

# Introduction to Agent-Based Modelling

# Historical Background

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- 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

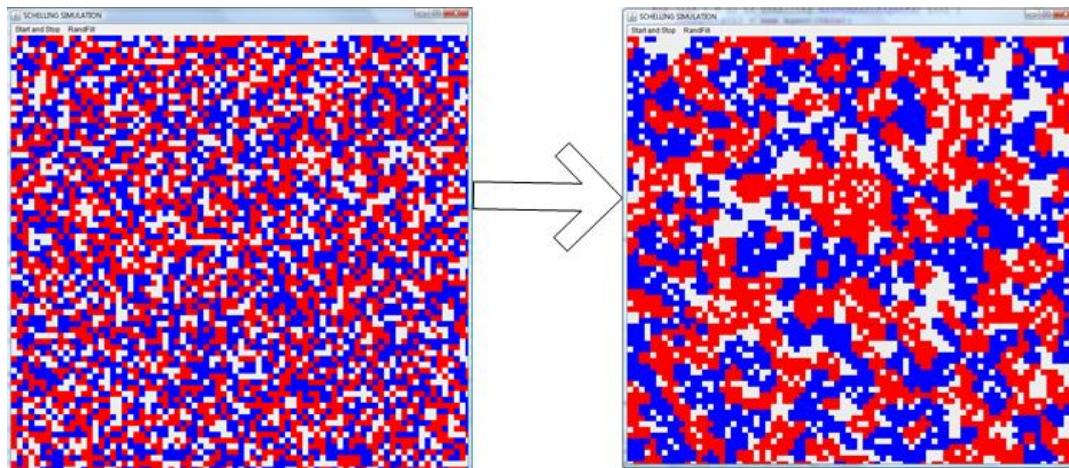
Model segregation behaviour between individuals with different races in US in the 1970s

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# Historical Background

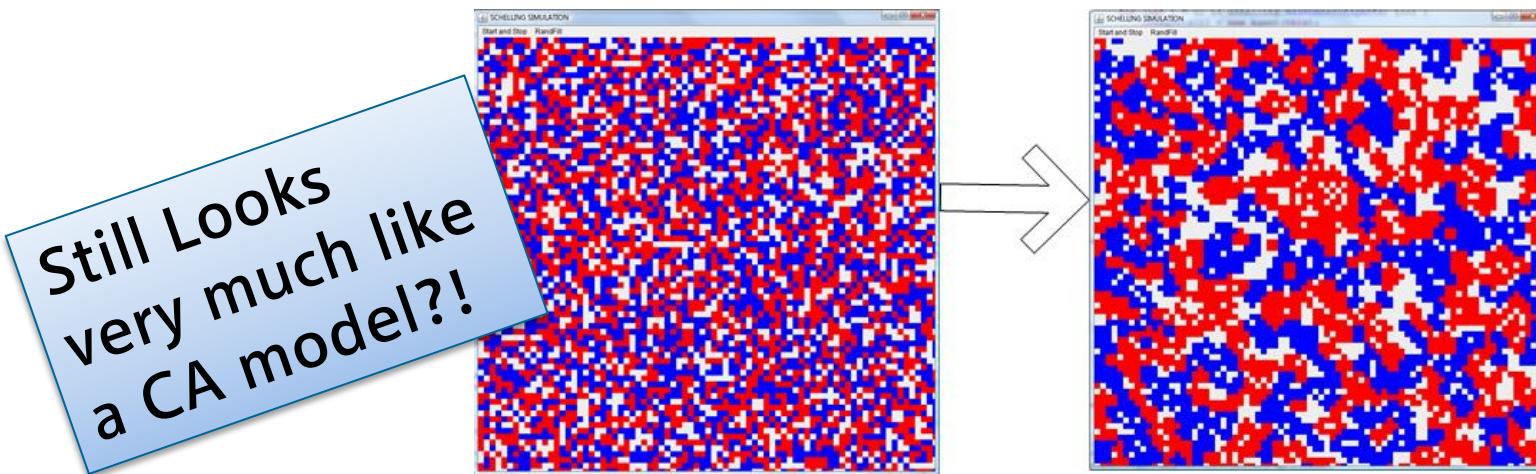
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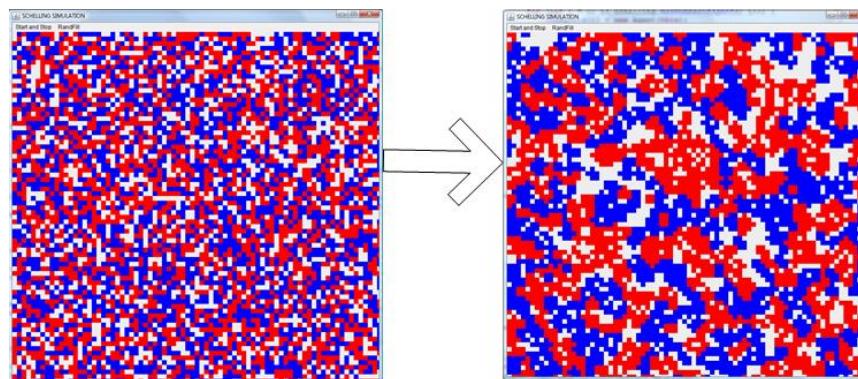
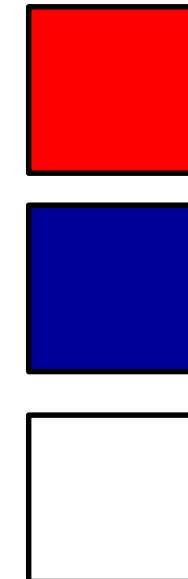
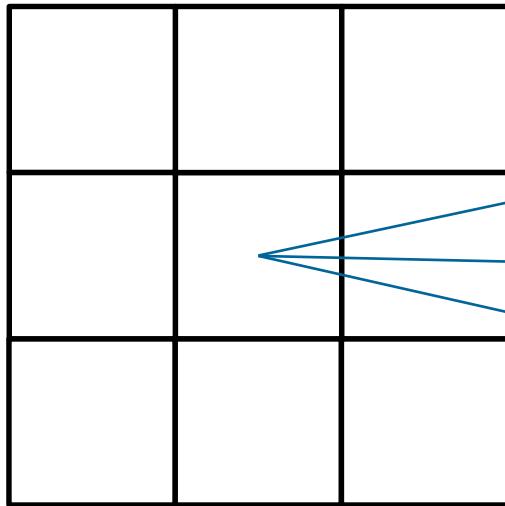


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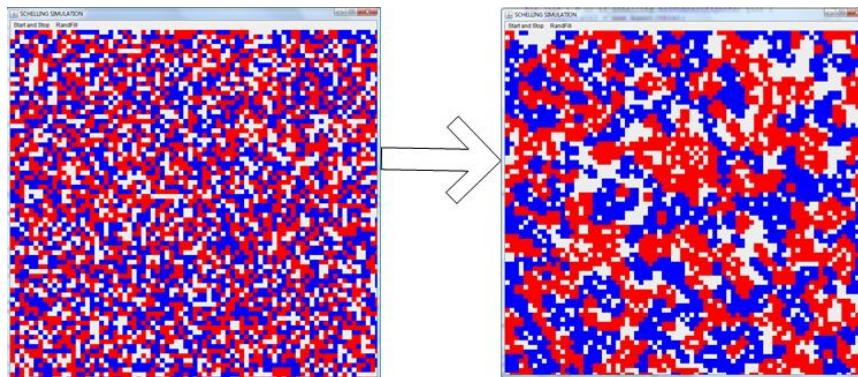
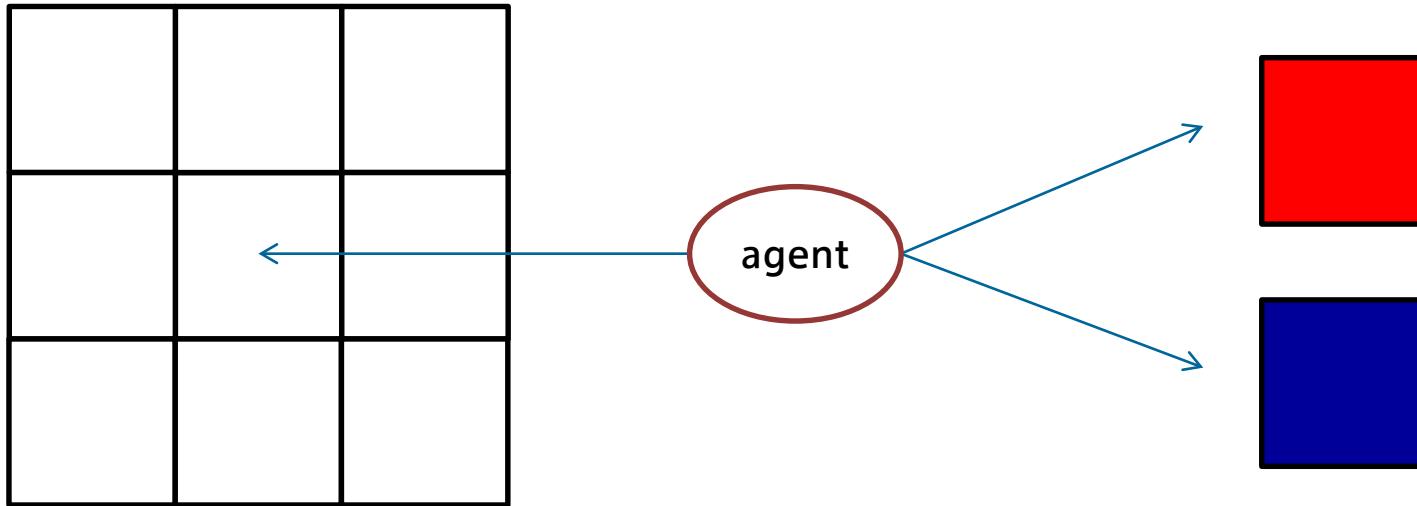
# A Small but Powerful Difference...



## CA Model

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

# A Small but Powerful Difference...



## Agent Based Model (ABM)

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

# A Small but Powerful Difference...

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...

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

We do not have to use a discrete time-step!

It could be some „grayscale“ in between if we want to

It is easier to explain the model as it is a more natural description!

ABM

We do not have to use a cell-space

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

We could introduce death of agents

We could distinguish between male and female agents (persons)

We could include more realistic distributions

We could add some immigrants

# Agent

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Why Agent?



