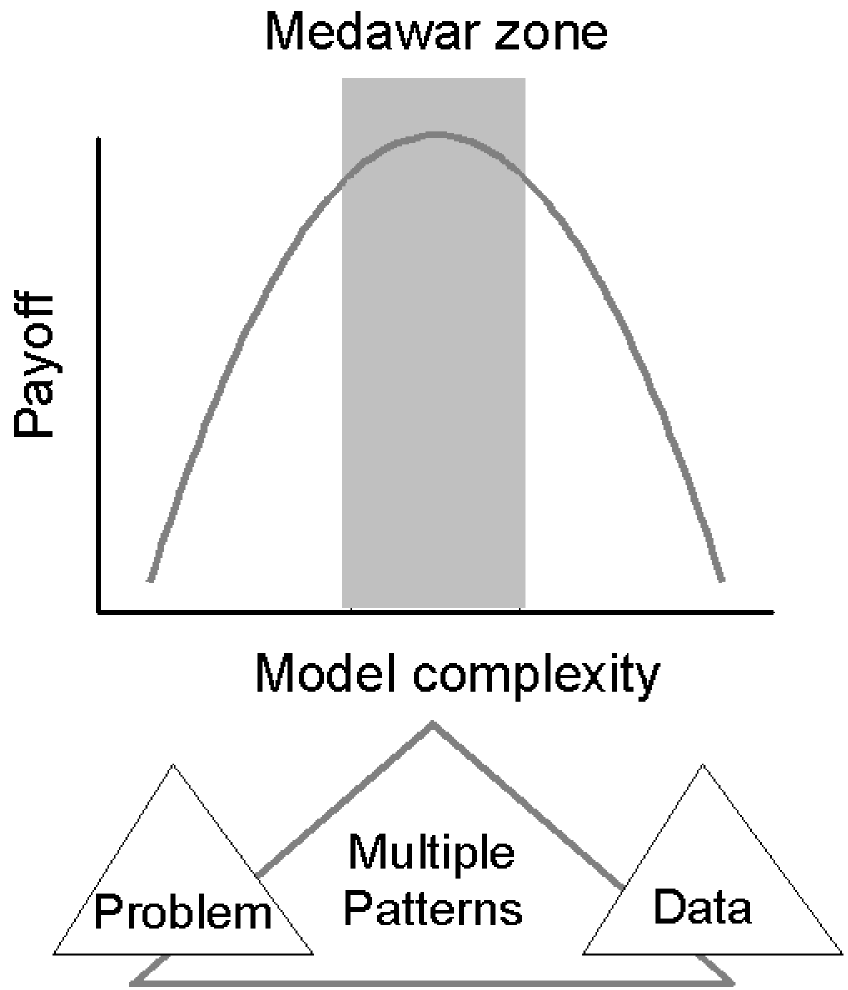
POM = Systematic use of Multiple Patterns



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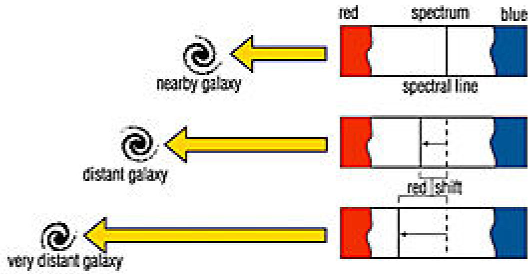
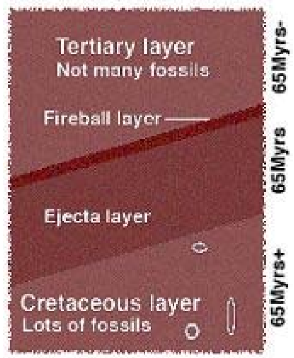
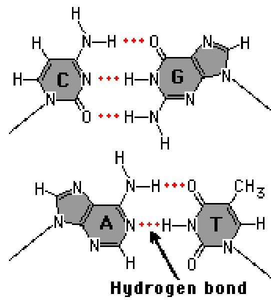
Patterns: Examples

