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THE POWER OF ALGORITHMS:

part 6

Учебное пособие

Саратов

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PREFACE

Настоящее учебное пособие включает актуальные тексты (2018-2019гг.) учебно-познавательной тематики для студентов механико-математического факультета (направления 02.03.01 «Математика и компьютерные науки», 01.03.02 «Прикладная математика и информатика», 38.03.05 «Бизнес-информатика»). Целью данного пособия является формирование навыка чтения и перевода научно-популярных текстов, а также развитие устной речи студентов (умение выразигь свою точку зрения, дать оценку обсуждаемой проблеме).

Пособие состоит из 5 разделов, рассматривающих значение информационных технологий в современном мире. Каждый из них содержит аутентичные материалы (источники: *Aeon, Quanta Magazine, Logic Magazine, Wired magazine, The Guardian*) и упражнения к ним.

Раздел “Supplementary reading“ служит материалом для расширения словарного запаса и дальнейшего закрепления навыков работы с текстами по специальности. Пособие может успешно использоваться как для аудиторных занятий, так и для внеаудиторной практики.

1. How the Brain Creates a Timeline of the Past

Exercise I.

Say what Russian words help to guess the meaning of the following words: cognitive, information, receptors, component, reconstruct, record, theory, stimulus, cooperate, theoretical.

Exercise II.

Make sure you know the following words and word combinations.

firing, slew, to roam, to parse, stoked, to trail, to recede, to ascertain, tangible, to dampen

How the Brain Creates a Timeline of the Past

The brain can't directly encode the passage of time, but recent work hints at a workaround for putting timestamps on memories of events.

It began about a decade ago at Syracuse University, with a set of equations scrawled on a blackboard. Marc Howard, a cognitive neuroscientist, and Karthik Shankar, who was then one of his postdoctoral students, wanted to figure out a mathematical model of time processing: a computable function for representing the past, like a mental canvas onto which the brain could paint memories and perceptions. "Think about how the retina acts as a display that provides all kinds of visual information," Howard said. "That's what time is, for memory. And we want our theory to explain how that display works." But it's fairly straightforward to represent a tableau of visual information, like light intensity or brightness, as functions of certain variables, like wavelength, because dedicated receptors in our eyes directly measure those qualities in what we see. The brain has no such receptors for time. "Color or shape perception, that's much more obvious," said Masamichi Hayashi, a cognitive neuroscientist at Osaka University in Japan. "But time is such an elusive property." To encode that, the brain has to do something less direct. Pinpointing what that looked like at the level of neurons became Howard and Shankar's goal. Their only hunch going into the project, Howard said, was his "aesthetic sense that there should be a small number of simple, beautiful rules."

They came up with equations to describe how the brain might in theory encode time indirectly. In their scheme, as sensory neurons fire in response to an unfolding event, the brain maps the temporal component of that activity to some intermediate representation of the experience — a Laplace transform, in mathematical terms. That representation allows the brain to preserve information about the event as a function of some variable it can encode rather than as a function of time (which it can't). The brain can then map the intermediate representation back into other activity for a temporal experience — an inverse Laplace transform — to reconstruct a compressed record of what happened when. Just a few months after Howard and Shankar started to flesh out their theory, other scientists independently uncovered neurons, dubbed "time cells," that were "as close as we can possibly get to having that explicit record of the past," Howard said. These cells were each tuned to certain points in a span of time, with some firing, say, one second after a stimulus and others after five seconds, essentially bridging time gaps between experiences. Scientists could look at the cells' activity and determine when a stimulus had been presented, based on which cells had fired. This was the inverse-Laplace-transform part of the researchers' framework, the approximation of the function of past time. “I thought, oh my god, this stuff on the blackboard, this could be the real thing,” Howard said. “It was then I knew the brain was going to cooperate,” he added. Invigorated by empirical support for their theory, he and his colleagues have been working on a broader framework, which they hope to use to unify the brain’s wildly different types of memory, and more: If their equations are implemented by neurons, they could be used to describe not just the encoding of time but also a slew of other properties — even thought itself. But that’s a big if. Since the discovery of time cells in 2008, the researchers had seen detailed, confirming evidence of only half of the mathematics involved. The other half — the intermediate representation of time — remained entirely theoretical.Until last summer.

In 2007, a couple of years before Howard and Shankar started tossing around ideas for their framework, Albert Tsao spent the summer in the lab of May-Britt Moser andEdvard Moser, who had recently discovered the neurons responsible for spatial navigation. Tsao wondered what the entorhinal cortex might be doing, maybe it harbored a signal of time. The kind of memory-linked time Tsao wanted to think about is deeply rooted in psychology. For us, time is a sequence of events, a measure of gradually changing content. That explains why we remember recent events better than ones from long ago, and why when a certain memory comes to mind, we tend to recall events that occurred around the same time. But how did that add up to an ordered temporal history, and what neural mechanism enabled it?Tsao didn’t find anything at first. Even pinning down how to approach the problem was tricky because, technically, everything has some temporal quality to it. He examined the neural activity in rats as they foraged for food in an enclosure, but he couldn't make heads or tails of what the data showed. No distinctive time signal seemed to emerge. Tsao tabled the work and for years left the data alone. Later he decided to revisit it, this time trying a statistical analysis of cortical neurons at a population level. That's when he saw it: a firing pattern that, to him, looked a lot like time. He, the Mosers and their colleagues set up experiments to test this connection further. In one series of trials, a rat was placed in a box, where it was free to roam and forage for food. The researchers recorded neural activity from the brain regions. After a few minutes, they took the rat out of the box and allowed it to rest, then put it back in. They did this 12 times over about an hour and a half, alternating the colors of the walls (which could be black or white) between trials. What looked like time-related neural behavior arose mainly in the entorhinal cortex. The firing rates of those neurons abruptly spiked when the rat entered the box. As the seconds and then minutes passed, the activity of the neurons decreased at varying rates. That activity ramped up again at the start of the next trial, when the rat reentered the box. Meanwhile, in some cells, activity declined not only during each trial but throughout the entire experiment; in other cells, it increased throughout. Based on the combination of these patterns, the researchers — and presumably the rats — could tell the different trials apart (tracing the signals back to certain sessions in the box) and arrange them in order. Hundreds of neurons seemed to be working together to keep track of the order of the trials, and the length of each one. "You get activity patterns that are not simply bridging delays to hold on to information but are parsing the episodic structure of experiences," said

Matthew Shapiro, a neuroscientist at Albany Medical College in New York. The rats seemed to be using these "events" — changes in context — to get a sense of how much time had gone by. The researchers suspected that the signal might therefore look very different when the experiences weren't so clearly divided into separate episodes. So they had rats run around a figure-eight track in a series of trials, sometimes in one direction and sometimes the other. During this repetitive task, the entorhinal cortex's time signals overlapped, likely indicating that the rats couldn't distinguish one trial from another: They blended together in time. The neurons did, however, seem to be tracking the passage of time within single laps, where enough change occurred from one moment to the next.

Tsao and his colleagues were excited because, they posited, they had begun to tease out a mechanism behind subjective time in the brain, one that allowed memories to be distinctly tagged. "It shows how our perception of time is so elastic," Shapiro said. "A second can last forever. Days can vanish. It's this coding by parsing episodes that, to me, makes a very neat explanation for the way we see time. We're processing things that happen in sequences, and what happens in those sequences can determine the subjective estimate for how much time passes." The researchers now want to learn just how that happens. Howard's mathematics could help with that. When he heard about Tsao's results, he was ecstatic: The different rates of decay Tsao had observed in the neural activity were exactly what his theory had predicted should happen in the brain's intermediate representation of experience. "It looked like a Laplace transform of time," Howard said — the piece of his and Shankar's model that had been missing from empirical work. "It was sort of weird," Howard said. “We had these equations up on the board for the Laplace transform and the inverse around the same time people were discovering time cells. So we spent the last 10 years seeing the inverse, but we hadn’t seen the actual transform. Now we’ve got it. I’m pretty stoked. There was a nonzero probability that all the work my colleagues and students and I had done was just imaginary. That it was about some set of equations that didn’t exist anywhere in the brain or in the world. Seeing it there, in the data from someone else’s lab — that was a good day.”

If Howard’s model is true, then it tells us how we create and maintain a timeline of the past — what he describes as a “trailing comet’s tail” that extends behind us as we go about our lives, getting blurrier and more compressed as it recedes into the past. That timeline could be of use not just to episodic memory, but to working memory and conditioned responses. These “can be understood as different operations working on the same form of temporal history,” Howard said. Even though the neural mechanisms that allow us to remember an event like our first day of school are different than those that allow us to remember a fact like a phone number or a skill like how to ride a bike, they might rely on this common foundation. The discovery of time cells in those brain regions (“When you go looking for them, you see them everywhere,” according to Howard) seems to support the idea. So have recent findings — soon to be published by Howard and other collaborators — that monkeys viewing a series of images show the same kind of temporal activity in their entorhinal cortex that Tsao observed in rats. “It’s exactly what you’d expect: the time since the image was presented,” Howard said. He suspects that record serves not just memory but cognition as a whole. The same mathematics, he proposes, can help us understand our sense of the future, too: It becomes a matter of translating the functions involved. And that might very well help us make sense of timekeeping as it's involved in the prediction of events to come (something that itself is based on knowledge obtained from past experiences). Howard has also started to show that the same equations that the brain could use to represent time could also be applied to space, numerosity (our sense of numbers) and decision-making based on collected evidence — really, to any variable that can be put into the language of these equations. "For me, what's appealing is that you've sort of built a neural currency for thinking," Howard said. "If you can write out the state of the brain, what tens of millions of neurons are doing as equations and transformations of equations, that's thinking." He and his colleagues have been working on extending the theory to other domains of cognition.

One day, such cognitive models could even lead to a new kind of artificial intelligence built on a different mathematical foundation than that of today's deep learning methods. Only last month, scientists built a novel neural network model of time perception, which was based solely on measuring and reacting to changes in a visual scene. (The approach, however, focused on the sensory input part of the picture: what was happening on the surface, and not deep down in the memory-related brain regions that Tsao and Howard study.) But before any application to AI is possible, scientists need to ascertain how the brain itself is achieving this. Tsao acknowledges that there's still a lot to figure out, including what drives the entorhinal cortex to do what it's doing and what specifically allows memories to get tagged. But Howard's theories offer tangible predictions that could help researchers carve out new paths toward answers. Of course, Howard's model of how the brain represents time isn't the only idea out there. Some researchers, for instance, posit chains of neurons, linked by synapses, that fire sequentially. Or it could turn out that a different kind of transform, and not the Laplace transform, is at play. Those possibilities do not dampen Howard's enthusiasm. "This could all still be wrong," he said. "But we're excited and working hard."

