



Trans4Num: Exchange on agent-based modelling between CAU/CAAS & FiBL

Workshop

26.03.2024

Team



Anke Möhring
Department of
Food System Sciences



Claudia Meier
Department of
Food System Sciences



Christian Grovermann
Department of
Food System Sciences



Adrian Müller
Department of
Food System Sciences
Project Leader Trans4Num

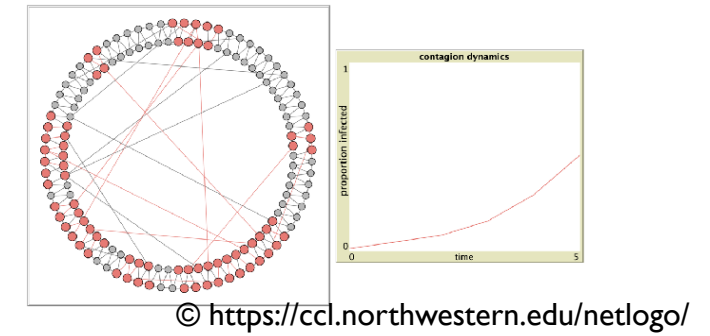
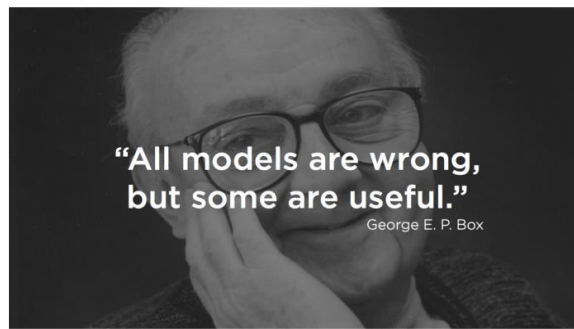
Workshop Goals

- What are ABMs and when and why are they used?
- How to implement and analyze an ABM using the NetLogo framework?
- What are solutions and particularities related to the Trans4Num model?

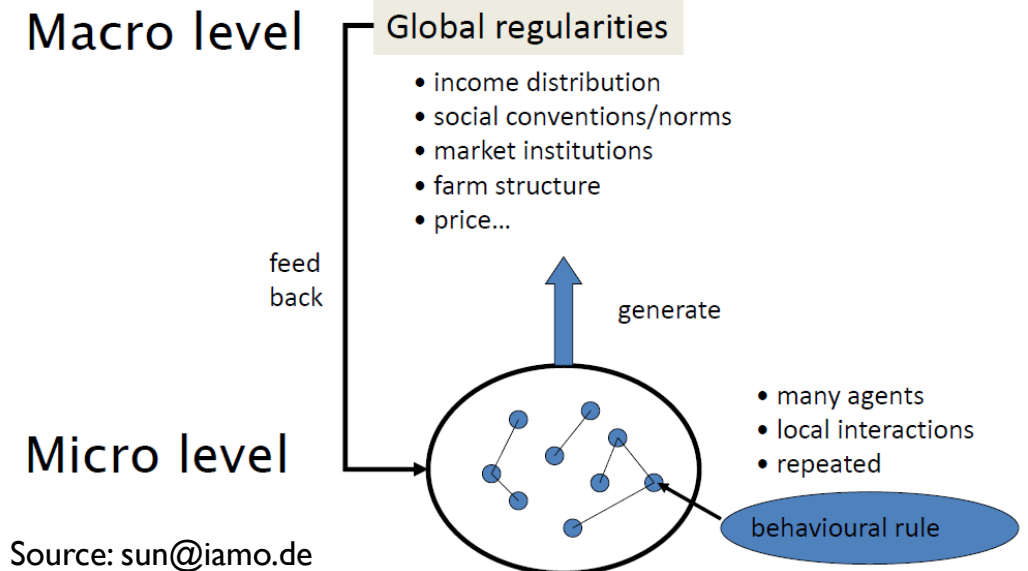
Workshop Outline

1. Welcome & Introduction FiBL (10')
2. Introduction agent-based models (15')
3. Introduction to NetLogo (15')
4. Data requirements (15')
5. Overview Dutch NBS-Site and model application particularities (10')
6. Questions (15')
7. Wrap up (10')

Models

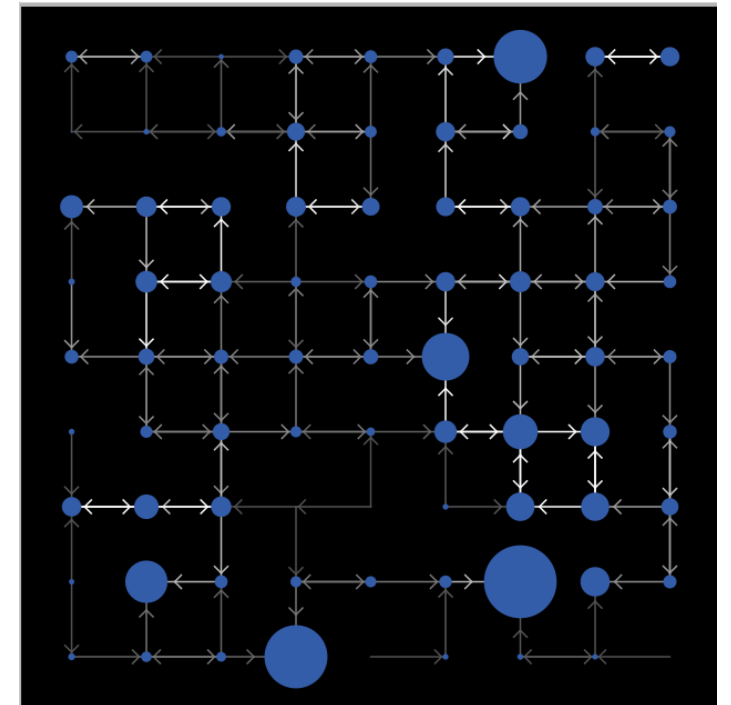


- Models are structures (abstract or physical) that can potentially represent real-world phenomena.
- “If we want to make reality and therefore truth useful to science, we must do violence the reality. ... In nature, everything is equally essential. By seeking out the relationships that seem essential to us, we order the material in a surveyable way at the same time. Then we are doing science.” Source: Jakob von Uexküll, 1909
- “Scientific modelling is a scientific activity, the aim of which is to make a particular part or feature of the world easier to understand, define, quantify, visualize, or simulate by referencing it to existing and usually commonly accepted knowledge”.
Source: https://en.wikipedia.org/wiki/Scientific_modelling



Agent based models (ABM)

- A type of formal model in which individuals (agents) are simulated as explicit computational entities
- Main elements:
 - Agents
 - Environment (spatial structure)
 - Interactions (network structure)
 - Dynamics (time)
- Benefits:
 - Can account for greater complexity, heterogeneity, and structure.
 - Can help us to understand emergent phenomena. Provides a natural description of a system.



