

Basics of infectious disease modelling

MMID Summer School 2025



Swiss TPH



Lesson 5

How to construct a mathematical model

Zenabu Suboi

Learning Objectives

By the end of this lesson, you will be able to:

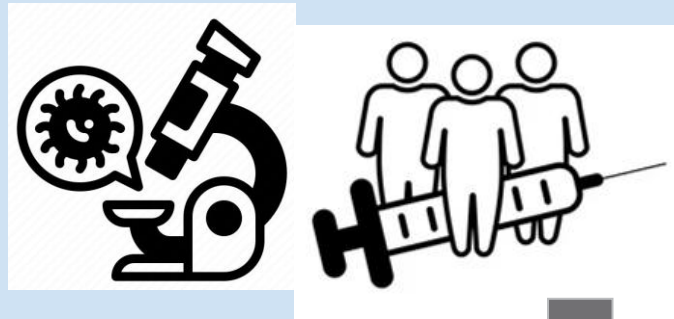
- Move from **verbal** description of symptoms in the community to logic of contagion
 - Move from storytelling and “mind map” to diagrams

Learning Objectives

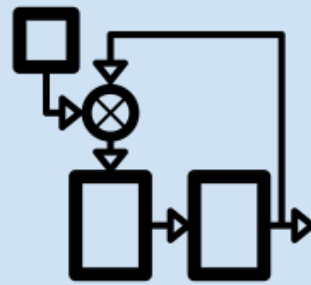
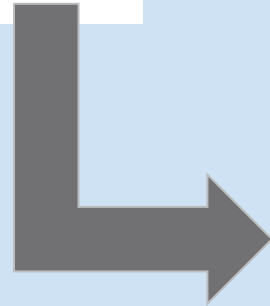
By the end of this lesson, you will be able to:

- Move from **verbal** description of symptoms in the community to logic of contagion
 - Move from storytelling and “mind map” to diagrams
- **Construct** a basic disease transmission model using a flow diagram, starting from the mind map of the disease story

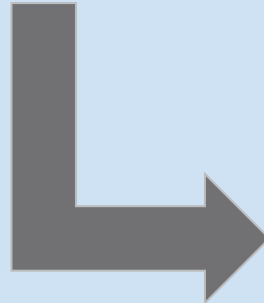
Modeling = a process where people from different worlds meet on a common ground



biologist/epidemiologist/entomologists:
translate biological and population-level observations into flow diagrams

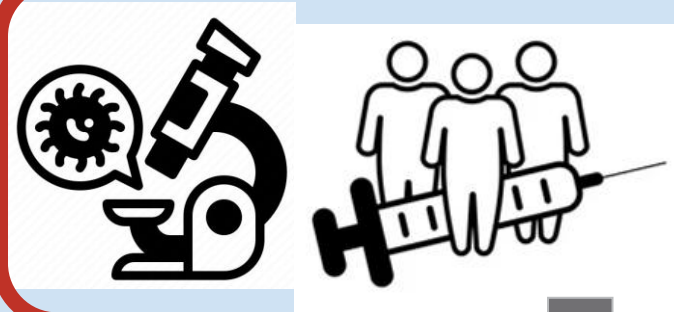


mathematician:
translates flow diagrams into equations

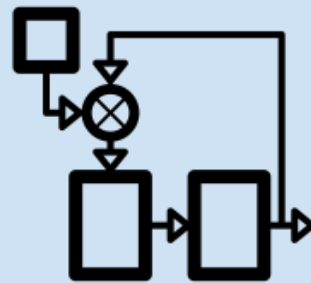


software engineer/computer science:
translates equations into computer code

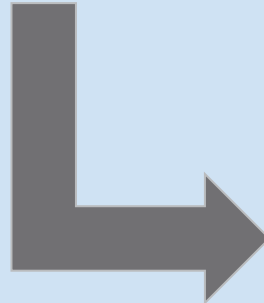
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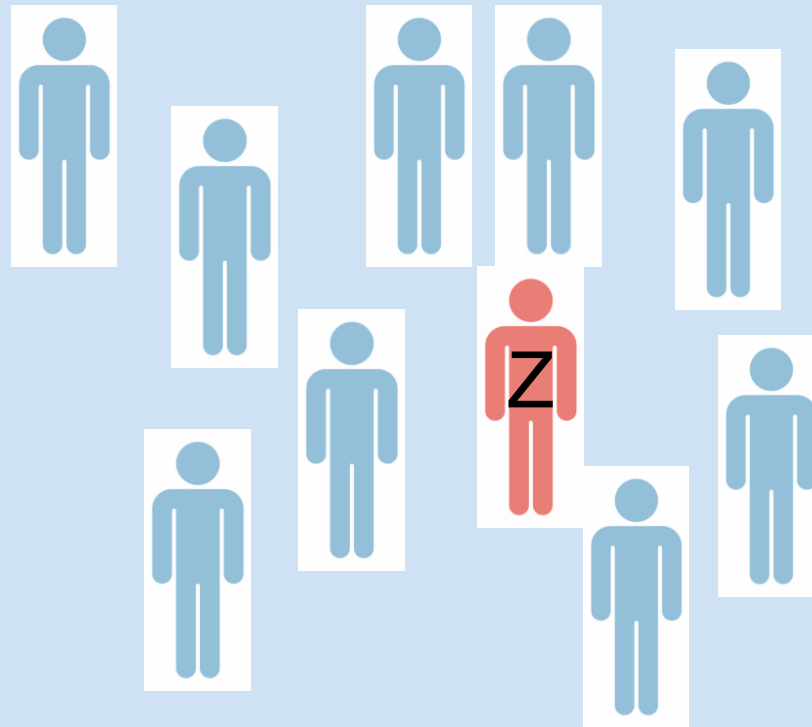


Learning Objective 1

From Storytelling to Logic of contagion
(mind map)

Individual destinies

Contagion process



healthy: 9

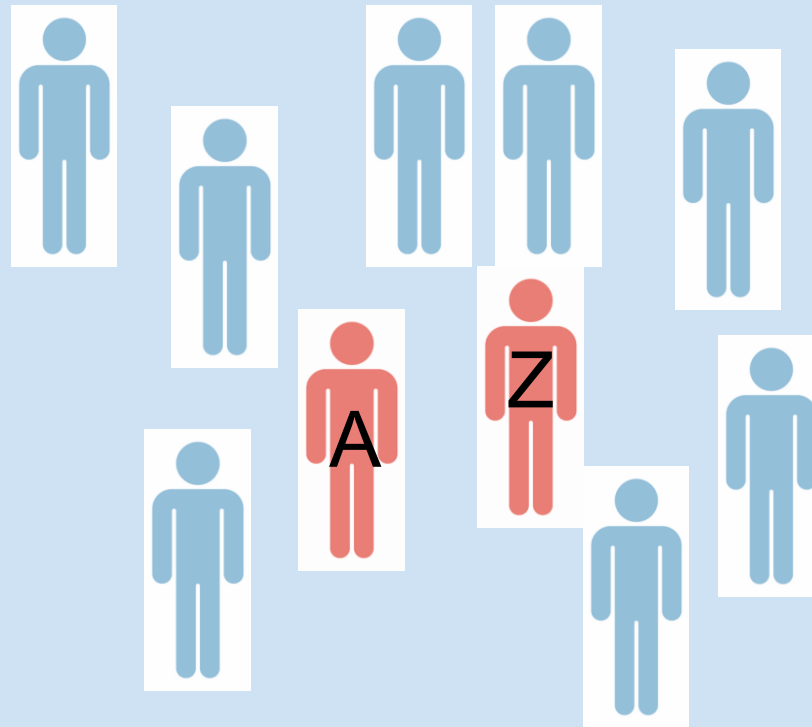
sick: 1

day: 0

*“At first, **Zenabu** feels really sick. But she still comes to class.”*

Individual destinies

Contagion process



healthy: 8

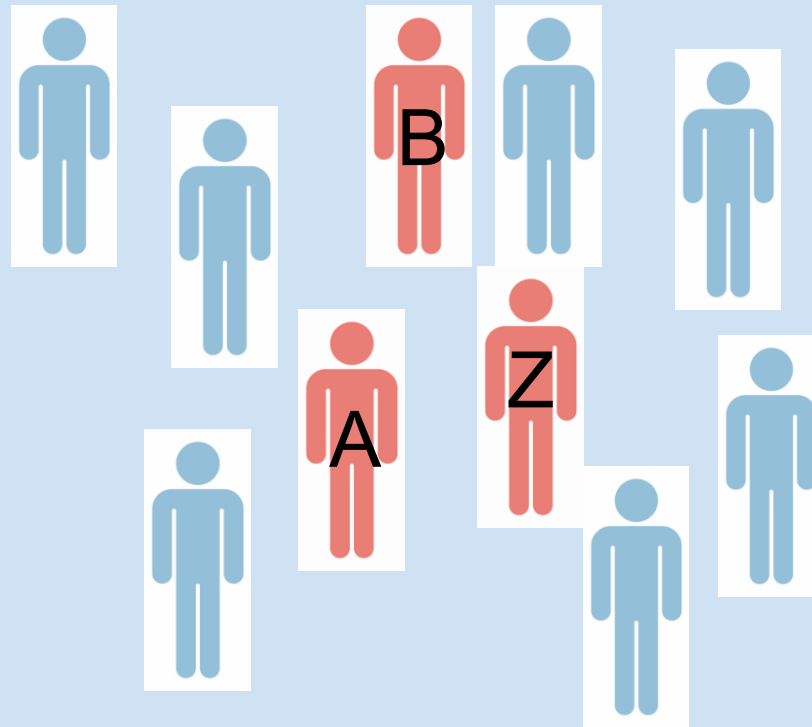
sick: 2

day: 1

*“The following day, Z feels a bit better, but her colleague, **A**gnes, starts to have similar symptoms, fever, nausea, etc.”*

