# APOLLO'S ARROW

## THE PROFOUND AND ENDURING IMPACT OF CORONAVIRUS ON THE WAY WE LIVE

NICHOLAS A. CHRISTAKIS

Little, Brown Spark
New York Boston London

Little, Brown Spark
Hachette Book Group
1290 Avenue of the Americas, New York, NY 10104
littlebrownspark.com
twitter.com/lbsparkbooks
facebook.com/littlebrownspark

First Edition: October 2020

Little, Brown Spark is an imprint of Little, Brown and Company, a division of Hachette Book Group, Inc. The Little, Brown Spark name and logo are trademarks of Hachette Book Group, Inc.

The publisher is not responsible for websites (or their content) that are not owned by the publisher.

The Hachette Speakers Bureau provides a wide range of authors for speaking events. To find out more, go to hachettespeakersbureau.com or call (866) 376-6591.

Illustrations designed by Cavan Huang

ISBN 978-0-316-62822-8

E3-20200924-DA-ORI

# Contents

*For my teacher and dear friend*
*Renée C. Fox,*
*who survived and studied epidemics, who deeply understands how illness and society intersect, and who has influenced generations of fortunate students*

*And for my many other teachers across a lifetime, including Paul V. Piazza, Tom S. Reese, Leopold J. Pospisil, John B. Mulliken, Allan M. Brandt, Arthur M. Kleinman, Paul D. Allison, Sankey V. Williams, and Arthur H. Rubenstein*


LITTLE, BROWN AND COMPANY

And [Apollo] descended from the summits of Olympus, enraged in heart, having upon his shoulders his bow and quiver covered on all sides. But as he moved, the shafts rattled forthwith upon the shoulder of him, enraged; but he went along like unto the night. Then he sat down apart from the ships, and sent among them an arrow, and terrible arose the clang of his silver bow. First, he attacked the mules, and the swift dogs. But afterward dispatching a pointed arrow against [the Greeks] themselves, he smote them, and frequent funeral piles of the dead were continually burning. Nine days through the army went the arrows of the god; but on the tenth, Achilles called the people to an assembly; for to his mind the white-armed goddess [Hera] had suggested it; for she was anxious concerning the Greeks, because she saw them perishing.

—Homer, *The Iliad*

# Acronyms

**CDC:** Centers for Disease Control and Prevention, the leading government agency charged with epidemic control, based in Atlanta, Georgia.

**COVID-19:** The clinical disease caused by SARS-2, involving a range of symptoms and severities; also used to refer to the pandemic itself.

**NIAID:** National Institute of Allergy and Infectious Diseases, the leading government agency charged with scientific research into infectious disease, based in Bethesda, Maryland.

**NPI:** A nonpharmaceutical intervention, such as quarantining, used instead of or in addition to drugs to combat an epidemic.

**PPE:** Personal protective equipment, such as masks, face shields, gloves, etc., worn by health-care personnel and others to avoid contracting an infection.

**SARS:** Severe acute respiratory syndrome, a serious clinical illness involving shortness of breath that can result from infection with various pathogens or from other injuries to the lungs; also used as the name of a condition caused by the SARS-1 virus.

**SARS-1:** Virus from the coronavirus family that emerged in 2003 and caused a small pandemic.

**SARS-2:** Virus, also known as SARS-CoV-2, from the coronavirus family that emerged in 2019 and caused a large pandemic.

# Preface

The gods of Greek mythology were ever present in my childhood. They were constant companions of my imagination, the subjects of my immigrant parents' bedtime stories, and even the names of children I played with when we visited our cousins in Greece. I was fascinated by the gods' duality: immortality and power contrasted with frailty and vice. The god Apollo, for example, was both a healer and the bringer of disease. During the Trojan War, with his silver bow and quiver of arrows, he rained a plague down on the Greeks to punish them for kidnapping and enslaving Chryseis, the daughter of one of his favored priests.

I found myself thinking again about Apollo and his vengeance as I contemplated our own twenty-first-century barrage more than three thousand years after the events described in *The Iliad*. It seemed to me that the novel coronavirus was a threat that was both wholly new and deeply ancient. This catastrophe called on us to confront our adversary in a modern way while also relying on wisdom from the past.

Despite the advances we have made in medicine, sanitation, communication, technology, and science, this pandemic is nearly as ruinous as any in the past century. Lonely deaths. Families unable to say goodbye to loved ones or perform proper funerals and acts of mourning. Destroyed livelihoods and stunted educations. Bread lines. Denial. Fear and sadness and pain. As I write, on August 1, 2020, over 155,000 Americans and over 680,000 people worldwide have died, and many more are still uncounted. A second wave of the pandemic is imminent, whether or not the hopes for a rapid vaccine are realized.

However, even in the midst of the onslaught, many people

believe that the efforts to contain the virus have been excessive. Some Americans feel that our response has been overblown, yet another reflection of this nation's modern inability to accept hard realities. But I believe this thinking is wrong on two counts. First, it has required extraordinary force, including all our twenty-first-century wealth and know-how, to contain the virus to "only" this many deaths. I share the view of many good scientists that vastly more Americans would have died—perhaps a million—had we failed to deploy the resources we marshaled, belatedly, in the spring of 2020 to cope with the first wave of the pandemic. To compare this COVID-19 pandemic without mitigation efforts (or even with mitigation efforts!) to a typical flu season, as some have done, is a misreading of reality. Second, it is a misreading of history to think that in our time we would somehow be spared the burden of having to deal with a pandemic or that other people in other times have not faced the same fear and loneliness, the same polarization, the same fights over masks and business closures, the same call to neighborliness and cooperation. They have.

In late January 2020, as the virus was gathering force, I shifted the work of the many talented young scientists and staff in my research group at Yale to focus on it. First, working with Chinese colleagues, we published a study that used the mobile-phone data of millions of people in China to track the spread of the virus in January and February 2020. Then my lab began to plan studies of the biology and impact of the virus in the isolated region of Copan, Honduras, where we had a long-term field site and close relationships with thirty thousand residents in one hundred seventy-six villages. We also started exploring how mass gatherings, like elections and protests, might intersect with the spread of the virus throughout the United States. And in May 2020, we developed and released Hunala, an app based on network science and machine-learning techniques that people could use to assess their risk of infection.

The atmosphere in the whole scientific community in early 2020 was charged with urgency and probity. Colleagues all around the

world pivoted to work on the coronavirus and broke down barriers to research, collaboration, and publishing. But very quickly it also became clear that there was an emerging vacuum of public information and few effective ways to communicate the problem that was unfolding. Along with a broad range of scientists, including epidemiologists, virologists, physicians, sociologists, and economists, I turned to Twitter to post tutorial threads on coronavirus-related topics such as the mortality rate in children and the elderly, the reasons we had to "flatten the curve," the nature of immunity after infection with the virus, and the extraordinary approach China had used to deal with the outbreak.

This book is another way I hope to help our society cope with the threat before us. In the middle of March 2020, Yale University closed down—though many laboratories, including my own, continued to work remotely. I wrote this book between March and August 2020 while in isolation with my wife, Erika, and our ten-year-old son in our home in Vermont. Our adult children intermittently sheltered with us as well, as they too were cut off from the lives they led before the disease struck.

I hope to help others understand what we are confronting, both biologically and socially, to outline how humans have faced similar threats in the past, and to explain how we will get to the other side of this, which we will, albeit after tremendous sorrow. The ability to understand a contagious and deadly disease builds directly on my years of teaching about public health, implementing global health interventions, serving as a hospice physician caring for the dying and bereaved, analyzing contagions using network science, and working as an academic sociologist studying social phenomena.

