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The Potential of Simulation Technologies : Multi Agent Simulation & Reinforcement Learning

Satoki Fujita, Shogo Miyazawa, Ryo Kiguchi, Yuki Yoshida,
Katsunari Hirano, Yoshitake Kitanishi

Shionogi & Co., Ltd.

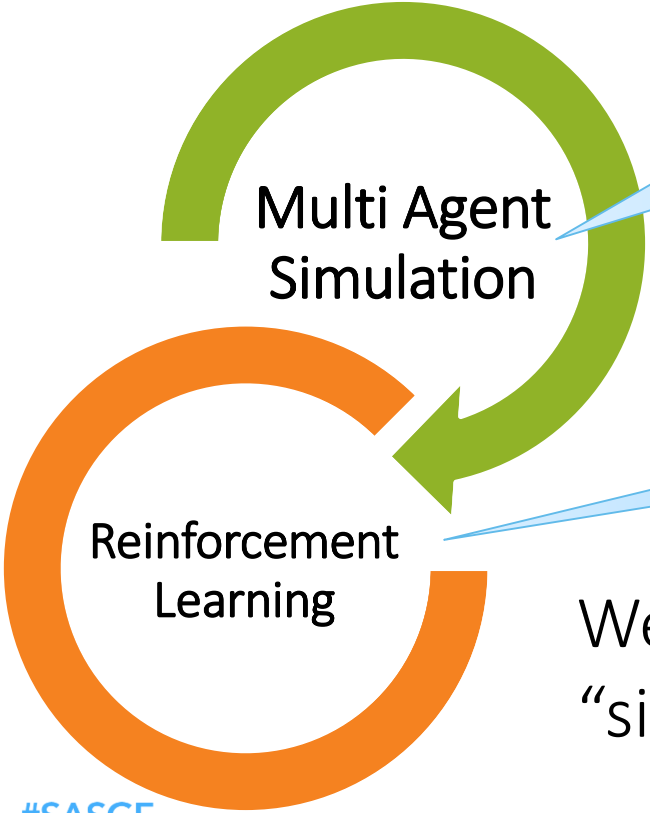
The Potential of Simulation Technologies :
Multi Agent Simulation & Reinforcement Learning

Satoki Fujita, Shionogi & Co., Ltd.

Satoki Fujita has been working for Shionogi for two years as a Data Scientist. He is actively working on the application of artificial intelligence technology by using various analysis software.

Introduction

Motivation



Flexible reproduction of various situations

Optimal decision making

We introduce the usefulness of "simulation" in this era of rapid change.

Background

Needs for simulation

- Pandemic
- Traffic jam
- Christmas Day
- Earthquake
- Launch of new products

How do these events affect the subjects (society, economy, people etc.) ?

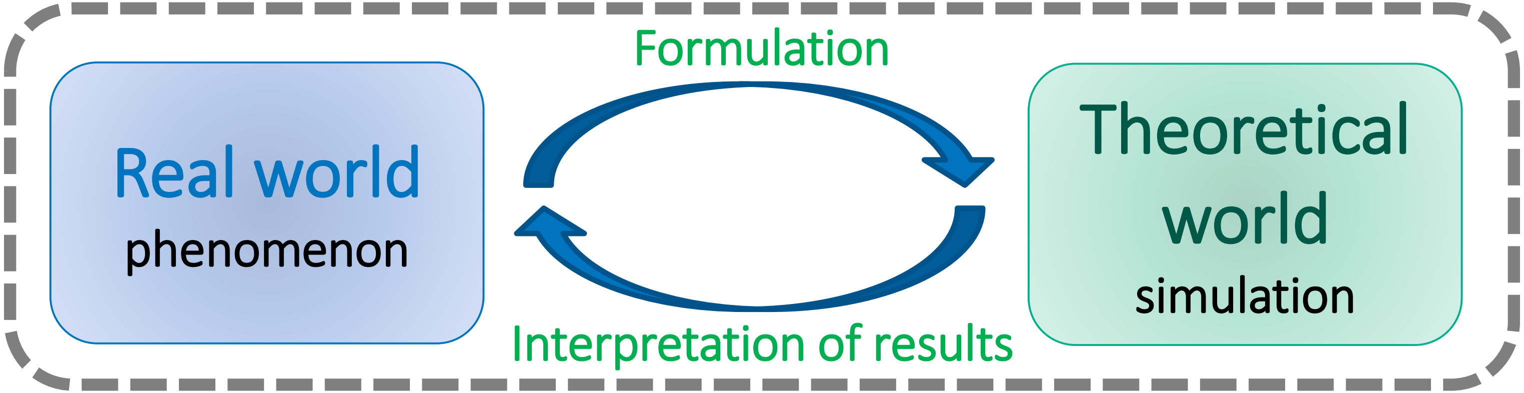
Background

Needs for simulation

What kind of phenomenon can occur due to the influence of various changes (events) ?

How to predict and deal with it?

→ Formulate and Reproduce the phenomenon by "Simulation" !

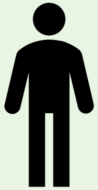


Background

Multi Agent Simulation

- There are many situations where it is difficult to accurately incorporate the whole phenomenon itself into a mathematical model

Example）Infection spread



- With or without mask
- Frequent outings or refrain from going out
- Vaccination or not
- Occupations etc.

Problem **Each person's environment, behavior pattern are not same**

➡ It is difficult to predict how each person interacts with each other and how the infection spreads as a whole.

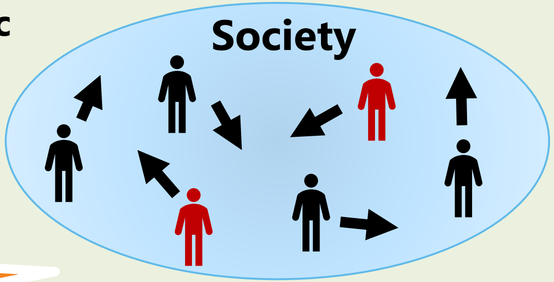
We can solve this problem by using the simulation method "Multi Agent Simulation"！

Background

Multi Agent Simulation

- **Multi Agent Simulation (MAS)**
  - ➢ A method of grasping the entire target phenomenon by making agents (people, things etc.) act autonomously based on certain rules and seeing the results caused by their interaction.

Example) Pandemic



= Agent (Healthy)   = Agent (Infected)

By making each agent act autonomously, we want to know how the infection spreads.

Moreover

Is it possible to realize optimal decision-making through the virtual space reproduced by simulation?

→ Reinforcement Learning !

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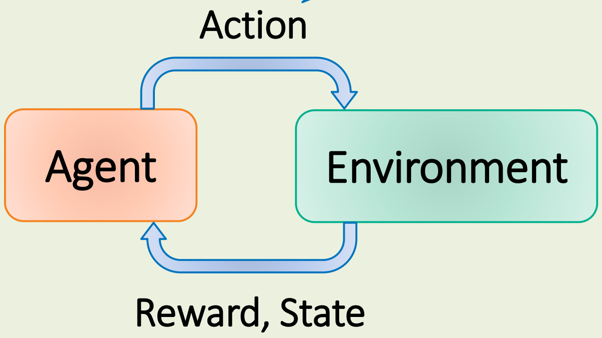
Background

Decision making using simulation

Choose Action to maximize Reward

- **Reinforcement Learning (RL)**
  - ➢ A method of searching for the optimum action that adapts to the environment through trial and error on a simulation.