- Red shift in spectra of galaxies and stars
- Atomic spectra
- Iridium layer: mass extinctions
- Chargaff's rule
- DNA
- Exercise: Scan your textbooks for patterns that were key to decode internal organizations







Spatial patterns in ecology

http://www.gov.nf.ca/nfmuseum/images/empetrumnigrumlivedeadwaveforestmistakenpoint.jpg

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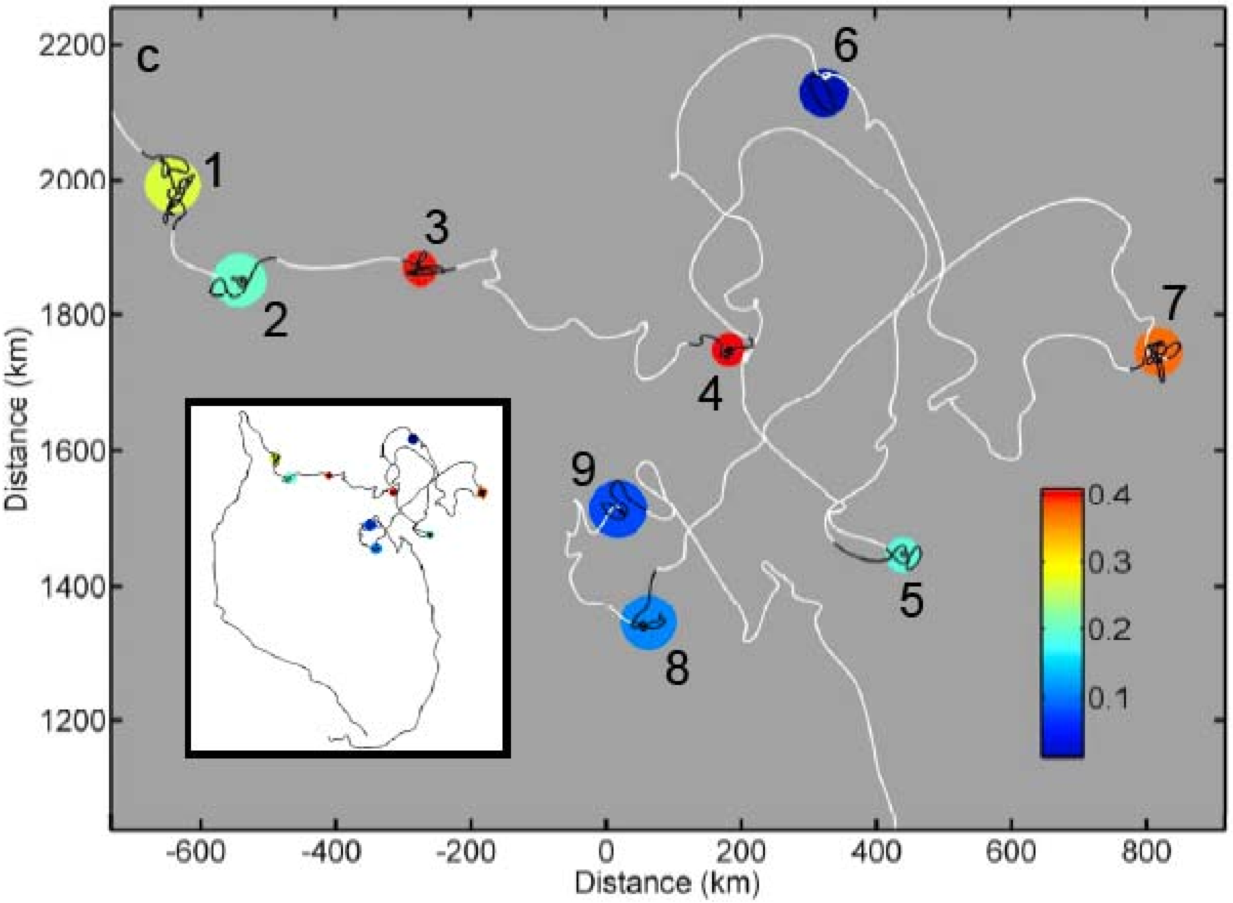
Spatial patterns in marine ecology