The COVID-19 pandemic is still a moving target, however. As of this moment, there is much that is unknown—biologically, clinically, epidemiologically, socially, economically, and politically. In part, the reason is that our actions are changing the outcome of the story. It's hard to know for sure what will happen. And there is much that only the passage of time will reveal, including the long-

term health effects of the infection and the long-term consequences of our response to the contagion (such as how our physical and social distancing might affect the mental health and education of our children and the economic prospects of a generation of young people presently entering adulthood). We also do not know whether or when a vaccine will be available, how risky it will be, and how long the immunity it confers might last. Despite these uncertainties, we must all, as individuals and as a society, make the best decisions we can at the moment, informed by the broadest consideration of views and the best understanding of scientific facts.

The plague Apollo unleashed at Troy did eventually end due to the intercession of Achilles and of Hera, the queen of the gods. After ten days and many deaths, Apollo's terrible arrows ceased, and he put down his bow. Epidemics end. But how we get to that point defines us and our own moment facing down this ancient threat.

# 1.

# An Infinitesimal Thing

> Humanity has but three great enemies: fever, famine, and war; of these by far the greatest, by far the most terrible, is fever.
>
> —Sir William Osler, "The Study of the Fevers of the South" (1896)

In the late fall of 2019, an invisible virus that had been quietly evolving in bats for decades leaped in an instant to a human being in Wuhan, China. It was a chance event whose most subtle details we will probably never know. Neither the person to whom the virus gravitated nor anyone else was fully aware of what had transpired. It was a tiny, imperceptible change.

Scientists later came to suspect that this initial move by the virus might have happened at the Huanan Seafood Wholesale Market in Wuhan, because many of the first recorded patients were vendors or visitors there. But the picture was confusing. Huanan is known as a wet market because, as at many other markets throughout the world, one can buy fresh produce, fish, meat, and live animals there, and sometimes even wildlife (such as hedgehogs, badgers, snakes, and turtledoves). Some of these animals are butchered in the market, on the spot. Unlike the antiseptic supermarkets many of us are accustomed to, the

pavements in such places are hosed down during the day to keep them clean. Hence, the markets are "wet."[1]

As far as we know, bats were not for sale at Huanan, though bats are consumed in China.[2] In a prescient article published a year before the virus slipped unseen into our species, scientists suggested that "bat-animal and bat-human interactions, such as the presence of live bats in wildlife wet markets and restaurants in Southern China, may lead to devastating global outbreaks."[3]

The first person with a confirmed case of the disease that would come to be known as COVID-19 developed symptoms of severe acute respiratory syndrome (SARS) on December 1, 2019. There may have been other patients earlier; we do not know. However, this patient (and a few other early cases) did not have contact with bats or wildlife or the Huanan market. This has led to concerns that perhaps the virus initially leaped to humans in some other way, such as through researchers in Wuhan who collected samples of the virus directly from wild bats and analyzed them in laboratories with inadequate protective procedures.[4] The Wuhan Center for Disease Control and Prevention, which does research with bat viruses, is just a few blocks from the Huanan market, and the Wuhan Institute of Virology is also a few miles away from it. However, Chinese authorities have claimed that there was no chance the virus leaked from these facilities.[5]

Notwithstanding the mysterious origin of the virus, 66 percent of the first forty-one people to contract the disease, during the month of December, did indeed have a direct connection to the Huanan market as shoppers, traders, or visitors.[6] If the market was not the place where the virus first found its way to humans, it was the place where it first became easy for us to detect. The market, with its densely packed stalls and large number of people, provided a fertile environment for the virus to spread rapidly and easily, generate a localized cluster of cases, and therefore come to our attention.[7]

One of the first doctors to sound the alarm about the disease was Dr. Jixian Zhang of the Hubei Provincial Hospital of Integrated

Chinese and Western Medicine. On December 26, 2019, she noticed seven cases of atypical pneumonia; three patients were in the same family, and four were from the Huanan market and knew each other. She reported them to the Wuhan Center for Disease Control the next day.[8] Eventually, as part of an effort to cover up their initial inaction as the pandemic took root, the authorities gave her a merit award for reporting the cases.[9] But later investigation revealed that there had been other cases of atypical pneumonia earlier in December, above the threshold for notifying the central Chinese Center for Disease Control in Beijing, that had gone unreported. Precious time to contain the outbreak was lost. In fact, a later analysis documented that there were 104 cases and 15 deaths during the month of December.[10]

The authorities began to realize what was happening and shut down the market on January 1, 2020.[11] By then, the initial patients, dispersed to various hospitals, were being collected and transferred to a specially designated facility, Jinyintan Hospital.[12] On January 27, 2020, analyses released by the Chinese CDC (and later regarded by some as possible misinformation) noted that 33 of 585 environmental samples (such as swabs of surfaces) collected at Huanan from January 1 to January 12 contained the RNA of a novel coronavirus, later named SARS-CoV-2. The positive samples were highly concentrated on surfaces in the western part of the market, where the wild animals were sold.[13]

On December 30, 2019, two days before the market was shut down, a thirty-three-year-old ophthalmologist, Dr. Wenliang Li, became aware of the emerging cluster of cases after reading an alarming report by one of his colleagues. Dr. Ai Fen, the head of the emergency department at Wuhan Central Hospital, had received a lab report for a patient with atypical pneumonia indicating that the patient had SARS.[14] On a private WeChat group with a few medical-school classmates, Li spread the alarm. “There are seven confirmed cases of SARS at Huanan Seafood Market,” he said. “The latest news is, it has been confirmed that they are coronavirus infections, but the exact virus strain is being

subtyped. Protect yourselves from infection and inform your family members to be on the alert."[15]

By January 3, 2020, local authorities caught wind of Li's communications. There was a Chinese Communist Party meeting scheduled for later in the month, on January 12, and news of a local outbreak, much less a serious one, was not welcome. Indeed, until at least January 11, the public was wrongly assured that no new cases had been observed in Wuhan.[16] Li was called to meet with the police and accused of "rumor-mongering" and "making false statements on the internet." He was forced to retract what he had said and sign a letter promising that he would not engage in "illegal activities."[17] This was not the last time that the truth about COVID-19 would be suppressed or ignored as the pathogen spread around the world.

Of course, Dr. Li was completely correct. Later, the authorities would publicly apologize, and he would become a hero to ordinary Chinese people tired of constraints on free expression and disillusioned by misinformation from their leaders.[18] Alas, as eventually happened to many other health-care workers in China (and in many other countries), Li died of COVID-19, on February 7.[19] He had contracted the disease on January 8 while taking care of a glaucoma patient. That patient was a shopkeeper at the Huanan market.

The Chinese became aware fairly quickly that the disease could spread from person to person and was not independently and repeatedly acquired from a fixed animal reservoir. This worrisome fact was confirmed in a report about the first forty-one known cases published online in the British medical journal *The Lancet* on January 24.[20] The Chinese were also aware that the disease was serious. Of these first patients, six (15 percent) died. The article concluded that the virus "still needs to be deeply studied in case it becomes a global health threat."

The virus spread—first slowly, then quickly—through Wuhan and then through all of Hubei Province, home to fifty-eight million people. By January, while the overall percentage of infected people

in Wuhan was still tiny, it was high enough that when large numbers of people left the city, some of them carried the pathogen with them.