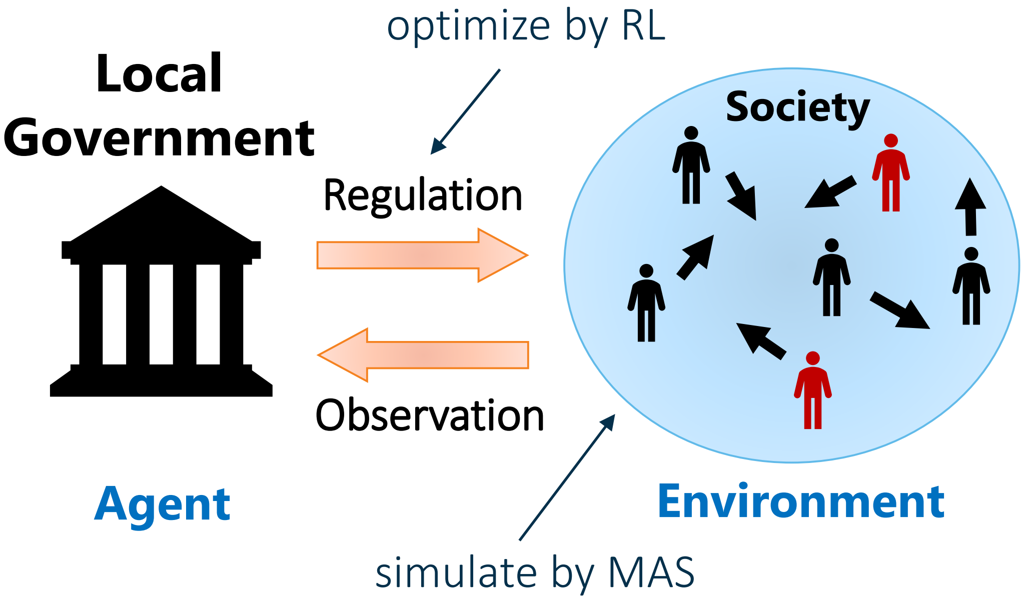


MAS + RL → **Reproduction of the real world & Optimal decision making !**

Background

Decision making using simulation

Example : Local Government response to pandemics



- Simulate the spread of infection in society, taking into account fine-grained interactions
- Optimize the number and timing of regulations (class closure, lockdown etc.) within the range that does not impact the economy by RL

In this presentation

Talking today

- As the first step to utilize simulation technologies in the situations where it is difficult to see ahead (like a pandemic), we will introduce about below

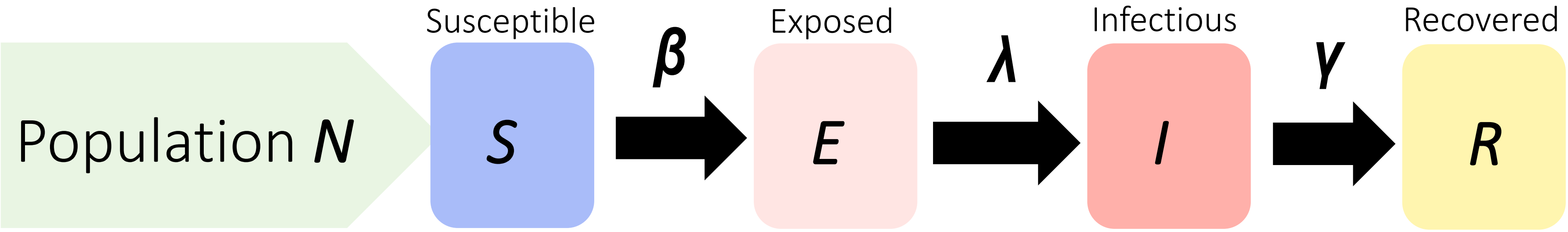
1. Typical infectious disease model : SEIR model
   - A brief overview
2. Reproduction of infection spread by MAS
   - Basic example
   - Application example
3. Optimal decision making by RL
   - Application example

This time, we will show our results in the infectious disease area.

Typical infectious disease model : SEIR model

Typical infectious disease model : SEIR model

A brief overview



This model indicate state transition of human (or other animals).
Basically, It is based on ordinary differential equation.

$$\frac{dS(t)}{dt} = -\beta S(t)I(t)$$

$$\frac{dE(t)}{dt} = \beta S(t)I(t) - \lambda E(t)$$

$$\frac{dI(t)}{dt} = \lambda E(t) - \gamma I(t)$$

$$\frac{dR(t)}{dt} = \gamma I(t)$$

β: infection rate

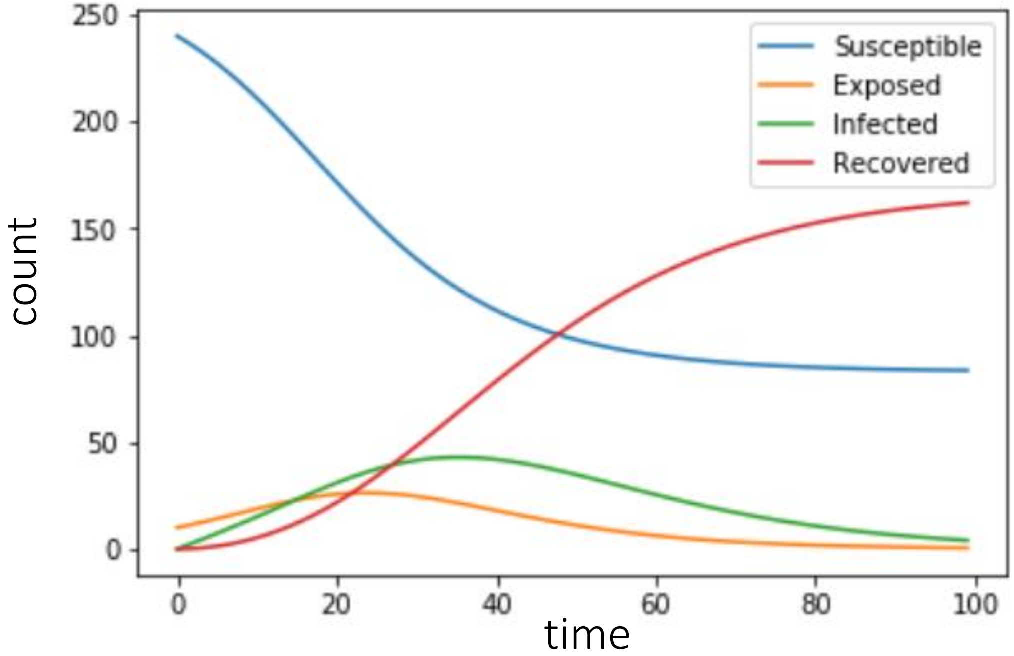
$1/\lambda$: average incubation period

$1/\gamma$: average infectious period

Typical infectious disease model : SEIR model

A brief overview

- By setting parameters (β, λ, γ), the SEIR model can represent the basic transition of infection spread status.



