RESEARCH PROGRAM ON Dryland Systems

Food security and better livelihoods for rural dryland communities

Introduction to multi-agent systems modelling

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Definition

A multi-agent system (MAS) is a community of agents, situated in an environment

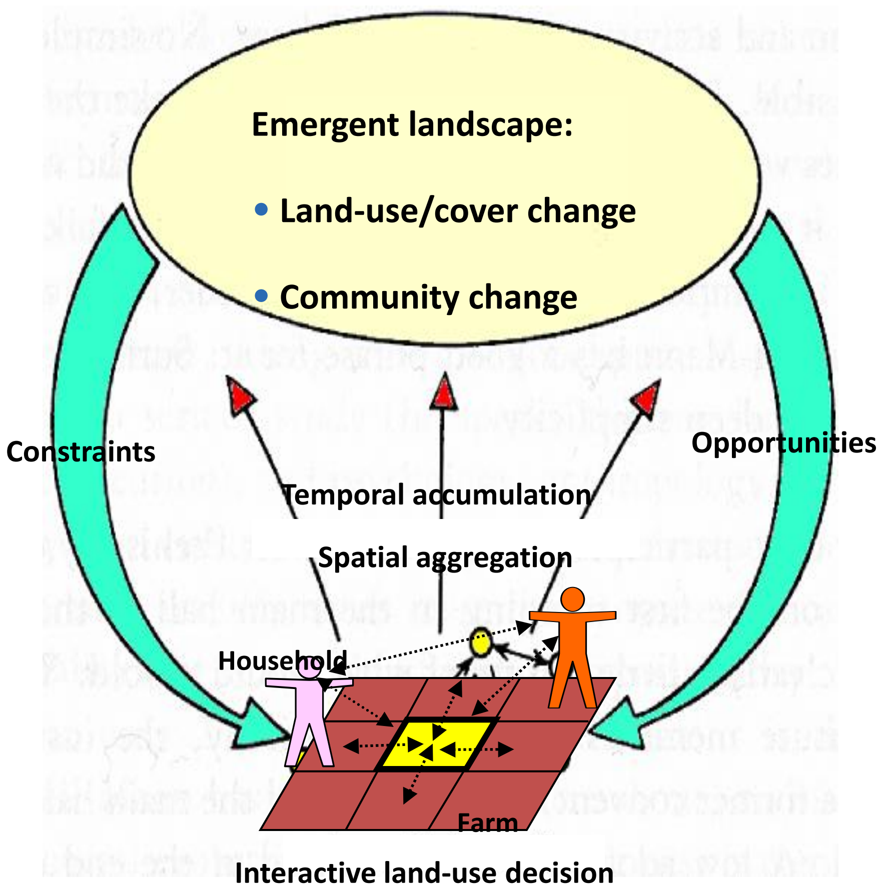
Agent: autonomous behaving (incl. decision-making) entities within the system

Environment: the space that houses agents and supports their activities

Community: an "organized society" of agents in which each agent plays specific roles and interacts with other agents

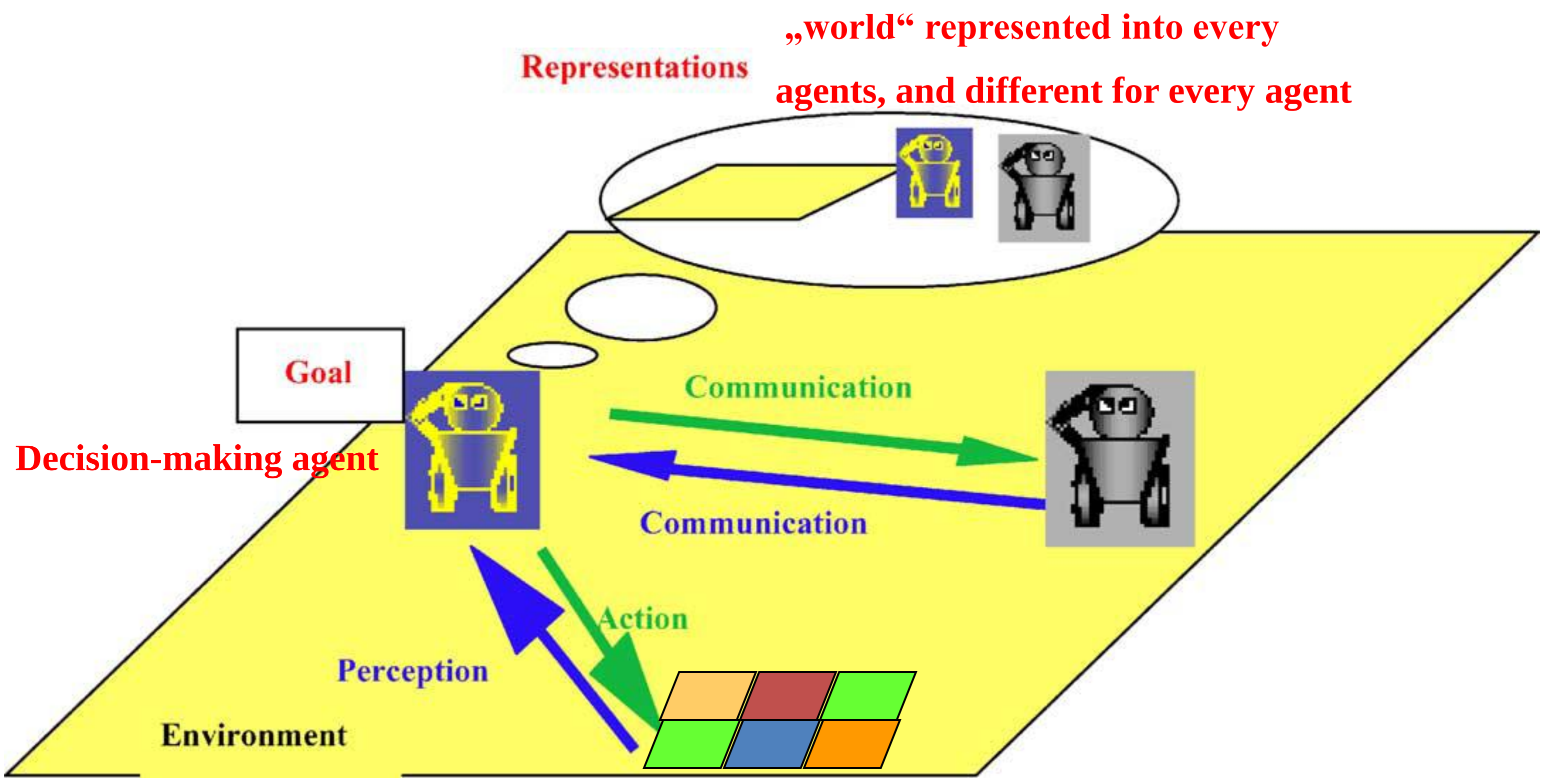
Source: Benenson and Torrens (2004)

