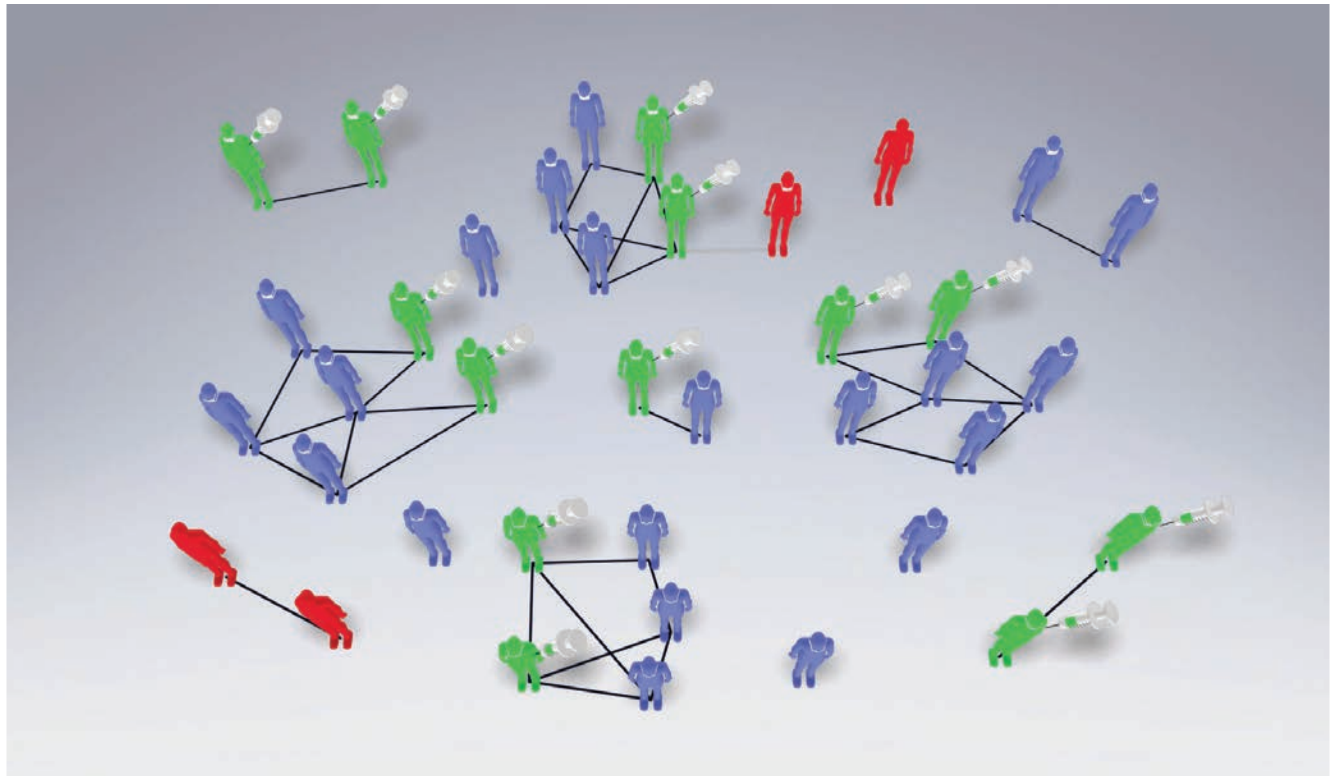

HOW AI MADE SENSE OF COVID-19 COMPLEXITY

By adopting a mathematical approach called 'multi-agent modelling' and embracing machine learning, Japanese researchers have created INNOVATIVE WAYS to predict the path of pandemics.

As the summer of 2020 approached, Japan's COVID cases were rising daily, schools had abruptly shut, and the Tokyo 2020 Summer Olympics had just been postponed.

Daily government updates on the unfolding crisis were "generating serious emotions and feelings," adding to heightened anxieties, but initially there appeared to be little data to support decisions about restrictions, says Setsuya Kurahashi, of the University of Tsukuba in Tokyo.

▲ **Agent-based modelling takes the behaviour of individuals into account.**

So, when he was asked to join the government's COVID-19 AI & Simulation Project, he was excited to have the opportunity to contribute.

"Understanding the evidence behind government decisions is very important," as it helps reduce people's fears, says Kurahashi. The new virus was spreading rapidly across the world, but data was scarce, meaning that his simulations would help make sense of the unprecedented situation.

CAPTURING COMPLEXITY

Researchers had to first understand how the disease was transmitted. Simulations are particularly useful for this, providing insights into the dynamics of an outbreak, the factors that influence a pathogen's spread, and the potential effects of any interventions.

Traditionally, the 'Susceptible-Exposed-Infectious-Removed' (SEIR) mathematical model is used for such analysis. But it quickly proved inadequate in the case of COVID-19, Kurahashi explains.

Though it is simple and relatively easy to use, SEIR couldn't describe the complexities of this new fast-spreading virus. For one, the approach models behaviour as a whole system, using the population — rather than an individual — as the smallest unit of analysis. This means its resolution is fairly low and that it can only provide a bird's eye view of the situation, says Kurahashi.

It also implies that only one parameter may be characterized at a time, says Akimasa Hirata, a public health engineer at the Nagoya Institute of Technology who was also involved in the national simulation effort. At the beginning of the pandemic the simplicity of the SEIR model

COVID-19
AI & Simulation Project

worked very well for countries where people's movements are uniform, such as under lockdown measures, he says, but not for nations such as Japan, which had yet to declare such restrictions, and there were still large and complex movements of people.

