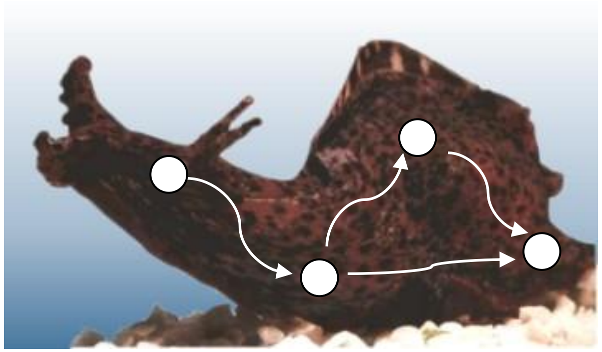
Modelling Social Processes

Dynamic Modelling for Human-centered Systems

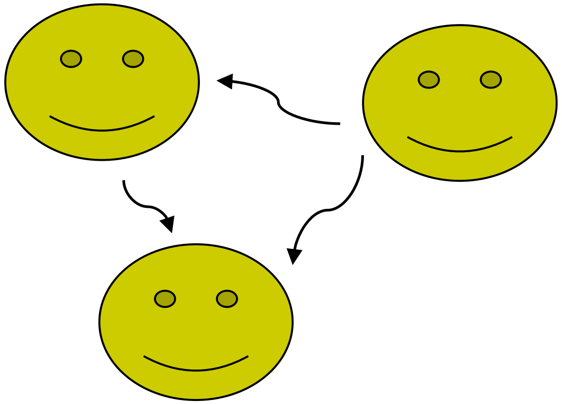
lecture 3

Individual behaviour and global perspective

- Up to now:
  - modelling individual entities
    - physiological aspects
    - useful, gives detailed information



- This lecture:
  - global perspective: processes that occur in groups of individuals
    - collective perspective



Course outline

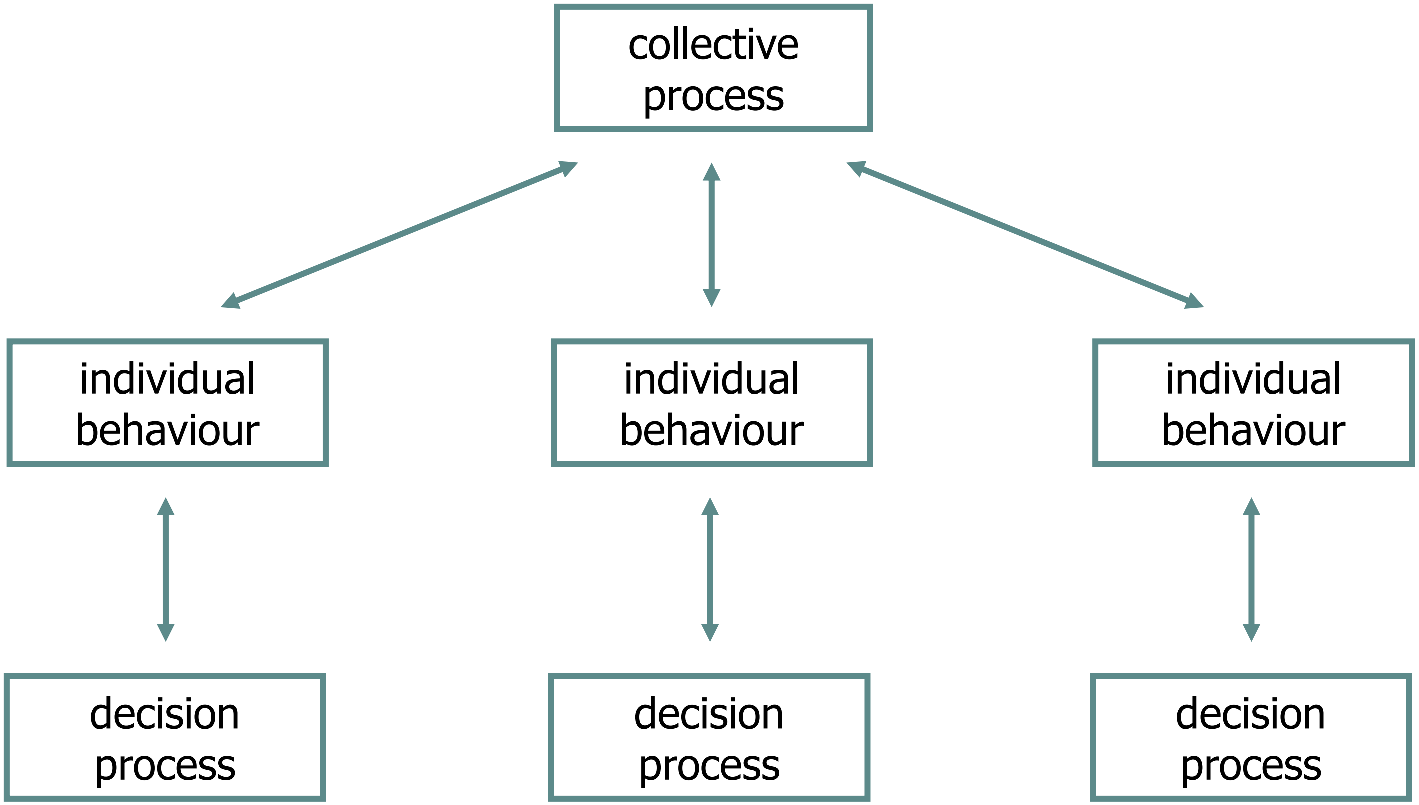
- First lecture: what is dynamic modelling?
- Previous lecture: creating models of physiological processes
- This lecture: creating models of social processes
- Next lecture: modelling behaviour
- Even later: embedding models within intelligent systems…

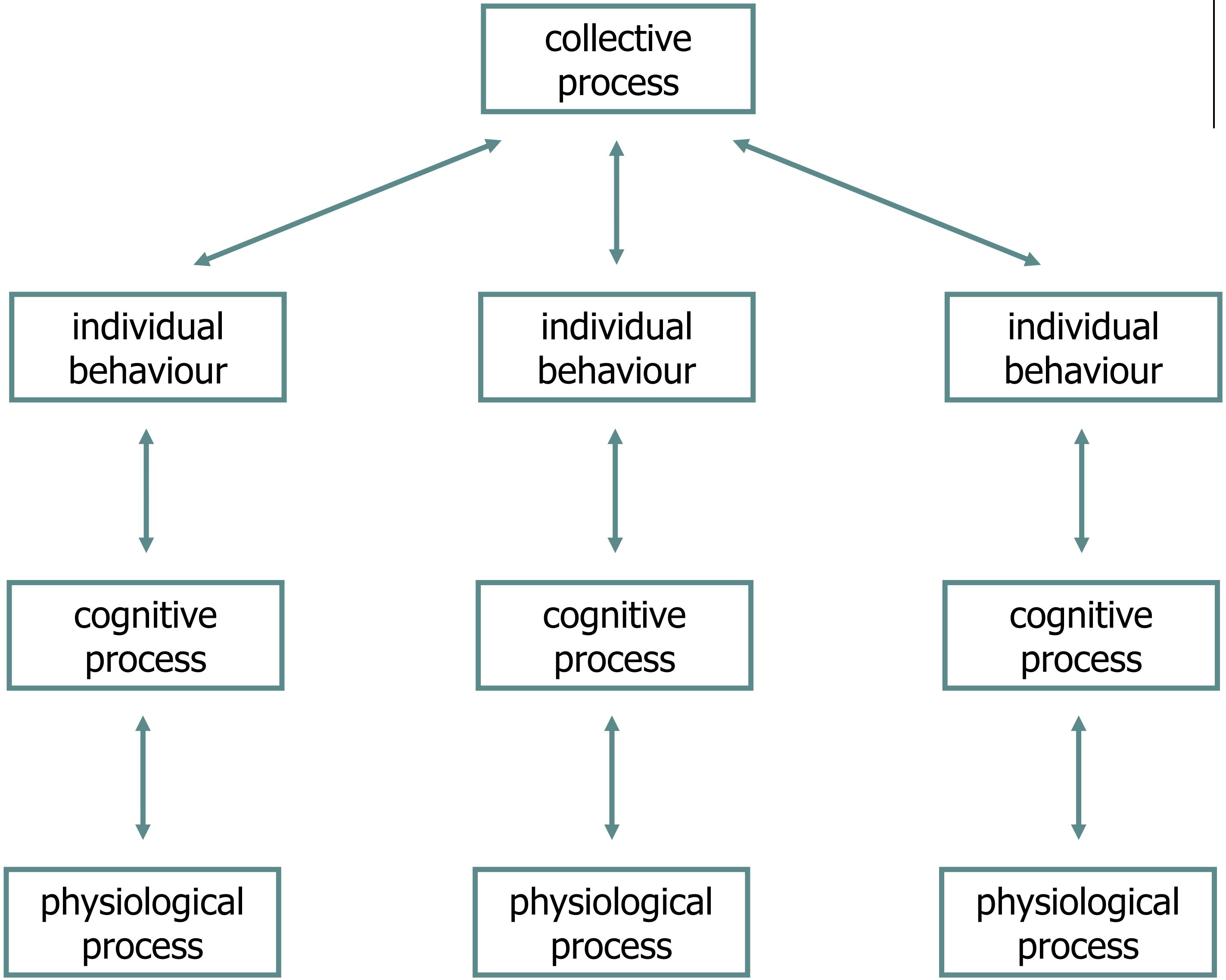
domain models

Relation between individual behaviour and global patterns

- Decisions of individual persons…
  - e.g. choosing time to go home
- …affect global patterns
  - e.g. traffic jams
- Relations in two directions:
  - upward interaction
    - e.g. washing hands causes less virus spread
  - downward interaction
    - e.g. high oil prices causes energy saving behaviours of individuals

Collective pattern and individual behaviour




collective process
individual behaviour
individual behaviour
individual behaviour
cognitive process
cognitive process
cognitive process
physiological process
physiological process
physiological process

level	interlevel relations	content sciences
external collective societal level	*collective processes*	
	↑ emerging from	social perspective
external individual behavioural level	*individual behaviours*	
	↑ emerging from	psychological perspective
internal cognitive level	*cognitive processes*	
	↑ emerging from	biological perspective
internal physiological level	*physiological processes*	

Outline of this lecture

- Illustration of modelling social process based on individual behaviours (Ch. 5)
  - honeybee task distribution
- Another example modelling social process based on individual behaviour (Ch. 6)
  - virus spread
- Same example, but now *without* modelling individual behaviour (Ch. 6)

Syllabus: Chapter 5

SELFORGANISATION IN HONEYBEE SOCIETIES

Questions?