Adapted from Quanta Magazine

Exercise III.

Fill in the gaps.

1) While the museum gives the facts, guided tours of the grounds _____________ a visit.

2) The ______________ is, I think, from our perspective often preferable to the implicit.

3) While these values may appear exact, they're actually an ________________, at best.

4) Efforts are under way to ______________ research by hiring some experienced analysts.

5) I've come to the conclusion that we've got to be careful about how we _______________ the term bully.

6) We were going to see a handful of the Christmas reindeer in a separate__________________.

7) As the universe expands, the most distant objects ______________ at the highest velocity.

8) What motivates people to seek the American presidency is difficult to ________________.

9) Coming up with something truly original and ______________ in yogurt was no mean feat.

10) The film has also received some criticism, which may ___________ its Oscar prospects.

Exercise IV.

Make up sentences of your own with the following word combinations:

to flesh out, to toss around, to tease out from, to figure out, to come up with equations, in mathematical terms, to flesh out theory, to uncovere neurons, to bridge time gaps between experiences, to work on a broader framework

Exercise V.

Match the words to the definitions in the column on the right:

to scrawl	a value or quantity that is nearly but not exactly correct
retina	a document or object placed in an envelope together with a letter
tableau	give strength or energy to
elusive	(of a person or animal) search widely for food or provisions
explicit	postpone consideration of
approximation	stated clearly and in detail, leaving no room for confusion or doubt
to invigorate	difficult to find, catch, or achieve

enclosure	a group of models or motionless figures representing a scene from a story or from history
to table	a layer at the back of the eyeball containing cells that are sensitive to light and that trigger nerve impulses that pass via the optic nerve to the brain, where a visual image is formed
to forage	write (something) in a hurried, careless way

Exercise VI.

Identify the part of speech the words belong to: cognitive, visual, surface, regions, application, possible, scientists, tangible, predictions, instance

Exercise VII.

Match the words to make word combinations:

Laplace	intensity
temporal	transform
sensory	information
computable	model
light	neurons
mental	neuroscientist
visual	students
mathematical	component
cognitive	canvas
postdoctoral	function

Exercise VIII.

Summarize the article “How the Brain Creates a Timeline of the Past”.

2. The growth mindset problem

Exercise I.

Say what Russian words help to guess the meaning of the following words: classify, anatomy, individuals, niche, army, recruits, progressive, potential, heroes, practice

Exercise II.

Make sure you know the following words and word combinations.

self-efficacy, to festoon, platitudinous, impediment, to proselytize, robustly, grit, counterintuitive, wooly, scaffolding

The growth mindset problem

A generation of schoolchildren is being exhorted to believe in their brain's elasticity. Does it really help them learn?

Over the past century, a powerful idea has taken root in the educational landscape. The notion of intelligence as something innate and fixed has been supplanted by the idea that intelligence is instead something malleable; that we are not prisoners of immutable characteristics and that, with the right training, we can be the authors of our own cognitive capabilities. Nineteenth-century scientists including Francis Galton and Alfred Binet devoted their own considerable intelligence to a quest to classify and understand human cognitive ability. If we could codify the anatomy of intelligence, they believed, we could place individuals into their correct niche in society. Binet would go on to develop the first IQ tests, laying the foundations for a method of ranking the intelligence of job applicants, army recruits or schoolchildren that continues today. In the early 20th century, progressive thinkers revolted against this idea that inherent ability is destiny. Instead, educators such as John Dewey argued that every child's intelligence could be developed, given the right environment. The self, according to Dewey, is not something 'ready made' but rather 'in continuous formation through choice of action'. In the 1960s and '70s, psychologists such as Albert Bandura bridged some of the gap between the innate and the learned models of intelligence with his idea of social cognitive theory, self-efficacy and motivation. One can recognise that there are individual differences in ability, Bandura argued, but still emphasise the potential for growth for each individual, wherever one's starting point. Growth mindset theory is a relatively new – and wildly popular – iteration of this belief in the malleability of intelligence, but with a twist. In many schools today you will see hallways festooned with motivational posters, and hear speeches on the mindset of great sporting heroes who simply believed their way to the top. These are all attempts to put growth mindset theory into practice through motivation. However a growth mindset is not really about motivation, but rather about the way in which individuals understand their own intelligence. According to the theory, if students believe that their ability is fixed, they will not want to do anything to reveal that, so a major focus of the growth mindset in schools is shifting students away from seeing failure as an indication of their ability, to seeing failure as a chance to improve that ability. As Jeff Howard noted almost 30 years ago: 'Smart is not something that you just are, smart is something that you can get.' Despite extraordinary claims for the efficacy of a growth mindset, however, it's increasingly unclear whether attempts to change students' mindsets about their abilities have any positive effect on their learning at all. And the story of the growth mindset is a cautionary tale about what happens when psychological theories are translated into the reality of the classroom, no matter how well-intentioned.

The idea of the growth mindset is based on the work of the psychologist Carol Dweck at Stanford University in California. Dweck's findings suggest that beliefs about ourselves can have a profound effect on academic achievement and beyond. Her seminal work stems from a paper 20 years ago that reported on a research project with schoolchildren that probed the relationship between their understanding of their own abilities and their actual performance. In the experiment, a group of 10- to 12-year-olds were divided into two groups. All were told that they had achieved a high score on a test but members of the first group were praised for their intelligence in achieving this, while the others were praised for their effort. The second group were far more likely to put effort into future tasks while the former took on only those tasks that would not risk their initial sense of worth. Praising ability actually made the students perform worse, while praising effort emphasised that change was possible. Dweck's work suggests that when people believe that failure is not a barometer of innate characteristics but rather view it as a step to success (a growth mindset), they are far more likely to put in the kinds of effort that will eventually lead to that success. By contrast, those who believe that success or failure is due to innate ability (a fixed mindset) can find that this leads to a fear of failure and a lack of effort. Imagine two children who are faced with taking a test on a tricky maths problem. The first child completes the first few steps but then hits a wall, and instantly feels demotivated. For this child, the small failure is incontrovertible evidence of simply not being good at maths. By contrast, for the second child, this small failure is merely a barrier to eventual success, and confers an opportunity to improve overall maths ability. The second child relishes the challenge, and works to improve – that child is displaying a growth mindset. According to the theory, the key to encouraging this disposition is to praise the effort and not the ability. By telling children that they are smart or intelligent, you are merely confirming the idea of innate ability, fostering a fixed mindset, and actually undermining their development. Dweck's claims are supported by a lot of evidence, indeed she and her associates have spent more than 30 years exploring this phenomenon, including taking the time to respond to criticism in an open and transparent way.

Growth mindset theory has had a profound impact on the ground. It is difficult to think of a school today that is not in thrall to the idea that beliefs about one's ability affect subsequent performance, and that it's crucial to teach students that failure is merely a stepping stone to success. Implementing these ideas has been much harder, however, and attempts to replicate the original findings have not been smooth, to say the least. A recent national survey in the United States showed that 98 per cent of teachers feel that growth mindset approaches should be adopted in schools, but only 50 per cent said that they knew of strategies to effectively change a pupil's mindset. The truth is we simply haven't been able to translate the research on the benefits of a growth mindset into any sort of effective, consistent practice that makes an appreciable difference in student academic attainment. In many cases, growth mindset theory has been misrepresented and miscast as simply a means of motivating the unmotivated through pithy slogans and posters. A general truth about education is that the more vague and platitudinous the statement, the less practical use it has on the ground. ‘Making a difference’ rarely makes any difference at all. A growing number of recent studies are casting doubt on the efficacy of mindset interventions at scale. It was found that claims for the growth mindset might have been overstated, and that there was ‘little to no effect of mindset interventions on academic achievement for typical students’ One of the greatest impediments to successfully implementing a growth mindset is the education system itself. A key characteristic of a fixed mindset is a focus on performance and an avoidance of any situation where testing might lead to a confirmation of fixed beliefs about ability. Yet we are currently in a school climate obsessed with performance in the form of constant testing, analysing and ranking of students. Schools create a certain cognitive dissonance when they proselytise the benefits of a growth mindset but then hand out fixed target grades in lessons based on performance. Aside from the implementation problem, the original growth mindset research has also received harsh criticism and been difficult to replicate robustly. An enduring criticism of growth mindset theory is that it underestimates the importance of innate ability, specifically intelligence. If one student is playing with a weaker hand, is it fair to tell the student that he is just not making enough effort? Growth mindset – like its educational-psychology cousin ‘grit’– can have the unintended consequence of making students feel responsible for things that are not under their control: that their lack of success is a failure of moral character. The US psychiatrist

Scott Alexander sees growth mindset as a 'noble lie', and notes that saying to kids that a growth mindset accounts for success is not exactly denying reality so much as 'selectively emphasising certain parts of' it. Much of this criticism is not lost on Dweck, and she deserves great credit for responding to it and adapting her work accordingly. In a recent blog, she noted that growth mindset theory 'is on a firm foundation, but we're still building the house'. In fact, she argues that her work has been misunderstood and misapplied in a range of ways. She has also expressed concerns that her theories are being misappropriated in schools by being conflated with the self-esteem movement: 'The thing that keeps me up at night is that some educators are turning mindset into the new self-esteem, which is to make kids feel good about any effort they put in, whether they learn or not. But for me the growth mindset is a tool for learning and improvement. It's not just a vehicle for making children feel good.' For Dweck, it's not just about more effort, but rather purposeful and meaningful effort. And it's not just in the classroom where she feels that the growth mindset is being misunderstood, it seems to be happening in the home too: 'We're finding that many parents endorse a growth mindset, but they still respond to their children's errors, setbacks or failures as though they're damaging and harmful,' she said in an interview. 'If they show anxiety or overconcern, those kids are going toward a more fixed mindset.'