Individual destinies

Contagion process



healthy: 7

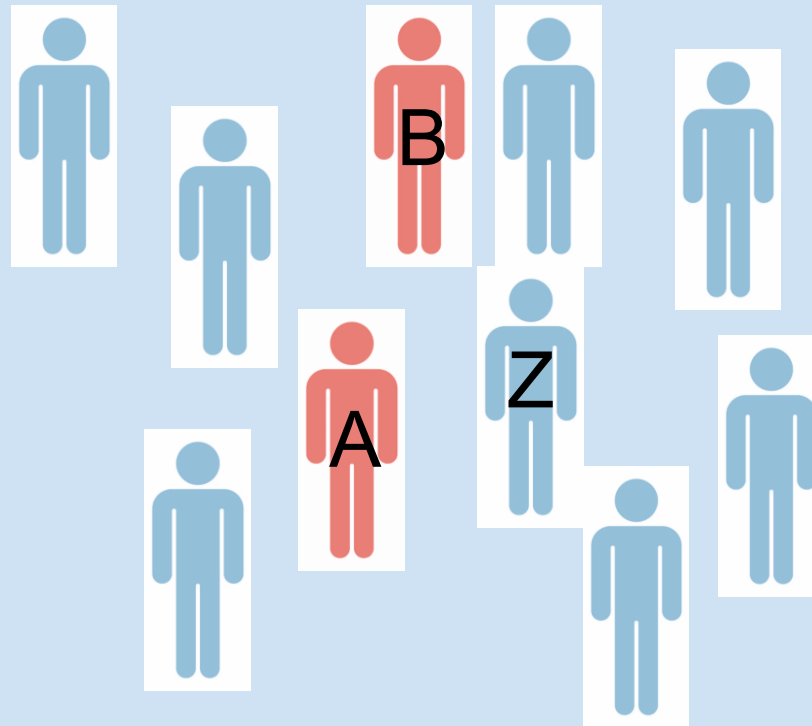
sick: 3

day: 2

*“On day 2, three people in class (**Z**, **A**, and **B**ashir) have the same symptoms, but with different intensity.”*