Tremblay et al. (unpublished)

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Learn to see also “weak patterns”

Patterns as filters

- Multiple (3 or more) „weak“ patterns may narrow down model structure better than one single „strong“ pattern
- Cycles in small mammals („strong“)
- Abundance within certain bounds
- Recovery after disturbance needs 10 years
- Territory size changes with abundance in a certain way

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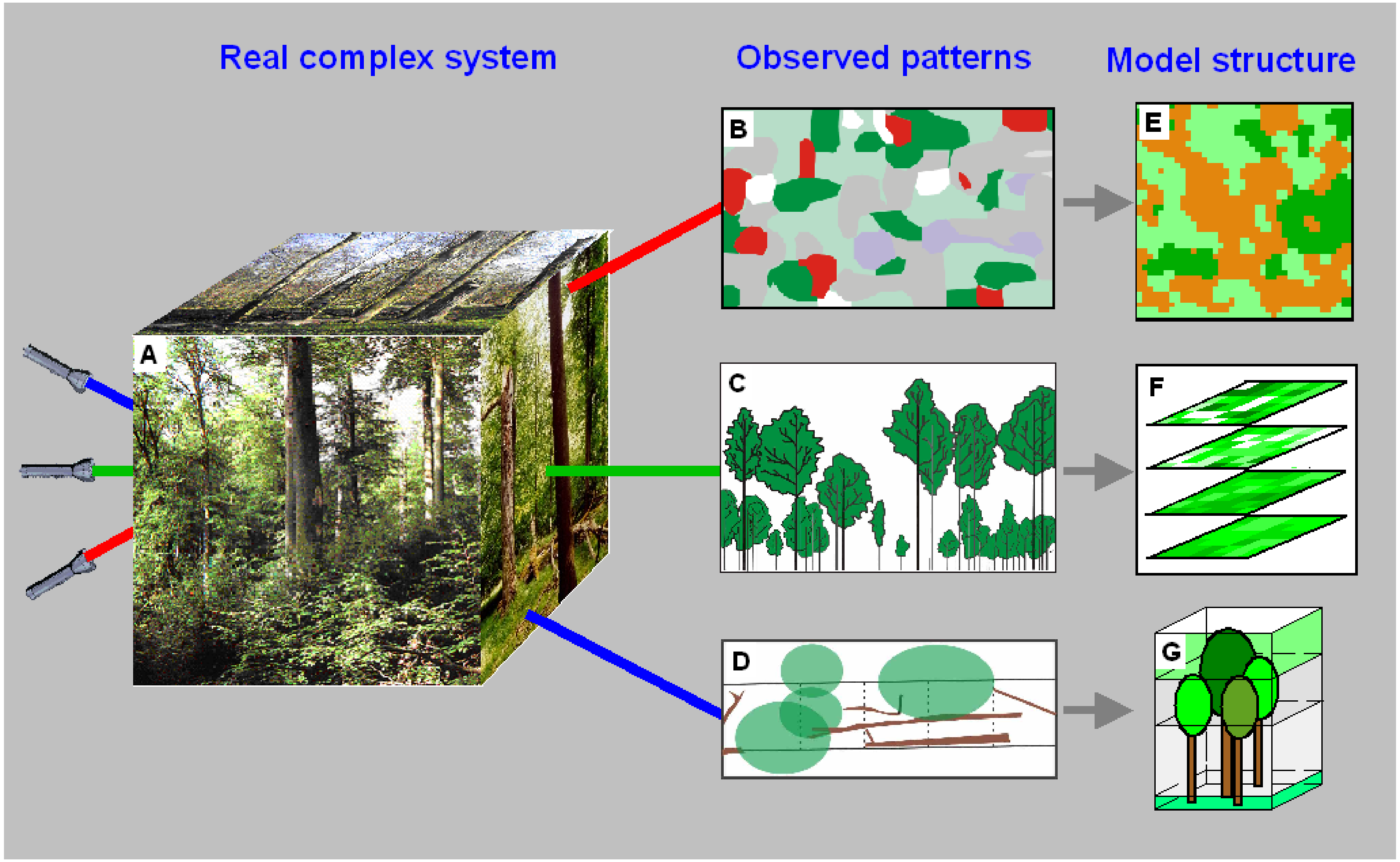
Pattern-oriented Modelling: Three elements