Typical infectious disease model : SEIR model

A brief overview

- However, in the real world, people with various characteristics and thoughts have their own behaviors, and it is doubtful whether the original SEIR model can express the spread of infection in consideration of their interaction.

"Multi Agent Simulation" can solve it

Reproduction of infection spread by MAS

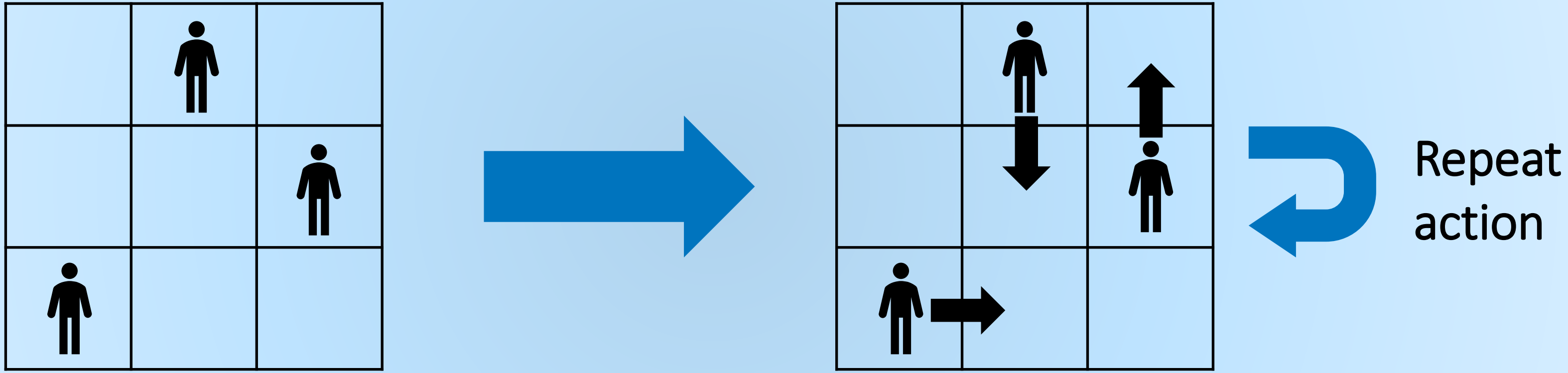
Reproduction of infection spread by MAS

Basic example

Infection spread simulation based on SEIR model

We assumed a grid-like field and placed each agent (person) in it

Each agent acts autonomously according to predetermined rules

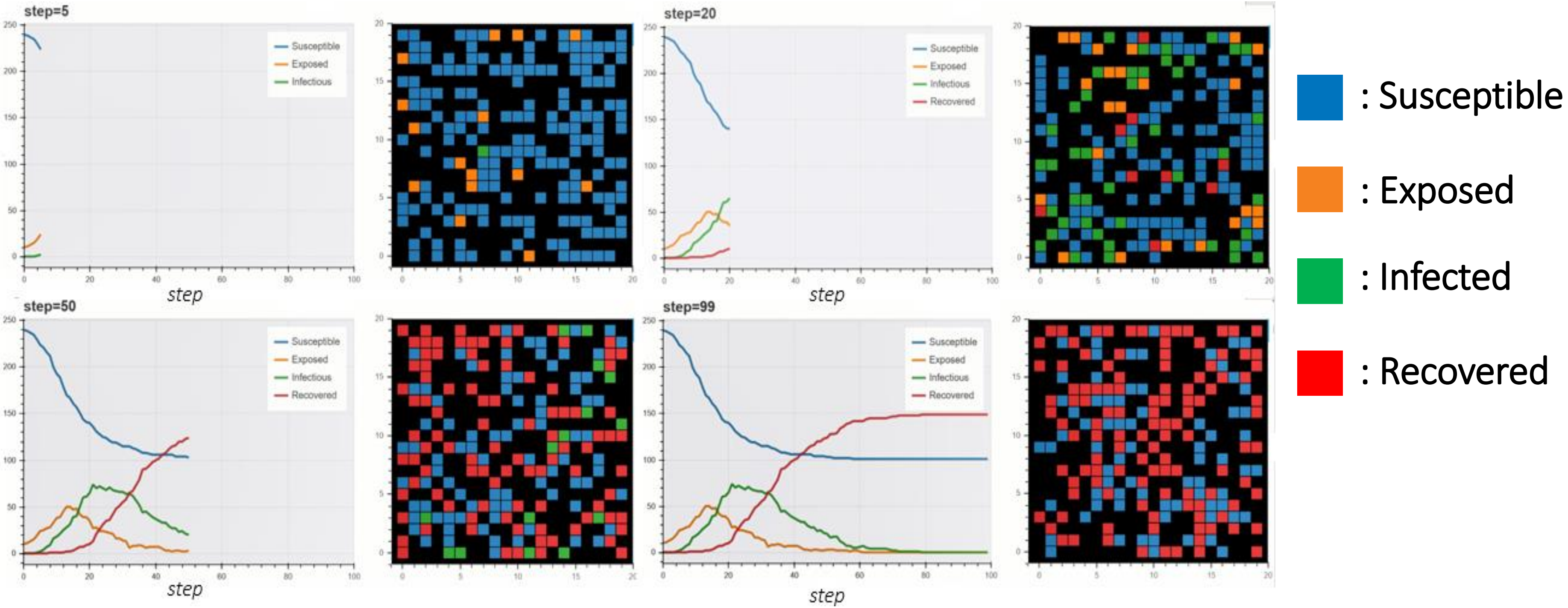


- Susceptible agents are infected from close Exposed agents in a constant rate (S⇒E)
- In about 3~9 days, Exposed individual transit to Infected states (E⇒I)
- Recover from Infection in about 7~21 days (I⇒R)