The virus had announced itself with extremely unfortunate timing, right at the start of the annual *chunyun* (春运) migration in China that was taking place in the run-up to the Lunar New Year festival, on January 25, 2020. During this period, over three billion trips are typically made, a mass movement that puts the annual Thanksgiving travel in the United States to shame.[21] To make matters worse, Wuhan is a central transportation hub for China. Nearly twelve million trips were taken through Wuhan in January (as research in my lab, in collaboration with Chinese scientists, later documented), thus carrying the virus throughout China by the middle of February.[22] The more people from Wuhan who went to a particular destination, as shown in figure 1, the worse the SARS-2 outbreak at that destination would later be. The initial "imported" cases set off local outbreaks via cascades of what epidemiologists term *community transmission.*

Authorities initially silenced voices like Li's, but later they abruptly yielded to reality and changed course—as other politicians in dozens of other countries would also eventually do. China scrambled to contain the outbreak, and more honest reporting was now encouraged. As Chinese president Xi Jinping said in his first public statements regarding the situation, on January 20: "It's necessary to release epidemic information in a timely manner and deepen international cooperation."[23] The Communist Party's central political and legal affairs commission, a group not known for encouraging transparency, offered its own stern warning on a popular social media site in China: "Whoever deliberately delays and conceals reports will forever be nailed to history's pillar of shame." The post was later deleted.[24]

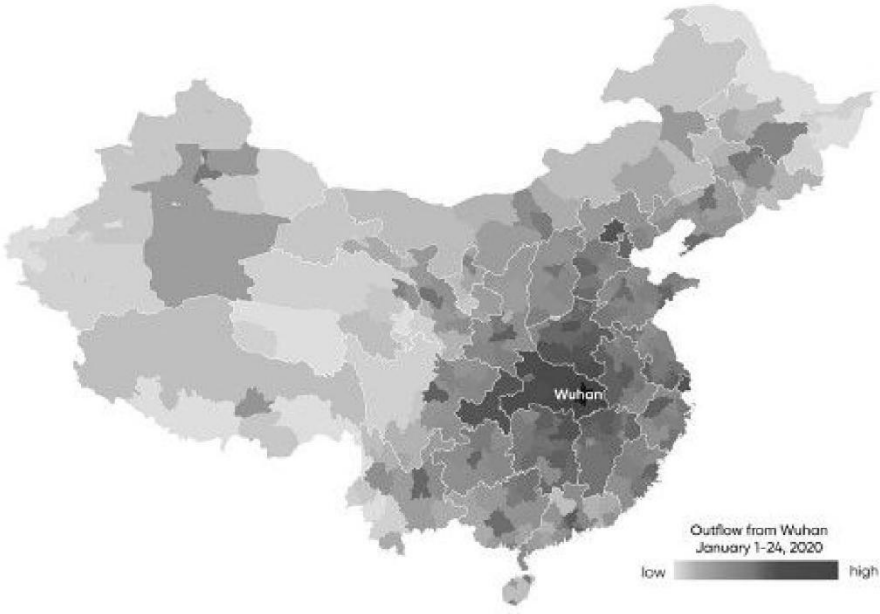


*Figure 1: Population outflow from Wuhan in January 2020 carried the SARS-2 virus.*

On January 17, nine days after Dr. Wenliang Li contracted SARS-2, seventy-two-year-old Dr. Lanjuan Li, a well-known physician and epidemiologist at Zhejiang Medical University in Hangzhou, one of China's oldest medical schools, learned from private communications that some medical personnel in Wuhan had fallen ill with a new kind of pneumonia.[25] That day, she contacted the National Health Commission in Beijing seeking permission to go to Wuhan, and the next day, China sent her there as part of a six-member team. Also on the team was Dr. Nanshan Zhong, an eighty-three-year-old pulmonologist renowned for his role in identifying the nature and severity of the prior SARS viral outbreak in 2003. Both Li and Zhong enjoyed tremendous respect in China and around the world. Dr. George Fu Gao, the head of the Chinese CDC in Beijing, had been alarmed at what was happening in Wuhan (since hearing of informal reports in late December, he had been prodding local authorities to be more forthcoming), and he also joined the mission.[26]

On January 19, the team visited hospitals, the Wuhan Center for

Disease Control and Prevention, and the Huanan market. The city's health-care system was already inundated. In a few days, China would begin construction of a 645,000-square-foot field hospital with thirty intensive care units and a thousand beds to supplement the existing infrastructure in Wuhan. Construction would be completed in ten days.[27] On the evening of January 19, the team returned to Beijing and briefed the National Health Commission. Their report was alarming. At eight thirty a.m. the next day, January 20, the six experts took part in a cabinet meeting in Zhongnanhai, the Chinese leadership compound adjacent to the Forbidden City. Because the disease could spread from person to person, the team advised the government to implement stronger control measures, and they recommended closing off Wuhan. The Wuhan government announced at two a.m. on January 23 that it would impose a lockdown at ten o'clock that morning. A lockdown of the whole surrounding province of Hubei followed almost immediately.[28]

By January 25, nearly all of China was shut down.[29] According to an analysis conducted by one of my Chinese students soon afterward, 934 million people lived in provinces that were subject to new rules, described as "closed-off management" (封闭管理). The scale of the practices, reminiscent to some extent of the degree of social control under Chairman Mao, was breathtaking. It was the largest imposition of public health measures in human history.

"Closed-off management" involved many features.[30] People were required to shelter in their homes and were given permission to leave only once or twice a week for essentials. Shoppers waited in lines and kept six feet of separation between themselves and others—a development that stunned both local and foreign observers familiar with the usual press of bodies in China. And simply everyone wore a mask in public. Movement of people and vehicles was checked with special exit-entrance permits in every area, often down to the neighborhood level. Collectivist slogans made a reappearance everywhere, from little notations on these

permits ("It is everyone's responsibility to fight the virus") to huge red banners in the streets. Every person's temperature was checked at the entrance to every community. Schools were moved online for millions of pupils. Vehicles and public places were regularly disinfected. Food and other essentials were carefully delivered on an enormous scale. The Chinese authorities encouraged delivery companies to distribute goods, and the companies vouched, via the ubiquitous apps used to place orders, that their drivers were wearing masks and did not have fevers.

The rules were enforced by block captains, local officials, and Communist Party members.[31] This was made easier by the authoritarian government and collectivist norms in China, and enforcement of this new regime was not just top-down. For instance, rural residents set up crude roadblocks of felled trees to keep outsiders out, and they interrogated visitors in local dialects in order to detect interlopers.[32]

This control sometimes came with modern twists. In February, a state-run military electronics company released an app that allowed citizens to enter their names and ID numbers and be informed of whether they might have come into contact with a carrier of the virus while using planes, trains, or buses. This technology struck many people in countries around the world as creepy, yet similar ideas would soon strike them as desirable, even normal.[33]

The Chinese government began to gingerly lift some of these restrictions in some parts of the country in late March, but the Chinese continued to implement many other procedures on a large scale.[34] For instance, people in elevators used disposable toothpicks, provided on wall-mounted pincushions, to push the buttons. Elevators in many cities allowed only four people at a time, their positions marked by tape newly placed on the floor. Signs in the elevators said PLEASE BE PATIENT AND WAIT FOR THE NEXT ELEVATOR. LET'S UNITE TOGETHER TO FIGHT THE VIRUS IN THIS SPECIAL PERIOD. As workers returned to offices and factories, the restaurants and cafeterias that served them were modified. Customers were

separated by cardboard or Plexiglas dividers and instructed to eat quickly. Only one person was allowed per table, and there was no talking and no socializing. Gallows humor emerged, as with other aspects of the lockdowns, and many workers observed, "This one-table-per-person experience reminds me of my old school days taking exams."