- Individual decisions influence global processes

- Simple internal process based on observations of external world is sufficient to model complex behaviors

Honeybee Colony

- A Society Based on Decentralised Decision Making
  - individual decisions influence global processes

- Within honeybee colonies:
  - every worker bee has the same skills
  - there are a number of roles
  - taking up a role is triggered by environmental cues

The Forager

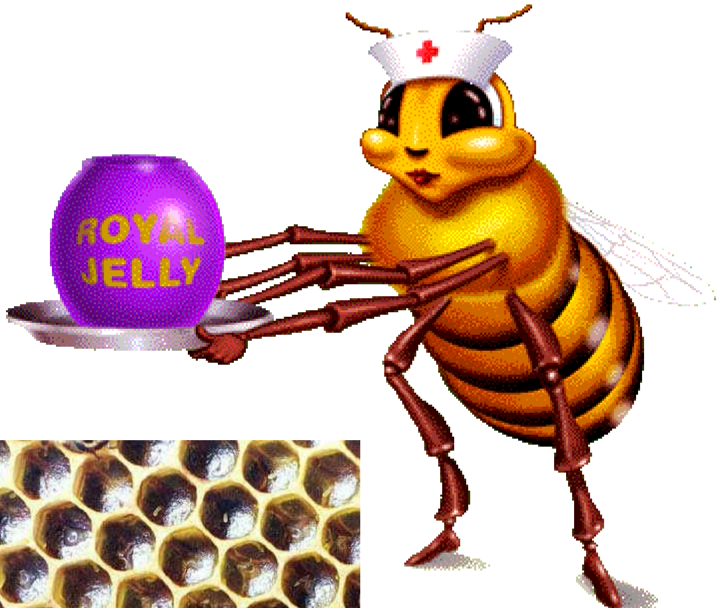
Tasks

- Get food from outside
- Store the food in the hive

Triggers to perform role

- Amount of food present

The Brood Carer



Tasks

- Get food available in the hive
- Feed hungry larvae with the food

Triggers to perform role

- Pheromones emitted by larvae

The Undertaker

Tasks

- Remove corpses from the hive

Triggers to perform role

- Amount of corpses in the hive

The Patroller

Tasks

- Patrols the hive
- Fights enemies it encounters in and around the hive

Triggers to perform role

- Enemies observed

Global aspects influencing individual behavior

- Food availability
- Larvae strength
  - pheromone rate
- Cleanness
  - dead bodies
- Safety
  - enemies

Observations in honeybee colony

- Different bees take on different roles
- All together, the work is distributed in such a way that the most pressing tasks are performed by most bees
  - doesn't run "out of hand"
- Some bees are taking up specific roles more often
  - bees specialize

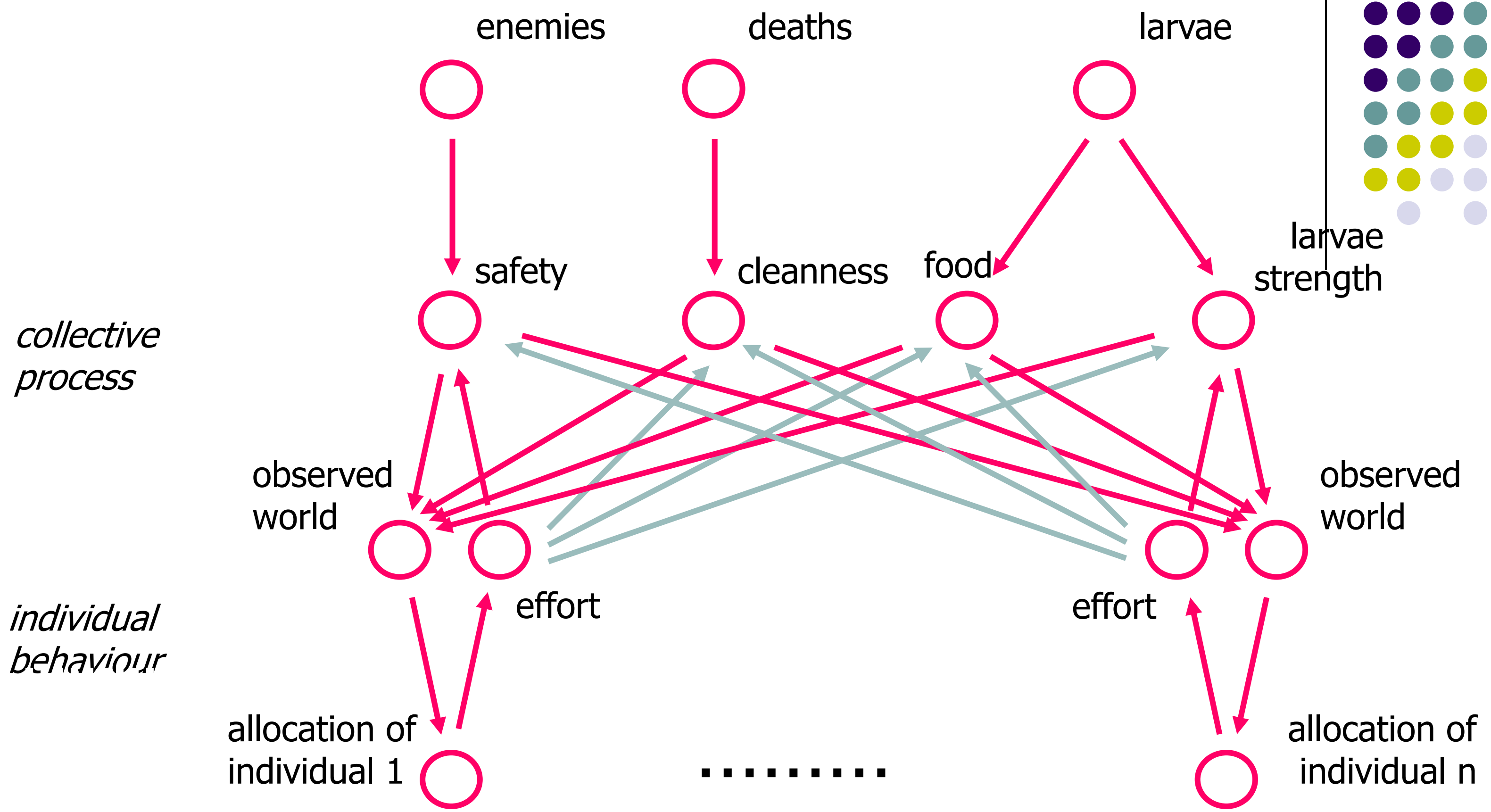
Expected patterns of model

- Environmental **parameters are kept between certain bounds** by the individual decision making processes
  - larvae strength, safety, food storage, and cleanness
- Bees tend to keep their roles over longer periods
  - **specialisation** of individuals is emerging in the process.

Possible research question

- **How long** does it take to **address** sudden **threats** of the society's parameters:
  - in how far are fast changing environments a problem.