Reproduction of infection spread by MAS

Basic example

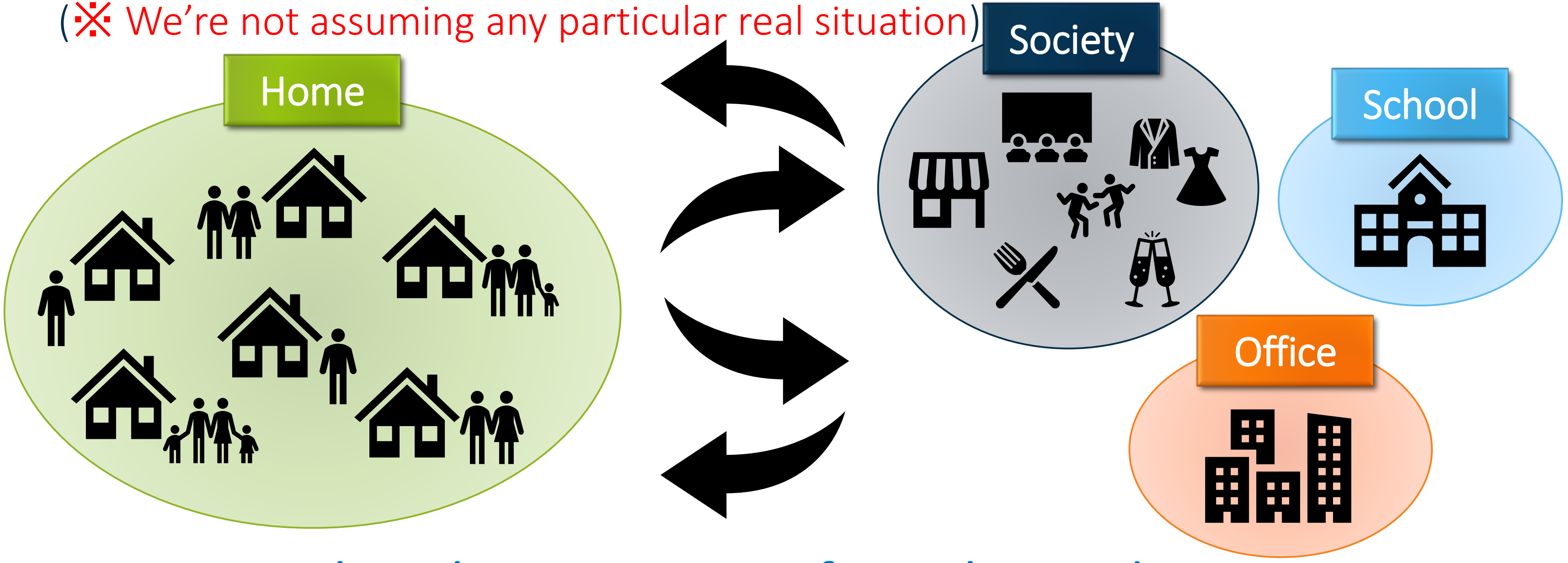
- Progress of infection spread using MAS



Reproduction of infection spread by MAS

Application example

- Reproduce a small community as a more realistic simulation
  (※ We're not assuming any particular real situation)

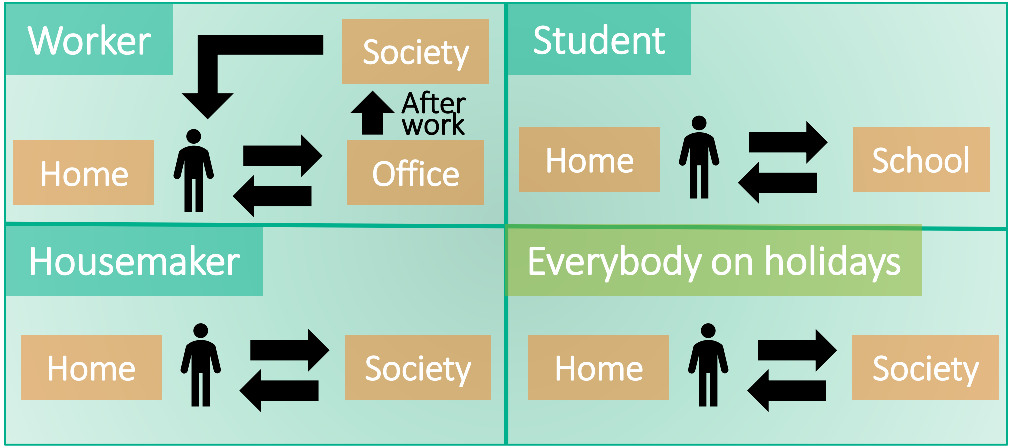


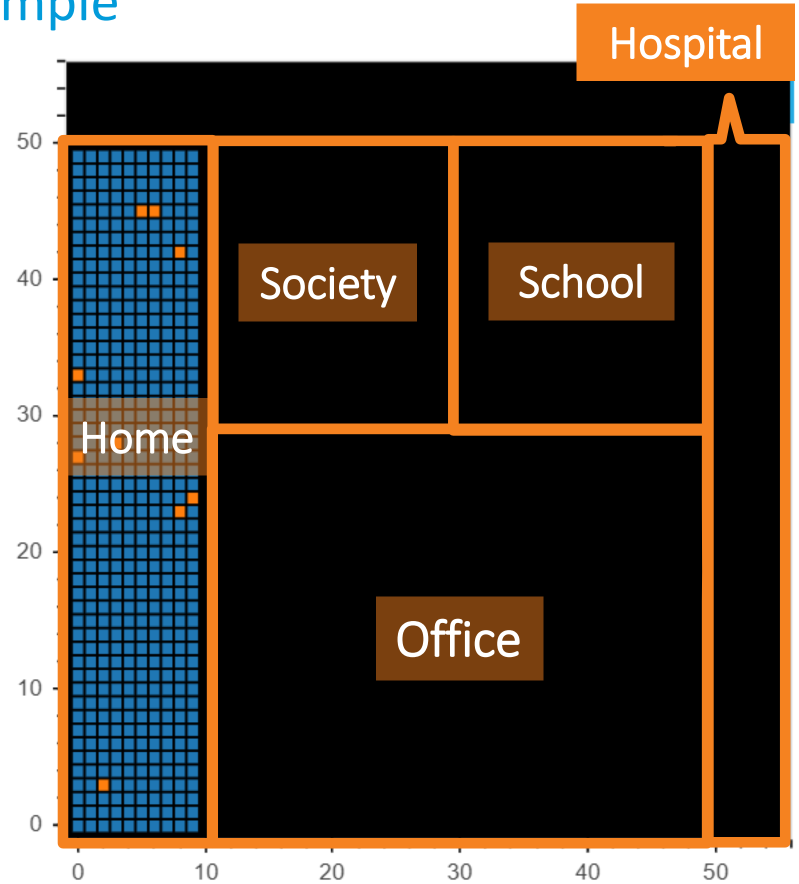
Simulate the movement of people in a day and see the spread of infection in it

