6

AI Today

DEEP LEARNING OPENED the floodgates for applications of AI. In the second decade of the twenty-first century, AI has attracted more interest than any new technology since the World Wide Web in the 1990s. Everyone with data and a problem to solve started to ask whether deep learning might help them—and in many cases, the answer proved to be *yes*. AI has started to make its presence felt in every aspect of our lives. Everywhere that technology is used, AI is finding applications: in education, science, industry, commerce, agriculture, health care, entertainment, the media and arts, and beyond. While some applications of AI will be very visible in the future, others will not. AI systems will be embedded throughout our world, in the same way that computers are today. And in the same way that computers and the World Wide Web changed our world, so too will AI. I could no more tell you what the full range of applications of AI will be than I could tell you about all the applications of computers, but here are a few of my favorite examples that have emerged during the past few years.

In April 2019, you may recall seeing the first ever pictures of a black hole.[1] In a mind-boggling experiment, astronomers used data collected from eight radio telescopes across the world to construct an image of a black hole that is forty billion miles across and fifty-five million light-years away. The image represents one of the most dramatic scientific achievements this century. But what you might *not* know is that it was only made possible through AI: advanced computer vision algorithms were used to reconstruct the image, “predicting” missing elements of the picture.

In 2018, researchers from the computer processor company Nvidia demonstrated the ability of AI software to create completely convincing but completely fake pictures of people.[2] The pictures were developed by a new type of neural network, one called a **generative adversarial network.** The pictures are uncanny: at first sight, they look utterly realistic, and it is hard to believe that they are not real people. The evidence of our eyes tells us that they are—but they were created by a neural net. This capability, unimaginable at the turn of the century, will be a key component of virtual reality tools in the future: AI is on the way to constructing convincing alternative realities.

In late 2018, DeepMind researchers at a conference in Mexico announced AlphaFold, a system to understand a fundamental issue in medicine called *protein folding*.[3] Protein folding involves predicting the shape that certain molecules will take on. Understanding the shapes that they will form is essential for progress in treating conditions such as Alzheimer’s disease. Unfortunately, the problem is fearsomely difficult. AlphaFold used classic machine learning techniques to learn how to predict protein shapes and represents a promising step on the road to understanding these kinds of devastating conditions.

In the remainder of this chapter, I want to look in more detail at two of the most prominent opportunities for AI: the first is the use of AI in health care; the second is the long-held dream of driverless cars.

AI-POWERED HEALTH CARE

Anybody with even the vaguest interest in politics and economics will recognize that the provision of health care is one of the most important global financial problems for private citizens and for governments. On the one hand, improvements in health care provision over the past two centuries are probably the most important single achievement of the scientific method in the industrialized world: in 1800, life expectancy for someone in Europe would have been less than fifty years;[4] someone born in Europe today could reasonably expect to live late into their seventies. Of course, these improvements in health care and life expectancy have not yet found their way to all the parts of the globe, but overall, the trend is positive, and this is, of course, a cause for celebration.

But these welcome advances have created challenges. First, populations are, on average, becoming older. And older people typically require more health care than younger people, which means that the overall cost of health care has risen. Second, as we develop new drugs and treatments for diseases and other afflictions, the overall range of conditions that we can treat increases—which also leads to additional health care costs. And of course, a key underlying reason for the expense of health care is that the resources required to deliver health care are expensive, and people with the skill and qualifications to do so are scarce.

Because of these problems, health care—and more particularly *funding* for health care—is everywhere a perennial issue for politicians to wrangle with. Wouldn't it be wonderful, then, if there was a *technological* fix to the health care problem?

The idea of AI for health care is nothing new—we saw earlier that the seminal MYCIN expert system was widely acclaimed after demonstrating better-than-human performance when diagnosing the causes of blood diseases in humans. No surprise, then, that MYCIN was followed by a wave of similar health care–related expert systems, although it is fair to say that relatively few of these made it far from their research labs. But nowadays, interest in AI for health care is back with a vengeance, and this time, there are several developments that suggest it has a better chance of succeeding on a large scale.

One important new opportunity for AI-powered health care is what we might call *personal health care management*. Personal health care management is made possible by the advent of *wearable technology*—smartwatches like the Apple Watch, and activity/fitness trackers such as Fitbit. These devices continually monitor features of our physiology such as our heart rate and body temperature. This combination of features raises the fascinating prospect of having large numbers of people generating data streams relating to their current state of health on a continual basis. These data streams can then be analyzed by AI systems, either locally (via the smartphone you carry in your pocket) or by uploading them to an AI system on the internet.

