TU WIEN Mathematical Modelling and Simulation

# Introduction to Agent-Based Modelling

# Historical Background



- Agent-based modelling is a comparably young modelling technique.
- Were inspired by Cellular Automata (Von Neumann, Ulam, etc)
- Thomas Schelling‘s Model of Segregation (1971) is broadly denoted as the first agent-based model

Model segregation behaviour between individuals with different races in US in the 1970s

# Historical Background

Mathematical Modelling and Simulation

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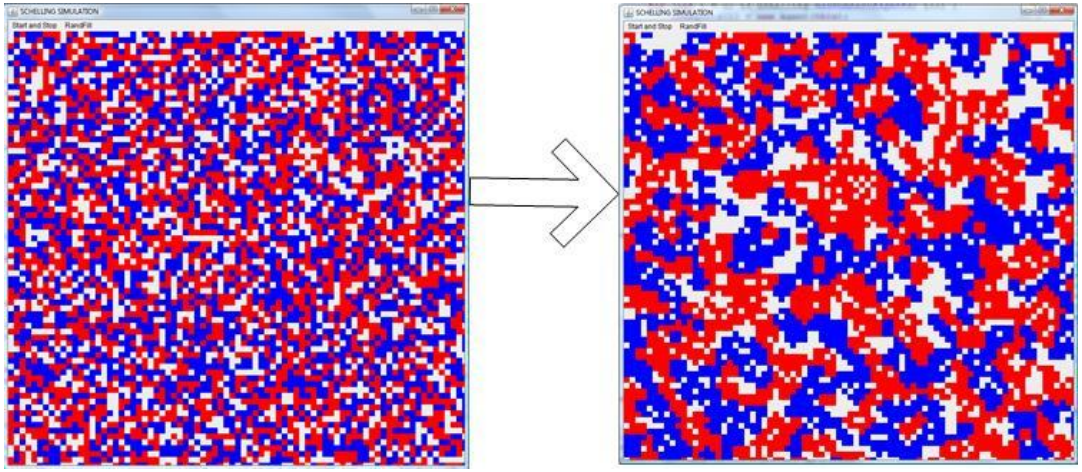

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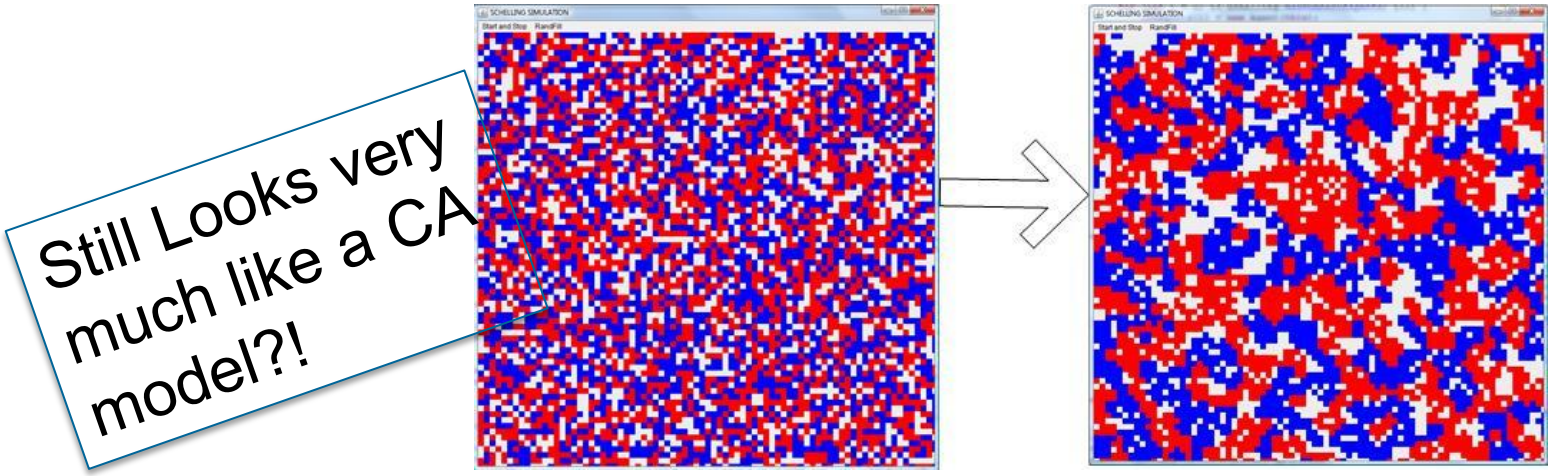
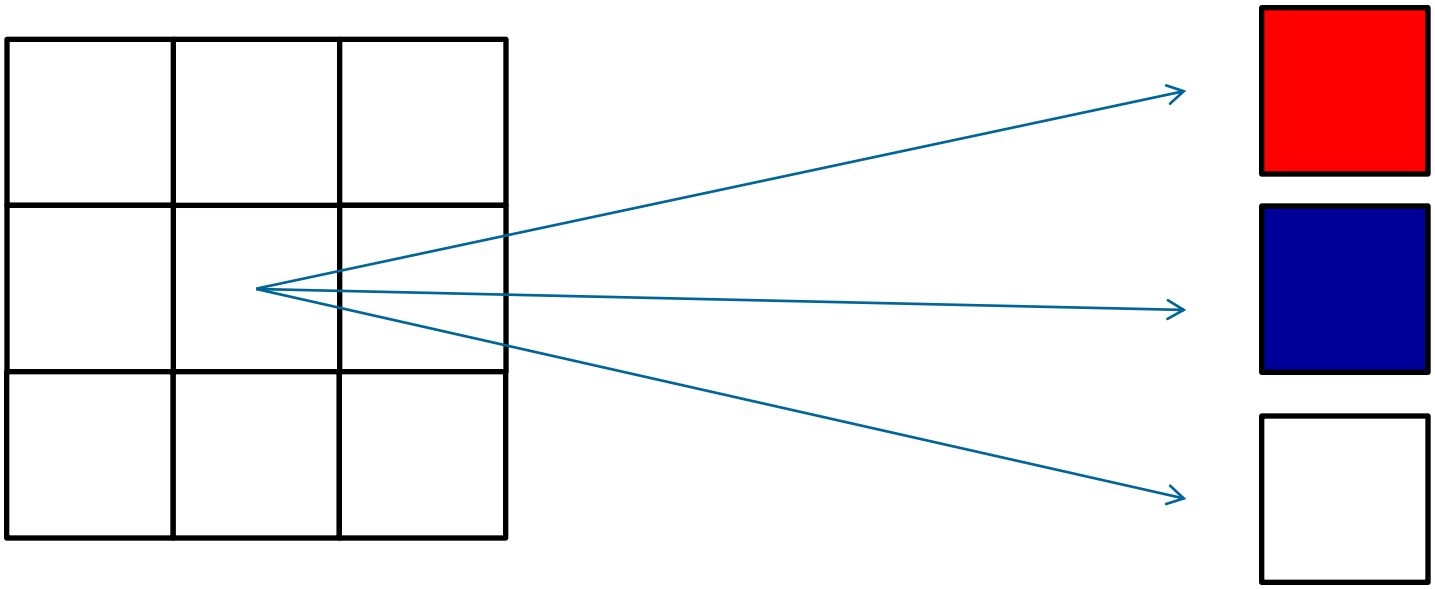
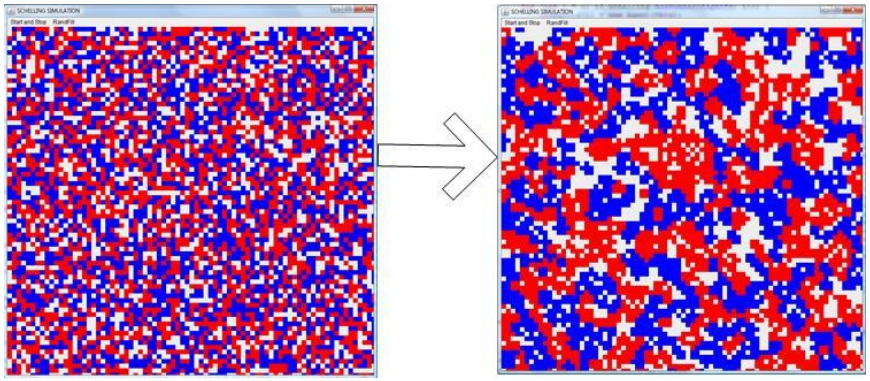


# A Small but Powerful Difference…

Mathematical Modelling and Simulation



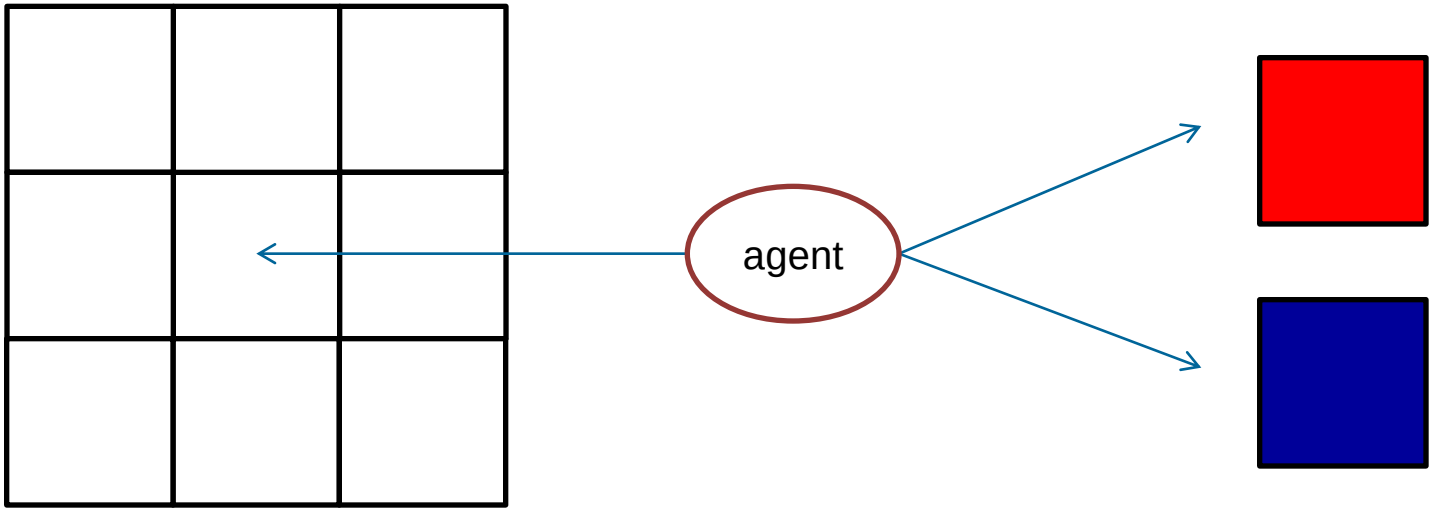


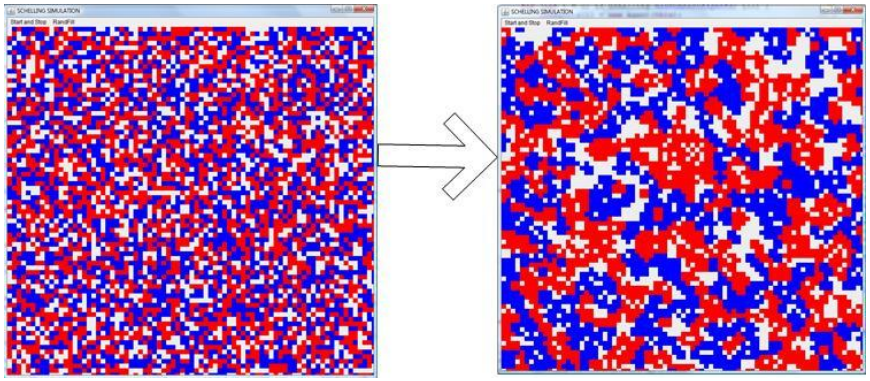
## CA Model

Each cell is assigned a colour
(= a person if colour is not white)

# A Small but Powerful Difference…

Mathematical Modelling and Simulation
TU WIEN



## Agent Based Model (ABM)

Each agent (= person) is assigned a colour (blue or red) ***and*** a cell

# A Small but Powerful Difference…

Mathematical Modelling and Simulation

In principle both representations make sense for this application. Yet Schelling used the second concept to describe the model for its benefits.