Reproduction of infection spread by MAS

Application example

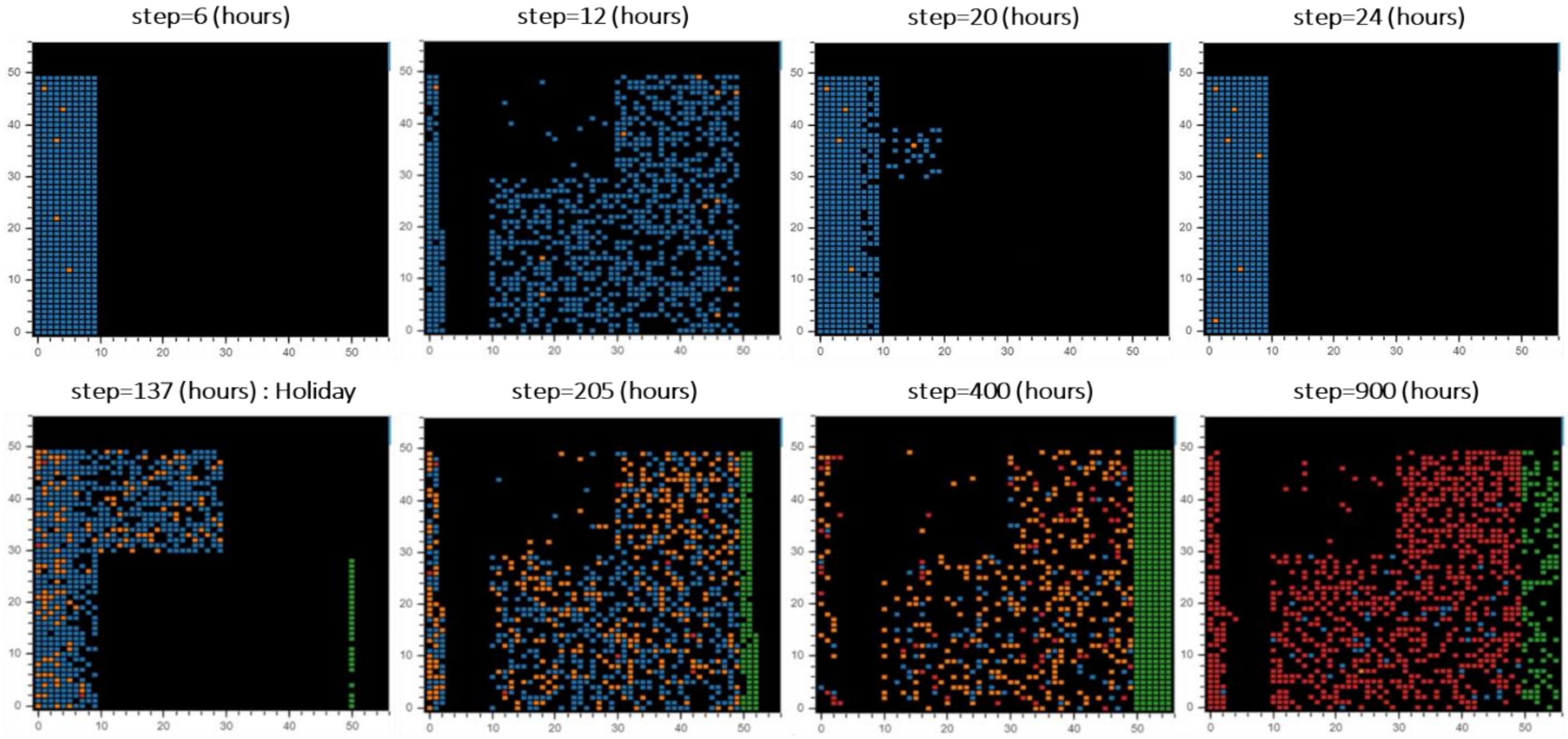
- 1step = 1hour
- Risk of infection within the same mass
- In the Home area, one mass represents one family house (or or or or)





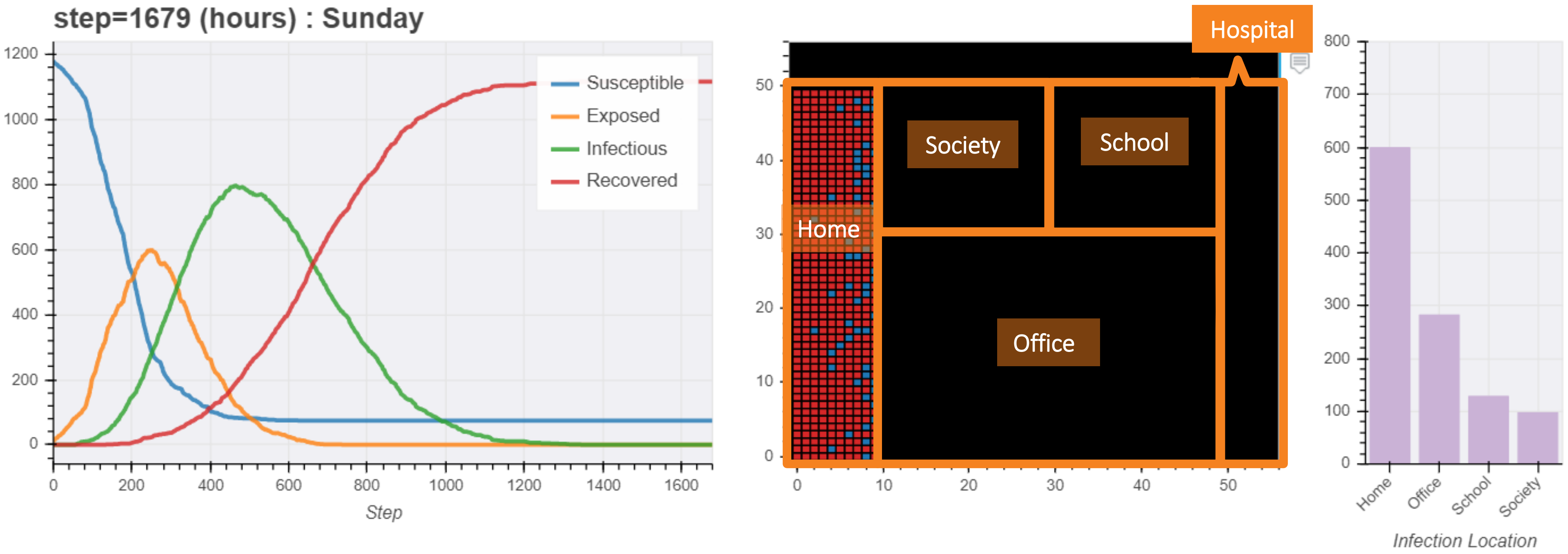
Reproduction of infection spread by MAS

Application example



Reproduction of infection spread by MAS

Application example



- In this simulation, infection within the family is the main cause of spread.

Reproduction of infection spread by MAS

Application example

- See what happens when we add regulations

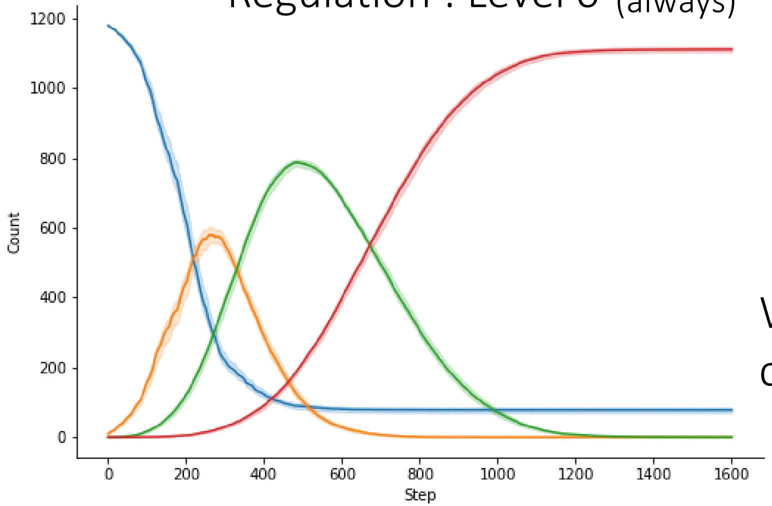
strict

Regulation	Wear facial coverings	Stay home after close contact with E state person uncovering	Telework (about a half Workers)	Going out restrictions	School Locked
Level 0	No	No	No	No	No
Level 1	Yes	No	No	No	No
Level 2	Yes	Yes	No	No	No
Level 3	Yes	Yes	Yes	No	No
Level 4	Yes	Yes	Yes	Yes	No
Level 5	Yes	Yes	Yes	Yes	Yes