# Agent

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Latin: „agere“ (to act)



# What is an Agent? (1)

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- 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)

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# What is an Agent? (2)

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- With respect to Winter Simulation Conference (2005 & 2006) an agent has to...
  - ... be uniquely identifiable
  - ... cohabit in 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)

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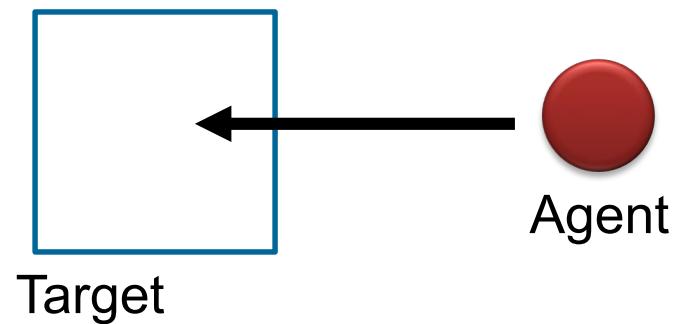
Optional properties (Wintersimulation Conference 2015)

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Agent

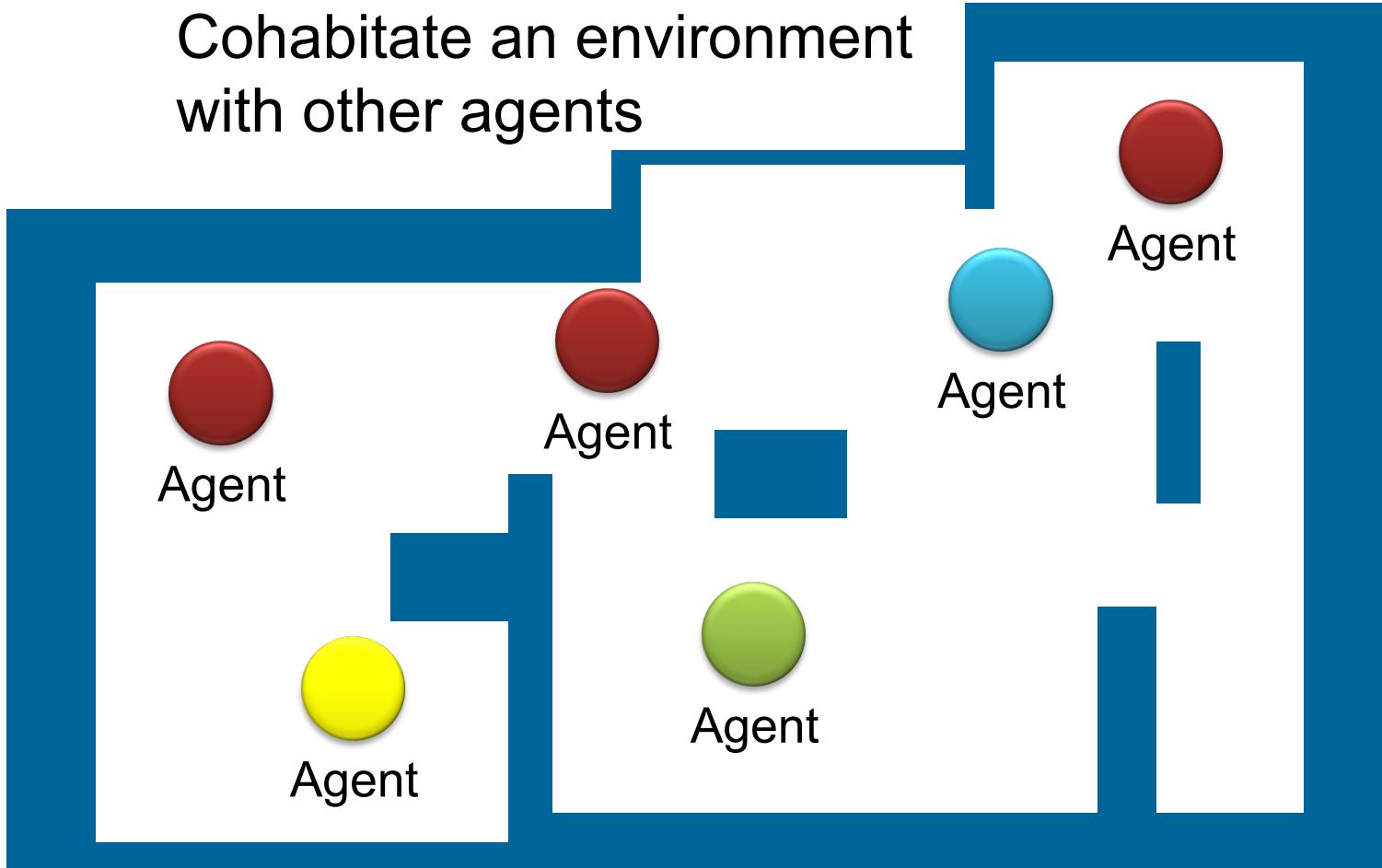
## Act Targeted



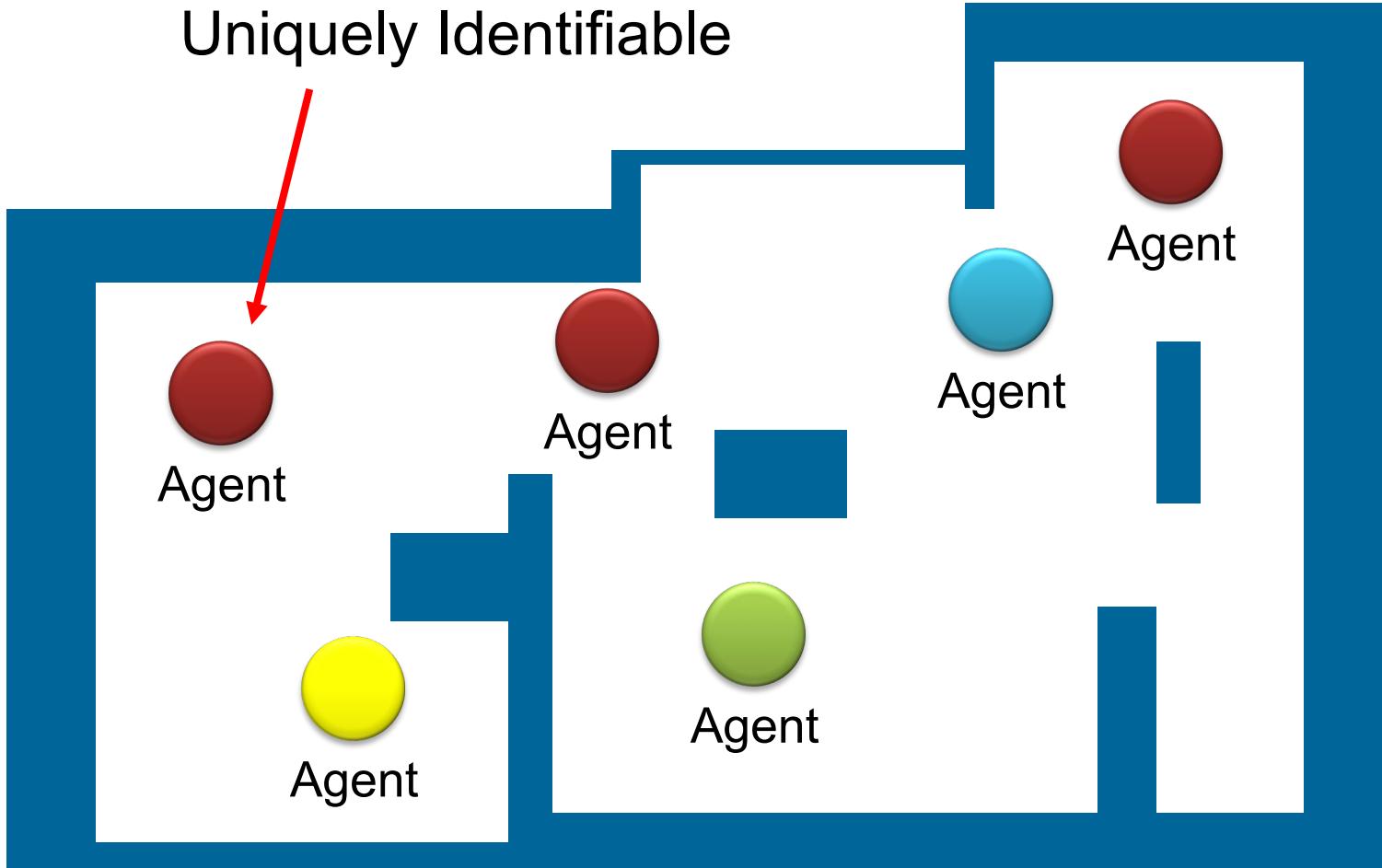
## Act Targeted



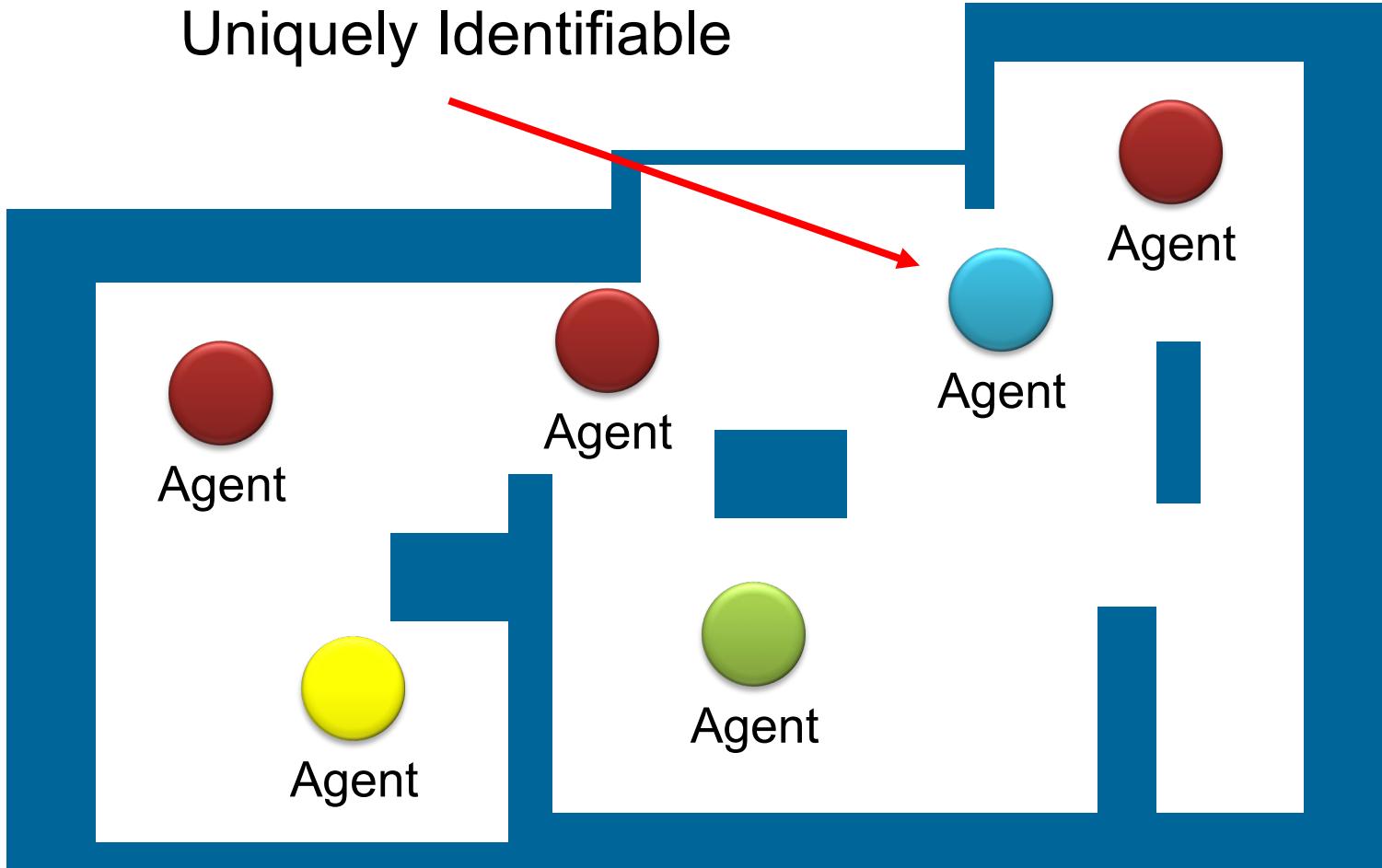
Cohabitate an environment  
with other agents



