Agent-Based Modelling and Simulation Processes-Summary

Overview

Agent-based modelling (ABM) is a computational approach for simulating the interactions of agents to assess their effects on the system as a whole. Here an extensive overview of the key elements of ABM, including verification, sensitivity analysis, parameterization, and validation is discussed.

Verification

Key Points:

- **Simulation History Analysis**: Essential for understanding the model output by evaluating the details of a simulation history.
    - **Methods**:
        - Key events in chronological order.
        - History of an individual agent.
        - Global viewpoint (large-scale patterns).
- **Ensuring Model Specifications**: Verification ensures the model meets the specifications. Axelrod's methods emphasize the need for repeating simulations and performing statistical analyses to determine if results are typical or sensitive to initial conditions and parameters.

Verification Methods:

- **Face Validation**: Repeated simulations and statistical analyses to ensure that the results are typical and robust. Sensitivity analysis checks the impact of variations in initial conditions and parameters on the model output.

Sensitivity Analysis

Key Points:

- **Local Sensitivity Analysis**: Examines how sensitive the model is to the value of each individual parameter.
- **Global Sensitivity Analysis**: Assesses the model's sensitivity when varying all parameters simultaneously. It addresses the complexity due to numerous possible parameter combinations.

Considerations:

- Robustness and uncertainty in model outputs are examined to determine the reliability of results under different parameter values.
- Stability checks include plotting the accumulative average of the state variable over increasing runs and calculating the coefficient of variation.

Parameterization

Key Points:

- **Parameterization**: The selection of values for a model's parameters.
- **Calibration**: A specific type of parameterization aimed at aligning the model with empirical data.
  - **Purposes**:
    - Matching empirical data.
    - Estimating parameters that are difficult to measure directly.
    - Testing structural realism by calibrating sub-models separately.

Methods:

- **Categorical Calibration**: Finding parameter values that produce results within a predefined acceptable range.
- **Best-fit Calibration**: Identifying a set of parameters that best match specific criteria.

Validation

Key Points:

- **Validation**: Ensuring the model accurately represents the phenomenon being simulated.
  - **Types**:
    - **Input Validation:** Ensuring the accuracy of input data.
    - **Process Validation:** Verifying the processes within the model.
    - **Output Validation:** Checking if the output aligns with empirical data.
    - **Macro and Micro Validation:** Comparing aggregated and individual agent behaviors.

Challenges:

- The stochastic nature of models and systems.
- Path dependency, where the initial setup significantly impacts the outcome.
- Potential discrepancies between model predictions and known past states due to data limitations.

Pattern-Oriented Modelling

Key Points:

- Utilizes spatial and temporal patterns to validate the model's ability to reproduce observed phenomena.
- Examples include modelling cholera diffusion and COVID-19 scenarios, where patterns in infection spread and intervention effects are analyzed.

Applications:

- **Spatial Patterns**: Evaluating if the model can replicate patterns of change over time and space.
- **Model Integration**: Combining different model aspects, such as governmental risk perception in COVID-19 models.

Conclusion

Here a comprehensive approach to ABM is discussed, emphasizing the importance of verification, sensitivity analysis, parameterization, and validation in creating robust and reliable models.

By addressing each of these elements, modelers can ensure that their simulations accurately reflect real-world phenomena and provide valuable insights for decision-making and policy development.

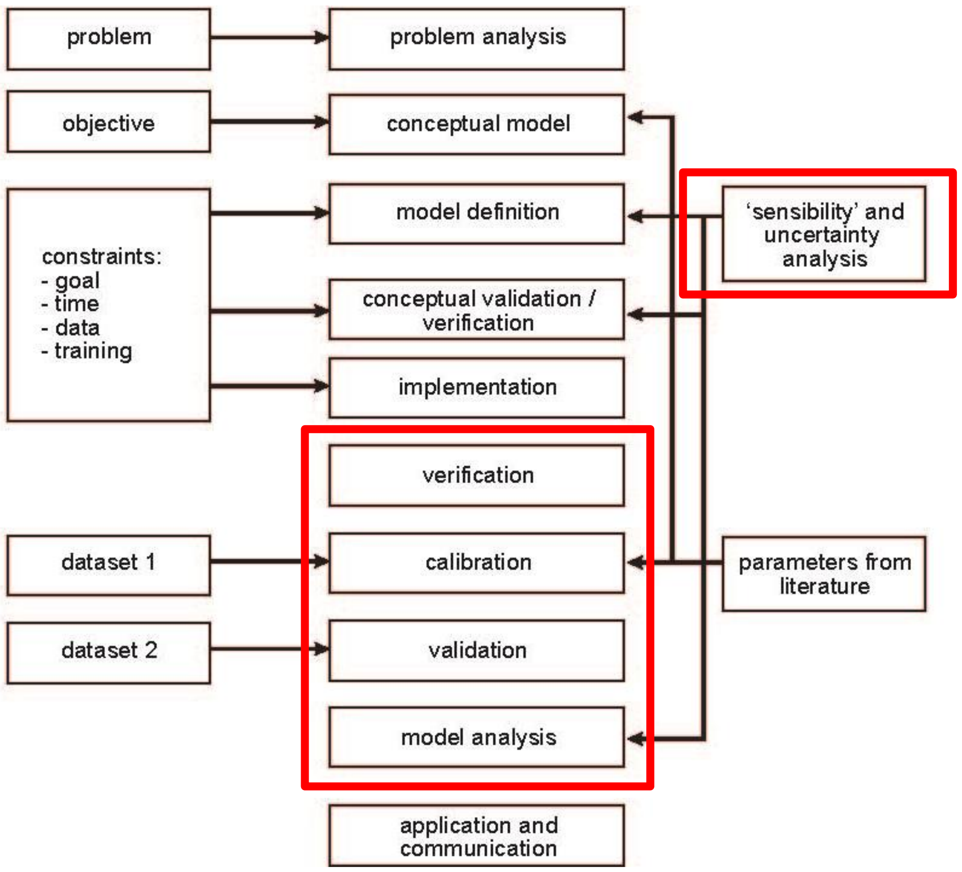
ABM3

ELLEN-WIEN AUGUSTIJN

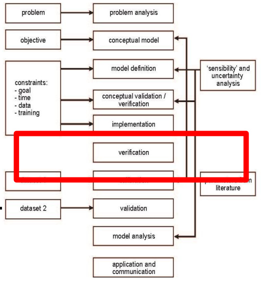
OVERVIEW

- Verification
- Sensitivity Analysis
- Parameterization
  - Direct parameterization
  - Indirect Parameterization (Calibration)
    - One at a Time
    - All at a Time
- Validation
  - Input validation
  - Process validation
  - Descriptive output validation
  - Predictive output validation

- What about pattern-oriented Modelling?



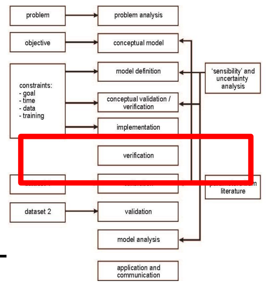
VERIFICATION



- To understand the output of an agent-based model it is often necessary to evaluate the details of a simulation 'history'.
- This can be done in three ways (Axelrod):
  - Key events in chronological order
  - History of one agent can be documented → check agent behavior, agent's trajectory
  - History from a global viewpoint can be noted (distribution of pedestrians) –large scale patterns → aggregated level

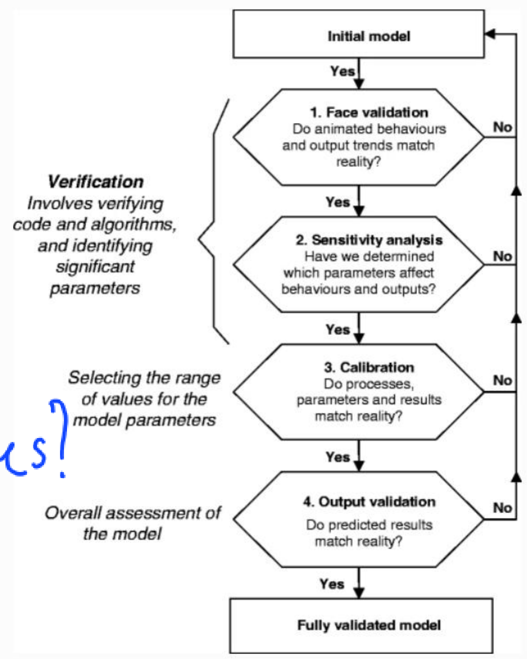
- Verification is the task of ensuring that a model satisfies the specifications

VERIFICATION – FACE VALIDATION



if it's sensitive to some params, we might need "calibration"

- History of an individual agent can be "misleading" especially when the simulation contains random effects.
- To determine if the results are typical, it is necessary to repeat the simulation. → how many times?
- Statistical analysis of the results is necessary.

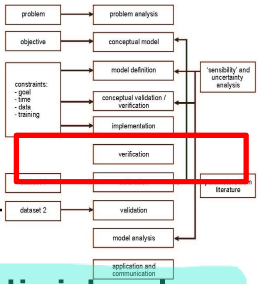


- Sensitivity analysis can proof if the output is sensitive to variation in initial conditions and parameters.
- The effect of different model versions can also be assessed by running controlled experiments.
- Difference in the logic of the model can be studied by comparison of different versions.

Ngo, T.A., See, L. (2012). Calibration and Validation of Agent-Based Models of Land Cover Change. In: Heppenstall, A., Crooks, A., See, L., Batty, M. (eds) Agent-Based Models of Geographical Systems. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-8927-4_10

Castle, C. J. E. and A. T. Crooks (2006). Principles and Concepts of Agent-Based Modelling for Developing Geospatial Simulations. Working paper series UCL - paper 110 - Sep 06.