Dweck might be right that the theory is not always well understood or put into practice. There is always the danger of disappointment in the translation from educational laboratory to classroom, and this is partly due to the Chinese whispers effect, whereby research becomes diluted and distorted as it goes through its journey. But there is another factor at work here. The failure to translate the growth mindset into the classroom might reflect a profound misunderstanding of the elusive nature of teaching and learning itself. Effective teaching, at its best, defies prescription. The same resources and the same approaches that are successful in one classroom can be completely ineffective in another. Good teachers are like good actors, not in the sense that they are both artists, but in the sense that the best teachers teach you without you realising that you've been taught. If students get a whiff of being part of an 'intervention', then it is likely that the very awareness of this will have a detrimental effect. The growth mindset advocates claim that these interventions should be delivered in a stealthy way to maximise their effectiveness – miles away from the standard use of motivational stories and explanations of brain plasticity. Teaching is not medicine, after all, and students do not want to be treated as patients to be cured. How students learn well can be very counterintuitive. You might think it is safe to assume that, once you motivate students, the learning will follow. Yet research shows that this is often not the case: motivation doesn't always lead to achievement, but achievement often leads to motivation. If you try to 'motivate' students into public speaking, they might feel motivated but can lack the specific knowledge needed to translate that into action. However, through careful instruction and encouragement, students can learn how to craft an argument, shape their ideas and develop them into solid form. A lot of what drives students is their innate beliefs and how they perceive themselves. There is a strong correlation between self-perception and achievement, but there is some evidence to suggest that the actual effect of achievement on self-perception is stronger than the other way round. To stand up in a classroom and successfully deliver a good speech is a genuine achievement, and that is likely to be more powerfully motivating than woolly notions of 'motivation' itself. Clearly, something has gone wrong somewhere along the way between the laboratory and the classroom. Yet creating a culture in which students can believe in the possibility of improving their intelligence through their own purposeful effort is something few would disagree with. Teaching students concrete skills such as how to write an effective introduction to an essay through close instruction, specific feedback, examples and careful scaffolding, and then praising their effort in getting there, is probably a far more effective way of improving confidence than talking about how unique they are, or how capable they are of changing their own brains. The best way to achieve a growth mindset might just be not to mention the growth mindset at all.

Adapted from Aeon

Exercise III.

Fill in the gaps.

1) In a time of desperation, tax should not be about fairness but about _________________.

2) This will make supercomputers usable and _______________ tools for humanities majors.

3) By the _______________ laws of gravity, all must one day come plunging down toward earth.

4) Descartes modified it to account for a truth he found to be ___________________.

5) This is an extreme example, of course, but it should serve as a_________________ tale.

6) Each state, however, plots the trajectory by which it plans to ______________ that goal.

7) It is ponderous, _____________ incoherent, and even self-contradictory.

8) Initially, this pressure only makes the king's speech _________________ more pronounced.

9) The focus is not to ________________, but rather to teach a technique and its origin.

10) It is also very strongly evidenced that ________________ play more than a small part in gossip.

Exercise IV.

Make up sentences of your own with the following word combinations:

at scale, to play with a weaker hand, smth is not lost on, to misappropriate, to dilute, to defy, to whiff, to exhort, to codify,

Exercise V.

Match the words to the definitions in the column on the right:

iteration	the action or process of intervening
cautionary	enjoy greatly
to confer	encourage or promote the development of (something, typically something regarded as good)
pithy	the way in which something is placed or arranged, esp.

	in relation to other things
to miscast	succeed in achieving (something that one desires and has worked for)
to attain	allot an unsuitable role to (a particular actor)
disposition	concise and forcefully expressive
to foster	grant or bestow (a title, degree, benefit, or right)
to relish	serving as a warning
intervention	the repetition of a process or utterance

Exercise VI.

Identify the part of speech the words belong to.

elasticity, supplant, malleable, immutable, incontrovertible, elasticity, powerful, notion, intelligence, malleable

Exercise VII.

Match the words to make word combinations:

progressive	recruits
army	applicants
Chinese	thinkers
job	capabilities
IQ	landscape
correct	whispers
cognitive	characteristics
immutable	elasticity
educational	tests

brain’s	niche

Exercise VIII.

Summarize the article “The growth mindset problem”.

3. The lottocracy

Exercise I.

Say what Russian words help to guess the meaning of the following words: lottery, anonymous, petition, protest, television, interview, echoes, republican, democrat, extreme

Exercise II.

Make sure you know the following words and word combinations.
unrivaled, deference, freeloader, hard-pressed, legislature, eligible, constituency, coherence, negligence, tinker

The lottocracy

Elections are flawed and can't be redeemed – it's time to start choosing our representatives by lottery

It is easy to feel that what you do won't make any difference. Recycle that can, bike or drive, buy from this company not that one, march in the streets against the factory closing or the looming war. It's never enough: the forces are large and anonymous, and there aren't enough of us. Or there are too many of us. Vote, petition, protest. We care about the horror: the steady-warming planet; the children born into hard, sad futures; the millions of homeless, and hungry, and unjustly imprisoned; the growing gap between the rich and the poor in Philadelphia, Kansas, and Kentucky, in Moscow and Paris. The problem, at bottom, is that we feel that we can't make a difference. Ethically and politically, we are ghosts in a machine. The celebrity comic Russell Brand is gesticulating wildly, urgently, in a hotel room, under the bright lights of a television interview.

‘Stop voting, stop pretending, wake up. Be in reality now. Why vote? We know it’s not going to make any difference. We know that already.’ He is responding to his interviewer, Jeremy Paxman, who is taking him to task for never having voted. We are brought up to think that voting is important, that it is a necessary condition of being a politically serious person, that we can’t complain about politics if we don’t vote. This last principle has echoes of the more reasonable parental admonition, said of lima beans or cauliflower: don’t knock it until you’ve tried it. But that principle is based on sound epistemological grounds: you might, for all you know, like cauliflower or lima beans. The voting thing is, as Brand argues, stupid. There are ways of participating in public affairs other than voting. For example, one can become a celebrity and call for revolution in a television interview. More to the point, the inference from not voting to not caring is a poor one. As Brand points out, you might care a lot about what happens and what the system is doing, but still realise that voting doesn’t affect what happens or what the system does. In most elections, the chance that your vote will make any difference to who wins is much smaller than the chance that you will be hit by a car on the way to cast your vote. But people still turn out to vote. They even drive through snow, miss work, and wait in line for hours. This has puzzled political scientists and economists. Why do people vote? This is an empirical question; it concerns our actual motivations. Many answers have been given: we vote because we enjoy it; because we think others will think badly of us if we don’t; because we want to express ourselves; or cheer for our team; or because we believe that we have a duty to do so. One worry about all of these answers is that they seem disconnected from what makes voting seem so morally significant, something that it might be worth fighting and dying for the right to do.   In the modern world, we often find ourselves in the following situation. I know that whether I do X rather than Y won't make a difference by itself. I also know that everyone else knows this about me and about themselves. I also know that if all of us do X, rather than Y, it will make a difference. And everyone else knows this, too. So it's striking and surprising that a celebrity such as Brand would come out and say, to millions, 'Don't vote,' rather than 'Vote for X.' That was the revolutionary part of the interview. Very few have gone on TV and said 'Don't vote.' Very few have gone on TV and said, essentially, X and Y can both go f*** themselves. One reason not to vote is that your vote — your one vote — is unlikely to make a difference to who wins the election. Another reason not to vote is that it doesn't matter who wins the election, that there is no difference between X and Y, republican and democrat. An extreme version of this thesis — which is obviously false — is that there is no difference between our Xs and our Ys. Much more plausible versions of this thesis are that there is not enough difference between our Xs and Ys, or that with respect to some important issues there is no difference between our Xs and Ys. Brand's view is clear: 'I'm not refusing to vote out of apathy,' he says. 'I'm not voting out of absolute indifference and weariness and exhaustion from the lies, treachery, deceit of the political class that has been going on for generations.' Brand says that many of us don't engage with the current political system, because we see that it doesn't work for us, we see that it makes no difference. 'The apathy doesn't come from us, the people,' he says. 'The apathy comes from the politicians. They are apathetic to our needs. They are only interested in servicing the needs of corporations.' Is this true? Why would this be? Wasn't the whole point of democratic elections to ensure that power would be in the hands of the people?

The theory of modern democracy goes something like this. Each of us is fundamentally autonomous and of equal moral worth, so that we have a claim to self-government, self-rule, to the extent that such self-government is compatible with an equal right to self-government of others. This suggests something like direct democracy, in which each of us would have an equal say in determining whether we go to war, what policies and laws to adopt, what should be taxed and how much taxes should be, and so on. But — we quickly realise — modern politics is very complex; it is a full-time job to be even modestly well-informed about political issues. Ideally, one would spend all of one's time doing it, in addition to having staff and resources to help. This suggests a move from direct democracy to representative democracy, where we would each have an equal vote in choosing that individual whom we think will best represent our interests and views. That person will act as our representative — and not as an elected tyrant — because to stay in power, she or he will have to be re-elected. If our representatives do things that we don't like, we can vote them out. That's the theory, and its simplicity and power — and the successes of actual electoral representative democracies — have led representative democracy to be the ascendant and unrivalled political system around the world. So, what's the problem? The problem is that despite the elections, elected representatives are not actually accountable to those over whom they govern. Even in established democracies there are concerns about the openness and fairness of elections. There are huge financial barriers to running for office, and considerable advantages to incumbency. Corporate money and television advertising have an outsized influence. There are logistical hurdles to keep poor, marginalised citizens from successfully registering to vote, and gerrymandering reduces competition, considerably. Even if these problems were addressed, they would succeed only in making elections fair. But meaningful accountability requires not just open and fair elections; it also requires that we are capable of engaging in informed monitoring and evaluation of the decisions of our representatives. And we are not capable of this. Not because we are stupid, but because we are ignorant: ignorant about what our representatives are doing, ignorant about the details of complex political issues, and ignorant about whether what our representative is doing is good for us or for the world. Our ignorance means that representatives can talk a good game, and maybe even try to do a few things that benefit the majority of us, but the basic information asymmetries at the heart of the representative system ensure that, for many issues — defence manufacturing and spending, policy that affects the insurance and pharmaceutical industries, agribusiness policy and regulation, energy policy, regulation of financial services and products — what we get is what the relevant business industries want. In the presence of widespread citizen ignorance and the absence of meaningful accountability, powerful interests will effectively capture representatives, ensuring that the only viable candidates — the only people who can get and stay in political power — are those who will act in ways that are congenial to the interests of the powerful. These concerns are brought to the fore if we think about how little we know about most of what our representatives do, how little real choice goes into the election of our representatives, and how much deference to the goodwill of our favoured political party is required. Even when we step outside partisan information streams, most issues are complex, and much of what we believe about them is a result of information provided by a few dominant media institutions. But there might be a way to overcome these difficulties, if we rethink the fundamentals of democracy itself. One response to these problems is to go small. In a small community, collective action problems are less prevalent, and can be solved organically. We can detect and shun violators or freeloaders. And information asymmetries disappear: I know the issues and problems that affect us, as do you. We understand their complexities. They are within our daily life. If we need to use representatives for some reason, we will know them personally, as friends or neighbours. We can easily see what they do. One difficulty with this response is that it is not obvious how to go small. We know we can make a difference by connecting to people in more direct ways: talking to people we see during our day, providing food and shelter for local families, teaching in a prison. But it can be hard to see how our political communities can be made smaller in this way. And many of us are hard-pressed for time, energy, and the resources to make these efforts. Worse still, the going small strategy can seem inadequate when compared with the forces at hand, the foundations of the horror. We are globally connected now. We can't roll back the technological development and population increases that threaten the planet, and make it so that my small choices and your small choices all have such large, global effects. This is where the political system is supposed to be of help, but our system is broken.