In its approach, China had essentially detonated a social nuclear weapon. And so it was able to stop the spread of the virus. By late March, the number of new reported cases in the nation dropped from thousands per day to less than fifty per day.[35] By April, the daily case count hit zero, and this in a country of 1.4 billion people. There has been some criticism of the Chinese standards for reporting cases (for instance, initially they did not include asymptomatic cases of infection in their counts) and of the honesty of the reporting (certainly, information about the earliest cases in Wuhan was suppressed).[36] But the enormous reduction in cases once China mobilized to control the epidemic was an astonishing achievement from a public health point of view, even if some of the Chinese numbers were fuzzy.

To be clear, China, and other countries that subsequently implemented their own lockdowns, had not eradicated the virus; it had merely temporarily stopped its spread. When the lockdowns were lifted, the virus would come back.[37]

My personal involvement with COVID-19 research began the day after Wuhan initiated its lockdown. On January 24, I was contacted by some Chinese colleagues with whom I had been collaborating for several years, analyzing mobile-phone data from China. Previously, we had been looking at how high-speed rail lines and earthquakes reshaped how people interacted with one another to form social networks, a topic of interest to me since 2001. Maybe, we thought in late January 2020, we could use similar data to study the burgeoning epidemic. As a result, I began to concentrate on what was happening in China. And I became increasingly alarmed. I realized that COVID-19 was not going to be an epidemic solely in China. It would be a serious pandemic of

historic proportions.

As I was studying all these things happening in China, I began to realize that the inundated hospitals, the lockdowns, the homeschooling, the Plexiglas partitions, even the toothpicks would all be coming to the United States before long. I could not think of a reason they would not. But when I tried to sound the alarm in my own household in early February, my wife, who usually takes me reasonably seriously, thought I was having prepper fantasies.

* * *

By the time the outbreak in China was brought under control, SARS-2 was well into its spread all over the world. In fact, it had made it to at least one person in America by the middle of January. The first case to come to public attention was a thirty-five-year-old man who was diagnosed in Snohomish, Washington. This information was announced by the CDC in a press release on January 21. The patient had returned to Washington from Wuhan on January 15.[38] Genetic analysis found he had a variant of the virus, recorded as USA/WA1/2020, or WA1 for short, that was closely related to variants seen in Fujian, Hangzhou, and Guangdong Provinces in China.[39] By pure chance, one of the forty-one initial patients in Wuhan or some intermediate person had infected this man. By the time the case was announced, the United States had started to do some cursory checks on incoming passengers from Wuhan, but only at certain airports, such as New York, Los Angeles, and San Francisco, and only beginning on January 17, two days after this man had arrived. This patchy approach illustrated what later became abundantly clear: border closings usually have a very limited effect on a pandemic like COVID-19.

This same CDC press release noted "growing indications that limited person-to-person spread is happening." And the published clinical report about this first detected case would provide additional evidence of this: the patient had not visited the Huanan market or any health-care facilities and had not had contact with

anyone he knew to be sick. He had acquired the disease from a person who had almost certainly been asymptomatic. This shortly proved to be one of the most bedeviling aspects of the infection—as the pandemic spread around the globe, asymptomatic transmission made the disease much harder to track and control. We could not rely on people's symptoms to know who had it.

That the patient was diagnosed at all was a stroke of luck. He had seen a CDC alert about the virus, and when he developed a slight temperature and a cough four days after returning from Wuhan, on January 19, he sought treatment at an urgent-care clinic north of Seattle. The clinic staff knew to take a specimen and send it to the CDC on an overnight flight. The patient was discharged and told to self-isolate at home, which he did. On the afternoon of January 20, his test came back positive. And by eleven o'clock that night, he was in a plastic-enclosed isolation gurney heading to a biocontainment ward previously set up to handle Ebola patients at Providence Regional Medical Center in Everett, Washington. He had become—to use a term that should not imply the man had any personal responsibility for his predicament—our first known, test-confirmed case, our "Patient Zero."[40]

He worsened and developed pneumonia. While he was in the hospital, he was cared for by staff wearing protective equipment, including face masks, and a robot was used to take his vital signs. He often used a video link to communicate with his doctors and nurses so that they could keep their distance and avoid contracting a disease that might kill them as it had Wenliang Li and many health-care workers in Wuhan. This impersonal, isolated medical care forecast the sort of care many other hospitalized patients would later receive. By January 30, Patient Zero was much better, and he was discharged soon after. By February 21, he was deemed no longer infectious, and he was allowed to leave home isolation.

Contact tracing—the gumshoe work of the public health system whereby one goes backward from a known case to see who the patient has been in contact with—revealed that at least sixty

people had been exposed to Patient Zero. Amazingly, none of them got sick. Later genetic analyses confirmed that this patient was very likely not responsible for the epidemic taking hold in Seattle. The existence of such dead ends in viral transmission is another important, if perplexing, feature of this pandemic. Based on such analyses, which are discussed in more depth below, it seems that some other unknown person, possibly an American citizen with ties to China, arrived from Hubei Province around February 13 and seeded the outbreak in Washington with a different variant of the virus.[41]

It was this later variant of the virus that wound up in the Life Care Center nursing home in the nearby city of Kirkland. The large number of intrinsically vulnerable elderly people provided fertile ground for the virus to spread; it caused a localized cluster of cases that soon drew attention. In February, paramedics noticed that they were making much more frequent emergency visits to this facility—there had been seven visits in January but roughly thirty in February. First responders were getting sick themselves. The fire department declared Life Care a hot zone and required ambulance personnel to wear full protective equipment to enter. And the Life Care staff was sometimes asked to wheel out the patients, in masks, and leave them at the curb for the paramedics to pick up. It became clear that the deaths were due to the novel coronavirus only when positive test results came back on February 28. Two days afterward, on March 1, a man in his seventies became the first Life Care resident to die of the disease.[42] A CDC report published later, on March 27, revealed a total of 167 cases linked to the facility: 101 residents (more than two-thirds of the facility's population), 50 health-care personnel, and 16 visitors; at least 35 of these people eventually died.[43] As of March 8 in Seattle, there were only 118 documented infections and 18 deaths—and almost all of the deaths were from Life Care.

The clustering of vulnerable elderly people in nursing homes provided a kind of petri dish for the virus around the country. Soon, the small morgues typically present in such facilities proved

hopelessly inadequate to the rapid pace of death. By April, disturbing newspaper headlines appeared: "After Anonymous Tip, 17 Bodies Found at Nursing Home Hit by Virus" and "Almost Every Day Has Brought a New Death from Coronavirus at the Soldiers' Home in Holyoke; 67 Have Died So Far." In the latter case, this meant that one-third of all the residents at the facility had died.[44] Nursing homes had become the inadvertent "pesthouses"—shelters once used for plague victims—of the early twenty-first century. Other old people living at home alone would sometimes die of COVID-19 so fast that statisticians later had to revise their estimates of the lethality of the virus upward to take into account these previously unnoticed deaths.

Given that the Seattle area was home to Patient Zero, the first reported cluster of infections, and the first deaths of the epidemic, it seemed like it must have been where the virus first took hold in the United States. However, later studies identified patients who became ill even earlier in other parts of the West Coast. In the United States, the bodies of those who have died unattended or whose deaths are deemed suspicious are subject to autopsy by the local medical examiner. This is how the medical examiner in Santa Clara, California, came to perform an autopsy on fifty-seven-year-old Patricia Dowd, who had fallen ill with flu-like symptoms in late January. She stayed home from work and told her family she could not make it to a reunion in nearby Stockton. At eight o'clock on the morning of February 8, she was in touch with a colleague from work, but she was found dead two hours later.[45] Initially, her death was thought to be due to a heart attack, but subsequent testing revealed the presence of SARS-2. Since the time from infection to death from COVID-19 is typically about three weeks, the virus likely arrived in the Bay Area in the middle of January, roughly when Patient Zero arrived in Seattle. And since Dowd had not been to China herself, this meant that community transmission had already begun.