Individual destinies

Contagion process



healthy: 8

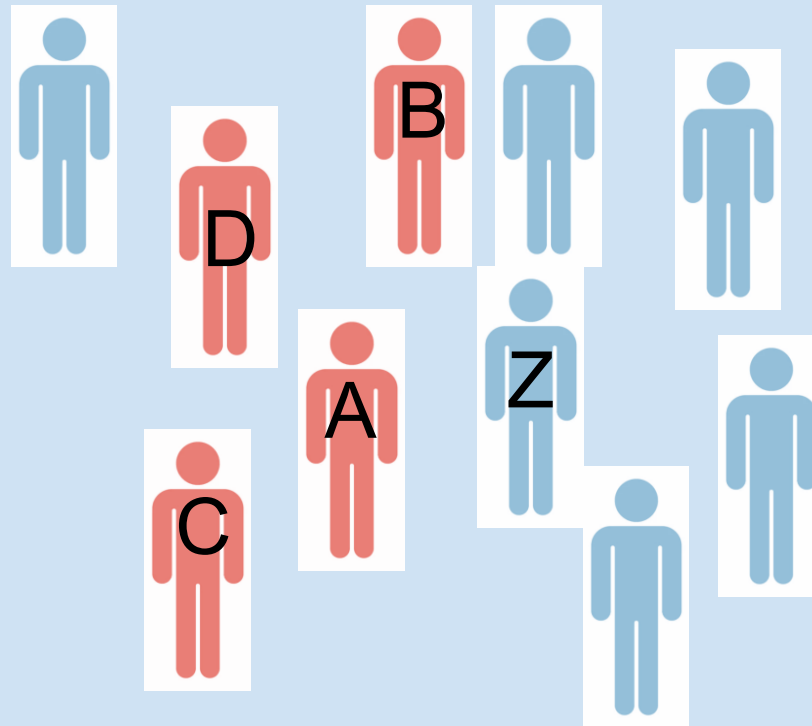
sick: 2

day: 3

*“Finally, **Z** is healthy again.”*

Individual destinies

Contagion process



healthy: 6

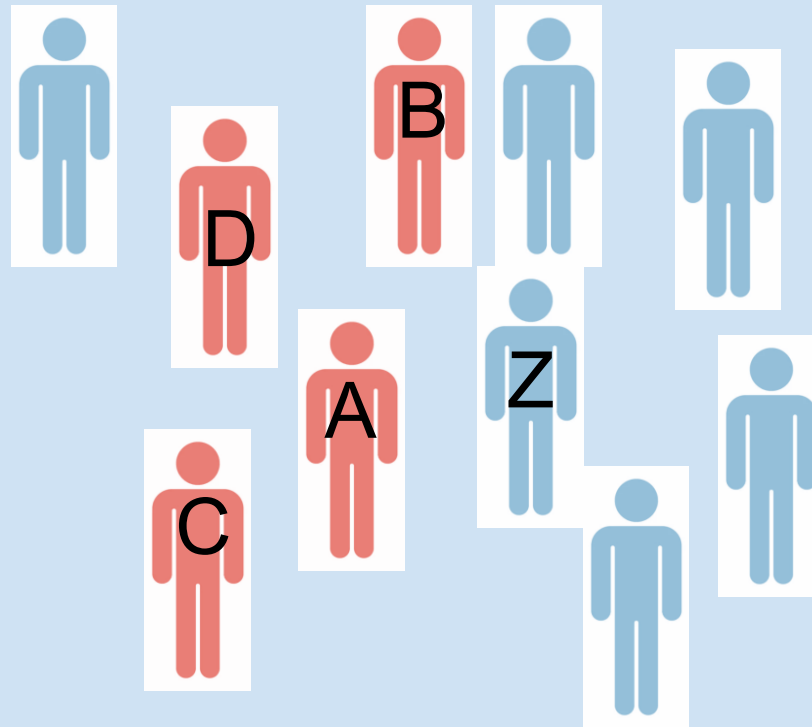
sick: 4

day: 4

*“On day 4, two new colleagues (**C**harles and **D**avid) become infected.”*

Individual destinies

Contagion process

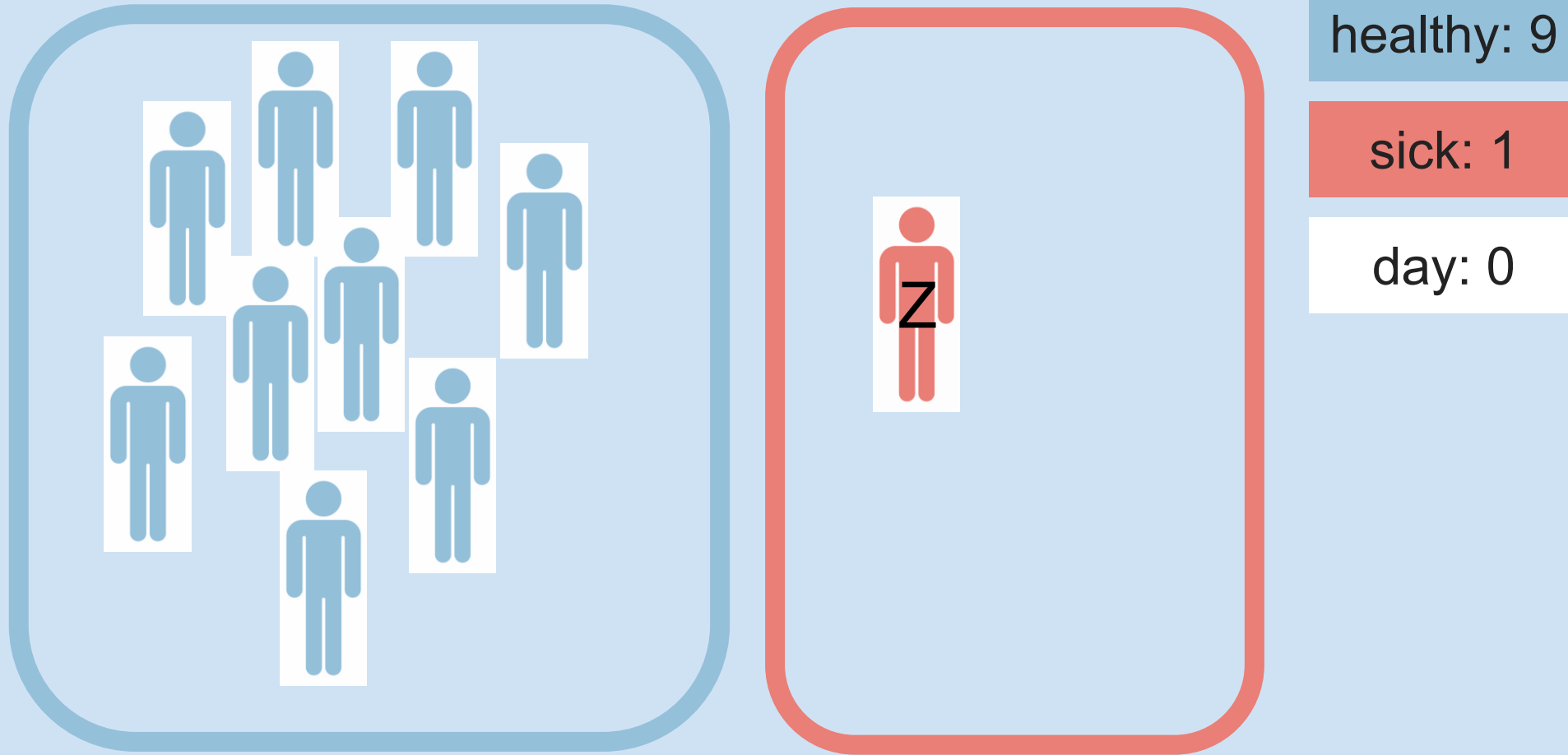


*After several small outbreaks,
there seems to be a mechanism:*

*More infected \Rightarrow More new
infections \Rightarrow Still more infected*

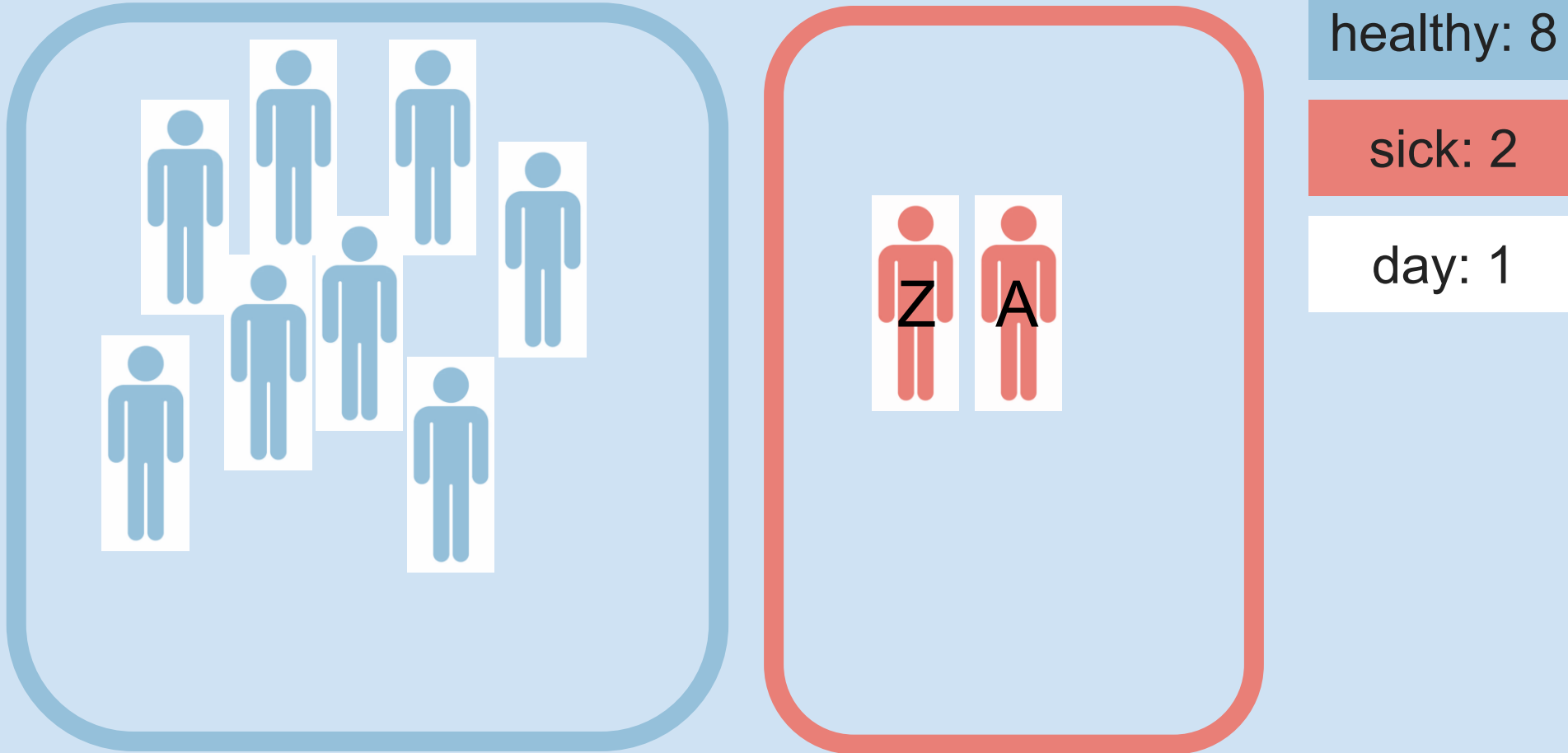
Putting people into boxes - compartments

Contagion process - simplified



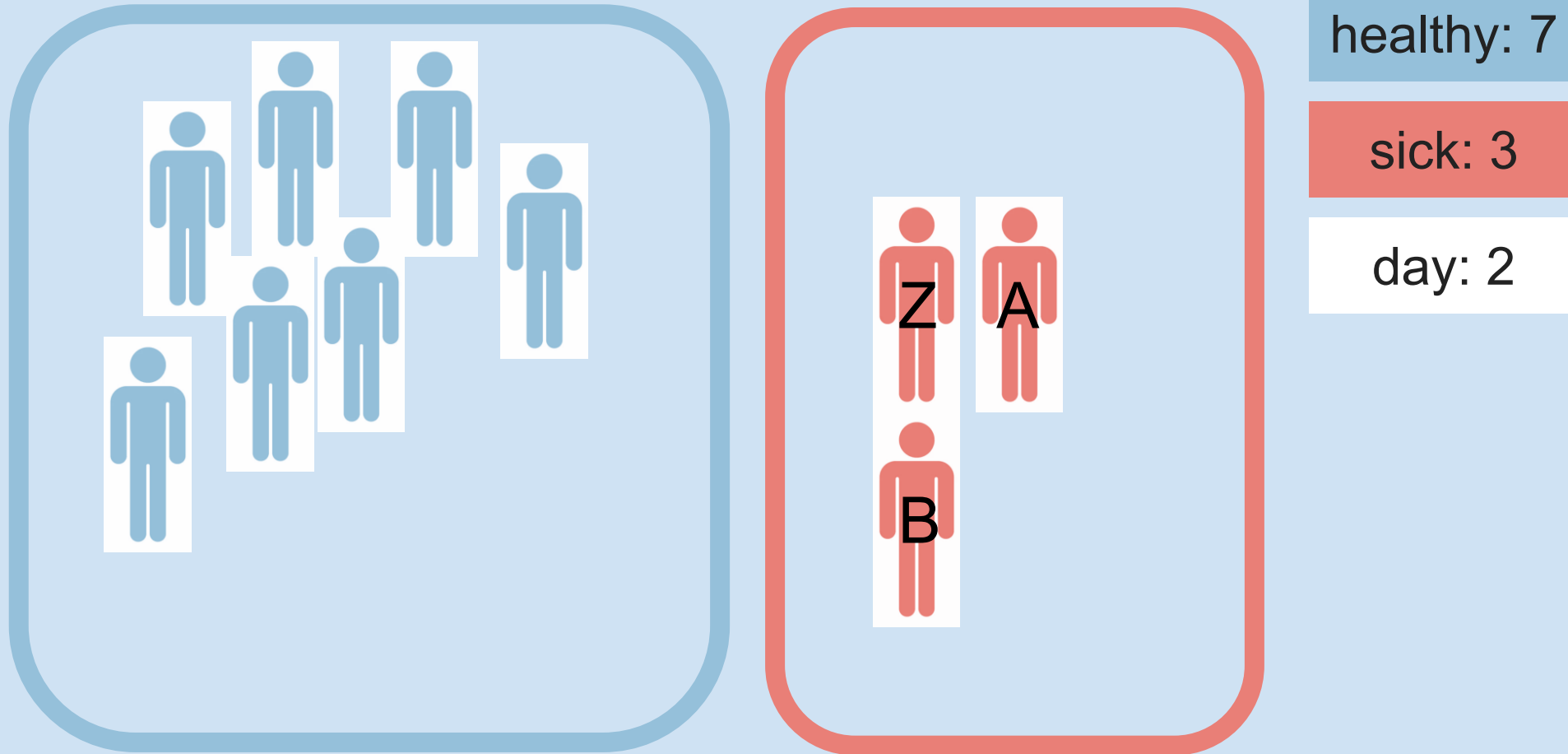
Putting people into boxes - compartments

Contagion process - simplified



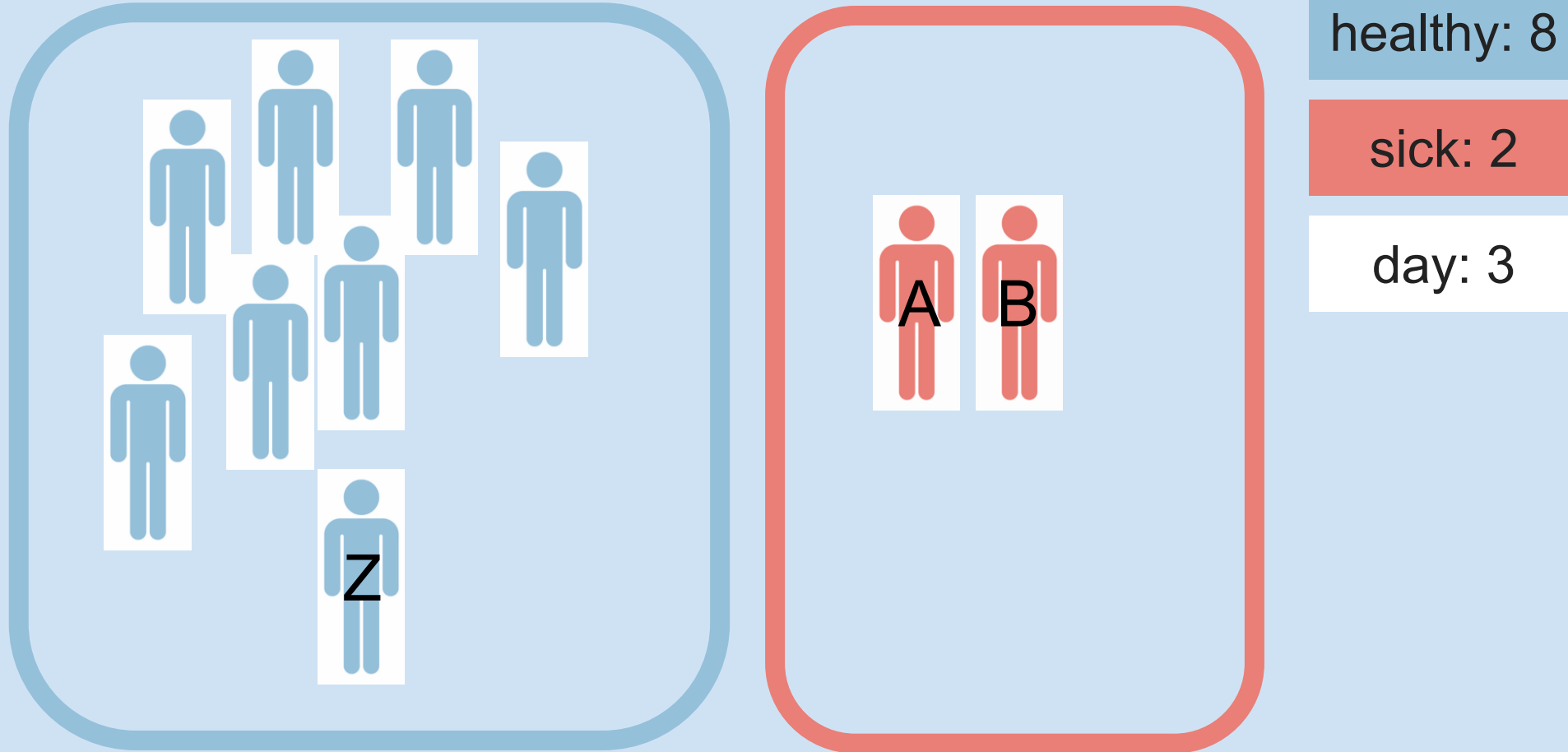
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Contagion process - simplified