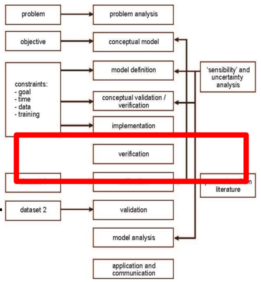
Local or global sensitivity analysis



- Local sensitivity analysis: test how sensitive the model is to the value of each individual parameter.
  - Does not allow us to capture parameter interactions: how the model's sensitivity to one parameter might change as other parameters change

- Global sensitivity analysis: test how sensitive the model is when varying all parameters at the same time.
  - Problem is that many different combinations are possible

Sensitivity analysis, uncertainty, robustness



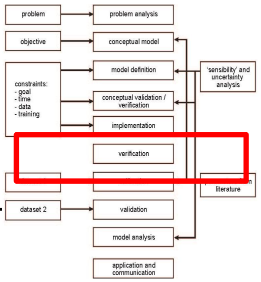
- Does the model reproduce patterns *robustly*, or are these results *sensitive* to changes in model *parameters*?
- How uncertain are the model's outputs? (would it produce the same results if different plausible parameter values are used)
- Uncertainty analysis (UA) looks at how uncertainty in parameter values affects the reliability of model results
- Robustness analysis (RA) explores the robustness of results and conclusions of a model to changes in its structure.

ex. wolf-sheep model

if we change number of sheeps/wolf at initial, model isn't able to reproduce same pattern

Stability

stochastic elements (สุ่ม)

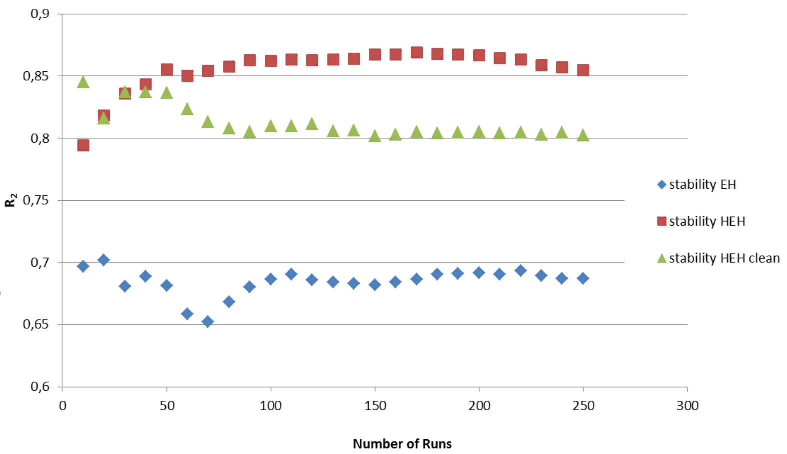


Two methods to check stability (robustness):

- Plotting the accumulative average of the state variable (output) over an increasing number of runs.
- The coefficient of variation is defined as the ratio between the standard deviation of a sample and the mean of that sample resulting in the following formula: $Cv = \sigma\mu$

in which *Cv* is the coefficient of variation, *σ* the standard deviation of the sample and *μ* the mean of the sample

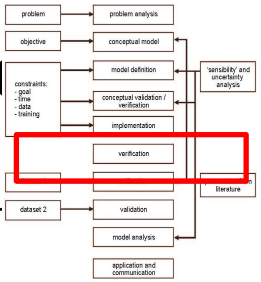
(average R^2 depends on number of runs)



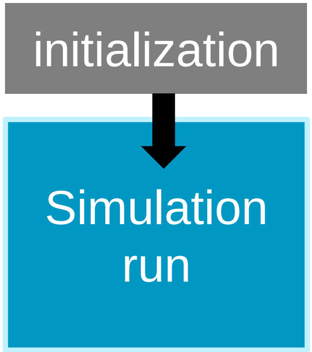
N	Cv
5	0.0022
10	0.0024
25	0.0024
50	0.0021
100	0.0021

(Lorscheid, Heine, & Meyer, 2012),

Determine how many times a new population should be constructed



- Agent-based models use a re-created "synthetic population"
- The synthetic population is normally generated based on statistical data (CBS).



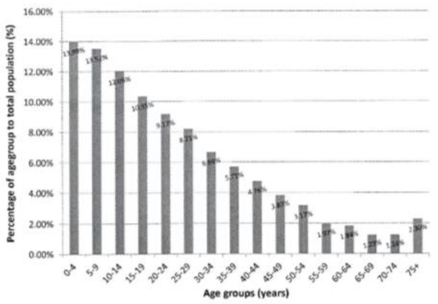


Figure D.4: Ashanti region population divided by age and group (GSS, 2012)

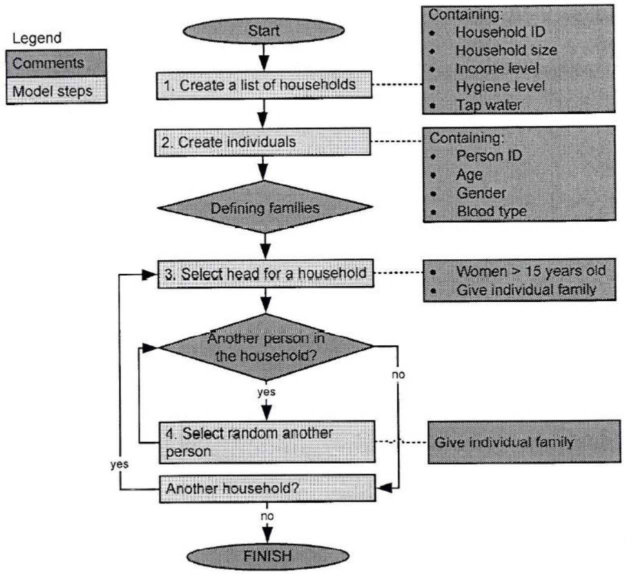
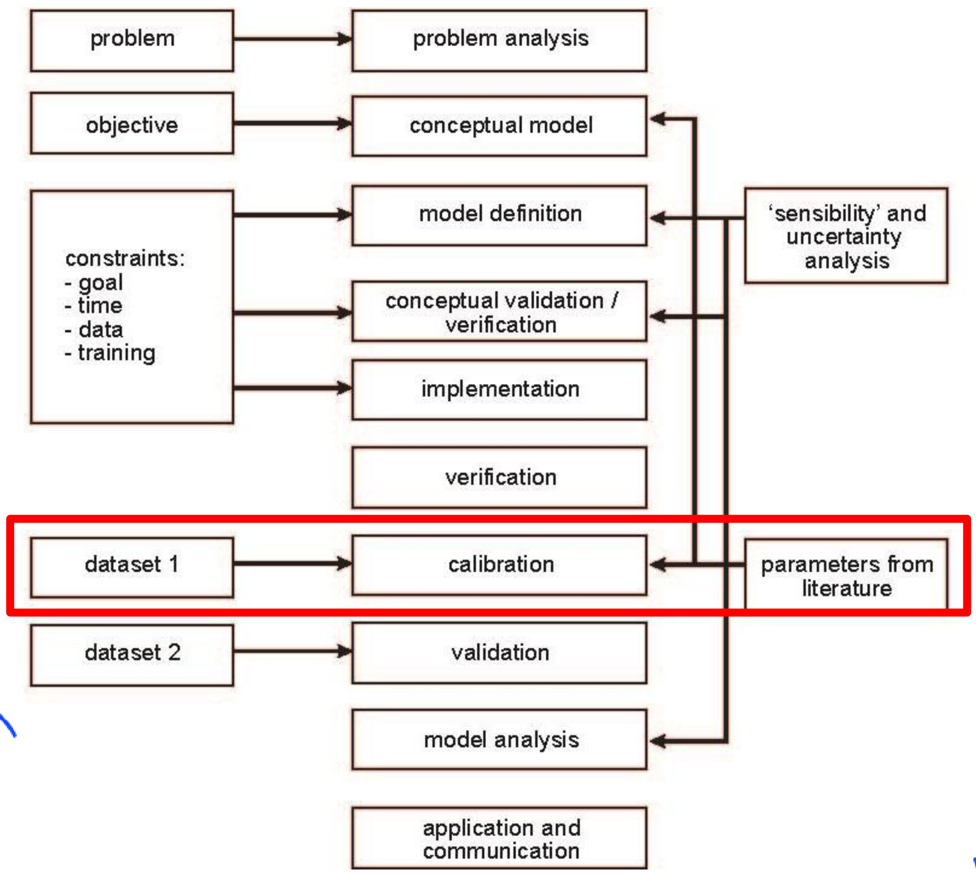
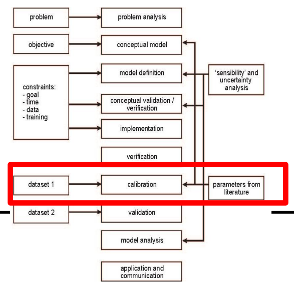


Figure 6.2: Synthetic population generator after Moeckel (2003)

THE MODELLING PROCESS





independent data

Parameters are the constants in the equations and algorithms that are used in your model

Parameterization: selection of values for a model's parameters

Calibration: specific type of parameterization in which we try to find a set of values for important parameters.

Purposes of model calibration

- Model calibration serves the following purposes:
  - Force the model to match empirical data
  - Estimate the value of parameters that cannot be evaluated (measured) directly
  - To test the model's structural realism: can we calibrate it to match the observations within a reasonable range?

- Calibrate each sub-model separately

Categorical versus Best-fit Calibration

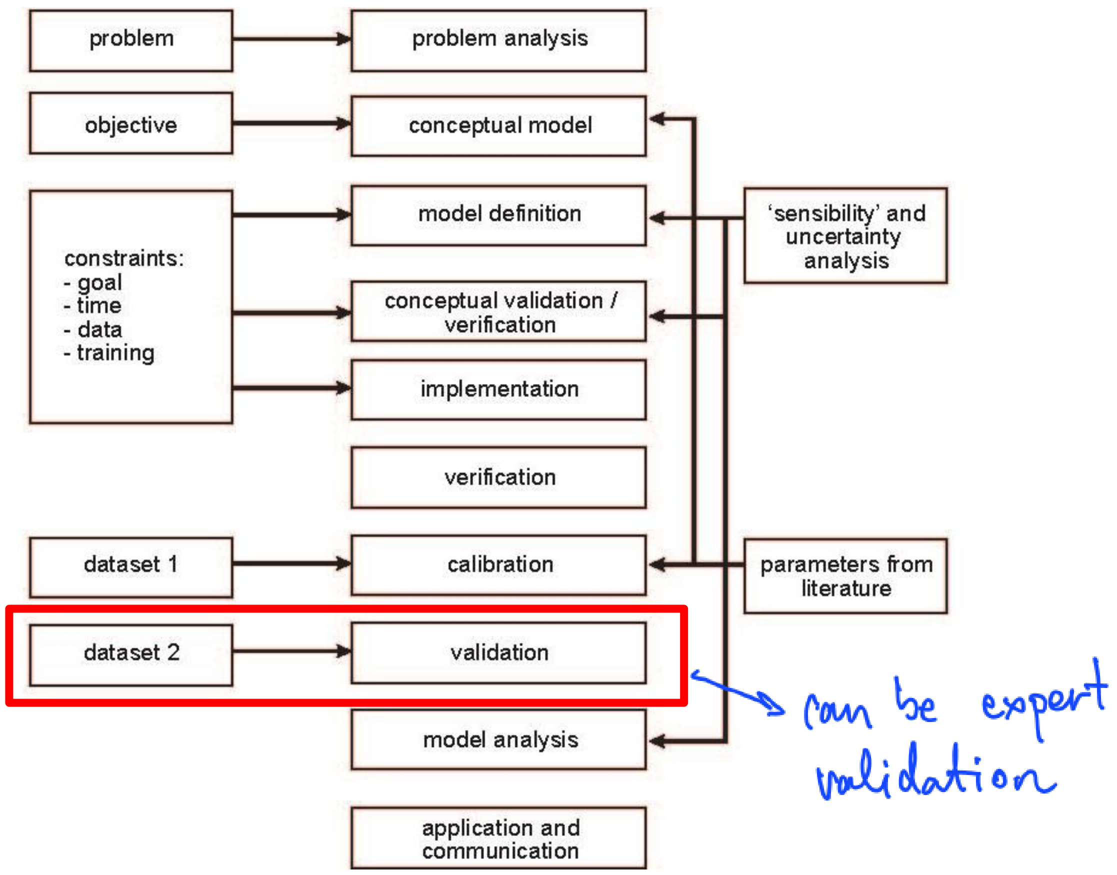
range

- *Categorical Calibration*: search for parameter values that produce model results within a category or range you defined as acceptable (mean number of agents between 120 and 150)

exact no.