It is important not to underestimate the potential of this technology. For the first time ever, we can monitor our state of health on a continual basis. At the most basic level, our AI-based health care systems can then provide impartial advice on managing our health. This is, in some sense, what devices like Fitbit already do—they monitor our activity and can also set us targets.

Mass-market wearables are in their infancy, but there are plenty of indications of what is to come. In September 2018, Apple introduced the fourth generation of its Apple Watch, which included a heart monitor for the first time. Electrocardiogram apps on the phone can monitor the data provided by the heart-rate tracker and have the potential to identify the symptoms of heart diseases, perhaps even calling for an ambulance on your behalf if necessary. One possibility is monitoring for the elusive signs of atrial fibrillation—an irregular heartbeat—which can be the precursor to a stroke or other circulatory emergency. An accelerometer in the phone can be used to identify the signature of someone falling, potentially calling for assistance if needed. Such systems require only fairly simple AI techniques: what makes them practicable now is the fact that we can carry a powerful computer with us, which is continually connected to the internet, and which can be linked to a wearable device equipped with a range of physiological sensors.

Some applications of personal health care may not even require sensors, just a standard smartphone. Colleagues of mine at the University of Oxford believe it may be possible to detect the onset of dementia *simply from the way that someone uses their smartphone.* Changes in the way that people use their phone or changes in patterns of behavior recorded by their phone can indicate the onset of the disease, before any other person notices these signs and long before a formal diagnosis would normally be made. Dementia is a devastating condition and presents an enormous challenge for societies with aging populations. Tools that can assist with its early diagnosis or management would be very welcome. Such work is still at the very preliminary stages, but it provides yet another indicator of what might come.

This is all very exciting, but the opportunities presented by these new technologies come with some potential pitfalls too. The most obvious of these is privacy. Wearable technology is *intimate*: it continually watches us, and while the data it obtains can be used to help us, it also presents boundless opportunities for misuse.

One area of immediate concern is the insurance industry. In 2016, the health insurance company Vitality started offering Apple Watches along with their insurance policies. The watches monitor your activity, and your insurance premiums are then set according to how much exercise you undertake. If, one month, you decided to be a couch potato and undertook no exercise, you might pay a full premium; but you could offset this the next month by going on a fitness frenzy, leading to a reduced premium. Perhaps there is nothing directly wrong with such a scheme, but it suggests some much more uncomfortable scenarios. For example, in September 2018, the U.S.-based insurance company John Hancock announced that in the future, it will *only* offer insurance policies to individuals who are prepared to wear activity-tracking technology.[5] The announcement was widely criticized.

Taking this kind of scenario further, what if we were only able to access national health care schemes (or other national benefits) if we agreed to be monitored and to meet daily exercise targets. You want health care? Then you have to walk ten thousand steps per day! Some people see nothing wrong with such a scenario; for others, it represents a profound intrusion and an abuse of our basic human rights.

Automated diagnosis is another exciting potential application for AI in health care. The use of machine learning to analyze data from medical imaging devices such as x-ray machines and ultrasound scanners has received enormous attention over the past decade. At the time of writing, it seems as if a new scientific article is announced showing that AI systems can effectively identify abnormalities from medical images every single day. This is a classic application of machine learning: we train the machine learning program by showing it examples of normal images and examples of abnormal images. The program learns to identify images with abnormalities.

A well-publicized example of this work came from DeepMind. In 2018, the company announced they were working with Moorfields Eye Hospital in London to develop techniques to automatically identify diseases and abnormalities from eye scans.[6] Eye scans are a major activity for

Moorfields: they typically undertake one thousand of them every working day, and analyzing these scans is a large part of the work of the hospital.

DeepMind's system used two neural networks, the first to "segment" the scan (identifying the different components of the image), and the second for diagnosis. The first network was trained on about nine hundred images, which showed how a human expert would segment the image; the second network was trained on about fifteen thousand examples. Experimental trials indicated that the system performed at or above the level of human experts.

You don't have to look far to find many other striking examples of how current AI techniques are being used to build systems with similar capabilities—for identifying cancerous tumors on x-rays, diagnosing heart disease from ultrasound scans, and many other examples.