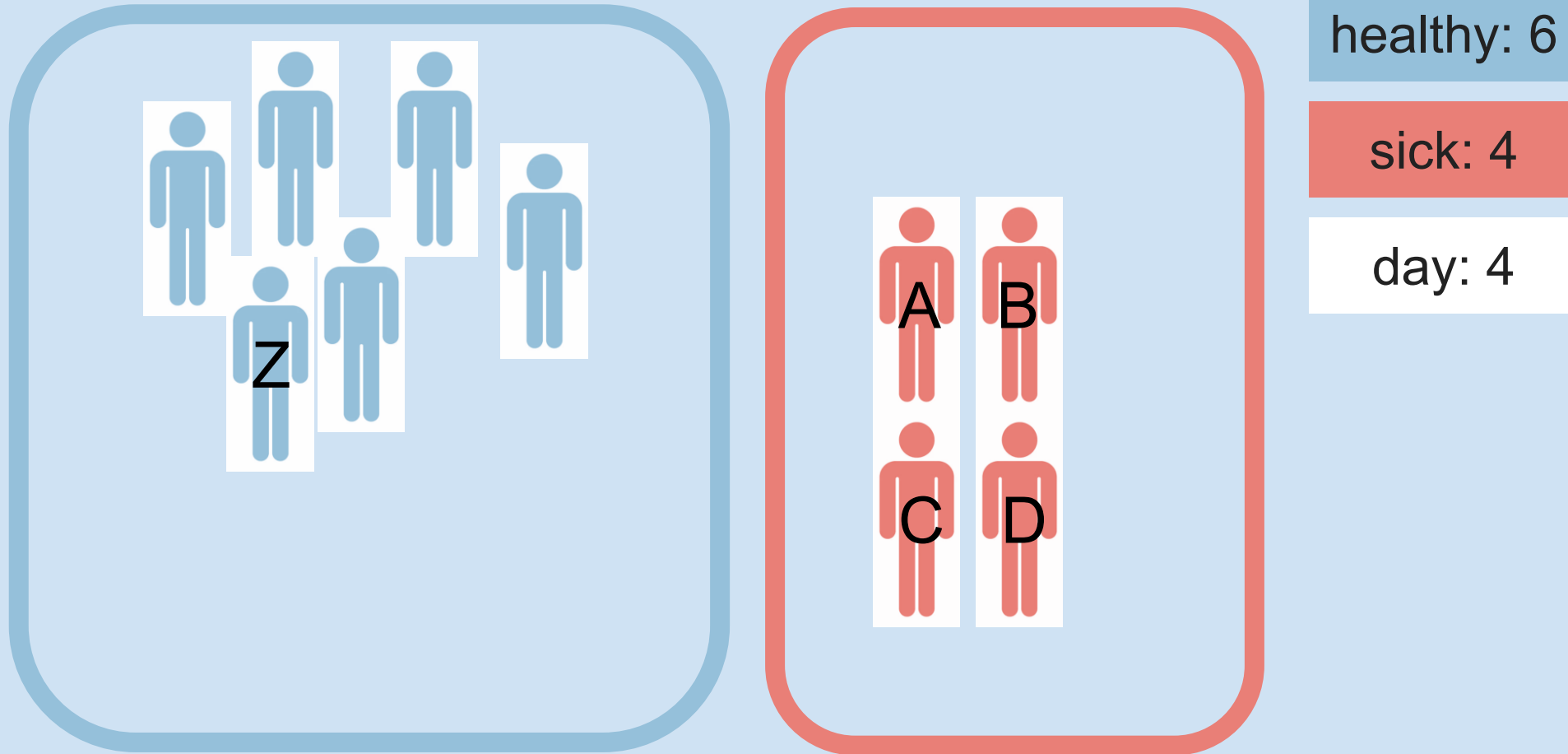
Putting people into boxes - compartments

Contagion process - simplified



Putting people into boxes - compartments

Contagion process - simplified





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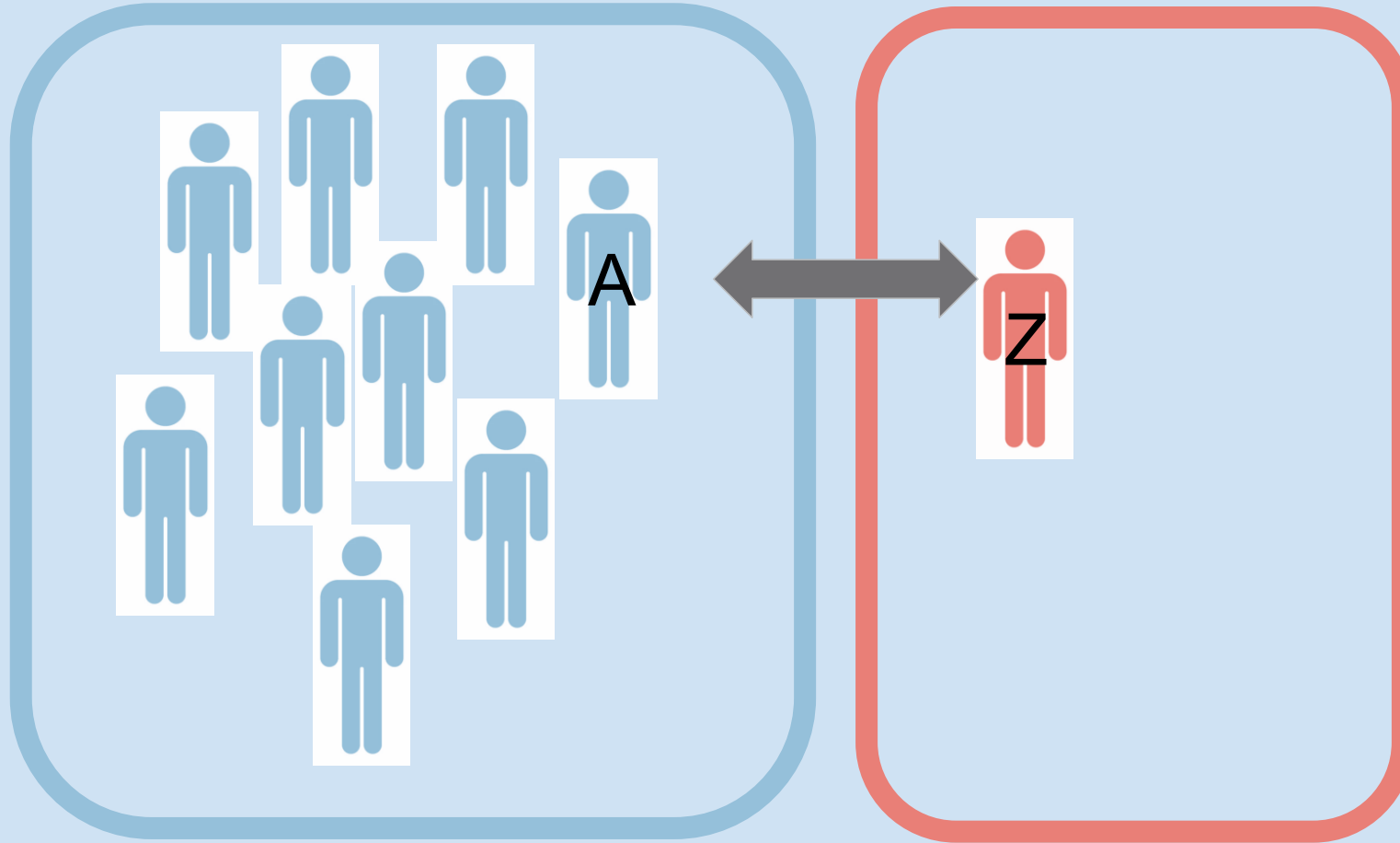


Learning Objective 2

From Logic of contagion to flow diagrams

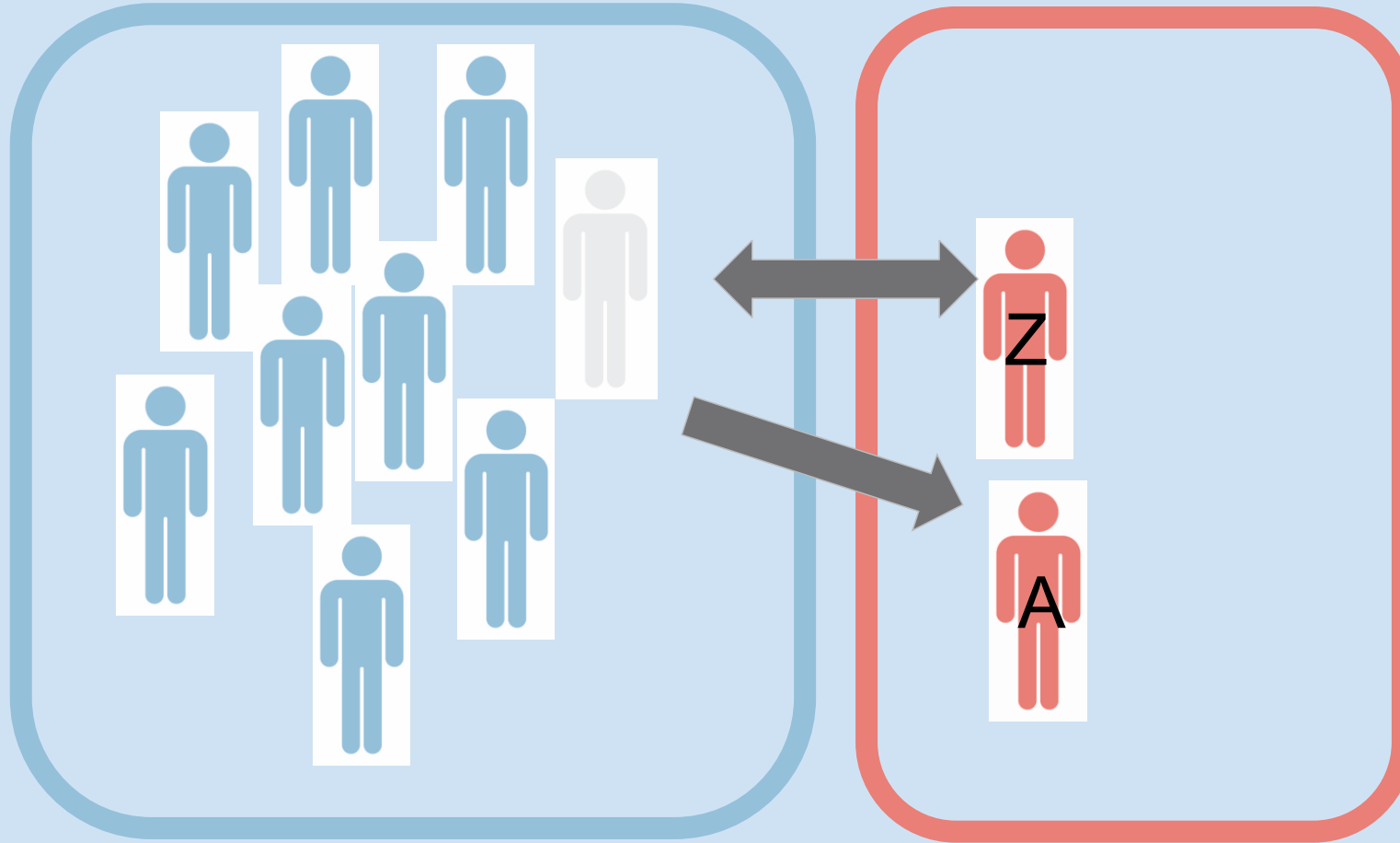
Transferring people between boxes - transitions