To simulate the complex situation that was unfolding on the ground, the researchers had to devise a new mathematical model. They turned to an approach called agent-based modelling, which, in contrast to SEIR, analyses and simulates things at the micro-level, right down to the behaviours of individuals, or 'agents', rather than working with a broad overview of populations.

Creating something with this level of detail will have ongoing benefits. "Now it's relatively easy to expand our model to consider factors like a new variant, or vaccination, or countermeasure, which are very difficult to embed into an SEIR model," says Tatsuo Unemi at Soka University in Tokyo.

Agent-based or 'multi-agent' models can use this fine-grained data to simulate how larger-scale patterns might emerge from combined individual behaviours.

"We can visualize what's going to happen among the people, based on their behaviours, like going shopping or going to school," says Unemi. "With this kind of detail, it makes it easier for ordinary people to understand how their actions will affect the likelihood of them becoming infected."

A MICROLEVEL ANALYSIS

Unemi and his team had to first gather together numerous types of data. They turned to the population census, anonymized mobile phone records, papers in medical journals and other sources to figure out how people were moving about and encountering each other, as well as how they were being infected and how well vaccinations were protecting them.

They then set about building their multi-agent models, making sure to "employ as many agents as possible" — analysing up to one million people at a time. In one simulation that the team ran in February 2022, as the Omicron variant of SARS-CoV-2 was sweeping through Japan, some prefectures decided to extend restrictions, while others lifted them.

Unemi wanted to see what would happen under both scenarios. From their simulations, the team mapped how the number of positive cases and patients with severe illness might change. The team found that lifting the restrictions early would result in a higher number of severe COVID-19 cases, despite overall infection numbers falling, explains Unemi.

In a similar vein, fellow simulation project researcher, Satoshi Kurihara, at Keio University in central Tokyo also built multi-agent models. "My purpose was to understand and predict infection by simulation," explains the AI expert. "I model human mobility on a small scale, for example the way people move from their home to school or work."

Kurihara has carried out 50 or so simulations for the national project. One looked at whether the slowing trend in COVID-19 cases at the start of 2022 was due to a rise in immunity against the virus in the population at large, or due to the effects of restricted movement. His team used data from telecom providers to track pedestrian levels in Shibuya, Shinagawa and other very busy parts of central Tokyo.

In other simulations, he analysed how people's

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▲ **Data from telecom providers was used to track pedestrian levels at busy areas like Shibuya, Japan (pictured).**

emotions — such as anxiety, joy and fear — were impacting their behaviours, such as their levels of self-restraint and propensity to venture outdoors. More recently in June, Kurihara has been modelling how the COVID variant XBB1.5 might spread under various scenarios, and with different levels of predicted infectivity.

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▲ The COVID-19 AI and Simulation Project modelled how infection rates might change due to vaccinations.

BEST OF BOTH WORLDS

Tsukuba's Kurahashi took a different tack — crafting simulations that combined both SEIR models and multi-agent models. "It is the relationship between people that causes the spread," he explains. "So, my research is focused on human situations and the relationships between people."

Kurahashi's hybrid models examined scenarios, such as how the virus would likely spread in primary schools, during face-to-face meetings, and when care workers visited patients in their homes. He also created simulations to model how infection rates might change in the face of vaccinations and public health measures, such as reducing restaurant and bar opening hours, and slashing the attendance capacity at events.

Hirata, from Nagoya Institute of Technology went one step further, applying deep learning in a new set of models. In particular, he was keen to incorporate infection trends from other countries into his simulations, from places where emerging variants had spread ahead of Japan.

It was also useful to look to other nations to see how vaccination had curtailed disease spread, he says, given that Japan began its vaccination drive comparatively late. For this, data from Israel, which had vaccinated early and fast, was particularly useful.

The results from his team's machine learning models were consistent with those obtained from their multi-agent counterparts, which was helpful for the government in dealing with the crisis, says Hirata. "For policy decisions, I believe consistency is important."

DATA SCIENCE HAS ITS LIMITS ESPECIALLY AT THE BEGINNING OF PANDEMICS WHEN DATA IS SCARCE.

Keio's Kurihara agrees. "If our team has only one model, then that's a very bad story. We need many models," to accurately map the situation, he says.

THE NEXT PANDEMIC

All of this detailed work armed the Japanese government with a wealth of information, allowing it to make well-informed decisions that balanced public health with economic concerns. The models allowed the government to evaluate various scenarios, for example: when to roll out vaccines and boosters; which population groups to prioritize; how soon to lift emergency measures after the Olympics; and they helped establish proactive infection control measures.

COVID-19 taught the researchers many lessons when it comes to studying the dynamics of an emerging disease. For one, it revealed that data science has its limits, especially at the beginning of pandemics when data is scarce, says Kurahashi. Simulation modeling is badly needed in situations like this, he says.

Moreover, the COVID pandemic has highlighted the importance of collaboration, among the research, public health and medical communities. The Japanese government recognized this early on, as the launching of the COVID-19 AI & Simulation Project proved, says Kurihara. "They got the country's researchers together very quickly to make sense of all the information," he says.

The four researchers all agree that the work done in this pandemic has put them in good stead for the next one. "We should be able to extend the code for future pandemics," says Hirata.

Unemi agrees: "Nobody knows what will happen next, but I believe our experience will be useful." ■

COVID-19 AI & Simulation Project

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