Reproduction of infection spread by MAS

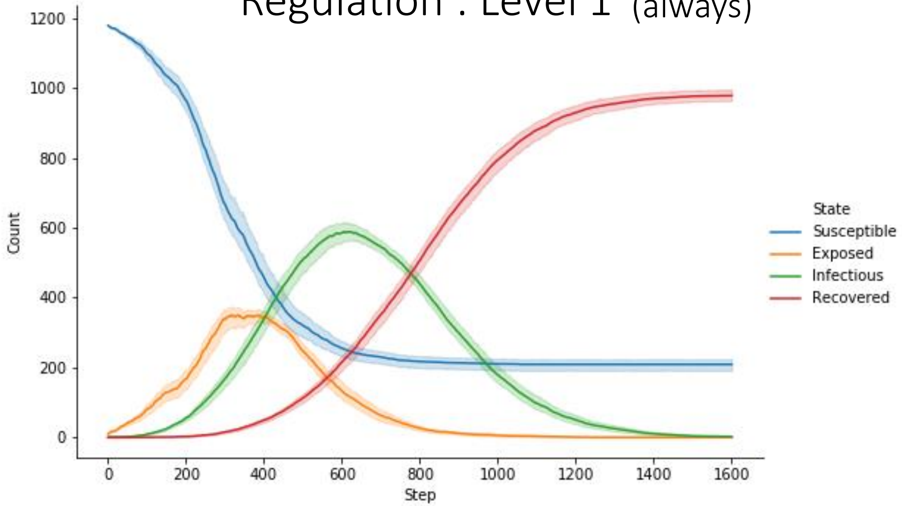
Application example

Regulation : Level 0 (always)



Wear facial coverings

Regulation : Level 1 (always)



- Assuming everyone wears facial coverings outside the Home (Infection rate at the time of close contact : 5%⇒3%)
- The maximum number of Infectious people has been reduced by about 200
  ⇒It is important to have a little awareness of infection prevention even when close contact.

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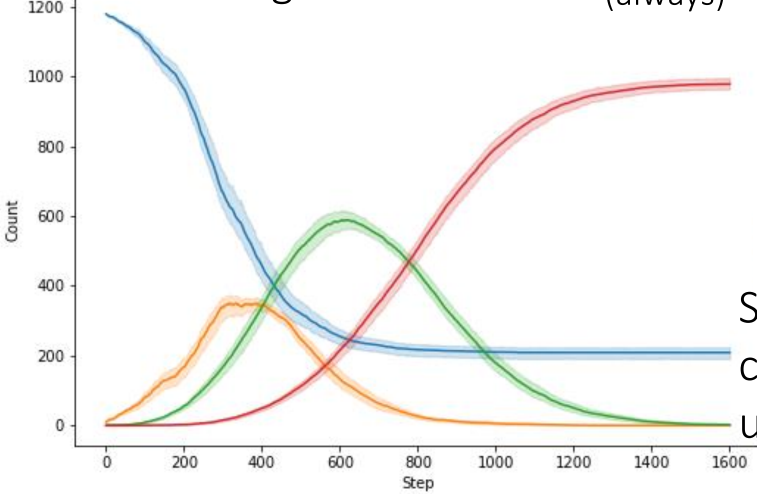
Reproduction of infection spread by MAS

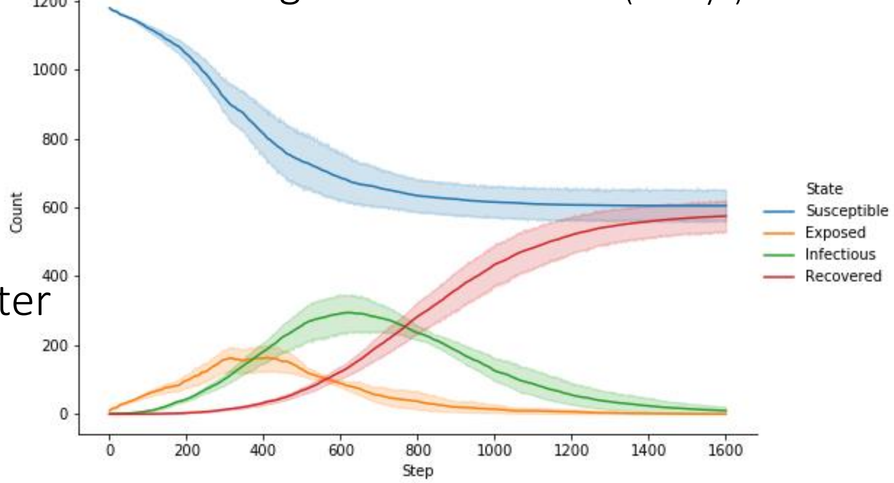
Application example

Regulation : Level 1 (always)



Stay home after close contact uncovering

Regulation : Level 2 (always)

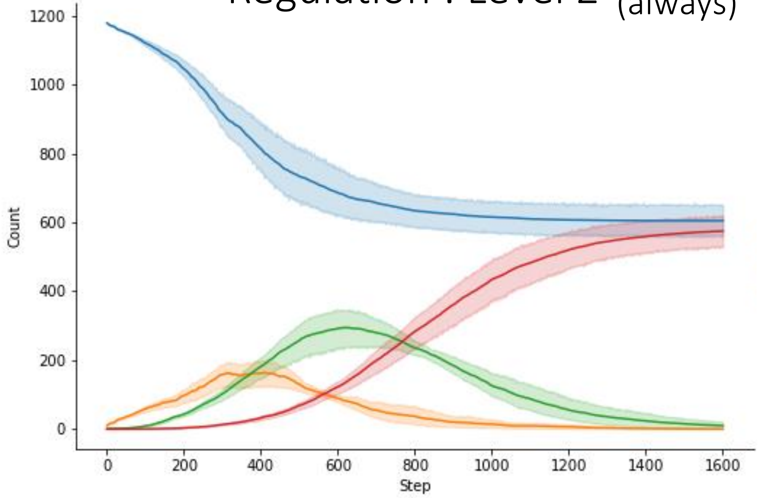


- A person who has had close contact with Exposed person in the past stays at home for 14 days from the timing when that person becomes Infectious.
- More people who have never been infected when the infection spread is over
  ⇒ Thorough facial coverings and Home quarantine can adequately control infection.