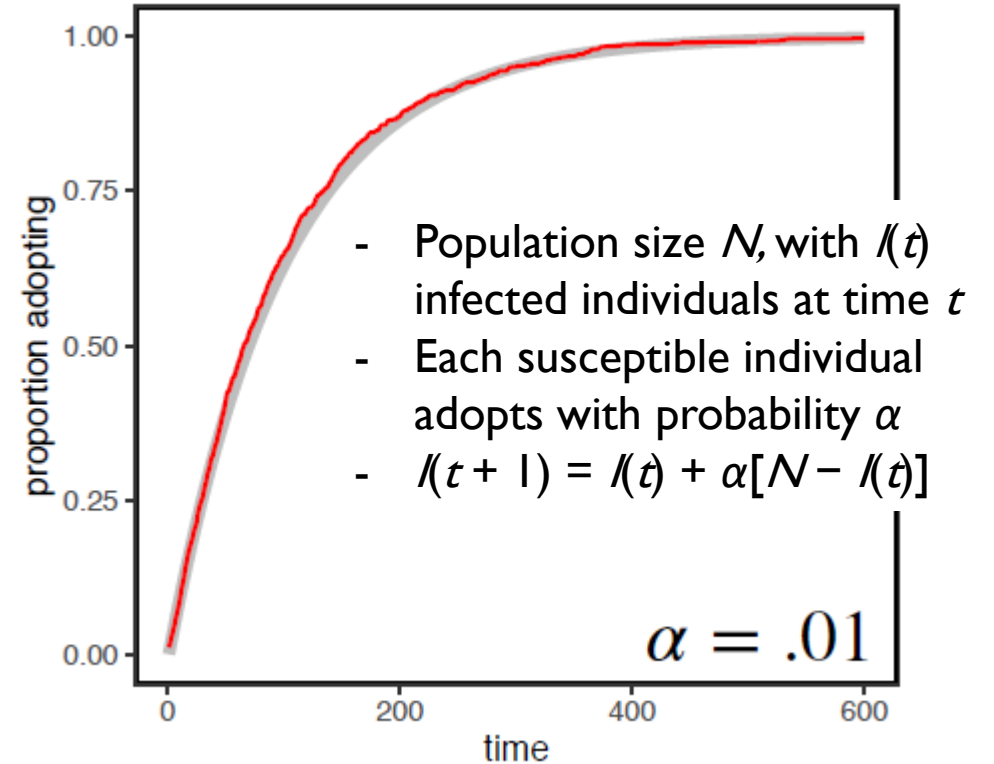
Granularity

- Fine-grained models
 - Highly detailed
 - There are data in the world that can be used to precisely parameterize and test the models
- Coarse-grained models
 - Focus on broad, qualitative patterns in the data
 - Rarely reproduce exact measurements



Diffusion of innovation → A form of contagion models

- What if innovations spread like diseases, if a new innovation is introduced?
 - Highly simplified = spontaneous adoption:
 - Individuals are either susceptible (have not adopted) or infected (have adopted)
 - Individuals do not vary in their propensity to adopt
 - They each adopt with a fixed probability at every time step



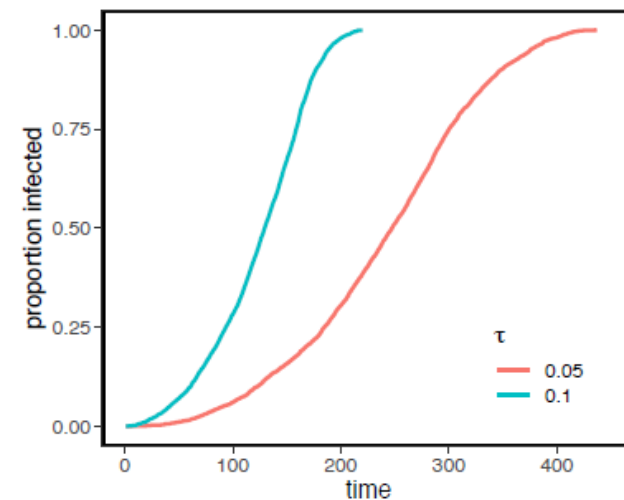
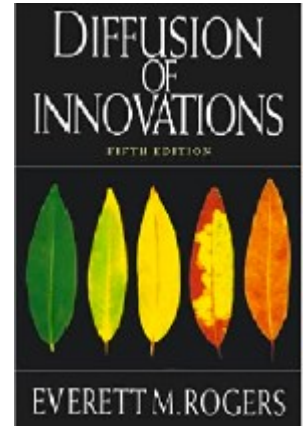
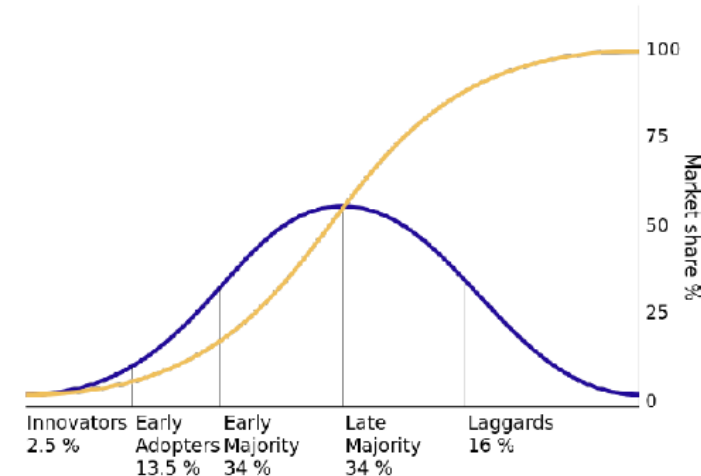
➤ Innovations don't diffuse this way!

Source: Smaldino, 2023.

Diffusion of innovation

$$\text{Transmissibility} = P(\text{adopt}) = 1 - (1 - \tau)n$$

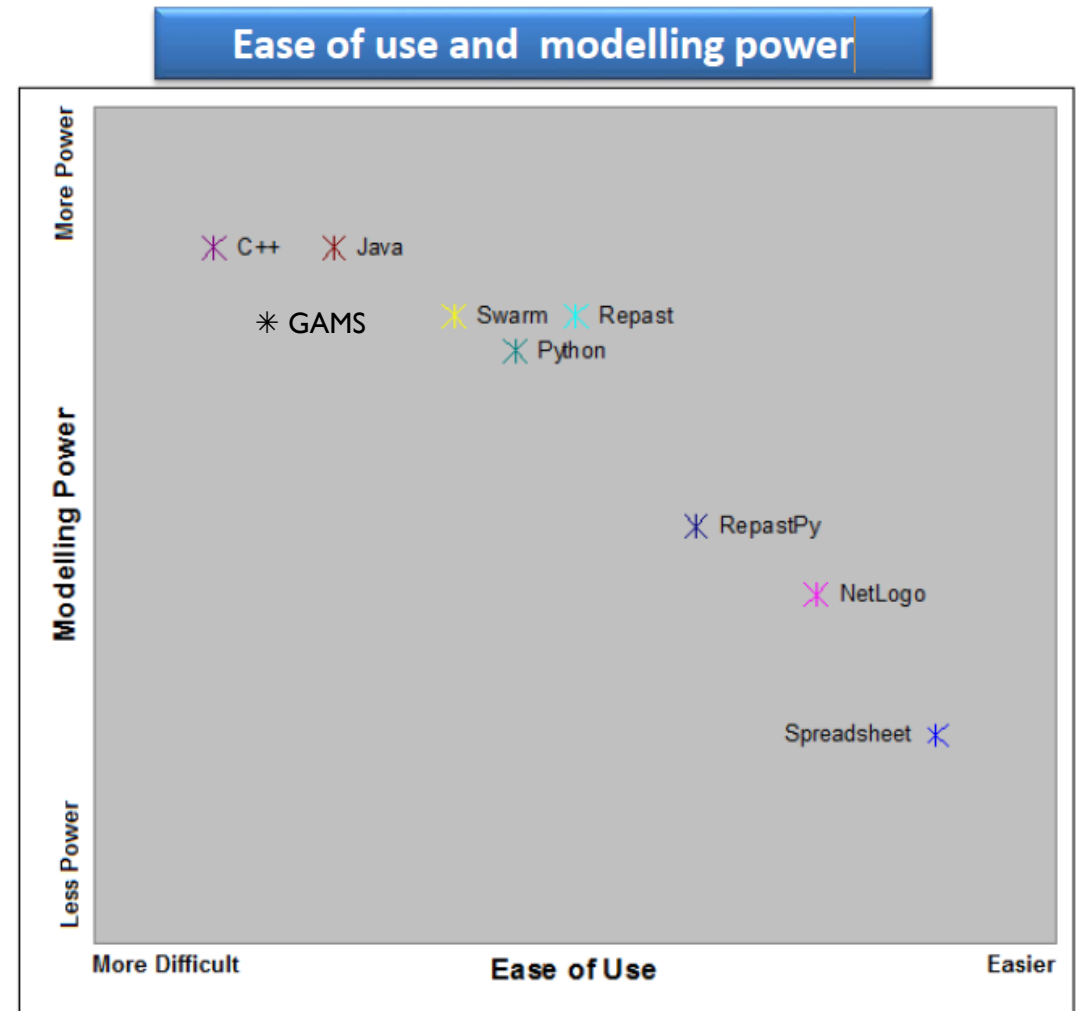
- Assumption: Everyone has same information but adopts with different probability.
- Each encounter with an “infected” individual leads to adoption with a fixed probability τ
- τ = the probability of a contact leading to adoption
- n = number of neighbors who have adopted
- Probability of not becoming "infected" from each neighbor is $(1 - \tau)$



How to code an agent-based model?