1. **Provide state variables so that patterns observed in reality in principle also can emerge in the model**
2. **Contrast alternative theories (=models) of certain adaptive behaviours**
3. **Use multiple patterns to determine entire sets of unknown parameters („inverse modelling“)**

Pattern-oriented Modelling

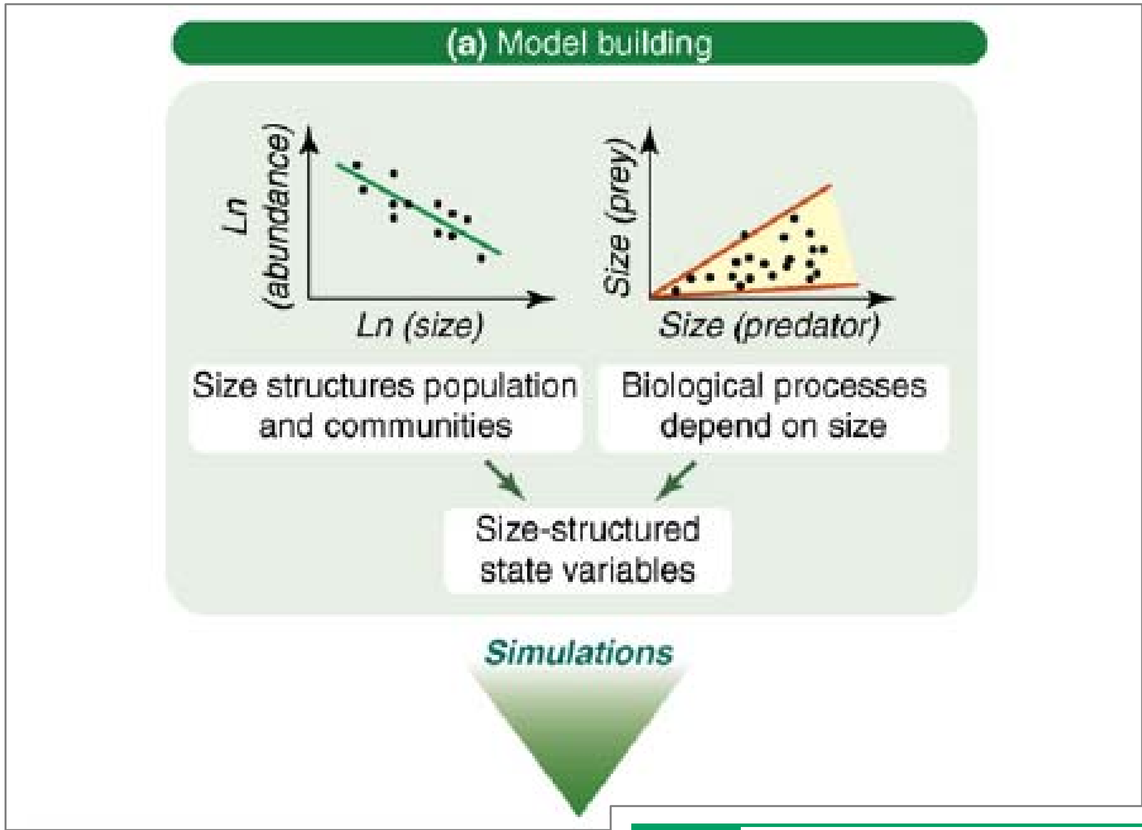
1. **Multi-criteria design of models**
2. **Multi-criteria assessment of models (verification, validation)**
3. **Multi-criteria inverse parameterization of models**