Contagion process - simplified



Transferring people between boxes - transitions

Contagion process - simplified

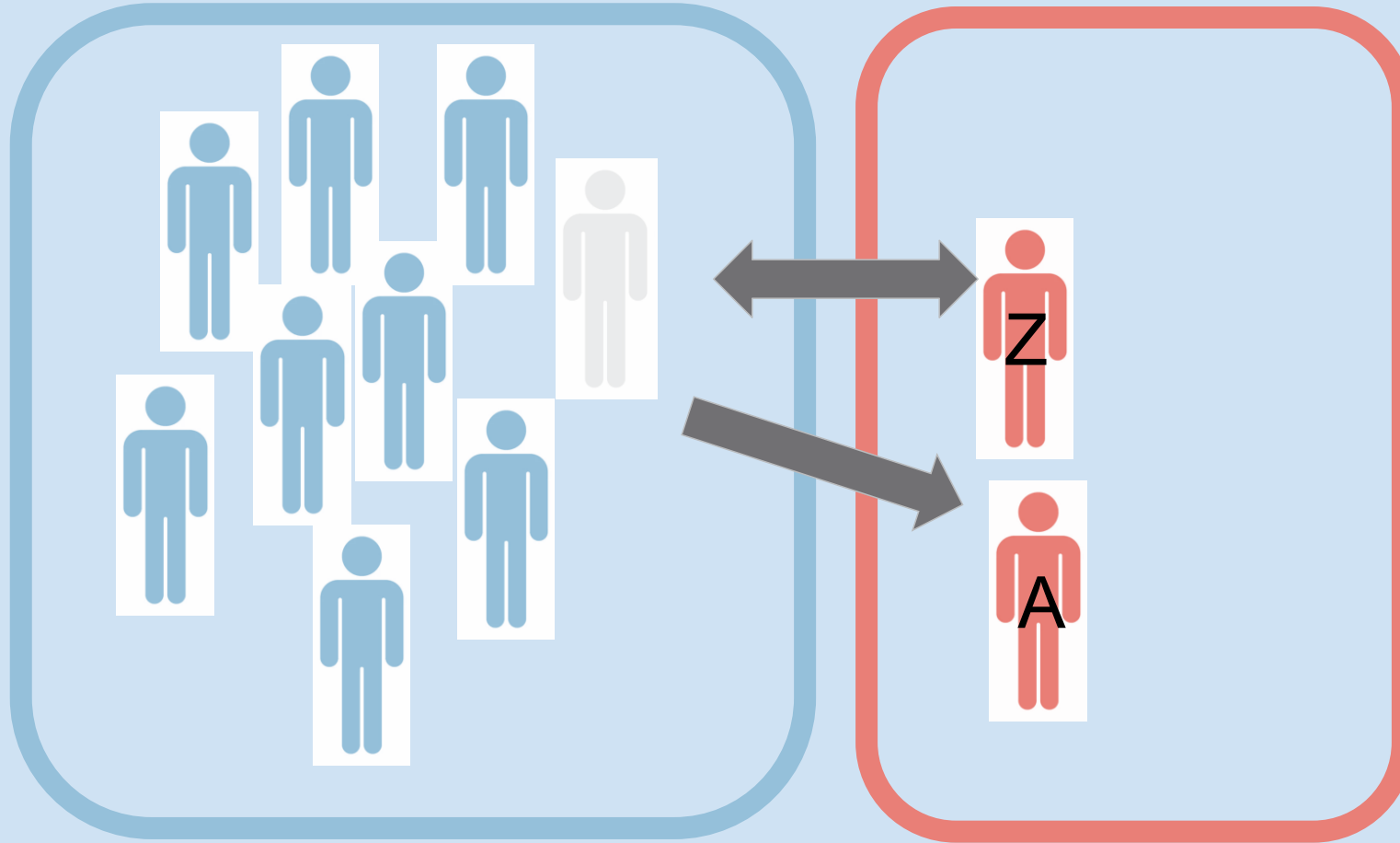


from healthy to sick
TRANSMISSION

depends on **encounter**
between sick and healthy
individual

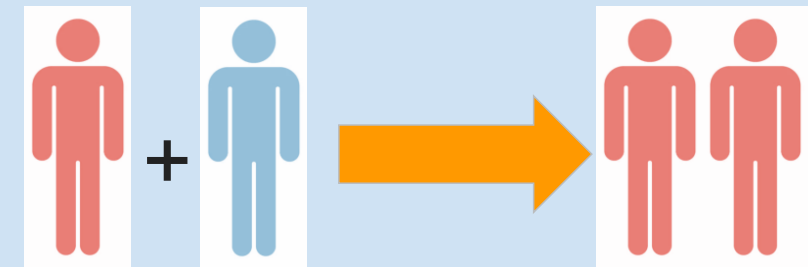
Transferring people between boxes - transitions

Contagion process - simplified



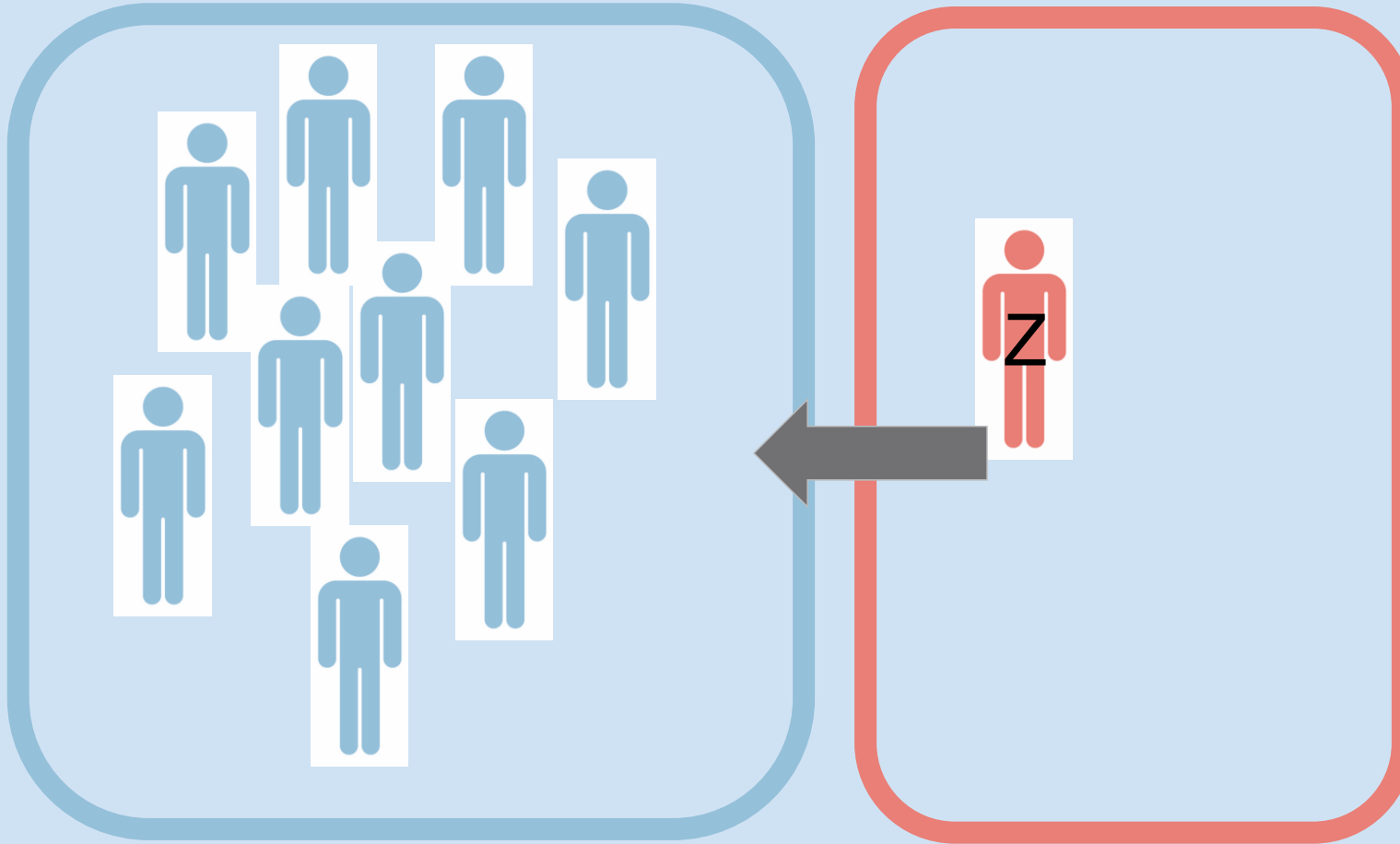
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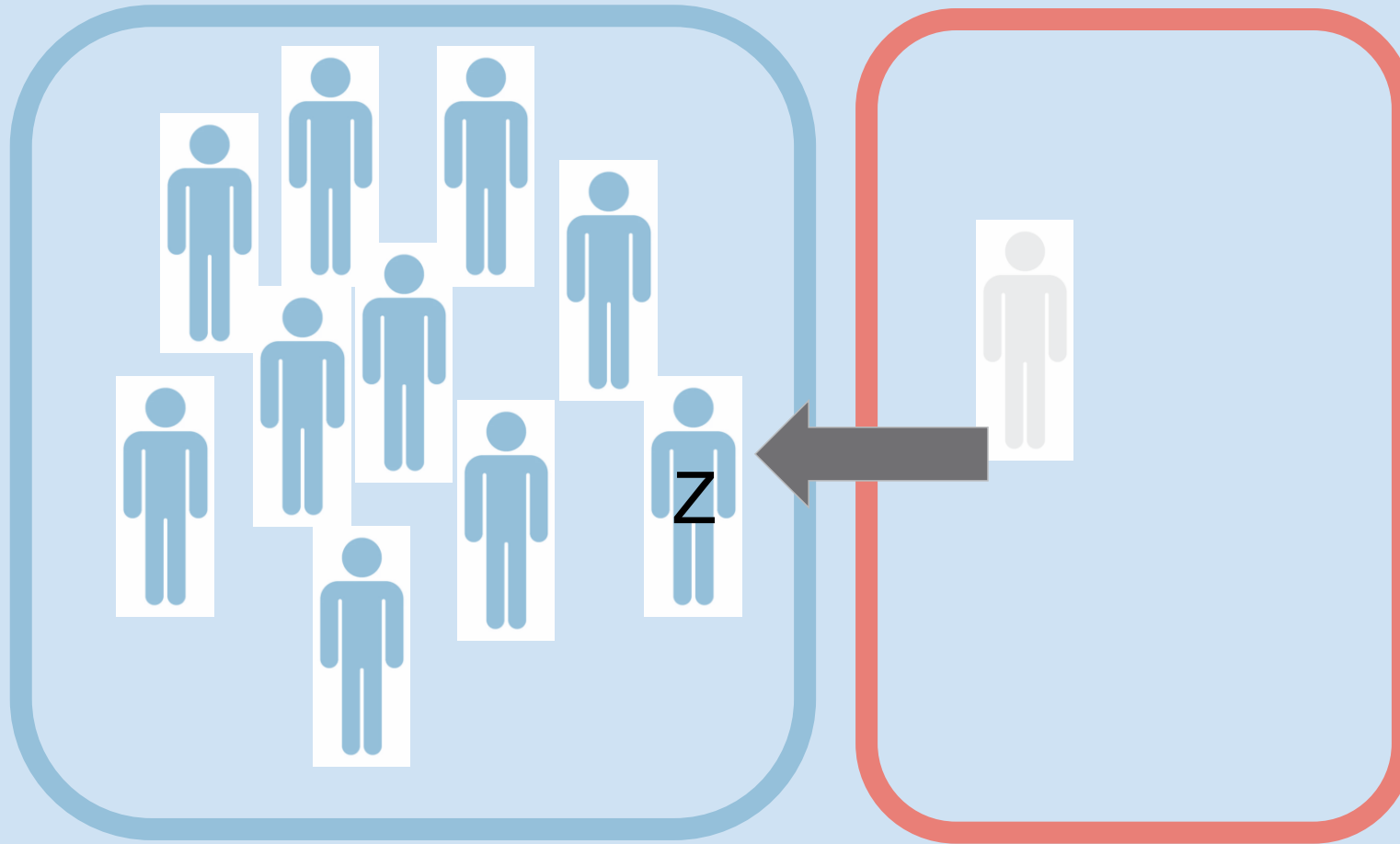
Transferring people between boxes - transitions