Example: MAS conceptualization of land-use change



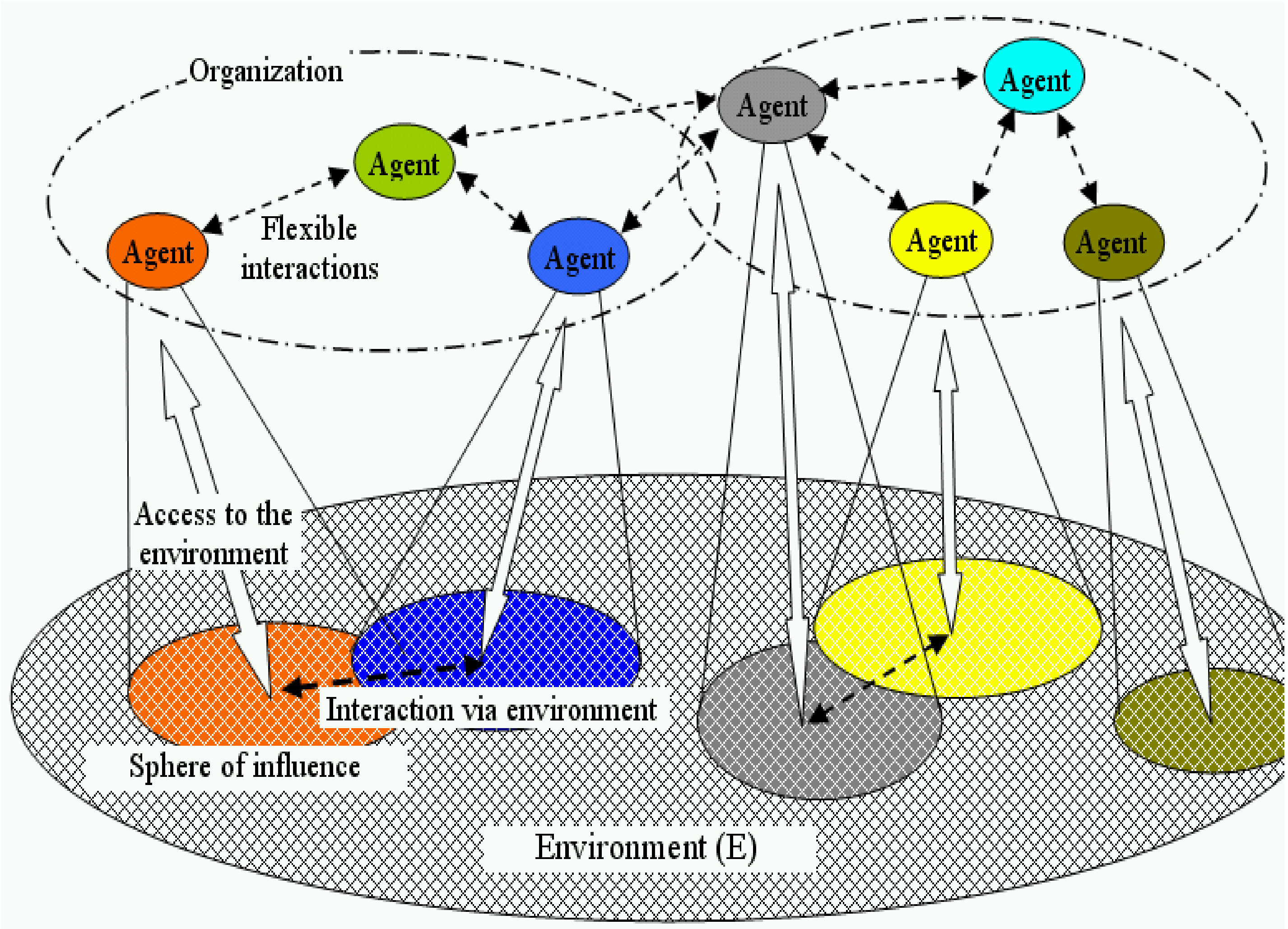
Source: Le (2005)

Multi-Agent System: agent structure and interactions



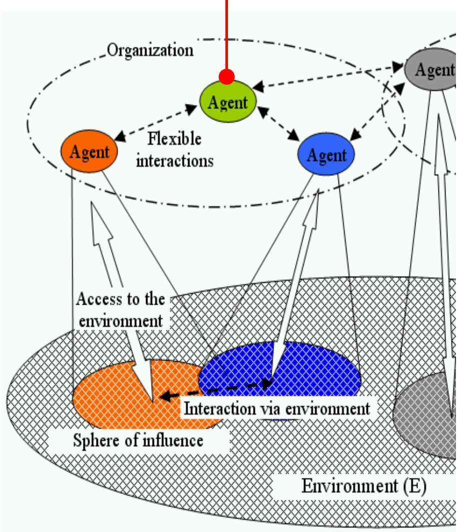
Source: Bousquet and Le Page (2004)

Multi-Agent System: Role of social interactions

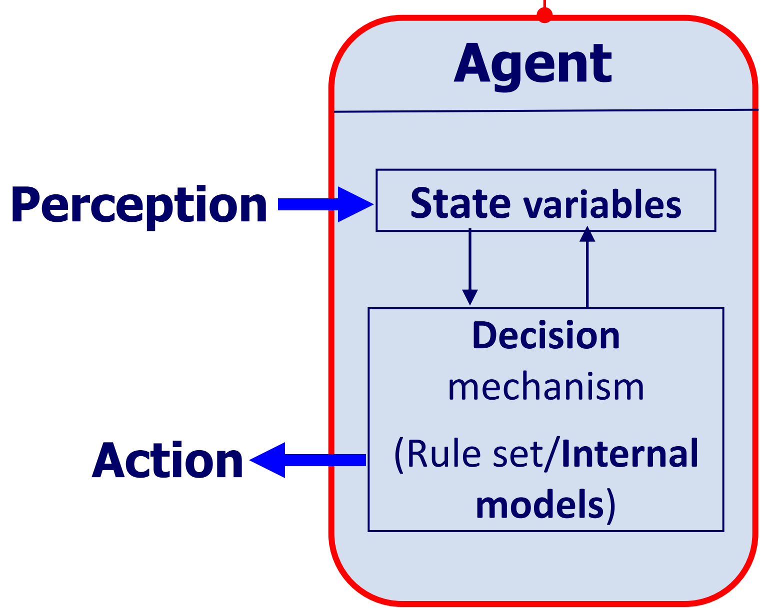


Source: modified from Woodridge (2002)

Agent as a situated decision-making entity



MAS – naturally representing real world



Encapsulation of data and sub-model
→ self-control/autonomous entity

Characteristics of agents

Minimal

Optional

Property	Meaning
Reactive	Senses and responds in a timely fashion to environmental changes
Autonomous	Controls own actions
Flexible	Actions not predefined in time and space
Goal-oriented	More than responsive to environment (proactive and/or purposeful)
Temporally continuous	Behaves as a continuously running process
Interactively physically	Individual actions affect (directly or indirectly) other agents
Interactive socially	Interact as groups of actors to effect others
Communicative	Communicates with other agents
Mobile	Can transport self to other locations
Adaptive	Changes behaviour based on previous and/or surrounding situations
Character	Believable personally or emotions