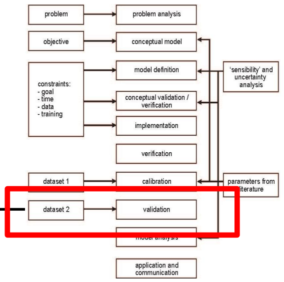
- *Best-fit Calibration* you search for one set of parameters that cause the model to best match some exact criteria (mean 135 agents)

THE MODELLING PROCESS



- Validation is checking if the model is a good model of the simulated phenomenon
- *Validation – the model shows the macro-level regularities (pattern) that the research is seeking to explain. If so, this is evidence that the interaction and behavior of the agents is the cause of the regularities (pattern).*
- After comparing the macro behavior it is desirable to compare the output of the model with empirical data.

VALIDATION



- A model has a degree of validity (Law and Kelton, 1991)

A model is valid to the extent that it adequately represents the system being modelled (Casti, 1997)

Casti, J.L. (1997) Would-Be-Worlds: How Simulation is Changing the Frontiers of Science, John Wiley & Sons, New York, USA.
Law A.M., and W.D. Kelton (1991), Simulation modeling and analysis; Second Edition, McGraw-Hill, New York
Axelrod, R. (1997). Advancing the Art of Simulation in the Social Sciences. Simulating Social Phenomena, Berlin, Heidelberg, Springer Berlin Heidelberg.

VALIDATION – POSSIBLE PROBLEMS

- Both model and system under analysis are likely to be stochastic. → random
- A model might be able to produce plausible future predictions but may not be able to recreate known past system states. → can't recreate past bec. there weren't there yet.
- Model could be correct but data from the real-world system may not.
- Many simulations are path dependant (i.e. the outcome of a simulation is dependant on the exact initial setup chosen) – history of a simulation is highly significant.

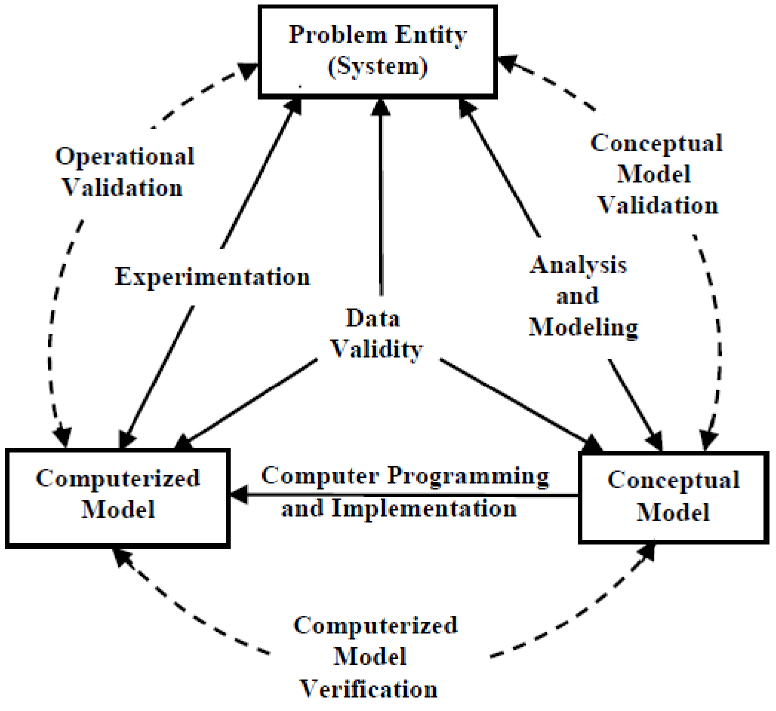


Figure 2: Simplified Version of the Modeling Process

Sargent, R. (2011). Verification and validation of simulation models.
January 2011, Proceedings - Winter Simulation Conference 37(2):166 - 183
DOI: 10.1109/WSC.2010.5679166

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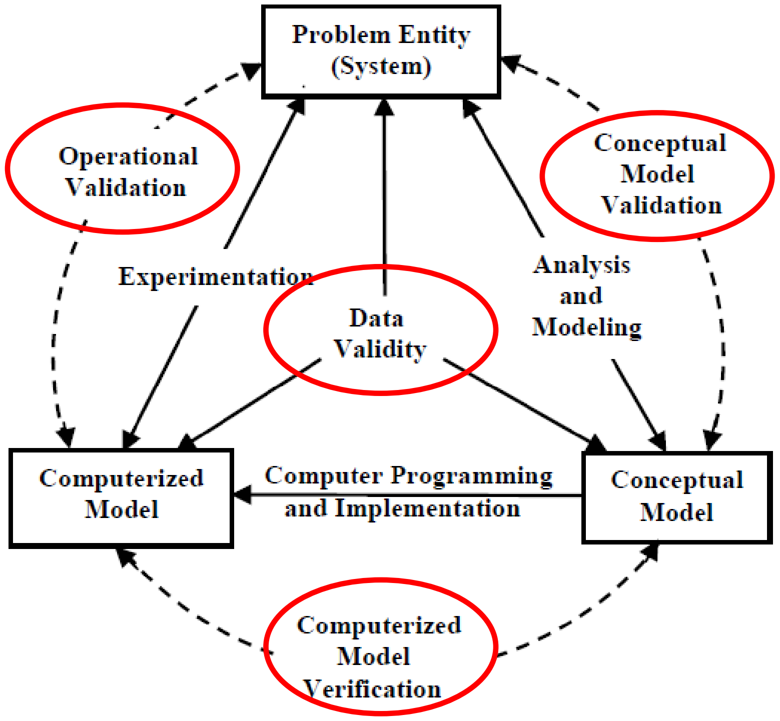

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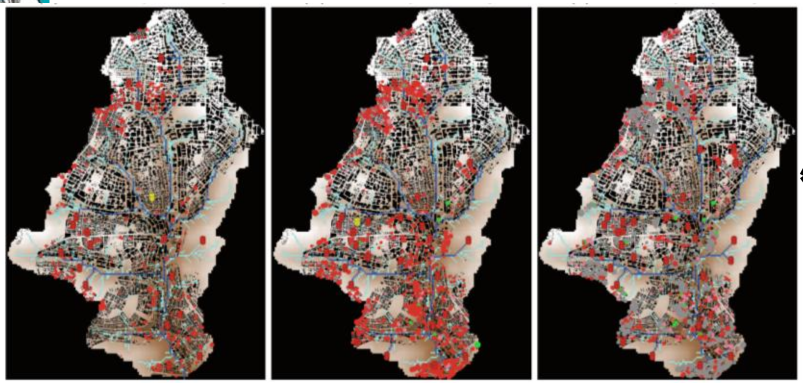
VALIDATION

- Validation
  - Input validation
  - Process validation Conceptual model
  - Descriptive output validation → pattern
  - Predictive output validation → data from the model match with real-world
  - Macro validation (at an aggregation level)
  - Micro validation comparing individual rules/agents
  - Face validation (do the general ideas about the behavior and properties compare to the real-word) versus empirical validations (data validation) ???

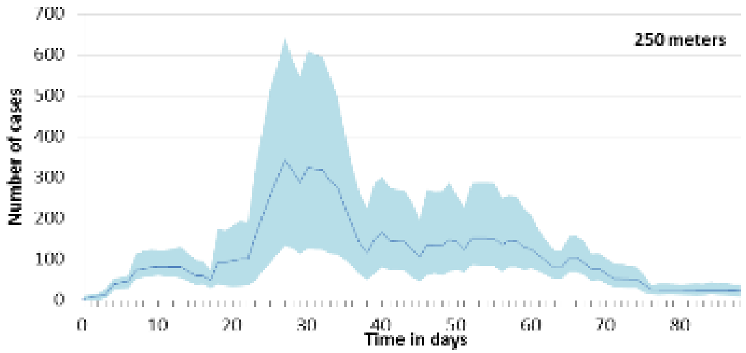
- Validity of a model is always related to the purpose of this model
- All models are simplifications, and all models are wrong

An Example: Using time series and spatial patterns

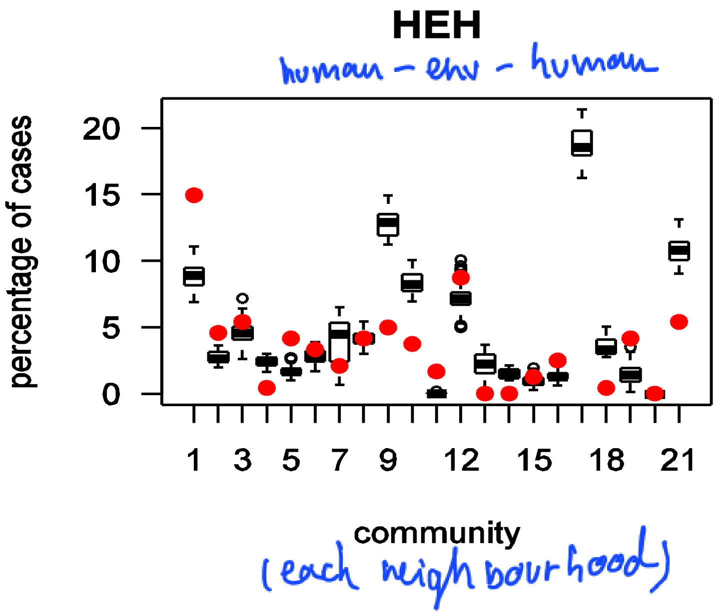


(d) Run 2: After 15 days (e) Run 2: After 30 days (f) Run 2: After 45 days

- Should your model be able to reproduce patterns of change over time?



- Should your model be able to reproduce patterns in space?

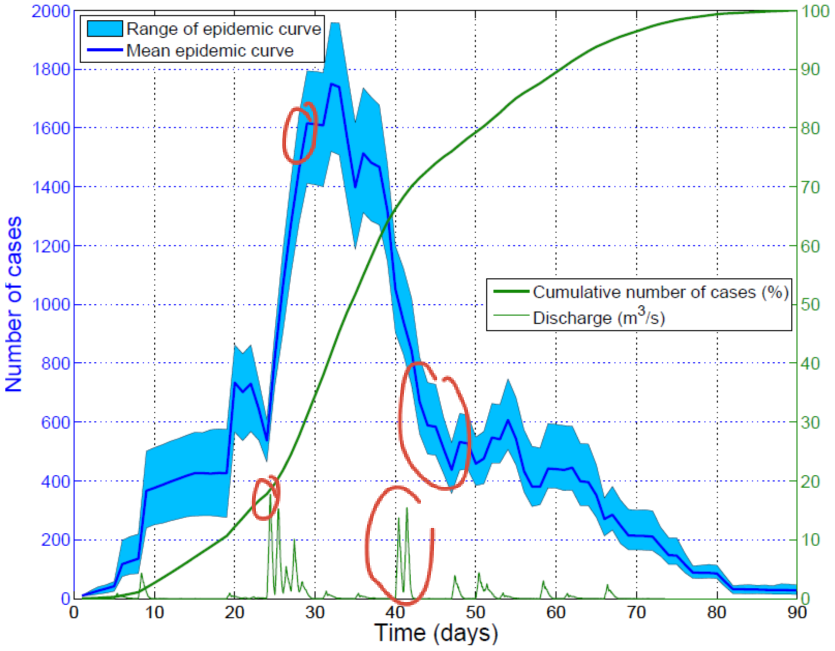


Augustijn, E.-W., et al. (2016). "Agent-based modelling of cholera diffusion." Stochastic Environmental Research and Risk Assessment **30**(8): 2079-2095.