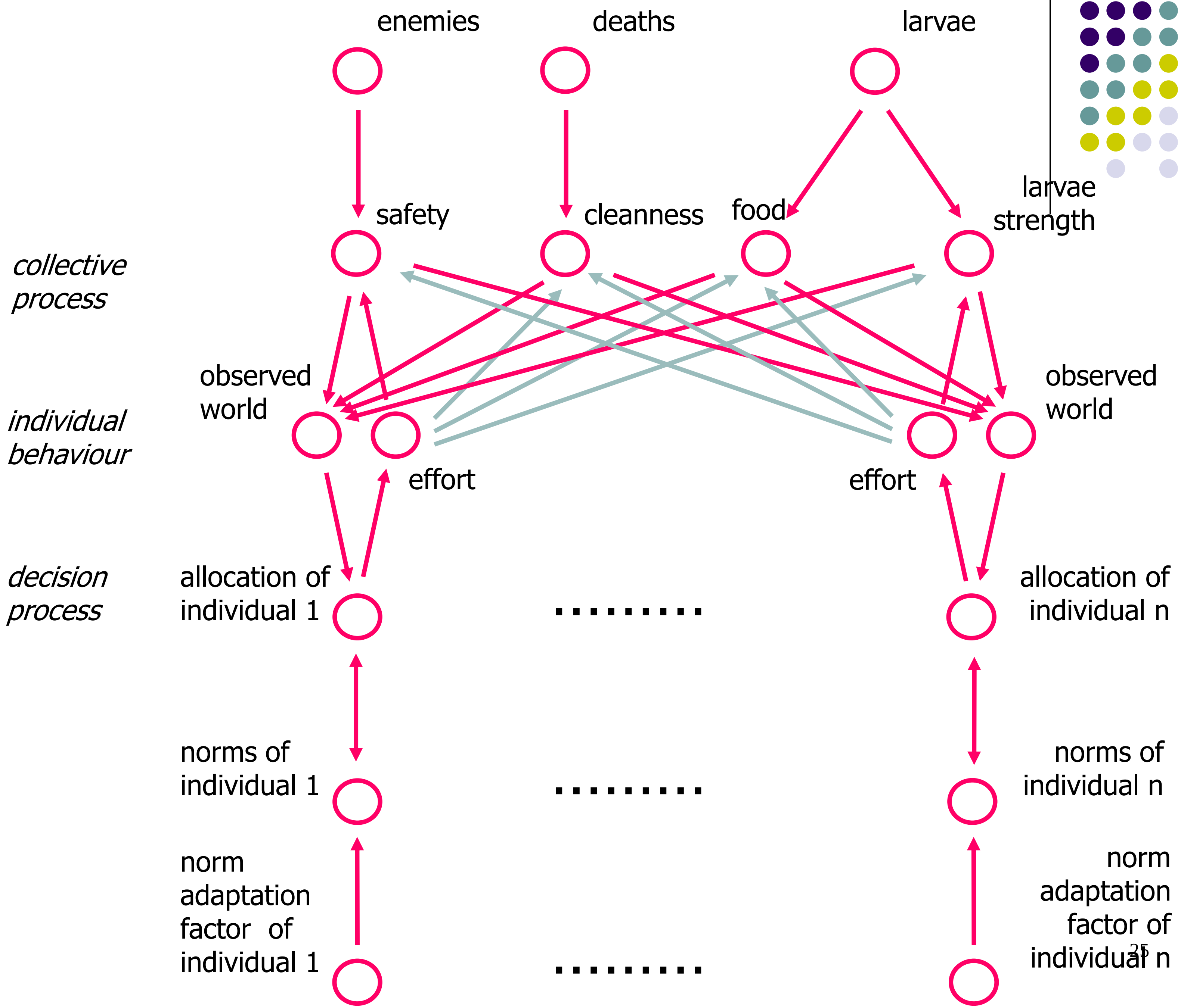
Concepts and Relations over Time



Cognitive Level Decision Model

- Each individual maintains **norms** for each of the aspects.
- For each aspect, the individual determines in how far the current state is unsatisfactory, expressed in a degree of **urgency** for that aspect.
- For each aspect the **relative urgency** is determined: the degree of urgency divided by the norm for that aspect.
- The most urgent aspect is the one with **highest relative urgency**; the role is taken that relates to this aspect.
- Norms are **adapted**: if an individual is in a role addressing a certain aspect, then the norm for that aspect is slowly decreased over time.

Concepts and Relations over Time



Formalization

forager, carer, undertaker, and patroller role	*1, 2, 3, 4*
individuals	*Bee1, Bee2, ….*
role allocations between individuals and roles	*Bee1Role, Bee2Role, …*
for each individual: norms used as thresholds for carer, forager, patroller, and undertaker role	*Bee1ForagerNorm*, *Bee1CarerNorm, Bee1UndertakerNorm, Bee1PatrollerNorm, …*
maximal urgency for each individual	*Bee1MaxUrgency, Bee2MaxUrgency, ….*
norm adaptation factor for individuals	*Bee1AdapFactor, Bee2AdapFactor, …*
effort per individual	*Effort*
food need, larvae weakness, uncleanness, unsafety	*FoodNeed, LarvaeWeakness, Uncleanness, Unsafety*
contributed work	*ForagingWork, CaringWork, PatrollingWork, CleaningWork*
number of (new) enemies	*NewEnemies*
number of (new) deaths	*NewDeaths*
the number of larvae	*Larvae*

Formalization (2)

If $Bee1Role(t) = 1$

$Bee1ForageNorm(t + \Delta t) = c^* \, Bee1AdapFactor^* \, Bee1ForagerNorm(t)$

$Bee1CarerNorm(t + \Delta t) = c^* \, Bee1CarerNorm(t)$

$Bee1UndertakeNorm(t + \Delta t) = c^* \, Bee1UndertakerNorm(t)$

$Bee1PatrolNorm(t + \Delta t) = c^* \, Bee1PatrollerNorm(t)$

where *c* is a factor that takes care that the sum of the new norms becomes *1* again:

$c = 1 / (1 – (1- Bee1AdapFactor)^* \, Bee1ForageNorm(t)))$

Formalization (3)

$FoodNeed(t+\Delta t) = FoodNeed(t) + FoodneedAddition(t) - ForagingWork(t)$

with

ForagingWork(t) = Effort number of individuals with role allocation Forager*

FoodneedAddition(t) = Larvae(t) + number of individuals

Implementation

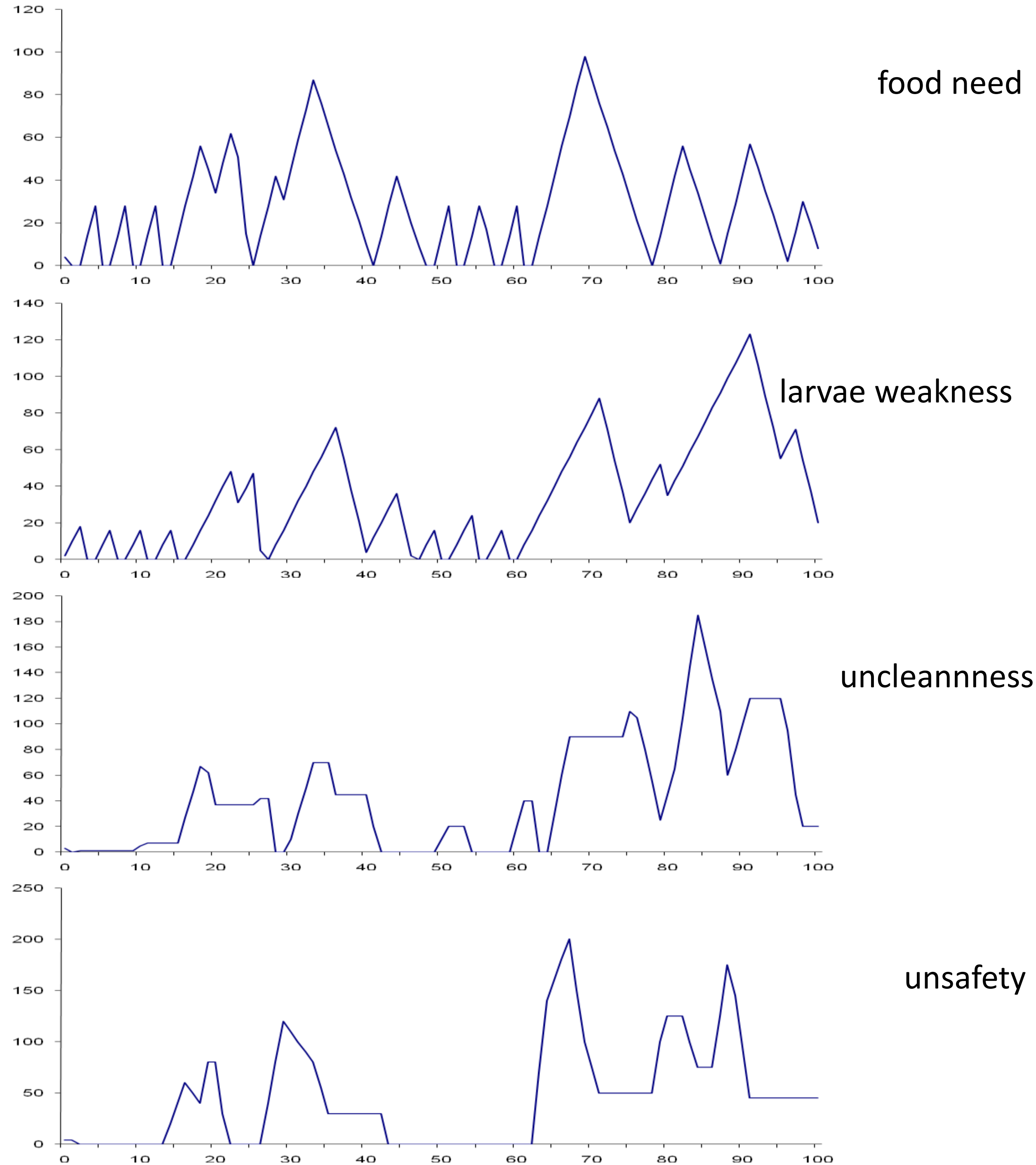
t	food need	larvae weak ness	unclean ness	unsafety	alloc ation	forager norm	carer norm	under taker norm	patroller norm
0	4	2	3	4	1	0.30	0.25	0.20	0.25
1	0	10	0	4	4	0.29	0.25	0.20	0.25
2	0	18	1	0	2	0.29	0.26	0.21	0.24
3	14	0	1	0	2	0.30	0.25	0.21	0.25
4	28	0	1	0	1	0.30	0.24	0.21	0.25
5	0	8	1	0	1	0.29	0.24	0.21	0.25