Environment in MAS

- **Human-induced dynamic environment**: no change unless affected by agent activities
- **Dynamic environment**: possibly change in a way that beyond agents' control
- Natural landscape units can be represented as **bio-physical agents**
- Environment can includes **neighbour agents**

Agent-based processes in MAS simulation

4. Landscape changes create new constraints and/or opportunities for local interactions (e.g. land scarcity + quality)

↑ ↓

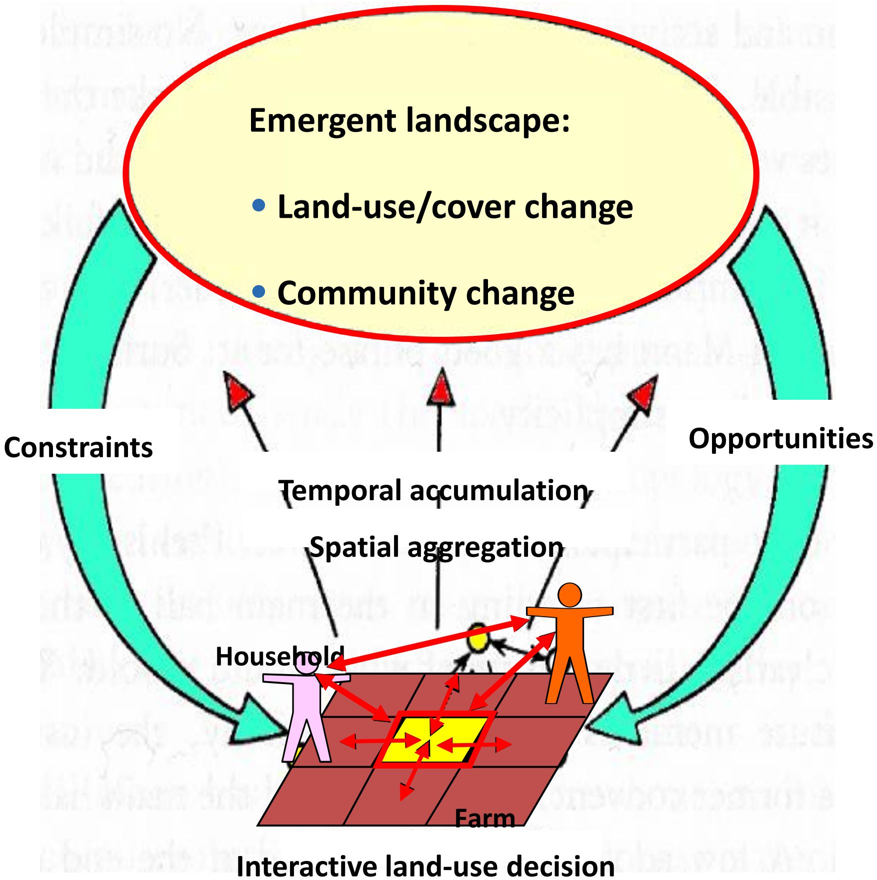
3. Interactions among agents cause emergent landscape-community phenomena (e.g. landscape - population dynamics)

↑ ↓

2. Agents have their specific roles and mechanisms enabling them to perceive the surrounding environment, and inter-act (e.g. land-use decision, yield response)

↑ ↓

1. **Autonomous agents** as natural descriptions of the human-environment system (e.g. households and farming parcels)



Key steps in doing MAS/ABM (different from others)

1. **Agents:** Identify the **agent types** and **other objects** with their attributes

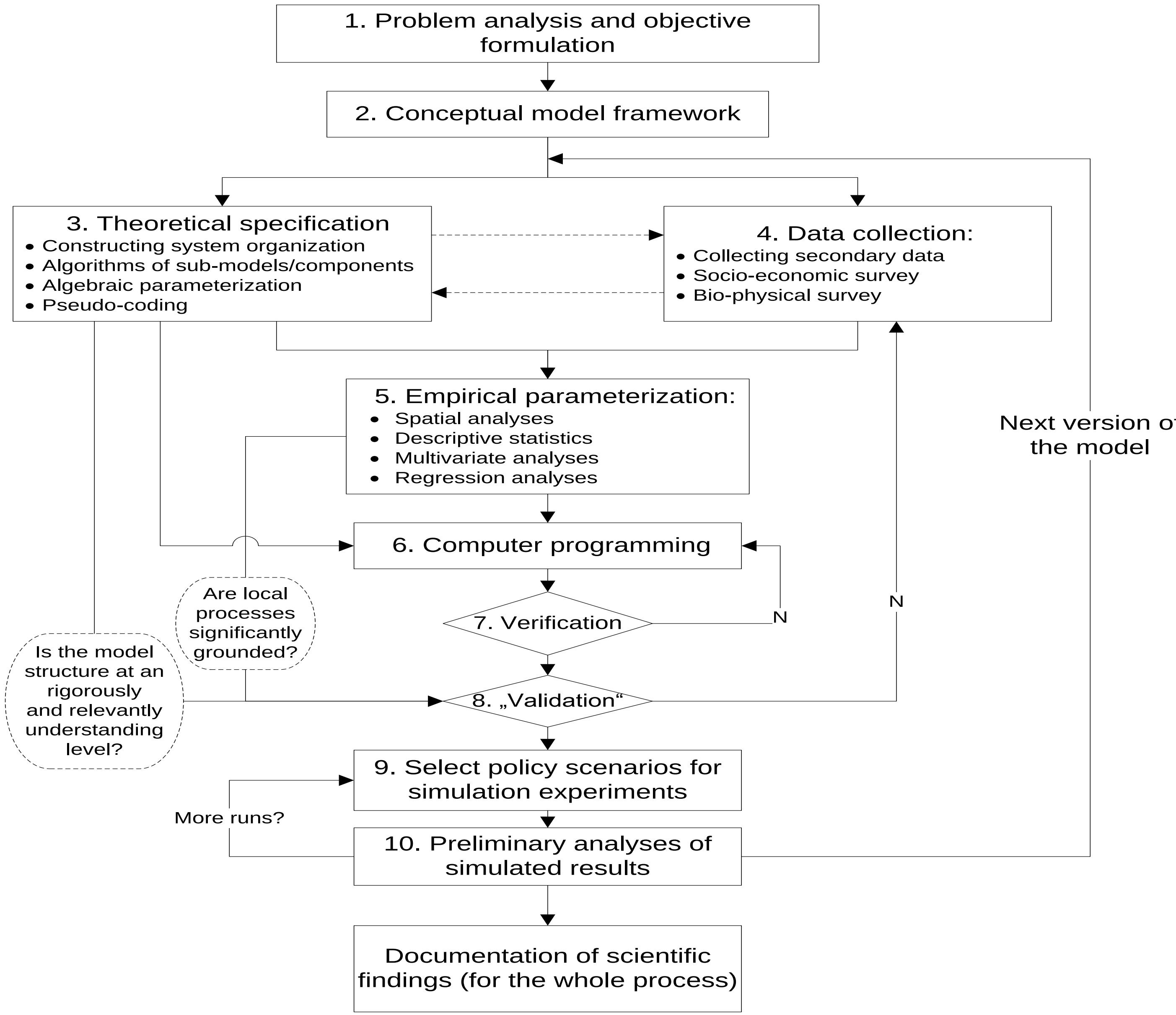
2. **Environment:** Define the environment the agents will live in and interact with.