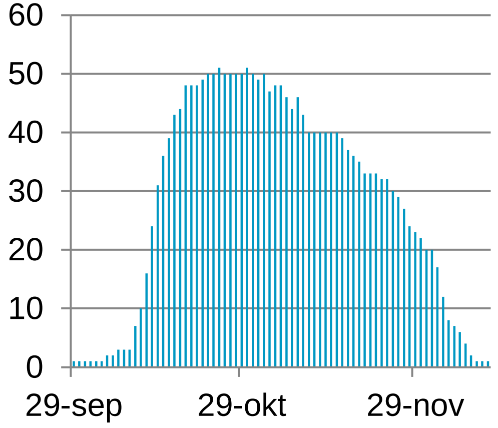
INTEGRATED MODEL

RESULTS

chrono logical order of events



Range of epidemic curves representing the minimum and maximum number of cases within a set of 90 runs.



Transmission mechanism	HH	HEH	EH	VT
Average number of cases	80	2461	683	22
Minimum and maximum number of cases	60-104	2237-2608	595-786	10-38
Contribution to total number of cases (%)	2.5	75.8	21.0	0.7

Augustijn, E.-W., et al. (2016). "Agent-based modelling of cholera diffusion." Stochastic Environmental Research and Risk Assessment **30**(8): 2079-2095.

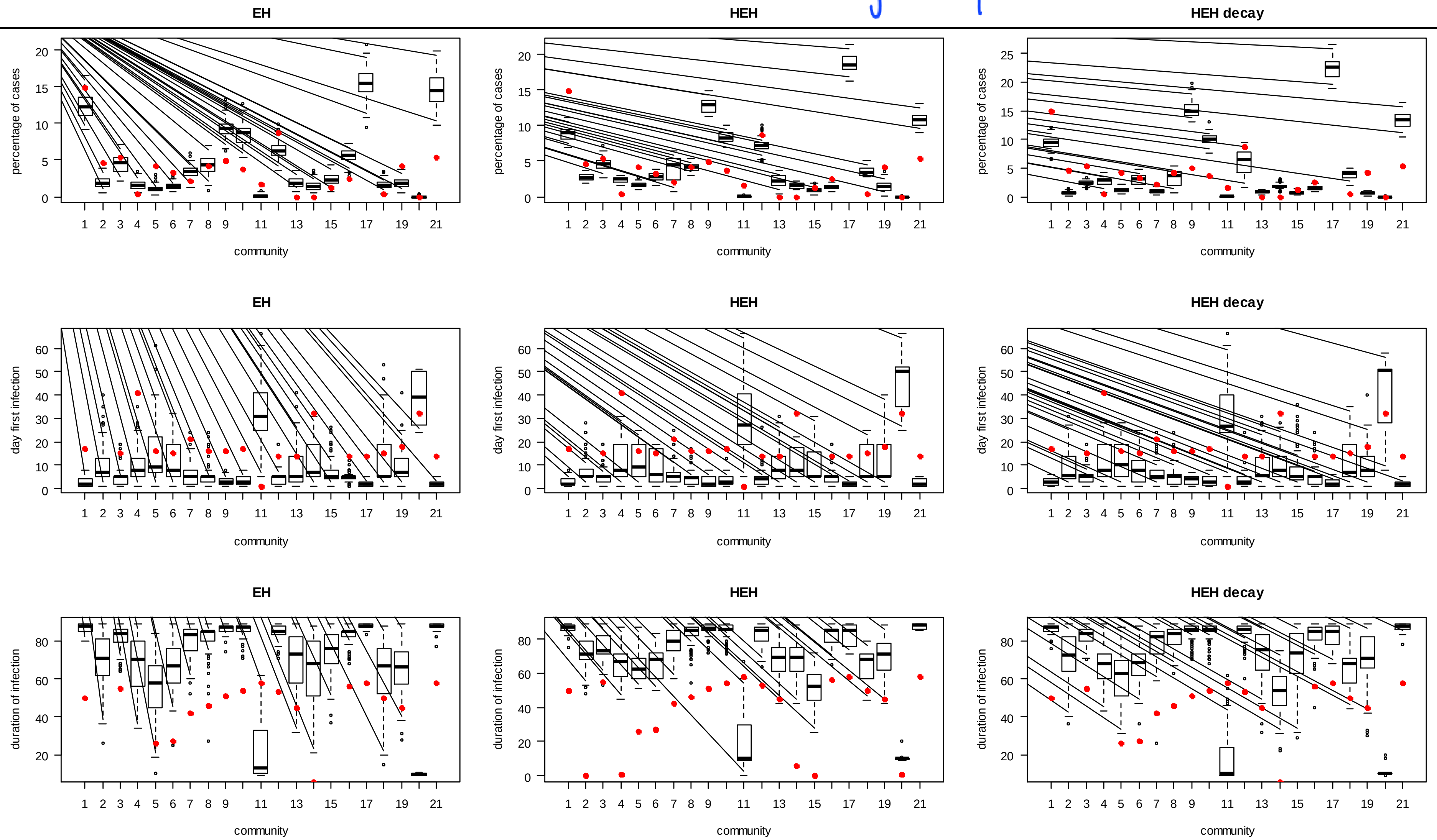
we can integrate ML to adjust the behavior of human → lead to good prediction of cases

EXPERIMENT 1: EVALUATION SPATIAL PATTERNS

Disease cases

Day first infection

Duration of infection



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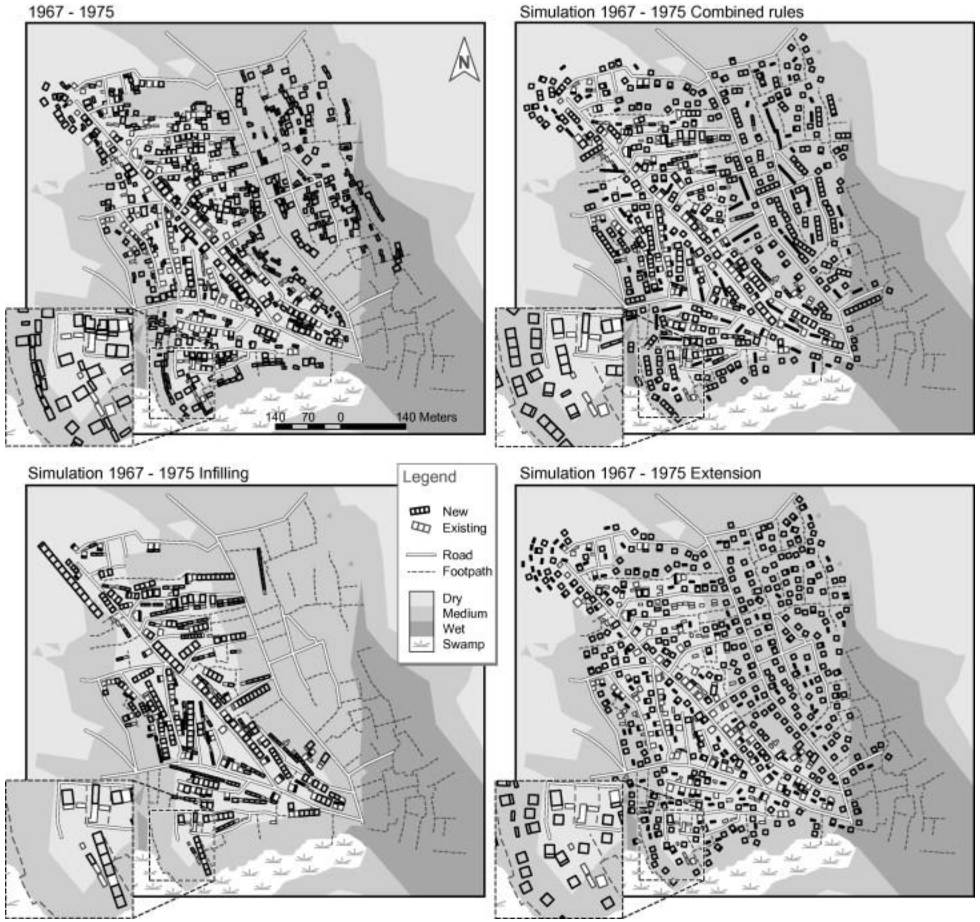
PATTERN ORIENTED MODELING