Many have urged caution in the push for AI's use in health care. For one thing, the health care profession is, above all, a *human* profession: perhaps more than any other role, it requires the ability to interact with and relate to people. A GP needs to be able to "read" her patients, to understand the social context in which she is seeing them, to understand the kinds of treatment plans that are likely to work for this particular patient versus those which aren't, and so on. All the evidence indicates that we can now build systems that can achieve human expert performance in analyzing medical data—but this is only a small part (albeit a phenomenally important part) of what human health care professionals do.

Another argument against AI's use in health care is that some people would prefer to rely on human judgment rather than that of a machine. They would rather deal with a person. I think there are two points to make here.

First, it is hopelessly naive to hold up human judgment as some sort of gold standard. We are, all of us, flawed. Even the most experienced and diligent doctor will sometimes get tired and emotional. And however hard we try, we all fall prey to biases and prejudices, and often, we just aren't very good at rational decision-making. Machines *can* reliably make diagnoses that are every bit as good as those of human experts—the challenge/opportunity in health care is to put that capability to its best use. My belief is that AI is best used not to replace human health care professionals but to *augment* their capabilities—to free them from routine tasks and allow them to focus on the really difficult parts of their job; to allow them to focus on people rather than paperwork; and to provide another opinion—another voice in the room—to give further context for their work.

Second, the idea that we have a choice between dealing with a human physician or an AI health care program seems to me to be a first-world problem. For many people in other parts of the world, the choice may instead be between health care provided by an AI system or *nothing.* AI has a lot to offer here. It raises the possibility of getting health care expertise out to people in parts of the world who don't have access to it at present. Of all the opportunities that AI presents us with, it is this one that may have the greatest social impact.

DRIVERLESS CARS

At the time of writing, more than a million people per year are dying in automobile-related accidents globally. A further fifty million people are injured every year in automobile accidents. These are staggering statistics, and yet we seem to be accustomed to the dangers of road travel—we accept the risk as an occupational hazard of living in the modern world. But AI holds out the real prospect of dramatically reducing those risks: driverless cars are a real possibility in the medium term, and ultimately, they have the potential to save lives on a massive scale.

There are, of course, many other good reasons for wanting autonomous vehicles. Computers can be programmed to drive cars *efficiently,* making better use of scarce and expensive fuel or power resources, resulting in environmentally friendlier cars with lower running costs. Computers could also potentially make better use of road networks, for example, allowing far greater throughput at congested road junctions. And if cars become safer, the need for them to have expensive and heavy protective chassis will be reduced, again leading to cheaper, more fuel-efficient vehicles. There is even an argument that driverless cars will make car ownership unnecessary: driverless taxis will be so cheap, goes the argument, that it won't make economic sense to own your own car.

For all these reasons and more, driverless cars are an obvious and compelling idea, and it will therefore be no surprise to you that there has been a long history of research in this area. As automobiles became mass-market products during the 1920s and 1930s, the scale of deaths and injuries that resulted—mostly because of human error—immediately prompted discussion about the possibility of automated cars. Although there have been a range of experiments in this field since the 1940s, it is only since the emergence of microprocessor technologies in the 1970s that they really began to be feasible. But the challenge of driverless cars is immense, and the fundamental problem is perception. If you could find a way for a car to know precisely where it was and what was around it, then you would have solved the problem of driverless cars. The solution to this problem was to be modern machine learning techniques: without them, driverless cars would not be possible.

The **PROMETHEUS** project, funded by the pan-governmental EUREKA organization in Europe, is widely seen as a forerunner of today's driverless car technology. PROMETHEUS, which ran from 1987 to 1995, led to a demonstration in 1995, in which a car drove itself from Munich in Germany to Odense in Denmark and back. Human interventions were required on average about every five and a half miles; the longest stretch managed without human intervention was about a hundred miles. This was a remarkable feat—all the more remarkable because of the limited computer power available at the time. Although PROMETHEUS was only a proof that the concept could work and therefore a long way from a fully finished vehicle, the results of the project led to innovations that are now conventional in commercial automobiles, such as smart cruise control systems. And above all, PROMETHEUS signaled that this technology would, eventually, be commercially viable.

By 2004, progress was such that the U.S. military research agency DARPA organized a **Grand Challenge,** inviting researchers to enter a competition in which vehicles would autonomously traverse 150 miles of the American countryside. A total of 106 teams entered, from universities and companies alike, each hoping to win the $1 million prize offered by DARPA. These were whittled down to fifteen finalists, but in the event, none of the fifteen finalists completed more than eight miles of the course. Some vehicles failed to even make it out of the starting area. The most successful entry, Sandstorm from Carnegie Mellon University, managed just seven and a half miles, before going off course and getting stuck on an embankment.