3. **Agent method I (Updating)** Specify the methods by which agent **attributes are updated** in response to either agent-to-agent interactions, or agent interactions with the environment.

4. **Agent method II (Interaction)** Add the methods that **control which agents** interact, **when** and **how** they interact during the simulation.

5. **Implementation:** Implement the designed model in a software to do **simulation experiments**.

MAS/ABM development lifecycle (similar to other simulation approaches)



MAS computer platforms

- Generic object-oriented programming (OOP) languages
  - C++, Delphi, Java, SmallTalks, Lisp, etc.
  - Strong programming skills needed

- Libraries/toolkits
  - Library of standardized routines for common tasks for supporting modelers to build their own models in an easier manner (compared to using generic OOP languages)
  - SWARM (Objective C-based), Repast and ASCAPE (both Java-based), etc.
  - Programming skills needed

- Packages
  - Collection of standardized routines and user interface, thus providing an environment for MAS modeling. In developing toward drag-drop packages.
  - NetLogo, CORMAS, etc.
  - Programming skills still needed, but non-programmers can learn and do within an bounded time frame.

NetLogo

- Why?
  - Most suitable for MAS beginners: (1) simplified language, (2) strong visual-aids, (3) strong supports from its development team, (4) persistent development
  - Can be used for quite complex models published in refereed scientific journals
  - Once experience it, you can learn yourself other platforms quickly!
  - Further reading: Railsback and Grimms (2006)

- Practicing guide today
  - See the Manual Lab 1 provided
  - Let’s follow me on the screen.

Simple Examples (MAS vs. SD)

Infectious disease model

- Problem:
  - Given a certain number of infected people as an initial condition, how will the infected population evolve?
  - Aim: Provide a simple model that describes the time pattern of an infectious disease

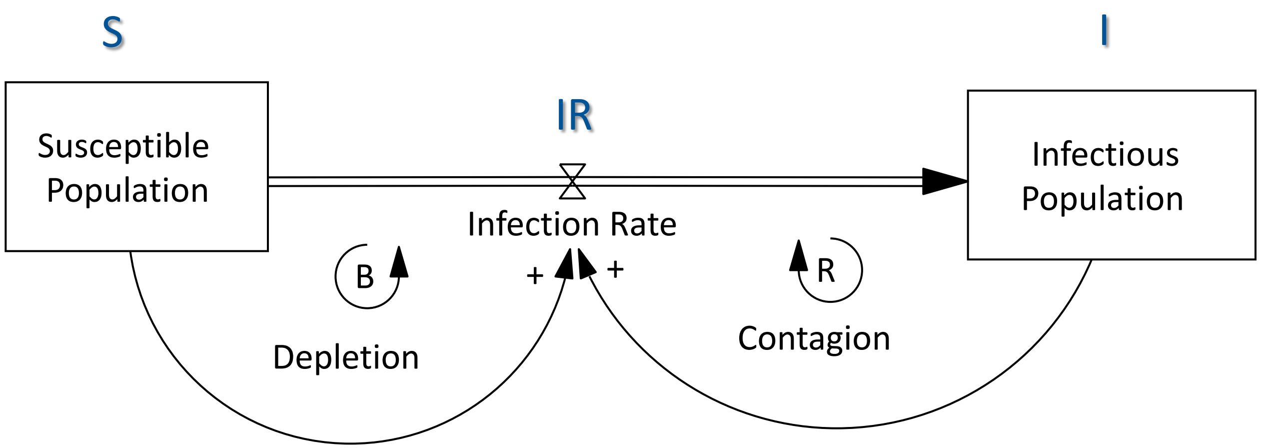
Conceptualization SI-Model

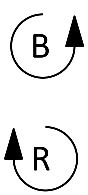
- Susceptible population S
- Infectious population I
- Infection rate IR
  - transition from susceptible to infectious

- *Logistic model*
- *Chronic infections*

The following diagrams and charts are based on/taken from:
Sterman (2000). *Business Dynamics. Systems Thinking and Modeling for a Complex World.* McGraw-Hill.