## CA Model

```
for C in Cellspace:
    if C is not white:
        N(C) = neighbourhood of C
        do update rules with C w.r. to N(C)
Update Cellspace
```

## ABM

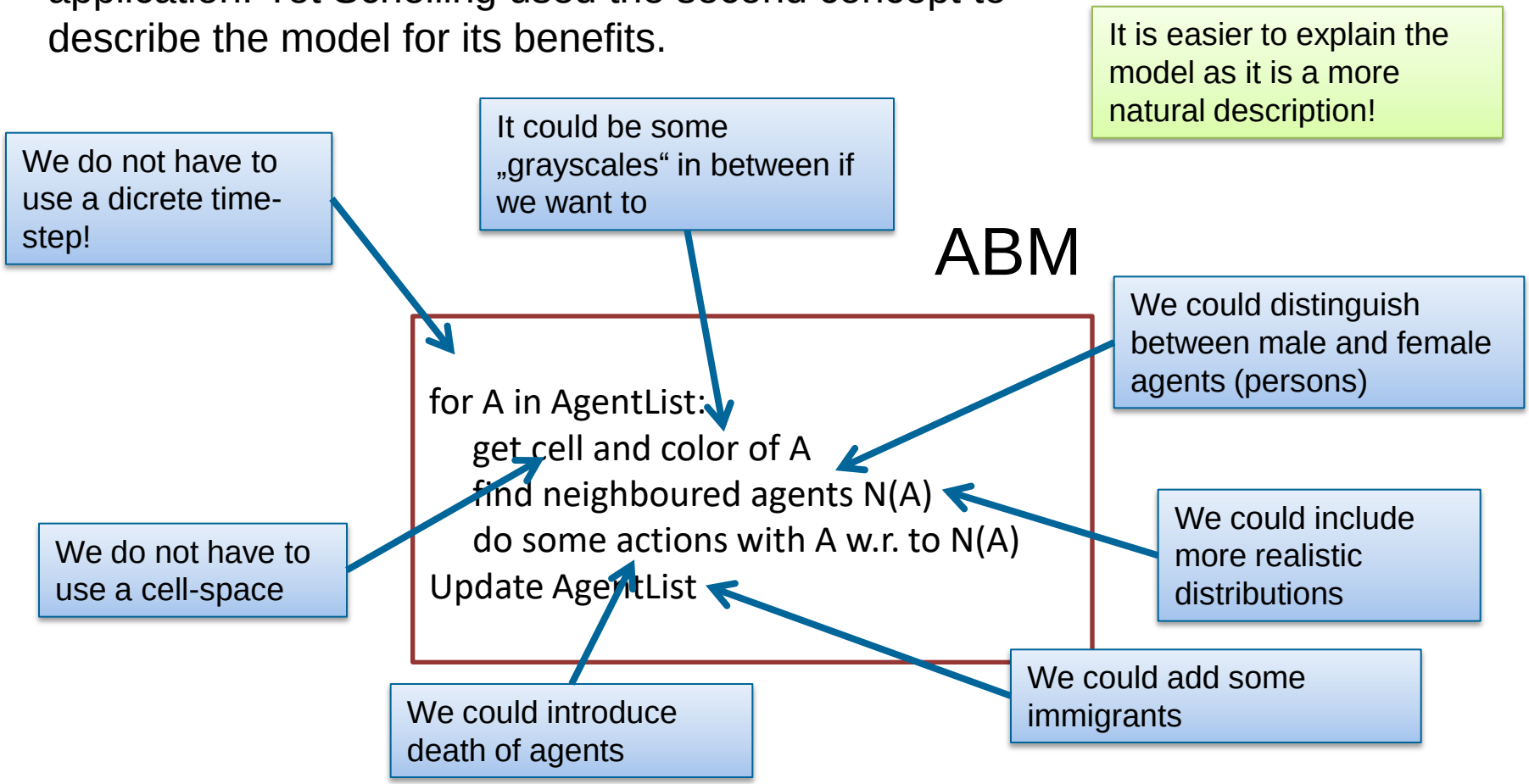
```
for A in AgentList:
    get cell and color of A
    find neighboured agents N(A)
    do some actions with A w.r. to N(A)
Update AgentList
```

Pseudocode representation of a time step in Schelling‘s model.

# A Small but Powerful Difference…

Mathematical Modelling and Simulation

In principle both representations make sense for this application. Yet Schelling used the second concept to describe the model for its benefits.



# Agent



Why Agent?

# Agent



Latin: „agere“ (to act)

# What is an Agent? (1)

Mathematical Modelling and Simulation

- Agent – lat. agere (act)
- There is no unique definition. The word is very broadly used.

**[Agent-based modelling is...]**
**„Rather a general concept“**
(Winter Simulation Conference 2005 & 2006)

# What is an Agent? (2)

Mathematical Modelling and Simulation

- With respect to Winter Simulation Conference (2005 & 2006) an agent has to...

  ... **be uniquely identifiable**
  ... **cohabitate an environment with other agents, and has to be able to communicate with them.**
  ... **be able to act targeted.**
  ... **be autonomous and independent.**
  ... **be able to change its behaviour.**

# What is an Agent? (2)

Mathematical Modelling and Simulation

- With respect to Winter Simulation Conference (2005 & 2006) an agent has to...

  **... be uniquely identifiable**
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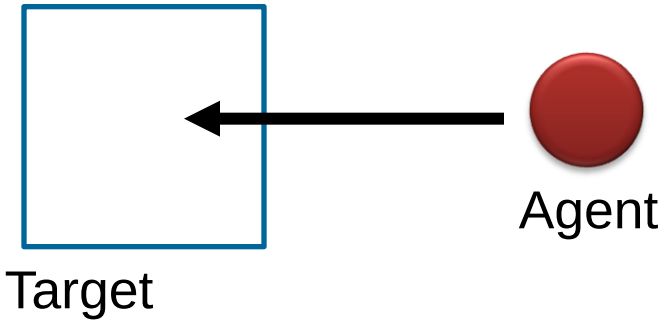
  **... be able to act targeted.**
  **... be autonomous and independent.**
  **... be able to change its behaviour.**

Optional properties (Wintersimulation Conference 2015)

