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trans4num
WP 4.1




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

Workshop

26.03.2024

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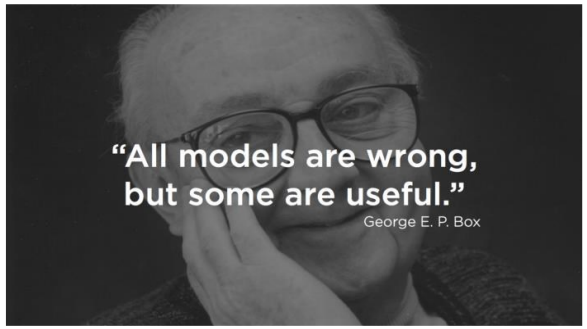
Workshop Goals

- 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



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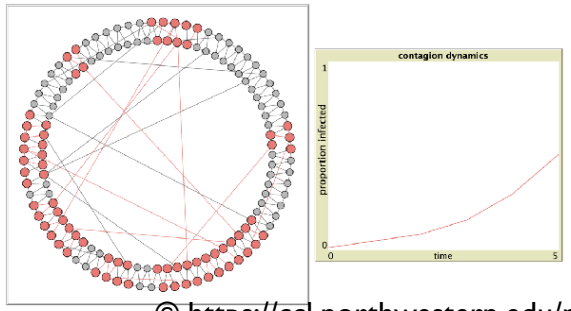

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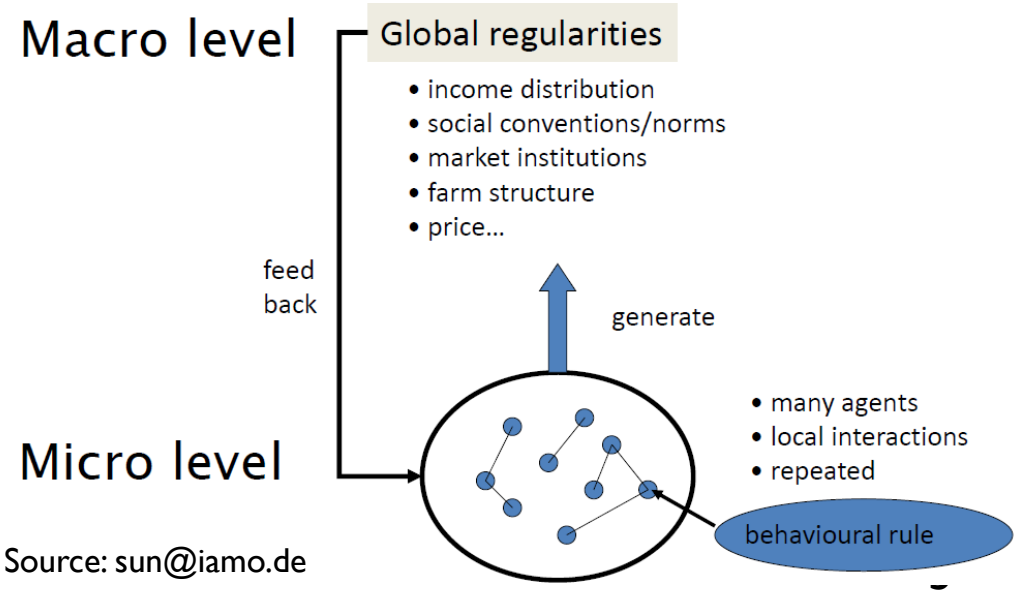
- Models are structures (abstract or physical) that can potentially represent real-world phenomena.

- "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



Source: sun@iamo.de

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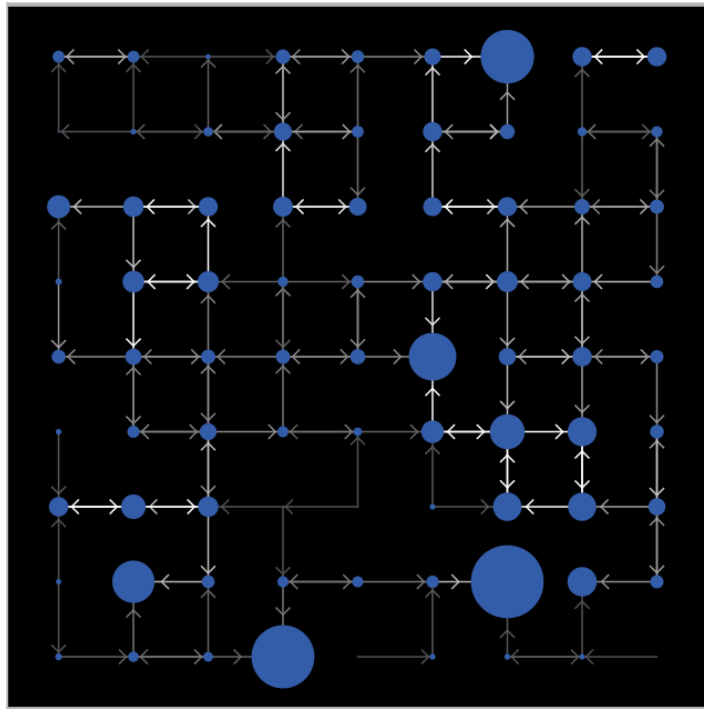
Agent based models (ABM)

- 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.



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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

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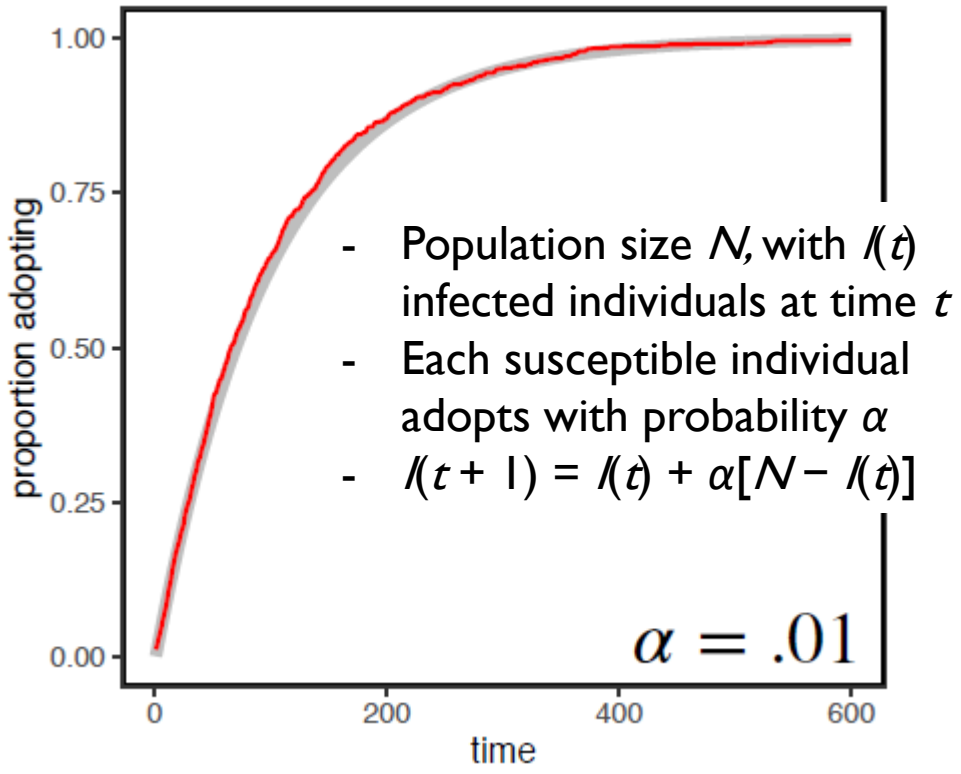
Diffusion of innovation → A form of contagion models

- 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 ever time step



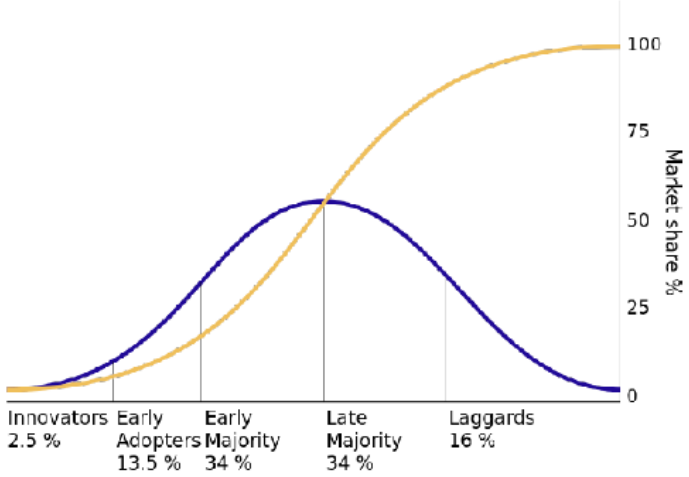
➢ Innovations don't diffuse this way!