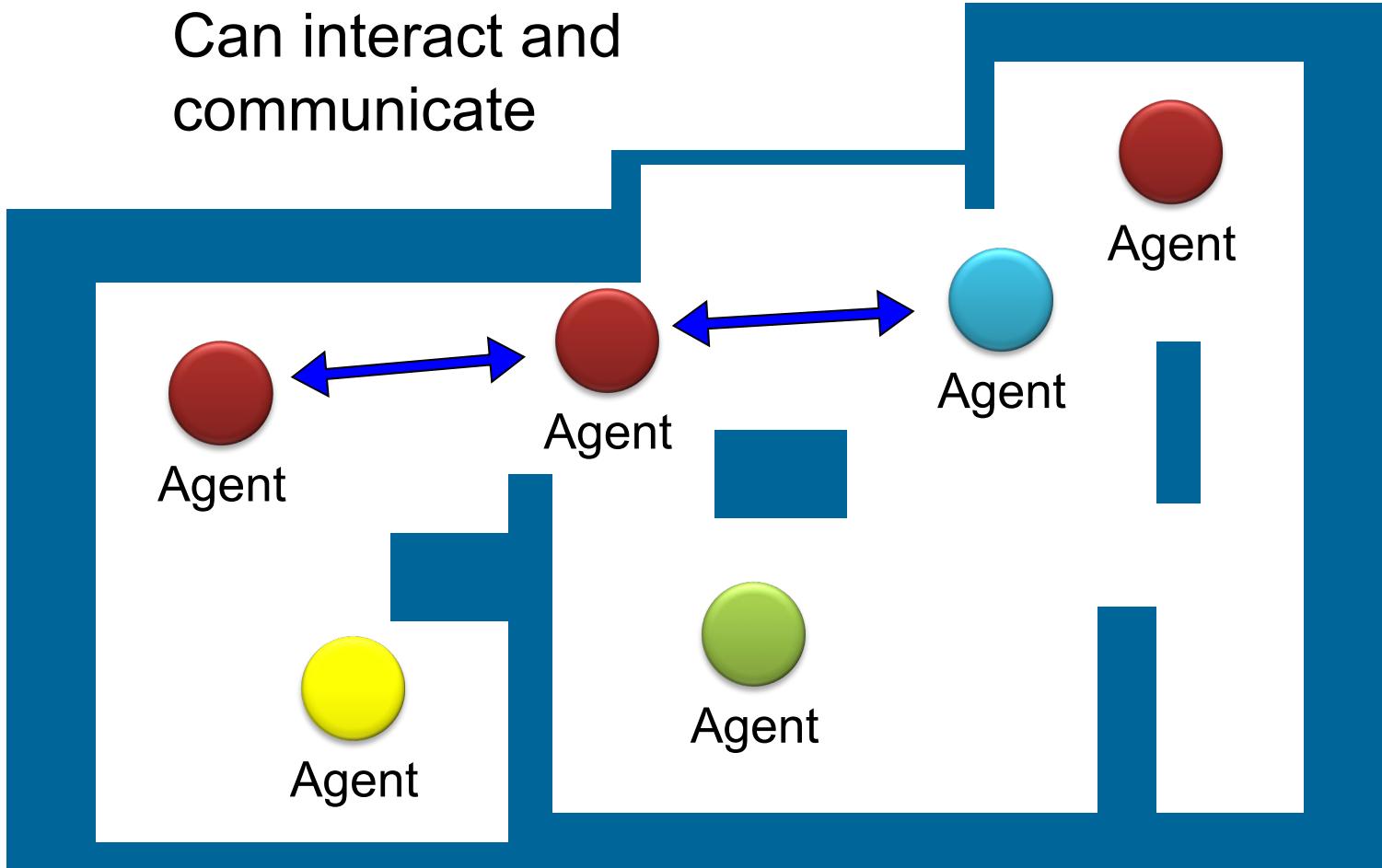
Uniquely Identifiable



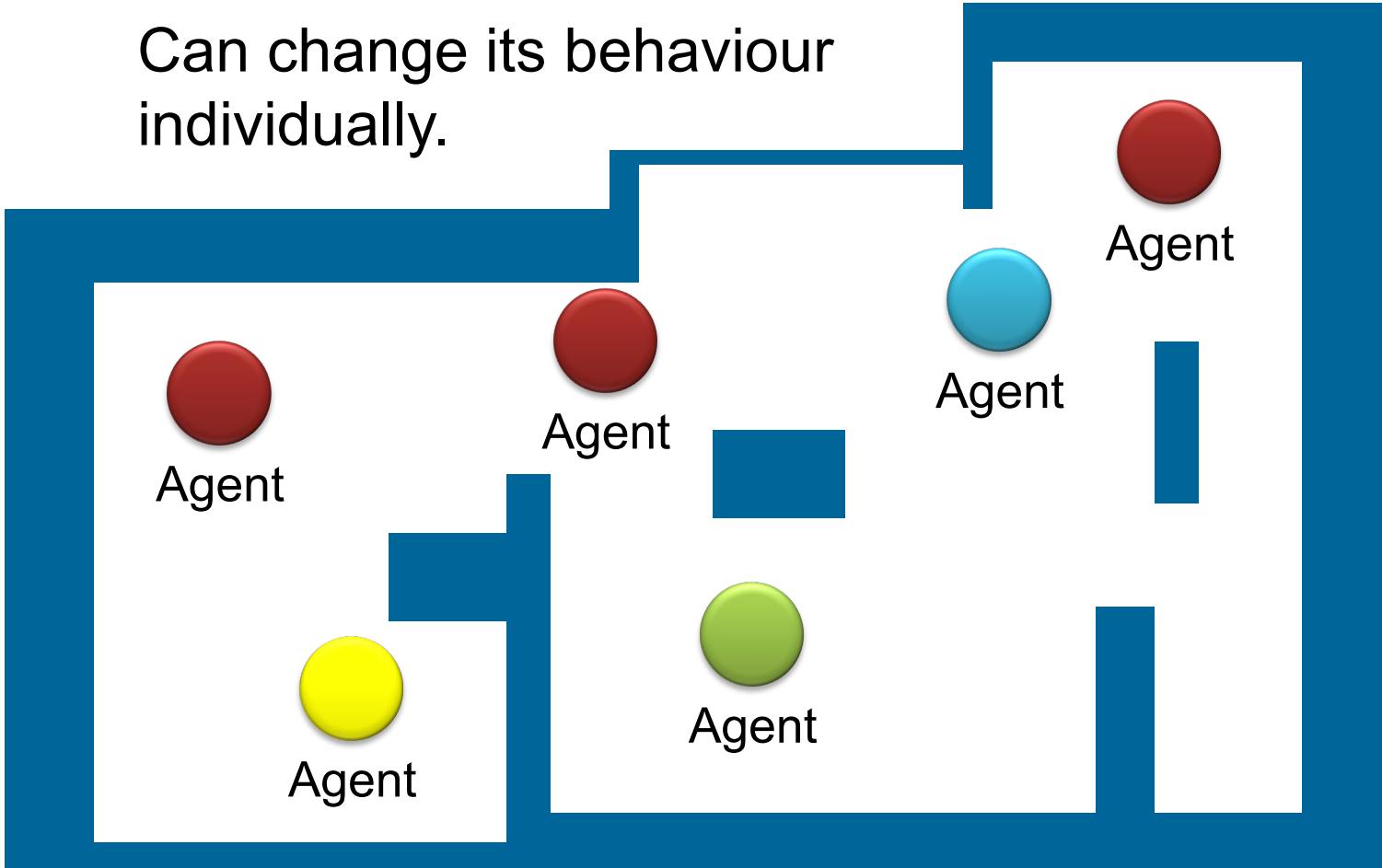
## Uniquely Identifiable



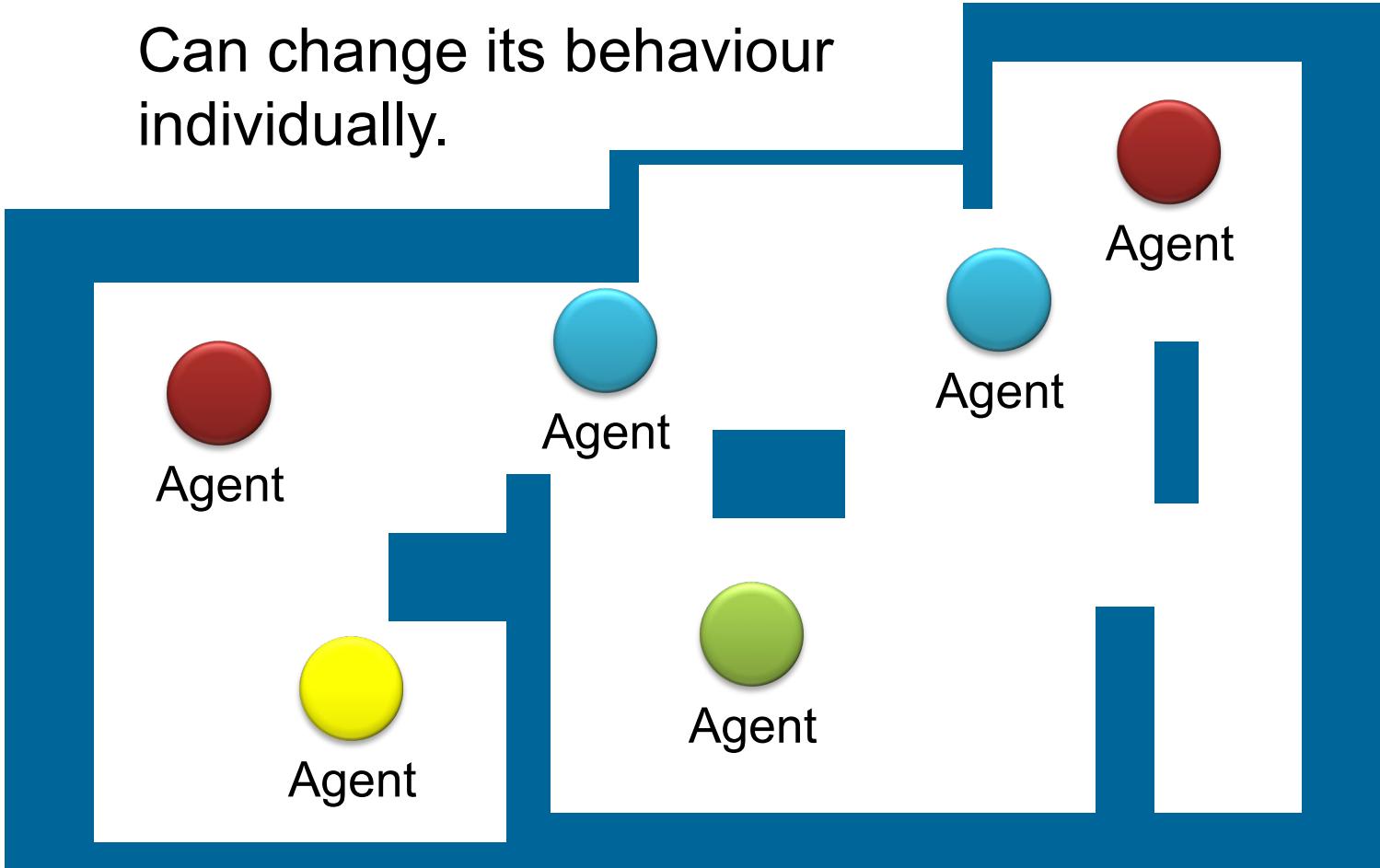
Can interact and communicate



Can change its behaviour  
individually.



Can change its behaviour  
individually.