The first documented case of person-to-person transmission, excluding Dowd, since she got the pathogen from an unknown

person, was between a married couple in Illinois.[46] The wife had returned to the United States from Wuhan on January 13, 2020, and she infected her husband. They were both hospitalized with serious illnesses, and they both recovered. Interestingly, however, like Patient Zero, this couple infected no one else. State public health officials traced 372 people they had come in contact with, including 195 health-care workers. The virus reached this couple and went no further.

Back in Seattle, however, after the other new importation noted above, the virus kept going. Dr. Helen Chu, an infectious disease expert, had worried about the first Seattle case when she heard about it in late January. And she was in a position to do something about her concerns. She was part of an ongoing effort, begun in 2018, called the Seattle Flu Study (supported by philanthropist Bill Gates), that had been collecting nasal swabs from people with respiratory symptoms as part of a surveillance project in the Puget Sound area. The team realized that they could test some of the more recent samples (from January and February) to determine if and when the coronavirus had begun to spread.

Unable to get permission from state and federal officials and increasingly frantic that the disease was spreading, Chu and her colleagues began to analyze incoming specimens without final approval on February 25. They immediately discovered that a fifteen-year-old teenager with no travel history to China (or anywhere else) had caught SARS-2 in the preceding weeks. He had sought medical care for an upper respiratory infection on February 24. Although he lived just fifteen miles from Patient Zero, the variant of the virus he had was different, meaning he did not contract it from Patient Zero.[47] When this diagnosis was made, local health-care workers, including a doctor I know very well, raced to track down the boy. They found him at school that day. And why shouldn't he have been at school? He had recovered from what seemed like a routine illness and gone about his business. The boy was yanked from the premises the moment he was reached, and his school was soon shut down.

Upon discovery of this case, Chu realized with dread that the disease was "just everywhere already."[48] The Seattle Flu Study researchers went on to test previously collected specimens through January and find more cases (but their earliest positive case was from February 21). Like the teenager, these patients were then informed of their infections. In fact, at this point, COVID-19 had already been responsible for the deaths of two people in the Seattle area. Both were older. This, too, rapidly became a familiar feature of the illness: the young largely seemed spared from its worst effects.

The fact that this teenager had contracted COVID-19 without leaving the country was additional clear evidence that community transmission was well under way in the United States. However, because of the scarcity of tests, the CDC initially recommended that people with respiratory complaints be tested only if they had a travel history to China or an exposure to a known COVID-19 case, guidance that would persist until February 27. As a result, in the six weeks after the identification of Patient Zero, only fifty-nine other cases were detected in the entire country.[49] Rules restricting access to tests were widespread, not for any clinical reason but simply because there were not enough of them. My wife, Erika, was seriously sick with flu symptoms in early March, but she was denied a test at our local hospital, a major medical center, on the grounds that she had "too many symptoms." Astoundingly, the inability to perform an adequate number of tests persisted, nationwide, through the summer.

Americans had put on blindfolds when they should have put on masks. The lack of testing was a huge blunder, and it drastically slowed the response to the early infections. Experts suspected then what we all know now: the disease was indeed everywhere. By March 25, Washington State alone, by virtue of more testing, confirmed 2,580 cases and 132 deaths. In the United States as a whole on that date, these numbers stood at 68,673 and 1,028.[50]

The infections in Seattle seem to have seeded the outbreak on the *Grand Princess* cruise ship, one of many instances where cruise

ships (and, eventually, even a U.S. nuclear aircraft carrier, the USS *Theodore Roosevelt*) became hot zones. In many cases, passengers died on these ships. Incredibly, ships were not allowed to make landfall and were kept offshore by authorities as the epidemic raged on board, taking more lives due to the lack of medical care and the close quarters.[51]

On February 11, with over 2,400 passengers and 1,111 crew members, the *Grand Princess* left San Francisco for a cruise to Mexico; it returned to port on February 21. Most of the crew and 68 passengers remained on board, and on February 21, the ship set sail for Hawaii with 2,460 mostly new passengers. On March 4, a case of COVID-19 was diagnosed in one of the passengers who had completed the first journey, and the ship diverted course in the Pacific and began to return to port. By then, as feared, COVID-19 had broken out on board, with two passengers and nineteen crew testing positive.[52] The ship made landfall on March 8, and passengers and crew were taken to military bases for quarantine.[53] By March 21, seventy-eight people had tested positive. The CDC would release a rather acerbic advisory shortly thereafter: "All persons should defer all cruise travel worldwide during the COVID-19 pandemic."[54]

Another ship, the *Diamond Princess*, was quarantined in Yokohama, Japan, on February 3, and it would play a crucial role in the epidemic, providing scientists with a kind of grim natural experiment. Despite how critical experiments are to scientific knowledge, there are many situations in which scientists *cannot* do experiments for practical or ethical reasons. For example, we cannot experimentally assess whether the loss of a spouse increases a person's risk of death (due to what is known as "broken-heart syndrome") because we cannot randomly kill or otherwise remove people's spouses!

But scientists can sometimes take advantage of natural experiments, situations where the "treatment" has been assigned to subjects by chance—such as observing the effects of people put in close physical contact with one another who are therefore at

risk of becoming infected with a deadly germ. Of course, natural experiments do not have the careful controls of designed experiments; we cannot always be sure that the treatments really are allocated truly by chance, among other limitations. For instance, with the *Diamond Princess*, scientists must take into account that the people who go on cruises are older and richer and possibly more sociable than other people.

But the ship still offered observable evidence, and in the confusing early days of the pandemic, scientists pored over the data in dozens of papers, searching for any kind of signal in the noise. This defined and contained population of 3,711 people who were not allowed to disembark allowed epidemiologists to ascertain what fraction of a population SARS-2 could infect and how many of those people, once afflicted, would die.[55] Analysis showed that at least 712 of the (relatively elderly) passengers contracted the virus, and at least 12 of them (or 1.7 percent) eventually died.[56] Both numbers alarmed experts. Indeed, the number of cases on the ship was so large that in the international league tables of COVID-19 cases maintained at the time by the WHO, the ship was listed just below China and Italy—as if it were its own country.

By the middle of March, the United States was jolted awake to the danger posed by COVID-19. The cluster of deaths at Life Care forced West Coast leaders to recognize that something had to be done. Beginning on March 5, heads of large Seattle technology firms, like Amazon and Microsoft, encouraged their employees to work from home if they could (a few days earlier, an Amazon employee had tested positive for the virus and had been quarantined).[57] Later analyses of the decline in restaurant bookings, among other data sets, showed that ordinary residents of the city, having read about the local events, stopped going out as much without having to be told. On March 17, the governor of Washington, Jay Inslee, issued orders for all bars, dine-in restaurants, and entertainment and recreation facilities to close. On March 19, California governor Gavin Newsom issued a

after this patient came to medical attention, ultimately causing the outbreak at Life Care and also afflicting the teenager detected by the Seattle Flu Study. The second possibility was that there was a second, parallel importation of the virus, or even several separate importations, leading to other local outbreaks.

Distinguishing between these possibilities is important in getting a sense of scale—it tells researchers how many fronts we are fighting the virus on. Such data are also very useful for assessing the infectiousness and course of the virus. In this way, it was possible to deduce that the variant of the virus responsible for the community transmission in Seattle did not originate with Patient Zero but rather with some later importation. By late February, this latter variant of the virus was responsible for 85 percent of the confirmed infections in the region, though other variants had also begun arriving in the area from still other travelers, all starting their own family trees.