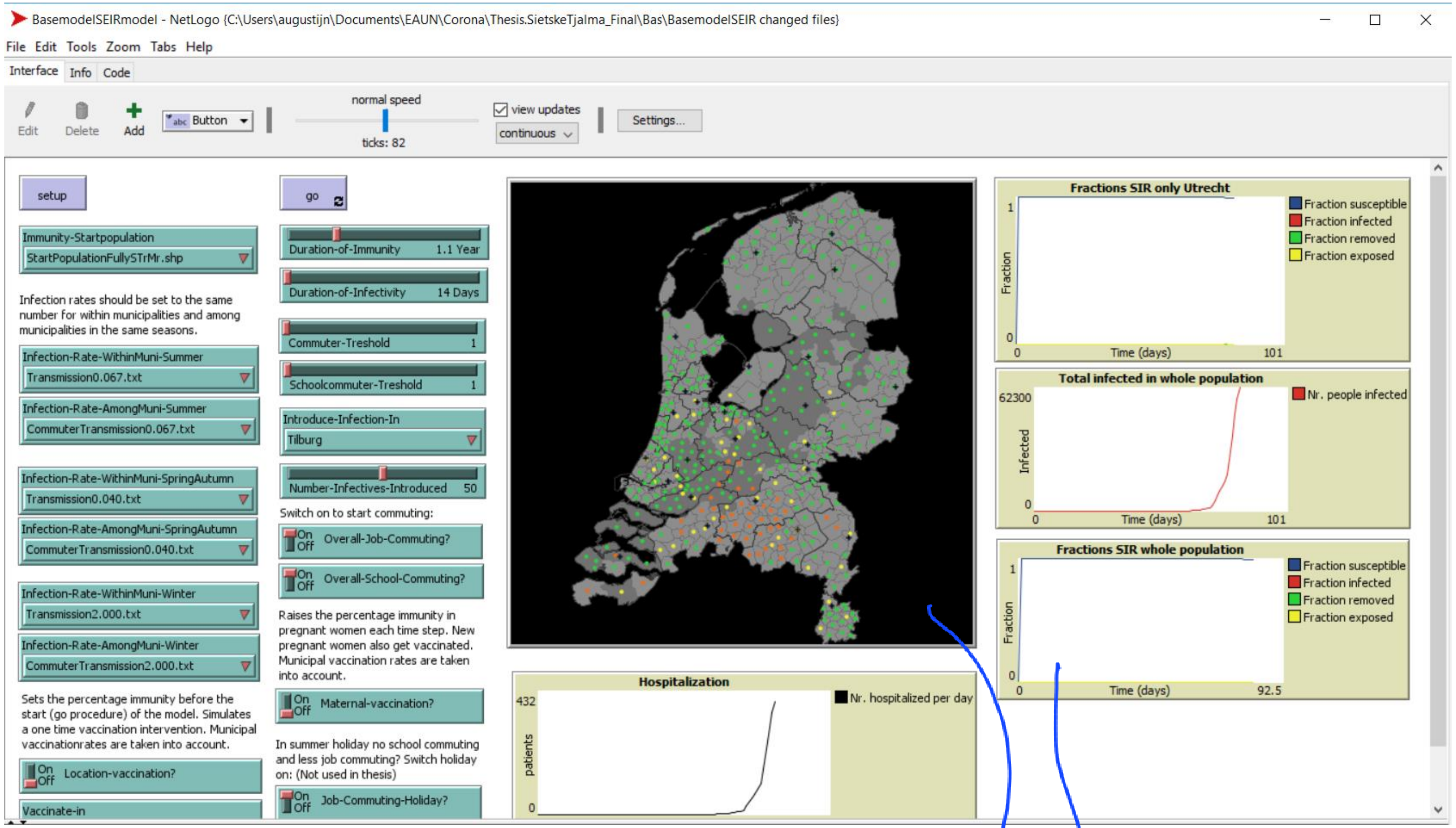
- Two differen/alternative hypothesis

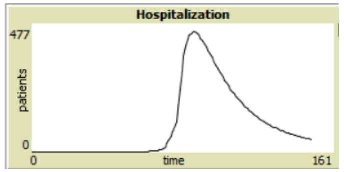
- Extension: use the complete area to find the optimal location
- Infilling: try to align to existing buildings

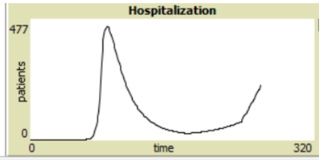


Augustijn-Beckers, P., Flacke, J., & Retsios, V. (2011). Simulating informal settlement growth in Dar es Salaam, Tanzania : an agent - based housing model. *Computers, environment and urban systems*, *35*(2), 93-103. https://doi.org/10.1016/j.compenvurbsys.2011.01.001

Covid-19 model



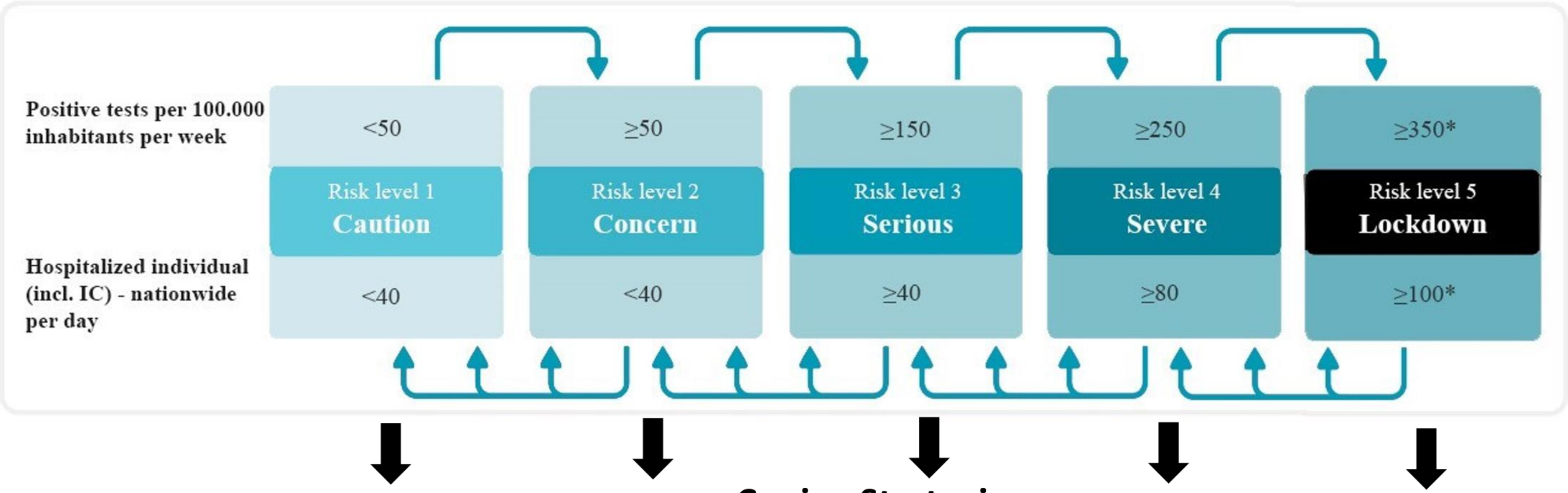




spatial pattern

pattern in time

Risk perception



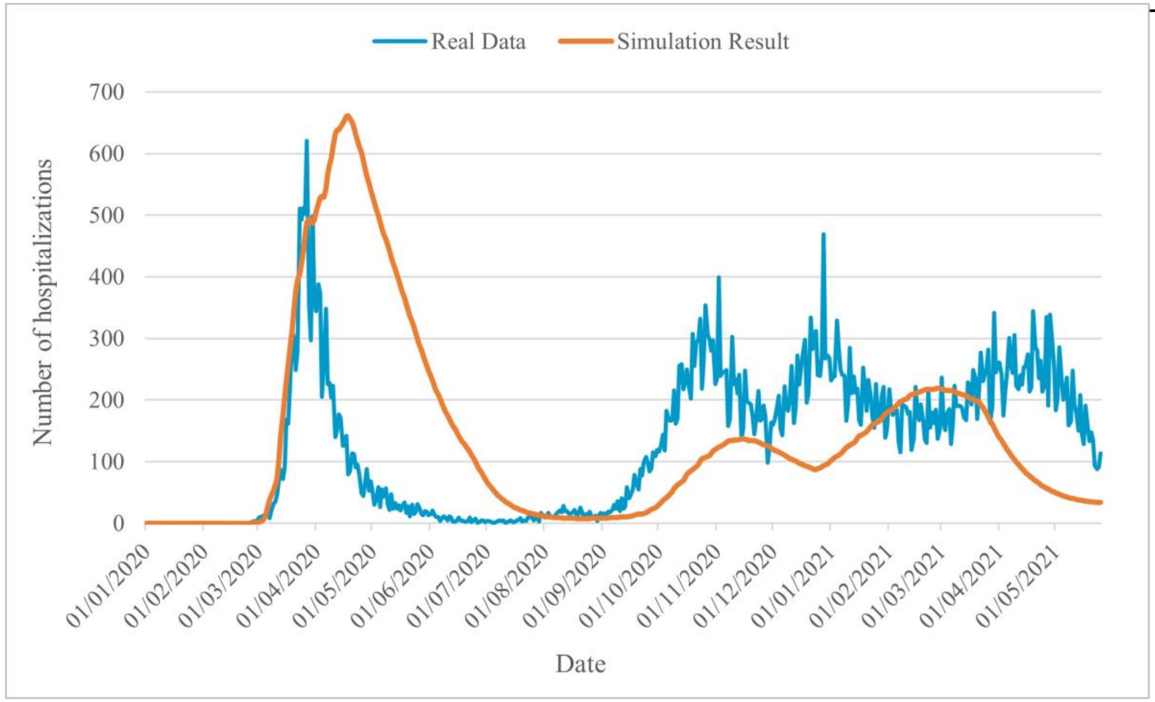
Coping Strategies

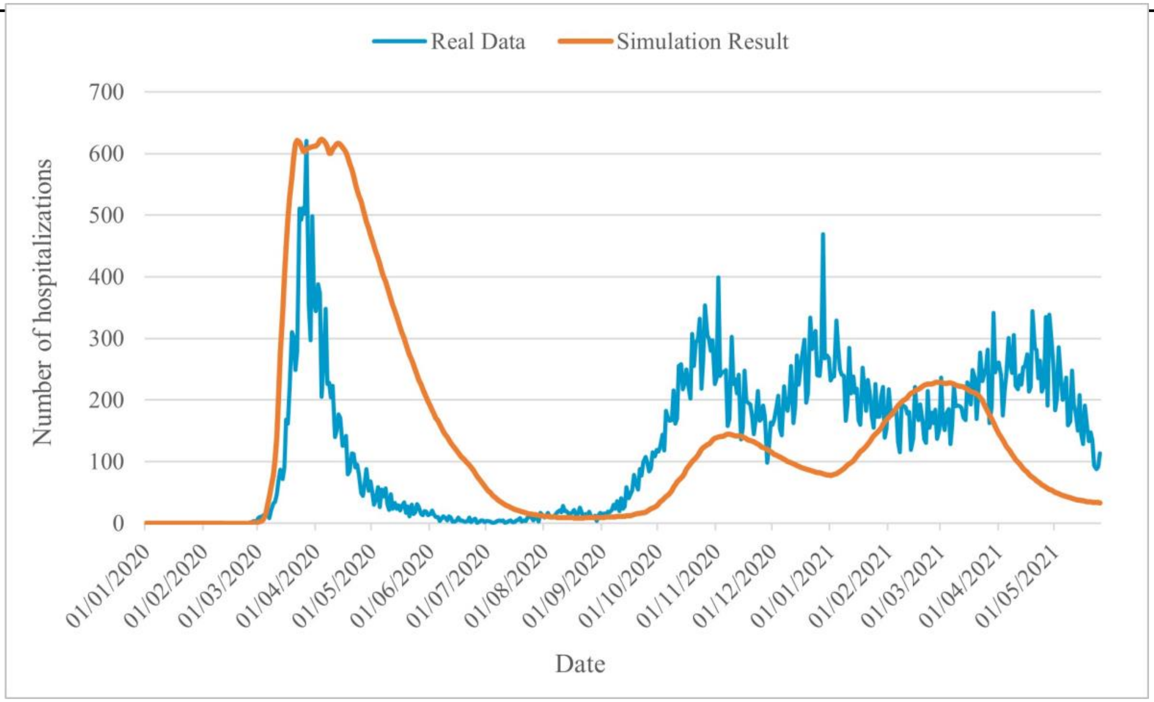
	Level 1	Level 2	Level 3	Level 4	Level 5
Contact Matrix	Normal	Normal	Reduced	Reduced	Further Reduced
Job Commuting	level 100%	Level 80%	Level 60%	40%	20%
School Commuting	level 100%	Level 100%	Level 100%	100%	0%
GAET commuting	level 100%	Level 80%	Level 60%	40%	20%
VT commuting	level 100%	Level 90%	Level 70%	50%	30%

Augustijn et al. (2022) Integration of governmental risk perception into a Covid-19 model for the Netherlands, 2022 VFGG
Ministerie van Volksgezondheid, 2020