Simulation Experiment

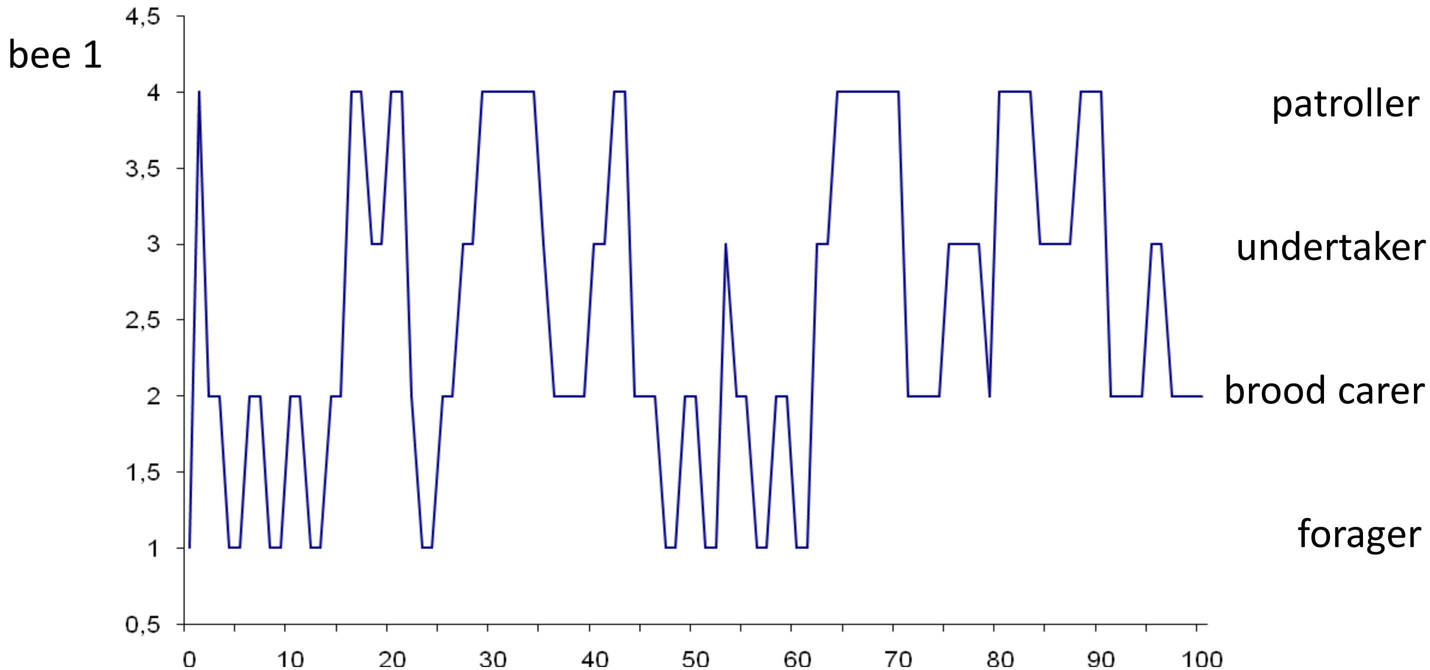
Validation of expected patterns:

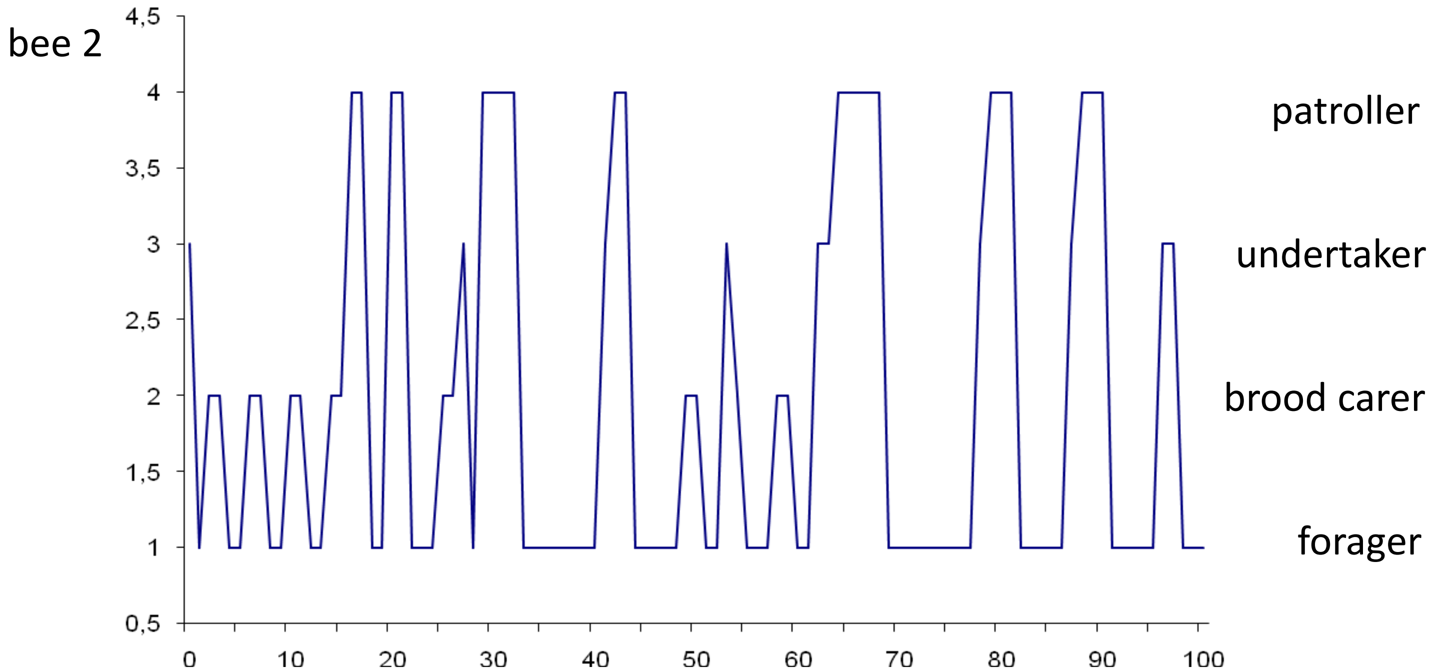
- Are the **aspects kept between bounds**?
- Does **specialisation** take place?