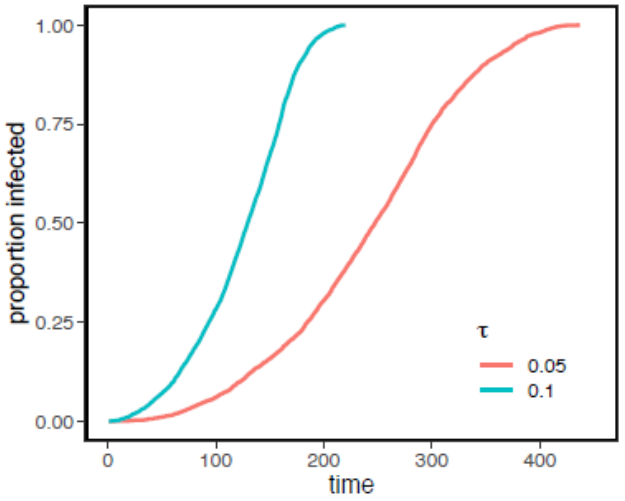
Source: Smaldino, 2023.

Diffusion of innovation

Transmissibility = P(**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 − τ)



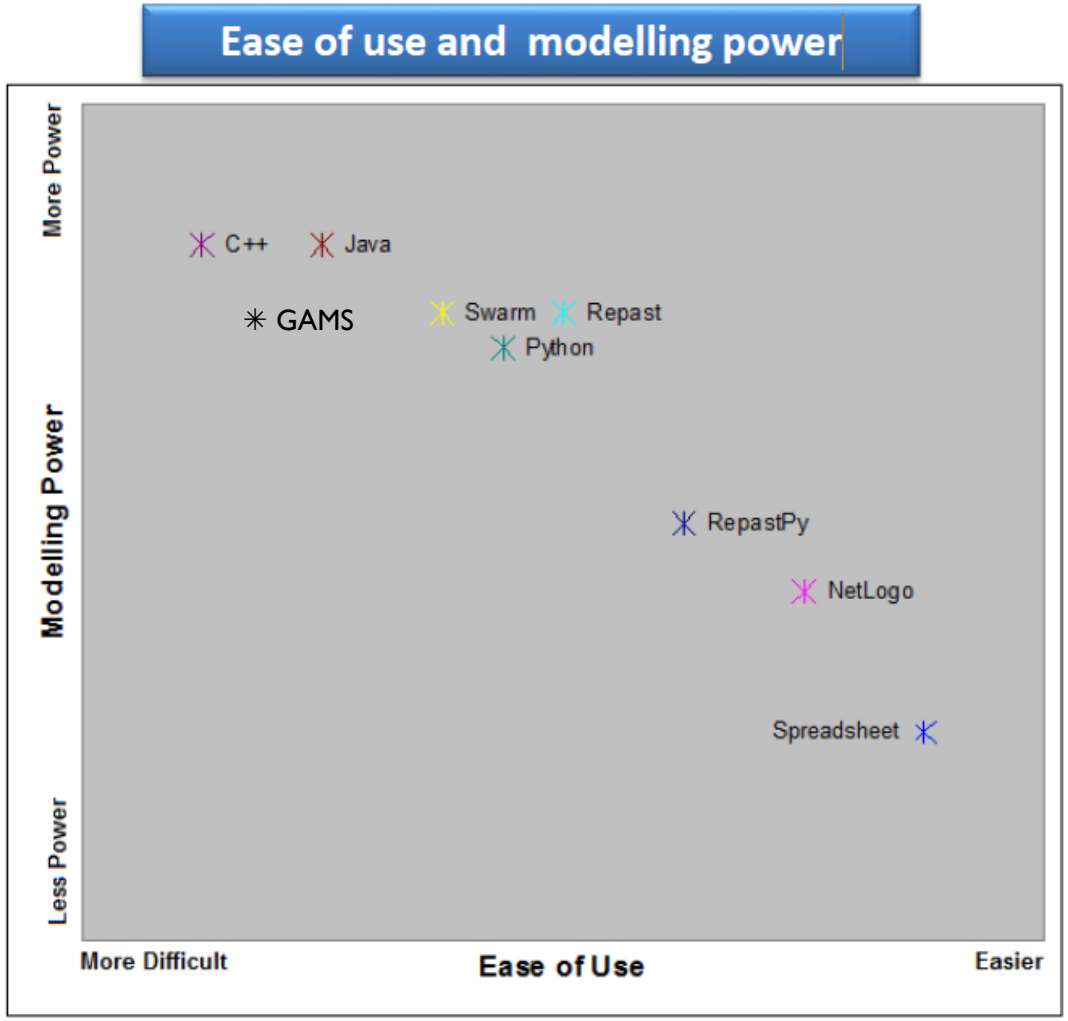


Source: Smaldino, 2023.

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.