Distinguishing among such alternatives is also difficult because it is not always possible to be absolutely certain. A key reason for this is that the rapid rate at which people transmit SARS-2 (the average interval between one person contracting it and then transmitting it to someone else is about a week) is faster than the rate at which the virus has a mutation that allows us to discern if it is unique (about once every two weeks). This is like visiting a new country every week but getting your passport stamped only every other week; it makes it hard to know exactly where you have been.

Figure 2 shows what these sorts of genetic trees look like. It's taken from work by the lab of Michael Worobey, an evolutionary biologist at the University of Arizona, in a collaboration with other labs. Each dot is a variant of the virus (as ascertained by sequencing its genome). The variant afflicting Patient Zero, WA1 (on the bottom left), was a dead end, spawning no subsequent variants or infected individuals. Other variants (in the upper right) seeded the outbreak in Washington sometime around February 13. And from there, they spread to California, New York, and elsewhere.[64]

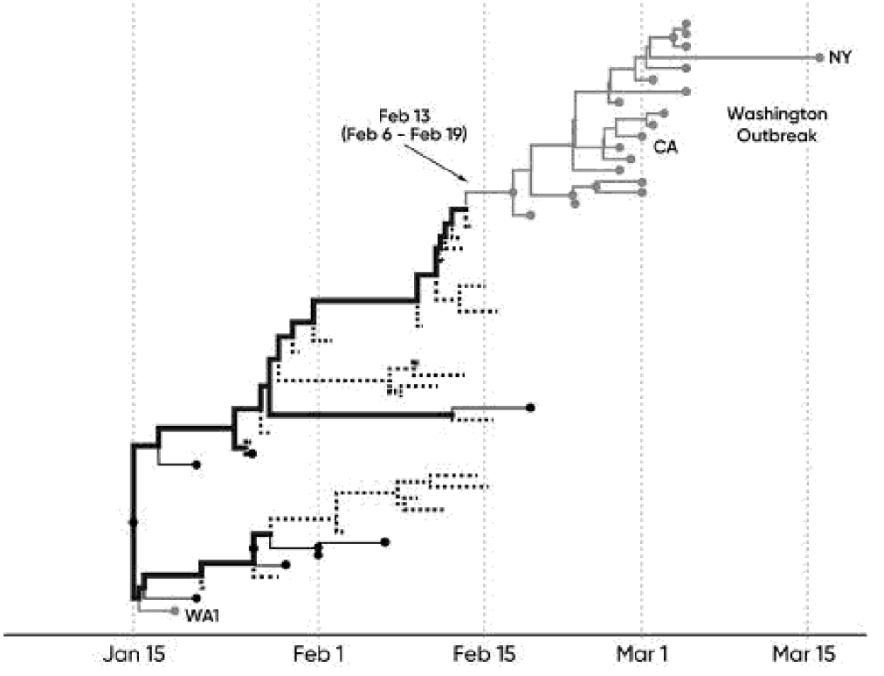


*Figure 2: Genetic mapping of variants of SARS-2 with estimated times of divergence makes tracing the path of the virus possible.*

Bedford's team sequenced the initial community-transmission case (in the teenager) and, like Dr. Zhang had done in China a month before, immediately posted the results. Bedford put the information on Twitter, which would become a major means for scientists to rapidly share information, on February 29. An international consortium began to share viral genome sequences from around the world on the online Nextstrain platform, which functions somewhat like the online tools that ancestry buffs use to define family trees in humans.

In March, after SARS-2 showed up in Connecticut, similar methods were used by researchers trying to trace whether cases stemmed from a domestic source or an international one.[65] Scientists sequenced the genomes of nine specimens of the virus and examined data regarding air travel at nearby airports. The United States had placed broad travel restrictions on China on January 31, on Iran on February 29, and on Europe on March 11.

But it became clear through these genetic analyses that the greatest risk to Americans was from *domestic* importations from other U.S. states rather than from foreign arrivals. The SARS-2 variants found in Connecticut at that time came from several other locations, mostly Washington, and none of the patients examined at that point had been abroad. Since there are numerically so many more domestic than international travelers, it should not be surprising that the domestic risk is greater. These scientists concluded that the imposition of restrictions on international travel had a limited effect on the virus's spread.

However, on March 1, 2020, the first confirmed case of coronavirus in New York State was reported—in a patient who had indeed traveled internationally and returned to New York City from Iran on February 25, just ahead of the travel ban.[66] Of course, the disease had been circulating for some time in New York City, and by late March, hospitals were inundated with patients. By early April, nearly one thousand patients were dying of the virus *every day* in the city, a statistic that dropped only a few weeks after widespread efforts to engage in physical distancing began. By March 19, the virus had been detected in all fifty U.S. states. Figure 3 shows the estimated dates of key early arrivals of the virus that successfully seeded the epidemic in our country.[67]


*Figure 3: Arrival trajectories of SARS-2 to the United States in February 2020 can be inferred from genetic analysis of viral variants.*

Sandwiched between China's outbreak in January and America's in March were major deadly outbreaks in Italy and Iran, both of which were devastating.[68] Spain, France, and many other European and some Asian and Latin American countries were also hit hard. By early April, for example, Ecuador was ravaged; dead bodies accumulated so fast that they were shrouded in sheets of plastic, covered in a few rocks, and abandoned on the sidewalks.[69] My lab has a public health field site involving over thirty thousand people in the rural state of Copan in western Honduras. We ceased our activity in March in order to avoid any risk of contributing to a similar calamity.

On March 11, roughly four months after the virus slipped into our species, the World Health Organization declared COVID-19 to be a pandemic. This was a formality, of course, since the virus's pervasiveness was already evident to all sophisticated observers and to countless residents of beleaguered cities around the globe. As of April 1, 2020, there were 219,622 known cases and 5,114 deaths in the United States and 936,851 cases and 47,210 deaths worldwide. By May 1, COVID-19 had become the leading daily killer in the United States, far eclipsing the deaths caused by the seasonal flu and even surpassing cancer and heart disease. By July 1, there were 130,761 recorded deaths in the United States and 518,135 deaths worldwide—and no end in sight.

* * *

The class of virus to which SARS-2 belongs gets its name from its appearance under an electron microscope. When this type of virus was first visualized, in 1968, it was seen to have a crown-like feature on the outside, hence the name *coronavirus* (*corona* comes from an old Greek word denoting a wreath worn as a crown).[70] This crown is actually composed of the *spike proteins* of the virus, and these proteins turn out to be crucial to its ability to harm us. The spike protein binds to a protein on the surface of human cells (known as ACE2) and thereby initiates the process that results in the virus being internalized into a cell. The virus then releases its RNA and uses our genetic machinery to reproduce itself, which releases more virus into our bodies.

As respiratory infections go, COVID-19 (which is the *disease* caused by the *virus* SARS-2) is particularly protean, encompassing a great variety of symptoms, from fever to cough to muscle pain to the loss of the sense of smell (anosmia). The symptoms that a patient experiences depend in part on which cells in the body the virus infects and how the body responds immunologically. The primary form of the disease is respiratory and involves cough and fever, the two most common symptoms, and shortness of breath. Two less common manifestations of the disease are

return from the hospital after severe cases of COVID-19, the coughing fits and weakness can last long after the fever has subsided. The recovery time can range from two weeks for a mild case to six weeks or more for a severe one.[80] Exhaustion from the physical toll of the virus is intensified by its emotional toll, given the contagious nature of the disease. Many patients felt guilty about having unknowingly transmitted the virus to others when they were still asymptomatic. Doctors also think that many patients may have long-term consequences of infection with SARS-2 in many organ systems, in what is called "post-COVID syndrome." Such patients may have permanently scarred or injured lungs or kidneys or hearts, for example, or even, in rare cases, neurological deficits. It will likely be some years before scientists truly understand the lasting implications of the disease for patients, including children, who, though uncommonly symptomatic, may indeed have rare complications.