# Short Summary

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- 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.
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- a. Representation of „emergent phenomena“
  - b. Flexibility  
(Bonabeau, 2002)
  - c. Natural description of the system
-

# Properties of Agent-Based Models

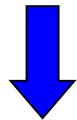
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- a. Representation of „emergent phenomena“
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-

# Representation of „Emergent Phenomena“

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Simple rules for individual agents



Complex dynamics of the whole system

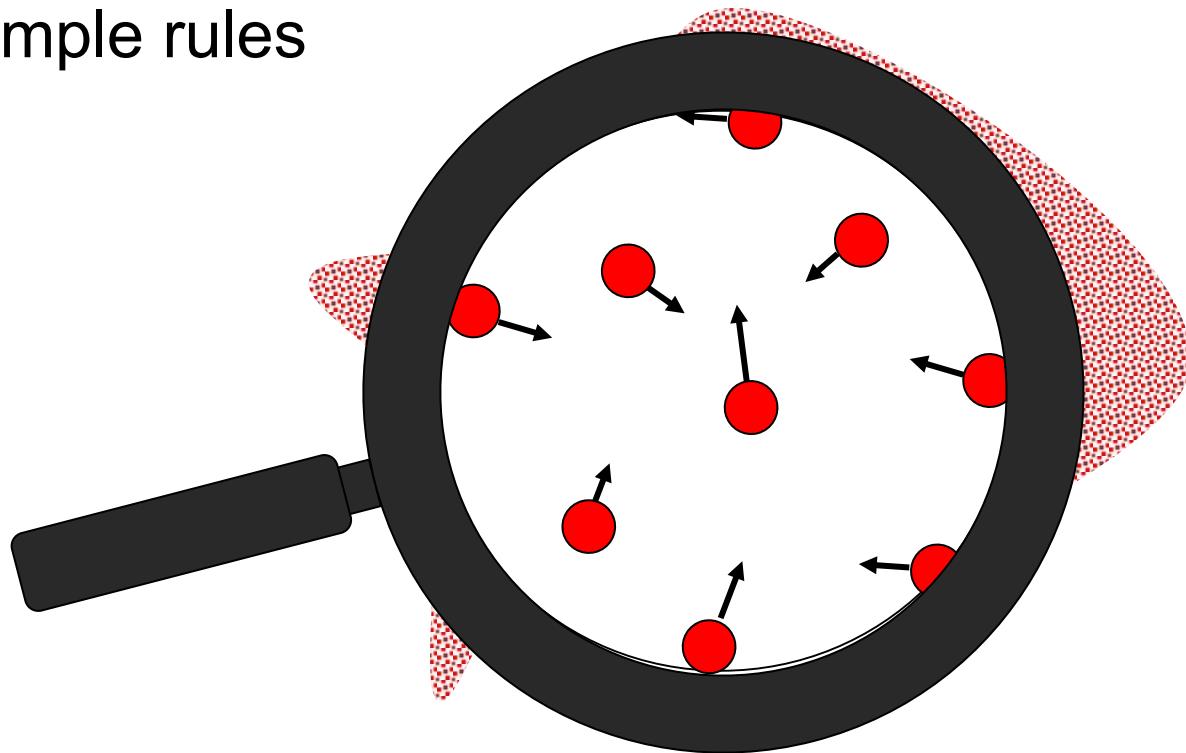
**group dynamics / swarm intelligence**

# Representation of „Emergent Phenomena“



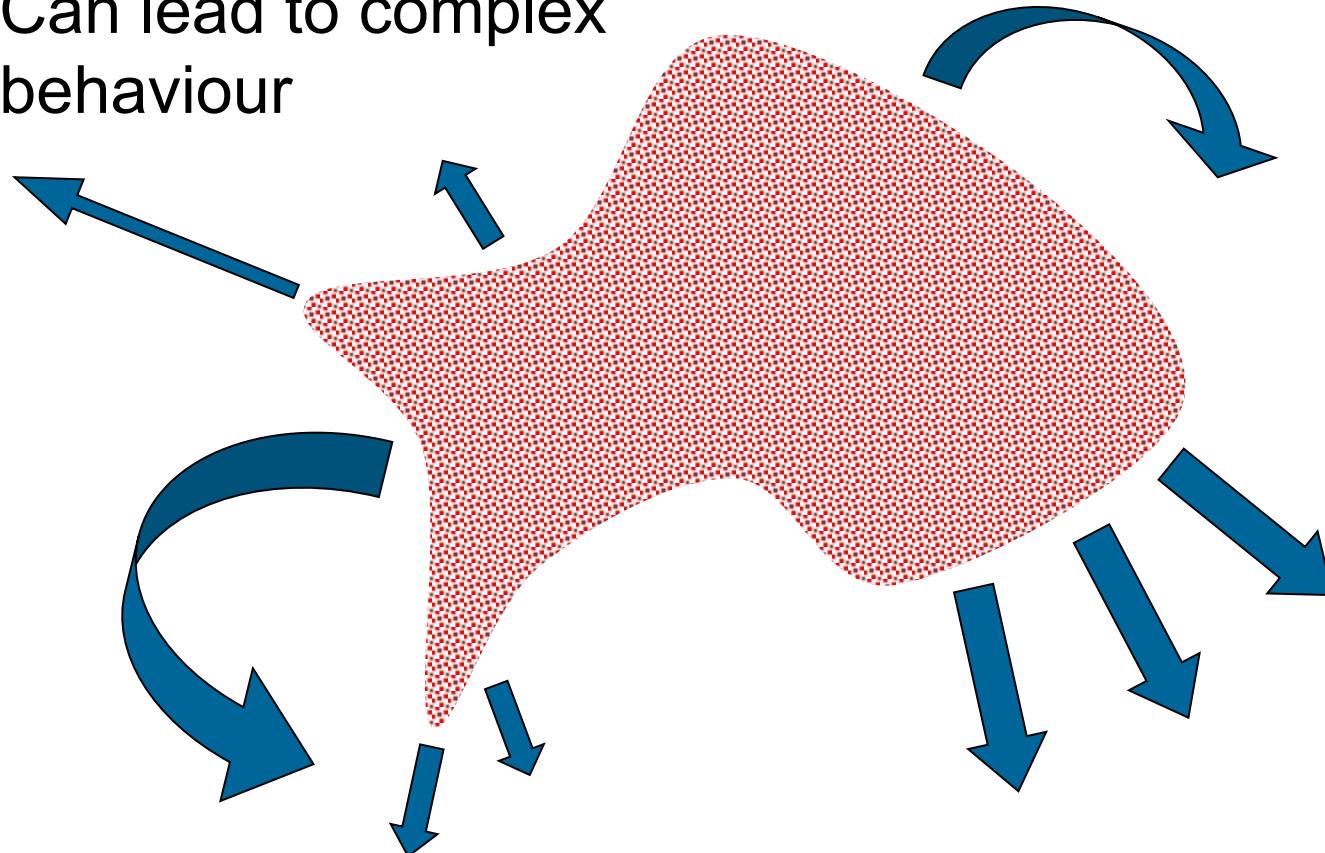
Mathematical  
Modelling and  
Simulation

Simple rules



# Representation of „Emergent Phenomena“

Can lead to complex  
behaviour



# Example: Fish or bird flocks

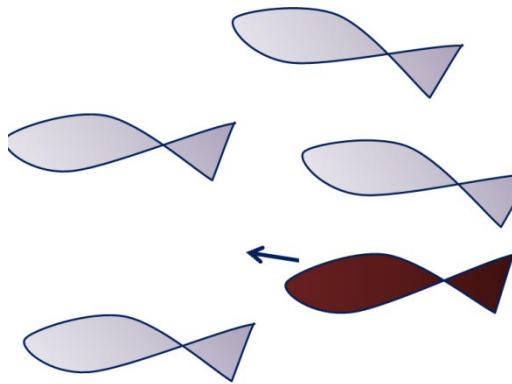
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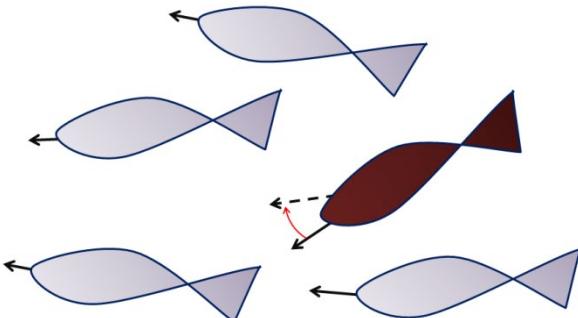
<https://www.youtube.com/watch?v=QOGCSBh3kmM>

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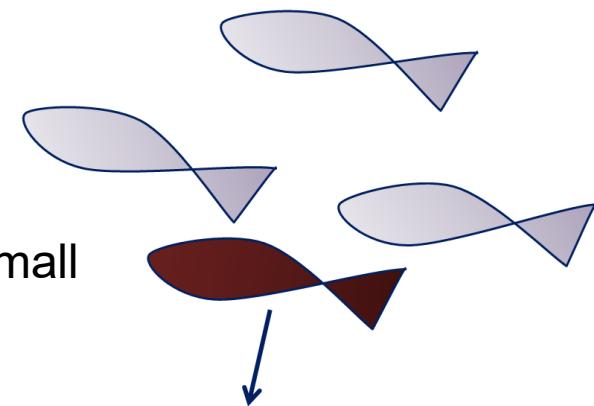
# Boids Flock Model



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

- a. Representation of „emergent phenomena“
  
  - b. **Flexibility**  
(Bonabeau, 2002)
  
  - c. Natural description of the system
-

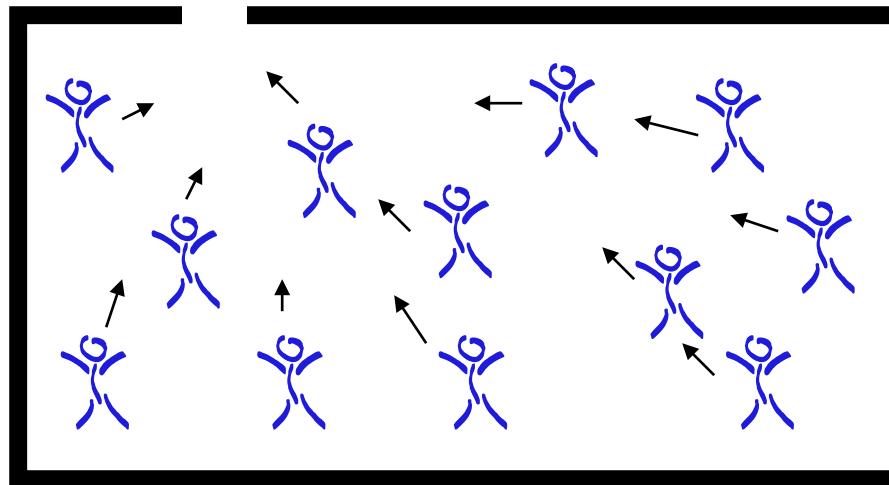
# Flexibility

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- 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).
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# Example: Emergency exit strategy