Source: Smaldino, 2023

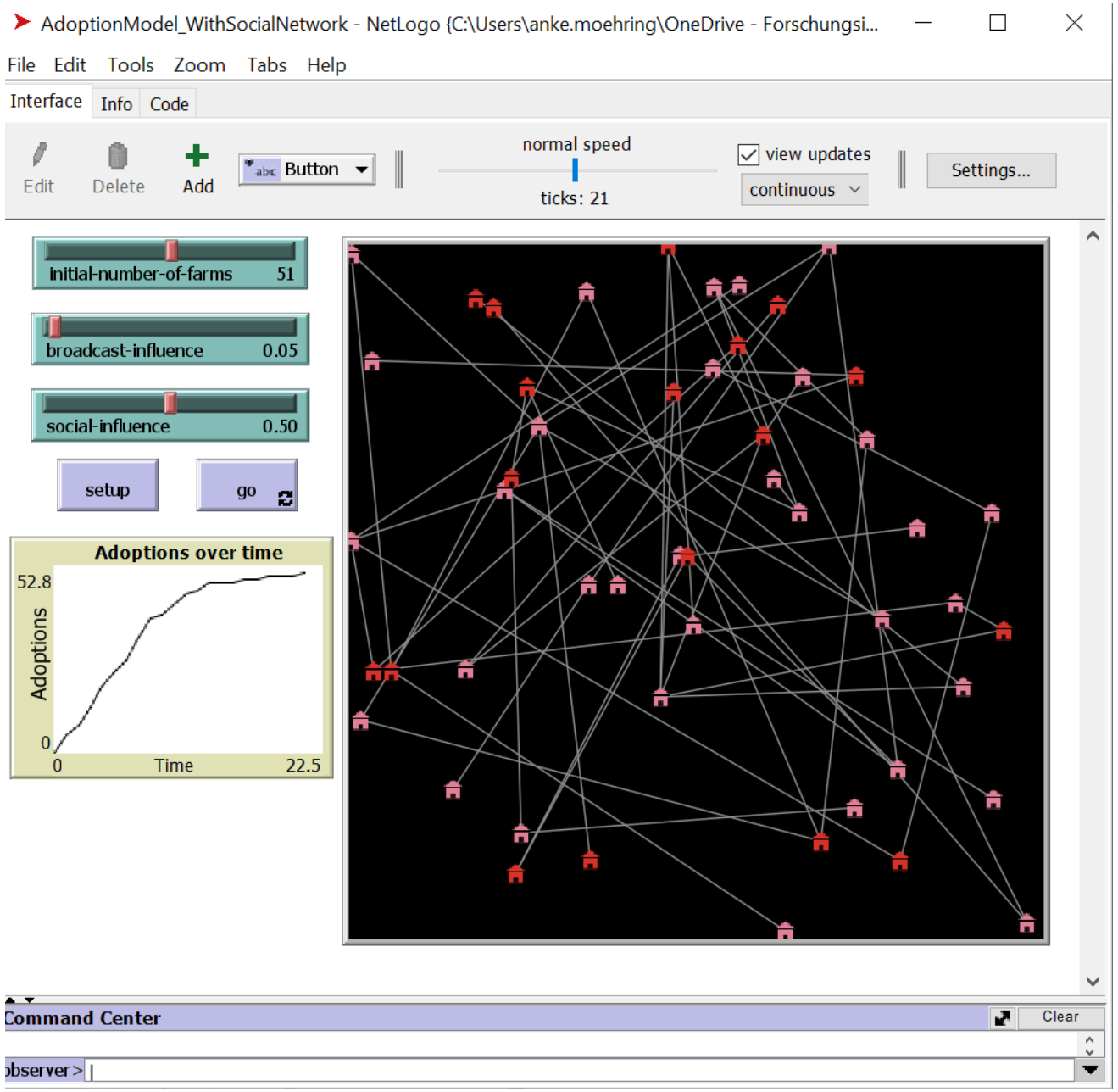
An Example

- For more, see also:

[CoMSES Net Computational Model Library]

[Welcome to the Modeling Commons! -- NetLogo Modeling Commons]

[NetLogo Models Library (northwestern.edu)]



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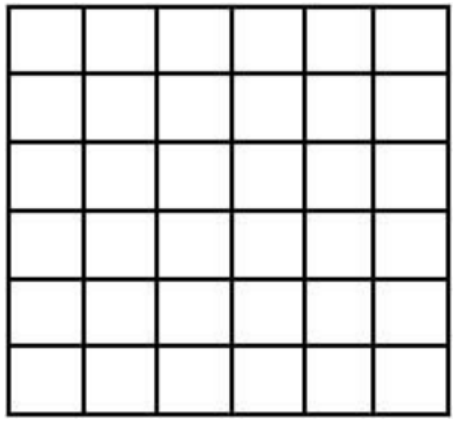
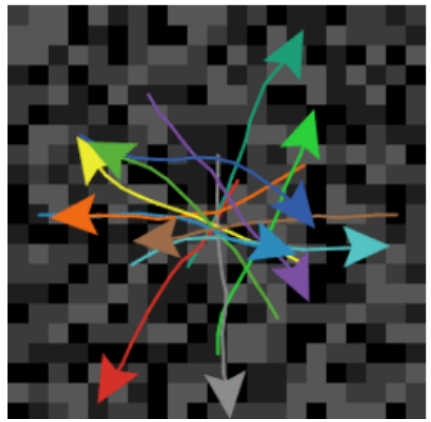
NetLogo basics: **Components**

Patches



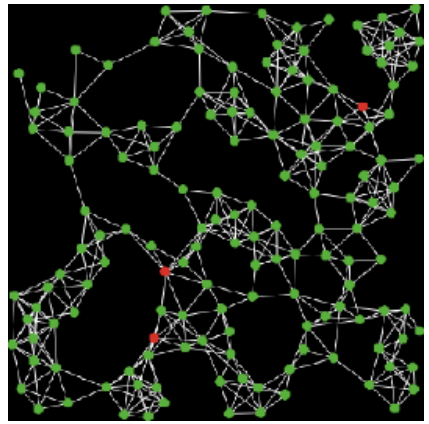
- stationary
- one per location
- forms the main graphical display

Turtles



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

Links



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

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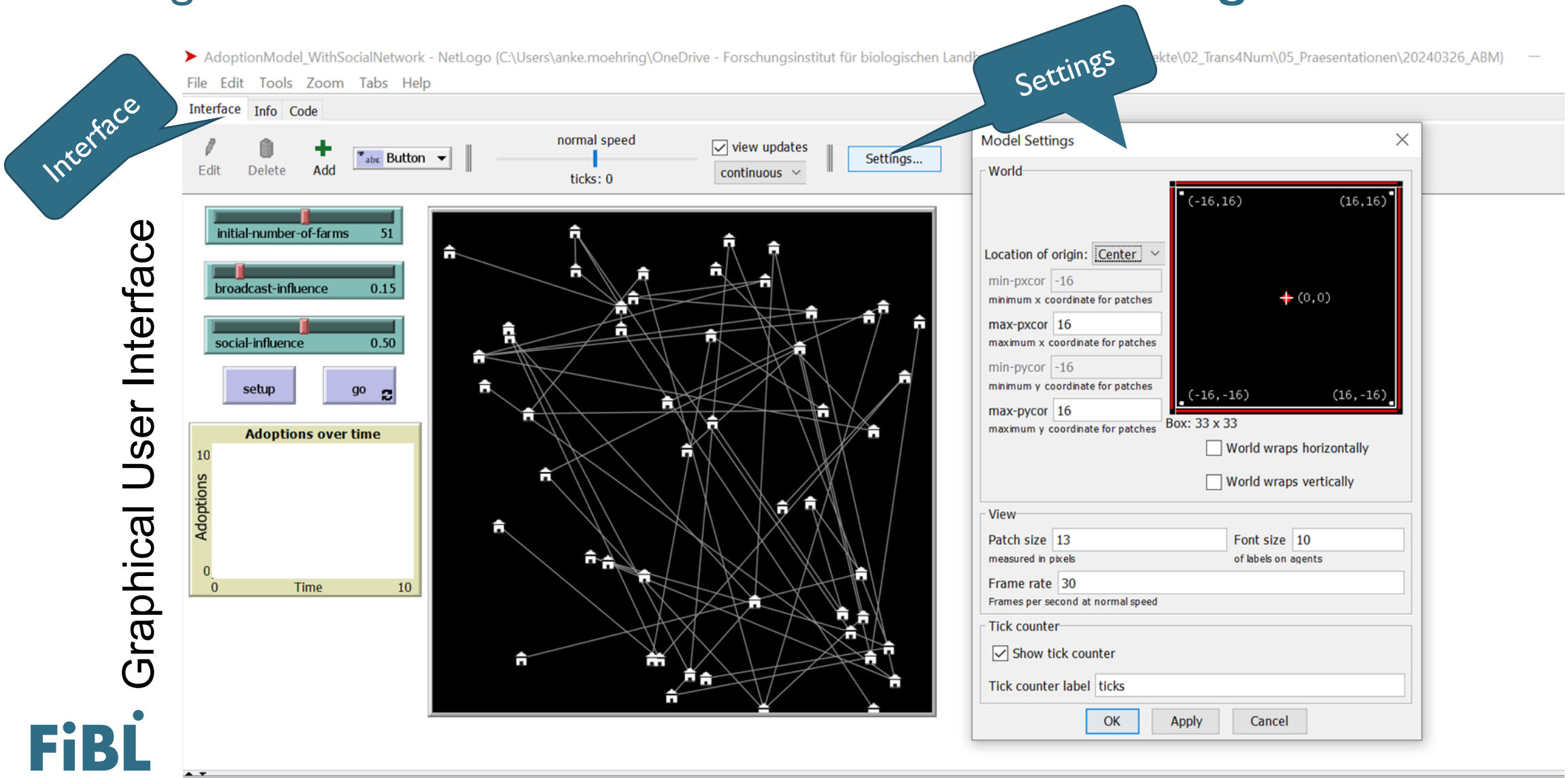
Source: Smaldino, 2023