Framework Differences

- Integrated Modelling / Simulation Environment
 - NetLogo
- Library – based
 - Repast, NetLogo
- Generic Applications
 - Spreadsheet
 - Java, C++, Python, R, etc.
- Combinations
 - GAMS/Repast/R
 - NetLogo/Python or R



Source: Graubner, IAMO, 2023, adapted



“Low threshold, low limits”

- Two potential limits:

1. Speed →

Use possibility to export models as Java JAR files, runnable on most clusters.

2. Functionality →

It’s a tradeoff. Having “baked-in” features makes coding fast and easy, especially for simple models, but can be limiting for complex or unconventional designs.

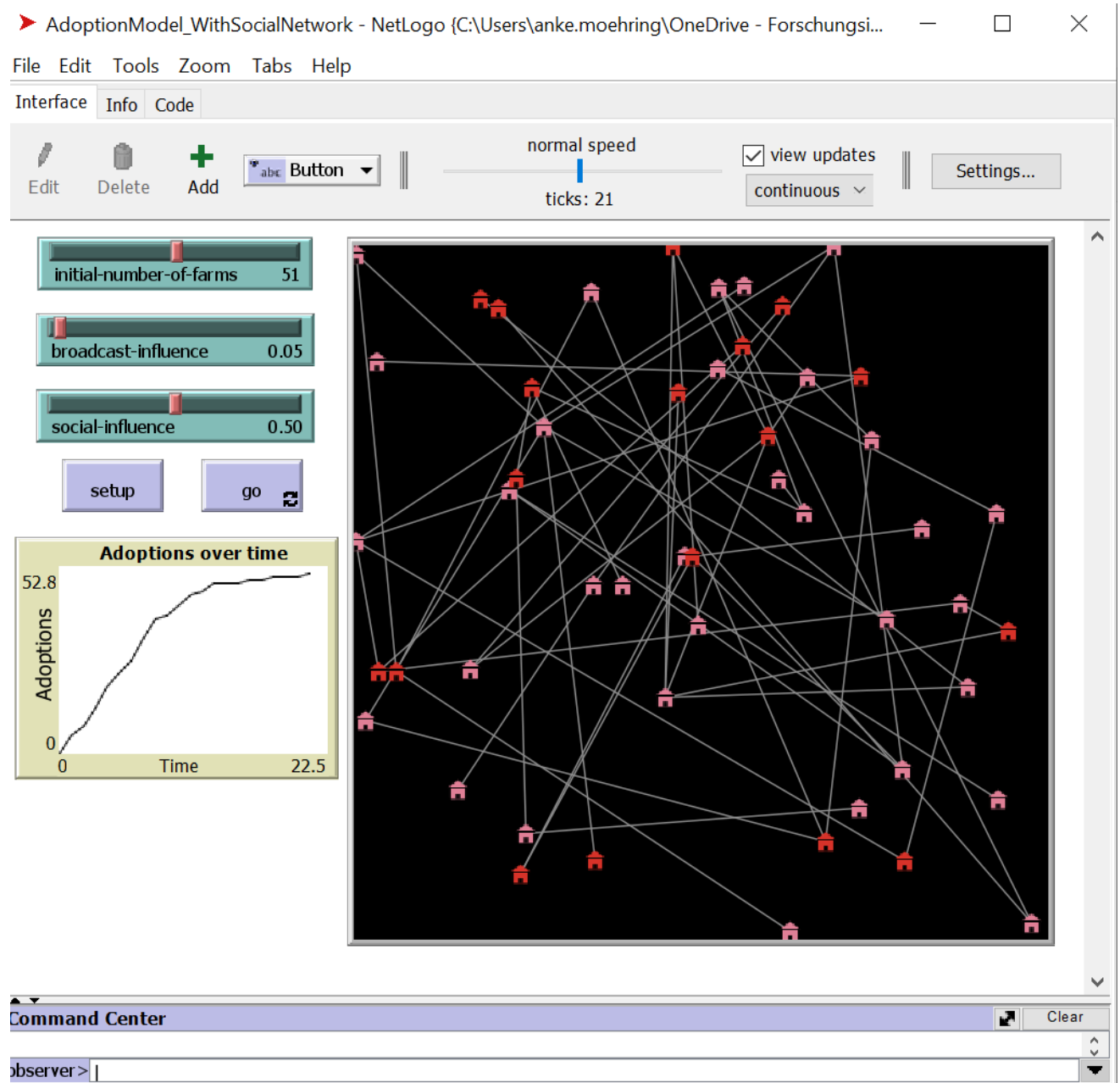
An Example

- For more, see also:

[CoMSES Net Computational Model Library](#)

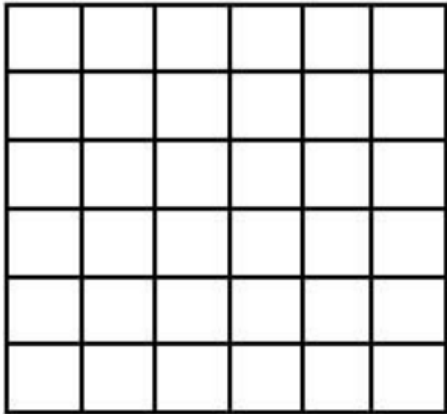
[Welcome to the Modeling Commons! -- NetLogo Modeling Commons](#)

[NetLogo Models Library \(northwestern.edu\)](#)



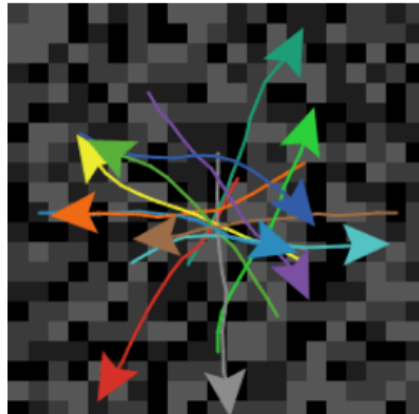
NetLogo basics: Components

Patches



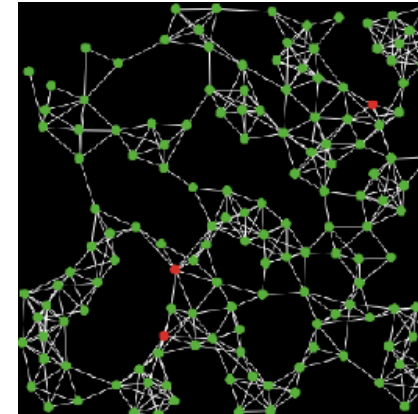
- stationary
- one per location
- forms the main graphical display

Turtles



- mobile
- can die and reproduce
- can be networked
- can occupy patches

Links



- connections between turtles
- can be directed or undirected
- visible as lines

NetLogo basics: Tabs «Interface» and «Model Settings»

The screenshot displays the NetLogo environment for a model titled "AdoptionModel_WithSocialNetwork". The main window is divided into several sections:

- Interface Tab:** Contains sliders for "initial-number-of-farms" (51), "broadcast-influence" (0.15), and "social-influence" (0.50). It also features "setup" and "go" buttons, a "normal speed" slider, and a "ticks: 0" counter.
- Model View:** A central black area showing a network of white house icons connected by lines, representing the social network.
- Adoptions over time:** A graph with "Adoptions" on the y-axis (0 to 10) and "Time" on the x-axis (0 to 10).
- Model Settings Window:** A dialog box with the following options:
 - World:** A 33x33 grid with origin (0,0) at the center. Coordinates range from -16 to 16 on both axes.
 - Location of origin:** Center (selected).
 - World wraps:** "World wraps horizontally" and "World wraps vertically" are both unchecked.
 - View:** "Patch size" is 13 (measured in pixels), "Font size" is 10 (of labels on agents), and "Frame rate" is 30 (frames per second at normal speed).
 - Tick counter:** "Show tick counter" is checked, and the "Tick counter label" is "ticks".