Aspects over Time

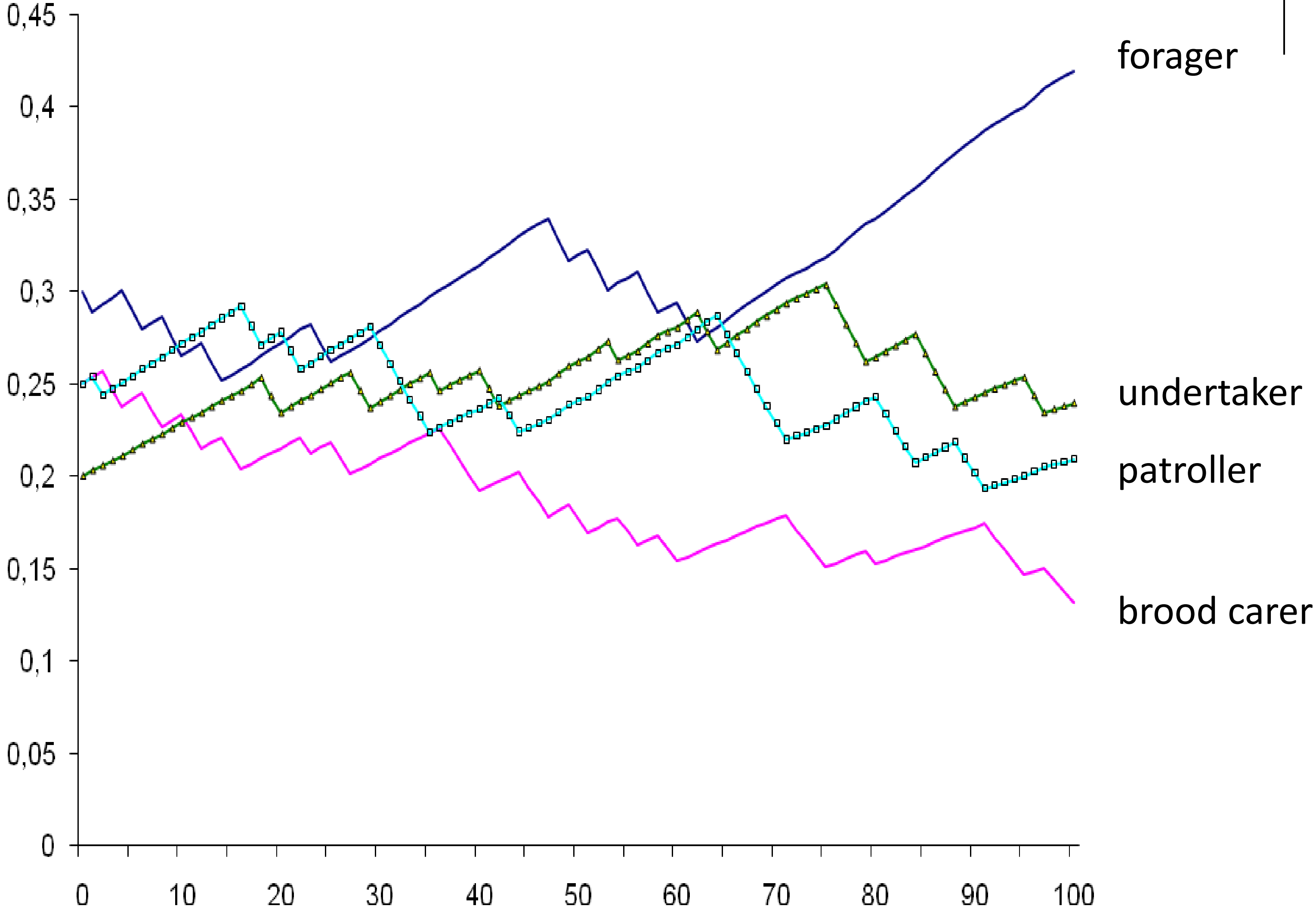


Roles over Time

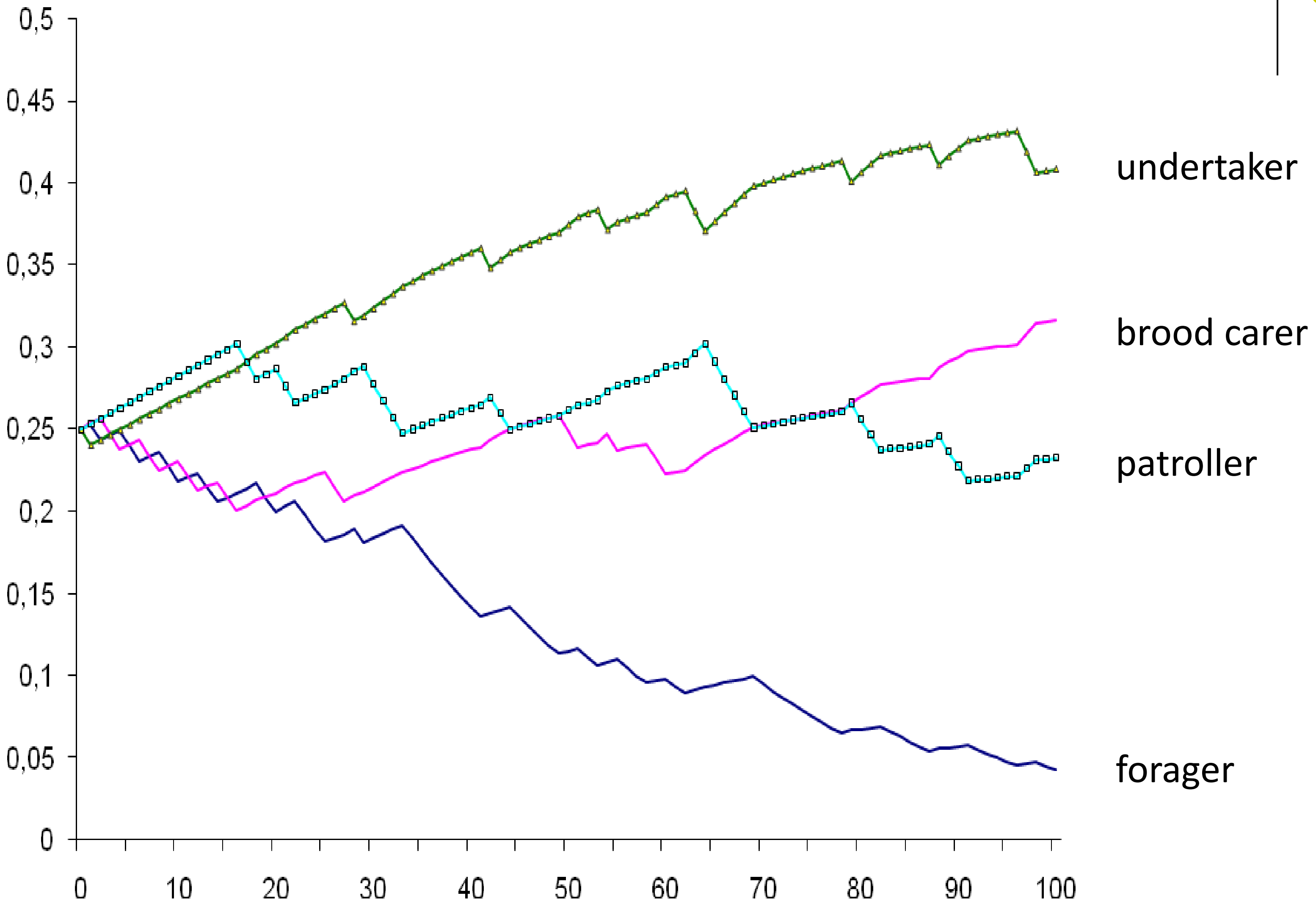




Norms of Bee 1 over Time



Norms of Bee 2 over Time



Simulation Experiment

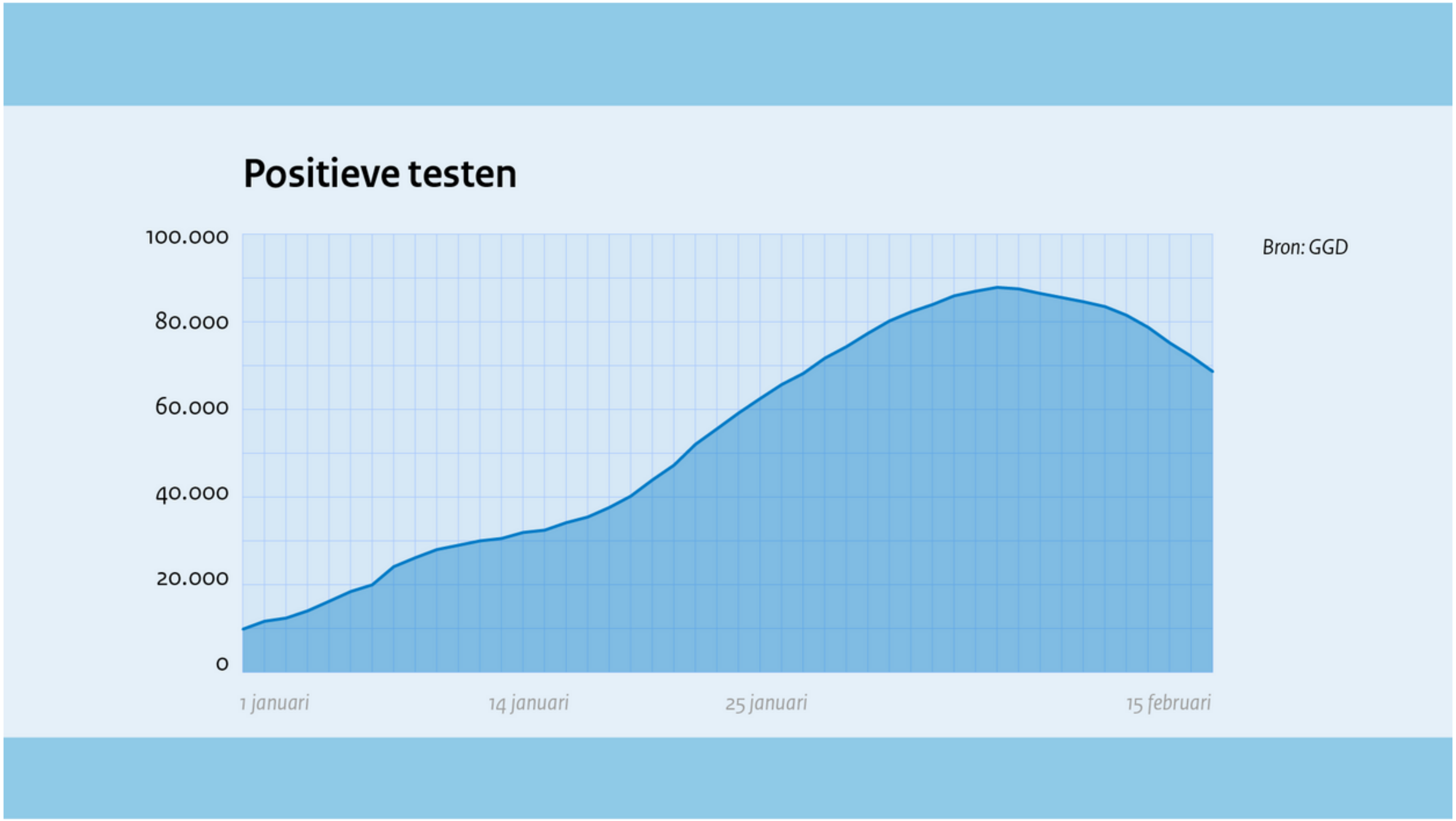
Validation of expected patterns:

- Are the aspects kept between bounds? **Yes**
- Does specialisation take place? **Yes**

Syllabus: Chapter 6

MODELLING EPIDEMICS FROM CONTACT BEHAVIOUR

Modelling virus spread in society



Also: spatial aspect

http://www.youtube.com/watch?v=3QM055uW43I

Use of virus simulation

- Understand the process of virus spread
- Predict future scenarios
  - burden on hospitals
- Compare different intervention strategies
- …

Our aim

- Create a model that can predict how virus spreads through society
- Possible research questions:
  - When **infections transmit easily**, will the whole population become infected?
  - Is it possible to **adapt contact behaviour** to avoid propagation through the whole population?
  - Is there a **threshold** for the amount of interaction such that the infection dies out?

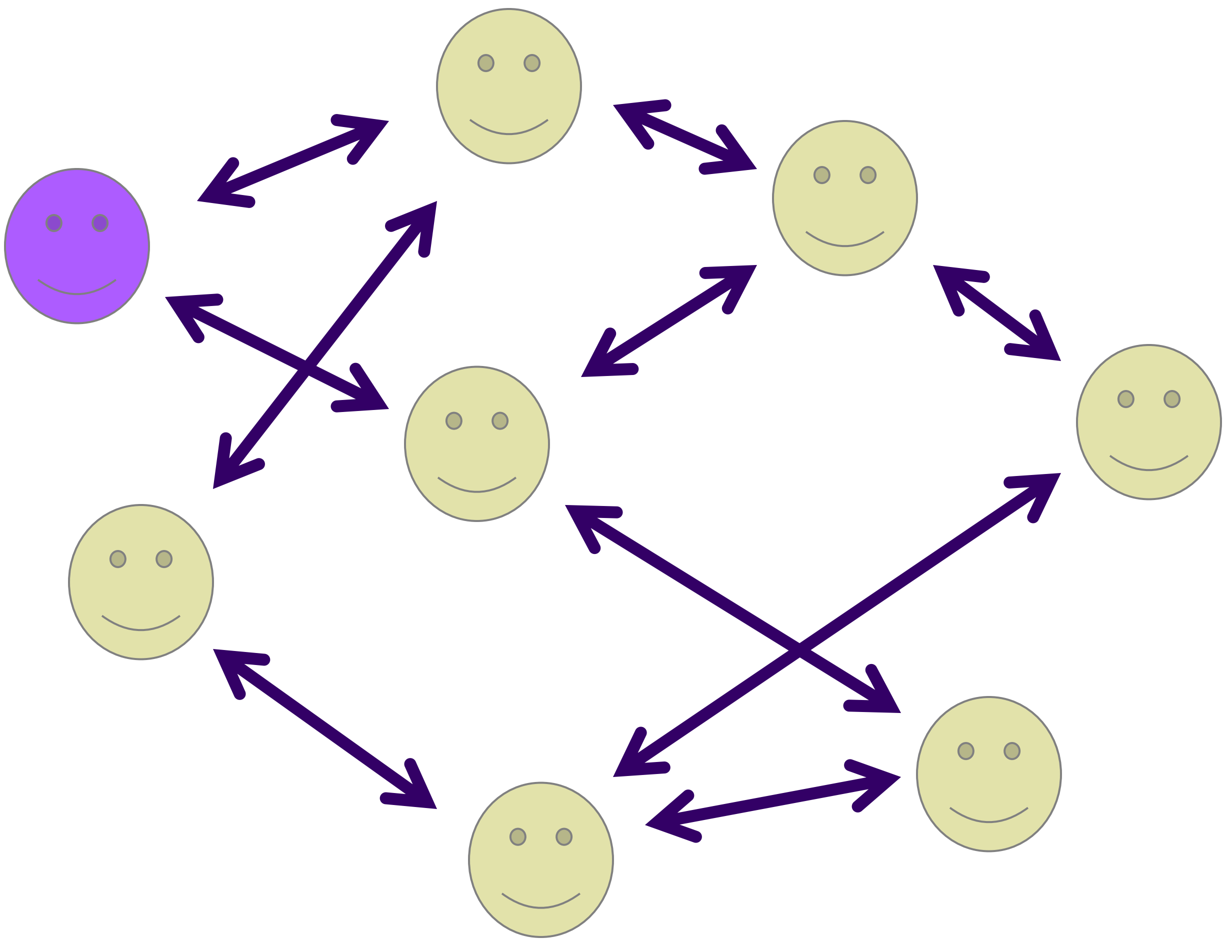
Expected patterns?