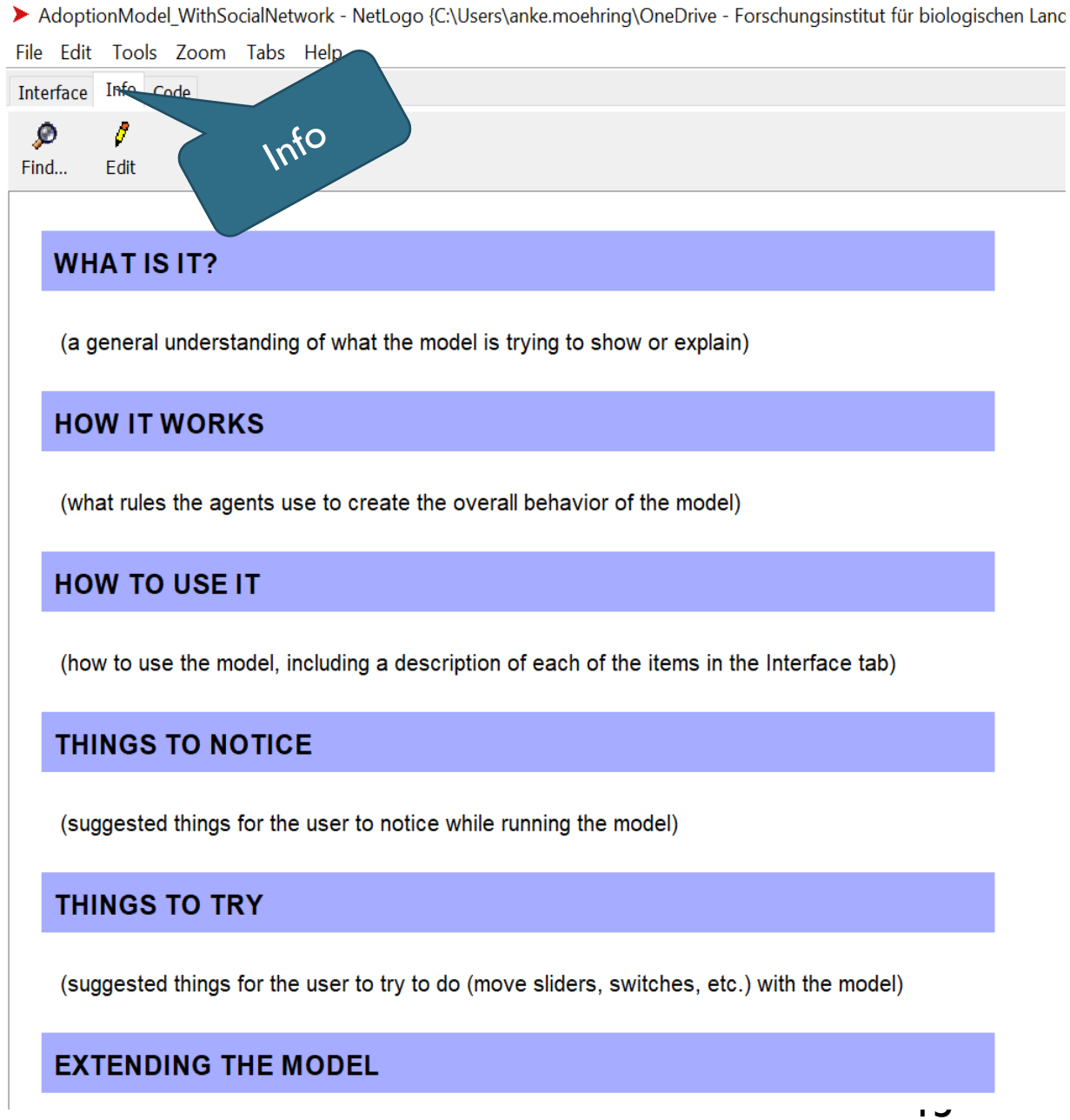
NetLogo basics: **Tabs «Interface» and «Model Settings»**



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



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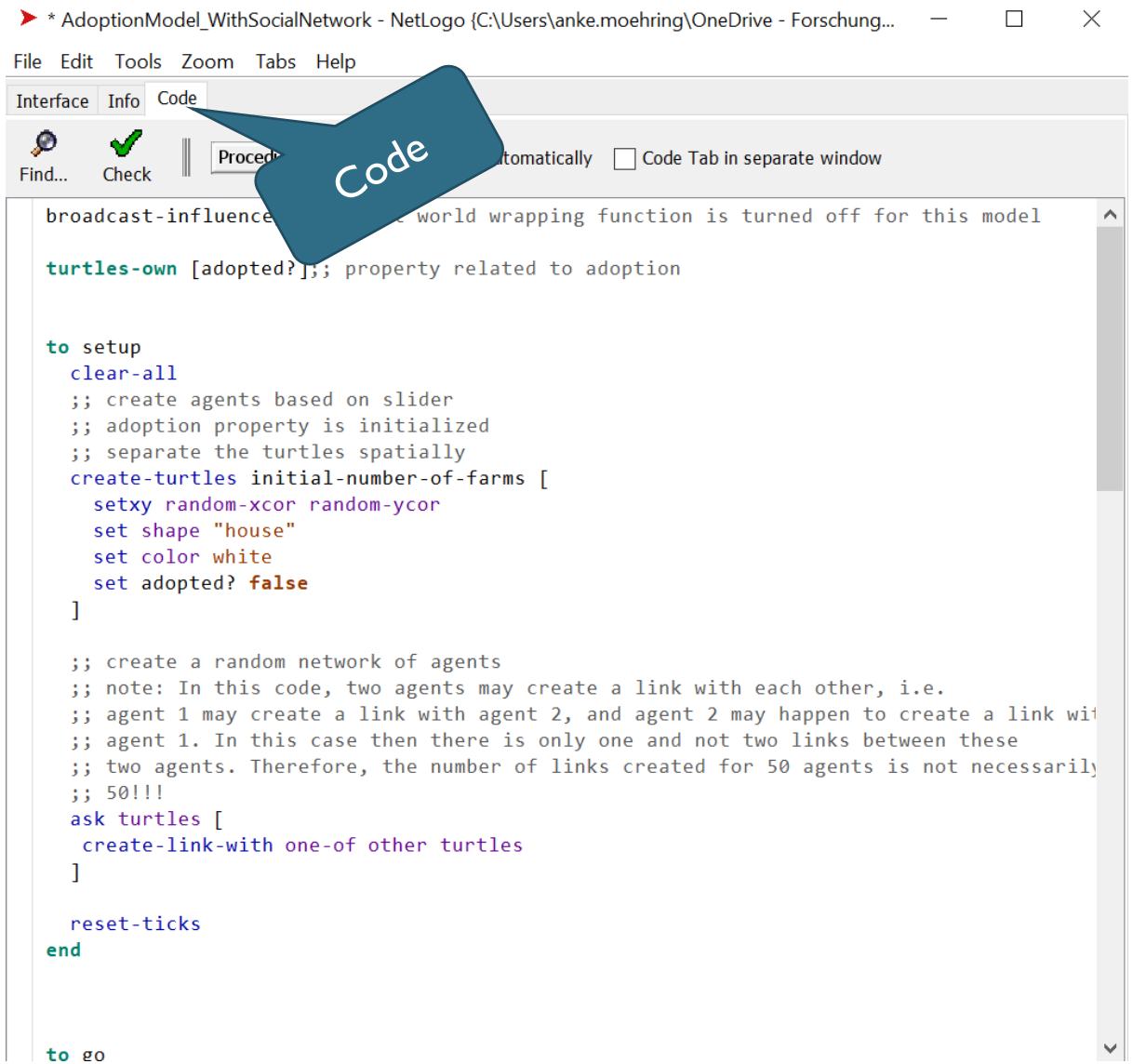
NetLogo basics: **Tab «Code»**