Agent

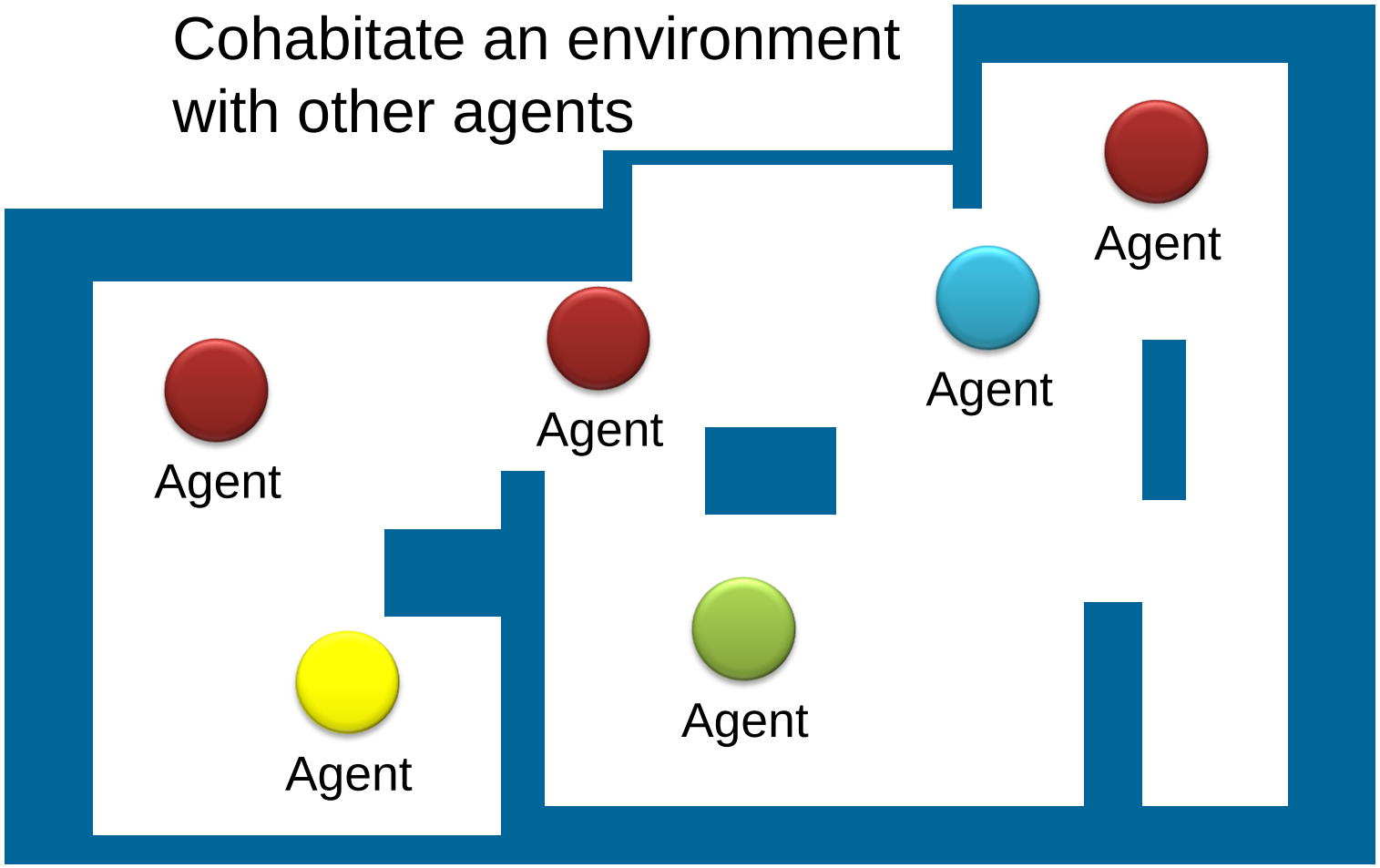
# Act Targeted

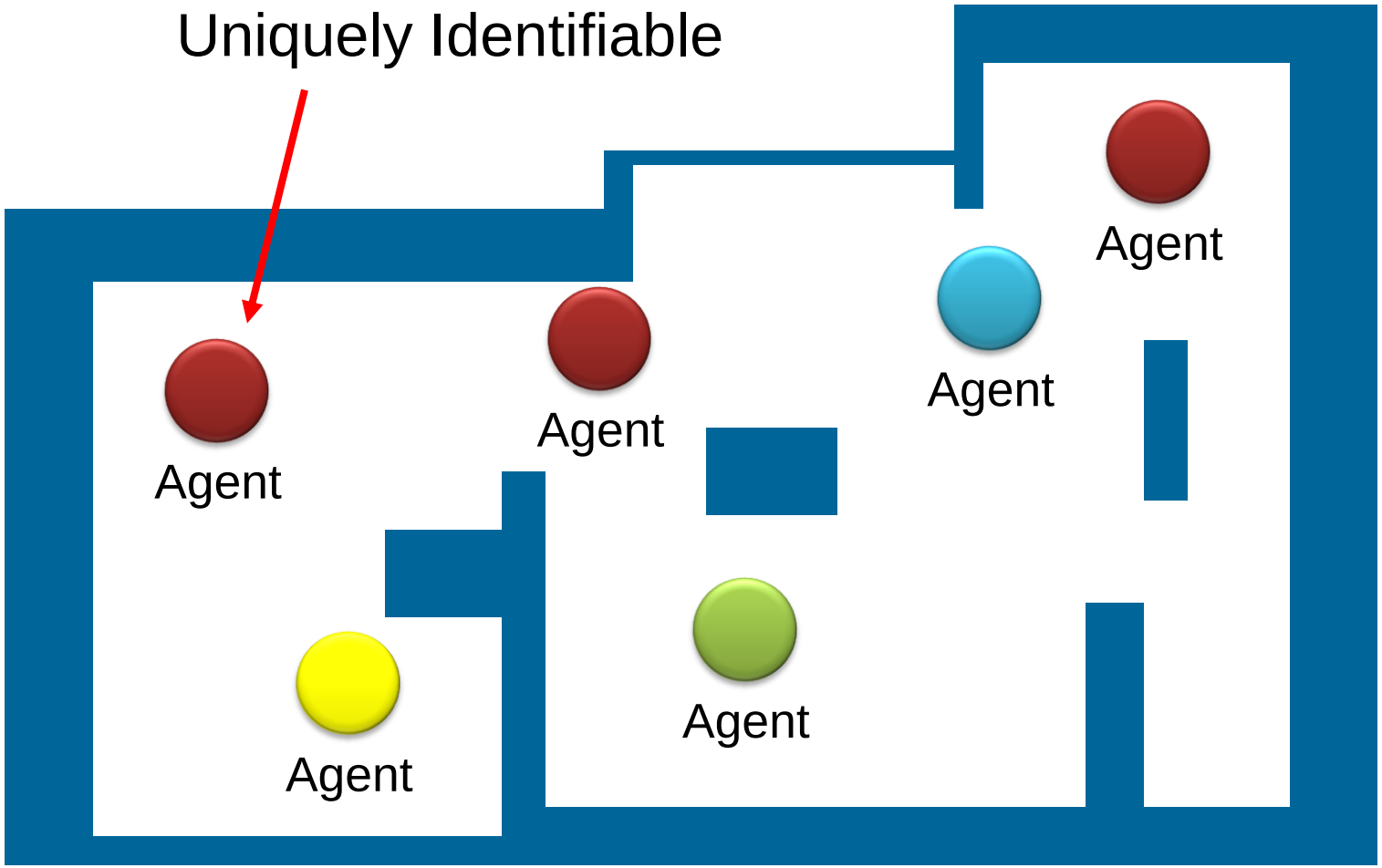


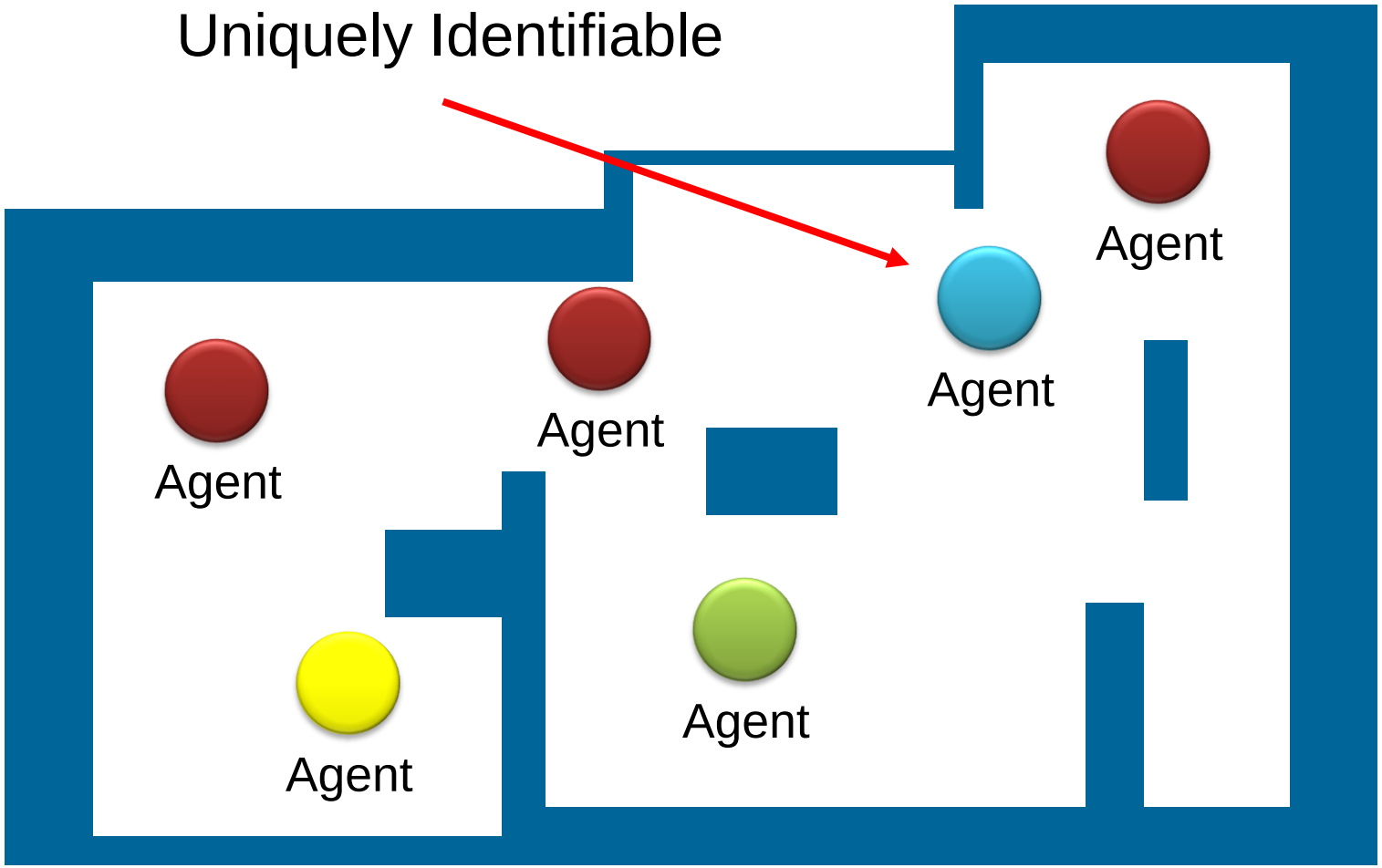
# Act Targeted


Target

Cohabitate an environment with other agents




Uniquely Identifiable
Agent
Agent
Agent
Agent
Agent
Agent


Uniquely Identifiable
Agent
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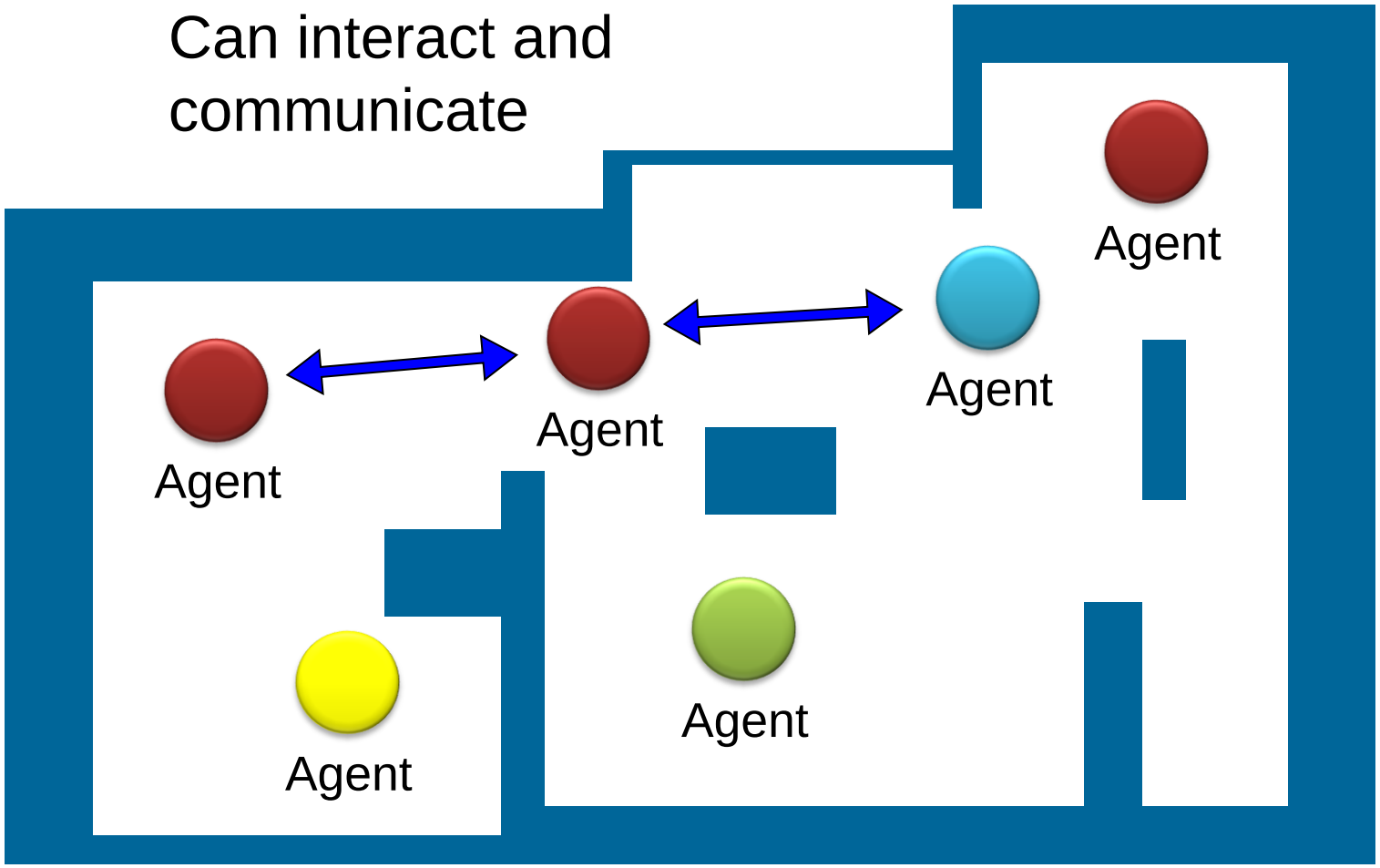
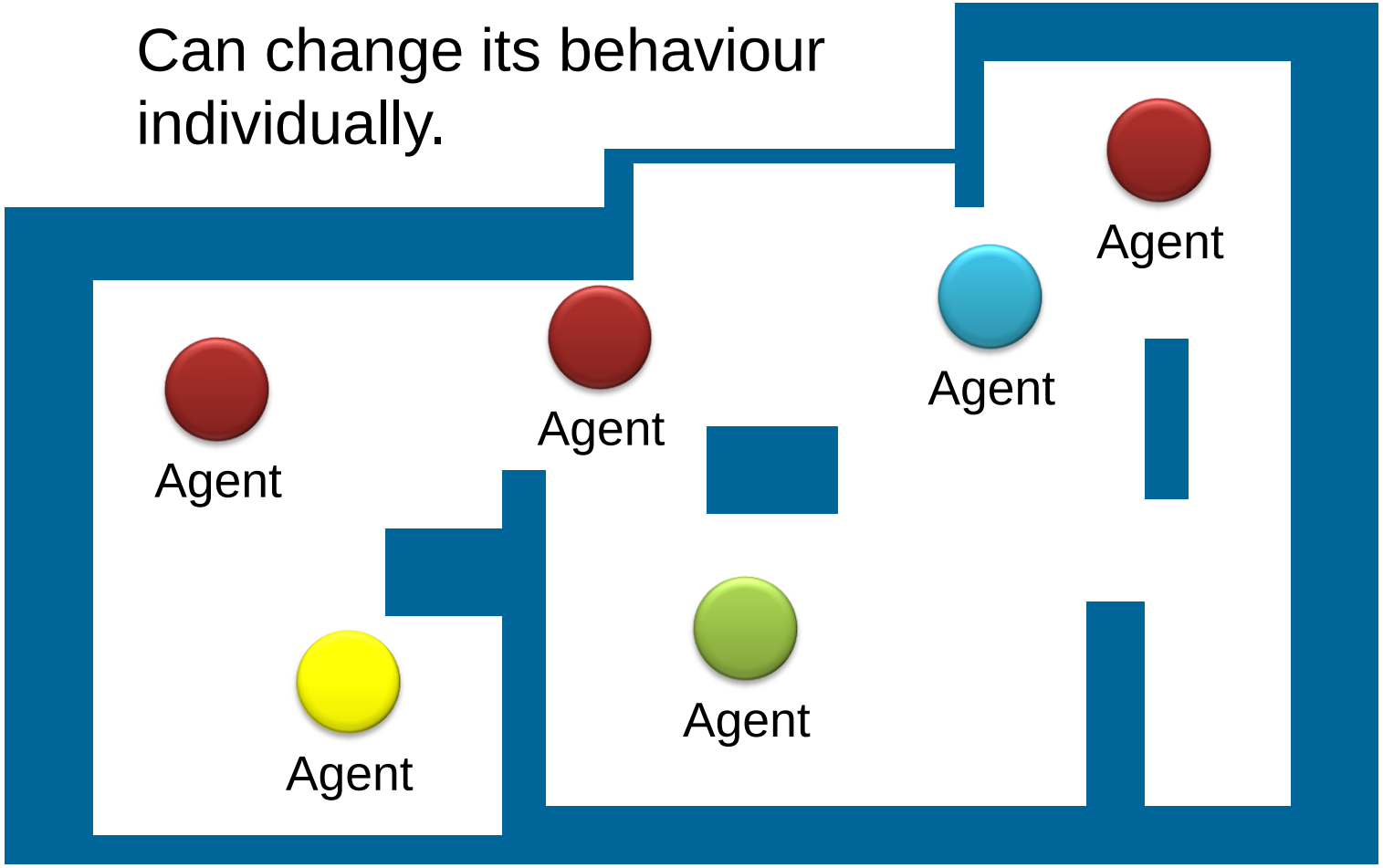
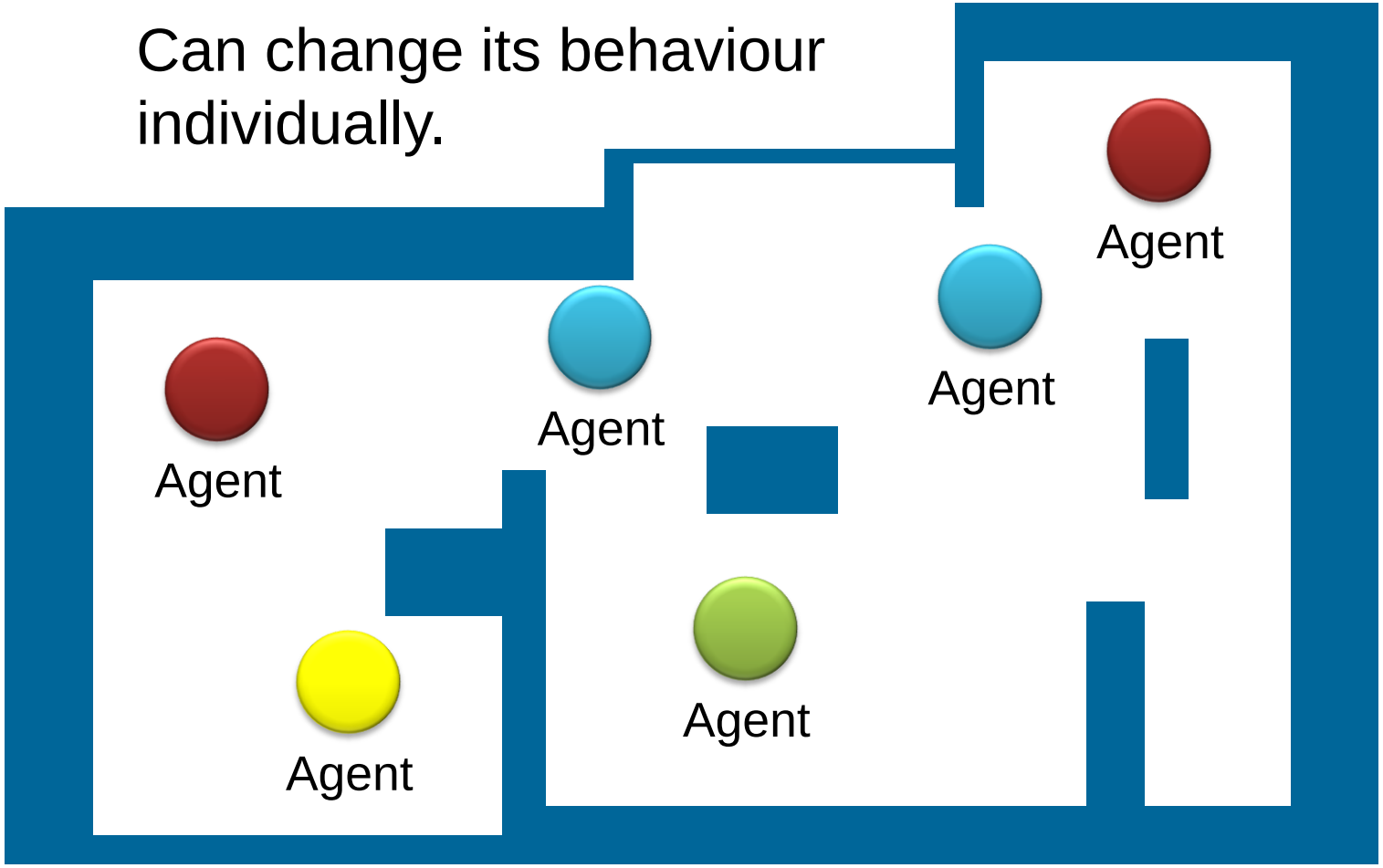

Can interact and communicate
Agent
Agent
Agent
Agent
Agent
Agent

Can change its behaviour individually.