Simple System Dynamics model

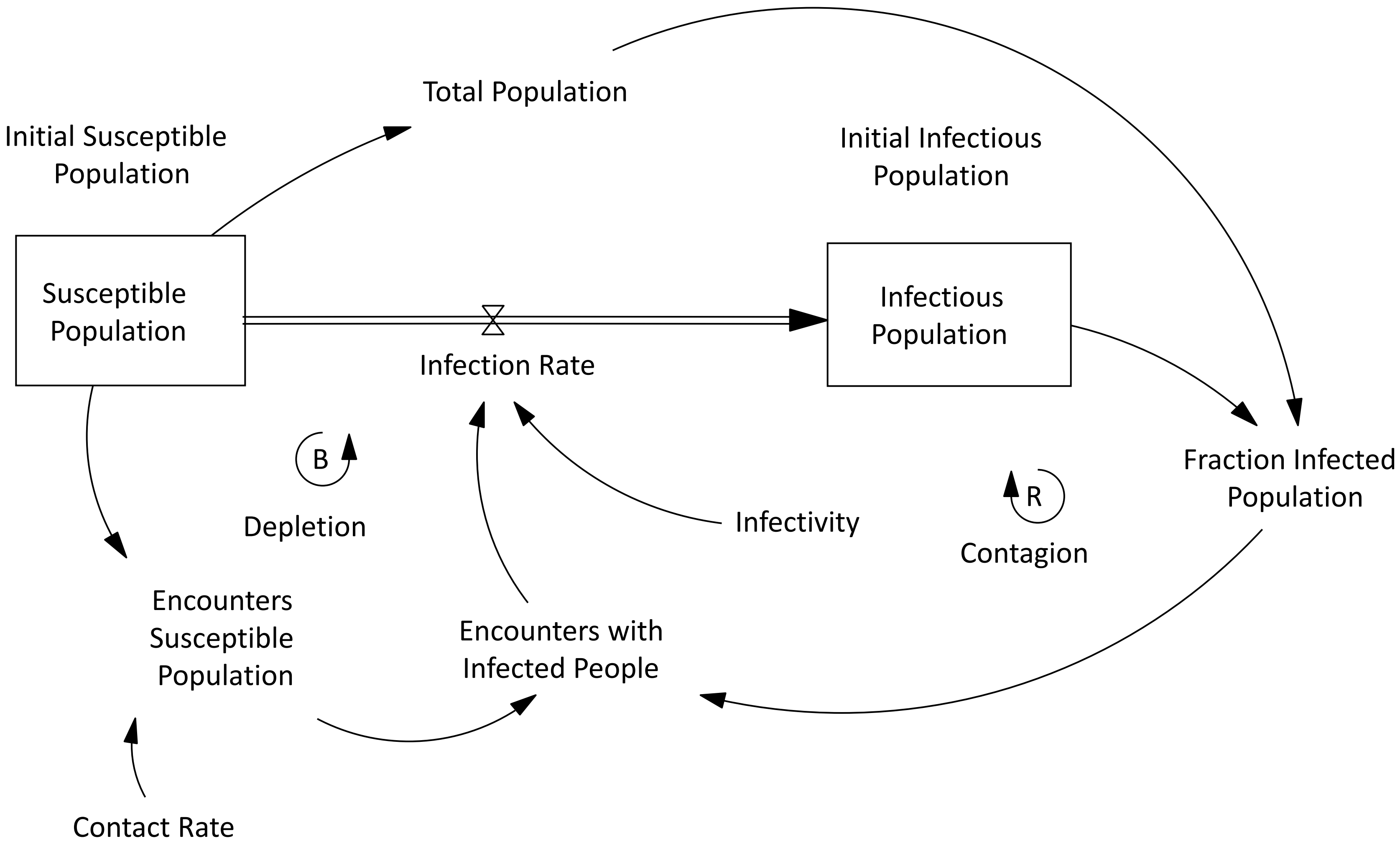




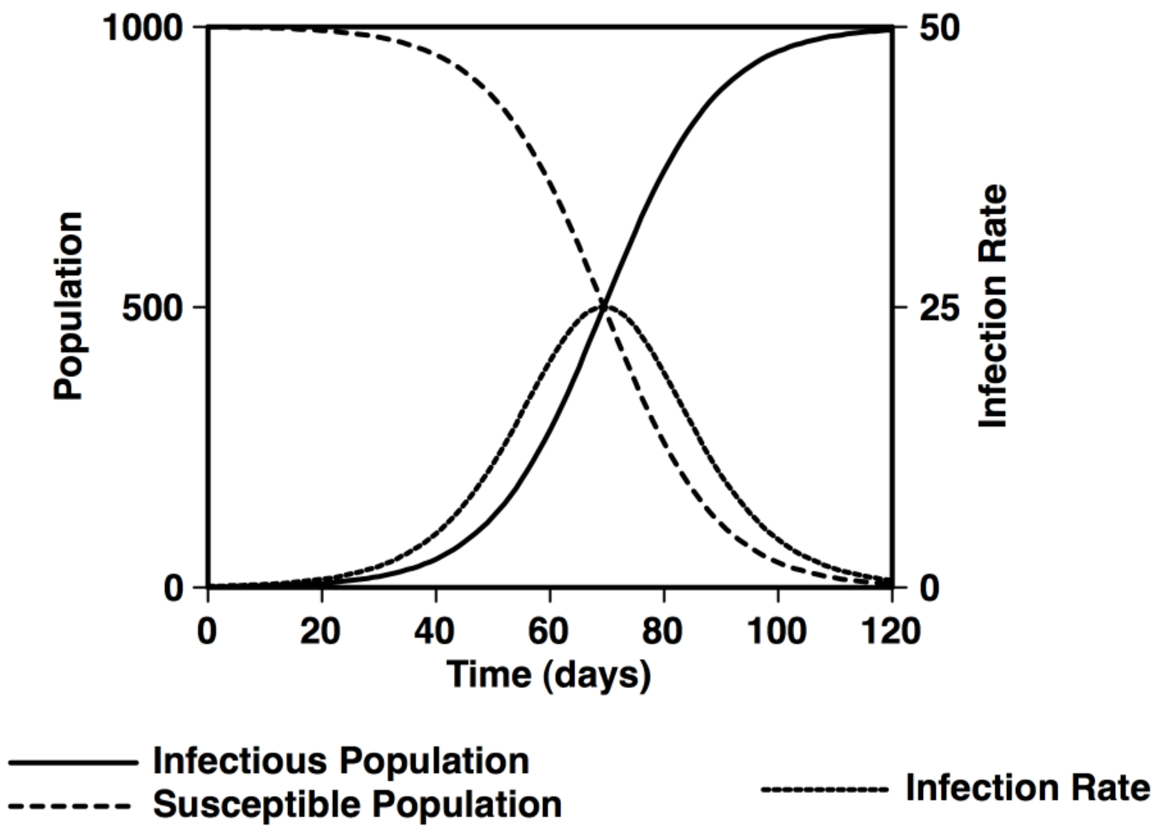
Balancing loop

Reinforcing loop

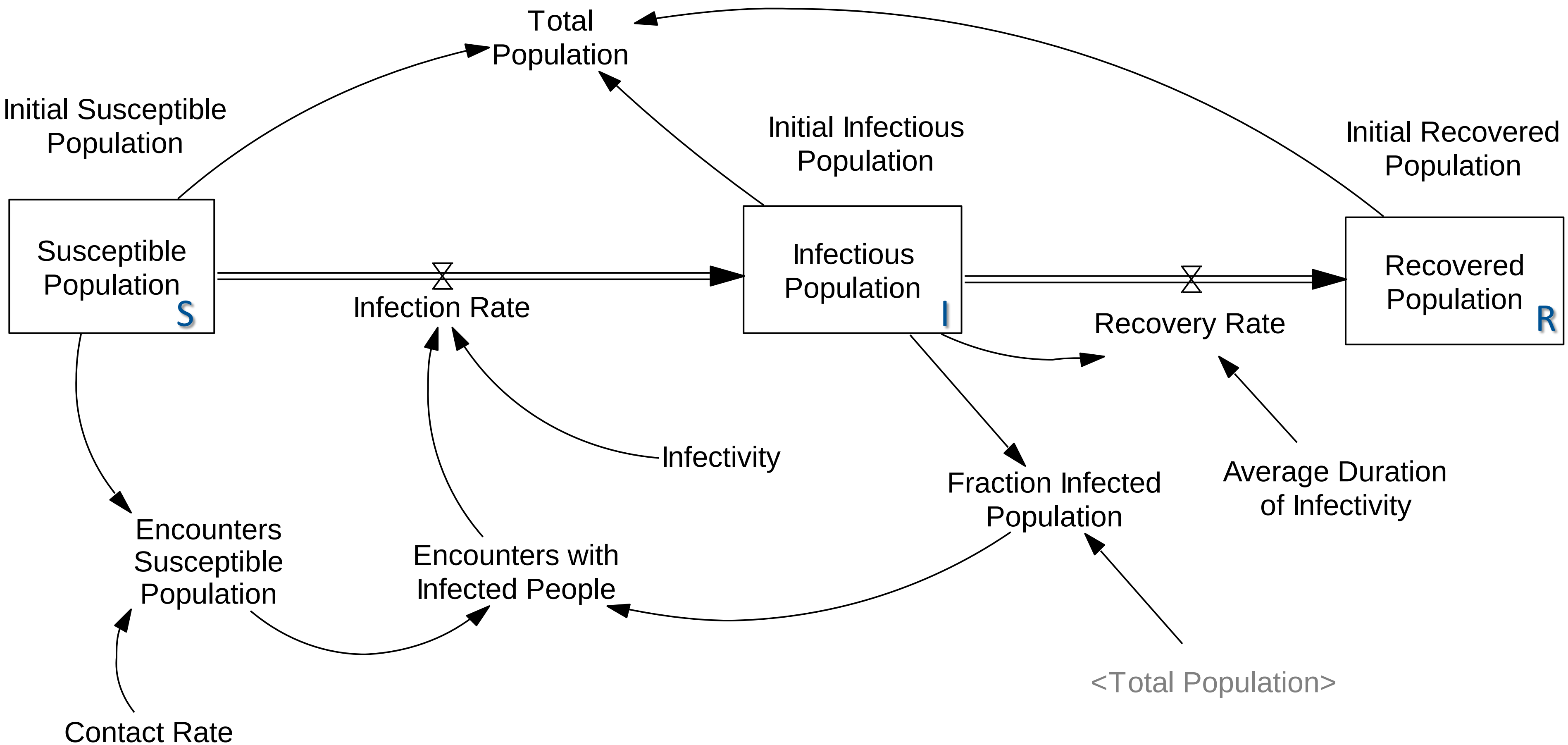
A more detailed System Dynamics model



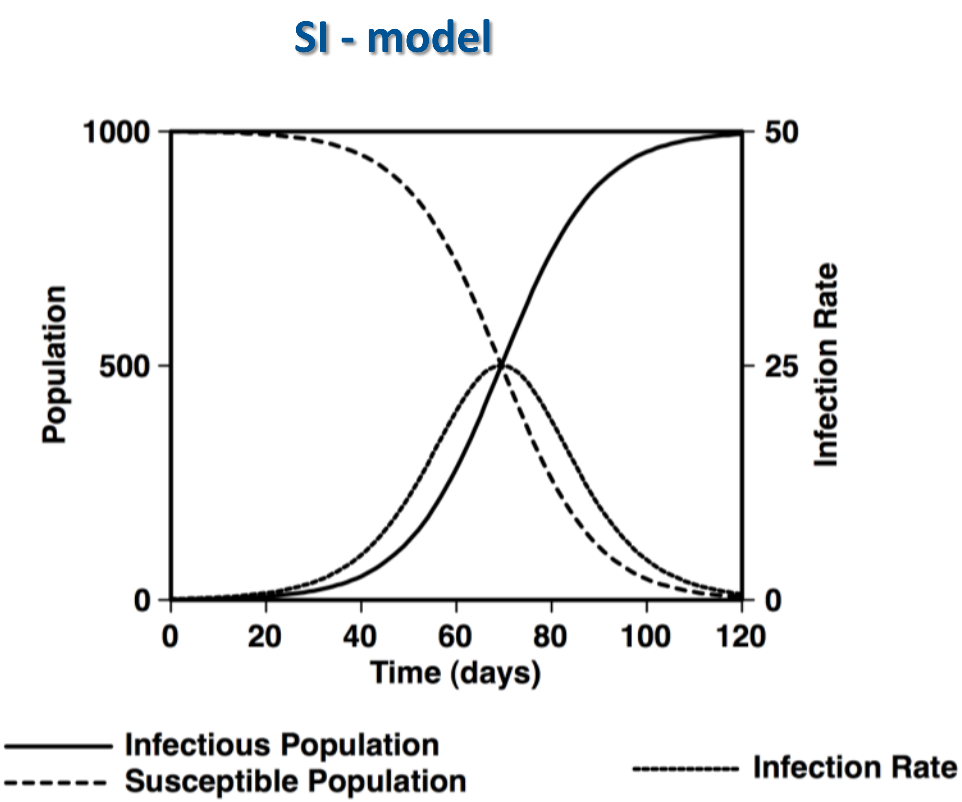
Results SI-model

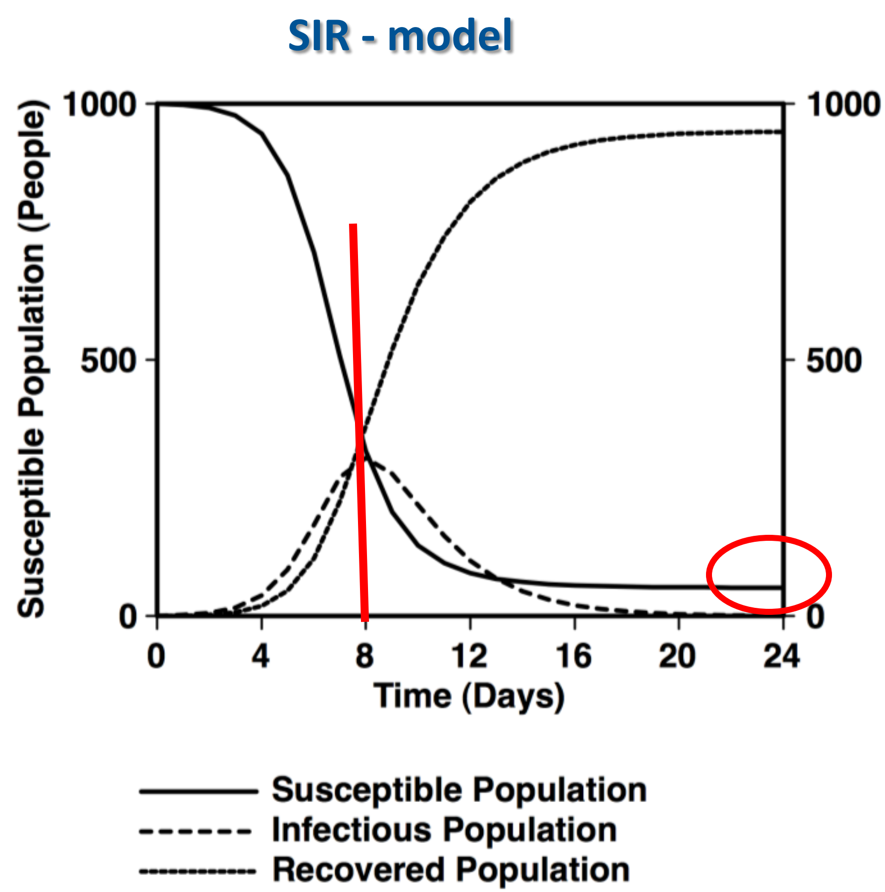


Recovery process included

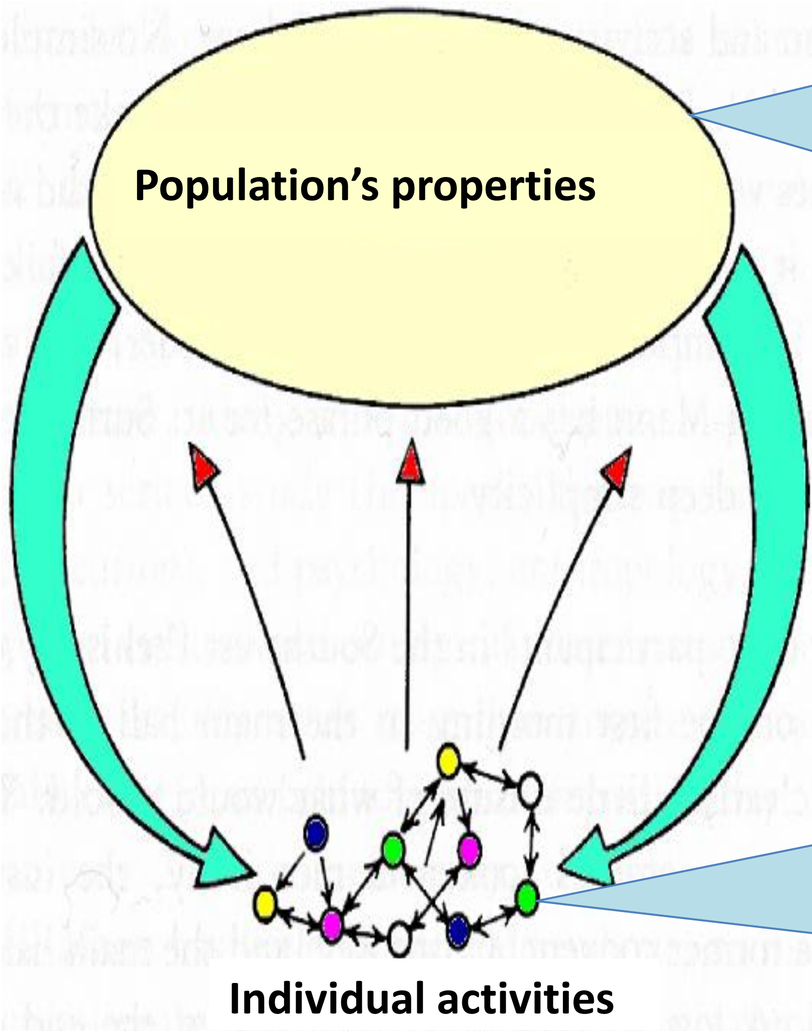


Results SIR-model (compared to SI-model)





MAS: A natural way for representing epidemic problem



2. Population observables

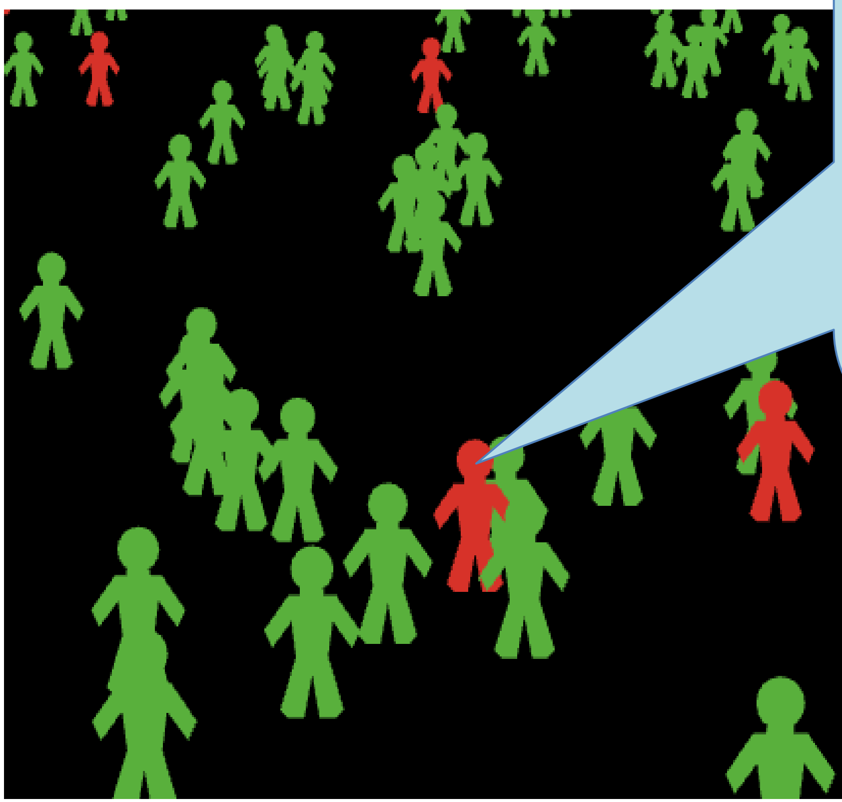
- No. of susceptive people (S)
- No. of infected (I)
- No. of recovered (R)

1. Individual processes