Code

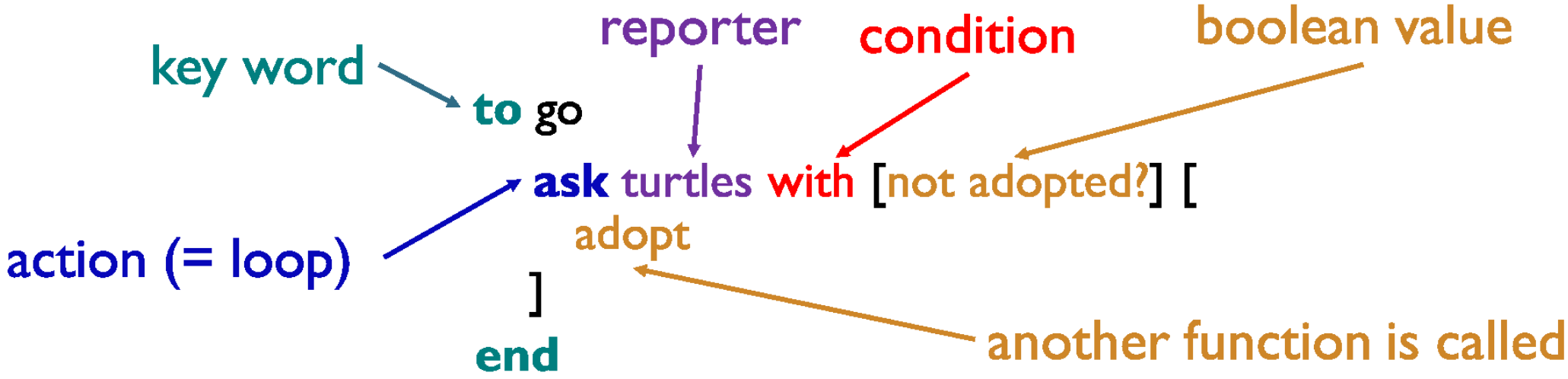
- Programming code
- Tell the computer what to do
- Save major changes with a new name (self-explanatory names are better)
- Think modular: core model plus extensions, that can be turned on/off



Source: Berea, A. 2023

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

See: NetLogo Interactive Dictionary | Beginner's Interactive NetLogo Dictionary (northwestern.edu)

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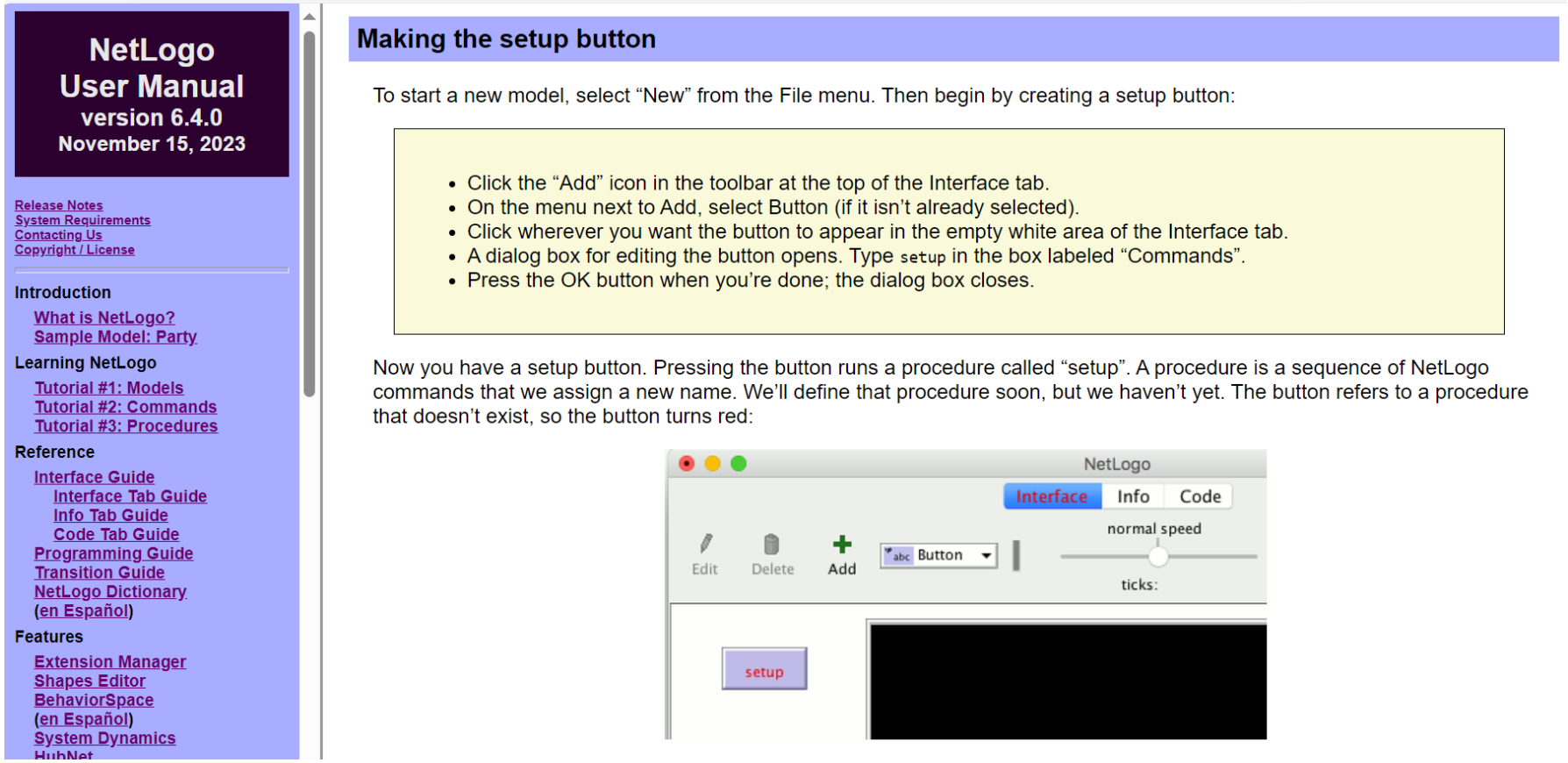
The User Manual is your friend!



See: NetLogo 6.4.0 User Manual (northwestern.edu)

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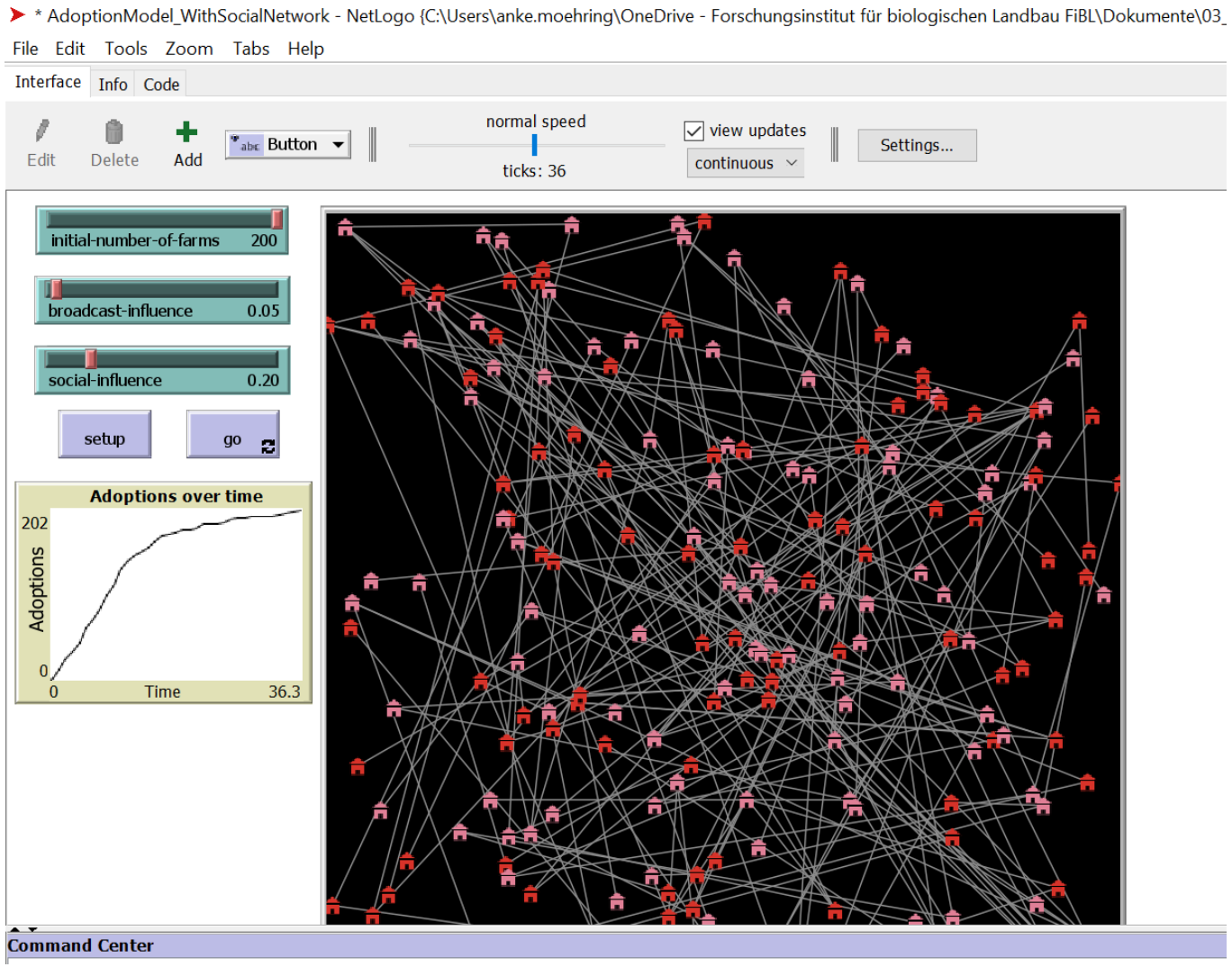
NetLogo basics: **Programming basics**