Can change its behaviour individually.



# Short Summary

Mathematical Modelling and Simulation

- Agent-Based modelling is a bottom up modelling approach using a big number of individual system components (agents).
- The components act independently (following given rules)
- As it requires a lot of processing resources ABM is a very young science with high potential.

# Properties of Agent-Based Models

Mathematical Modelling and Simulation

a. **Representation of „emergent phenomena“**

b. **Flexibility**
   **(Bonabeau, 2002)**

c. **Natural description of the system**

# Properties of Agent-Based Models

Mathematical Modelling and Simulation

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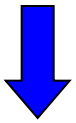
# Representation of „Emergent Phenomena“

Mathematical Modelling and Simulation

Simple rules for individual agents



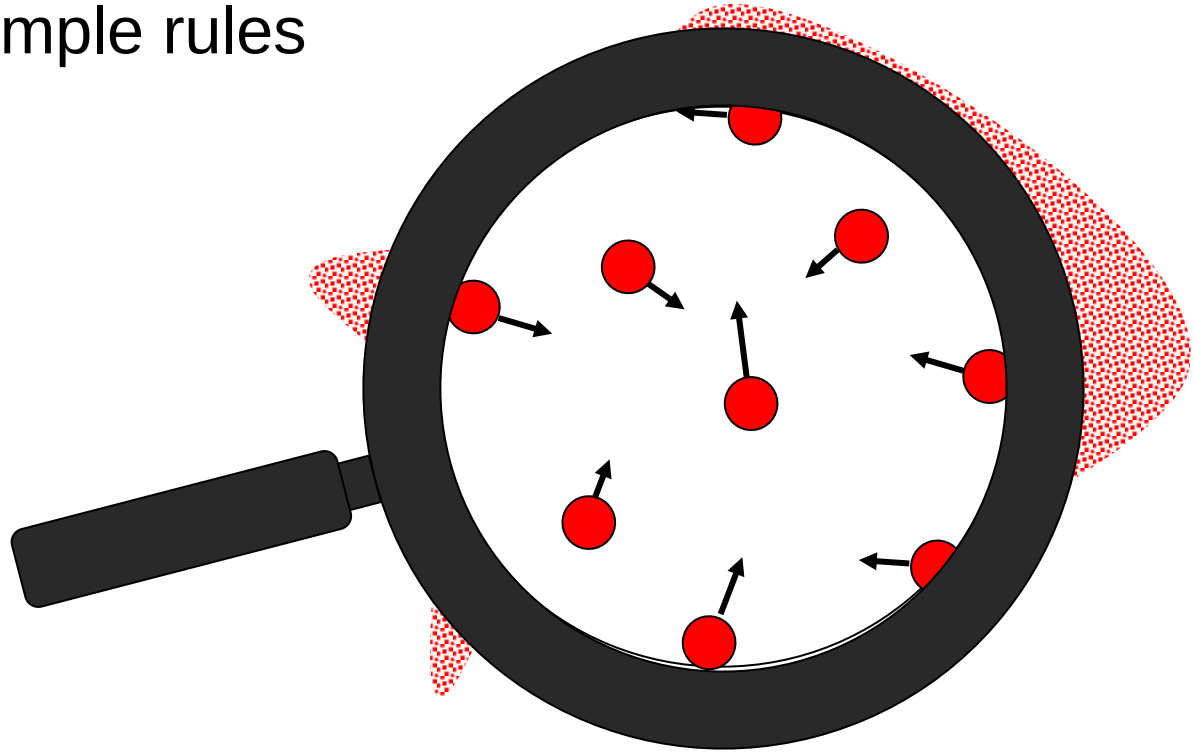
Complex dynamics of the whole system

**group dynamics / swarm intelligence**

# Representation of „Emergent Phenomena“

Mathematical Modelling and Simulation

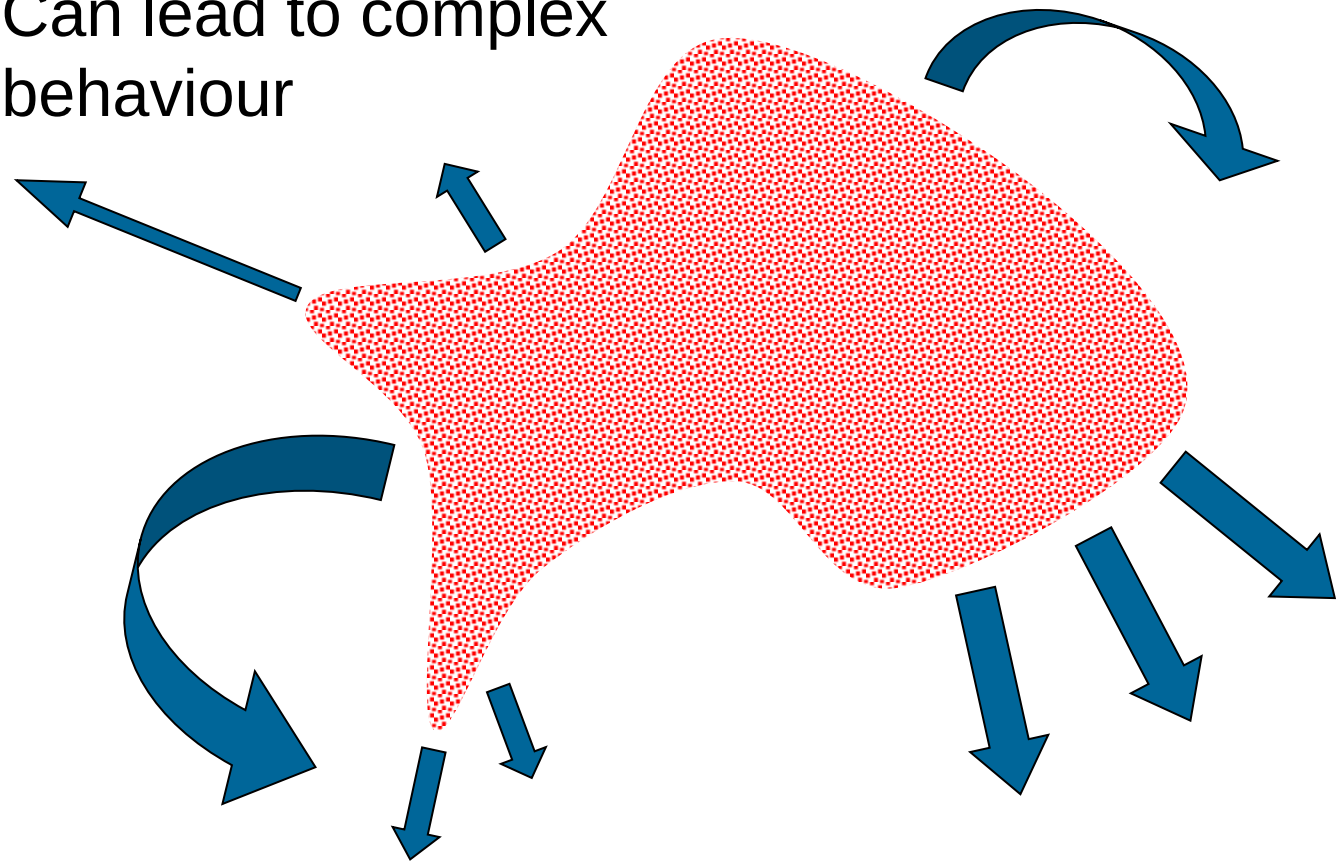
Simple rules



# Representation of „Emergent Phenomena“

Mathematical Modelling and Simulation

Can lead to complex behaviour



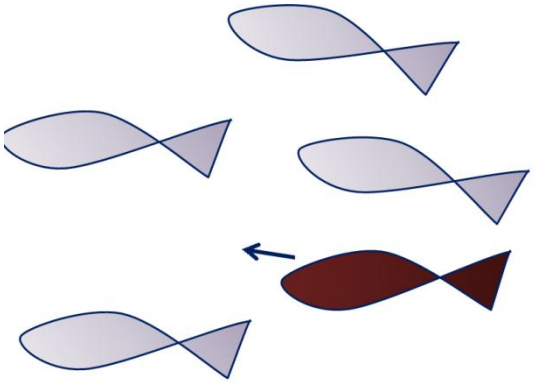
# Example: Fish or bird flocks

Mathematical Modelling and Simulation

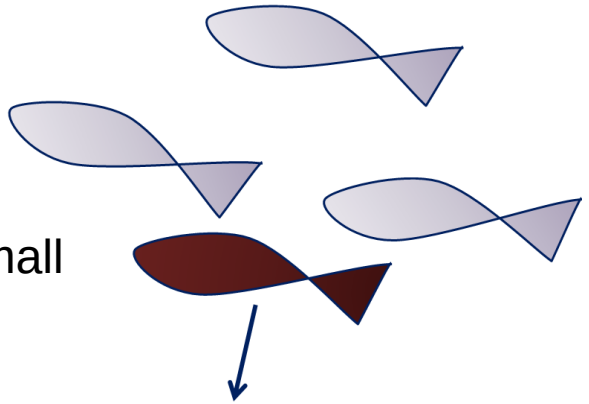
https://www.youtube.com/watch?v=QOGCSBh3kmM

# Boids Flock Model

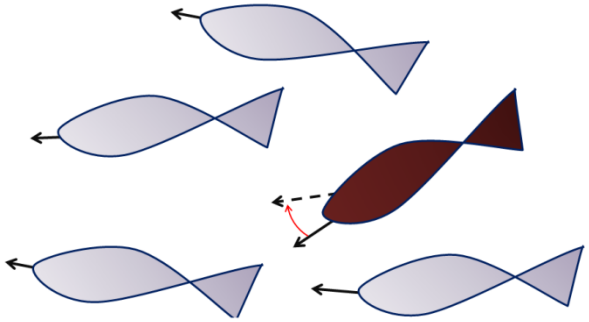
Mathematical Modelling and Simulation



Each agent tends towards
the centre of its neighbours



Keep a distance that is
neither too far nor too small



Swim in the same direction
as your neighbours

Wilensky, U. (1998). NetLogo Flocking model. http://ccl.northwestern.edu/netlogo/models/Flocking. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

# Properties of Agent-Based Models

Mathematical Modelling and Simulation

a. Representation of „emergent phenomena“

b. **Flexibility**
(Bonabeau, 2002)

c. Natural description of the system

# Flexibility

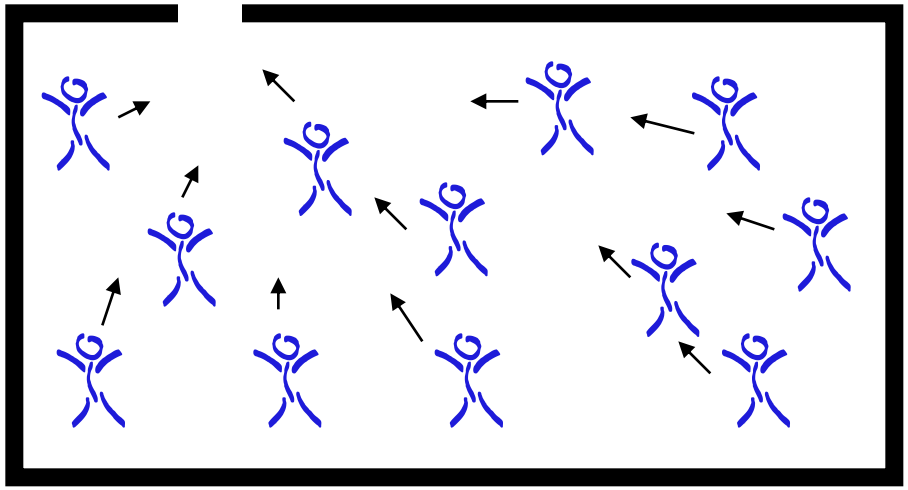


- Change of details is very easy compared to other (especially macroscopic) modelling approaches.
- Different parameterisation of single agents does not require changes within the system structure.
- Change or addition of (meta) rules for single agents does not influence the system structure as well (as long as they remain compatible with the system).