- In the first phase, the amount of infected people increases almost exponentially
- At some point in time, the infection rate decreases
- Eventually, the number of recovered people is large enough to stop the spread

Modeling epidemics

- Two approaches:
  - Modeling individuals
    - individual-based
  - Modeling groups
    - population-based (collective)
    - abstracted

Individual approach



Principle of individual approach

- Individuals can be in different states:
  - susceptible (not infected yet),
  - infective, or
  - recovered (immune and not infectious)
- Transmission of infection by contacts
  - when an infected and susceptible person meet
    - contact frequency
    - contact intensity

Concepts

- infection state of a person
  - susceptible
  - infective
  - recovered
- location of a person
- contact frequency per day
- contact intensity
- recovery rate
  - chance per day for infective to recover

Individual Level - Formalisation

susceptible **infective** **recovered**	***InfectionStateA1 = 0, InfectionStateA2 = 0, ……*** ***InfectionStateA1 = 1 , …*** ***InfectionStateA1 = 2 , …***
location of individuals	***LocationA1 = 1, LocationA1 = 2, ……*** ***LocationA2 = 1, LocationA2 = 2, ……***
contact frequency per day **(for one individual)**	***ContactFrequency***
contact intensity	***ContactIntensity***
recovery rate (chance per day for infective to recover)	***RecoveryRate***

Individual Level Model (1)

Per individual:

LocationA1(t) =
RandBetween(1, NumberOfLocations)

Individual Level Model (2)

Per individual:

InfectionStateA1(t+Δt) = 1

if

InfectionStateA1(t) = 0 and

r1 < ContactIntensity and

for some k,

LocationA1 = LocationAk and InfectionStateAk(t) = 1

or

InfectionStateA1(t) = 1 and r2 ≥ RecoveryRate

(where r1 and r2 are random numbers between 0 and 1)

Individual Level Model (3)

Per individual:

$InfectionStateA1(t+\Delta t) = 2$

if

$InfectionStateA1(t) = 1$ *and*

$r2 < RecoveryRate$

or

$InfectionStateA1(t) = 2$

In all other cases:

$InfectionStateA1(t+\Delta t) = 0$

Individual Level Model (4)

Per individual:

$ContactFrequency = N/L - 1$

(L = #locations, N #individuals)

And thus:

$L = N / (ContactFrequency + 1)$

- Use this to calculate next location:

$$LocationA1(t) = RandBetween(1, N/ ContactFrequency + 1))$$

Individual Level Model (5)

$Susceptibles(t) = \Sigma k \ if(InfectionStateAk(t) = 0, 1, 0)$

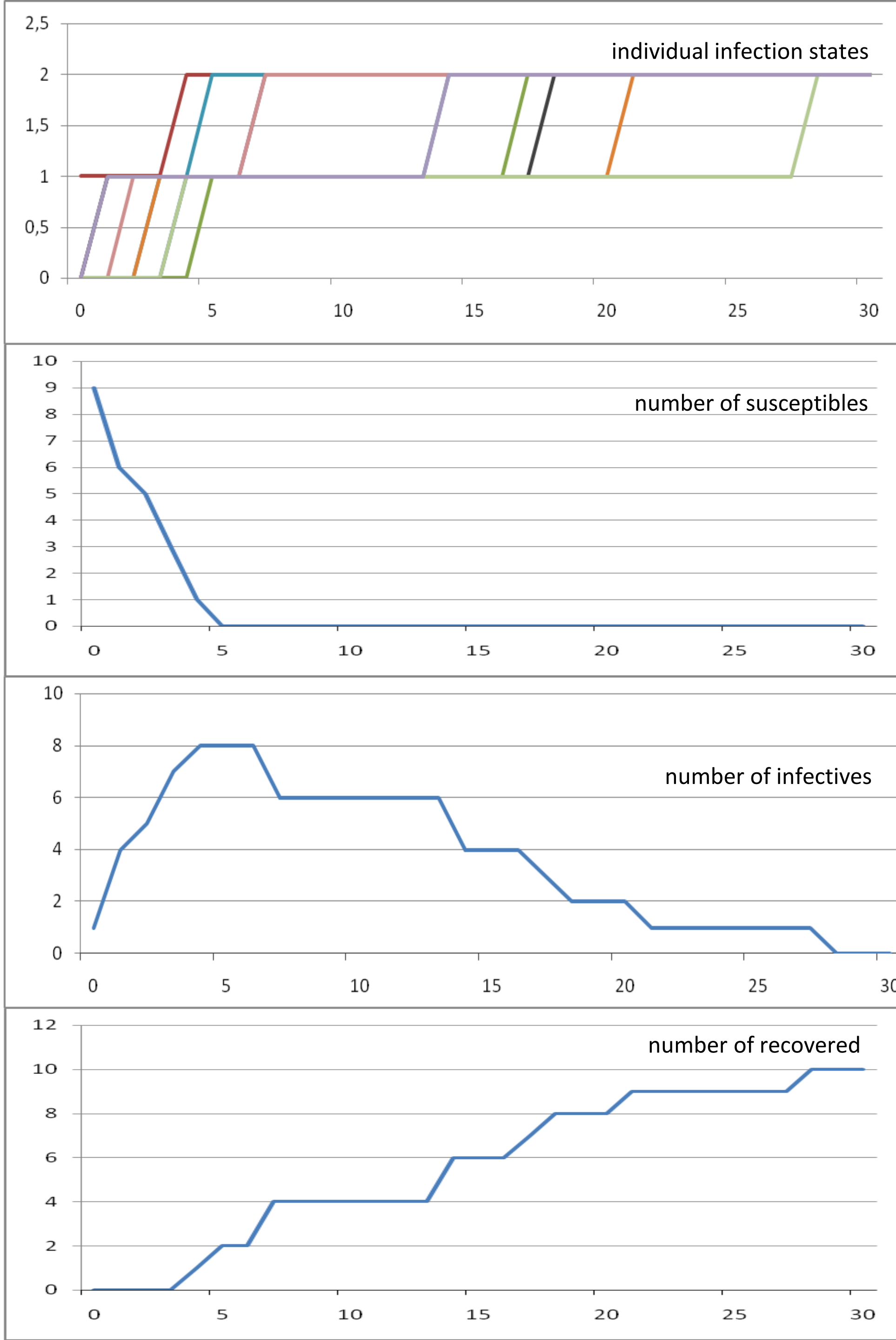
$Infectives(t) = \Sigma k \ if(InfectionStateAk(t) = 1, 1, 0)$

$Recovered(t) = \Sigma k \ if(InfectionStateAk(t) = 2, 1, 0)$

Format: if (condition, value if true, value iffalse)