- Variables
- Functions
- Loops
- Conditionals



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

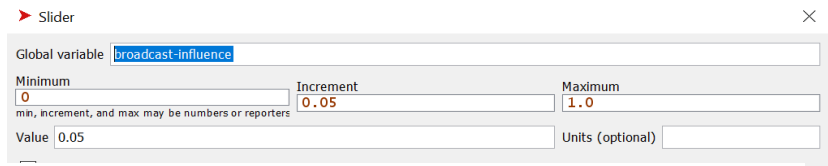
```
turtles-own [adopted?];; property related to adoption

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"!!

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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
```

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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
```

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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 (1)

	Workshop example
• 1.) **Formulation of the research question**	- How does the adoption of innovations evolve over time, considering the influence of broadcasting and social networks?
• 2.) **Identification of parts and properties** ○ 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).	- Agents: Adopters and Non-Adopters - Initial number of agents: $2 \leq n \leq 100$ - Attributes: color and shape
• 3.) **Definition of the agent's environment**, ○ agents' location and ○ neighbourhood	- Agents' location: random - Broadcast influence - Social influence

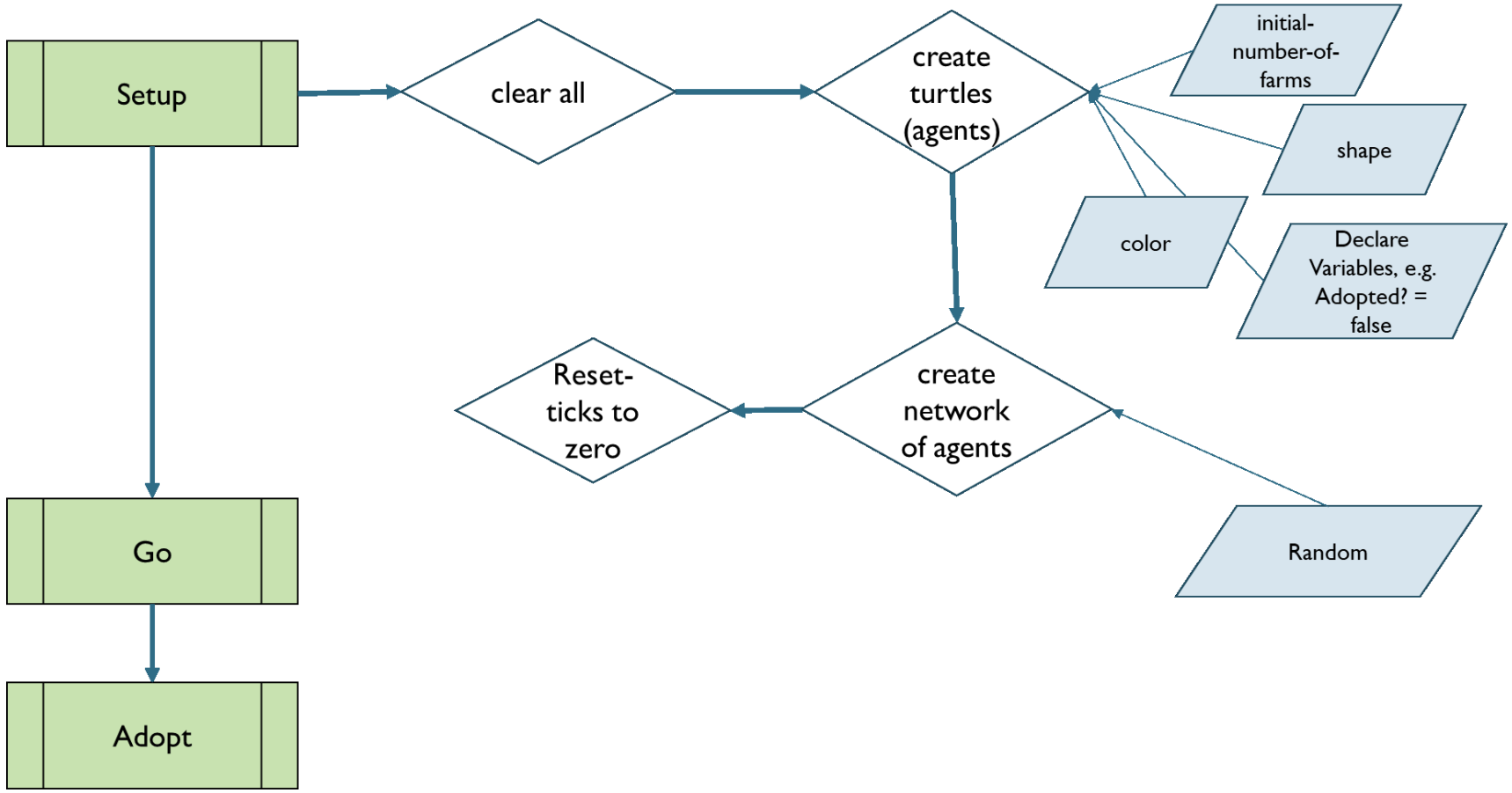
Proposal of the model specification procedure (II)

	Workshop example
• 4.) **Specification of agent interactions,** rules of ○ which agents interact, ○ when agents interact and how often ○ how do they interact during the simulation	- Adoption based on broadcast influence - Adoption based on social network structure: random
• 5.) **Definition of the model dynamics** ○ 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	- One tick = one adoption - Process diagram

Proposal of the model specification procedure (III)

	Workshop example
• 6.) **Definition of model outputs** (e.g. adoption rates, variables to measure farm level impact) • 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