My recollection of events at the time is that most AI researchers took the 2004 Grand Challenge as proof that driverless car technology was still some way from being practical. I was a little surprised to hear that DARPA had immediately announced a follow-up competition for 2005, with the prize money doubled to $2 million.

There were many more entries for the 2005 competition—195 in total, which were whittled down to 23 finalists. The final competition was held on October 8, 2005, and the goal was for the vehicles to cross 132 miles of the Nevada desert. This time, five teams completed the course. The winner was the robot **Stanley,** designed by a team from Stanford University, led by Sebastian Thrun. Stanley completed the course in just under seven hours, averaging about twenty miles per hour. A converted Volkswagen Touareg, Stanley was equipped with seven onboard computers, interpreting sensor data from GPS, laser range finders, radar, and video feed.

The 2005 Grand Challenge was one of the great technological achievements in human history. On that day, driverless cars became a solved problem, in the same way that heavier-than-air powered flight became a solved problem at Kitty Hawk just over a century earlier. The first flight by the Wright brothers lasted just twelve seconds, in which time the *Wright Flyer I* flew only 120 feet. But after that twelve-second journey, powered heavier-than-air flight was a reality—and so it was with driverless cars after the 2005 Grand Challenge.

The 2005 Grand Challenge was followed by a series of other challenges, of which probably the most important was the 2007 **Urban Challenge.** While the 2005 competition tested vehicles on rural roads, the 2007 challenge aimed to test them in built-up urban environments. Driverless cars were required to complete a course while obeying California road traffic laws and coping with everyday situations like parking, intersections, and traffic jams. Thirty-six teams made it to the national qualifying event, and of these eleven were selected for the final, held on a disused former airport on November 3, 2007. Six teams successfully completed the challenge, with the winner, from Carnegie Mellon University, averaging approximately fourteen miles per hour throughout the four-hour challenge.

We have seen massive investment in driverless car technology since then, both from established automobile companies, who are desperate not to be left behind, and from newer companies, who perceive an opportunity to steal a march on traditional manufacturers.

In 2014, the U.S. Society of Automotive Engineers provided a useful classification scheme to characterize the various different levels of autonomy within a vehicle:[7]

> **Level 0: No autonomy:** The car has no automated control functions whatsoever. The driver is in complete control of the vehicle at all times (although the vehicle may provide warnings and other data to assist the driver). Level 0 includes the vast majority of cars on the roads today.
>
> **Level 1: Driver assistance:** Here the car provides some level of control for the driver, typically on routine matters, but the driver is expected to pay complete attention. An example of driver assistance would be an adaptive cruise control system, which can maintain the car's speed, using brakes and accelerator.
>
> **Level 2: Partial automation:** At this level, the car takes control of steering and speed, although again the driver is expected to be continually monitoring the driving environment and to be ready to intervene if necessary.
>
> **Level 3: Conditional automation:** At this level, the human driver is no longer expected to be continually monitoring the driving environment, although the car may ask the user to take control if it encounters a situation that it cannot cope with.
>
> **Level 4: High automation:** Here, the car takes control under normal circumstances, although the driver can still intervene.
>
> **Level 5: Full automation:** This is the dream of driverless cars: you get in a car, state your destination, and the car does everything from there. There is no steering wheel.

At the time of writing, the state-of-the-art system for commercially available driverless car technology is probably Tesla's Autopilot, initially available on the Tesla Model S car. Released in 2012, the Model S was the flagship vehicle in Tesla's lineup of high-specification electric cars, and at the time of its release, it was probably the world's most technologically advanced commercially available electric car. From September 2014 onward, all Tesla Model S vehicles were equipped with cameras, radar, and acoustic range sensors. The purpose of all this high-tech gear was made plain in October 2015, when Tesla released software for the car that enabled its Autopilot feature—a limited automatic driving capability.

The media was quick to start hailing Autopilot as the first driverless car, although Tesla was at pains to point out the limitations of the technology. In particular, Tesla insisted that drivers should keep their hands on the steering wheel at all times while Autopilot was engaged. In terms of the levels of autonomy presented above, Autopilot seemed to be at Level 2.