Example: Emergency exit strategy



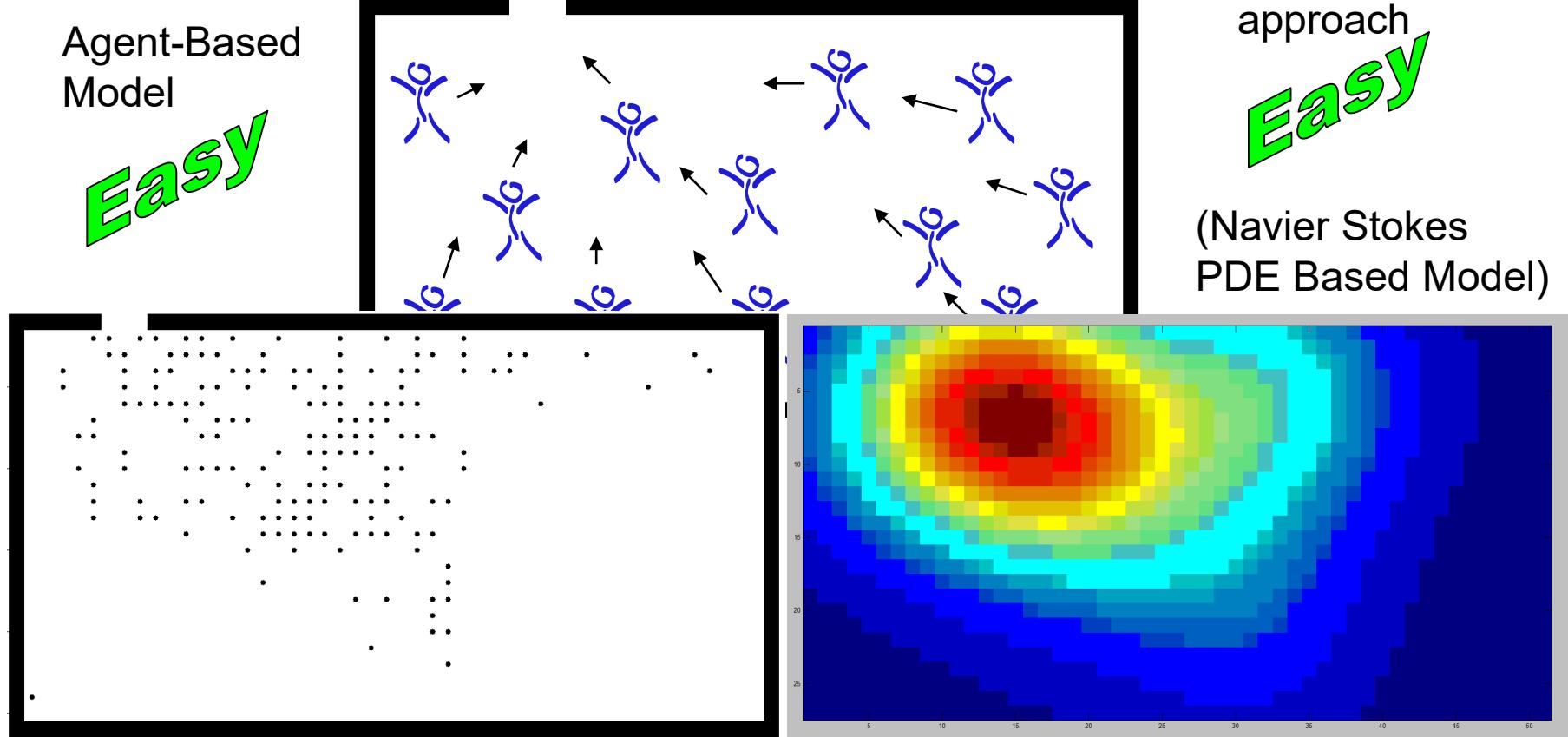
Agent-Based  
Model

**Easy**

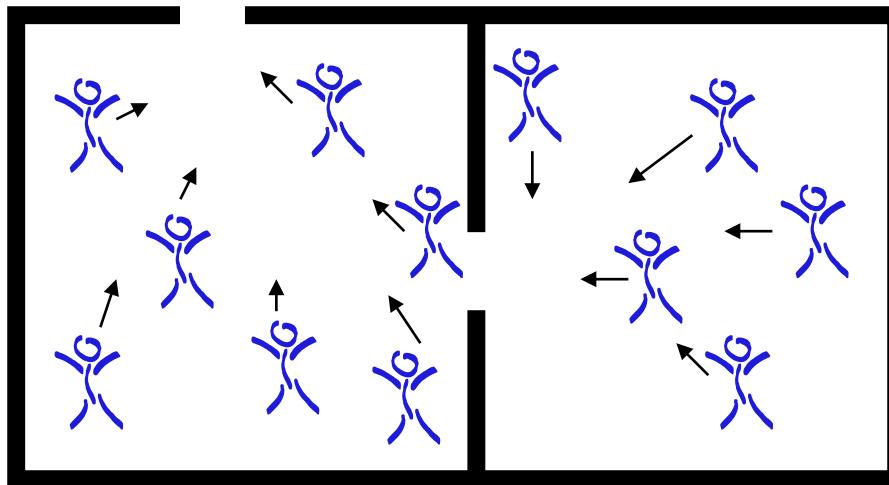
Macroscopic  
approach

**Easy**

# Example: Emergency exit strategy



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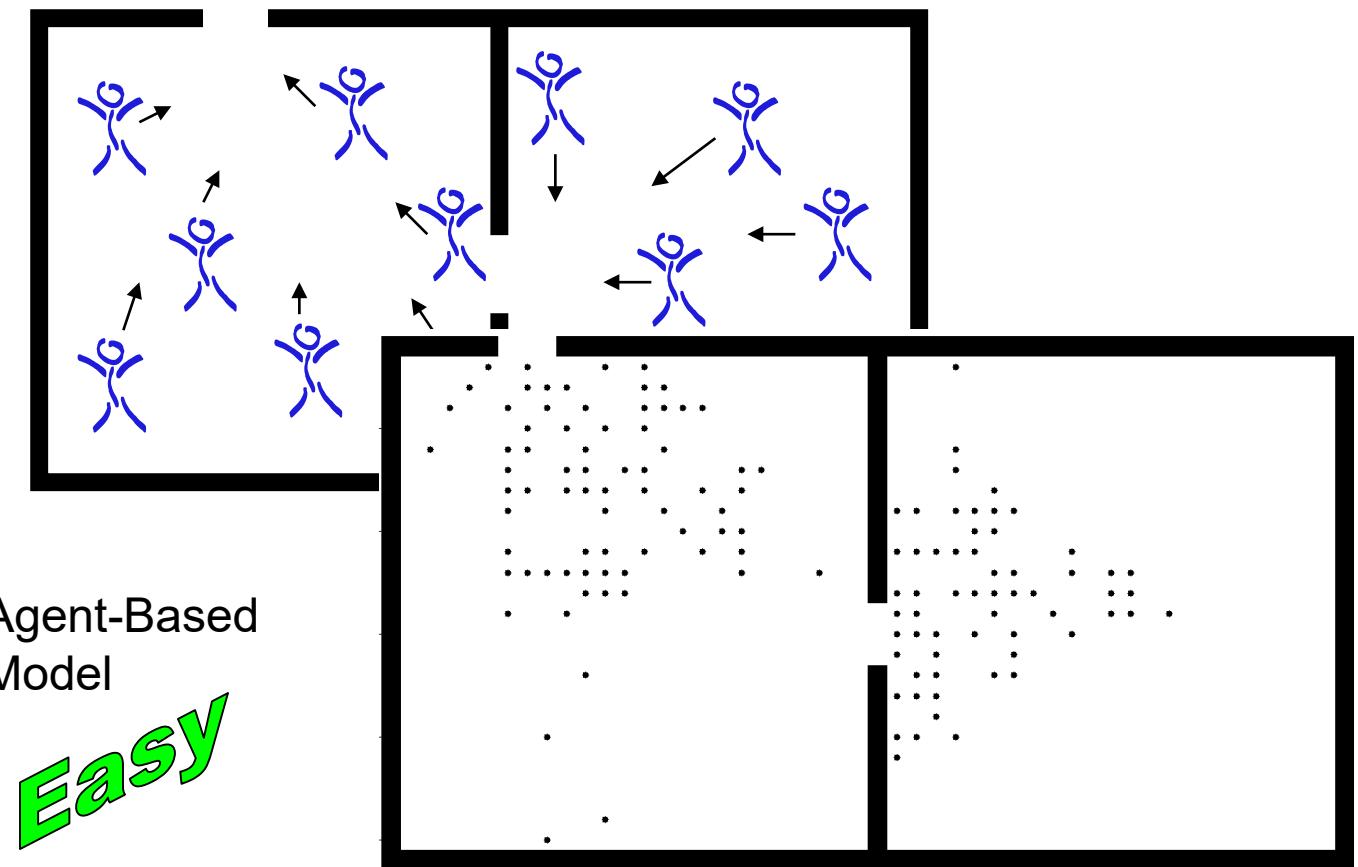
Agent-Based  
Model