Two callout boxes highlight the "Interface" tab and the "Settings" button. The "FiBL" logo is visible in the bottom left corner.

NetLogo basics: Tab «Info»

Info: documenting the model

- what system is being modeled
- how the model was created
- transparency supports the communication and credibility of your model results



AdoptionModel_WithSocialNetwork - NetLogo (C:\Users\anke.moehring\OneDrive - Forschungsinstitut für biologischen Land

File Edit Tools Zoom Tabs Help

Interface Info Code

Find... Edit

Info

WHAT IS IT?

(a general understanding of what the model is trying to show or explain)

HOW IT WORKS

(what rules the agents use to create the overall behavior of the model)

HOW TO USE IT

(how to use the model, including a description of each of the items in the Interface tab)

THINGS TO NOTICE

(suggested things for the user to notice while running the model)

THINGS TO TRY

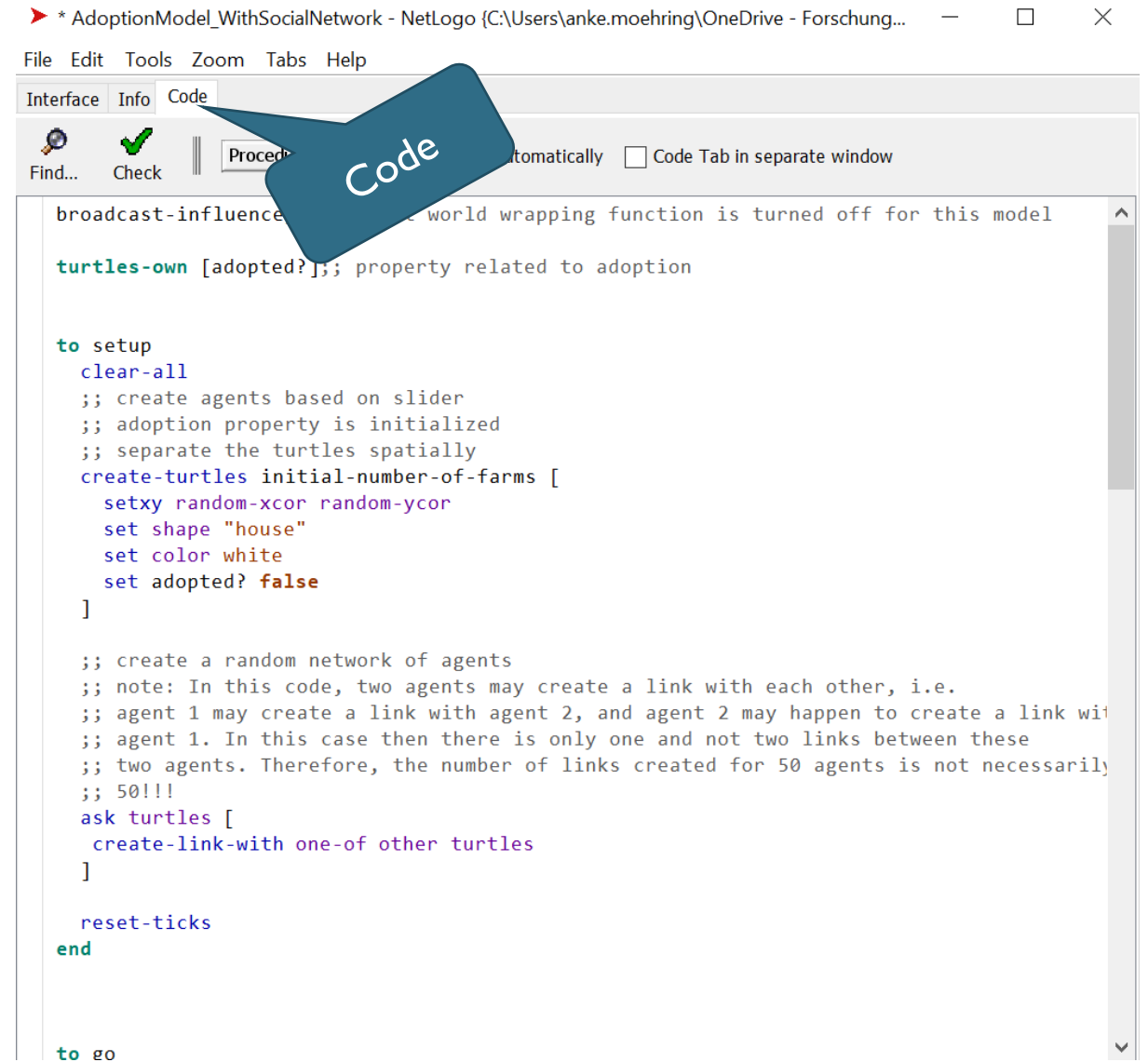
(suggested things for the user to try to do (move sliders, switches, etc.) with the model)

EXTENDING THE MODEL

NetLogo basics: Tab «Code»

Code

- Programming code
- Tell the computer what to do
- Save major changes with a new name (self-explanatory names are better)
- Think modular: core model plus extensions, that can be turned on/off



```
File Edit Tools Zoom Tabs Help
Interface Info Code
Find... Check Procedure Automatically Code Tab in separate window

broadcast-influence world wrapping function is turned off for this model

turtles-own [adopted?];; property related to adoption

to setup
  clear-all
  ;; create agents based on slider
  ;; adoption property is initialized
  ;; separate the turtles spatially
  create-turtles initial-number-of-farms [
    setxy random-pxcor random-ycor
    set shape "house"
    set color white
    set adopted? false
  ]

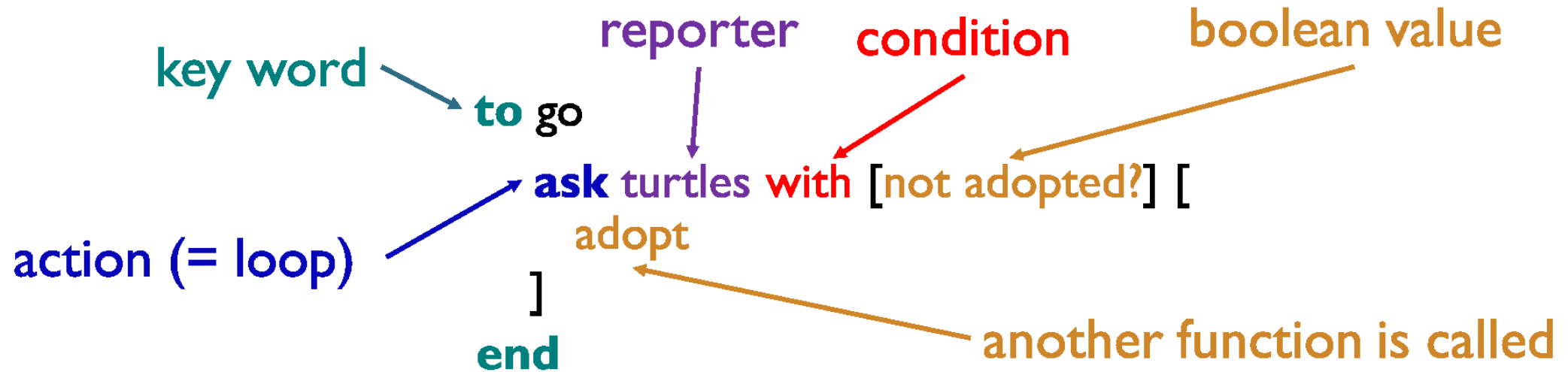
  ;; create a random network of agents
  ;; note: In this code, two agents may create a link with each other, i.e.
  ;; agent 1 may create a link with agent 2, and agent 2 may happen to create a link with
  ;; agent 1. In this case then there is only one and not two links between these
  ;; two agents. Therefore, the number of links created for 50 agents is not necessarily
  ;; 50!!!
  ask turtles [
    create-link-with one-of other turtles
  ]

  reset-ticks
end

to go
```




NetLogo basics: Primitives – Example

NetLogo **primitives** are values and functions that are pre-specified by the software.



!! One agent ("turtle" or "patch") → Agentset ("turtles" or "patches") !!