With closing of schools

Without closing of schools

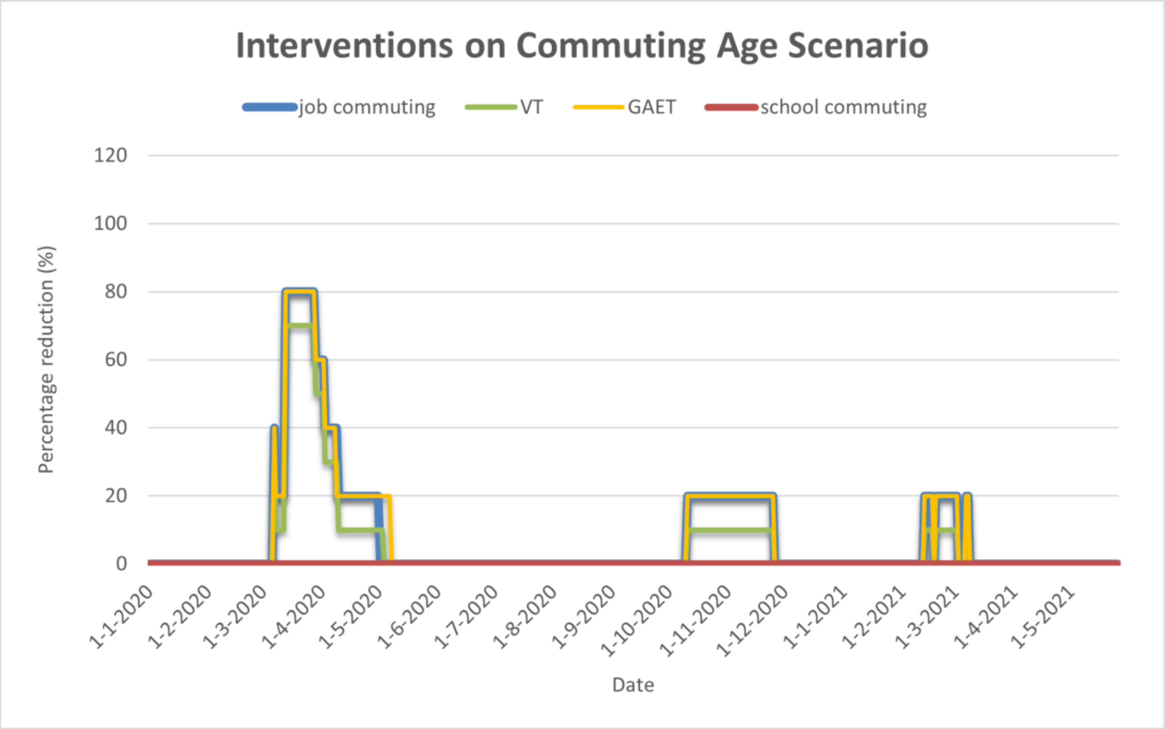




Number of hospitalized cases for the RoadMap Scenario

Number of hospitalized cases for the age-specific

Augustijn et al. (2022) Integration of governmental risk perception into a Covid-19 model for the Netherlands, 2022 VFGG (in press)



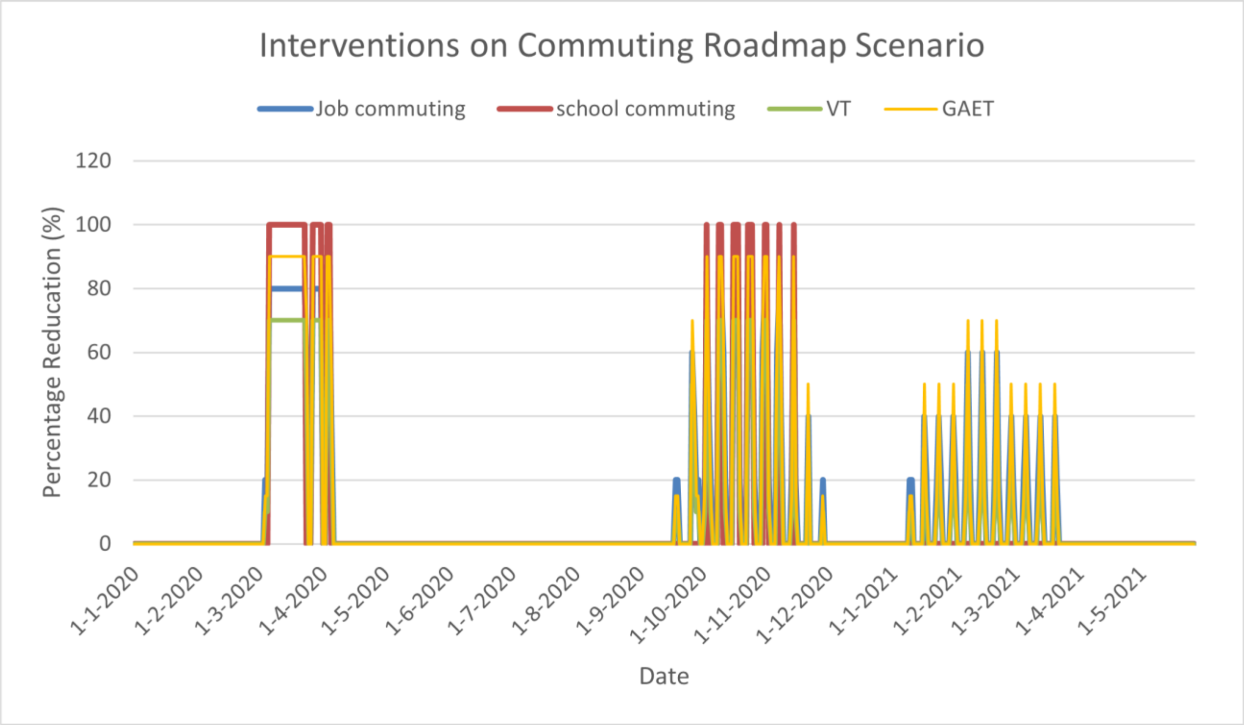
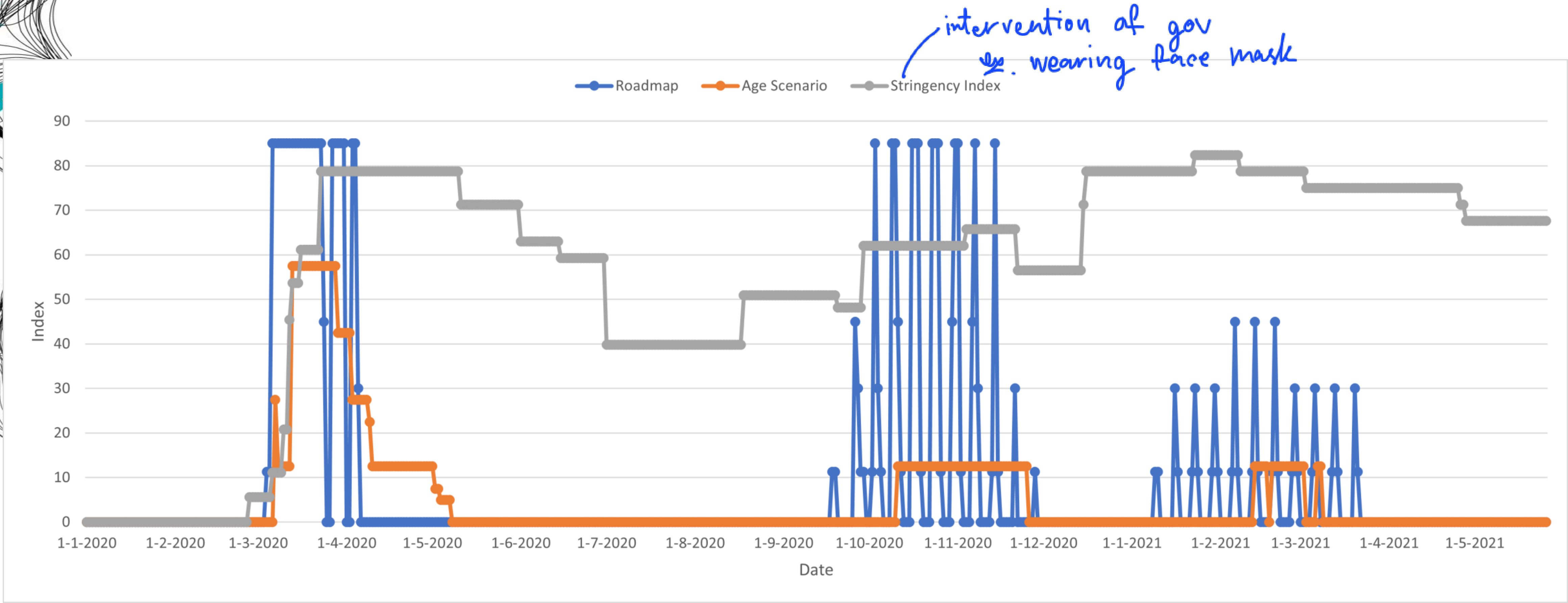


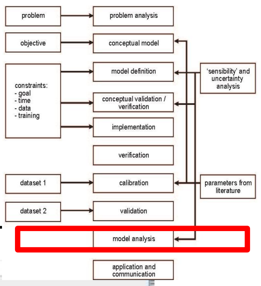
Figure 7: Interventions on Commuting for the RoadMap Scenario (a) and the Age Scenario (b).

Augustijn et al. (2022) Integration of governmental risk perception into a Covid-19 model for the Netherlands, 2022 VFGG (in press)