**Easy**

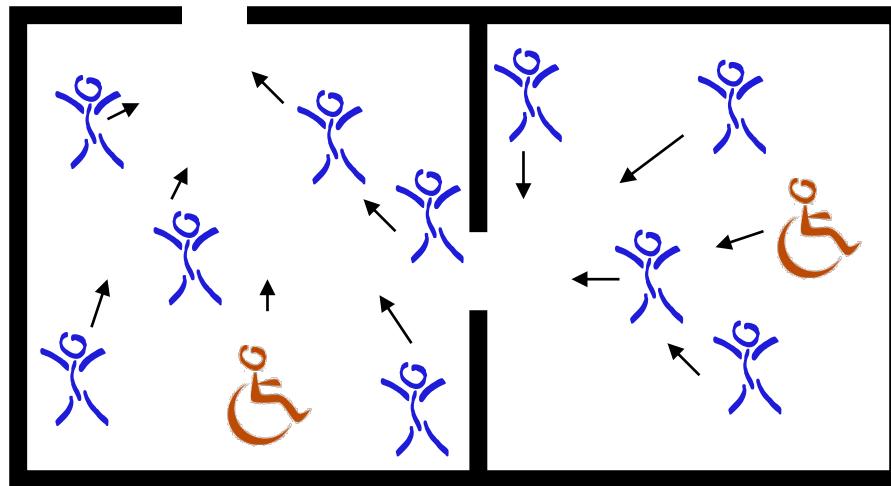
Macroscopic  
approach

**Tricky**

# Example: Emergency exit strategy



# Example: Emergency exit strategy



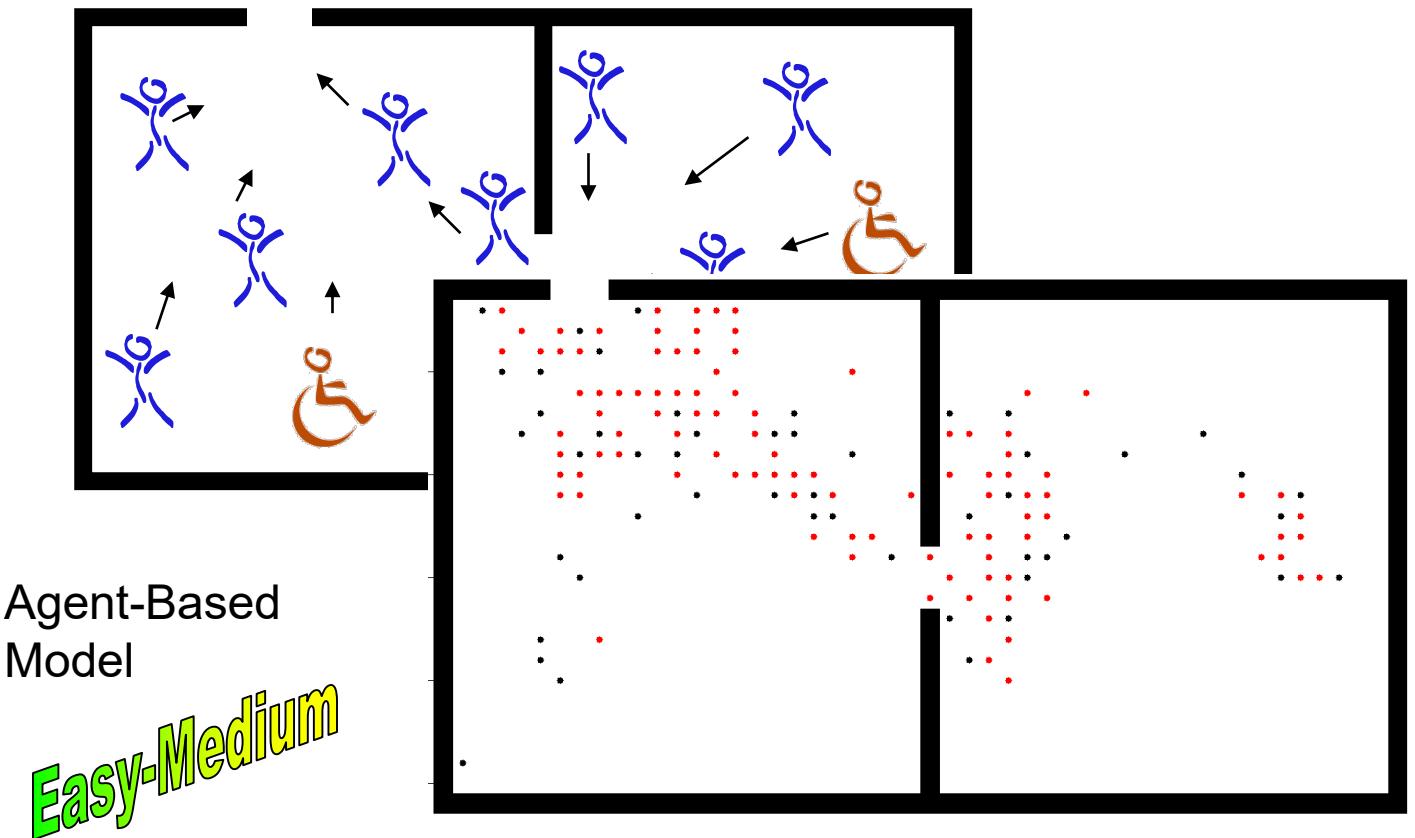
Agent-Based  
Model

*Easy-Medium*

Macroscopic  
approach

*Almost  
Impossible*

# Example: Emergency exit strategy



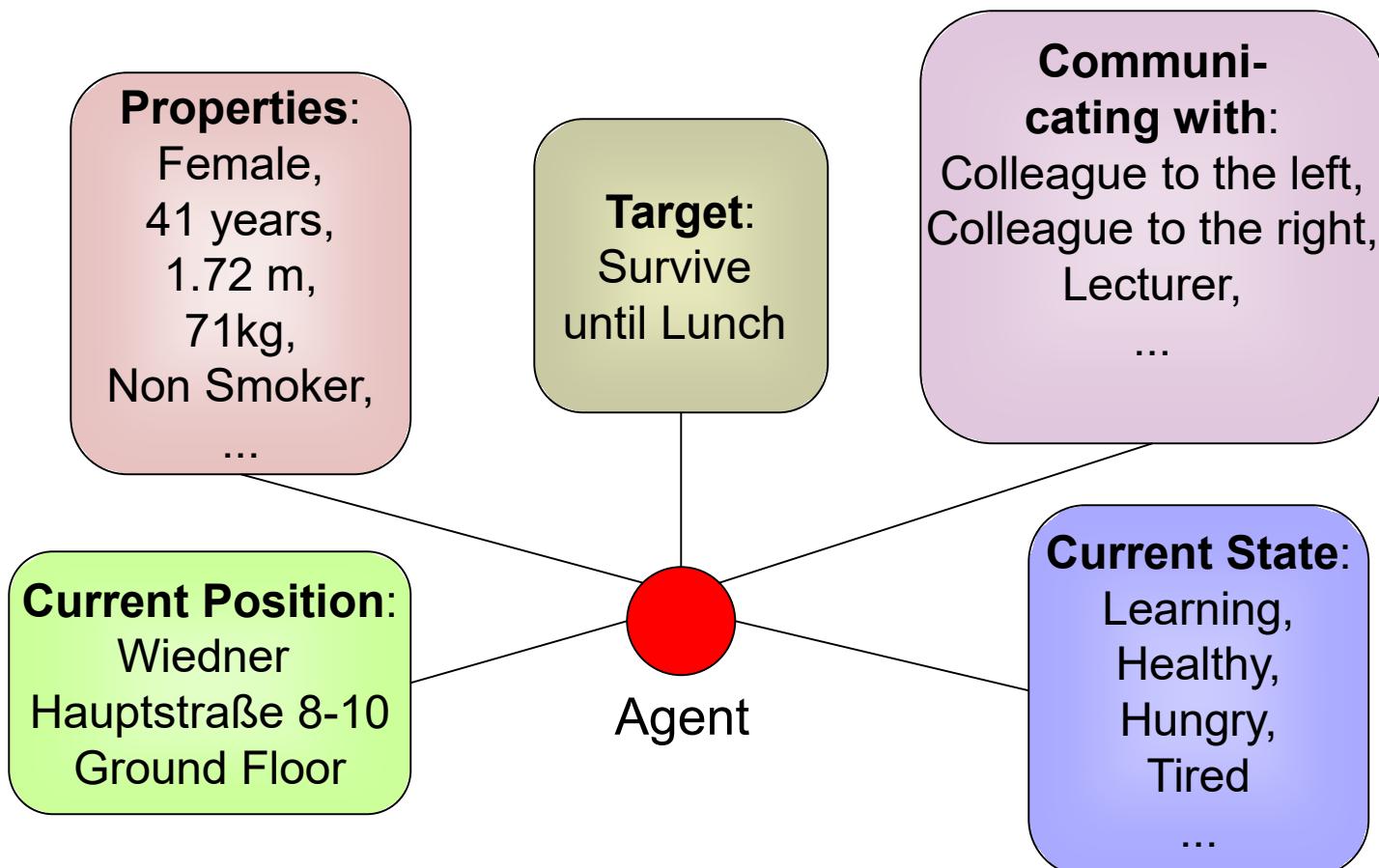
- a. Representation of „emergent phenomena“
  - b. Flexibility  
(Bonabeau, 2002)
  - c. Natural description of the system
-

# Natural description of the System

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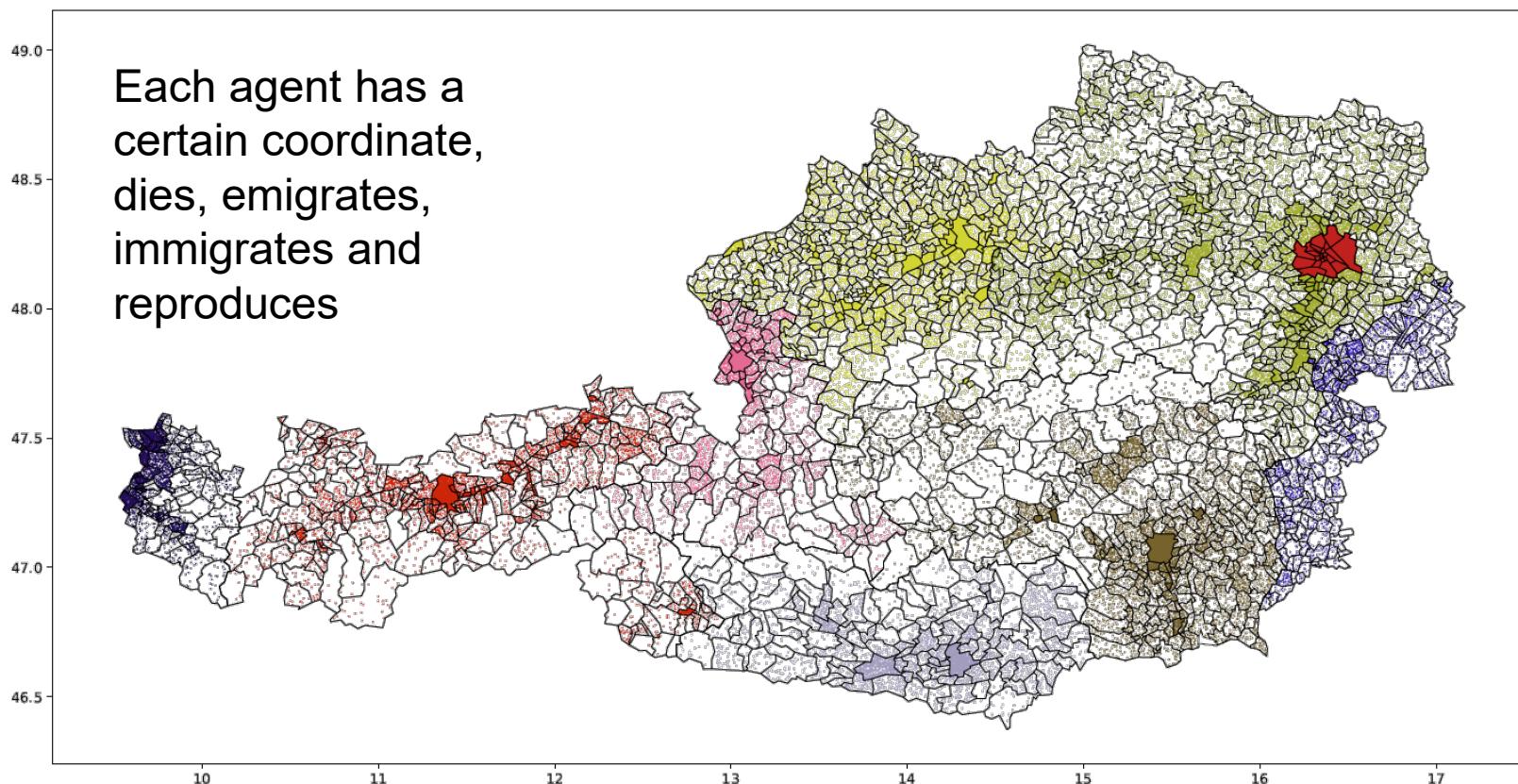
- Components of the system look like in reality
- Parameters can be seen like data or properties of individuals in reality
- No mathematical background knowledge is required in order to understand the modelling approach

# Natural description of the System



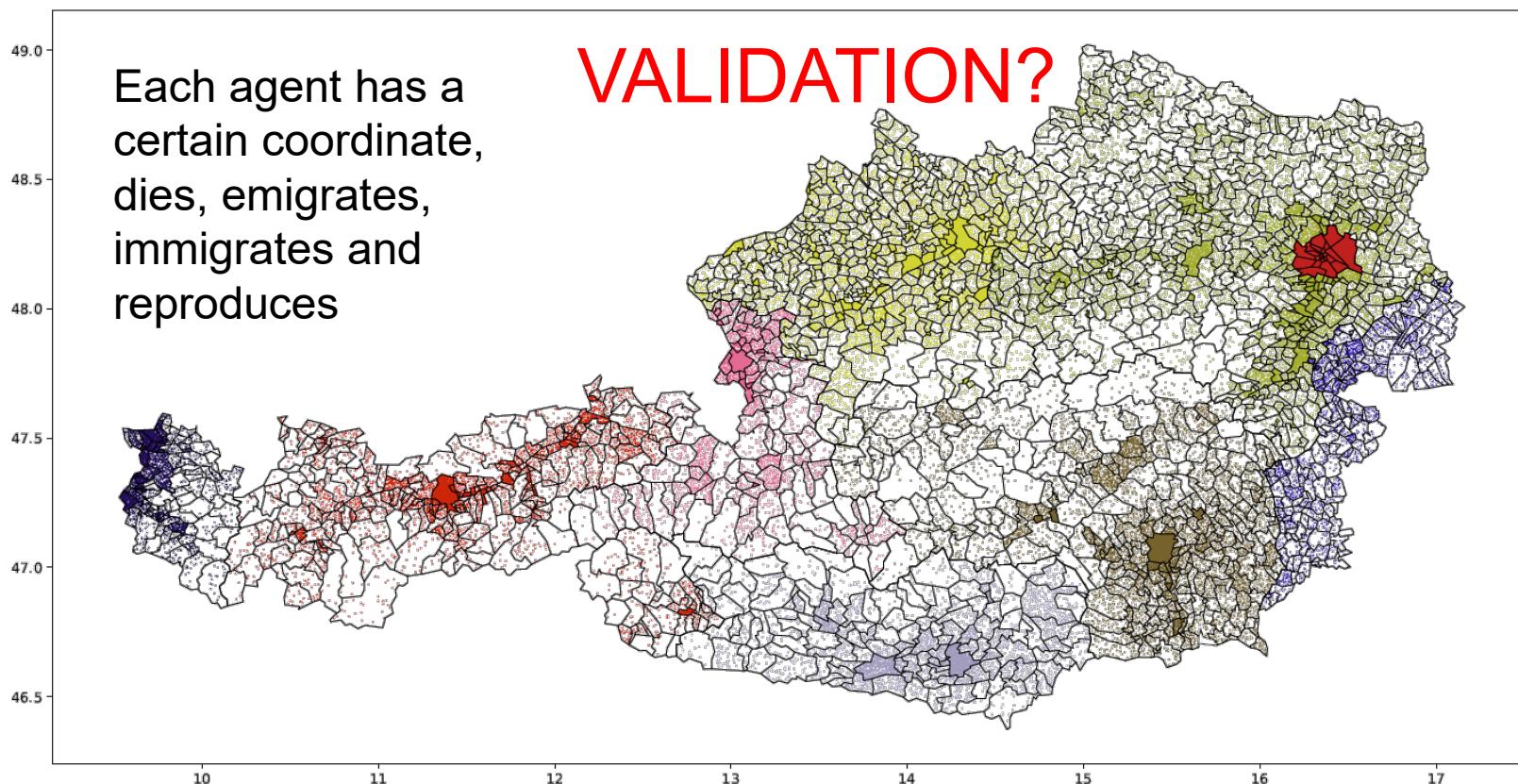
# Example: GEPOC (Generic Population Concept)