• 7.) **Implementation** of the ABM in the computational software **NetLogo**	AdoptionModel_WithSocial Network.nlogo

Process diagram of a simple adoption of innovation model (1)



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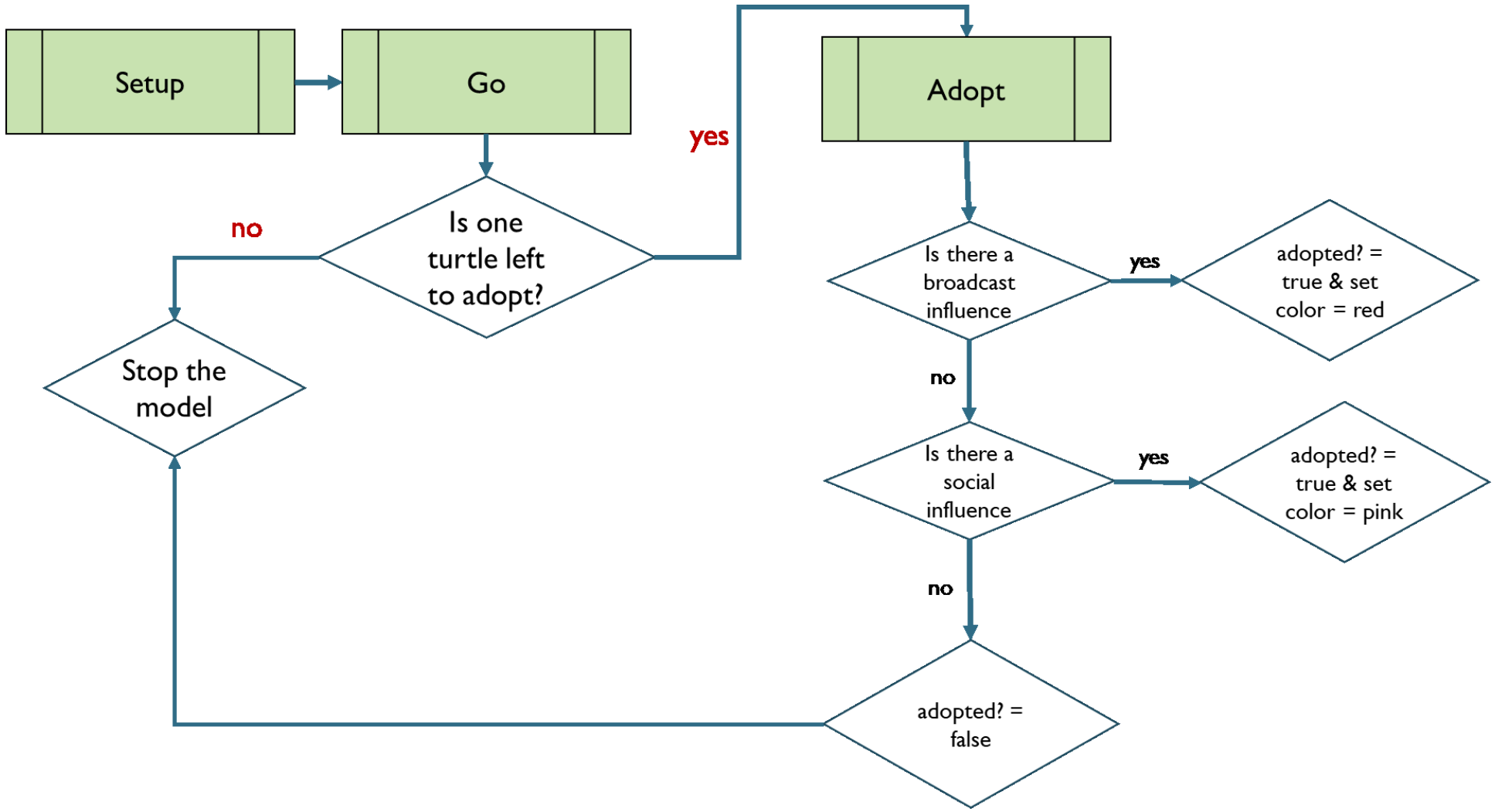
Process diagram of a simple adoption of innovation model (2)



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Data requirements and documentation

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

Parts and Properties

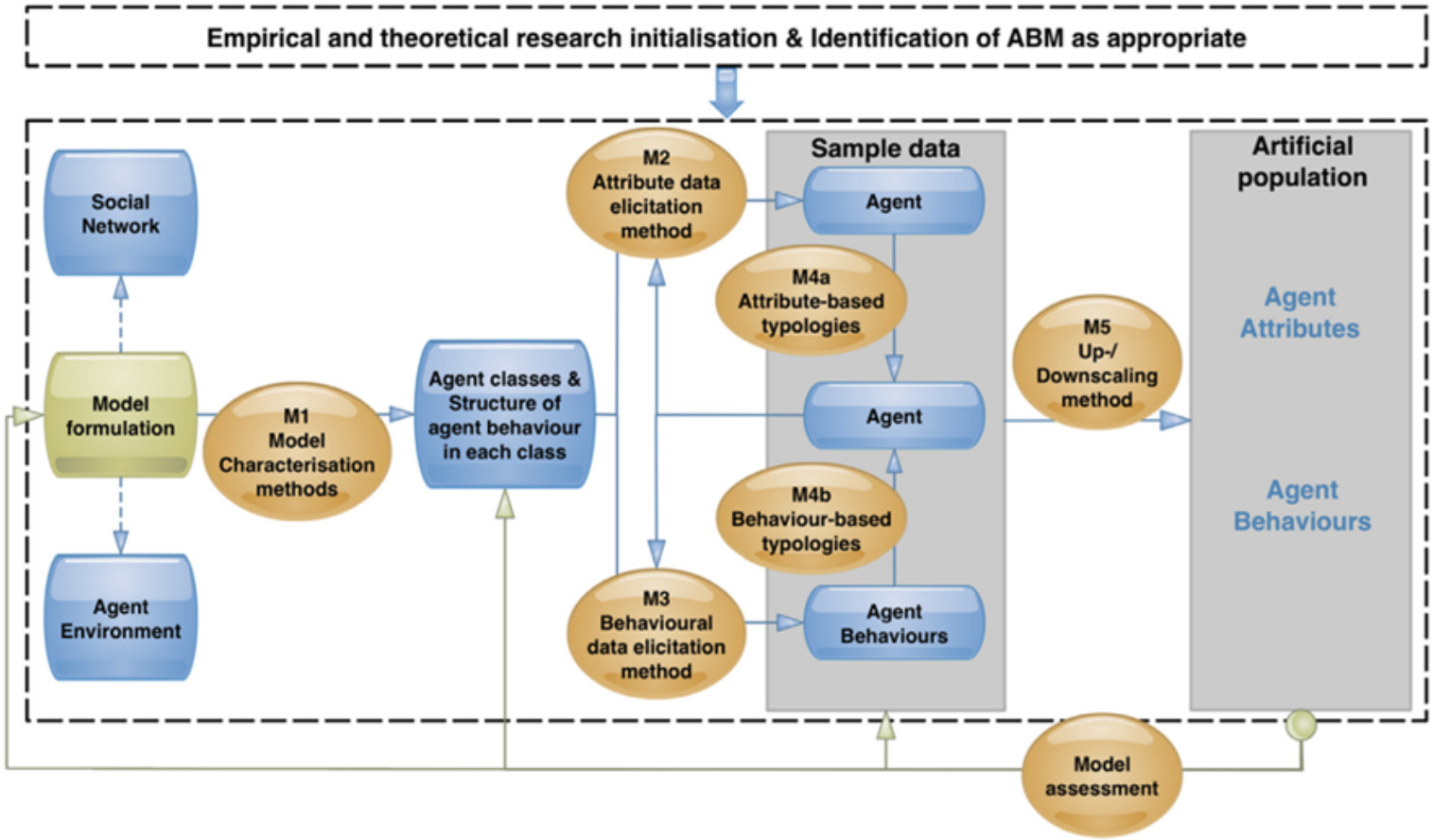
- A model is a decomposition of the system into the critical **parts**.

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?

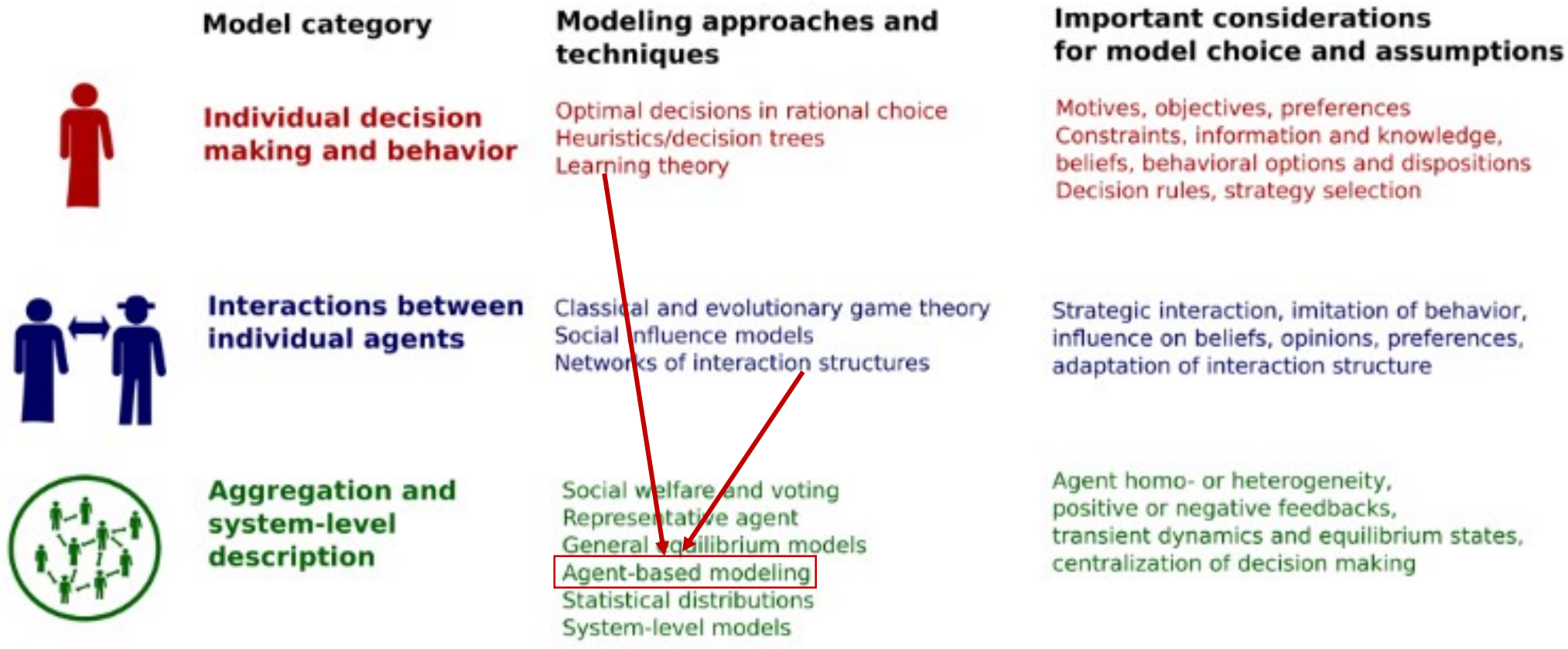
Characterisation and parameterisation of (human) agents



M1	M2 (Attribute)	M3 (Behaviours)	M4a (Attribute)	M4b (Behaviours)	M5 (Upscaling)
• Expert Knowledge • Participant Observation • Lab Experiments • Interviews • Role-playing Games	• Survey • Census (incl GIS data)	• Survey • Interviews • Field experiments • Participant Observation • Role-playing Games • Time series data • Expert knowledge	• Clustering & Regression • Correlation & Expert Knowledge • Expert Knowledge • Dasymetric Mapping	• Clustering & Regression • Correlation & Expert Knowledge • Expert Knowledge • Participant Observation	• Proportional • Census/GIS based assignment • Monte Carlo

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

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

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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.

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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?

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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

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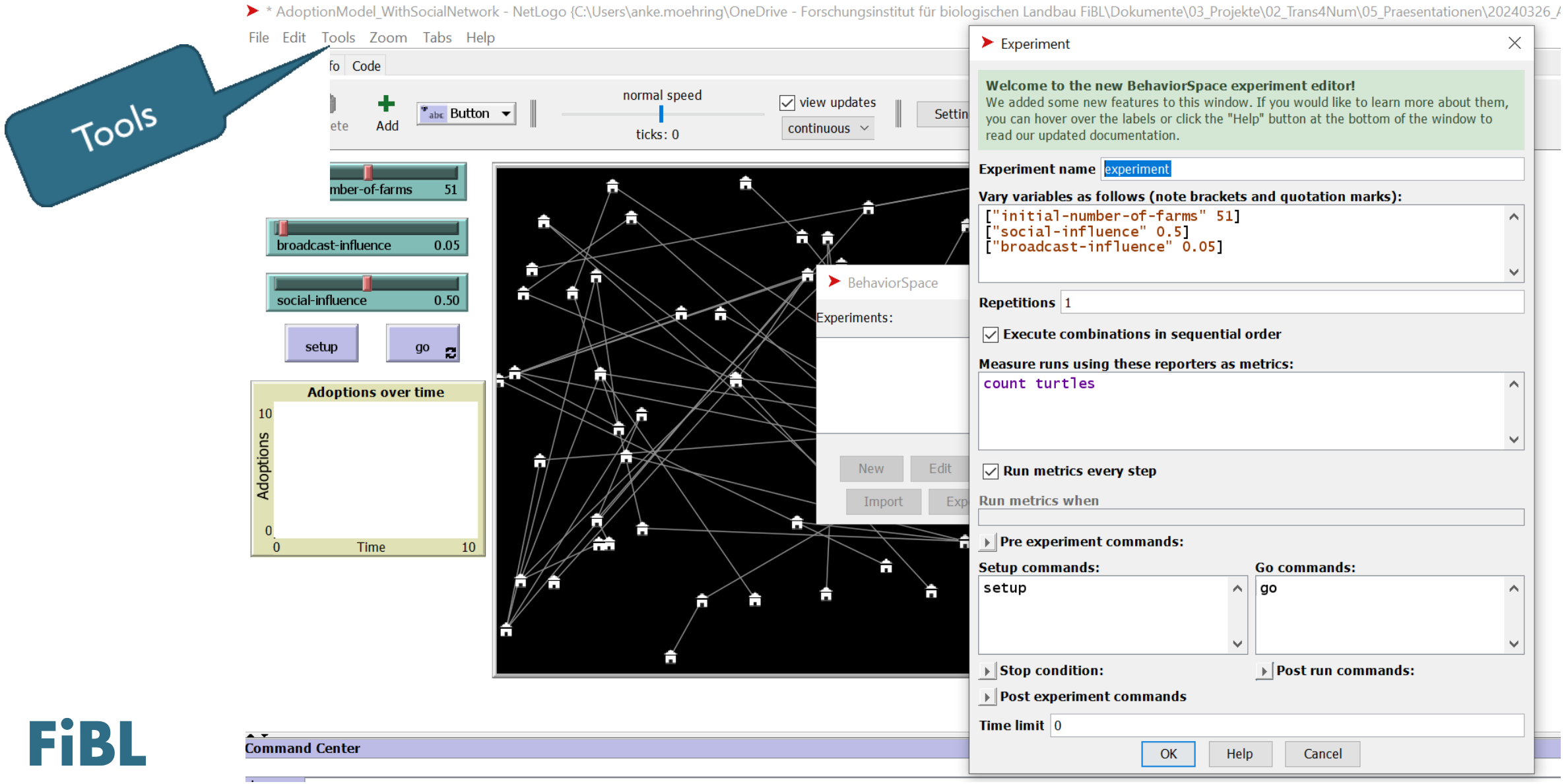