Contagion process - simplified



Transferring people between boxes - transitions

Contagion process - simplified



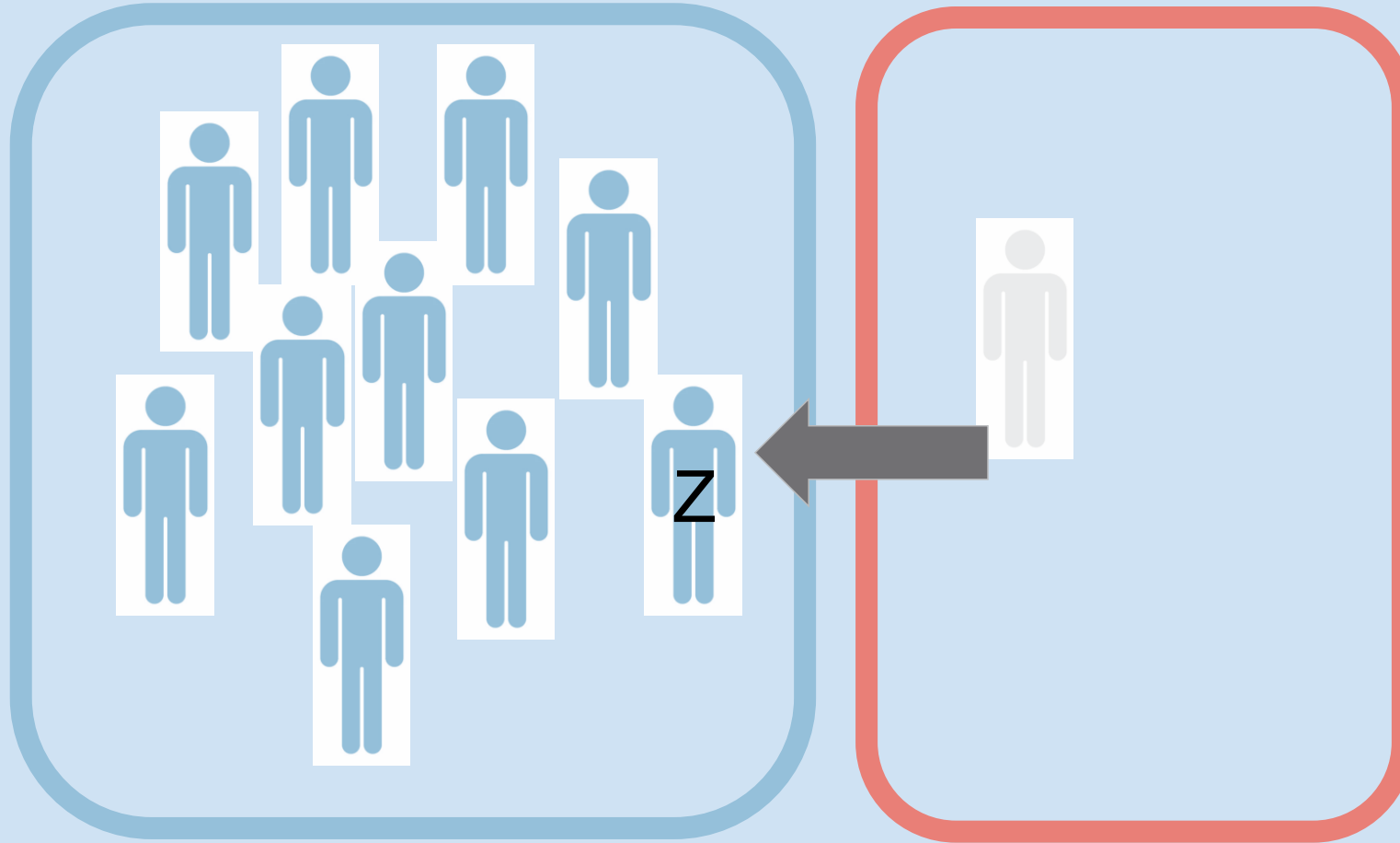
from sick to healthy

RECOVERY

depends **only** on **sick**
individual

Transferring people between boxes - transitions

Contagion process - simplified

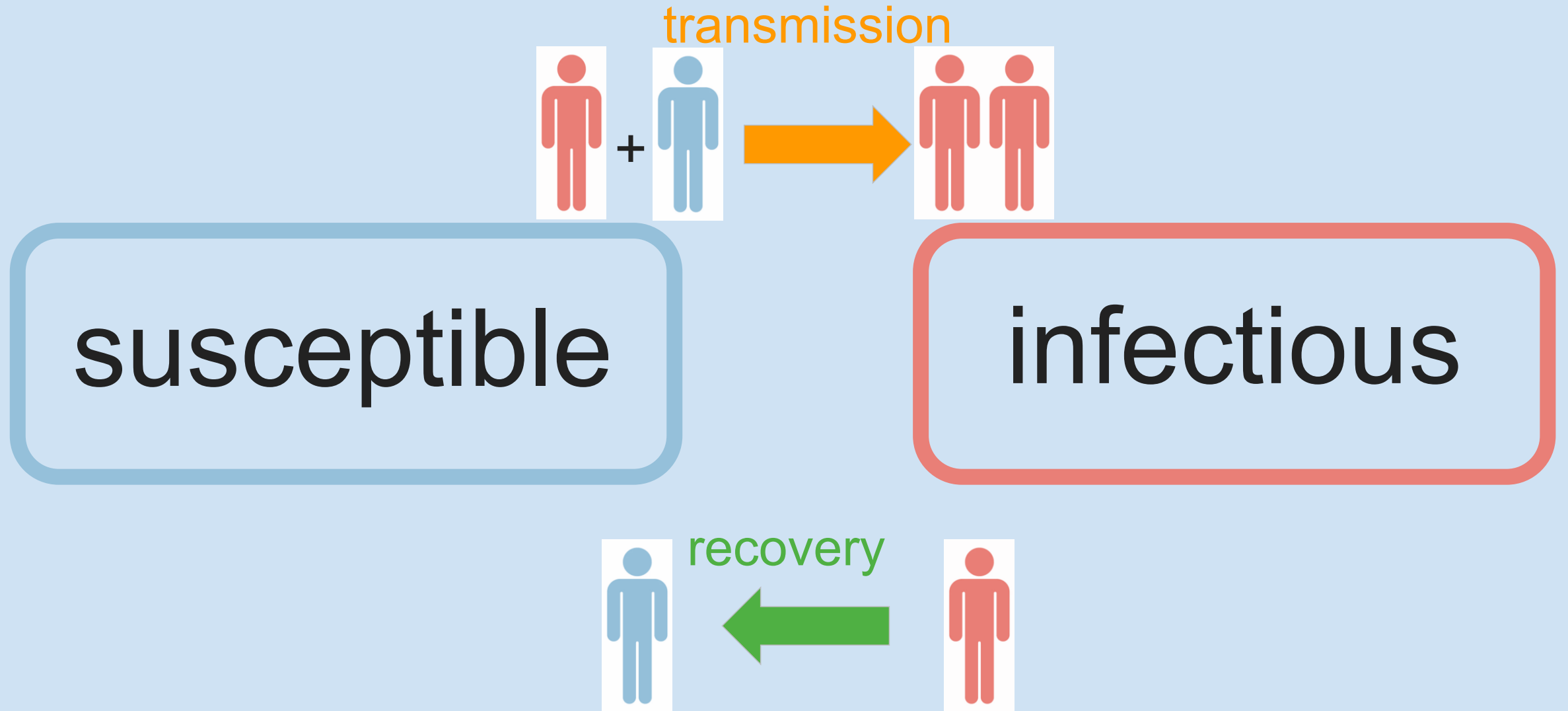


from sick to healthy
RECOVERY

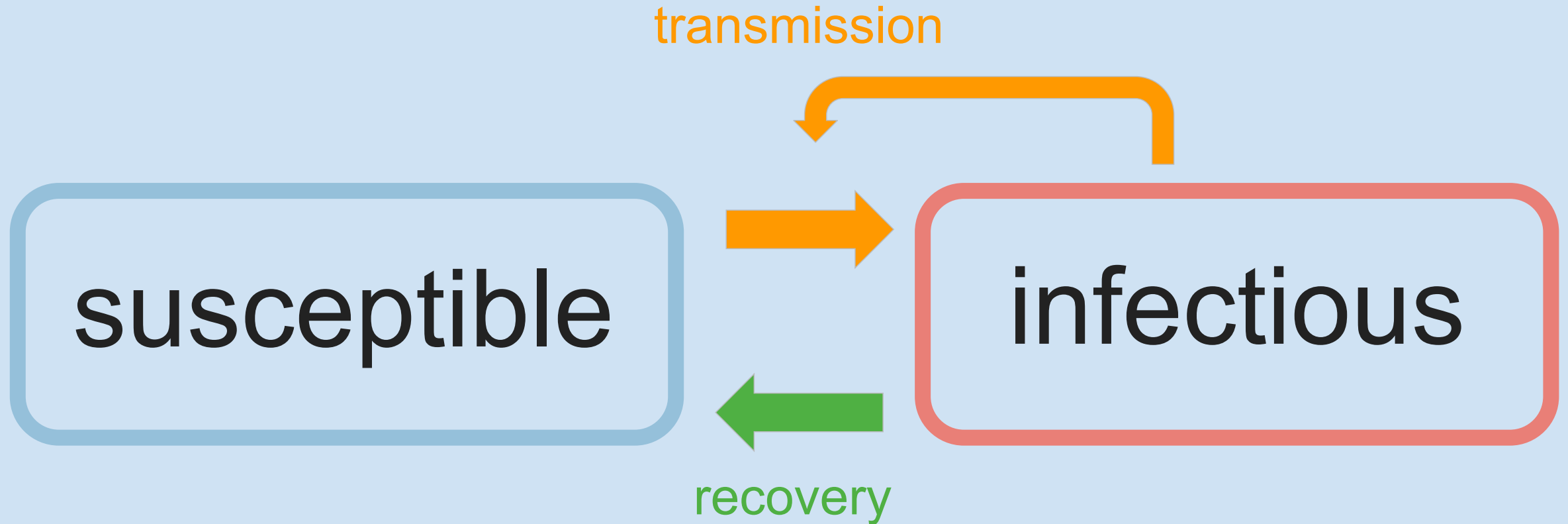
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individual