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

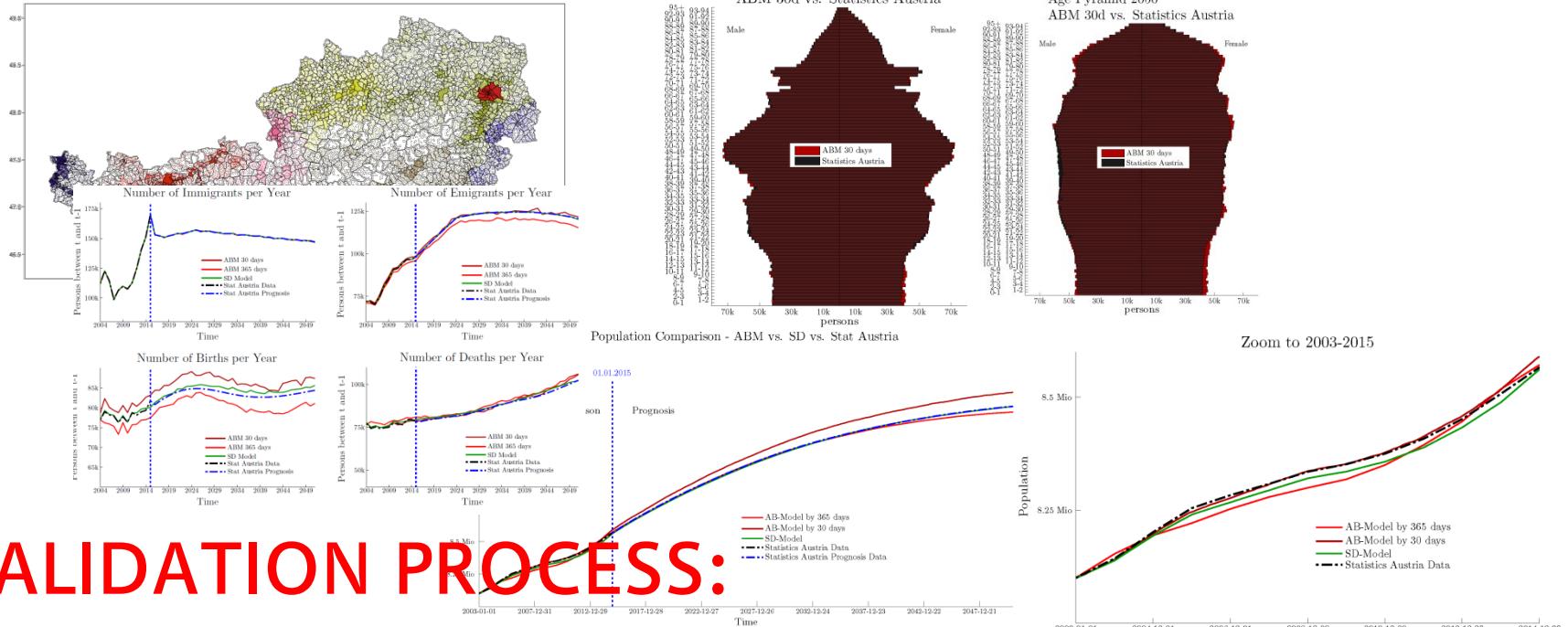


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# Example: GEPOC (Generic Population Concept)



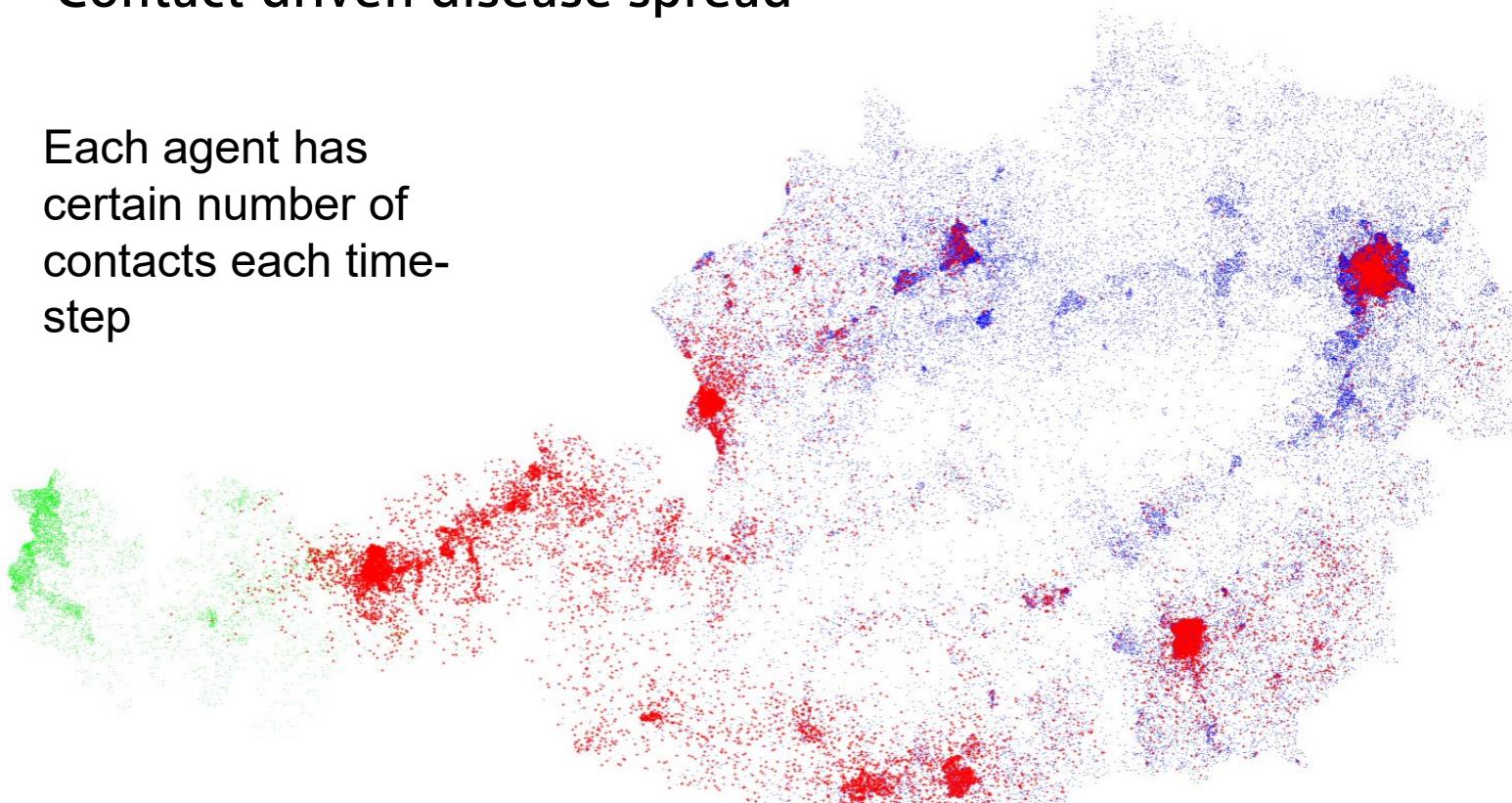
## VALIDATION PROCESS:

- 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

- Simulation of 2014 Flu
- Contact driven disease spread

Each agent has  
certain number of  
contacts each time-  
step



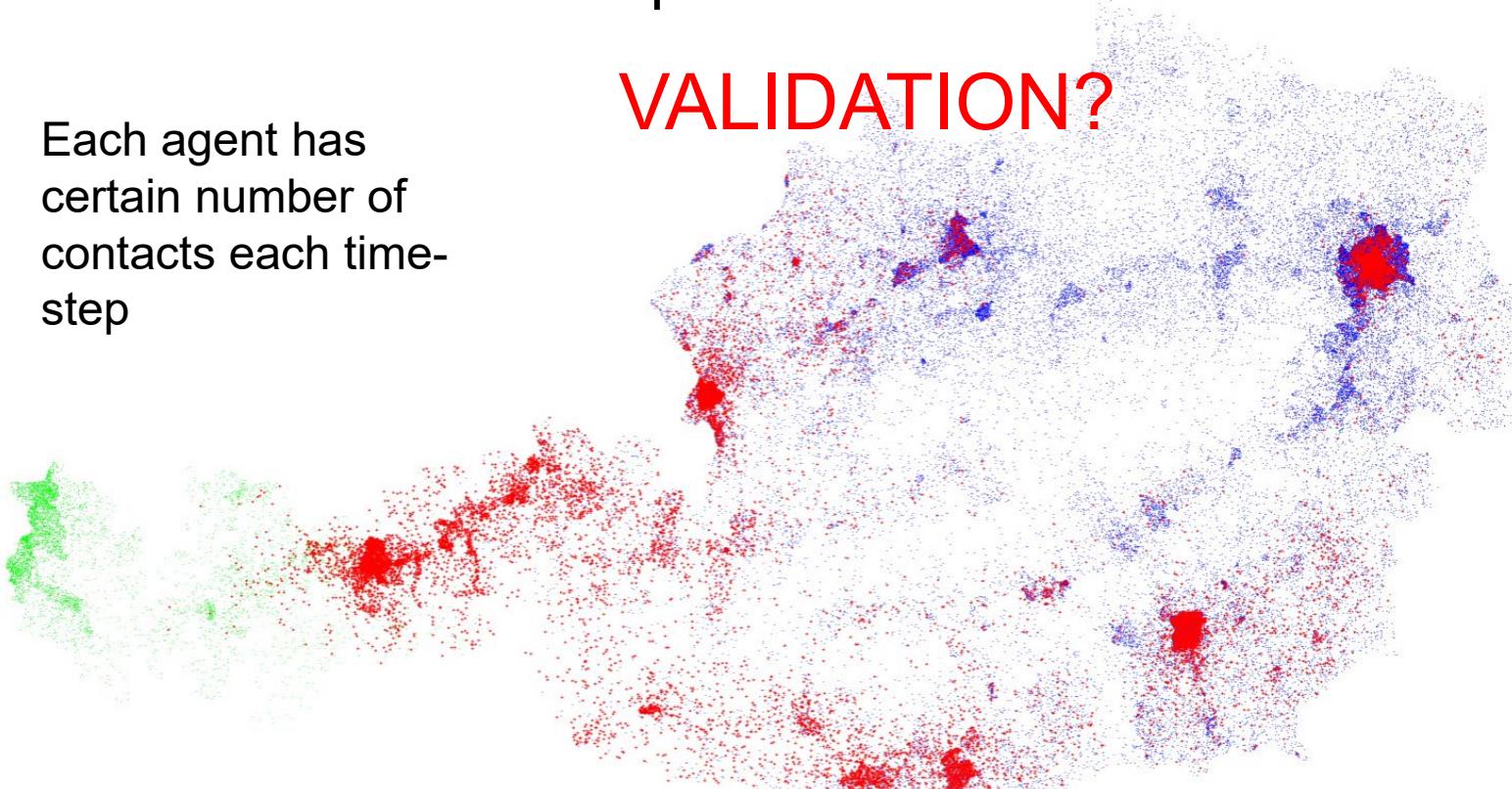
[movie.html](#)

# Example: GEPOC Flu

- Simulation of 2014 Flu
- Contact driven disease spread

VALIDATION?