# Example: Emergency exit strategy



Example: Emergency exit strategy



Agent-Based Model

Easy

Macroscopic approach

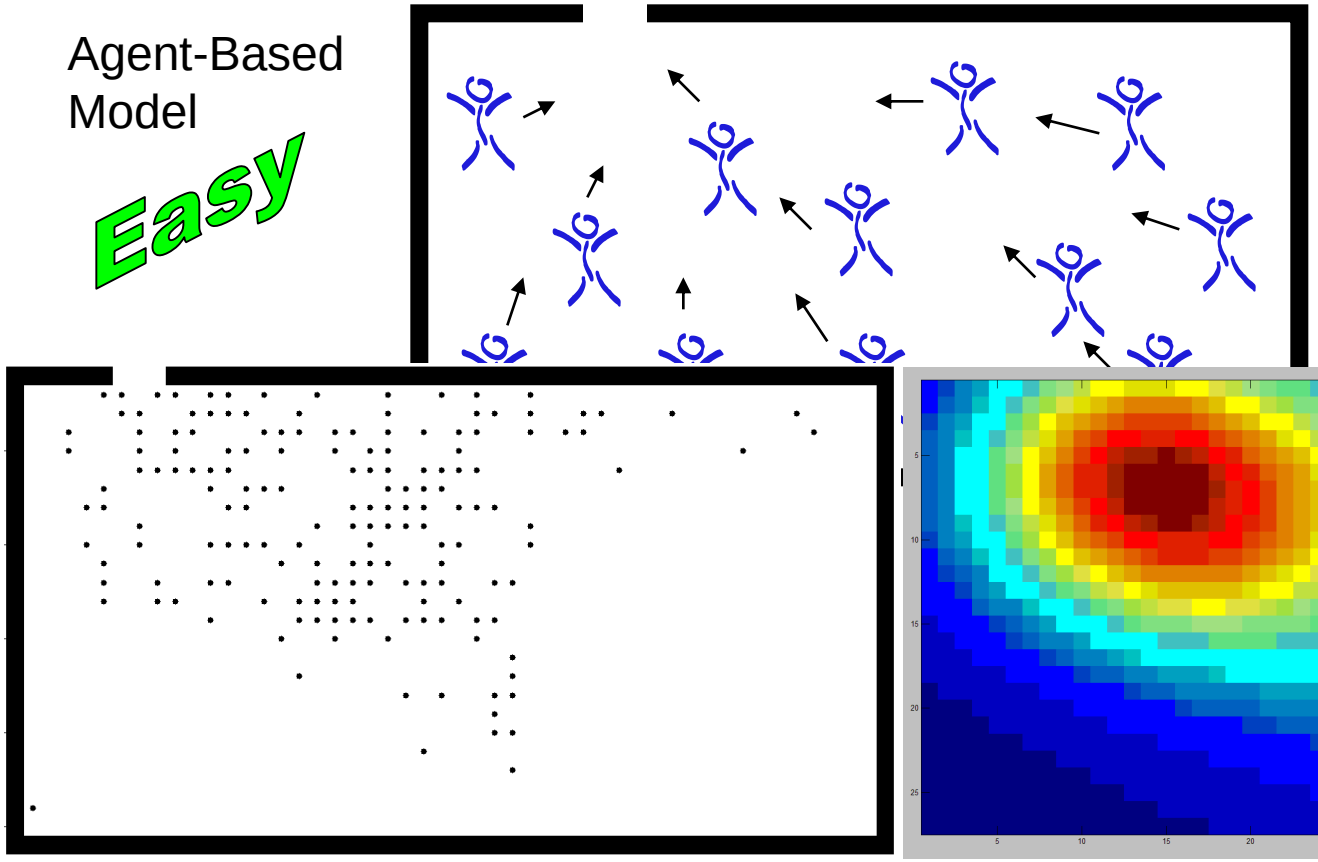
Easy

# Example: Emergency exit strategy

Mathematical Modelling and Simulation

Agent-Based Model

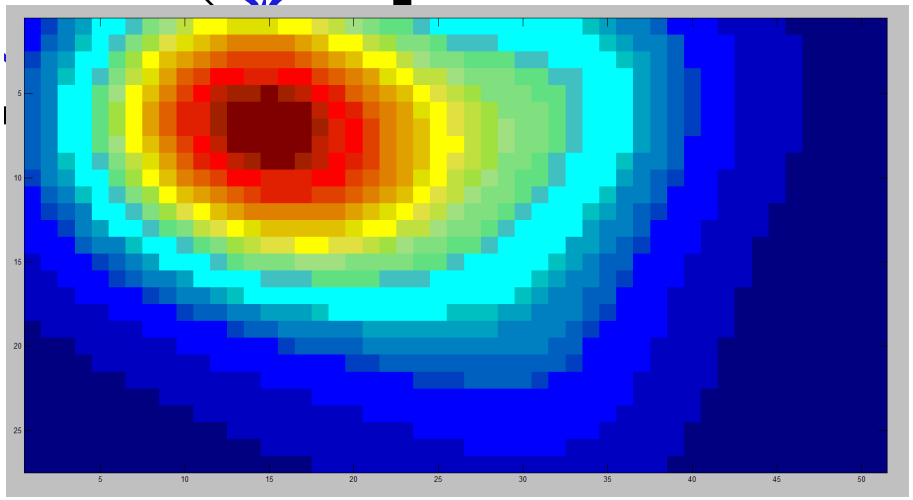
Easy



Macroscopic approach

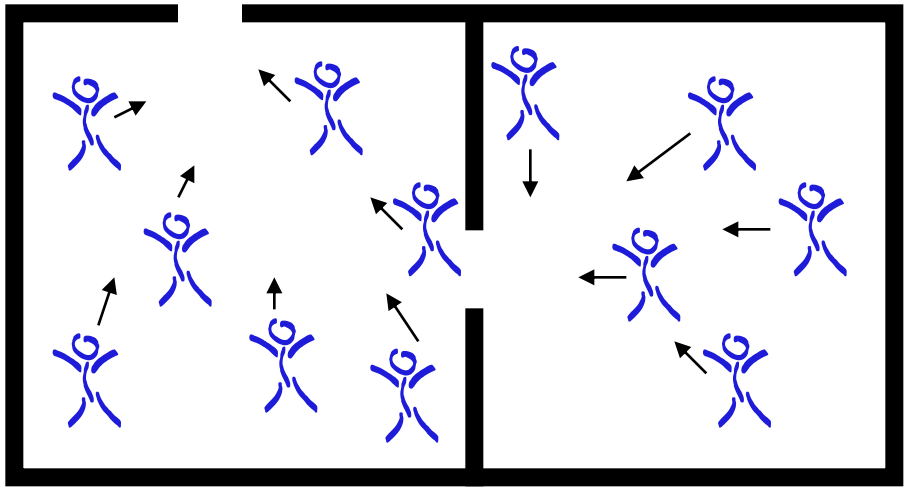
Easy

(Navier Stokes PDE Based Model)