* * *

Most people have not had personal experience with deadly epidemics. But plagues have always afflicted human beings, at least since we started living in large enough groups in cities about three thousand years ago. There was the plague of Athens in 430 BCE. The plague of Justinian in 541 CE. The Black Death in 1347. The Spanish flu in 1918. There were gods of plagues in ancient times—not only the Greek god Apollo, but the Vedic god Rudra and the Chinese deity Shi Wenye. Plague is an old, familiar enemy. And so, in 2020, a plague once again appeared.

How do humans in the twenty-first century respond, personally and collectively, to this reappearance? The challenges and responses, both good and bad, are timeless. Plagues reshape our familiar social order, require us to disperse and live apart, wreck economies, replace trust with fear and suspicion, invite some to blame others for their predicament, embolden liars, and cause grief. But plagues also elicit kindness, cooperation, sacrifice, and ingenuity.

The world is quite different now than it was during prior plagues; today we have exceedingly dense cities, electronic technology, modern medicine, better material circumstances, and the ability to know what is happening in real time. Scientists can track the outbreaks from space—as they watch cities shut down. And from the ground—as they observe people's mobile phones ceasing their translocation. And at a molecular level—as they use genetic techniques to analyze mutations, capturing the spread of the virus.

But from the point of view of the virus, the climate is ripe and things are as simple as ever. It is having a field day. In terms of evolutionary biology, the virus has had what is known as an "ecological release." This refers to the expansion of range and the population explosion that occurs when a species is freed from constraints it previously faced. The typical example of this is invasive species introduced by humans such as the cane toads that overwhelmed Australia, the rats that overwhelmed New Zealand (nearly wiping out the dinosaur-like tuataras that had occupied the island for millions of years, until 1250 CE), and the kudzu plants in the southeastern United States. The new arrivals suddenly find wide-open terrain for them to exploit. Our species has no natural immunity to the virus. We have never seen this particular pathogen before. It is a "virgin soil epidemic."[81] And so the coronavirus swept through humanity like a wave.

There is some debate among experts about whether viruses are living things. But this virus is surely acting like any other living thing would: it found available and untouched habitat, and it seized it. And the virus will keep infecting humans until we develop immunity or invent a vaccine. Even then, SARS-2 will most likely become like other viruses that circulate in our species, such as influenza, measles, and the common cold. No matter what, humans will have to reach a modus vivendi with this virus. But it will kill many of us before we do. A new pathogen has been introduced into our species, and in some form, it will now circulate among us forever.

* * *

When I was fifteen, my father, who had trained as a nuclear physicist, told me a story about a butterfly flapping its wings in China and causing a hurricane offshore from where we lived, in Washington, DC. I did not believe that could happen.

This image had first been conjured by an MIT professor of meteorology, Edward Lorenz, on December 29, 1972, at the 139th meeting of the American Association for the Advancement of Science. The details were not exactly the same; Lorenz had used the image of a butterfly flapping its wings in Brazil setting off a tornado in Texas.[82] But the image was so powerful that, with a puff, it gave rise to countless expressions about where exactly the butterfly was flapping its wings (China, Brazil), what exactly it caused (storms, tsunamis, people falling off skyscrapers, stock market crashes), and where exactly it had these effects (Japan, London, New York City).

This idea also changed diverse branches of mathematics and physics. Lorenz was proposing that minuscule disturbances and seemingly irrelevant modifications to the starting conditions in a complex system could, over time, result in dramatically different final outcomes. Some of us remember Jeff Goldblum's character describing this idea in the 1993 film *Jurassic Park*—he placed a drop of water on Laura Dern's knuckle and explained how tiny perturbations could affect which way the water flowed.

Lorenz had chanced on his observation because of a small jostle in his own life. In the winter of 1961, he was using a primitive computer to model the weather and predict weather patterns. At one point, he decided to rerun a program in order to take a closer look at what was happening. The previous run had yielded 0.506127 as an output. Lorenz rounded it to 0.506 and resumed the calculations. He went down the hall to get a cup of coffee, and when he came back, he discovered that the computer had generated forecasts that were completely at odds with the ones it had generated before. This tiny numerical alteration had drastically changed the two months of simulated weather that his

model was predicting.[83]

And so was born the idea that infinitesimal things can have huge effects. Some systems are exquisitely sensitive to their initial conditions, and to the extent this is true, predicting the future can be nearly impossible. In 1963, Lorenz wrote a paper about this titled "Deterministic Nonperiodic Flow."[84] The paper was initially ignored, but it eventually became a classic. Ultimately, it had an impact far outside meteorology, and by the 1970s and 1980s, it was recognized as a foundational effort in the emerging field of chaos theory.

A colleague of Lorenz observed that, if his theory was correct, the flap of a seagull's wings "would be enough to alter the course of the weather forever." Lorenz later noted, "The controversy has not yet been settled, but the most recent evidence seems to favor the gulls."[85] Eventually, Lorenz shifted to the more poetic metaphor of a butterfly, and he expressed a bit more hesitancy. For the rest of his life, he struggled with the answer to the question he had raised. "Even today, I am unsure of the proper answer," he said in a lecture in 2008, over forty years after the rounding of 0.506127 to 0.506 had sent his life in a radically new direction.[86]

One of the reasons the butterfly metaphor has engaged so many people and entered popular culture is, I think, that it is so disturbing. It upends our belief that the world should be predictable, ordered, or even comprehensible. It threatens the idea that things happen for reasons and that we might, by using science, be able to discern those reasons, however obscure they might be. It threatens the idea that we can make rational predictions and plans.

And although I have devoted much of my career to understanding the inertia of social systems—their unchanging reality, their fundamental evolutionary origins, and the ways in which they are stable and fixed—it has now been impressed upon me that social systems, in ways that had not previously engaged me, can indeed be extraordinarily unstable, like the weather.

As the virus was leaping into our species in late 2019, I was, like most people, still making plans that I thought would come to fruition. This idea of unpredictability was nowhere in my mind. My family was planning to travel to Greece to see my elderly father. We were looking forward to our daughter's college graduation. My university was deciding which faculty members to recruit and what conferences to hold. I was assigning new projects in my lab, and we were doing community-health research in Honduras and India. People throughout the world had no inkling that their jobs and livelihoods might soon evaporate, that their loved ones might be separated from them, that the next couple of months would be so utterly and unfathomably different from the past few. Who could have predicted that the most innocuous acts—a handshake, brushing hair across one's face, singing in a choir—would suddenly seem unthinkable, even repellent? In November of 2019, staffers on political campaigns were planning their strategies for the spring. Owners of small businesses were ordering inventory. Farmers were choosing crops. And economists were forecasting ongoing growth.

None of these events would happen—because of a tiny thing that we cannot see that made a move we could not observe. A butterfly flapping its wings in China could cause a hurricane in Washington, DC.

in Guangdong Province who developed symptoms on November 16, 2002.[4] This virus also came from bats and was characterized by fever, dry cough, shortness of breath, muscle pains, and sometimes a deadly pneumonia. And it too spread far and wide, reaching the United States and twenty-nine other countries.[5]

But what we now call SARS-1 had certain intrinsic epidemiological qualities that kept it from overwhelming us. Efforts to respond to SARS-1 were ultimately so successful that the World Health Organization declared the pandemic "contained" on July 5, 2003, just eight months after it had begun.[6] As of August 1, 2003, a total of just 8,422 people had been infected worldwide, roughly the same number of COVID-19 cases detected just in the state of Idaho as of July 1, 2020, seven months into the pandemic.[7] Examining the difference between the two viruses helps us appreciate why SARS-2 overwhelmed the world while its cousin SARS-1 did not.