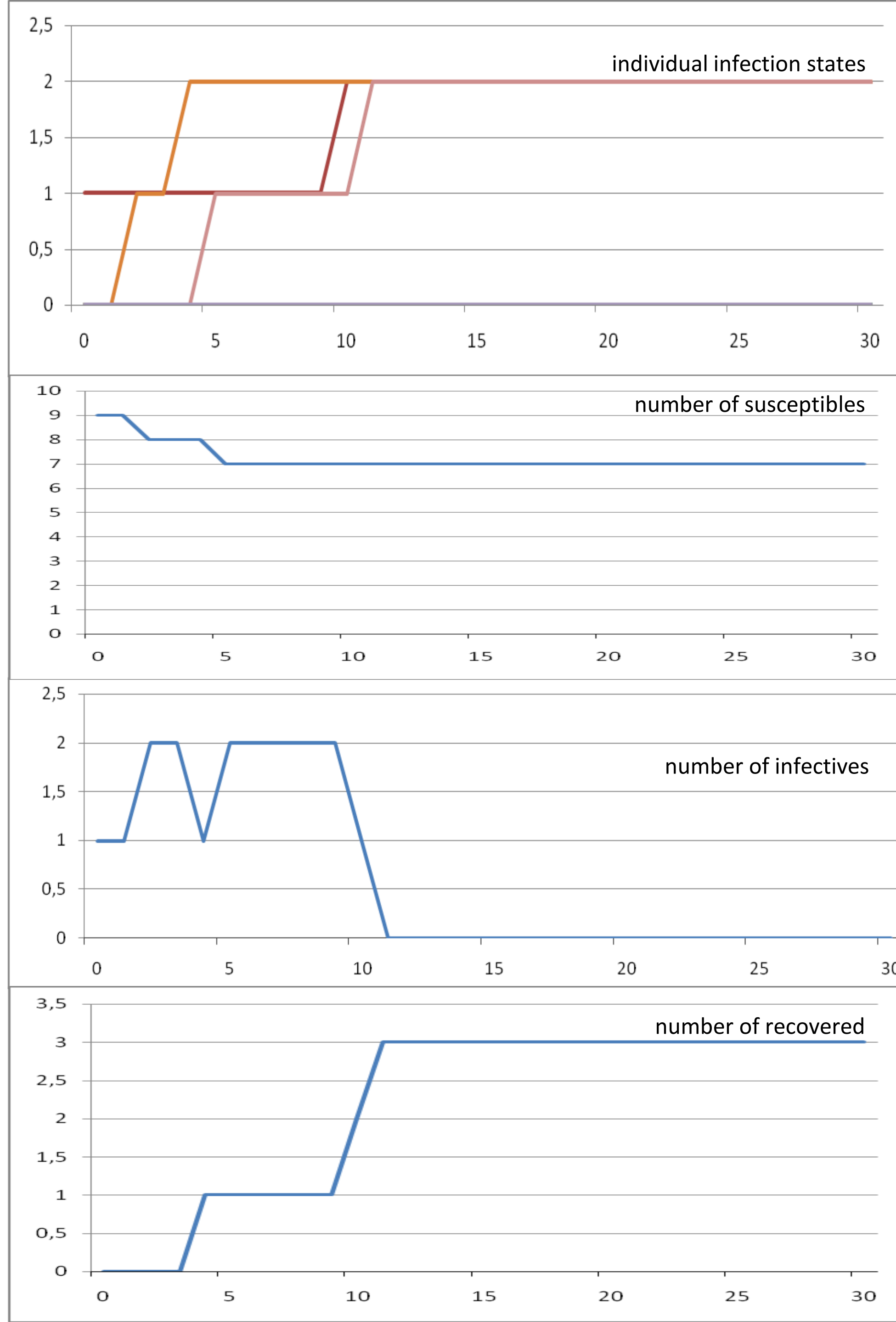
Individual Level Simulation

ContactFrequency	0.8
ContactIntensity	0.5
RecoveryRate	0.05



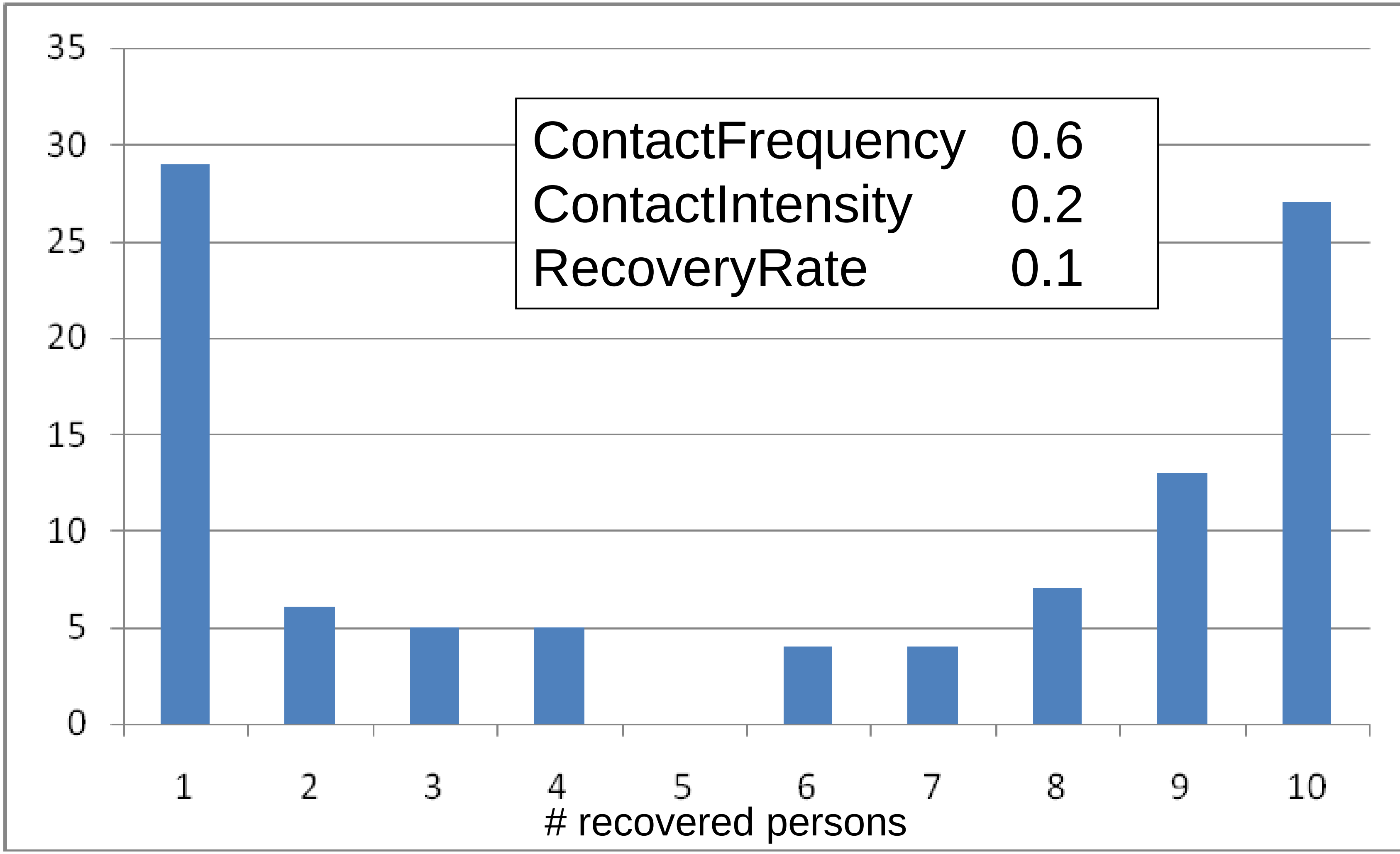
Individual Level Simulation

ContactFrequency	0.6
ContactIntensity	0.2
RecoveryRate	0.1



Overview of 100 simulations

Frequency of number of recovered persons at time point 30

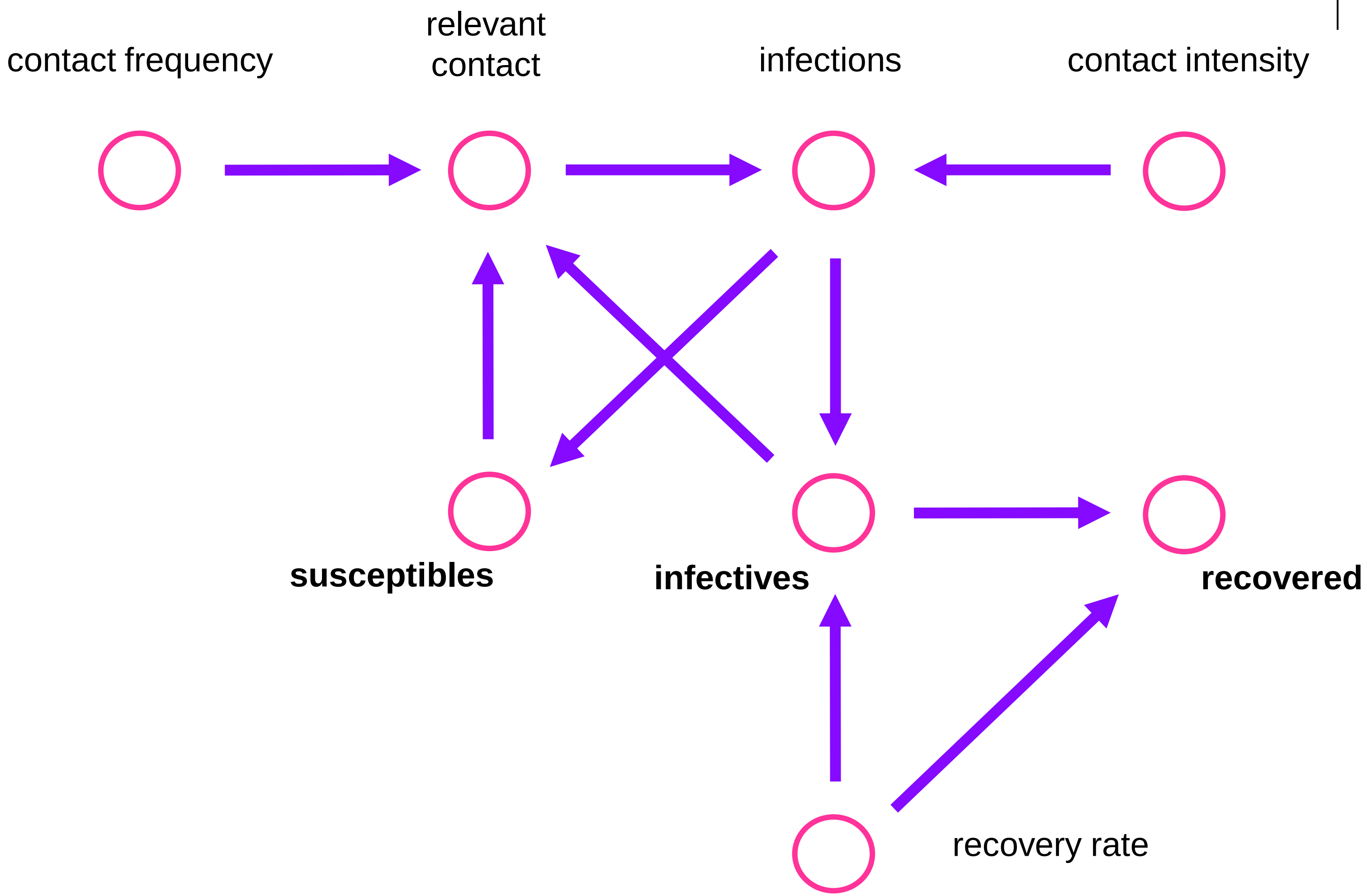


What are the limitations of our model?