← ↻ 🔒 https://ccl.northwestern.edu/netlogo/bind/ 🔍 🗄️ 🗨️ 🌟 📄 🌟 📄 📄 📄 📄 📄 📄

Contents ▾ Search  Beginner's Interactive NetLogo Dictionary  Download NetLogo

The Beginner's Guide to NetLogo Programming

Learn how to create computational models with the NetLogo agent-based modeling environment with novice-friendly explanations and interactive code examples.

[What is NetLogo?](#) [What is a primitive?](#) [The first 11 primitives to learn](#)



```
to learn-netlogo
ask patches [be-the-world]
ask turtles [do-things-in-the-world]
ask links [connect-turtles]
end
```

[See: NetLogo Interactive Dictionary | Beginner's Interactive NetLogo Dictionary \(northwestern.edu\)](#)

The User Manual is your friend!

NetLogo
User Manual
version 6.4.0
November 15, 2023

[Release Notes](#)
[System Requirements](#)
[Contacting Us](#)
[Copyright / License](#)

Introduction
[What is NetLogo?](#)
[Sample Model: Party](#)

Learning NetLogo
[Tutorial #1: Models](#)
[Tutorial #2: Commands](#)
[Tutorial #3: Procedures](#)

Reference
[Interface Guide](#)
[Interface Tab Guide](#)
[Info Tab Guide](#)
[Code Tab Guide](#)
[Programming Guide](#)
[Transition Guide](#)
[NetLogo Dictionary \(en Español\)](#)

Features
[Extension Manager](#)
[Shapes Editor](#)
[BehaviorSpace \(en Español\)](#)
[System Dynamics](#)
[HubNet](#)

Making the setup button

To start a new model, select "New" from the File menu. Then begin by creating a setup button:

- Click the "Add" icon in the toolbar at the top of the Interface tab.
- On the menu next to Add, select Button (if it isn't already selected).
- Click wherever you want the button to appear in the empty white area of the Interface tab.
- A dialog box for editing the button opens. Type `setup` in the box labeled "Commands".
- Press the OK button when you're done; the dialog box closes.

Now you have a setup button. Pressing the button runs a procedure called "setup". A procedure is a sequence of NetLogo commands that we assign a new name. We'll define that procedure soon, but we haven't yet. The button refers to a procedure that doesn't exist, so the button turns red:

See: [NetLogo 6.4.0 User Manual \(northwestern.edu\)](http://northwestern.edu)

NetLogo basics: Programming basics

- Variables
- Functions
- Loops
- Conditionals

* AdoptionModel_WithSocialNetwork - NetLogo (C:\Users\vanke.moehring\OneDrive - Forschungsinstitut für biologischen Landbau FiBL\Dokumente\03_

File Edit Tools Zoom Tabs Help

Interface Info Code

Edit Delete Add || normal speed view updates || Settings...
ticks: 36 continuous

initial-number-of-farms 200
broadcast-influence 0.05
social-influence 0.20
setup go

Adoptions over time
Adoptions 202
0
0 Time 36.3

Command Center

Programming basics: Variables

- Important variables that are fixed for the duration of a simulation are called **parameters**.
- Can be **global** (used by any part of the code), **agent-level** (unique values held by individual agents), or **local** (used only in a particular function or loop).
- Can be numbers, strings, booleans (true/ false), even agents!

variable declaration at agent-level

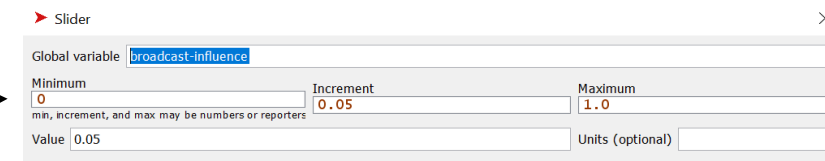
```
turtles-own [adopted?];; property related to adoption

to setup
  clear-all
  ;; create agents based on slider
  ;; adoption property is initialized
  ;; separate the turtles spatially
  create-turtles initial-number-of-farms [
    setxy random-xcor random-ycor
    set shape "house"
    set color white
    set adopted? false
  ]
reset-ticks
end
```

built-in agent variables (local)



edit



!! "You can make a **global variable** by adding a switch, slider, chooser, or input box to your model, or by using the globals keyword at the beginning of your code"!!

Programming basics: **Functions**

- A **function** (or **procedure**) is a label that designates a set of command that are run together when the function is **called**.
- A function may take **arguments**, values that are assigned to variables in the function definition
- Functions may also return, or **report** values

A normal function

```
to reset-diffusion
  ask turtles [
    set adopted? false
    set color white
  ]
  clear-all-plots
end
```

A reporter (function)

```
;; get adjacency matrix to be used in the Message Passing algorithm

to-report report-matrix
  let n-cr count turtles
  let new-mat matrix:make-constant n-cr n-cr 0
  ask links [
    let from-t [who] of end1
    let to-t [who] of end2
    matrix:set new-mat from-t to-t 1
  ]
  report new-mat
end
```

Programming basics: **Loops**

Several NetLogo primitives for looping:

- **loop** repeats the commands forever, or until the enclosing procedure exits
- **foreach** command for each item of a list
- **repeat** runs commands number times
- **while** runs commands until some condition becomes false
- **ask** each member of some agentset execute some commands

```
ask agents [  
  right 45  
  forward 1  
]
```

```
while [any? other turtles-here]  
  [ fd 1 ]  
;; turtle moves until it finds a patch that has  
;; no other turtles on it
```

Programming basics: **Conditionals**

Three NetLogo primitives for conditions:

- `if` run commands if some condition is true (**Boolean** variables)
- `ifelse` separate commands for when condition is true and false – can also be used as a switch
- `ifelse-value` shortcut to assign values depending on condition

```
;;this procedure will determine whether or not to adopt.  
to adopt  
  
;;adopt based on broadcast influence  
;; random-float prints a number at least 0 but less than 1.0  
if random-float 1.0 < broadcast-influence [  
set adopted? true  
set color red ]
```


Proposal of the model specification procedure (I)

	Workshop example
<ul style="list-style-type: none"> • 1.) Formulation of the research question 	<ul style="list-style-type: none"> - How does the adoption of innovations evolve over time, considering the influence of broadcasting and social networks?
<ul style="list-style-type: none"> • 2.) Identification of parts and properties <ul style="list-style-type: none"> ○ Identification of agents (e.g. farmers, processors, information hubs) and ○ their attributes, e.g. their willingness to adopt (innovators, early adopters, early and late majority, laggard scale). 	<ul style="list-style-type: none"> - Agents: Adopters and Non-Adopters - Initial number of agents: $2 \leq n \leq 100$ - Attributes: color and shape
<ul style="list-style-type: none"> • 3.) Definition of the agent's environment, <ul style="list-style-type: none"> ○ agents' location and ○ neighbourhood 	<ul style="list-style-type: none"> - Agents' location: random - Broadcast influence - Social influence