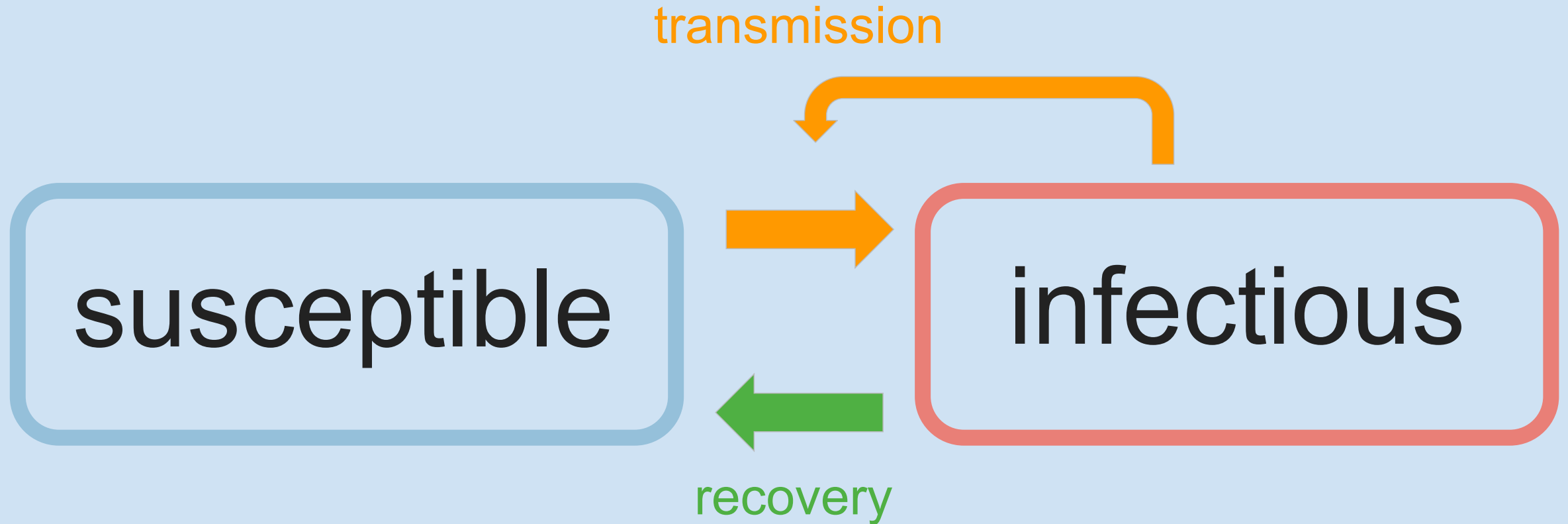
Flow diagrams for disease transmission



Flow diagrams for disease transmission

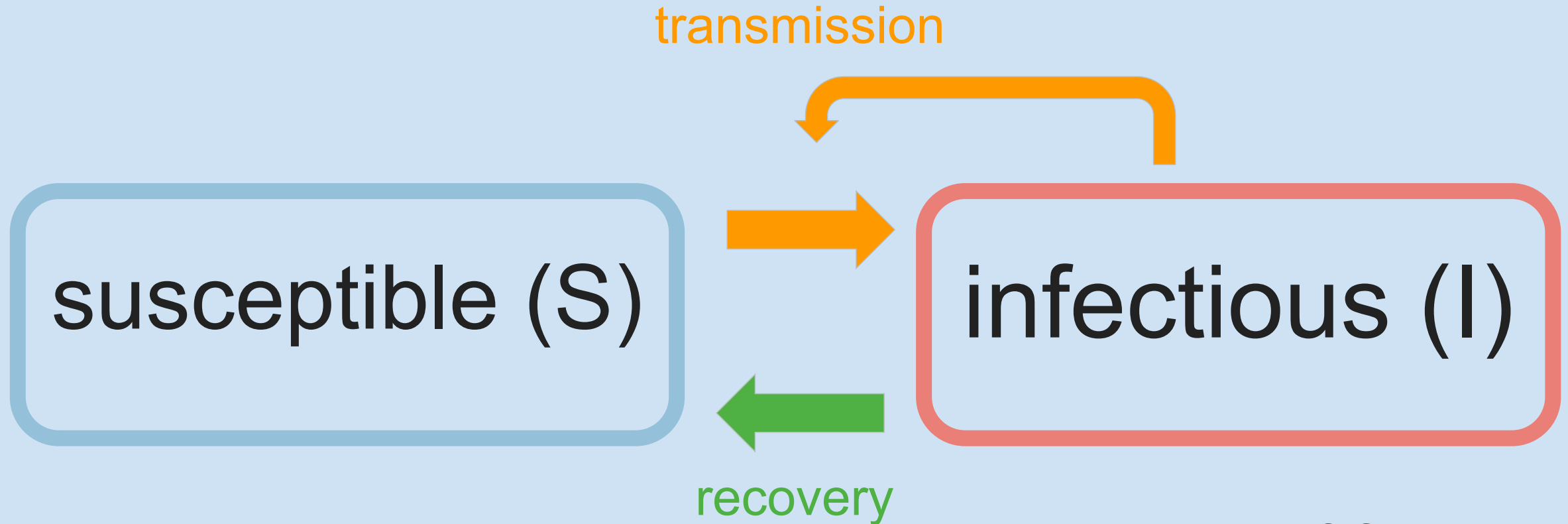


Flow diagrams for disease transmission



SIS model

Flow diagrams for disease transmission



SIS model

the name **SIS** is
shorthand for the
compartment labels
and **flow** of the
contagion process

Flow diagrams for disease transmission: assumptions!

We need to be clear about the underlying assumptions:

Hypothesis A: Individuals become immediately also infectious upon infection

Hypothesis B: There are no births or deaths in the population, there is no migration.

Hypothesis C: Once an individual recovers, it will become immediately susceptible again.

Hypothesis D: All susceptible hosts are equally likely to meet an infected host.



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Flow diagrams for disease transmission: assumptions!

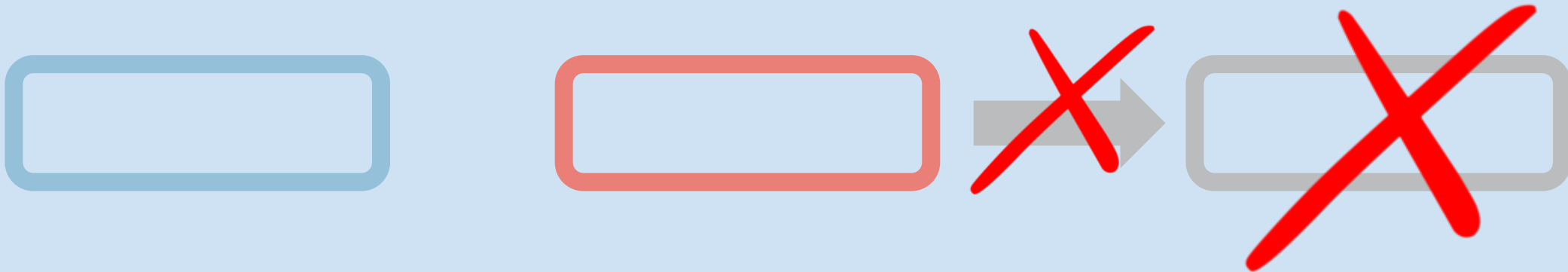
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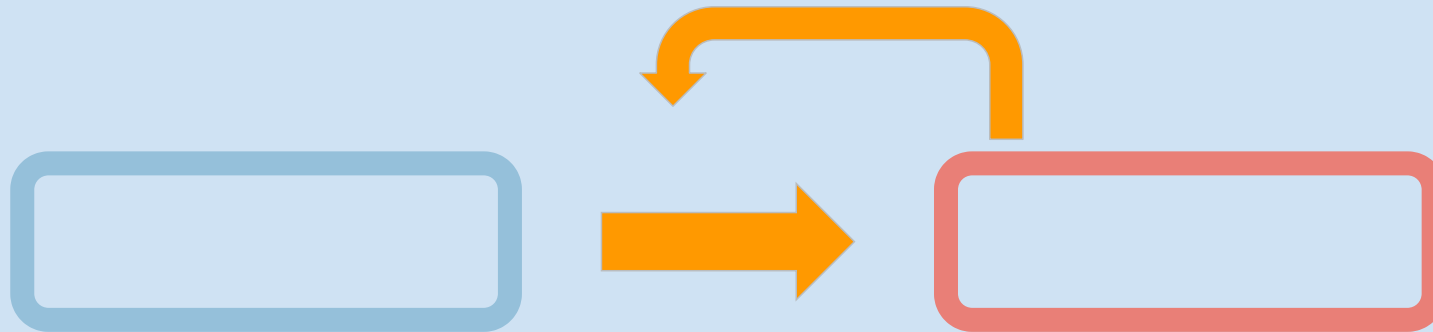
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Hypothesis D: All susceptible hosts are equally likely to meet an infected host.

rate for new infection depends on relative proportion of infectious individuals



Flow diagrams for disease transmission

- **What are some of the diseases that the SIS model can be applied to?**
 - Individuals can get reinfected after recovery

Flow diagrams for disease transmission

- **What are some of the diseases that the SIS model can be applied to?**
 - Individuals can get reinfected multiple times
 - **Eg: Common cold, malaria, STIs, etc**