Political systems are a kind of technology, inventions of human beings to bring about things we care about: peace, prosperity, freedom. Representative democracy is old technology. It dates back to the Roman Republic. Russell Brand says don't vote, the system is broken, and I think he's right: we do need a new system. But it is important to stress that in saying that, one needn't be committed to the view that everything is awful. It's not. Modern democratic governments do many things well, even if imperfectly: food safety and quality control, traffic safety and road maintenance, regulation and enforcement of building codes, public health crisis response, air-travel regulation, market competition regulation, hospital and health care support, energy and telecommunications regulation, court systems, public libraries and basic public education, police and fire protection, support for basic and applied scientific research. It's true that for each item I just listed, there are 20 legitimate, serious complaints that could be made about the way some particular government handles that responsibility. It's also true that modern governments collect an extraordinary amount of money in taxes, so it should be no surprise that some things get done. Still, it would be a mistake to think that representative democracy is a disaster. It's good, but that shouldn't keep us from trying to make an even better system by paying attention to the ways in which it falls short. It is now time to reform the heart of the system: the election. Modern policy is too complex for there to be meaningful electoral accountability. Electoral capture is too easy and too important for powerful interests. So, what's the alternative? Get rid of elections. Use lotteries to select political officials. There are hard questions about how exactly to structure a political system with lottery-selection at its heart. Here's one approach, which I am in the process of developing, that I call lottocracy. The basic components are straightforward. First, rather than having a single, generalist legislature such as the United States Congress, the legislative function would be fulfilled by many different single-issue legislatures (each one focusing on, for example, just agriculture or health care). There might be 20 or 25 of these single-issue legislatures, perhaps borrowing existing divisions in legislative committees or administrative agencies: agriculture, commerce and consumer protection, education, energy, health and human services, housing and urban development, immigration, labour, transportation, etc.These single-issue legislatures would be chosen by lottery from the political jurisdiction, with each single-issue legislature consisting of 300 people. Each person chosen would serve for a three-year term. Terms would be staggered so that each year 100 new people begin, and 100 people finish. All adult citizens in the political jurisdiction would be eligible to be selected. People would not be required to serve if selected, but the financial incentive would be significant, efforts would be made to accommodate family and work schedules, and the civic culture might need to be developed so that serving is seen as a significant civic duty and honour. In a normal year-long legislative session, the 300 people would develop an agenda of the legislative issue or two they would work on for that session, they'd hear from experts and stakeholders with respect to those issues, there would be opportunities for gathering community input and feedback, and they would eventually vote to enact legislation or alter existing legislation. Single-issue focus is essential to allow greater learning and engagement with the particular problems, especially given the range of backgrounds that members would bring to the institutions, and the fact that these individuals would be amateurs at the particular task of creating legislation. Lottery-chosen representatives would have more time to learn about the problems they're legislating than today's typical representatives, who have to spend their time learning about every topic under the sun, while also constantly travelling, claiming and raising funds to get re-elected. In the lottocratic system representatives will be — at least over a long enough run — descriptively and proportionately representative of the political community, simply because they have been chosen at random. But they will not have in mind the idea that they are to represent some particular constituency. Instead, they will be like better-informed versions of ourselves, coming from backgrounds like ours, but with the opportunity to learn and deliberate about the specific topic at hand.

No pure lottocratic system has ever existed, and so it's important to note that much could go wrong. Randomly chosen representatives could prove to be incompetent or easily bewildered. Maybe a few people would dominate the discussions. Maybe the experts brought in to inform the policymaking would all be bought off and would convince us to buy the same corporate-sponsored policy we're currently getting. There are hard design questions about how such a legislative system would interact with other branches of government, and questions about the coherence of policymaking, budgeting, taxation, and enforcement of policy. That said, it's worth remembering the level of dysfunction that exists in the current system. We should be thinking about comparative improvement, not perfection, and a lottocratic system would have a number of advantages over the current model. The most obvious advantage of lotteries is that they help to prevent corruption or undue influence in the selection of representatives. Because members are chosen at random and don't need to run for office, there will be no way for powerful interests to influence who becomes a representative to ensure that the only viable candidates are those whose interests are congenial to their own. Because there is no need to raise funds for re-election, it should be easier to monitor representatives to ensure that they are not being bought off. Another advantage of lotteries over elections is that they are likely to bring together a more cognitively diverse group of people, a group of people with a better sense of the full range of views and interests of the polity. Because individuals are chosen at random, they are much more likely to be an ideologically, demographically, and socio-economically representative sample of the people in the jurisdiction than those individuals who are capable of successfully running for office. Elections lead elected officials to focus on those problems for which they can claim credit for addressing, and to ignore or put on the back burner those problems with a longer horizon or those solutions for which it is harder to get credit. This negligence is made possible by voter ignorance and made inevitable by the perverse short-term incentives that elections provide. Lottery selection can help us to avoid this problem. Perhaps the most urgent issue we face is climate change, a complex collective action problem that will almost certainly require a political solution to solve. But many of the worst effects of climate change won't be realised for decades, and so politicians are unlikely to pay the short-term political cost given that they won't see the longer-term political benefits. Even when there are clear steps that need to be taken, many elected officials will avoid acting out of fear of the immediate consequences. Individuals chosen at random won't be hamstrung by these skewed incentives. If there is agreement on a viable solution, to climate change or to the myriad other issues that affect our children and grandchildren, lottocratic representatives will have the luxury of looking beyond this week's poll or next week's fund-raiser. This task of radically redesigning government is usually dismissed as utopianism, but there is no reason to think that electoral representative democracy can't be improved upon, just like every other kind of technology. Of course, one must be aware of limitations in the materials; we must think critically and carefully about what we know, what we have learned from psychology, economics, history, political science, law, and philosophy. And we have to be mindful of the dangers that attend our tinkering. Some of the worst horrors of the 20th century were the result of political design projects gone terribly wrong. So, we must tread carefully and take small steps. But we can't continue to stand still.

Adapted from Aeon

Exercise III.

Fill in the gaps.

1) Scammers who prey on people with fake employment opportunities need to be ________________.

2) But _______________ is just how is the impression of search speed implemented.

3) In my next post I wanted to give you a design to start this with some ______________.

4) Both prime ministers have been accused in their respective countries of _________________.

5) The American edition of Vogue is __________________ in its power in fashion publishing.

6) It is not hard to build _________________ moral and political views on such a foundation.

7) Anyone who's ever loved or lived in this city would be ________________ to disagree.

8) Children must be 5 years old before Aug. 1 to be _________________ to enter kindergarten.

9) It's also a reminder that freedom can _____________, that a life unbarred still has constraints.

10) In pretty much every other aspect of our lives _______________ can get us in trouble.

Exercise IV.

Make up sentences of your own with the following word combinations:

to be taken to task, more to the point, to take a good game, to redeem, to loom, to shun, to stagger, to bewilder, to hamstring

Exercise V.

Match the words to the definitions in the column on the right:

inference	a strong supporter of a party, cause, or person
treachery	(of a person) Pleasant because of a personality, qualities, or interests that are similar to one's own
ascendant	capable of working successfully; feasible
incumbency	larger than normal for its kind
viable	manipulate the boundaries of (an electoral constituency) so as to favor one party or class
outsized	the holding of an office or the period during which one is held
gerrymander	rising in power or influence
congenial	a state of extreme physical or mental fatigue
partisan	betrayal of trust; deceptive action or nature
exhaustion	a conclusion reached on the basis of evidence and reasoning

Exercise VI.

Identify the part of speech the words belong to. lottocratic, representatives, incompetent, dominate, discussions, experts, inform, legislative, interact, coherence

Exercise VII.

Match the words to make word combinations:

defense	grounds
public	policy
epistemological	interview
energy	beans
television	affairs
lima	manufacturing
hotel	planet
celebrity	room
sad	comic
steady-warming	futures

Exercise VIII.

Summarize the article "The lottocracy".

4. The marvel of the human dad

Exercise I.

Say what Russian words help to guess the meaning of the following words: anthropologists, periodically, discussions, exclusively, symptomatic, figure, antisocial, role, distance, stereotypes

Exercise II.

Make sure you know the following words and word combinations.
child-rearing, startlingly, resilience, arguably, to aspire, hands-on

The marvel of the human dad

Among our close animal relatives, only humans have involved and empathic fathers. Why did evolution favour the devoted dad?

What separates us from our fellow apes is a question that, rightly or wrongly, distracts anthropologists periodically. Their discussions generally focus on language, tool use, creativity or our remarkable abilities to innovate, and it is certainly the case that two decades ago these answers would have been top of the 'exclusively human' list. But as our knowledge of the cognitive and behavioural abilities of our primate cousins increases, the dividing line between us and them becomes more blurred, being about the extent and complexity of – rather than the presence or absence of – a behaviour. Take tool production and use. Chimps are adept at selecting and modifying grass stalks to use as 'fishing rods' when dipping for termites, but their ability to innovate is limited, so there's no rapid forward momentum in tool development as would be the case with humans.