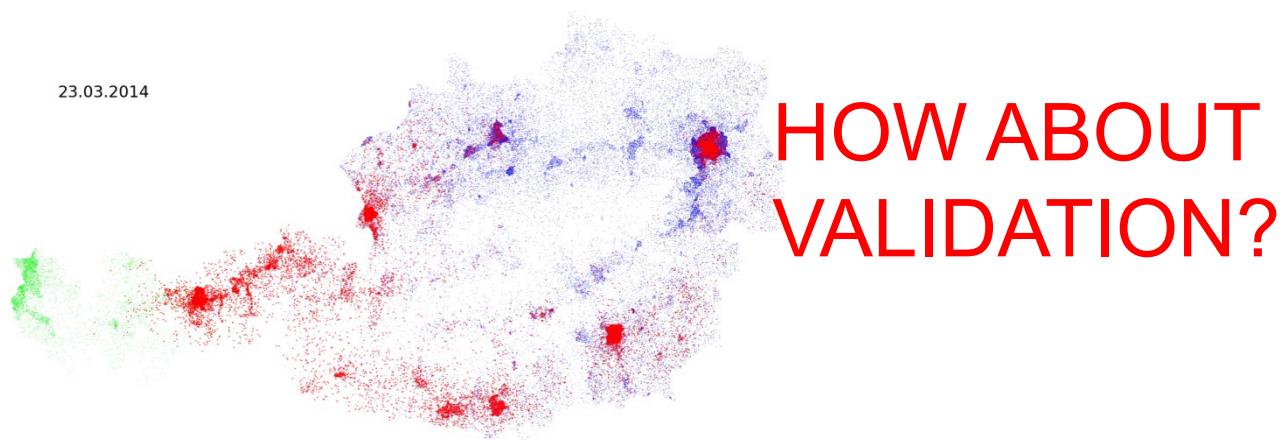
Each agent has  
certain number of  
contacts each time-  
step



[movie.html](#)

# Example: GEPOC Flu

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

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# Beware of wrong ideas!

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

BUT



**CREDIBLE  $\neq$  VALID**

**PICTURESQUE  $\neq$  VALID**

---

Basically two classes of agent-based models can be observed

ABMs for qualitative investigation

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

ABMs for quantitative investigation

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

Research Question?

# Interpretation of Agent-Based Model Results

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

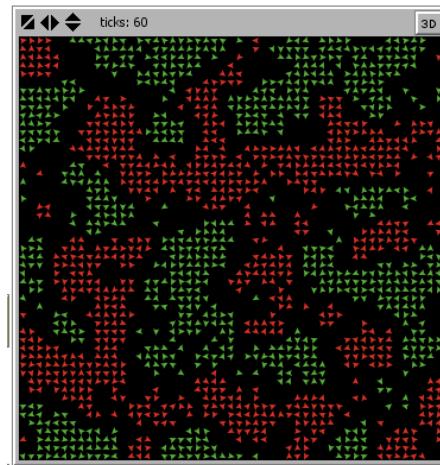
- Rather simple agent interactions
  - A lot of data involved for model parametrisation and validation
- Usually less famous

Model?

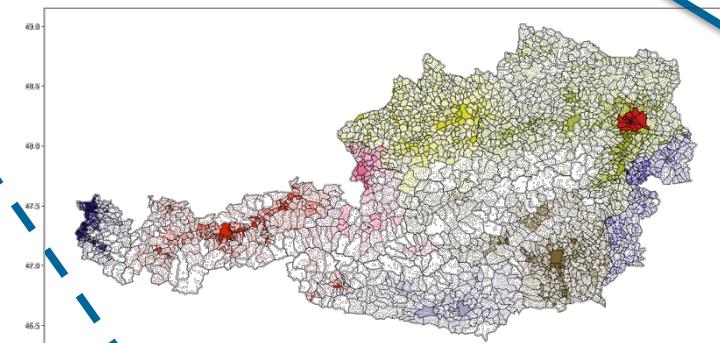
# Interpretation of Agent-Based Model

## Results : Examples

ABMs for qualitative  
investigation



ABMs for quantitative  
investigation

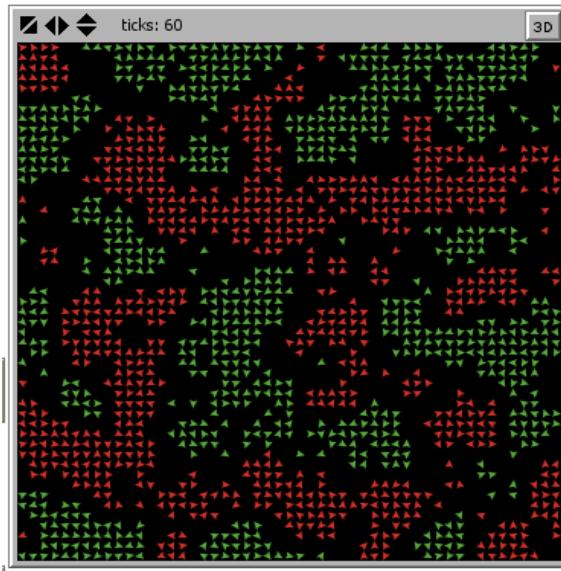


GEPOC

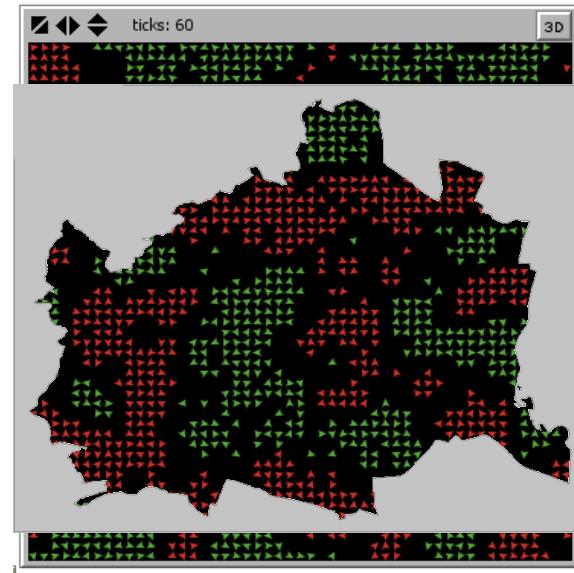
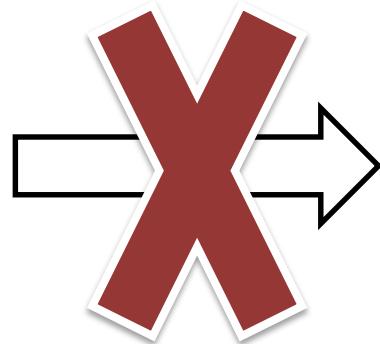
Schelling's Segregation Model

# Interpretation of Agent-Based Model

## Results : Examples



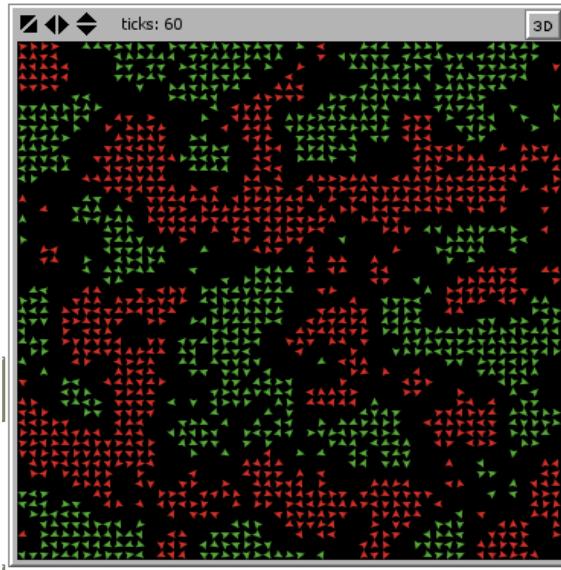
WRONG  
INTERPRETATION



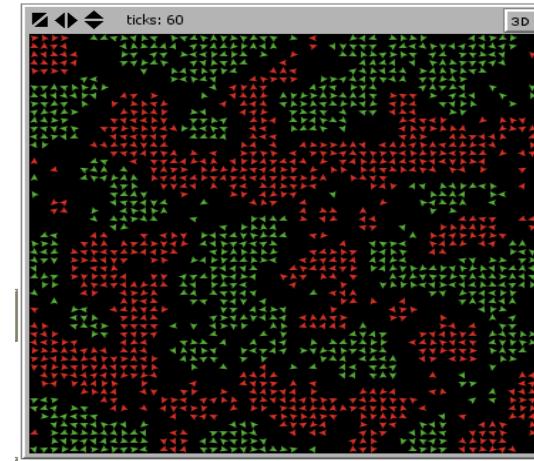
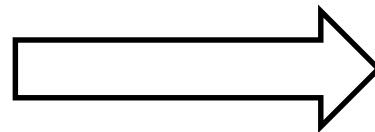
„Schelling‘s model  
predicts: In a few years  
only immigrants in Wien  
Hietzing!“

# Interpretation of Agent-Based Model

## Results : Examples



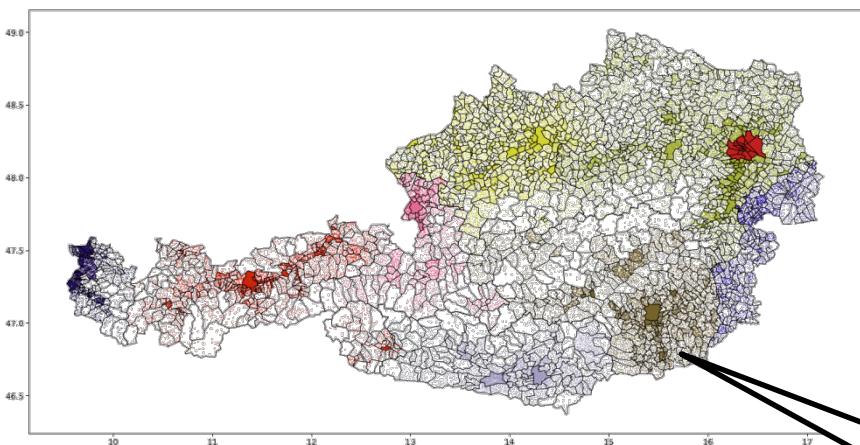
CORRECT  
INTERPRETATION



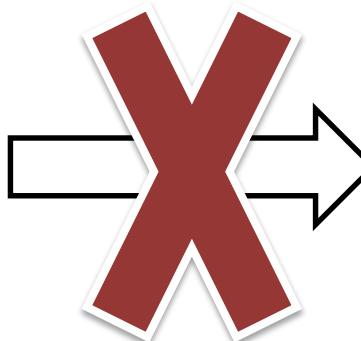
„If we do not take care on our migration policy human homophobia might lead to spatially visible ghettoism as seen above in Austria as well!“

# Interpretation of Agent-Based Model

## Results : Examples



WRONG  
INTERPRETATION



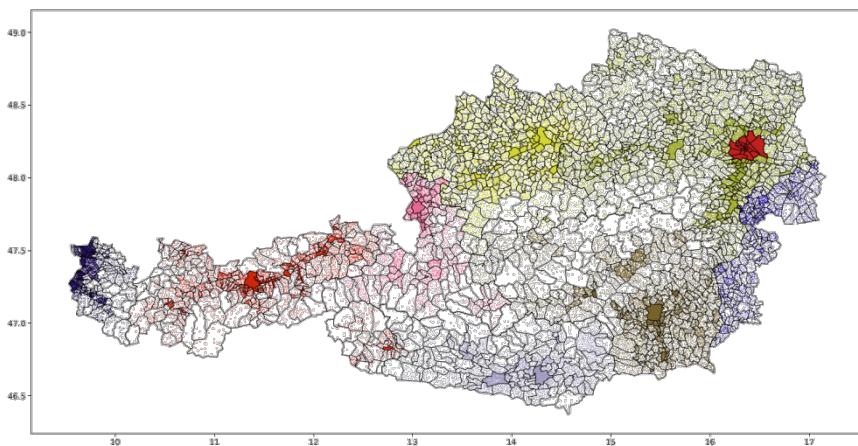
„GEPOC predicts:  
In two years there  
will be a 50 year  
old immigrant in  
Leibnitz“

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

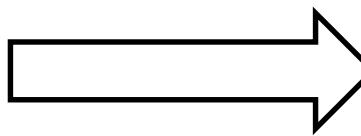
Hi guys, i'm  
Mike

# Interpretation of Agent-Based Model

## Results : Examples



CORRECT  
INTERPRETATION



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

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.
  - ... communicating models to non-experts. The modelling approach 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.
- ... communicating 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 resources. ABMs require high performance CPUs and a lot of RAM.
-

# Questions?