- Move and contact
- Be infected, or transmit disease
- Undergo infectious duration
- Be removed (recovered or died)

Means of analysis: behavior rules

Green: susceptive person
Red: infected person



Internal rules that govern person's actions:

- Move and contact check
- Be infected
- Recover
- Die (due to either too old or the disease)

→ Can be expressed in a logic programming language

Rule and Interactions

- *If-then* rule (or: production rule, stimulus-response rule)
  - IF <a ***condition*** becomes> THEN <do an ***action***>

- Individual's interactions occurred through firing if-then rules
  - Interaction occurred when: the "*condition"* relates to, or the "*action*" objects to other individuals or the natural environment
  - E.g.

```
IF other persons-here with [infected = true]
       and random-float < infection-rate
   THEN [get-sick]
```

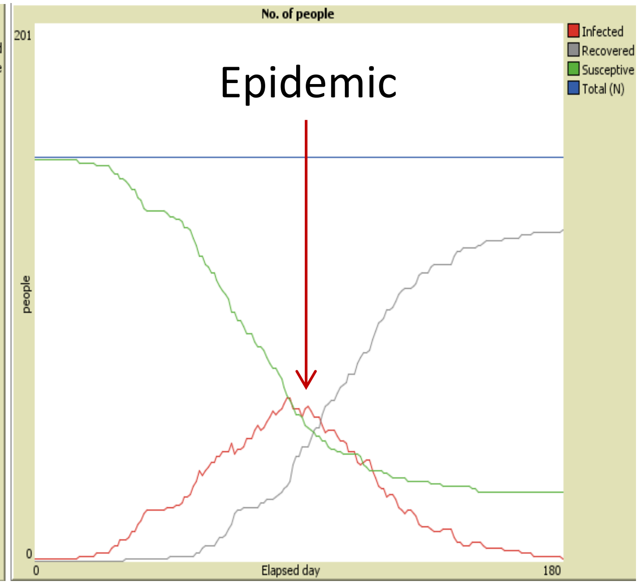
Agent-based SIR model: Basic version

- To be simplified, we assume:
  - There is no birth and death ($S + I + R = N =$ constant)
  - People move randomly
  - Incubation time is negligible
- Threshold Theorem: basic reproduction rate $R_0 = S_0/\rho$, where ρ relative recovery rate (= recovery rate/infection rate)
  - If $S_0 < \rho$ (i.e., $R_0 < 1$): the infection dies out (no epidemic)
  - If $S_0 > \rho$ (i.e., $R_0 > 1$): there is an epidemic