Reproduction of infection spread by MAS

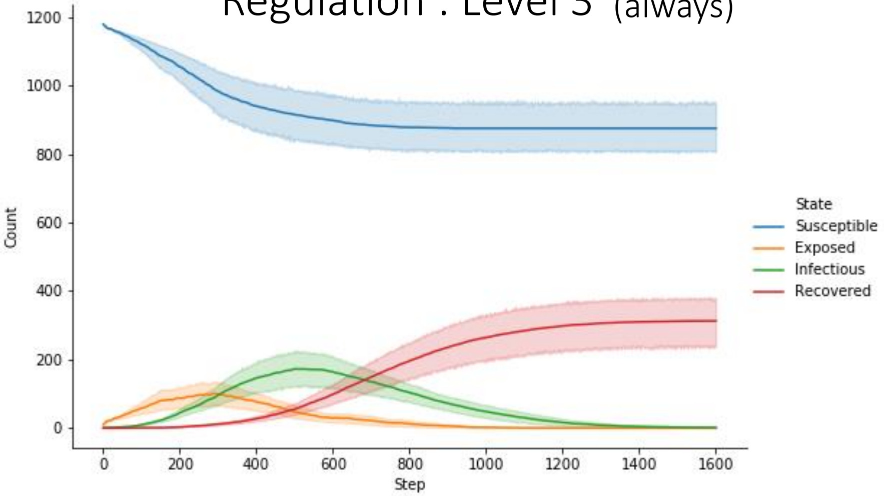
Application example

Regulation : Level 2 (always)



Telework

Regulation : Level 3 (always)



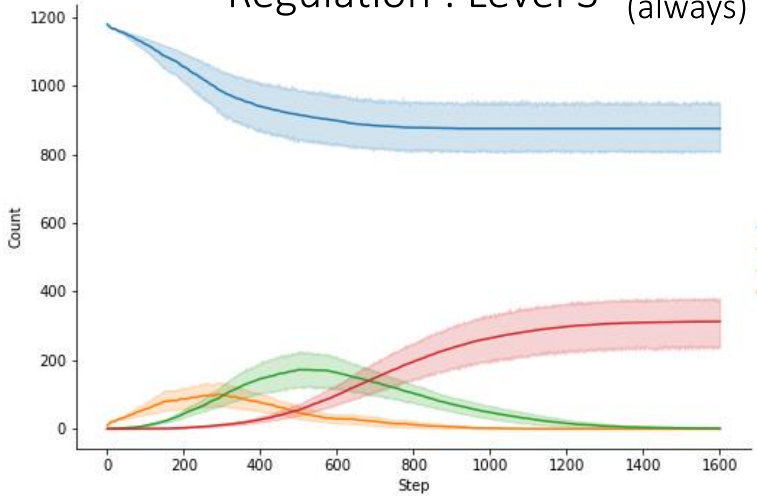
- Assuming about 50% of the Workers are teleworkers (do not go to Office)
- Things return to normal, leaving most people unaffected

  ⇒Closing the main source of infection is certainly an effective measure

Reproduction of infection spread by MAS

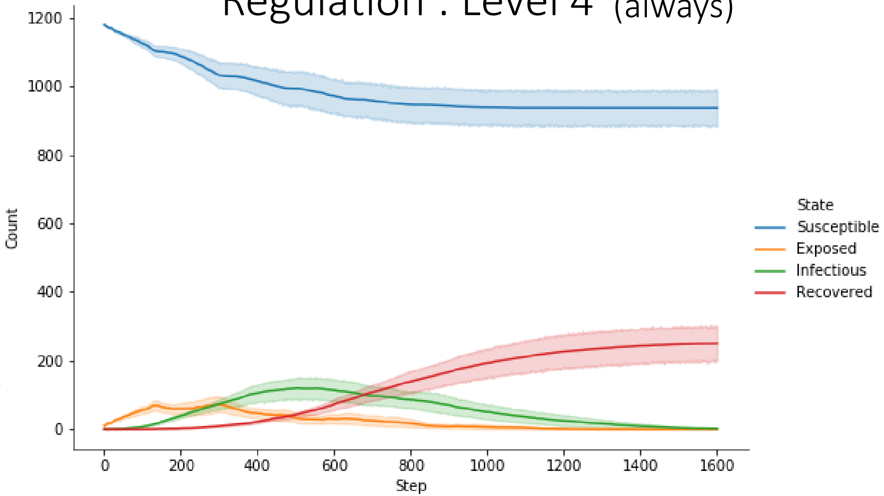
Application example

Regulation : Level 3 (always)



Going out restrictions

Regulation : Level 4 (always)

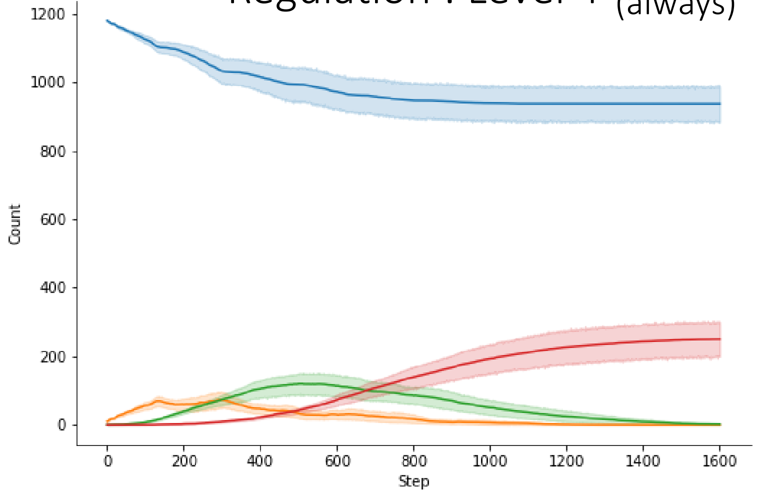


- Reduce maximum outing time on holidays for all people (12 hours→3 hours)
- Reduce maximum outing time on weekdays for Homemakers (2 hours→1 hours)
- Workers return home without detouring to Society after leaving the company
- The number of Infectious people has decreased slightly, but there is no big change because the spread has already been sufficiently suppressed by the regulations so far.

Reproduction of infection spread by MAS

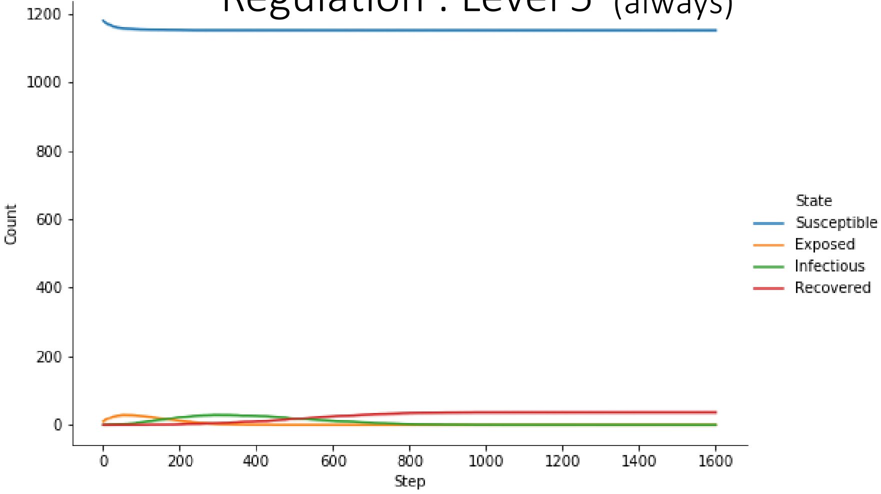
Application example

Regulation : Level 4 (always)



School Locked

Regulation : Level 5 (always)



- School closed and all Students studying at home
- Infection spread are controlled almost completely

However, if high-level regulations are maintained for a long time, it will not be effective in terms of economics and people's mental health etc..