However good the technology was, it was obvious that serious accidents involving Autopilot would eventually occur and that the first fatality involving Autopilot would make headlines across the world. And this indeed proved to be the case when, in May 2016, a Tesla owner in Florida was killed when his car drove into an eighteen-wheel truck. Reports suggested that the car's sensors had been confused by the view of the white truck against a bright sky: as a consequence, the car's AI software failed to recognize there was another vehicle present and drove directly into the truck at high speed, instantly killing the driver.

Other incidents highlight what seems to be a key problem with current driverless car technology. At Level 0 autonomy, it is completely clear what is expected of the driver: everything. And at Level 5 autonomy, it is similarly obvious: the driver is expected to do nothing. But between these two extremes, it is much less evident what drivers must expect to do, and the anecdotal evidence from the Florida incident and elsewhere is that drivers place far too much reliance on the technology—treating it as if it were Level 4 or 5, when in fact it is far below this. This mismatch between driver expectations and the reality of what the system can do seems to be driven at least in part by an overexcited press, who don't seem to be very good at understanding or communicating the subtleties of technological capability. (It probably doesn't help that Tesla named their system Autopilot.)

In March 2018, another high-profile accident involving driverless cars raised further doubts about the technology. On March 18, 2018, in Tempe, Arizona, a driverless car owned by Uber hit and killed a forty-nine-year old pedestrian, Elaine Herzberg, while in driverless mode. As is typically the way with accidents of this kind, there were a number of contributory causes. The car was traveling faster than the automatic emergency braking system could handle, so by the time the car recognized that emergency braking was required, it was too late to be able to do anything about it. Although the car's sensors recognized that there was an "obstacle" (the victim, Elaine Herzberg), which called for emergency braking, the software seems to have been designed to avoid doing this (suggesting some confusion, or at least, a rather strange set of priorities, in the mind of the programmers). But most important, the “safety driver” in the car, whose main purpose was to intervene in incidents like this, appears to have been watching TV on her smartphone, paying little attention to the outside environment. It may well be that she was too confident in the car’s driverless abilities as well. The tragic death of Elaine Herzberg was entirely avoidable—but the failure was human, not technological.

It seems depressingly inevitable that there will be more tragedies like these before we see practical, mass-market driverless cars. We need to do everything we reasonably can to anticipate and avoid such tragedies. But they will occur in any case; and when they do, we need to learn the lessons from them. The development of technologies such as fly-by-wire aircraft suggests that, in the long run, we will have much safer vehicles as a consequence.

The current flurry of activity around driverless vehicles suggests that the technology is tantalizingly close—but just *how* close is it? When will you be able to jump into a driverless car and state your destination? One of the most impartial indicators about this comes from information that driverless car companies are required to provide to the State of California in order to gain a license to test their cars within that state. The most important such piece of information is the Autonomous Vehicle Disengagement Report. The disengagement report must indicate how many miles the relevant car from which company drove in driverless mode and how many disengagements occurred during these tests. A disengagement is a situation in which a person had to intervene to take over control of the car—what *should* have occurred in the case of Elaine Herzberg. A disengagement doesn’t necessarily mean that the person had to intervene to avoid an accident—far less a fatality—but nevertheless this data gives an indication of how well the technology is performing. The fewer disengagements per autonomous mile driven, the better.

In 2017, twenty companies filed disengagement reports with the State of California. The clear leader, in terms of number of miles driven and lowest number of disengagements per 1,000 miles, was a company called Waymo, who reported, on average, a disengagement about every 5,000 miles; the worst performance was by automobile giant Mercedes, who reported no fewer than 774 disengagements per 1,000 miles. Waymo is Google’s driverless car company. Originally, it was an internal Google project, run by

2005 DARPA Grand Challenge winner Sebastian Thrun, and it became part of a subsidiary company of Google in 2016. In 2018, Waymo reported traveling 11,000 miles between disengagements.

So what does this data tell us? And in particular, how soon will driverless cars be an everyday reality?

Well, the first conclusion we can draw, from the relatively poor performance of automobile giants like BMW, Mercedes, and Volkswagen, is that a historical track record in the automotive industry is *not* the key requirement for success in driverless car technology. On reflection, this should come as no surprise: the key to driverless cars is not the internal combustion engine but *software*—AI software. No surprise, then, that the U.S. automobile giant General Motors acquired driverless car company Cruise Automation for an undisclosed (but obviously very large) sum in 2016, while Ford invested $1 billion in self-driving start-up company Argo AI. Both companies made public, very ambitious claims about the rollout of commercial driverless cars: Ford predicted they would have a "fully autonomous vehicle in commercial operation" by 2021.[8]

Of course, we don't know the precise criteria that companies use to decide when a disengagement occurs. It could be that Mercedes, for example, are just being overly cautious. But it seems hard to avoid the conclusion that, at the time of writing, Waymo are far ahead of the pack.