However, there is one aspect of human behaviour that is unique to us but is rarely the focus of these discussions. So necessary is this trait to the survival of our species that it is underpinned by an extensive, interrelated web of biological, psychological and behavioural systems that evolved over the past half a million years. Yet, until 10 years ago, we had neglected to try to understand this trait, due to the misguided assumption that it was of no significance – indeed, that it was dispensable. This trait is human fatherhood, and the fact that it doesn't immediately spring to mind is symptomatic of the overwhelming neglect of this key figure in our society. When I began researching fathers 10 years ago, the belief was that they contributed little to the lives of their children and even less to our society, and that any parenting behaviour a man might display was the result of learning rather than any innate fathering skill. Stories of fathers in the media centred on their absence and the consequences of this for our society in terms of antisocial behaviour and drug addiction, particularly among sons. There was little recognition that the majority of men, co-resident or not, were invested in their children's lives. It was a given that fathers did not develop the profound bonds with their children that mothers did, because their role was confined to that of a secondary parent who existed, as a consequence of work, at a slight distance from the family. The lack of breadth in the literature and its sweeping generalisations and stereotypes was truly shocking. As an anthropologist, I struggled to accept this portrayal for two reasons. In the first instance, as someone who began her career as a primatologist, I knew that fathers who stick around, rather than hot-footing it as soon as copulation is complete, are vanishingly rare in the primate world, limited to a few South American monkey species and completely absent from the apes, with the exception of ourselves. Indeed, we are among the only 5% of mammals who have investing fathers. I knew that, given the parsimonious nature of evolution, human fatherhood – with its complex anatomical, neural, physiological and behavioural changes – would not have emerged unless the investment that fathers make in their children is vital for the survival of our species. Secondly, as an anthropologist whose training encompassed the societal structures and practices that are so fundamental to an understanding of our species, I was surprised to learn how little time we had spent placing this key figure under the microscope of our analysis. Ethnography after ethnography focused on the family and the role of the mother, and duly acknowledged the cooperative nature of childrearing, but very rarely was dad the particular subject of observation. How could we truly call ourselves human scientists when there was such a glaring gap in our knowledge of our own species? As a consequence, I embarked on a research programme based around two very broad and open questions: who is the human father, and what is he for?

To understand the role of the father, we must first understand why it evolved in our species of ape and no other. The answer inevitably lies in our unique anatomy and life history. As any parent knows, human babies are startlingly dependent when they are born. This is due to the combination of a narrowed birth canal – the consequence of our bipedality – and our unusually large brains, which are six times larger than they should be for a mammal of our body size. This has meant that, to ensure the survival of mother and baby and the continued existence of our species, we have evolved to exhibit a shortened gestation period, enabling the head to pass safely through the birth canal. The consequence of this is that our babies are born long before their brains are fully developed. The minimum period of lactation necessary for a child to survive is likewise drastically reduced; the age at weaning of an infant child can be as young as three or four months. A stark contrast to the five years evident in the chimp. Why is this the case? If we, as a species, were to follow the trajectory of the chimpanzee, then our interbirth interval (the time between the birth of one baby and the next) would have been so long; so complex and so energy-hungry is the human brain that it would have led to an inability to replace – let alone increase – our population. So, evolution selected for those members of our species who could wean their babies earlier and return to reproduction, ensuring the survival of their genes and our species. But because the brain had so much development ahead of it, these changes in gestation and lactation lengths led to a whole new life-history stage – childhood – and the evolution of a uniquely human character: the toddler. Humans exhibit five life stages: infant, child, juvenile, adolescent and adult. The child stage lasts from the point of weaning to the time of dietary independence. We humans wean our babies from milk comparatively early, before they are able to find and process food for themselves. As a consequence, once weaned, they still need an adult to feed them until they are capable of doing this themselves, at which point they become juveniles. So mum births her babies early and gets to invest less time in breastfeeding them. Surely this means an energetic win for her? But since lactation is the defence against further conception, once over, mum would rapidly become pregnant again, investing more precious energy in the next hungry foetus. She would not have the time or energy to commit to finding, processing and feeding her rapidly developing toddler. At this point, she would need help. When these survival-critical issues first appeared around 800,000 years ago, her female kin would have stepped in. She would have turned to her mother, sister, aunt, grandma and even older daughters to help her. But why not ask dad? Cooperation between individuals of the same sex generally evolves before that between individuals of different sex, even if that opposite-sex individual is dad. This is because keeping track of reciprocity with the other sex is more cognitively taxing than keeping track of it with someone of the same sex. Further, it has to be of sufficient benefit to dad's genes for him to renounce a life of mating with multiple females, and instead focus exclusively on the offspring of one female. While this critical tipping point had not yet been reached, women fulfilled this crucial role for each other. But 500,000 years ago, our ancestors' brains made another massive leap in size, and suddenly relying on female help alone was not enough. This new brain was energetically hungrier than ever before. Babies were born more helpless still, and the food – meat – now required to fuel our brains was even more complicated to catch and process than before. Mum needed to look beyond her female kin for someone else. Someone who was as genetically invested in her child as she was. This was, of course, dad. Without dad's input, the threat to the survival of his child, and hence his genetic heritage, was such that, on balance, it made sense to stick around.

As time ticked on and the complexity of human life increased, another stage of human life-history evolved: the adolescent. This was a period of learning and exploration before the distractions that accompany maturity start to emerge. With this individual, fathers truly came into their own. For there was much to teach an adolescent about the rules of cooperation, the skills of the hunt, the production of tools, and the knowledge of the landscape and its inhabitants. Mothers, still focused on the production of the next child, would be restricted in the amount of hands-on life experience they could give their teenagers, so it was dad who became the teacher. This still rings true for the fathers whom my colleagues and I research, across the globe, today. In all cultures, regardless of their economic model, fathers teach their children the vital skills to survive in their particular environment. Among the Kipsigis tribe in Kenya, fathers teach their sons about the practical and economic aspects of tea farming. From the age of nine or 10, boys are taken into the fields to learn the necessary practical skills of producing a viable crop, but in addition – and perhaps more vitally – they are allowed to join their fathers at the male-only social events where the deals are made, ensuring that they also have the negotiation skills and the necessary relationships that are vital to success in this tough, marginal habitat. In contrast, children of the Aka tribe of both sexes join their fathers in the net hunts that take place daily in the forests of the Democratic Republic of Congo. The Aka men are arguably the most hands-on fathers in the world, spending nearly half their waking time in actual physical contact with their children. This enables them to pass on the complex stalking and catching skills of the net hunt, but also teaches sons about their role as co-parent to any future children. And even in the West, dads are vital sources of education. In my book The Life of Dad, I argue that fathers approach their role in myriad different ways dependent upon their environment but, when we look closely, all are fulfilling this teaching role. So, while Western dads might not appear to be passing on overtly practical life-skills, they do convey many of the social skills that are necessary to succeed in our competitive, capitalist world. It is still very much the case that the wheels of success in this environment are oiled by the niceties of social interaction – and knowing the rules of these interactions and the best sort of person to have them with gives you a massive head start, even if it is just dad's knowledge of a good work placement. Fathers are so critical to the survival of our children and our species that evolution has not left their suitability for the role to chance. Like mothers, fathers have been shaped by evolution to be biologically, psychologically and behaviourally primed to parent. We can no longer say that mothering is instinctive yet fathering is learned. The hormonal and brain changes seen in new mothers are mirrored in fathers. His brain structure alters in those regions critical to parenting. Regions linked to affection, nurturing and threat-detection see increases in grey and white matter. But crucially, dad has not evolved to be the mirror to mum, a male mother, so to speak. Evolution hates redundancy and will not select for roles that duplicate each other if one type of individual can fulfil the role alone. Rather, dad's role has evolved to complement mum's. This is no more clear than in the neural structure of the brain itself. Where a child was brought up by two fathers, rather than a father and a mother, the plasticity of the human brain had ensured that, in the primary caretaking dad, both areas – mum's and dad's – showed high levels of activity so that his child still benefited from a fully rounded developmental environment. Fathers and their children have evolved to carry out a developmentally crucial behaviour with each other: rough-and-tumble play. This is a form of play that we all recognise. It is highly physical with lots of throwing up in the air, jumping about and tickling, accompanied by loud shouts and laughter. It is crucial to the father-child bond and the child's development for two reasons: first, the exuberant and extreme nature of this behaviour allows dads to build a bond with their children quickly; it is a time-efficient way to get the hits of neurochemicals required for a robust bond, crucial in our time-deprived Western lives where it is still the case that fathers are generally not the primary carer for their children. Second, due to the reciprocal nature of the play and its inherent riskiness, it begins to teach the child about the give and take of relationships, and how to judge and handle risk appropriately; even from a very young age, fathers are teaching their children these crucial life lessons. And how do we know that dads and kids prefer rough-and-tumble play with each other rather than, say, having a good cuddle? Because analysis has shown that, when it comes to interacting with each other, fathers and children get their peaks in hormone, indicating increased reward, from playing together. The corresponding peak for mothers and babies is when they are being affectionate. So, again, evolution has primed both fathers and children to carry out this developmentally important behaviour together. Likewise, a father's attachment to his child has evolved to be crucially different than a mother's. Attachment describes a psychological state that we enter when we are in an intense, bonded relationship with someone – think of lovers, parents and children, even some best friendships. In all cases, having a strong attachment relationship acts as a secure base from which we can strike out and explore the world, safe in the knowledge we can always return to the focus of our attachment for affection and help. Where parent-child attachment is concerned, the attachment between a mother and her child is best described as exclusive, an inward-looking dyad based on affection and care. In contrast, a father's attachment to his child has elements of affection and care, but it is based on challenge. This crucial difference leads a father to turn his children's faces outward, encouraging them to meet fellow humans, build relationships, and succeed in the world. And it is because of this special type of attachment that studies repeatedly show fathers in particular encouraging their offspring to get the most out of their learning. It is fathers who aid the development of appropriate social behaviour, and build a child's sense of worth.