Concepts collective approach

- Same, but no individual infection state
- Instead: different concepts for **total number of people in a specific state**
  - (the group of) Susceptibles
  - (the group of) Infected
  - (the group of) Recovered

Collective approach: concepts and relations



Collective level – Formalisation

number of susceptible individuals (non-infected)	***Susceptibles***
number of infective individuals	***Infectives***
number of recovered individuals (immune or dead, non-infective)	***Recovered***
number of relevant contacts per day (infective with susceptible)	***RelevantContacts***
number of infections taking place per day	***Infections***
contact frequency per person per day	***ContactFrequency***
contact intensity	***ContactIntensity***
recovery rate (fraction of infectives recovering per day)	***RecoveryRate***

Collective Level Model (1)

Per susceptible:

ContactFrequency number of contacts per day

Infectives(t) /N fraction of risky contacts

N = total number of population

RelevantContacts(t) = *ContactFrequency*Susceptibles(t)*Infectives(t) /N*

From this a fraction *ContactIntensity* provides new infections

Infections(t) = *ContactIntensity*RelevantContacts(t)*

Collective Level Model (2)

$$Susceptibles(t+\Delta t) =$$
$$Susceptibles(t) - Infections(t)*\Delta t$$

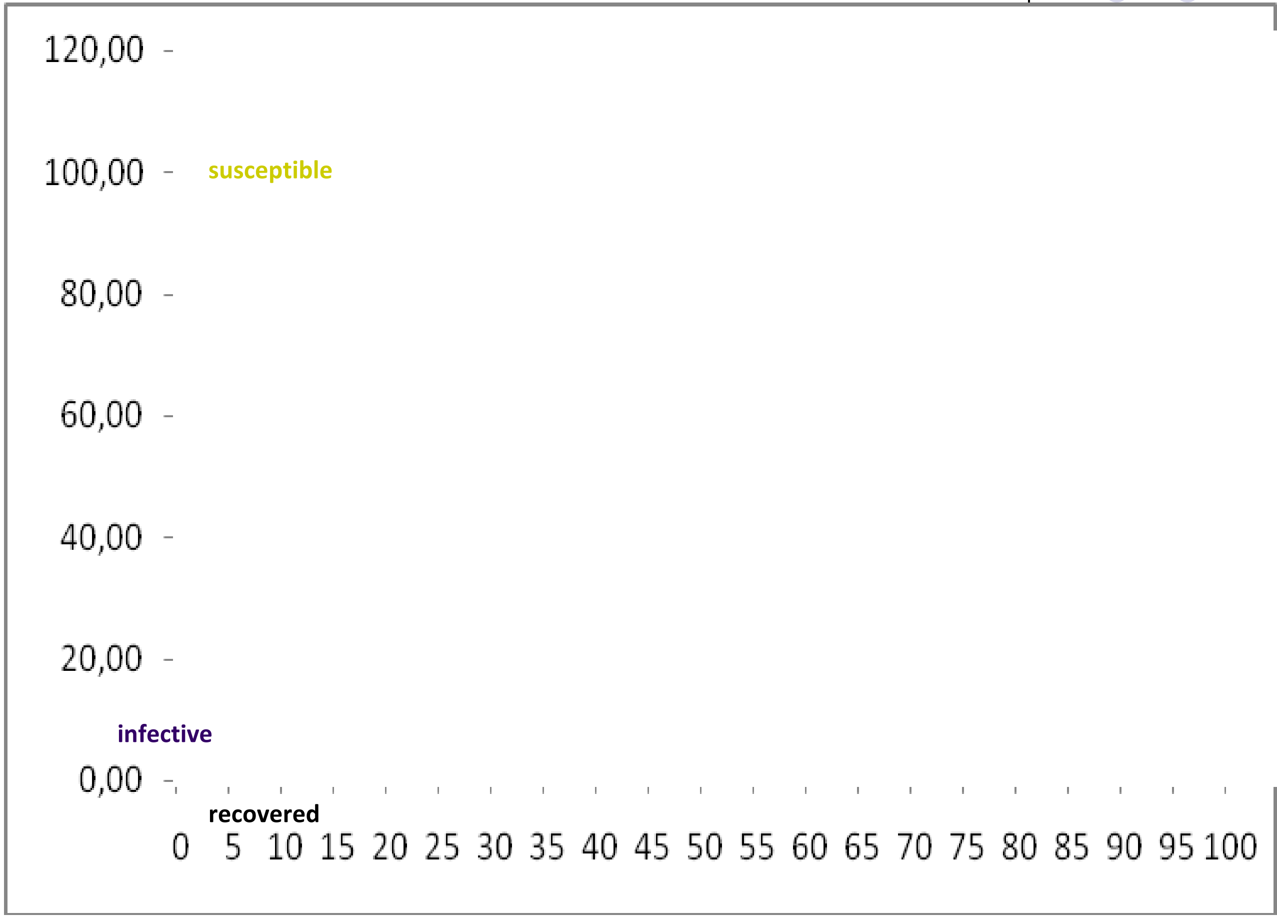
$$Infectives(t+\Delta t) =$$
$$Infectives(t) + Infections(t)*\Delta t$$
$$- RecoveryRate * Infectives(t)*\Delta t$$

Collective Level Model (3)

$$Recovered(t+\Delta t) = Recovered(t) + RecoveryRate * Infectives(t) * \Delta t$$

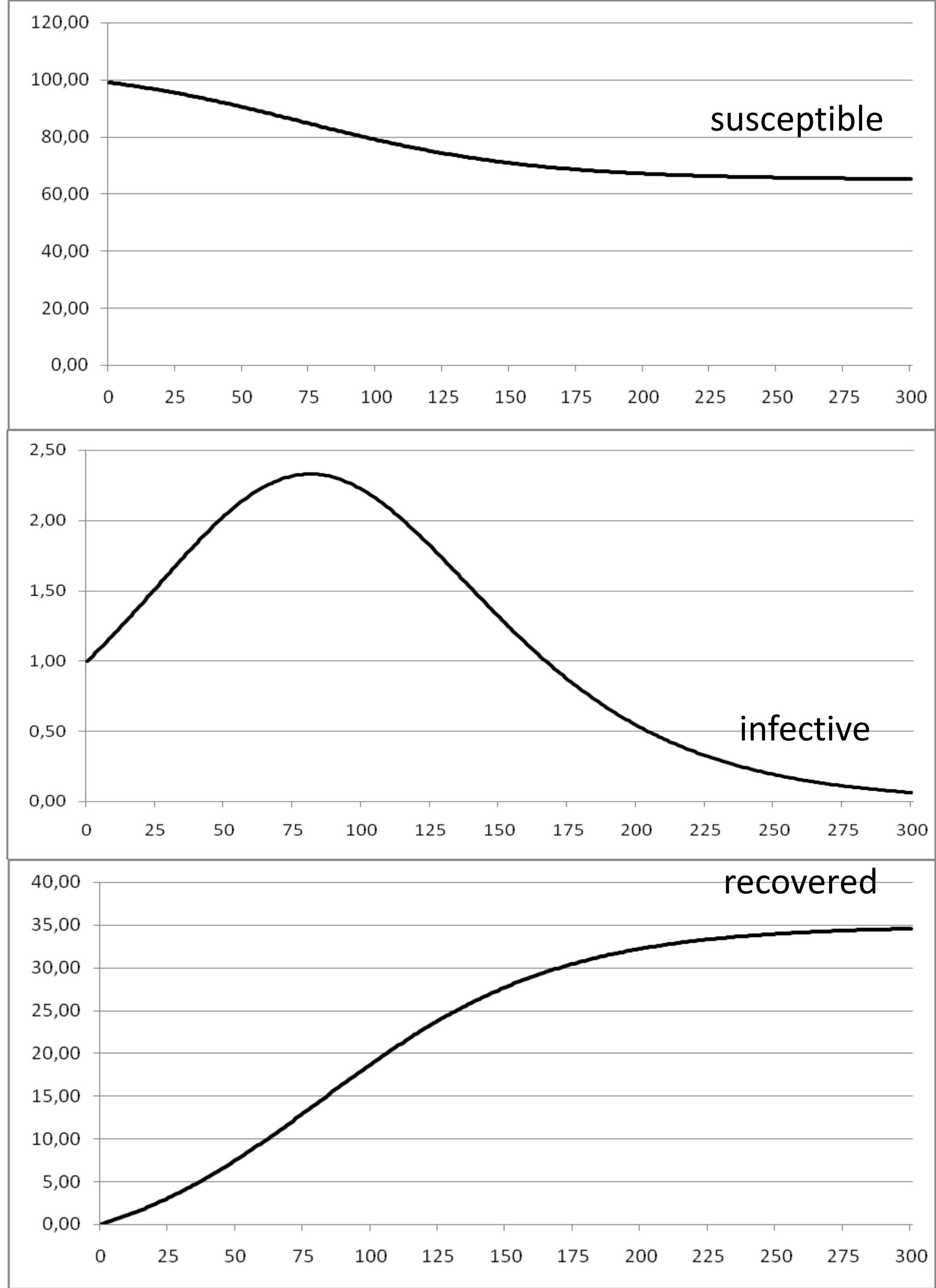
Simulation Experiment 1

ContactFrequency 0.8
ContactIntensity 0.5
RecoveryRate 0.05



Simulation Experiment 2: 35% Infected

ContactFrequency	0.6
ContactIntensity	0.2
RecoveryRate	0.1



Collective vs. Individual Level

- Collective Level:
  - Sub-groups represented by numbers
  - Abstraction from reality
  - Computationally efficient
- Individual Level:
  - Each individual represented separately
  - More faithful
  - Computationally complex
  - Probabilistic element needed

Further Explorations

- **Compare** the results of simulations by the model at the individual level and the model at the collective level.
- Incorporate **individual differences in contact behaviour**.
  - For example, consider a (core) population that has higher contact frequencies or intensities than other individuals.
- Consider the case that recovered individuals become **susceptible again**:
  - no immunity after some time.
- Consider the typical children's diseases, where all the time **new births** are adding individuals to the population.
- Explore what can be done by **vaccination** programs.

Further Explorations

- Incorporate change of contact behaviour of individuals depending on the **number of infectives**.
  - For example, if the number of infectives becomes higher, the contact frequency and/or contact intensity become lower.
- Develop a model for **transmission** of an **influenza** infection from birds to humans.
- Incorporate internal **cognitive models** for decision making about contact behaviour; for example, based on beliefs, desires and intentions.