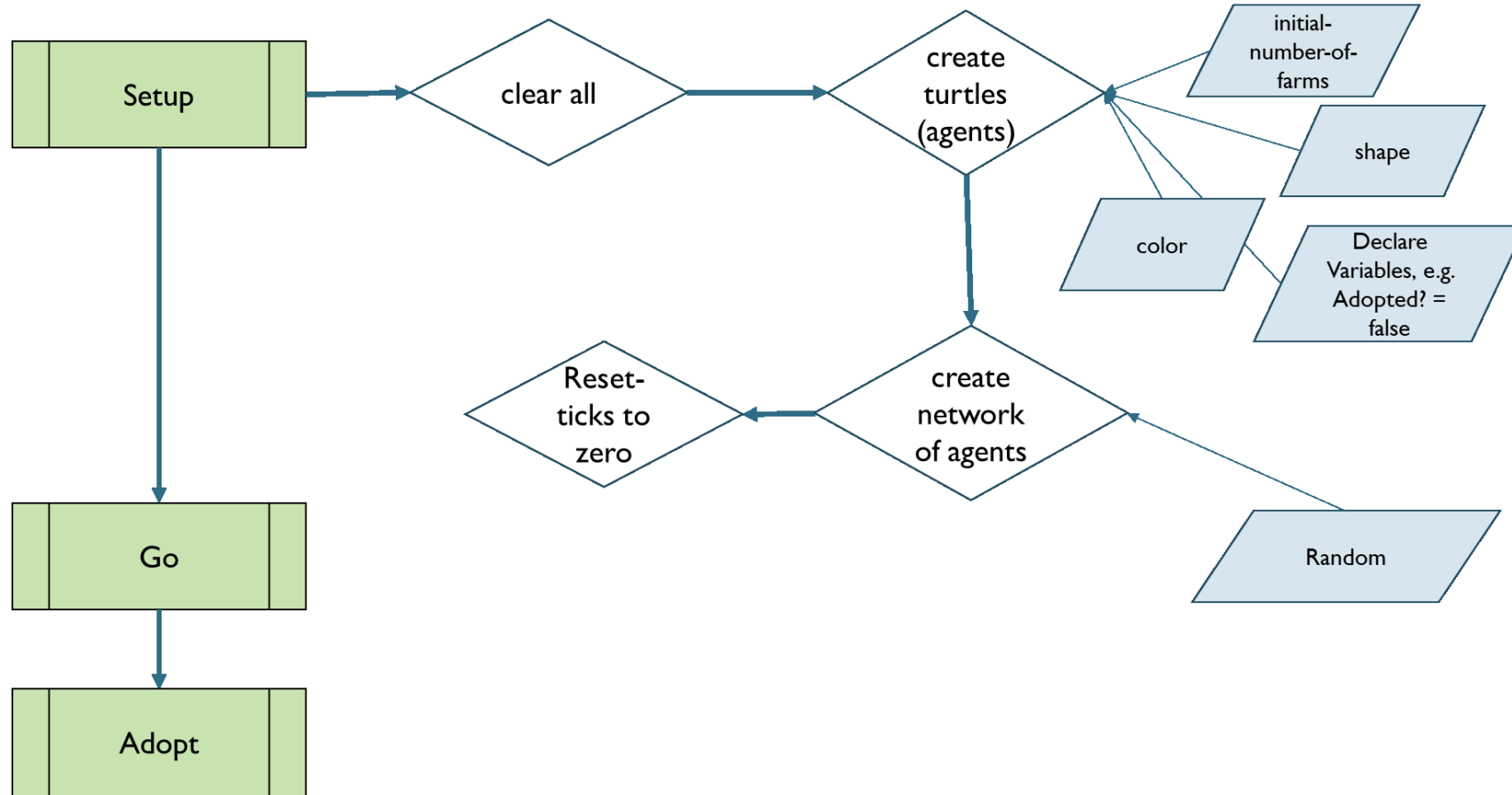
Proposal of the model specification procedure (II)

	Workshop example
<ul style="list-style-type: none">• 4.) Specification of agent interactions, rules of<ul style="list-style-type: none">○ which agents interact,○ when agents interact and how often○ how do they interact during the simulation	<ul style="list-style-type: none">- Adoption based on broadcast influence- Adoption based on social network structure: random
<ul style="list-style-type: none">• 5.) Definition of the model dynamics<ul style="list-style-type: none">○ for the specification of the methods by which agent attributes are updated, and for the scheduling of the order of computations performed during each discrete time step. --> use process diagrams	<ul style="list-style-type: none">- One tick = one adoption- Process diagram

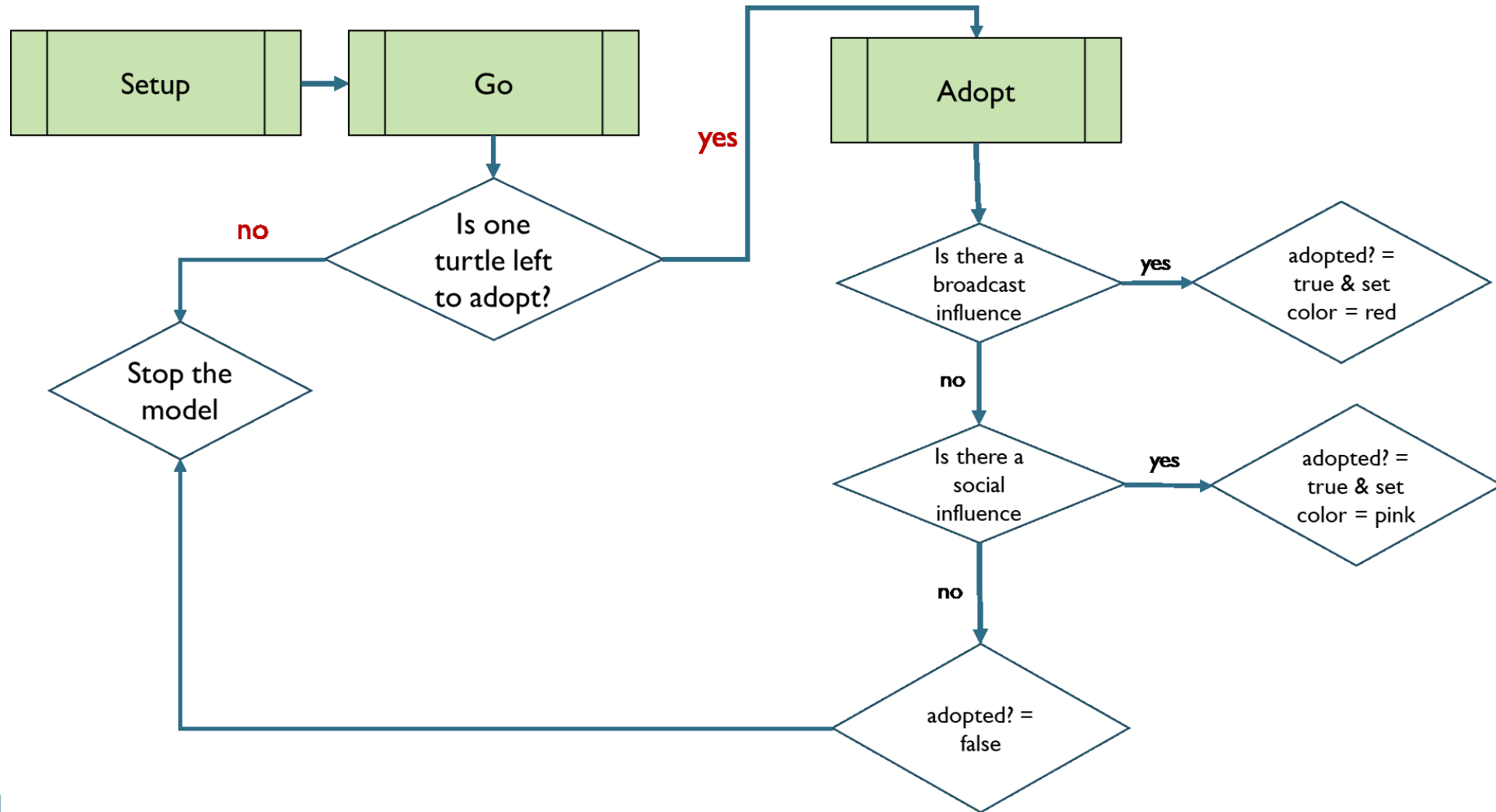
Proposal of the model specification procedure (III)

	Workshop example
<ul style="list-style-type: none">• 6.) Definition of model outputs (e.g. adoption rates, variables to measure farm level impact)<ul style="list-style-type: none">• developing sustainable future food system scenarios with improved nutrient management and reduced pollution levels in relation to the specific requirements of each NBS case study.	- Adoption over time
<ul style="list-style-type: none">• 7.) Implementation of the ABM in the computational software NetLogo	AdoptionModel_WithSocialNetwork.nlogo

Process diagram of a simple adoption of innovation model (I)



Process diagram of a simple adoption of innovation model (2)



Data requirements and documentation

- Parts and properties
- Assumptions
- Initialisation
- Dynamics
- Outcomes



Parts and Properties

- A model is a decomposition of the system into the critical **parts**.

Individuals **or**

Social collectives (households, neighborhoods, innovation hubs, etc.)

What are the agents? What type of agents are there?

Environment

Where are the agents in space? Neighborhood structure?

- In specifying the parts, you also specify their relevant **properties**.