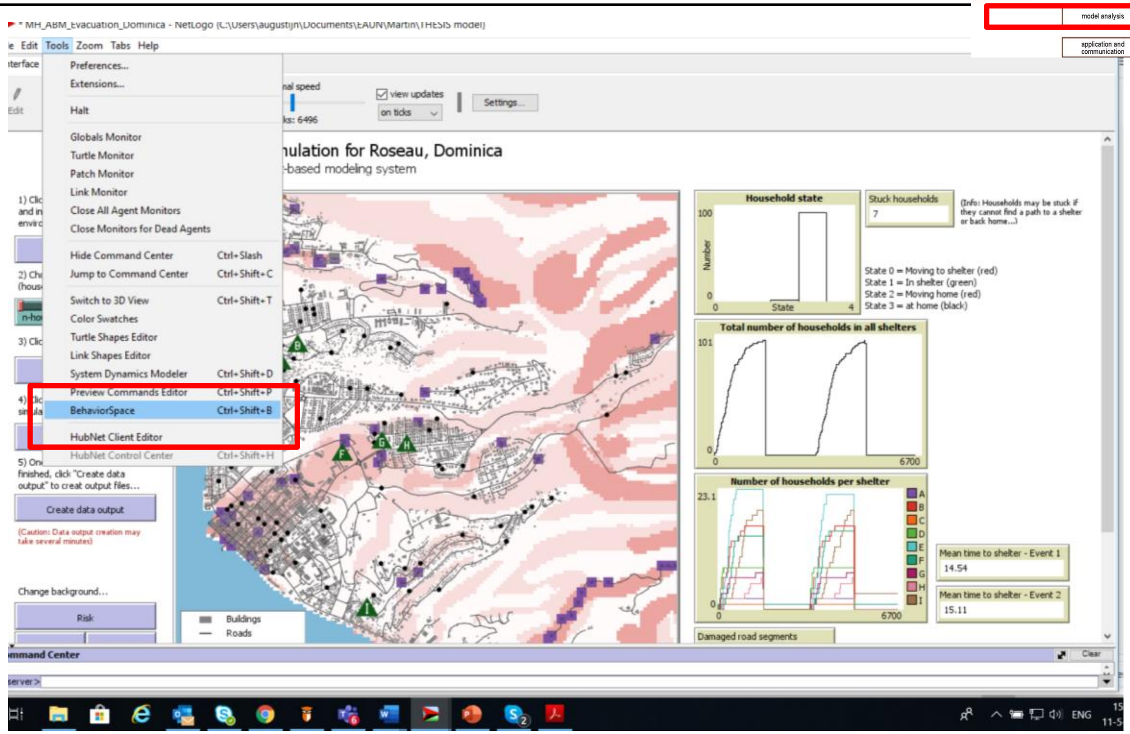
MODELING COVID-19

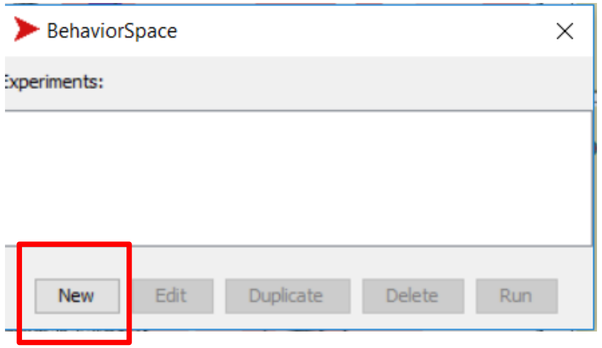


BEHAVIOR SPACE

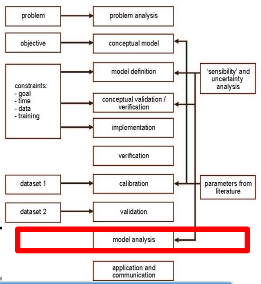


- Open behavior space via the **Tools menu**
- Create a new experiment
- Edit an existing experiment
- Run an experiment





BEHAVIOR SPACE



- Variables that are automatically added come from the user interface
- For models that are stochastic, increase the number of repetitions
- Carefully check the outputs → number of households per shelter
- Make sure your model does not keep on running for ever

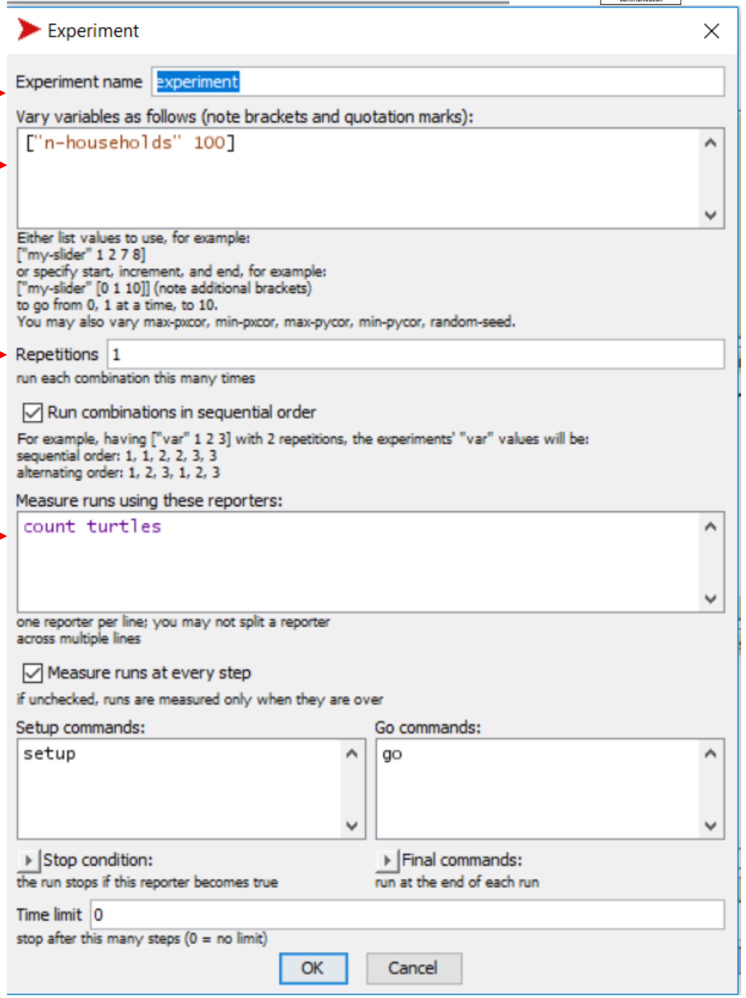
names

variables

repetitions

outputs

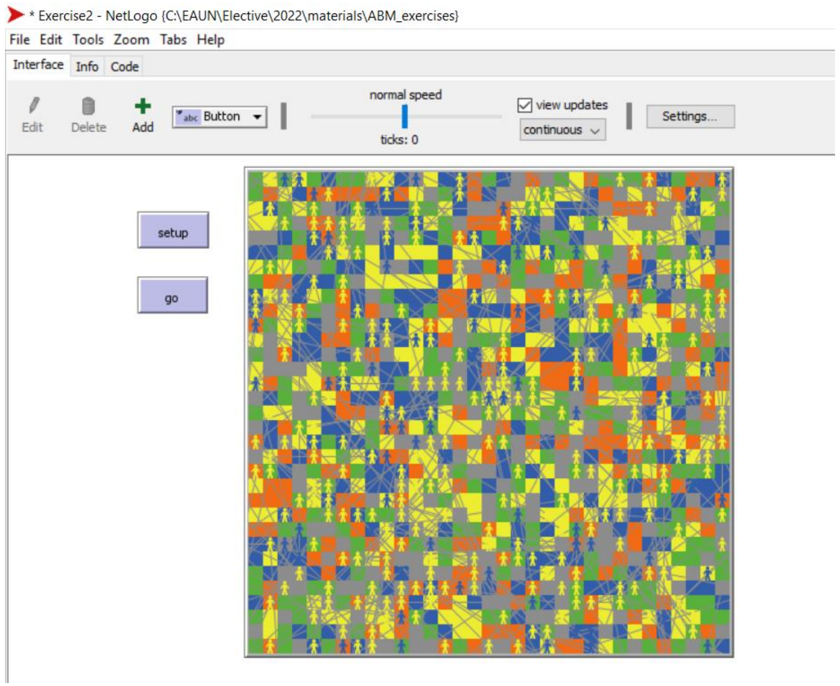
Stopping the model



CODE EXAMPLES

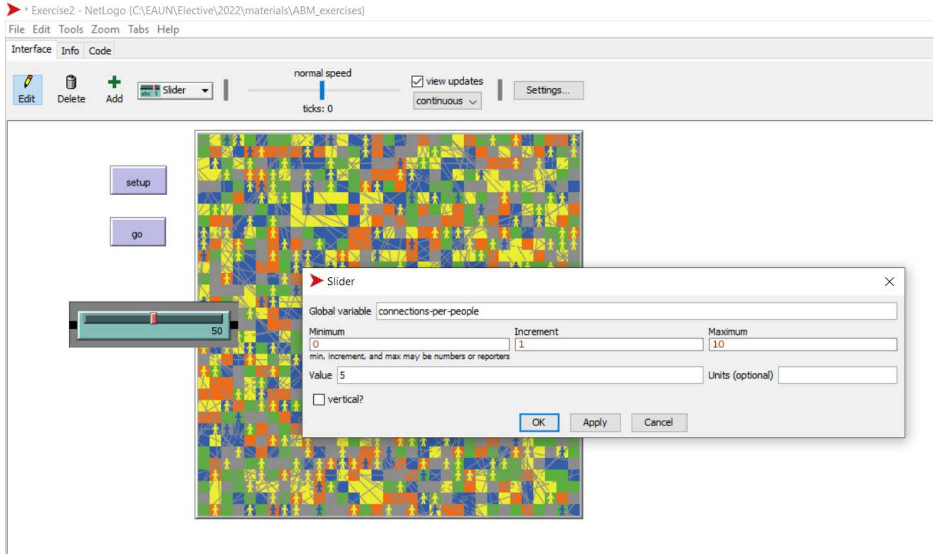
CREATING LINKS

```
to setup-agents
  create-residents 100
  ask residents [move-to one-of patches set color blue set shape "person"]
  create-tourists 300
  ask tourists [move-to one-of patches set color yellow set shape "person" set stay-duration (random 10 + 1) create-link-with one-of residents]
end
```

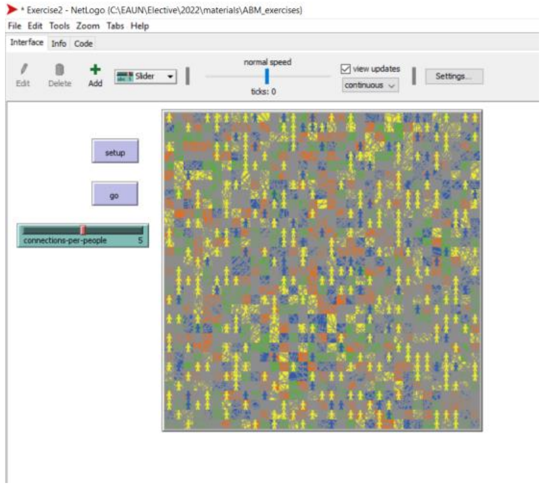


- You now see lines between the tourists and the residents when you run the setup