# Example: Emergency exit strategy





Agent-Based Model

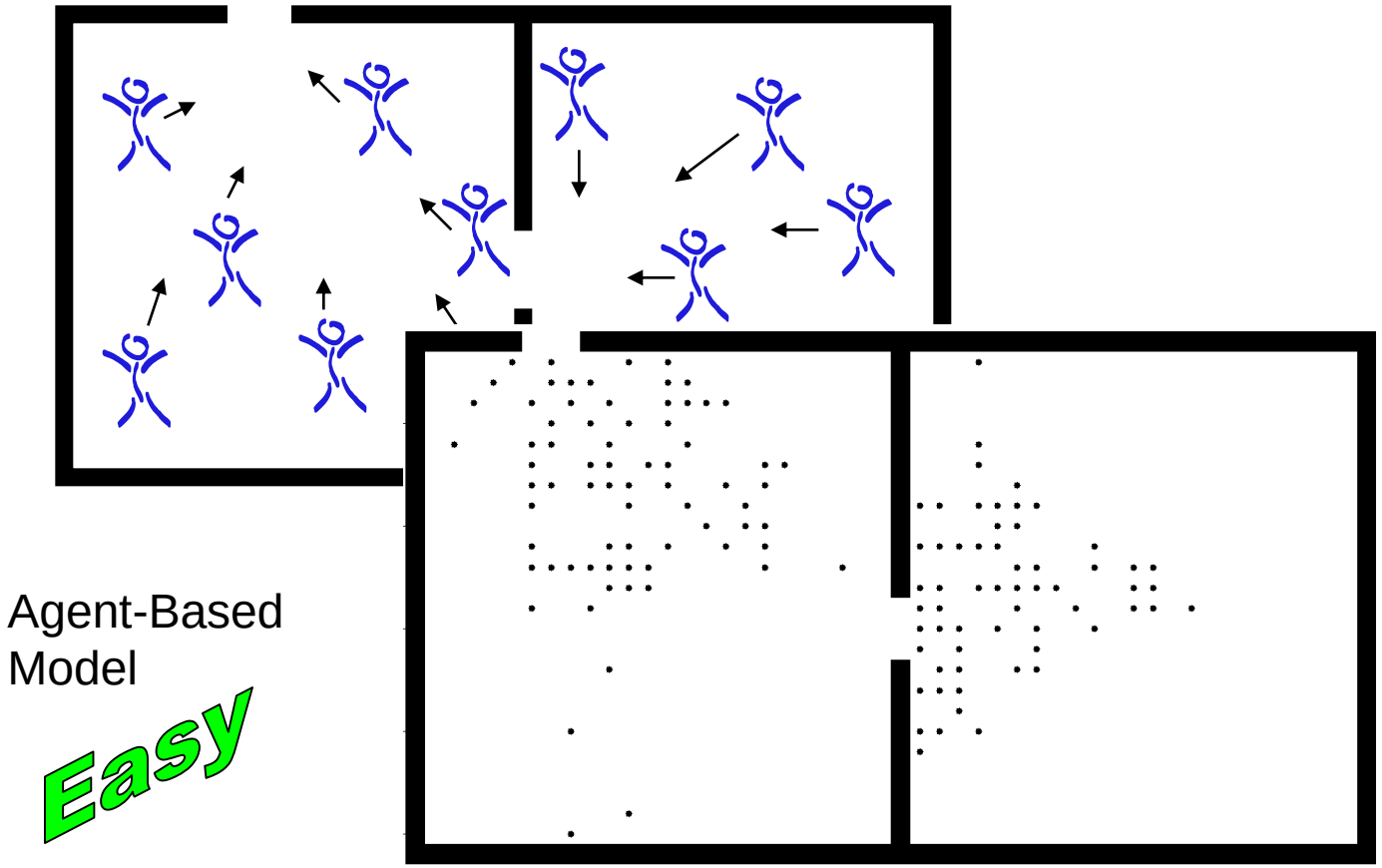
Easy

Macroscopic approach

Tricky

# Example: Emergency exit strategy

Mathematical Modelling and Simulation

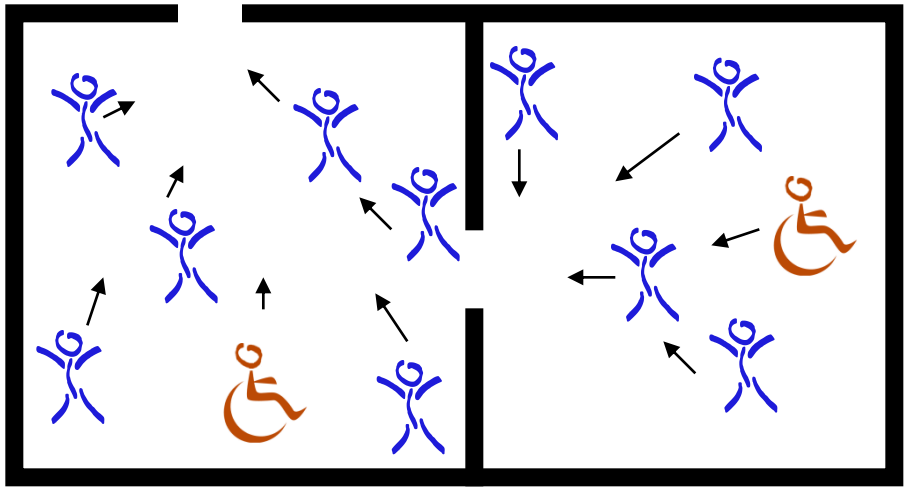


Agent-Based Model

Easy

# Example: Emergency exit strategy





Agent-Based Model

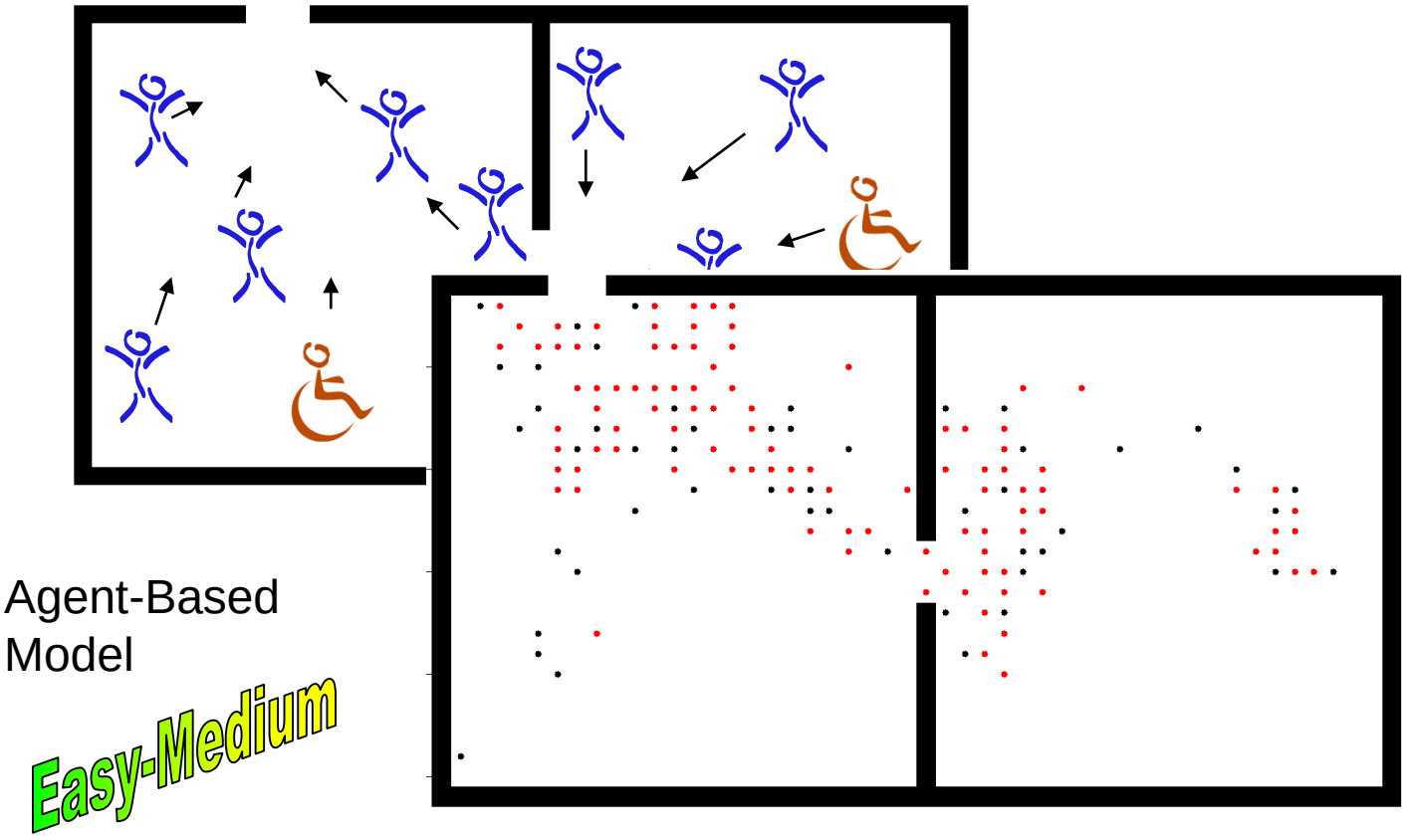
Easy-Medium

Macroscopic approach

Almost Impossible

# Example: Emergency exit strategy

Mathematical Modelling and Simulation



# Properties of Agent-Based Models

Mathematical Modelling and Simulation

a. Representation of „emergent phenomena“

b. Flexibility
(Bonabeau, 2002)

**c. Natural description of the system**

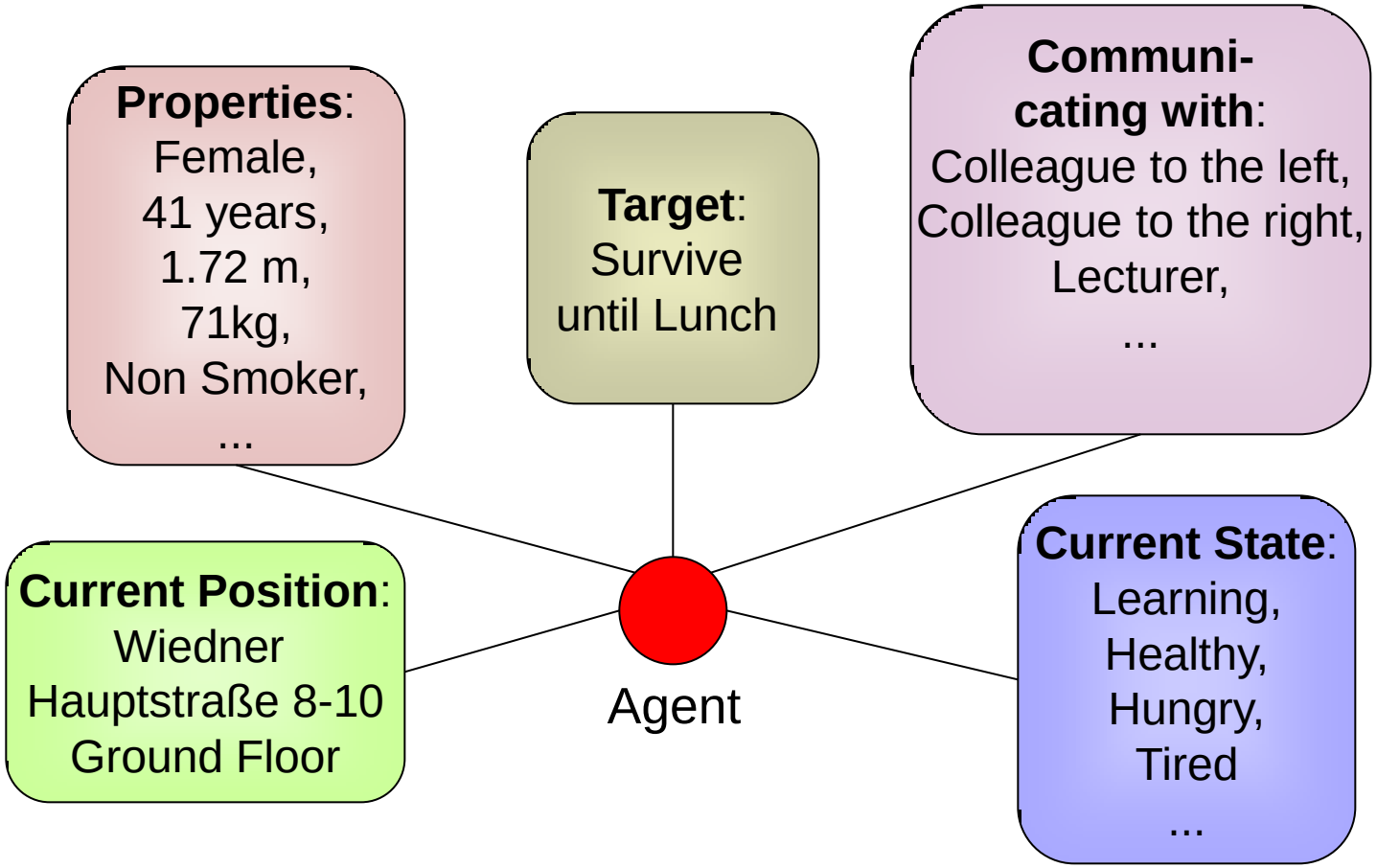
# Natural description of the System

Mathematical Modelling and Simulation

- Components of the system look like in reality
- Parameters can be seen like data or properties of individuals in reality
- No mathematical background knowledge is required in order to understand the modelling approach

# Natural description of the System

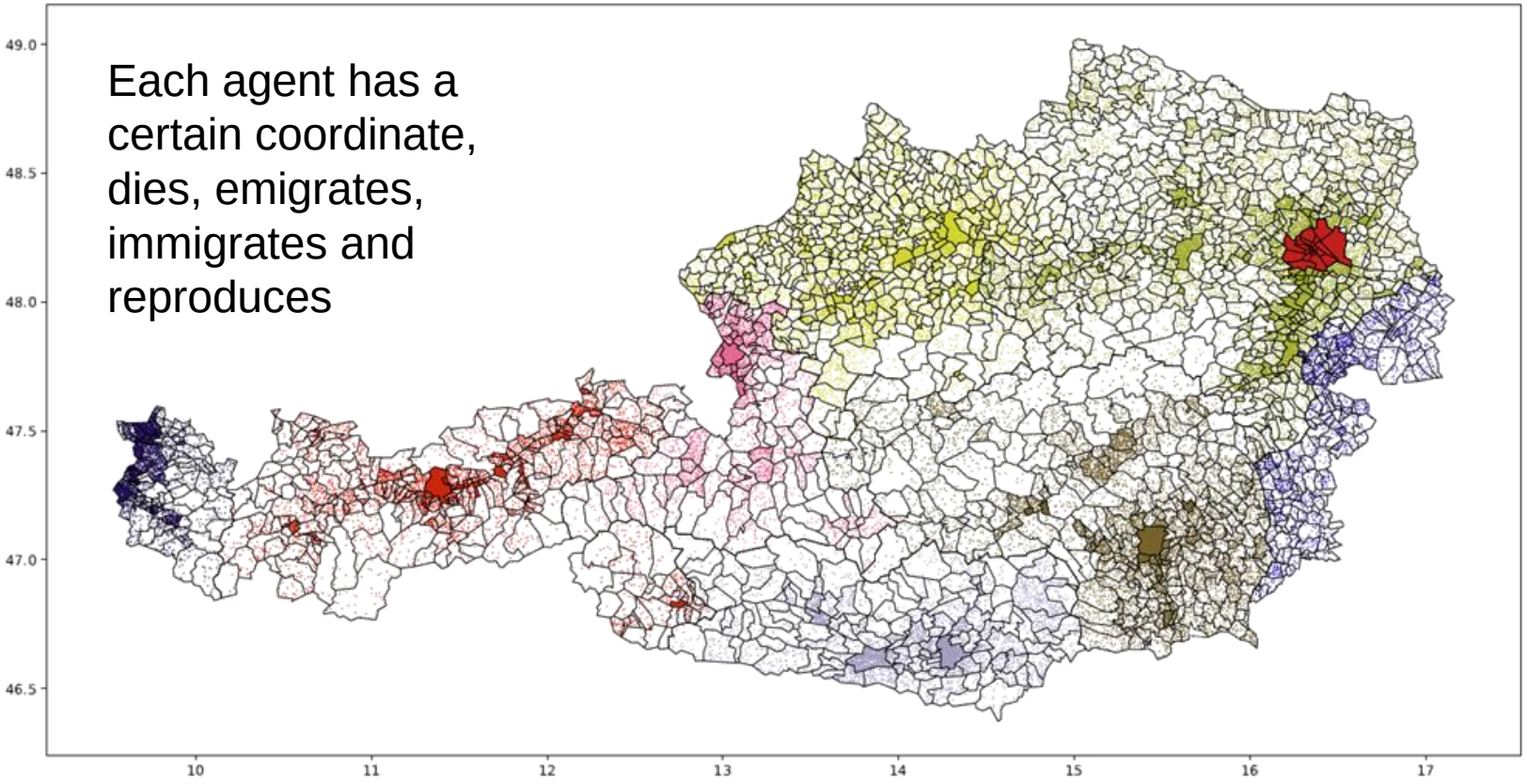
Mathematical Modelling and Simulation



# Example: GEPOC (Generic Population Concept)

Mathematical Modelling and Simulation

- Population model of Austria
- Simulation of Austria‘s population from 1999 to make prognosis until 2050