Looking back at our pool of knowledge from 10 years ago and comparing it to what we know today, my conclusion is this: we need to change the conversations we have about fathers. Yes, some fathers are absent, as are some mothers, and some might be the inept characters of marketing ads or cartoons, struggling to work the washing machine or to look after the baby alone. But the majority of fathers are not these people. We need to broaden our spectrum of who we think dad is to include all the fathers who stick around, investing in their children's emotional, physical and intellectual development, regardless of whether they live with their children or not. We need to discuss the dads who coach football, read bedtime stories and scare away the night-time monsters. Who encourage their children's mental resilience, and scaffold their entry into our increasingly complex social world. Who are defined not by their genetic relatedness to their children but because they step up and do the job – the stepdads, grandfathers, friends, uncles and boyfriends. And by broadening this conversation and sharing our newfound knowledge, we empower fathers to be more involved with their children, something that benefits us all. The sons of today who see dad as an equal to mum in the domestic setting will follow this role model when they themselves become parents. This leads to a change in culture; a move towards equality in domestic work, a sharing of the burden of the parenting tax on career development, something that is overwhelmingly borne by mothers today, and a narrowing of the gender pay gap. Further, a father's special role in preparing his child to enter the wider world outside the family – shaping emotional and behavioural development, teaching the rules of social behaviour and language, helping to build mental resilience by dealing with risk, confronting challenge and overcoming failure – is arguably more important than ever before, when we are beset by a crisis in adolescent mental health, and live in a world that operates on new social rules, shaped by our digital, online lives. Men have evolved to father and to be an equal but crucially different part of the parenting team. By not acknowledging who they are or supporting what they do, we are really missing a trick. Some 80 per cent of men aspire to become fathers. I believe it is time we made the effort to get to know who they really are.

Adapted from Aeon

<u>Exercise III</u>.

Fill in the gaps.

1) The negatives outweigh the value of these sentences, so they are ___________________.

2) We might expect this actually to lead to inflated rather than _______________ wages.

3) With a smile on my face I ______________ it to the bank and then into town to do some serious shopping.

4) So when people _____________ on the spiritual path they may imagine that money is evil.

5) Experts say his success stems from his _________________ style and his marketing prowess.

6) We had entered the ______________________ world of performance art and stand-up comedy.

7) Perhaps it speaks to their ________________ that such strains remain hidden from view.

8) Kanye West is ___________________ popular music's most compelling and controversial figure.

9) He had been in the job for only four months so did not get any ________________ money.

10) Growing numbers of Chinese graduates ________________ to join China's massive bureaucracy.

Exercise IV.

Make up sentences of your own with the following word combinations: on balance, rough-and-tumble, to strike out for, gender pay gap, to miss a trick, to focus on, to be of no significance, to spring to mind, a glaring gap

Exercise V.

Match the words to the definitions in the column on the right:

dispensable	having or showing no skill; clumsy
hotfoot	given, felt, or done in return
parsimonious	the state of being no longer needed or useful
societal	the natural home or environment of an animal, plant, or other organism
habitat	begin (a course of action, esp. one that is important or demanding)
to embark	of or relating to society or social relations
redundancy	unwilling to spend money or use resources; stingy or frugal
reciprocal	walk or run quickly and eagerly
inept	able to be replaced or done without; superfluous

Exercise VI.

Identify the part of speech the words belong to: conclusion, conversations, absent, majority, spectrum, emotional, physical, intellectual, development, regardless

Exercise VII.

Match the words to make word combinations:

antisocial	rods
fishing	addiction
tool	line
grass	behaviour
drug	use
fellow	cousins
dividing	stalks
empathic	relatives
primate	fathers
animal	apes

Exercise VIII .

Summarize the article "The marvel of the human dad"

SUPPLEMENTARY READING

With Category Theory, Mathematics Escapes From Equality

Two monumental works have led many mathematicians to avoid the equal sign. Their goal: Rebuild the foundations of the discipline upon the looser relationship of "equivalence." The process has not always gone smoothly.

The equal sign is the bedrock of mathematics. It seems to make an entirely fundamental and uncontroversial statement: These things are exactly the same.

But there is a growing community of mathematicians who regard the equal sign as math's original error. They see it as a veneer that hides important complexities in the way quantities are related — complexities that could unlock solutions to an enormous number of problems. They want to reformulate mathematics in the looser language of equivalence.

"We came up with this notion of equality," said Jonathan Campbell of Duke University. "It should have been equivalence all along."

The most prominent figure in this community is Jacob Lurie. In July, Lurie, 41, left his tenured post at Harvard University for a faculty position at the Institute for Advanced Study in Princeton, New Jersey, home to many of the most revered mathematicians in the world.

Lurie's ideas are sweeping on a scale rarely seen in any field. Through his books, which span thousands of dense, technical pages, he has constructed a strikingly different way to understand some of the most essential concepts in math by moving beyond the equal sign. "I just think he felt this was the correct way to think about mathematics," said Michael Hopkins, a mathematician at Harvard and Lurie's graduate school adviser.

Lurie published his first book, Higher Topos Theory, in 2009. The 944-page volume serves as a manual for how to interpret established areas of mathematics in the new language of "infinity categories." In the years since, Lurie's ideas have moved into an increasingly wide range of mathematical disciplines. Many mathematicians view them as indispensable to the future of the field. "No one goes back once they've learned infinity categories," said John Francis of Northwestern University.

Yet the spread of infinity categories has also revealed the growing pains that a venerable field like mathematics undergoes whenever it tries to absorb a big new idea, especially an idea that challenges the meaning of its most important concept. "There's an appropriate level of conservativity in the mathematics community," said Clark Barwickof the University of Edinburgh. "I just don't think you can expect any population of mathematicians to accept any tool from anywhere very quickly without giving them convincing reasons to think about it."

Although many mathematicians have embraced infinity categories, relatively few have read Lurie's long, highly abstract texts in their entirety. As a result, some of the work based on his ideas is less rigorous than is typical in mathematics.

"I've had people say, 'It's in Lurie somewhere,'" said Inna Zakharevich, a mathematician at Cornell University. "And I say, 'Really? You're referencing 8,000 pages of text.' That's not a reference, it's an appeal to authority."

Mathematicians are still grappling with both the magnitude of Lurie's ideas and the unique way in which they were introduced. They're distilling and repackaging his presentation of infinity categories to make them accessible to more mathematicians. They are performing, in a sense, the essential work of governance that must follow any revolution, translating a transformative text into day-to-day law. In doing so, they are building a future for mathematics founded not on equality, but on equivalence.

Mathematical equality might seem to be the least controversial possible idea. Two beads plus one bead equals three beads. What more is there to say about that?

But the simplest ideas can be the most treacherous.

Since the late 19th century, the foundation of mathematics has been built from collections of objects, which are called sets. Set theory specifies rules, or axioms, for constructing and manipulating these sets. One of these axioms, for example, says that you can add a set with two elements to a set with one element to produce a new set with three elements: 2 + 1 = 3.

On a formal level, the way to show that two quantities are equal is to pair them off: Match one bead on the right side of the equal sign with one bead on the left side. Observe that after all the pairing is done, there are no beads left over.

Set theory recognizes that two sets with three objects each pair exactly, but it doesn't easily perceive all the different ways to do the pairing. You could pair the first bead on the right with the first on the left, or the first on the right with the second on the left, and so on (there are six possible pairings in all). To say that two plus one equals three and leave it at that is to overlook all the different ways in which they're equal. "The problem is, there are many ways to pair up," Campbell said. "We've forgotten them when we say equals."

This is where equivalence creeps in. While equality is a strict relationship — either two things are equal or they're not — equivalence comes in different forms.

When you can exactly match each element of one set with an element in the other, that's a strong form of equivalence. But in an area of mathematics called homotopy theory, for example, two shapes (or geometric spaces) are equivalent if you can stretch or compress one into the other without cutting or tearing it.

From the perspective of homotopy theory, a flat disk and a single point in space are equivalent — you can compress the disk down to the point. Yet it's impossible to pair points in the disk with points in the point. After all, there's an infinite number of points in the disk, while the point is just one point.

Since the mid-20th century mathematicians have tried to develop an alternative to set theory in which it would be more natural to do mathematics in terms of equivalence. In 1945 the mathematiciansSamuel Eilenberg and Saunders Mac Lane introduced a new fundamental object that had equivalence baked right into it. They called it a category.

Categories can be filled with anything you want. You could have a category of mammals, which would collect all the world's hairy, warm-blooded, lactating creatures. Or you could make categories of mathematical objects: sets, geometric spaces or number systems.

A category is a set with extra metadata: a description of all the ways that two objects are related to one another, which includes a description of all the ways two objects are equivalent. You can also think of categories as geometric objects in which each element in the category is represented by a point.

Imagine, for example, the surface of a globe. Every point on this surface could represent a different type of triangle. Paths between those points would express equivalence relationships between the objects. In the perspective of category theory, you forget about the explicit way in which any one object is described and focus instead on how an object is situated among all other objects of its type.

"There are lots of things we think of as things when they're actually relationships between things," Zakharevich said. "The phrase 'my husband,' we think of it as an object, but you can also think of it as a relationship to me. There is a certain part of him that's defined by his relationship to me."

Eilenberg and Mac Lane's version of a category was well suited to keeping track of strong forms of equivalence. But in the second half of the 20th century, mathematicians increasingly began to do math in terms of weaker notions of equivalence such as homotopy. "As math gets more subtle, it's inevitable that we have this progression towards these more subtle notions of sameness," said Emily Riehl, a mathematician at Johns Hopkins University. In these subtler notions of equivalence, the amount of information about how two objects are related increases dramatically. Eilenberg and Mac Lane's rudimentary categories were not designed to handle it.

To see how the amount of information increases, first remember our sphere that represents many triangles. Two triangles are homotopy equivalent if you can stretch or otherwise deform one into the other. Two points on the surface are homotopy equivalent if there's a path linking one with the other. By studying homotopy paths between points on the surface, you're really studying different ways in which the triangles represented by those points are related.

But it's not enough to say that two points are linked by many equal paths. You need to think about equivalences between all those paths, too. So in addition to asking whether two points are equivalent, you're now asking whether two paths that start and end at the same pair of points are equivalent — whether there's a path between those paths. This path between paths takes the shape of a disk whose boundary is the two paths.