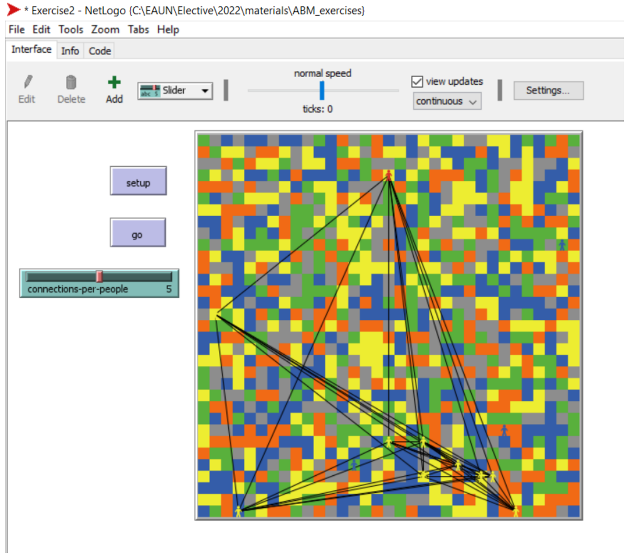
CREATE MORE LINKS



- Create a slider to define the number of links to create



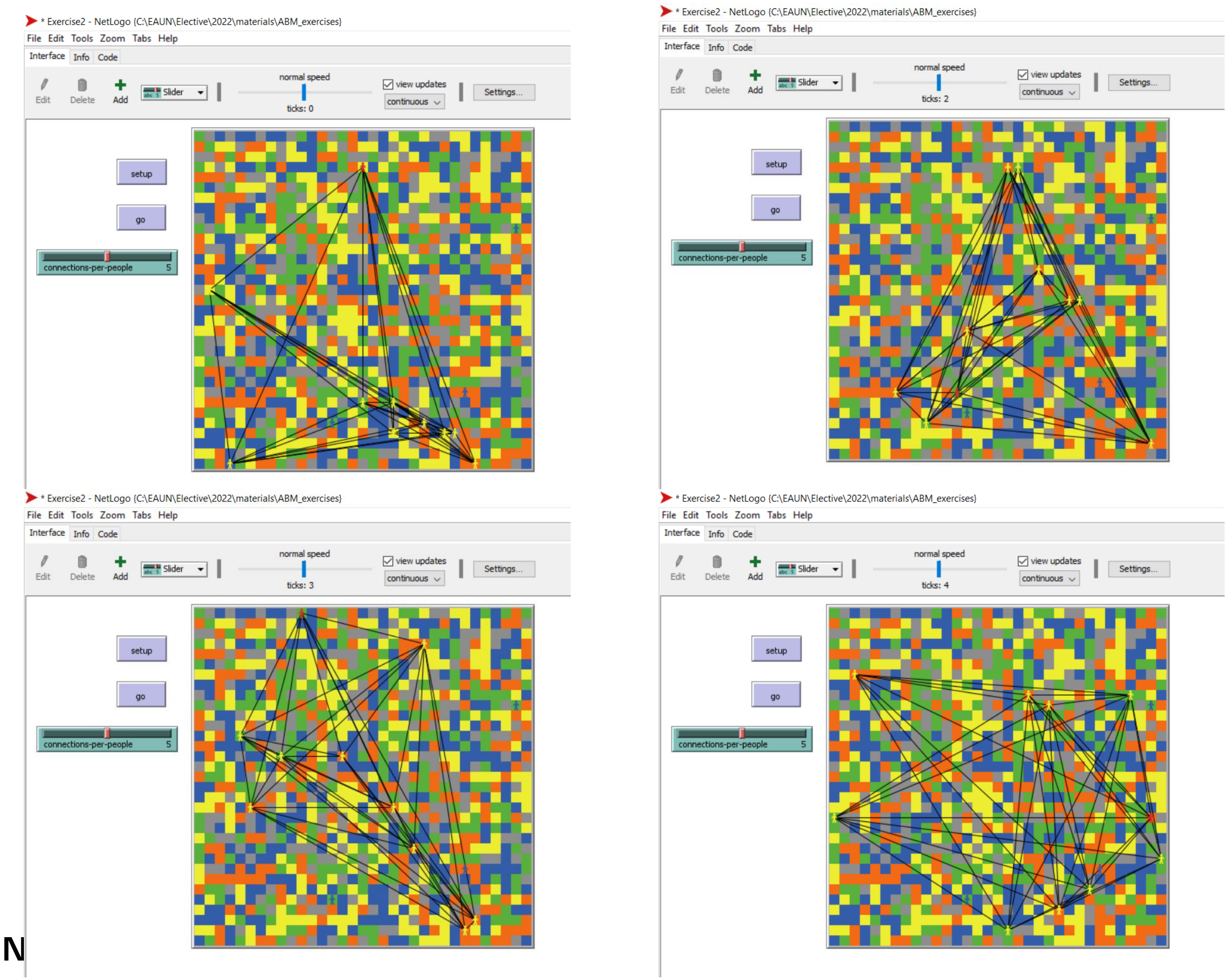
```
to setup-agents
  create-residents 100
  ask residents [move-to one-of patches set color blue set shape "person"]
  create-tourists 300
  ask tourists [move-to one-of patches set color yellow set shape "person" set stay-duration (random 10 + 1) create-links-with n-of connections-per-people other tourists]
end
```




```
to setup-agents
  create-residents 5
  ask residents [move-to one-of patches set color blue set shape "person"]
  create-tourists 10
  ask tourists [move-to one-of patches set color yellow set shape "person" set stay-duration (random 10 + 1) create-links-with n-of connections-per-people other tourists]
  ask one-of tourists [
    set color red
  ]
  ask links [set color black]
end
```

- Give the links another color
- Reduce the number of agents to see the links

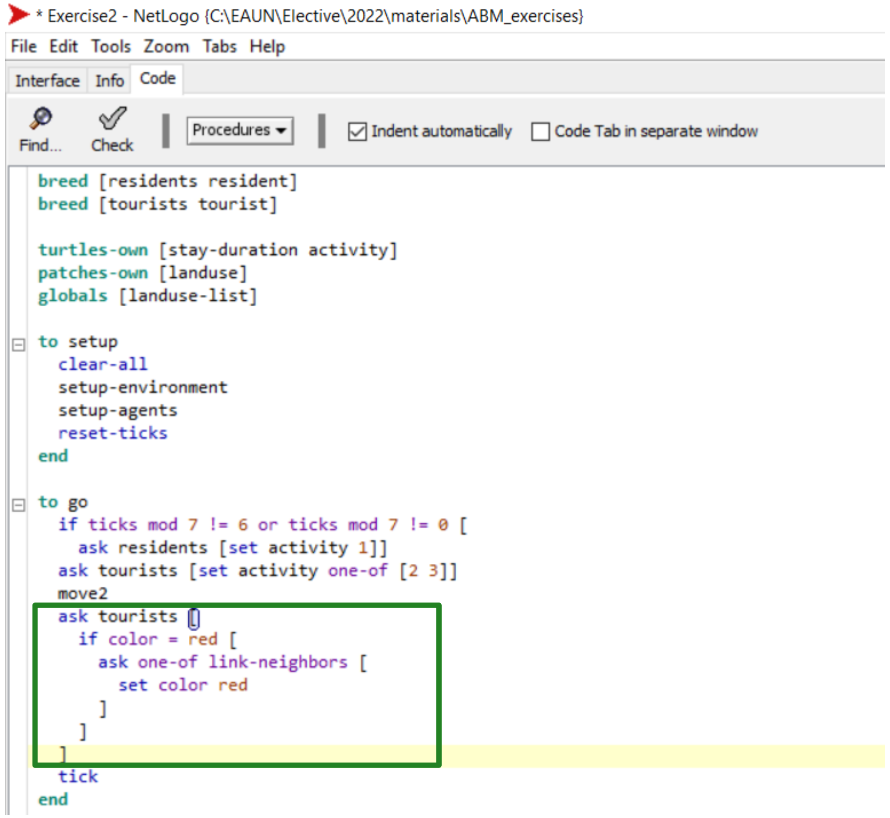
MOVING THE TURTLES

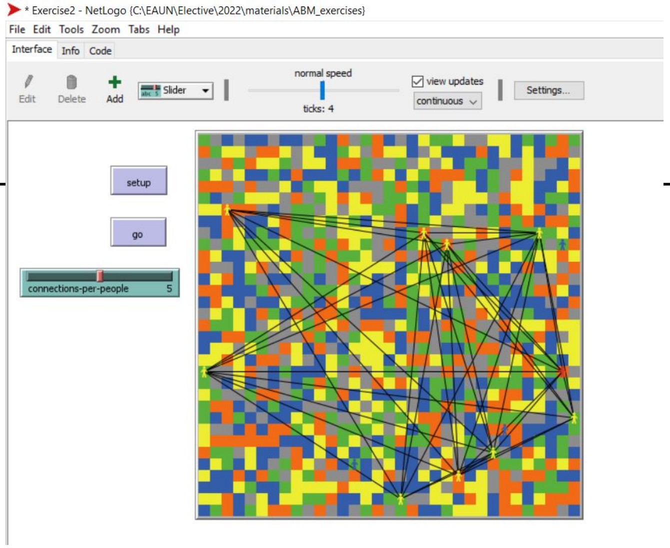


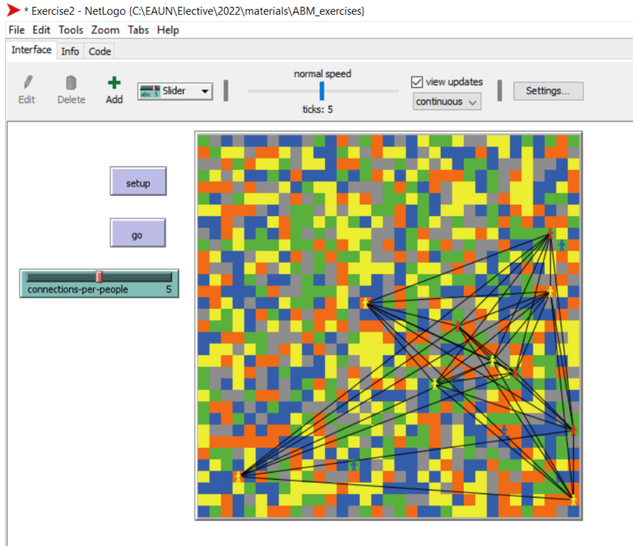
- When we run the go, and our turtles move, the network will remain as is (the links will move with the turtles)

UN

SPREAD MESSAGE







- We see all turtles turn red
- Spread the fact that you should be aware of tick risk

UNIVERSITY OF TWENTE.

TEAM BASED LEARNING 2

QUESTIONS VALIDATION

FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

Validation is regarded to be the most difficult part of ABMs. Which step in the validation process is the most difficult part of validating the Evacuation model? You can select multiple answers. Note:- Evacuation Model is towards to descriptive (pattern)-(ex. does spatial (building) matters?

a. **Input validation**, as we cannot set a building to fire to collect data that is correct/valid.
b. **Process validation**, as we do not know what people in a building are doing at the time an evacuation starts.
c. **Descriptive validation,** as there are no patterns that we can replicate.
d. **Predictive validation,** as there is no independent data available

Note: -
a. Input Validation: We can do experiment even if we aren't set fire, we can still collect data. We can set fire drill to collect how people move. (But fire drill might not be same as real situation.)
b. Process Validation: Main focus isn't what people doing at time start.
d. Predictive validation: Model isn't build for prediction thing.

To check the validity of a model, you should know the purpose of the model. Which of the statements below about the Wolf-Sheep-Grass model is correct?

a. This model does not have a purpose, and therefore, it cannot be validated.

b. The purpose of this model is to show that wolf-sheep dynamics is a complex system. Therefore, descriptive output validation is the most important aspect of the validation process.

c. The purpose of this model is to predict how many sheep can survive with a given number of wolves in a neighborhood. Therefore, predictive output validation is the most important aspect of the validation process.

d. The problem with this model is that not all processes, like flocking of sheep, are implemented, and therefore, the model cannot be validated.

In the Living Textbook, you find the concept “validation” as one of the steps in the ABM design steps. Under challenges, various issues are listed that might apply to the evacuation model. Select all correct statements below.

a. The stochastic nature
b. Predictive versus retrodictive capability
c. Data Quality
d. Path Dependency

Note: -
b. Predictive versus retrodictive capability: Mostly, we predict the things at the period that its happen which is not applicable for evacuation model.
c. Data Quality: Data that we collect during fire drills vs. real-situation