Pattern-oriented Modelling 1/3: Design



Grimm et al. 2005
Rademacher et al. 2004

Pattern-oriented Modelling 1/3: Design



Review

Ecosystem oceanography for global change in fisheries

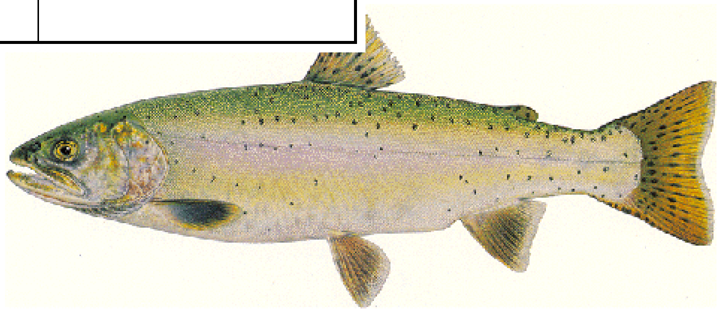
Philippe Maurice Cury[1], Yunne-Jai Shin[1], Benjamin Planque[2], Joël Marcel Durant[3], Jean-Marc Fromentin[4], Stephanie Kramer-Schadt[5], Nils Christian Stenseth[3,6], Morgane Travers[1] and Volker Grimm[7]

Grimm et al. 2005
Rademacher et al. 2004

Pattern-oriented Modelling 2/3: assessment

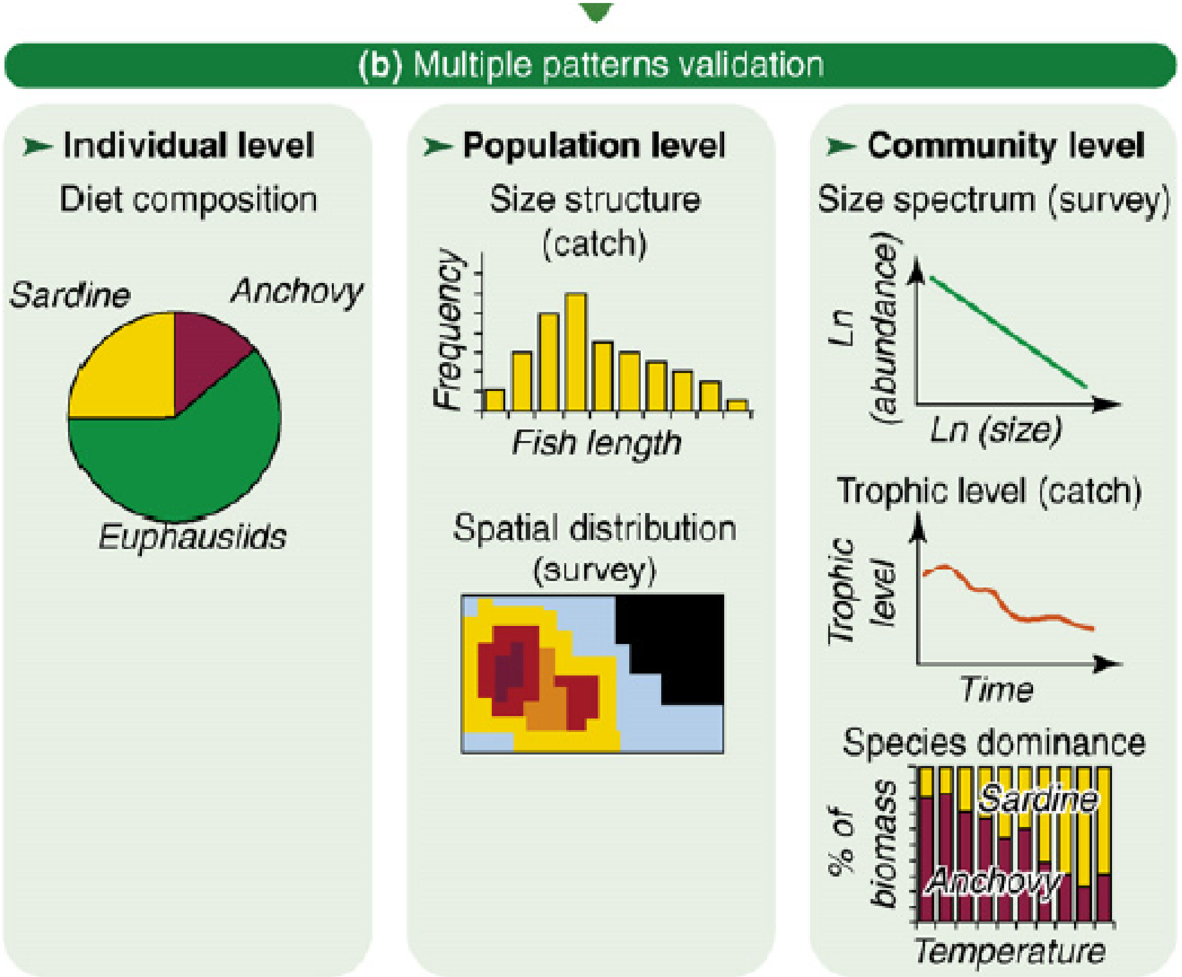
Pattern	Maximize growth	Maximize survival	State-based, predictive
Hierarchical feeding	✔		✔
Response to high flow	✔	✔	✔
Response to inter-specific competition	✔		✔
Response to predatory fish		✔	✔
Seasonal velocity preference			✔
Response to reduced food availability			✔