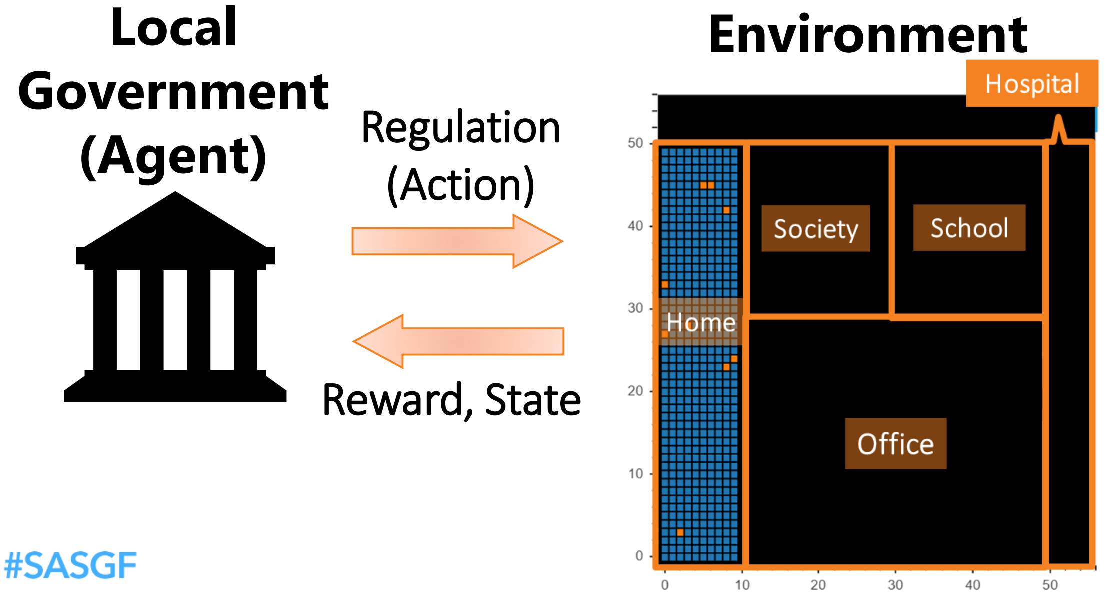
Find out the best regulation strategy with "Reinforcement Learning"

Optimal decision making by RL

Optimal decision making by RL

Application example

Use Reinforcement Learning to find the optimal strategy for preventing the spread of infection on the small community constructed by MAS earlier.



We need to set **Reward**, **State**, and **Action** in the framework of RL

Optimal decision making by RL

Application example

- Problem setting : Find the best Action strategy that
  - Do not allow the number of Infectious people ($:= n_I$) to exceed the maximum number of beds in hospital ($:= n_{bed}$) as much as possible
  - Do not make Regulation too strict

Regulation Level

- Action : select Regulation ($\in [0,1,2,3,4,5]$) on a weekly basis
- Reward : $= -\alpha \max\left(\frac{n_I - n_{bed}}{n_{bed}}, 0\right) - \beta \frac{\text{Regulation}^p}{\max \text{Regulation}^p}$

$(\alpha, \beta, p > 0)$

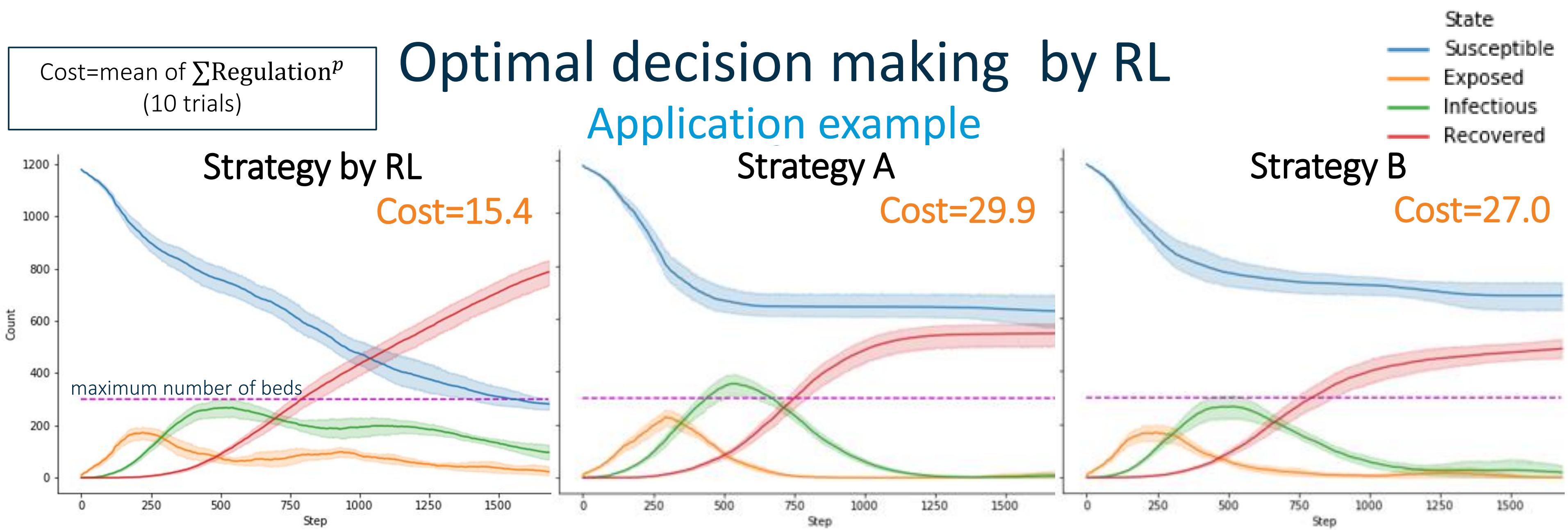
(Kompella et al. (2020))

- State (Observation) : the number of S, E, I, R people

Cost=mean of $\sum \mathrm{Regulation}^p$
(10 trials)

Optimal decision making by RL

Application example



ex. (1→3→3→1→0→2→1→0→0→0)

If ■ up⇒Regulation+1
else⇒Regulation-1
ex. (1→2→3→4→3→2→1→0→0→0)

If ■ up⇒ 3
else⇒Regulation-1
ex. (1→3→3→3→2→1→0→0→0→0)

- Settings : n_{bed}=300, period=10 weeks, starting level of Regulation=1
- The other two simple strategies may be better in terms of early convergence, but the strategies learned by RL are tuned so that they do not exceed the maximum number of beds while limiting their economic impact.

Conclusion

- In these days when the situation is changing rapidly, it is important to look ahead through simulation.
- Multi Agent Simulation is useful when micro-components can be described simply, even when it is difficult to model the entire phenomenon.
- If the phenomenon can be reproduced by simulation, it is possible to search for the best intervention strategy according to the request by Reinforcement Learning.
- In the future, We would like to apply them to more specific cases while paying attention to the validity of the model.

Conclusion

We would appreciate it if you feel
the potential of technologies such as

"Multi Agent Simulation"
and
"Reinforcement Learning",

and if this presentation could be the start
of utilizing these simulation technologies
in various fields.

Reference

1. Varun Kompella, Roberto Capobianco, Stacy Jong, Jonathan Browne, Spencer Fox, Lauren Meyers, Peter Wurman, and Peter Stone. 2020. Reinforcement Learning for Optimization of COVID-19 Mitigation policies. *arXiv preprint arXiv:2010.10560* (2020).
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Thank you!

Contact Information
satoki.fujita@shionogi.co.jp