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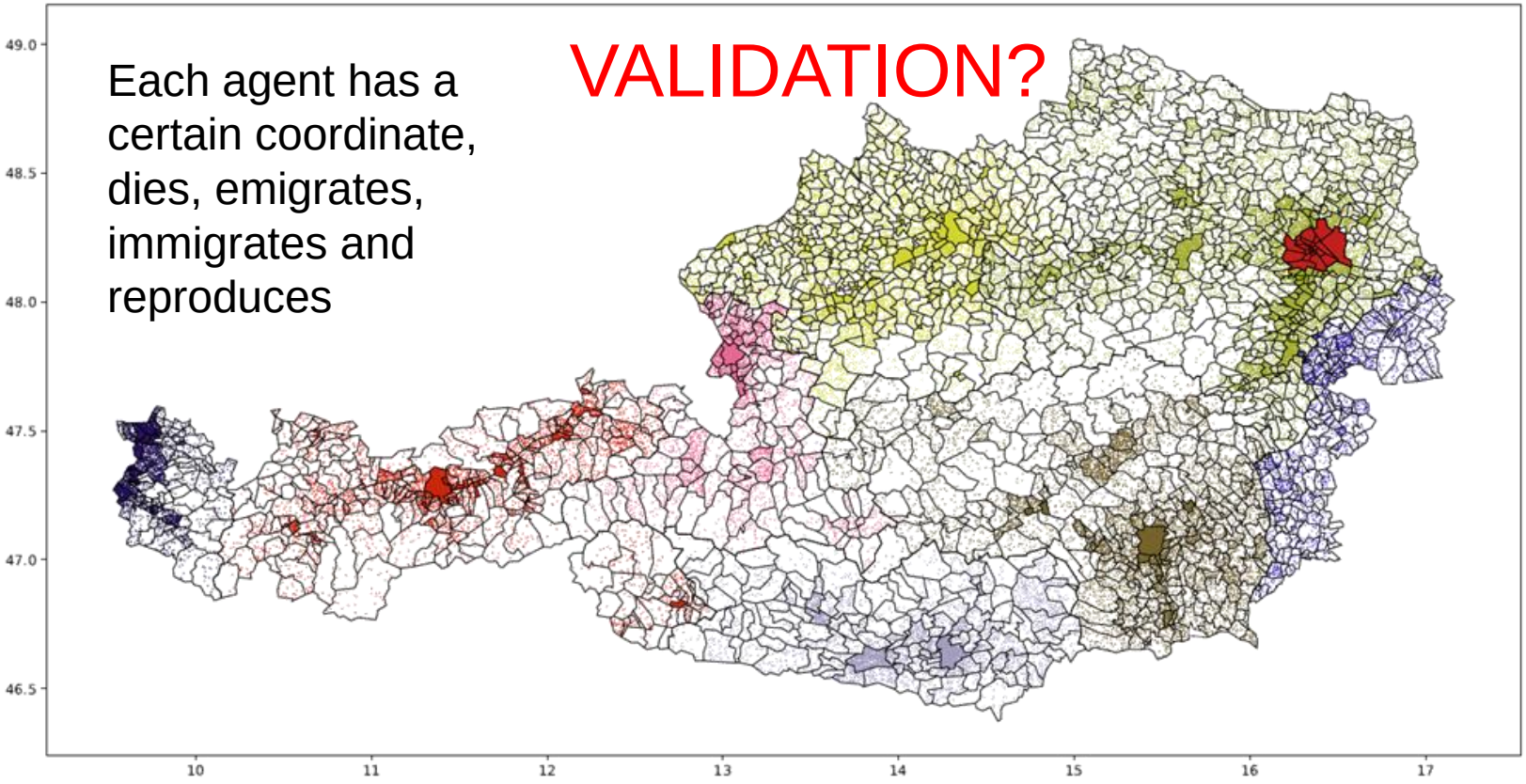

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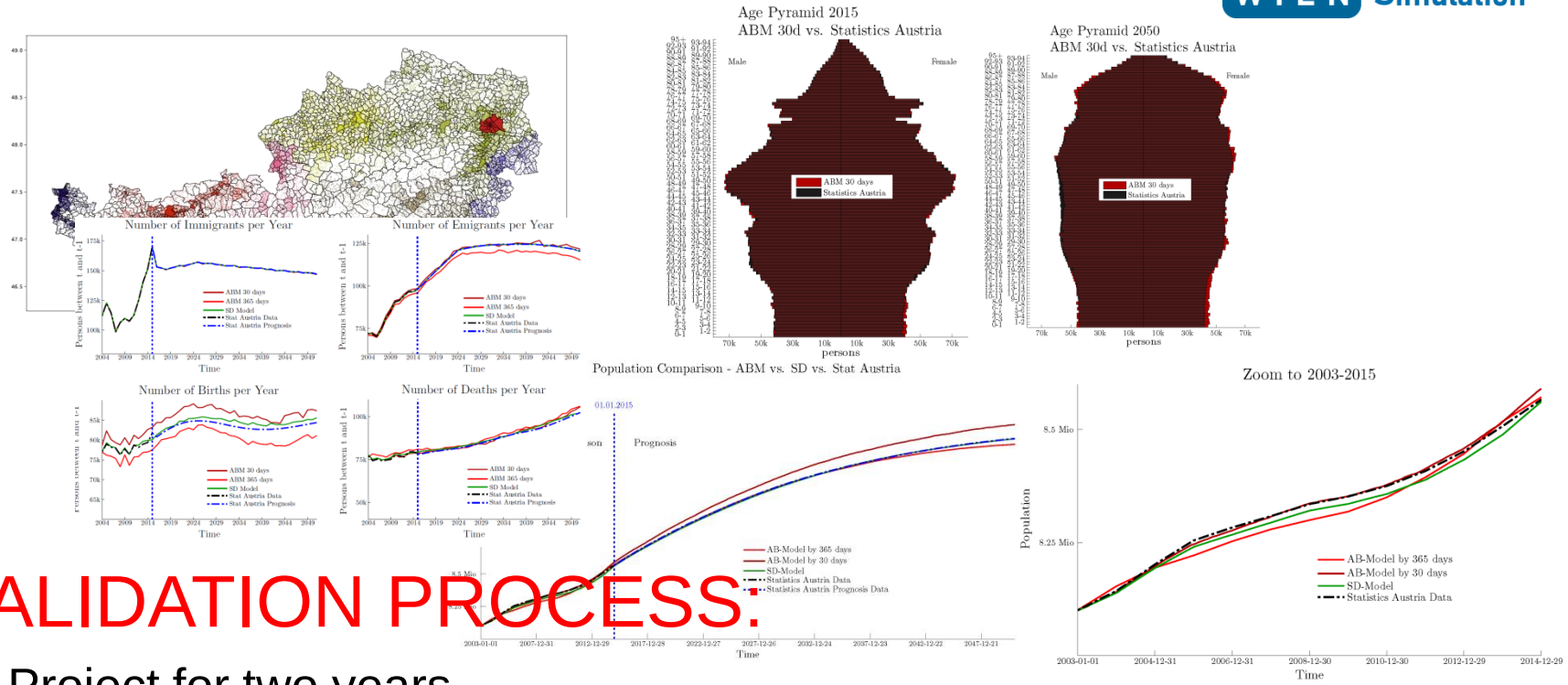



# VALIDATION PROCESS:

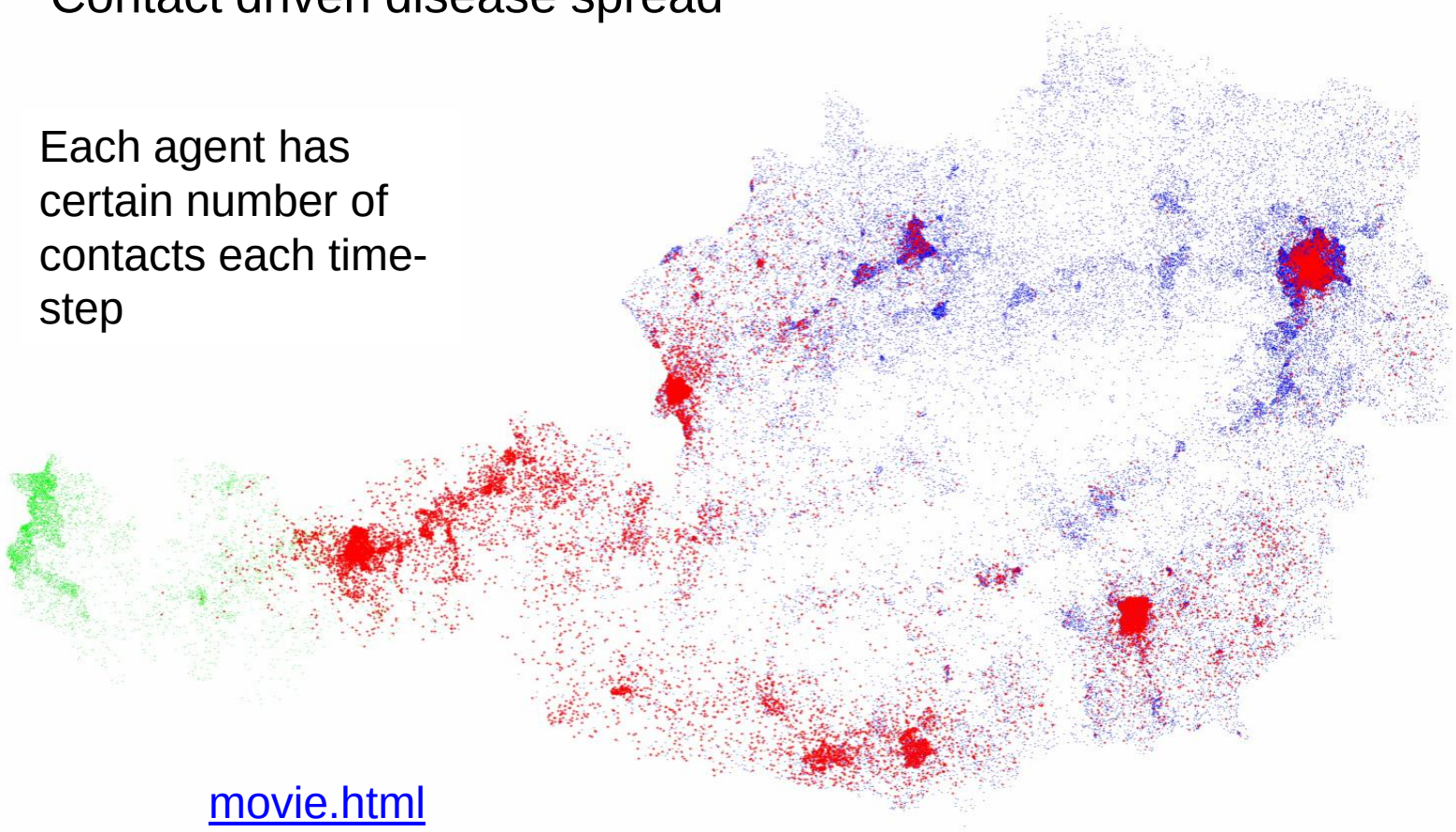
- Project for two years.
- Parametrisation and Validation data for time <2016 from Statistics Austria
- Parametrisation and Validation for time >=2016 matched with Statistics Austria Prognosis tool

# Example: GEPOC Flu

Mathematical Modelling and Simulation

- Simulation of 2014 Flu
- Contact driven disease spread

Each agent has certain number of contacts each time-step



movie.html

# Example: GEPOC Flu

Mathematical Modelling and Simulation

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VALIDATION?

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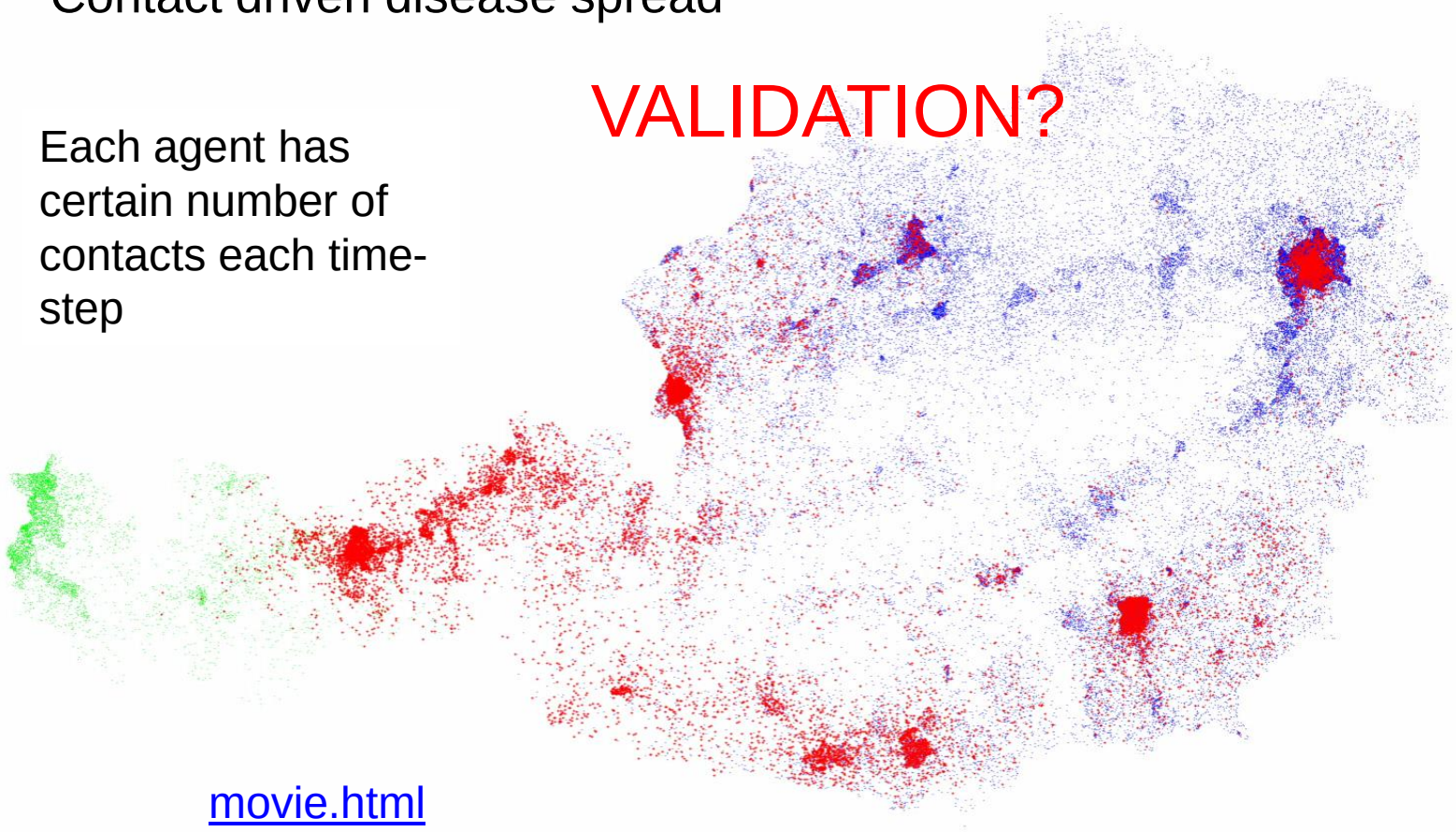

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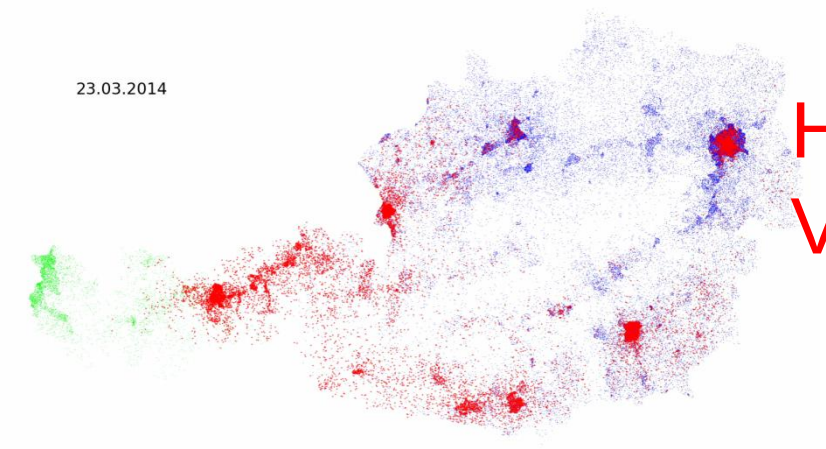
# Example: GEPOC Flu

Mathematical Modelling and Simulation




HOW ABOUT VALIDATION?