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Practical session

Practical 1

SIS with incubation = SEIS

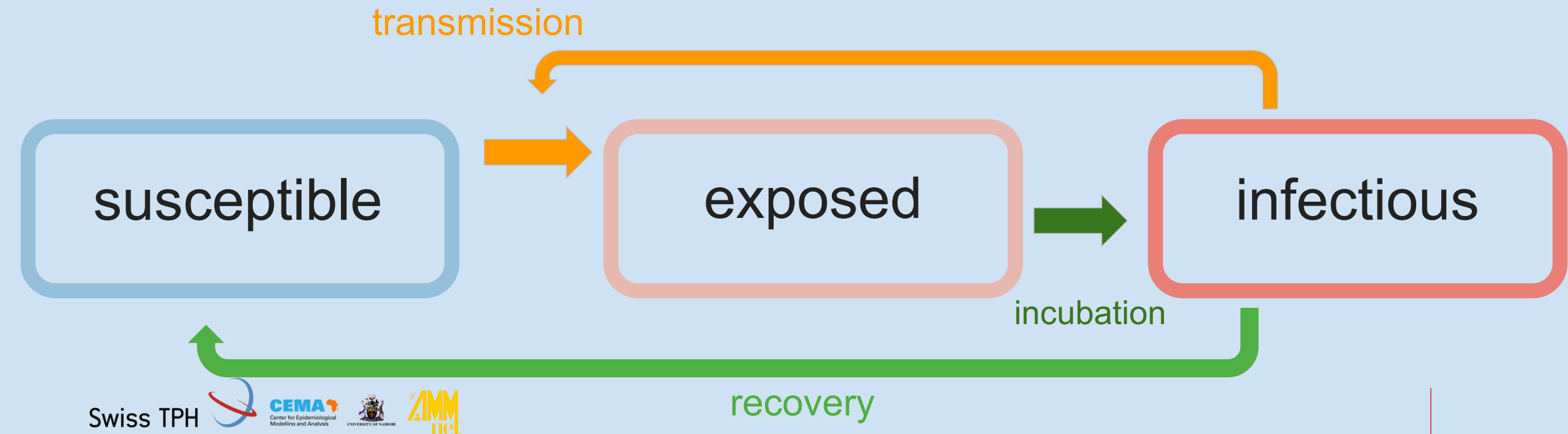
After being exposed to an infection, susceptible individuals do not immediately become infectious, the incubation period is the time it takes between exposure and infection:

- Draw flow diagrams for SEIS models treatment!

Practical 1 - solution 1

SIS with incubation = SEIS

After being exposed to an infection, susceptible individuals do not immediately become infectious, the incubation period is the time it takes between exposure and infection:



Practical 2

SIS with treatment = SITS

For the SIS disease, treatment is available

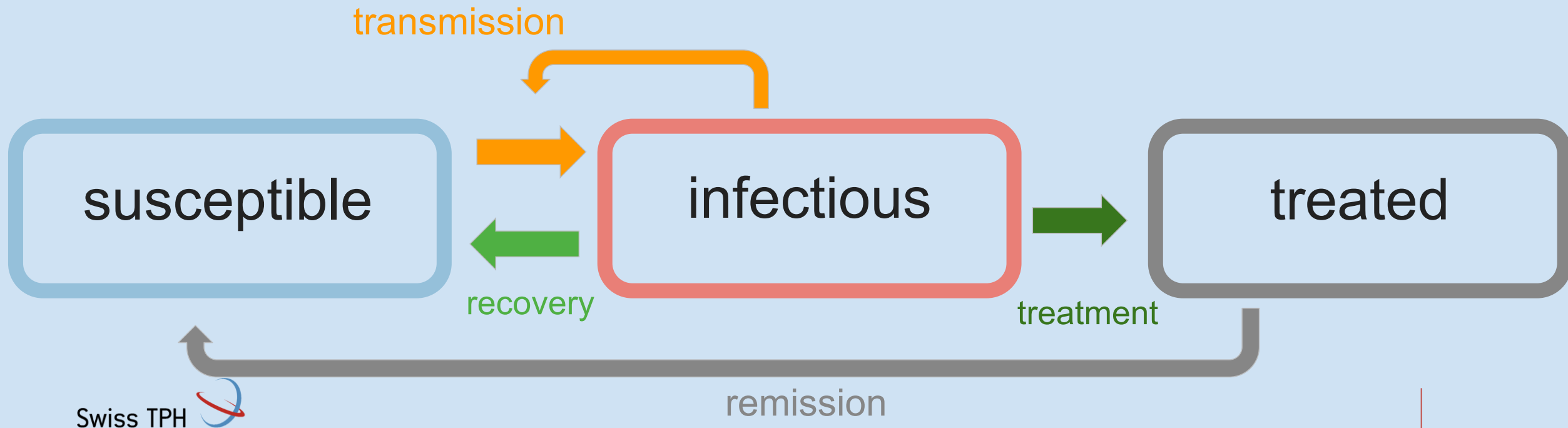
- only infected (presumably symptomatic) individuals get treated
 - while on treatment, individuals are not infectious
 - once the treatment period is over, individuals become susceptible again
-
- Draw flow diagrams for SITS models.

Practical 2 - solution 1

SIS with treatment = SITS

A treatment for the disease is available:

- only infected (presumably symptomatic) individuals get treated
- while on treatment, individuals are not infectious
- once the treatment period is forgone, individuals become susceptible again



Day 2 - Tutorial (Tasks 1 & 2)

Ebola transmission

A small rural village is home to many families. Most people are healthy and susceptible to Ebola. One day, a hunter prepares bushmeat from a wild animal that carries the Ebola virus. While butchering the animal, the hunter gets infected. At first, he does not feel sick — he is in the exposed stage, carrying the virus but not yet infectious.

After a few days, the hunter develops fever, weakness, and vomiting. He is now infectious and can spread Ebola to others through close contact with his blood, sweat, vomit, or other body fluids. Family members who care for him, and health workers without proper protective equipment, can also be infected.

Others sadly die. The bodies of people who die from Ebola remain highly infectious. During funeral rites, family and friends may touch or wash the body, leading to more people being exposed and infected.

Day 2 - Tutorial (Tasks 1 & 2)

Ebola transmission

Task 1: Draw a **flow diagram** showing these compartments and the arrows between them, including how transmission occurs from both infectious people in the community, in the hospital and at the funeral.

Task 2: The health authorities need to **counteract** the epidemic. Based on the model flow diagram, what is your recommendation?

Task 3: Researchers discovered that only a small number of the recovered individuals have broadly neutralizing antibodies (*bnAbs*) in their peripheral blood. Blood transfusions from these donors are used to cure infected individuals. Draw the flow diagram including the treatment with **bnAbs**.

Task 4: Later, the vaccine is introduced. Only individuals which have not yet been exposed can get vaccinated. Draw the flow diagram including **vaccination**.

Day 2 - Tutorial (Tasks 1 & 2)

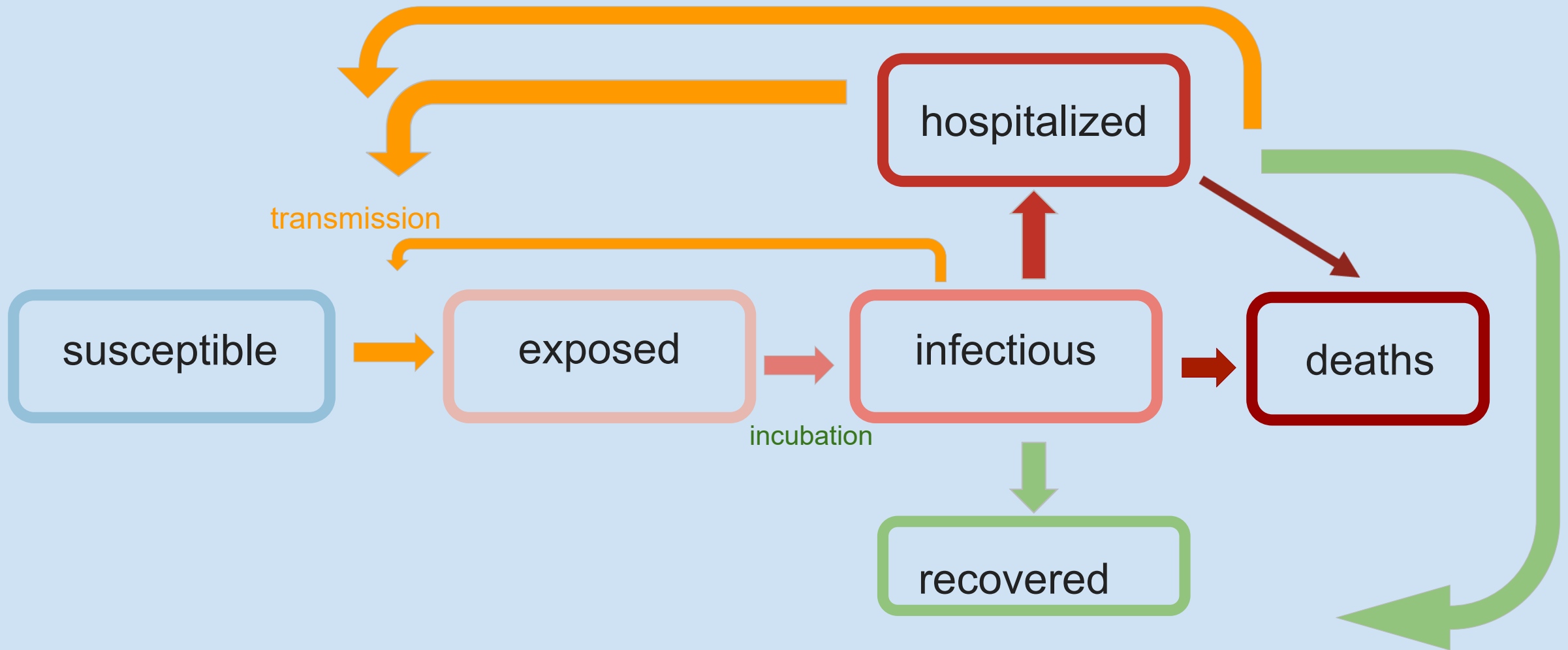
Ebola transmission

Hints:

- The SIS model that we did in class was not applied to any specific disease, but here we need to draw the flow diagram for Ebola.
- Therefore we need to have an understanding of Ebola transmission
- Understand the compartments we are interested in
- Understand the disease progression processes
- All these will inform our model assumptions

Practical 3 - solution 1

Ebola model



Acknowledgements



- Christian Selinger
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- Geoffrey Githinji

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