BehaviorSpace: Specification of an experiment



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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 Grimm[1], Steven F. Railsback[2], Christian E. Vincenot[3], Uta Berger[4], Cara Gallagher[5], Donald L. DeAngelis[6], Bruce Edmonds[7], Jiaqi Ge[8], Jarl Giske[9], Jürgen Groeneveld[10], Alice S. A. Johnston[11], Alexander Milles[1], Jacob Nabe-Nielsen[5], J. Gareth Polhill[12], Viktoriia Radchuk[13], Marie-Sophie Rohwäder[14], Richard A. Stillman[15], Jan C. Thiele[16], Daniel Ayllón[17]

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[5] Department of Bioscience, Aarhus University, Frederiksborgvej 399, DK-4000 Roskilde, Denmark
[6] U. 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

JASSS

O	1. Purpose and patterns	Basic principles
	2. Entities, state variables and scales	Emergence
	3. Process overview and scheduling *Submodel A* *Submodel B …*	Adaptation Objectives Learning
D	4. Design concepts	Prediction Sensing Interaction Stochasticity Collectives
D	5. Initialization	
	6. Input data	
	7. Submodels *Submodel A (Details)* *Submodel B (Details) …*	Observation

Grimm et al., 2020

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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…	≈ Adopter NBS technology • Arable / Fodder crops • Cattle / Dairy • Granivore Both, organic & conventional	• Biorefinery • Biogas producer • Slaughterhouse • Mushroom processor	• Farmer Community	• Farmer Group • Extension • Stakeholder / Public Sector • Value Chain	
	supply or	• Rotation • Biomass / Product	• Bio-fertilizer • Protein fodder	• Labour & Machinery	• Know how / Information	
	demand	• Bio-fertilizer • Protein fodder • Know how / Information • Labour & Machinery	• Biomass • Product (Mushrooms)		• 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?

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