You can keep going from there. Two discs are equivalent if there's a path between them — and that path will take the form of a three-dimensional object. Those three-dimensional objects may themselves be connected by four-dimensional paths (the path between two objects always has one more dimension than the objects themselves).

Ultimately, you will build an infinite tower of equivalences between equivalences. By considering the entire edifice, you generate a full perspective on whatever objects you've chosen to represent as points on that sphere.

"It's just a sphere, but it turns out, to understand the shape of a sphere, you need to go out to infinity in a sense," said David Ben-Zviof the University of Texas, Austin.

In the last decades of the 20th century, many mathematicians worked on a theory of "infinity categories" — something that would keep track of the infinite tower of equivalences between equivalences. Several made substantial progress. Only one got all the way there.

Jacob Lurie's first paper on infinity category theory was inauspicious. On June 5, 2003, the 25-year-old posted a 60-page document called "On Infinity Topoi" to the scientific preprint site arxiv.org. There, he began to sketch rules by which mathematicians could work with infinity categories.

This first paper was not universally well received. Soon after reading it, Peter May, a mathematician at the University of Chicago, emailed Lurie's adviser, Michael Hopkins, to say that Lurie's paper had some interesting ideas, but that it felt preliminary and needed more rigor.

"I explained our reservations to Mike, and Mike relayed the message to Jacob," May said.

Whether Lurie took May's email as a challenge or whether he had his next move in mind all along is not clear. (Lurie declined multiple requests to be interviewed for this story.) What is clear is that after receiving the criticism, Lurie launched into a multiyear period of productivity that has become legendary.

"I'm not inside Jacob's brain, I can't say exactly what he was thinking at that time," May said. "But certainly there's a huge difference between the draft we were reacting to and the final versions, which are altogether on a higher mathematical plane."

In 2006 Lurie released a draft of Higher Topos Theory on arxiv.org. In this mammoth work, he created the machinery needed to replace set theory with a new mathematical foundation, one based on infinity categories. "He created literally thousands of pages of this foundational machinery that we're all now using," said Charles Rezk, a mathematician at the University of Illinois, Urbana-Champaign, who did important early work on infinity categories. "I could not imagine producing Higher Topos Theory, which he produced in two or three years, in a lifetime."

Then in 2011, Lurie followed it up with an even longer work. In it, he reinvented algebra.

Algebra provides a beautiful set of formal rules for manipulating equations. Mathematicians use these rules all the time to prove new theorems. But algebra performs its gymnastics over the fixed bars of the equal sign. If you remove those bars and replace them with the wispier concept of equivalence, some operations become a lot harder.

Take one of the first rules of algebra kids learn in school: the associative property, which says that the sum or product of three or more numbers doesn't depend on how the numbers are grouped: 2 × (3 × 4) = (2 × 3) × 4.

Proving that the associative property holds for any list of three or more numbers is easy when you're working with equality. It's complicated when you're working with even strong notions of equivalence. When you move to subtler notions of equivalence, with their infinite towers of paths between paths, even a simple rule like the associative property turns into a thicket.

"This complicates matters enormously, in a way that makes it seem impossible to work with this new version of mathematics we're imagining," said David Ayala, a mathematician at Montana State University.

In Higher Algebra, the latest version of which runs to 1,553 pages, Lurie developed a version of the associative property for infinity categories — along with many other algebraic theorems that collectively established a foundation for the mathematics of equivalence.

Taken together, his two works were seismic, the types of volumes that trigger scientific revolutions. "The scale was completely massive," Riehl said. "It was an achievement on the level of Grothendieck's revolution of algebraic geometry."

Yet revolutions take time, and as mathematicians found after Lurie's books came out, the ensuing years can be chaotic.

Mathematicians have a reputation for being clear-eyed thinkers: A proof is correct or it's not, an idea works or it doesn't. But mathematicians are also human beings, and they react to new ideas the way human beings do: with subjectivity, emotion, and a sense of personal stakes.

"I think a lot of writing about mathematics is done in the tone that mathematicians are searching for these glittering crystalline truths," Campbell said. "That's not how it goes. They're people with their own tastes and own domains of comfort, and they'll dismiss things they don't like for aesthetic or personal reasons."

In that respect, Lurie's work represented a big challenge. At heart it was a provocation: Here is a better way to do math. The message was especially pointed for mathematicians who'd spent their careers developing methods that Lurie's work transcended.

"There's this tension to the process where people aren't always happy to see the next generation rewriting their work," Francis said. "This is one feature affecting infinity category theory, that a lot of previous work gets rewritten."

Lurie's work was hard to swallow in other ways. The volume of material meant that mathematicians would need to invest years reading his books. That's an almost impossible requirement for busy mathematicians in midcareer, and it's a highly risky one for graduate students who have only a few years to produce results that will get them a job.

Lurie's work was also highly abstract, even in comparison with the highly abstract nature of everything else in advanced mathematics. As a matter of taste, it just wasn't for everyone. "Many people did view Lurie's work as abstract nonsense, and many people absolutely loved it and took to it," Campbell said. "Then there were responses in between, including just full-on not understanding it at all."

Scientific communities absorb new ideas all the time, but usually slowly, and with a sense of everyone moving forward together. When big new ideas arise, they present challenges for the intellectual machinery of the community. "A lot of stuff got introduced at once, so it's kind of like a boa constrictor trying to ingest a cow,"

Campbell said. "There's this huge mass that's flowing through the community."

If you were a mathematician who saw Lurie's approach as a better way to do mathematics, the way forward was lonely. Few people had read Lurie's work, and there were no textbooks distilling it and no seminars you could take to get your bearings. "The way you had to learn about this stuff really precisely was to just sit down and do it yourself," said Peter Haine, a graduate student at the Massachusetts Institute of Technology who spent a year reading Lurie's work. "I think that's the hard part. It's not just sit down and do it yourself — it's sit down and do it yourself by reading 800 pages of Higher Topos Theory."

Like many new inventions, Higher Topos Theory requires mathematicians to interact a lot with the machinery that makes the theory work. It's like making every 16-year-old hoping for a driver's license first learn how to rebuild an engine. "If there was a more driver-friendly version, it would become instantly more accessible to a wider mathematical audience," said Dennis Gaitsgory, a mathematician at Harvard who has collaborated with Lurie.

As people started reading Lurie's work and using infinity categories in their own research, other problems emerged. Mathematicians would write papers using infinity categories. Reviewers at journals would receive them and say: What is this?
"You have this situation where [papers] either come back from journals with absurd referee reports that reflect deep misunderstandings, or they just take several years to publish," Barwick said. "It can make people's lives uncomfortable because an unpublished paper sitting on your website for years and years starts to look a little funny."

Yet the biggest problem was not papers that went unpublished, but papers that used infinity categories and did get published — with errors.
Lurie's books are the single, authoritative text on infinity categories. They are completely rigorous, but hard to completely grasp. They're especially poorly suited to serving as reference manuals — it's difficult to look up specific theorems, or to check that a specific application of infinity categories that one might encounter in someone else's paper really works out.

"Most people working in this field have not read Lurie systematically," said André Joyal, a mathematician at the University of Quebec in Montreal whose earlier work was a key ingredient in Lurie's books. "It would take a lot of time and energy, so we sort of assume what's in his book is correct because almost every time we check on something it is correct. Actually, all the time."

The inaccessibility of Lurie's books has led to an imprecision in some of the subsequent research based on them. Lurie's books are hard to read, they're hard to cite, and they're hard to use to check other people's work.

"There is a feeling of sloppiness around the general infinity categorical literature," Zakharevich said.

Despite all its formalism, math is not meant to have sacred texts that only the priests can read. The field needs pamphlets as well as tomes, it needs interpretive writing in addition to original revelation. And right now, infinity category theory still exists largely as a few large books on the shelf.

"You can take the attitude that 'Jacob tells you what to do, it's fine,'" Rezk said. "Or you can take the attitude that 'We don't know how to present our subject well enough that people can pick it up and run with it.'"

Yet a few mathematicians have taken up the challenge of making infinity categories a technique that more people in their field can run with.

In order to translate infinity categories into objects that could do real mathematical work, Lurie had to prove theorems about them. And to do that, he had to choose a landscape in which to create those proofs, just as someone doing geometry has to choose a coordinate system in which to work. Mathematicians refer to this as choosing a model.

Lurie developed infinity categories in the model of quasi-categories. Other mathematicians had previously developed infinity categories in different models. While those efforts were far less comprehensive than Lurie's, they're easier to work with in some situations. "Jacob picked a model and checked that everything worked in that model, but often that's not the easiest model to work in," Zakharevich said.

In geometry, mathematicians understand exactly how to move between coordinate systems. They've also proved that theorems proved in one setting work in the others.

With infinity categories, there are no such guarantees. Yet when mathematicians write papers using infinity categories, they often move breezily between models, assuming (but not proving) that their results carry over. "People don't specify what they're doing, and they switch between all these different models and say, 'Oh, it's all the same,'" Haine said. "But that's not a proof."

For the past six years, a pair of mathematicians have been trying to make those guarantees. Riehl and Dominic Verity, of Macquarie University in Australia, have been developing a way of describing infinity categories that moves beyond the difficulties created in previous model-specific frameworks. Their work, which builds on previous work by Barwick and others, has proved that many of the theorems in Higher Topos Theory hold regardless of which model you apply them in. They prove this compatibility in a fitting way: "We're studying infinity categories whose objects are themselves these infinity categories," Riehl said. "Category theory is kind of eating itself here."

Riehl and Verity hope to move infinity category theory forward in another way as well. They're specifying aspects of infinity category theory that work regardless of the model you're in. This "model-independent" presentation has a plug-and-play quality that they hope will invite mathematicians into the field who might have been staying away while Higher Topos Theory was the only way in.

"There's a moat you have to get across to get into this world," Hopkins said, "and they are lowering the drawbridge."

Riehl and Verity expect to finish their work next year. Meanwhile, Lurie has recently started a project called Kerodon that he intends as a Wikipedia-style textbook for higher category theory. Thirteen years after Higher Topos Theory formalized the mathematics of equivalence, these new initiatives are an attempt to refine and promote the ideas — to make the mathematics of equivalence more universally accessible.

"Genius has an important role in developing mathematics, but actually the knowledge itself is the result of the activity of a community," Joyal said. "It's the real goal of knowledge to become the knowledge of the community, not the knowledge of one or two persons."