THIS model is absolute rubbish and has hardly anything to do with reality!

# Beware of wrong ideas!

Mathematical Modelling and Simulation

- Natural desripion of the system makes the model easier to communicate.
- Therefore it becomes more credible than more abstract approaches

BUT

CREDIBLE ≠ VALID

PICTURESQUE≠ VALID

# Interpretation of Agent-Based Model Results

Mathematical Modelling and Simulation

Basically two classes of agent-based models can be observed

ABMs for **qualitative** investigation

- Usually interested in (temporal behaviour) of patterns
- Usually used for foundamental scientific research

ABMs for **quantitative** investigation

- Usually interested in temporal behaviour of aggregate numbers
- Usually used for some kind of resource planning

# Interpretation of Agent-Based Model Results

Mathematical Modelling and Simulation

Basically two classes of agent-based models can be observed

ABMs for **qualitative** investigation

- (On purpose) very abstract
- Usually very complex model behaviour
- Hardly any parameters identified with real data

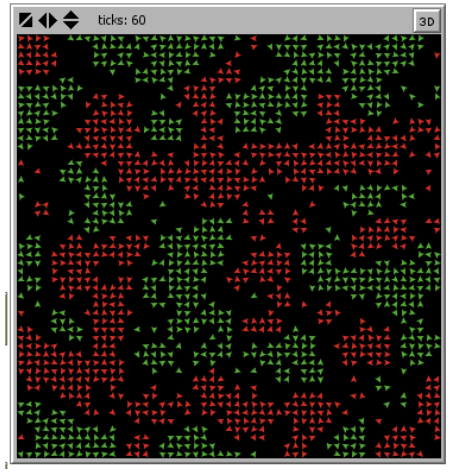
ABMs for **quantitative** investigation

- Rather simple agent interactions
- A lot of data involved for model parametrisation and validation
- Usually less famous

# Interpretation of Agent-Based Model Results : Examples

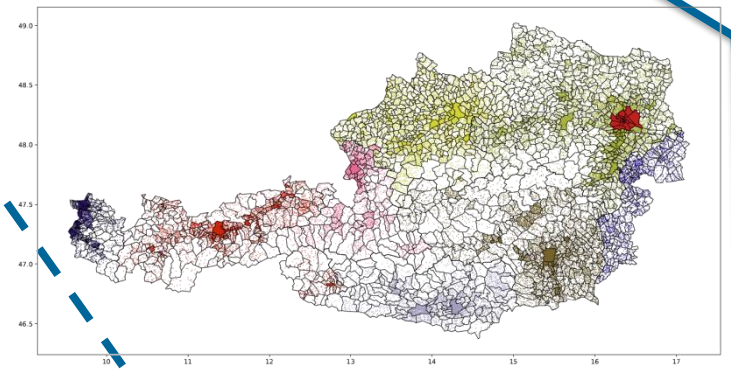
Mathematical Modelling and Simulation

ABMs for **qualitative** investigation




Schelling‘s Segregation Model

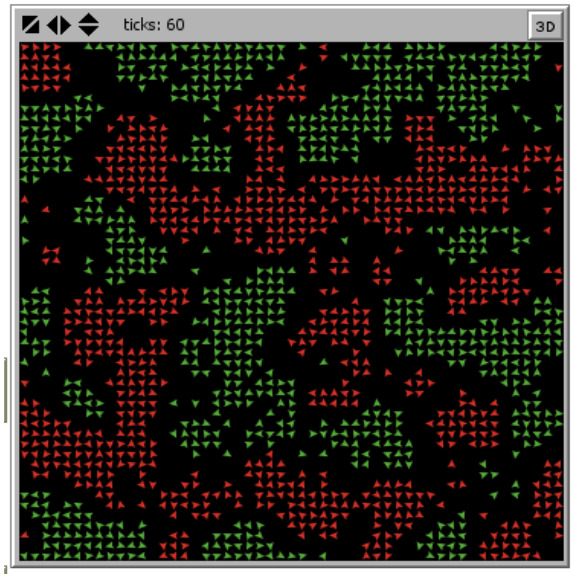
ABMs for **quantitative** investigation



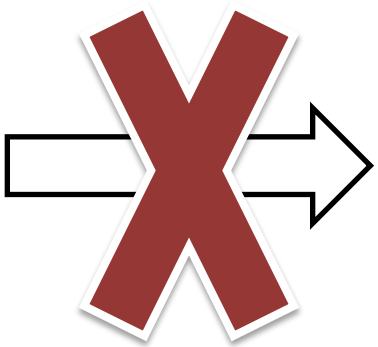
GEPOC

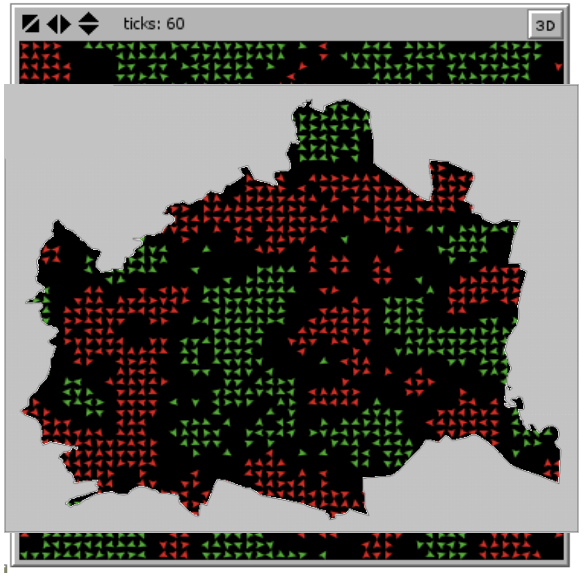
# Interpretation of Agent-Based Model Results : Examples

Mathematical Modelling and Simulation




WRONG INTERPRETATION

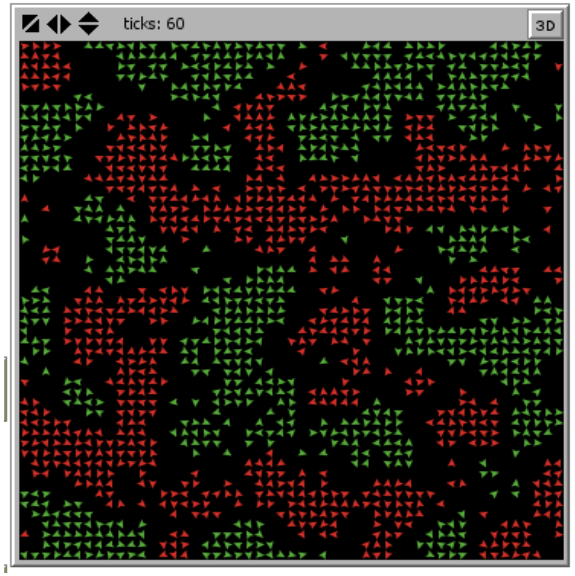




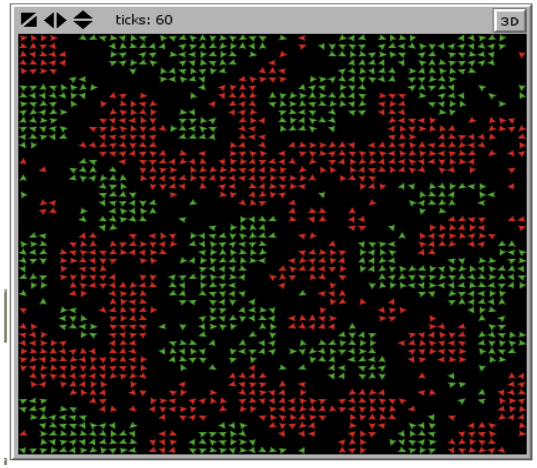

„Schelling‘s model predicts: In a few years only immigrants in Wien Hietzing!“

# Interpretation of Agent-Based Model Results : Examples

Mathematical Modelling and Simulation




CORRECT INTERPRETATION

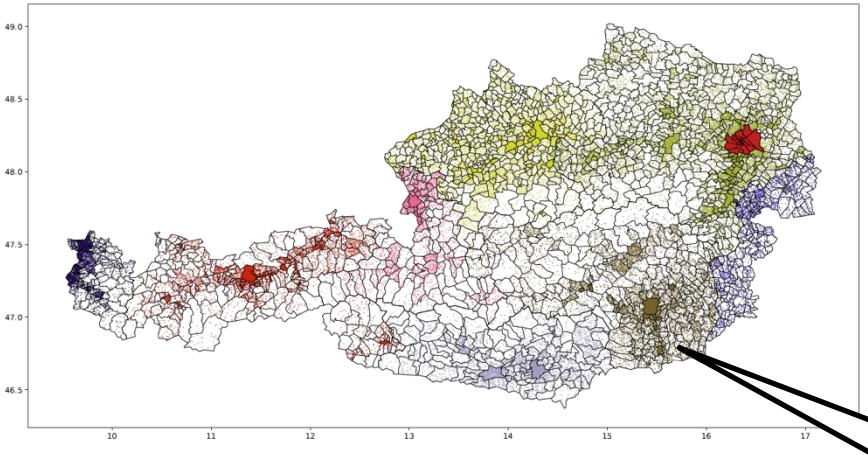



„If we do not take care on our migration policy human homophobia might lead to spatially visible ghettoism as seen above in Austria as well!“

# Interpretation of Agent-Based Model Results : Examples

Mathematical Modelling and Simulation

WRONG INTERPRETATION




„GEPOC predicts: In two years there will be a 50 year old immigrant in Leibnitz“

Hi guys, i'm Mike

In general: **Never** pick only one agent from an ABM!

# Interpretation of Agent-Based Model Results : Examples

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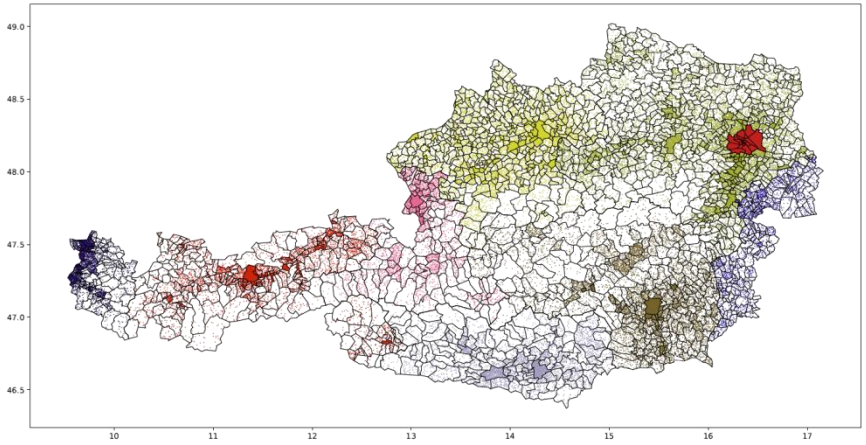


CORRECT INTERPRETATION

„GEPOC predicts: Austrian population is assumed to grow to x.x Mio people until 2030.“

# Summary: Agent-Based Models

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Agent-based models are good in…

- … analysis and discovery of complex group dynamic behaviour. This must not necessarily be a good thing as emergent behaviour may occur in models even if it is not correct.
- … communitcating models to non-experts.
  The modelling appoach is easy to understand, picturesque and no mathematical background is necessary.

# Summary: Agent-Based Models

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Agent-based models are good in…

- … analysis and discovery of complex group dynamic behaviour.
- … communitcating models to non-experts.

Agent-based modelling is problematic …

- … regards misinterpretation. If it looks like reality it must not necessarily be a valid model for it.
- … regards the validation process. Validation of ABMs is a difficult task due to complex model behaviour.
- … regards computer ressources. ABMs require high performance CPUs and a lot of RAM.

TU WIEN Mathematical Modelling and Simulation

# Questions?