Railsback and Harvey 2002



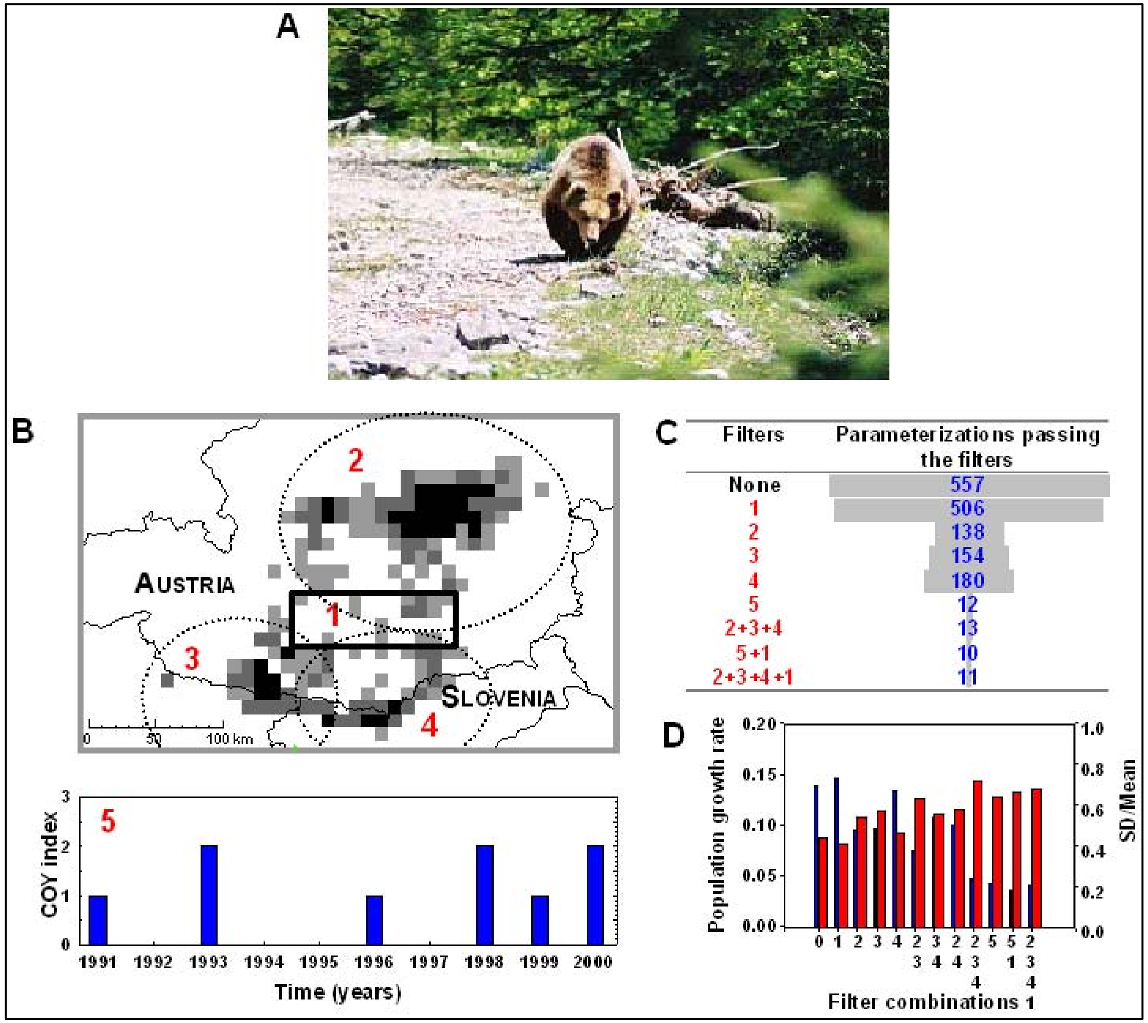
Lahontan Cutthroat Trout
Oncorhynchus clarki henshawi