Attributes

e.g. mobility, willingness to adopt (based on other attributes like age, education, farm type, etc.), supply, demand, ...

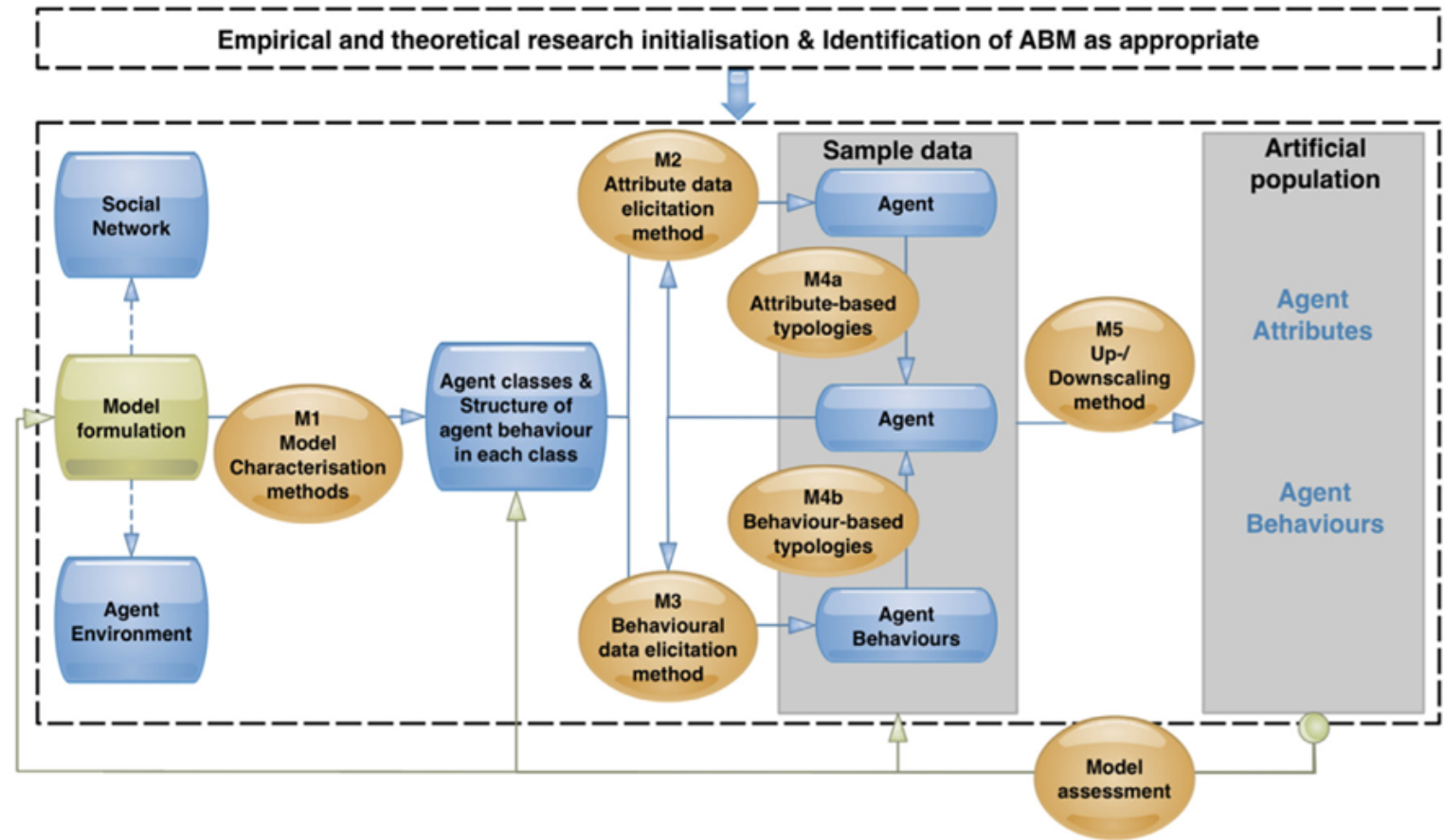
Behaviors

depends on the socio-economic group that is modeled: e.g. motives, objectives, preferences, constraints, knowledge, information, beliefs, behavioral options, decision rules, strategy selection

Relationships




Is there a network structure? What relationships are important?

Characterisation and parameterisation of (human) agents



M1	M2 (Attribute)	M3 (Behaviours)	M4a (Attribute)	M4b (Behaviours)	M5 (Upscaling)
<ul style="list-style-type: none"> Expert Knowledge Participant Observation Lab Experiments Interviews Role-playing Games 	<ul style="list-style-type: none"> Survey Census (incl GIS data) 	<ul style="list-style-type: none"> Survey Interviews Field experiments Participant Observation Role-playing Games Time series data Expert knowledge 	<ul style="list-style-type: none"> Clustering & Regression Correlation & Expert Knowledge Expert Knowledge Dasymetric Mapping 	<ul style="list-style-type: none"> Clustering & Regression Correlation & Expert Knowledge Expert Knowledge Participant Observation 	<ul style="list-style-type: none"> Proportional assignment Census/GIS assignment Monte Carlo

Overview of modeling approaches, model choice and assumptions about human behavior and decision making

	Model category	Modeling approaches and techniques	Important considerations for model choice and assumptions
	Individual decision making and behavior	Optimal decisions in rational choice Heuristics/decision trees Learning theory	Motives, objectives, preferences Constraints, information and knowledge, beliefs, behavioral options and dispositions Decision rules, strategy selection
	Interactions between individual agents	Classical and evolutionary game theory Social influence models Networks of interaction structures	Strategic interaction, imitation of behavior, influence on beliefs, opinions, preferences, adaptation of interaction structure
	Aggregation and system-level description	Social welfare and voting Representative agent General equilibrium models Agent-based modeling Statistical distributions System-level models	Agent homo- or heterogeneity, positive or negative feedbacks, transient dynamics and equilibrium states, centralization of decision making

Source: Müller-Hansen, F., Schlüter, M., Mäs, M., Donges, J. F., Kolb, J. J., Thonicke, K., and Heitzig, J. (2017). Towards representing human behavior and decision making in Earth system models – an overview of techniques and approaches. *Earth Syst. Dynam.* 8: 977–1007.

Assumptions

- «Agent-based models are basically a logical engine for turning assumptions into conclusions.»
- The decision of what is necessary and important in our system is also influenced from our assumptions we made about the system.
- Granularity of the model (fine-grained / coarse-grained) is influenced by our assumptions.



Needs to be discussed with stakeholders and with project partners before and during the model specification and scenario definition process.



Initialisation

- What is going on at the start of the model?
- How many agents are there, and what are their properties (at the baseline)?
- Where are they in their environment, and in relation to each other?
- What does the environment look like at the baseline?

Dynamics

- How does the state of the **model system change from one moment / tick to the next?**
- Usually we assume **discrete-time dynamics** → What happens during one «tick»? How long is one tick? (e.g. one year)
- Scheduling: The **ordering** of the computations performed during each time step.



Is one year time step the right tick when we are working with perennial crops and multi-year rotations?

Outcomes

- What am I recording about our system?
 - e.g. changes of yield, costs, income, nitrogen surplus, adoption rate, etc.
- Am I interested in the temporal dynamics, or equilibrium states (start/end)?
- Am I interesting in distribution of outcomes? (How many batch runs? BehaviorSpace: perform many runs per parameter combination)
- How to scale up?



Needs to be discussed with stakeholders and with project partners before and during the model specification and scenario definition process



BehaviorSpace: Specification of an experiment

Tools

* AdoptionModel_WithSocialNetwork - NetLogo {C:\Users\anke.moehring\OneDrive - Forschungsinstitut für biologischen Landbau FiBL\Dokumente\03_Projekte\02_Trans4Num\05_Praesentationen\20240326_...

File Edit Tools Zoom Tabs Help

fo Code

ete + Add abc Button || normal speed view updates ticks: 0 continuous Settings

number-of-farms 51

broadcast-influence 0.05

social-influence 0.50

setup go

Adoptions over time

Adoptions 10 0

Time 0 10

BehaviorSpace Experiments: New Edit Import Exp

Experiment

Welcome to the new BehaviorSpace experiment editor!
We added some new features to this window. If you would like to learn more about them, you can hover over the labels or click the "Help" button at the bottom of the window to read our updated documentation.