The virus made its appearance in November 2002, but the Chinese government did not notify the World Health Organization about the outbreak of disease until February 12, 2003, when it reported 305 total cases, including 105 health-care workers, and five deaths. The cause was unknown at the time. Later, China was much criticized for this reporting delay, which also involved an initial cover-up. The early stages of the outbreak were very slow, but the case count accelerated starting on January 31 when Zuofeng Zhou, a fishmonger, was admitted to the Sun Yat-sen Memorial Hospital in Guangzhou. During Zhou's hospital stay, thirty nurses and doctors were infected. As with the 2020 pandemic, this tight cluster of cases and the fact that the virus spread to health-care personnel sounded the alarm, prompting officials to take action and indicating both the severity of the disease and its contagiousness.

One of the doctors who got infected by Zhou was sixty-four-year-old Jianlun Liu. He was feeling well enough on February 21 that he embarked on a three-hour bus ride south to Hong Kong for his nephew's wedding. Liu felt a bit sick during the ride, but when

he and his wife arrived, they were easily able to go out for lunch and see his relatives.[8] At five o'clock p.m., they checked in to room 911 of the three-star Metropole Hotel in the Kowloon region of the city.

By the next morning, Liu was sicker. He walked five blocks down Waterloo Road to the Kwong Wah Hospital to seek treatment. Having cared for patients with SARS himself, he warned the personnel that he should be put in isolation (although he might not have needed to warn them, because they were already aware of the outbreak).[9] The next morning, February 23, Liu had to be sedated and intubated. One doctor and five nurses caring for him fell ill, but having been properly warned, they had all been wearing N95 masks, gloves, and gowns. This probably reduced the amount of virus they were exposed to, which tends to make such illnesses milder, and all of them recovered. Alas, Liu did not recover; he died on March 4.

While Liu was unconscious, on March 1, his brother-in-law was also admitted to the same hospital for the same condition. He, too, deteriorated and died, on March 19, but not before doctors biopsied his lungs. From that sample, a team at Hong Kong University was able to grow the virus, and on March 21, they announced that they had identified it: under a microscope, it had the characteristic surface spikes of a coronavirus.[10]

Like the fishmonger before him, Liu proved to be a super-spreader—twenty-three guests of the Metropole also developed SARS, including seven from the ninth floor, where he had stayed. These guests went on to seed the epidemic throughout the world. Later, the World Health Organization reported that nearly half of all the cases seen worldwide from this pandemic could be traced back to Liu's twenty-four-hour stay at the Metropole Hotel.

Maps of this floor of the hotel, shown in figure 4, became famous among epidemiologists. Just by looking at the map, one could see that being closer to room 911 was a big risk for contracting the disease. Ultimately, perhaps 80 percent of the 1,755 patients who were infected with the virus in Hong Kong

could be traced back to Liu.[11] A leading theory (never definitively proven) of why so many people got sick was that Liu had vomited on the carpet in the hallway outside his room. Cleaning up the mess involved a vacuum cleaner, which may have aerosolized viral particles, spreading them widely through the hall and possibly sending them into the ventilation system. Amazingly, however, none of the hotel's three hundred employees fell ill, a mystery that was never explained.

The outward spread of this pathogen from the point source of this hotel was prodigious. For instance, a twenty-six-year-old airport technician visited a friend at the Metropole several times from February 15 through February 23. On March 4, the same day that Liu died, the man was admitted to ward 8A of the Prince of Wales Hospital in Hong Kong.[12] While there, he was given a nebulizer treatment to ease his breathing. By design, this device produces a fine mist, and it appears to have accidentally spread the virus around the ward.[13] Eventually, at least ninety-nine hospital workers who came into contact with him became infected.

The beds in the hospital started to fill up with the hospital's own staff. Dr. Joseph Sung, the head of the medical faculty, observed, "There were two dozen of my colleagues sitting in the same room; everybody was shaking and running a high fever; many were coughing.... That was the beginning of the nightmare, because from that day on, every day we saw more and more people developing the same illness."[14] Sung divided the hospital staff into two teams. One would take care of all non-SARS patients, and the other—the "dirty team," as they called it—would risk infection and care for the SARS patients. Those with young children were exempted from service on the dirty team. But those who were single or whose children were grown were encouraged to volunteer. Sung would later describe their predicament: "I needed a continuous supply of manpower to go in. And I was very touched by the fact that after we exhausted everybody in the medical department, surgeons, orthopedic people, gynecologists, even ophthalmologists came to help us."

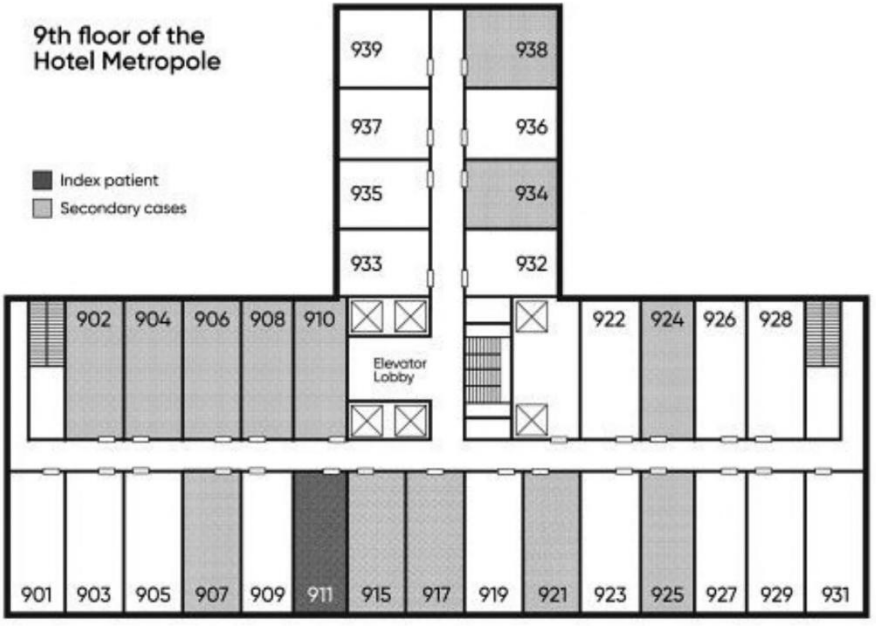


*Figure 4: The ninth floor of the Metropole Hotel in Hong Kong was a key location of spread of SARS-1 in 2003. Dr. Liu, the index patient who would be a super-spreader, stayed in room 911.*

A thirty-three-year-old patient with kidney disease who was hospitalized for some blood tests on ward 8A on March 13 contracted the infection while he was there. The next day and then again on March 19, he visited his older brother who lived on the seventh floor of the Amoy Gardens, a densely packed high-rise housing complex in Hong Kong. During his visit, the patient was sick with diarrhea and had to use the bathroom. In a bit of detective work that would become famous among epidemiologists, it was eventually determined that many of the later cases in the complex were related to dried-out sewage pipes in the apartment. Running exhaust fans and flushing toilets with buckets disturbed desiccated sewage and released virus-laden aerosols (termed *gaseous plumes*) into multiple bathrooms.[15] Within days, a large outbreak involving 321 patients had started at the Amoy Gardens.

This airborne mode of transmission is far more alarming to