Pattern-oriented Modelling 2/3: assessment



TRENDS in Ecology & Evolution

Pattern-oriented Modelling 3/3



Wiegand et al. 2005

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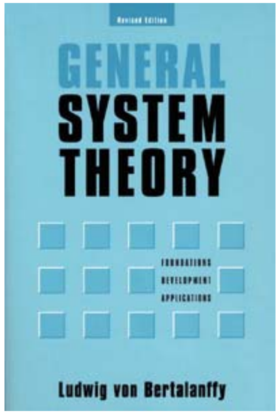
Pattern-oriented System Science



- It is neither bottom-up nor top-down, but we need both perspectives to capture the essence of complex systems
- **Patterns are the key to decode complex systems**
- **POM is good for you!**

Readings on POM

- **Ze Book I: Grimm and Railsback 2005**
- **Ze Book II: Railsback and Grimm 2010**
- **Review: Grimm et al. 2005**

REVIEW

Pattern-Oriented Modeling of Agent-Based Complex Systems: Lessons from Ecology

Volker Grimm,[1*] Eloy Revilla,[2] Uta Berger,[3] Florian Jeltsch,[4] Wolf M. Mooij,[5] Steven F. Railsback,[6] Hans-Hermann Thulke,[1] Jacob Weiner,[7] Thorsten Wiegand,[1] Donald L. DeAngelis[8]

Agent-based complex systems are dynamic networks of many interacting agents; examples include ecosystems, financial markets, and cities. The search for general principles underlying the internal organization of such systems often uses bottom-up simulation models such as cellular automata and agent-based models. No general framework for designing, testing, and analyzing bottom-up models has yet been established, but recent advances in ecological modeling have come together in a general strategy we call pattern-oriented modeling. This strategy provides a unifying framework for decoding the internal organization of agent-based complex systems and may lead toward unifying algorithmic theories of the relation between adaptive behavior and system complexity.

What makes James Bond an agent? He has a clear goal, he is autonomous in his decisions about achieving the goal, and he adapts these de-

Bottom-up models have been developed for many types of ACSs (*4*), but the identification of general principles underlying the organization of ACSs has been hampered by

Ecology, in the past 30 years, has produced as many individual-based models as all other disciplines together have produced agent-based models (*13*), and has focused more on bottom-up models that address real systems and problems (*14*).

We describe here how observed patterns can be used to optimize model structure, test and contrast theories for agent behavior, and reduce parameter uncertainty. Finally, we discuss POM as a unifying framework for the science of agent-based complex systems in general.

Patterns for Model Structure:

Summary POM

- Patterns characterize system
- POM means to „decode“ these patterns
- Try and identify „internal organization“ of systems
- Multiple patterns – multi-criteria assessment
- Patterns as filters

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Summary

- What is a model?
- Individual-based modelling
- The Modelling Cycle
- The ODD protocol
- NetLogo (including a demo tour)

- Pattern-oriented modelling

Study questions

1. Go through the NetLogo tutorials
2. Get copies of the ODD papers from the internet and formulate the Overview and Design concepts part of your model (or an existing model)
3. List patterns that characterize your system of interest (include references, if possible). How could they affect model design?
4. What would be the 1-3 key behaviors of individuals in your model?