It is interesting to compare the State of California disengagement reports with what we know about human-driver performance. There doesn't seem to be any definitive statistical data about the latter, but it seems that in the United States, humans drive on average hundreds of thousands of miles between serious incidents—possibly even a million. This suggests that even the market leader, Waymo, would have to improve their technology by up to two orders of magnitude before they can achieve a comparable level of safety on the road to that of human drivers. Of course, not all the disengagements reported by Waymo would have led to accidents, so the comparison is hardly scientific, but at least it gives some indication of the scale of the challenges still faced by driverless car companies.

Anecdotally, speaking to engineers who work with driverless cars, it seems the key difficulty for the technology is dealing with unexpected events. We can train cars to deal with *most* eventualities—but what happens when the car meets a situation that is unlike anything it has met in training?

While most driving scenarios are routine and expected, there is a long tail of completely unpredictable situations that could occur. In such a situation, a human driver would have their own experience of the world to fall back on. They could think about how to handle it, and if they don't have time to think, they can call upon their instincts. Driverless cars do not have this luxury—and won't, not for the foreseeable future.

Another major challenge is how to make the transition from the current state of affairs on our roads (all vehicles on the roads are driven by people) through a mixed scenario (some human-driven cars, some driverless) to a completely driverless future. On the one hand, autonomous vehicles just don't behave like people while driving, and this confuses and unnerves the human drivers they share the roads with. On the other hand, human drivers are unpredictable and don't necessarily follow the rules of the road to the letter, making it hard for AI software to understand their behavior and interact with them safely.

Given my upbeat assessment of the progress made in driverless car technology, this may sound surprisingly pessimistic. So let me do my best to explain how I think events might unfold in the decades ahead.

First, I believe driverless car technology *in some form* will be in everyday use soon—likely within the next decade. However, this doesn't mean that Level 5 autonomy is imminent. Instead, I think we will start to see the technology rolled out in specific "safe" niche areas and that it will gradually then start to make its way out into the wider world.

So in what niches do I think we will see the technology in widespread use? Mining is one example. Perhaps in the giant open-cast mines of Western Australia or Alberta, Canada: there are comparatively few people there—far fewer pedestrians and cyclists behaving erratically. In fact, the mining industry already uses autonomous vehicle technology on a large scale. For example, the British-Australian Rio Tinto mining group claimed in 2018 that more than a billion tons of ore and minerals had been transported by their fleet of giant autonomous trucks in the Pilbara region of Western Australia,[9] although from the publicly available information, it seems the trucks are quite some way from Level 5 autonomy—more "automated" than "autonomous." Nevertheless, this seems like a good example of driverless vehicles being used to great effect in a constrained environment.

In much the same way, factories, ports, and military installations all seem well suited to driverless vehicles. I feel confident that we will see large-scale take-up of driverless technology in these areas within the next few years.

For driverless technology in everyday use beyond these niche applications, there are several possible scenarios, some or all of which may come to pass. It seems quite likely that we will see low-speed “taxi pods” in well-mapped, constrained urban environments or on specified routes. Indeed, several companies are trialing similar services at the time of writing, albeit on a very limited basis (and for the time being, with human “safety drivers” present in cars to handle emergencies). Limiting such vehicles to low speeds is hardly likely to be seen as a problem in cities like London, where traffic moves very slowly in any case.

Another possibility is special driverless car lanes in cities and on major highways. Most cities already have bus lanes and cycle lanes, so why not driverless car lanes? Such lanes might be augmented by sensors and other technology to assist autonomous vehicles. The presence of such lanes would also send a clear signal to human drivers sharing the roads with autonomous vehicles: beware robot drivers!

As to the question of Level 5 autonomy, we are still some distance away, I’m afraid. But it is inevitable. My best guess is that it will be at least twenty years from the time of writing before Level 5 autonomous vehicles are widely available. But I am pretty confident that my grandchildren will regard the idea that their grandfather actually drove a car *on his own* with a mixture of horror and amusement.