Experiment name

Vary variables as follows (note brackets and quotation marks):
`["initial-number-of-farms" 51]
["social-influence" 0.5]
["broadcast-influence" 0.05]`

Repetitions

Execute combinations in sequential order

Measure runs using these reporters as metrics:
`count turtles`

Run metrics every step

Run metrics when

Pre experiment commands:

Setup commands:

Go commands:

Stop condition: Post run commands:

Post experiment commands

Time limit

OK Help Cancel

Command Center

Use an ODD Protocol

- Iterated model description:
 - **O**verview (the “story” of the model)
 - **D**esign (the computations involved)
 - **D**etails (all the algorithms)

The ODD Protocol for Describing Agent-Based and Other Simulation Models: A Second Update to Improve Clarity, Replication, and Structural Realism

Volker Grimm¹, Steven F. Railsback², Christian E. Vincenot³, Uta Berger⁴, Cara Gallagher⁵, Donald L. DeAngelis⁶, Bruce Edmonds⁷, Jiaqi Ge⁸, Jarl Giske⁹, Jürgen Groeneveld¹⁰, Alice S. A. Johnston¹¹, Alexander Milles¹, Jacob Nabe-Nielsen⁵, J. Gareth Polhill¹², Viktoriia Radchuk¹³, Marie-Sophie Rohwäder¹⁴, Richard A. Stillman¹⁵, Jan C. Thiele¹⁶, Daniel Ayllón¹⁷

¹Helmholtz Centre for Environmental Research - UFZ, Department of Ecological Modelling, Permoserstr. 15, 04318 Leipzig, Germany
²Department of Mathematics, Humboldt State University, 250 California Avenue, Arcata, CA, 95521, United States
³Department of Social Informatics, Kyoto University, Yoshida-honmachi, Sakyo-ku, Kyoto 606-8501, Japan
⁴Institute of Forest Growth and Computer Sciences, Technische Universität Dresden, Piener Strasse 8, 01735 Tharandt, Germany
⁵Department of Bioscience, Aarhus University, Frederiksborgvej 399, DK-4000 Roskilde, Denmark
⁶U. S. Geological Survey, Wetland and Aquatic Research Center, Biology Department, University of Miami, 1301 Memorial Drive, P. O. Box 249118, Coral Gables, Florida 33124 United States
⁷Center for Policy Modelling, Manchester Metropolitan University Business School, All Saints Campus, Oxford



O	1. Purpose and patterns
	2. Entities, state variables and scales
	3. Process overview and scheduling <i>Submodel A</i> <i>Submodel B ...</i>
D	4. Design concepts
D	5. Initialization
	6. Input data
	7. Submodels <i>Submodel A (Details)</i> <i>Submodel B (Details) ...</i>

Basic principles
Emergence
Adaptation
Objectives
Learning
Prediction
Sensing
Interaction
Stochasticity
Collectives
Observation

Project Outline



- **trans4num will study** the NBS innovations, particularly those related to **crop rotation** and **bio-based fertilisers**
- **trans4num will carry out** a systemic analysis and state of the art using a multi-level perspective for **system change-transformation** (SET concept)
- **trans4num will use** the multi-actor approach to **consider various societal concerns and interests** related to NBS in agricultural nutrient management

Source: trans4num – Transformation for sustainable nutrient supply and management

Proposal for Agent based model development in Trans4Num

- Specification and parameterization of the core model using two case studies (e.g. Netherlands & China-Inner Mongolia)
- Flexible modules that can be turned on and off to extend the core model for the other NBS sites, depending on data availability and requirements
- Benefits:
 - Reduce complexity of the core model
 - Refer to different systems, dimensions, locations, data availabilities, decompositions, etc.
 - Generate NBS-site specific output
 - Project partners can be more easily involved in model specification and validation process
 - Increase flexibility in terms of time and resources

Comparison of agent type and network structure

	Agents	Farmer	Processor	Social service entities	Innovation hub	Network property
	Identified Types , that can either...	<ul style="list-style-type: none"> ≈ Adopter NBS technology • Arable / Fodder crops • Cattle / Dairy • Granivore Both, organic & conventional	<ul style="list-style-type: none"> • Biorefinery • Biogas producer • Slaughterhouse • Mushroom processor 	<ul style="list-style-type: none"> • Farmer Community 	<ul style="list-style-type: none"> • Farmer Group • Extension • Stakeholder / Public Sector • Value Chain 	
	supply or	<ul style="list-style-type: none"> • Rotation • Biomass / Product 	<ul style="list-style-type: none"> • Bio-fertilizer • Protein fodder 	<ul style="list-style-type: none"> • Labour & Machinery 	<ul style="list-style-type: none"> • Know how / Information 	
	demand	<ul style="list-style-type: none"> • Bio-fertilizer • Protein fodder • Know how / Information • Labour & Machinery 	<ul style="list-style-type: none"> • Biomass • Product (Mushrooms) 		<ul style="list-style-type: none"> • Deployment of NBS, e.g. adjusted rotation 	
Case study	UK	X	X		(X?)	Directed network (provided that data available)
	HU	X			X	
	DK	X	X		X	
	NL	X			X	
	CN-1	X		X	X	
	CN-2	X	X		X	
	CN-3	X			X	

Concluding remarks

- The success of NBS adoption depends on its acceptance by society. The development of innovation must be a collaborative effort, and the impact of innovation must be widely understood.
- However, innovation also occurs through scalability and transferability. NBS are developed at the local level but provide solutions for regional level or even global level and must be transferable - to other communities, to other sites, to other framework conditions.
- The innovation in the field of modelling lies in the achievement of this flexibility and at the same time in the mastery of the complexity.

Questions?

References:

Grimm, V., Railsback, S. F., Vincenot, C. E., Berger, U., Gallagher, C., DeAngelis, D. L., Edmonds, B., Ge, J., Giske, J., Groeneveld, J., Johnston, A. S. A., Milles, A., Nabe-Nielsen, J., Polhill, J. G., Radchuk, V., Rohwäder, M.-S., Stillman, R. A., Thiele, J. C., and Ayllón, D. (2020). The ODD Protocol for Describing Agent-Based and Other Simulation Models: A Second Update to Improve Clarity, Replication, and Structural Realism. *Journal of Artificial Societies and Social Simulation* 23: 7.

IAMO 2023. Agent-based modelling in agricultural and resource economics. Halle, 08.-12.05.2023

Smaldino, P. E., 2023. Modeling social behavior. *Mathematical and Agent-Based Models of Social Dynamics and Cultural Evolution*.

Smaldino, P. E., 2024. *Introduction to Agent-Based Modeling*, University of California

Wilenski, U. (2024, February 20). NetLogo. Center for Connected Learning and Computer-Based Modeling. Northwestern University, Evanston, <https://ccl.northwestern.edu/netlogo/> last accessed 20 February 2024

Müller-Hansen, F., Schlüter, M., Mäs, M., Donges, J. F., Kolb, J. J., Thonicke, K., and Heitzig, J. (2017). Towards representing human behavior and decision making in Earth system models – an overview of techniques and approaches. *Earth Syst. Dynam.* 8: 977–1007.

Smajgl, A., and Barreteau, O. 2017. Framing options for characterising and parameterising human agents in empirical ABM. *Environmental Modelling & Software* 93: 29–41.

Berea, A. 2023. *Introduction to Agent-Based Modeling*. <https://www.complexityexplorer.org/>

FiBL online



www.fibl.org



www.bioaktuell.ch



[fiblfilm](https://www.youtube.com/fiblfilm)



[@fiblorg](https://twitter.com/fiblorg)



[@FiBLaktuell](https://www.facebook.com/FiBLaktuell)



[linkedin.com/company/fibl](https://www.linkedin.com/company/fibl)

Contact

anke.moehring@fibl.org

christian.grovermann@fibl.org

Research Institute of Organic Agriculture FiBL
Ackerstrasse 113, Box 219
5070 Frick
Switzerland

Phone +41 62 865 72 72

Fax +41 62 865 72 73

info.suisse@fibl.org

www.fibl.org