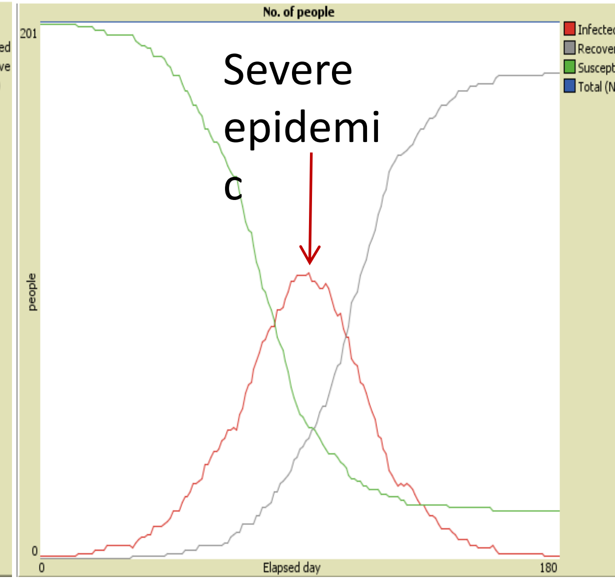
  → It is important to test model sensitivity to the initial population size S_0
- See and try the model **SIR-base.nlogo**
  - Let's fix the recovery rate and infectiousness (transmissibility), run simulation with different values of S_0: 120, 150, 200

Threshold in the effect of basic reproduction rate

S_0 = 120



S_0 = 150



S_0 = 200

- The sensitivity test suggests:

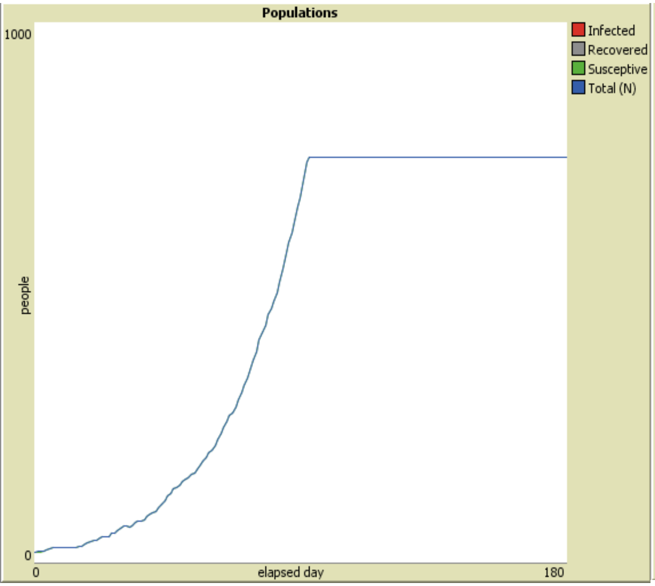
  There should be a threshold of S_0 between 120 and 150 that is critical in the appearance of epidemic.

Agent-based SIR model: Extension 1

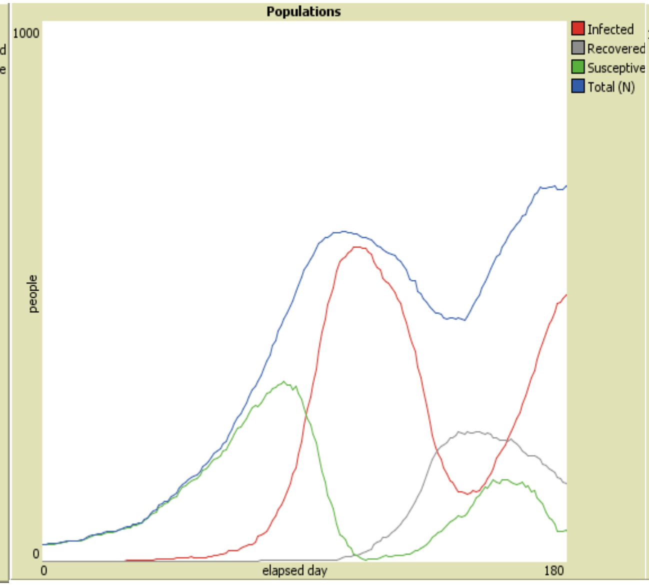
- From the base model, we remove the first assumption
  - S + I + R: not a constant
  - People move randomly
  - Incubation time is negligible

- See and try the model **SIR-extend1.nlogo**
  - Let's compare the simulation results among 3 cases:

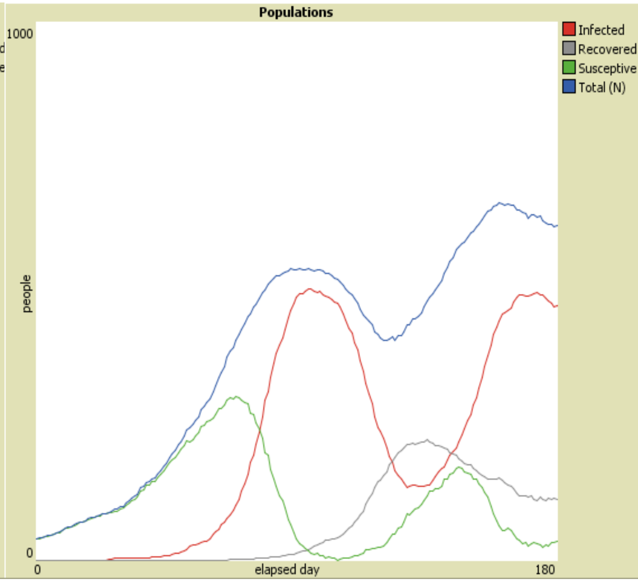
  The initial susceptive people S_0 = 20, 80, 140



$S_0 = 20$



$S_0 = 80$



$S_0 = 140$

There should be a threshold of S_0 between 20 and 80, which is much smaller than that in the base model.

→ Assumption of model is critically important

Agent-based SIR model: Extension 2

- From the base model, we remove the first and second assumptions
  - S + I + R: not a constant
  - People move following a spatial network
  - Incubation time is negligible

- See and try the model **SIR-extend2.nlogo**
  - Keeping S_0 constant, but allow change in the contacting network among people

The role of spatial dimension and its structure