Adapted from Quanta Magazine

How big data is changing science

New biomedical techniques, like next-generation genome sequencing, are creating vast amounts of data and transforming the scientific landscape. They're leading to unimaginable breakthroughs – but leaving researchers racing to keep up.

"This is when I start feeling my age," says Anne Corcoran. She's a scientist at the Babraham Institute, a human biology research centre in Cambridge, UK. Corcoran leads a group that looks at how our genomes – the DNA coiled in almost every cell in our bodies – relate to our immune systems, and specifically to the antibodies we make to defend against infection.

She is, in her own words, an "old-school biologist", brought up on the skills of pipettes and Petri dishes and protective goggles, the science of experiments with glassware on benches – what's known as "wet lab" work. "I knew what a gene looked like on a gel," she says, thinking back to her early career.

These days that skill set is not enough. "When I started hiring PhD students 15 years ago, they were entirely wet lab," Corcoran says. "Now when we recruit them, the first thing we look for is if they can cope with complex bioinformatic analysis." To be a biologist, nowadays, you need to be a statistician, or even a programmer. You need to be able to work with algorithms.

An algorithm, essentially, is a set of instructions – a series of predefined steps. A recipe could be seen as an algorithm, although a more obvious example is a computer program. You take your input (ingredients, numbers, or anything), run it through the algorithm's steps – which could be as simple as "add one to each number", or as complex as Google's search algorithm – and it provides an output: a cake, search results, or perhaps an Excel spreadsheet.

Researchers like Corcoran need to use algorithms because, in the 17 years since she became a group leader, biology has changed. And the thing that has changed it is the vast – the overwhelmingly, dizzyingly vast – flood of data generated by new biomedical techniques, especially next-generation sequencing.

Not long ago, sequencing an entire genome – determining the order of all 3 billion pairs of DNA letters in the helix – took years. The Human Genome Project, the first completed sequence of an entire human genome, took around 13 years from conception to its completion in 2003, and cost more than £2 billion. Today, next-generation sequencing can do the same thing in 24 hours for not much more than a thousand pounds.

This has completely changed how scientists work. It's not just that they get their hands dirty less often, nor simply that the required skills have changed. It's that the whole process of science – how you come by an idea and test it – has been upended.

This has left a lot of senior scientists needing to understand and supervise techniques that didn't exist when they trained. It's left universities playing catch-up, with many degrees not teaching the skills that modern biologists need. But above all, it's led to ground-breaking scientific discoveries – breakthroughs that simply wouldn't have been possible 20 or even 10 years ago.

A 10-minute drive from Babraham, in a village called Hinxton, there's another major life-sciences centre, the Wellcome Sanger Institute. It's 25 years old this week, and the rapidly moving history of genomics is written in its very architecture.

"I did my postdoc at the Sanger," says Moritz Gerstung, now a research group leader at the European Bioinformatics Institute next door. He chuckles at the memory. "You can almost sense when the building was conceived," he says. "There's so much space for laboratory work, and not so much for where scientists can sit and analyse data on a computer."

This is true everywhere, says Gil McVean, a professor of statistical genetics at the University of Oxford's Big Data Institute. Genomic research has become something done mainly on a laptop, not a workbench. "If you look at any 15-year-old research lab, they're 90 per cent wet lab," he says. "And if you go into one, almost all the people are sitting at computers. If you were to build a biomedical research centre today, you'd build it 10 per cent wet lab and 90 per cent computing."

But that's not the only change. "One of the big changes in science," says McVean, "has been the move away from a very focused, targeted, hypothesis-driven approach, the 'I've got this idea, I design the experiment, I run the experiment, and decide whether I was right or wrong' model."

It used to be that you had to have some plausible idea about why a gene might do something – that you could imagine some sensible-sounding biochemical pathway which could link the gene to a disease or trait. The time it took to sequence genes and the limited computing power available meant you had to be quite sure you were going to find something before you dedicated all that expensive lab and analysis time. Now you just collect a lot of data and let the data decide what the hypothesis should be, says McVean. If you look at 10,000 genomes of people with a disease and 10,000 without, you can use an algorithm to compare them, find the differences and then work out which genes are linked to the disease, without having to think in advance about which ones they might be.

This approach is known as a genome-wide association study, a common form of analysis in the data-driven era. It's a fairly simple idea. You take the genomes of a large number of people, sequence them, and then use an algorithm to compare all of the DNA – not just the 24,000 or so genes, which make up just 1–2 per cent of the genome, but also all of the still-somewhat-mysterious non-coding DNA too. The algorithm can be quite simple: for instance, comparing how frequently a certain DNA variant appears in people with a certain trait or condition and people without it. If the variant appears alongside a trait or condition significantly more often than you'd expect by chance, then the algorithm flags it up as a possible cause.

Where it gets difficult is that diseases are almost all complex, and have tens or sometimes hundreds of genes or sections of non-coding DNA involved. This quickly leads to the need for complicated multidimensional analysis, and while the maths involved isn't new, the sheer scale of the task means that algorithms are essential.

Often they can be comparing tens or hundreds of parameters at a time. It's a bit like the Google search algorithm. The process it uses to rank each web page isn't that complex – for instance, measuring how frequently your search terms appear on a page, then where on the page they appear, then how many links there are to that page, and so on. But it combines hundreds of these measures and applies them to billions of web pages simultaneously. It would be impossible for a human to do.

The algorithmic approach has brought great dividends. Gerstung's field, the genomics of cancer, has perhaps had the most exciting developments, for instance in relation to leukaemia.

This devastating and often fatal disease can – in some cases – be successfully treated with a full bone-marrow transplant. But that is a major procedure whose complications can sometimes be fatal themselves. You only want to give it to patients with the most deadly forms of leukaemia.

Predicting which leukaemias will be the most deadly, though, is enormously difficult. The symptoms are complex and don't always tell you enough about the prognosis.

So what Gerstung's team did was sequence the genomes of 1,500 people's cancers to find the DNA mutations driving them, and then see which mutations correlated with which outcomes. There were 5,000 different mutations among the patients, and around 1,000 different combinations, which the team divided up into 11 categories of greater or lesser risk. "It enables clinicians to make much more focused decisions," Gerstung says.

The influence of the data-driven approach extends much further. Sequencing the genomes of tumours has caused a "mind change" in our approach to cancer in general, says Edd James, a professor of cancer immunology at the University of Southampton. "We're now much more appreciative that a cancer isn't just a mass of copied cells."

A single cancer may contain dozens of different kinds of cell, each with different combinations of DNA mutations and each vulnerable to different drugs. So sequencing allows clinicians to better target drugs at the patients – and tumours – upon which they will work. “Before, people were treated as members of populations: ‘X per cent of people given this treatment will do well,’” says James. “But with this information, you can understand whether [individually] they’re going to get the benefit.”

As well as spotting differences, gene sequencing has revealed unexpected similarities between cancers too. Historically, says James, we’ve defined cancers by their anatomical site: as lung cancers, liver cancers, head-and-neck cancers and so on. “But using next-generation sequencing, you can see that there are cancers in different sites that share more in common with each other than with cancers in the same site. It’s made us realise that some drugs that work for, say, breast cancer might work on others,” he says.

Gerstung backs this up: “From a genetic perspective, there’s substantial overlap between cancers from different anatomical sites. One even finds BRCA1 [a gene heavily involved in breast cancer] in some prostate cancers.”

This is going to become increasingly important. The US Food and Drug Administration has recently licensed a cancer drug – pembrolizumab – for use in any cancer that shows signs of mismatch-repair deficiency, a form of DNA repair error. This is the beginning of drugs being licensed on the basis of a cancer’s genetics rather than location.

And it’s all because of the constant, gushing flow of data. “We got so good at producing data,” says Nicole Wheeler, a data scientist at the Sanger Institute who looks at the genomes of pathogenic bacteria, “that we ended up with too much of it.” McVean agrees. “In Moore’s Law, the computing power you have doubles every 18 months,” he says. “The growth of biomedical data capture – through sequencing genomes, but also through medical imaging or digital pathology – is much faster than that. We’re super-Moore’s-Law-ing in biomedical data.” It became completely impossible, in the early years of this century, for biological scientists to check their data themselves. And this meant that biologists had to recruit, or become, data scientists.

“We reached a bottleneck a few years ago,” says Anne Corcoran. “We had lots of data, but we didn’t know what to do with it. So algorithms had to be invented on the fly, to deal with the data and maximise it,” she continues. “When you’re looking at single genes, or a few, you can do it manually, but when you’re looking at the expression of 20,000 genes, you can’t even do the statistics by yourself.”

Biologists – many of whom grew up, as Corcoran did, working on benches with glassware, not desks and laptops – have had to learn to use these algorithms. “I think senior scientists are often intimidated by it,” she says, “and more reliant on their junior colleagues than they probably should be, or would like to admit that they are.”

She's evolved a "working knowledge" of how these algorithms function, but admits that "it's a slightly vulnerable period, where the people at the top don't have the skills to check the work of the people beneath them".

Wolf Reik, one of Corcoran's colleagues at the Babraham Institute, who runs a research team looking at epigenetics, agrees. Older scientists have a completely different mindset, he says. "It's quite funny – my staff in lab meetings think in terms of what the genome as a whole does. But I think about single genes and generalise from them – that's how I learned to think."

It's important for people in his position, he says, to understand junior scientists' work, and "most importantly develop an intuition about how to use the tools… because ultimately I put my name to the work".

The younger scientists, on the other hand, have grown up with data. Some of them have come from that background – Gerstung did a physics undergraduate degree – although that's true of some group leaders as well, such as McVean. But others who came through a more biological route have ended up talking in terms of coding. "I did biology as an undergrad, that's my domain knowledge," says Na Cai, a postdoctoral researcher at the Sanger Institute who studies how genotypes relate to various human traits.

"Now I'm doing statistical analysis every day. It's been like learning another language, or several," she says. "I had to switch my brain from thinking in terms of biochemical pathways and flowcharts to a more structured kind of thinking in terms of code."

The senior scientists she works with have all been "quite good at keeping up with the latest developments," she says. "They might not be able to write the code, but they understand what the analysis does."

Wheeler, a colleague of Cai's, also came through the biology route and ended up coding. "I don't have a traditional software-engineering background," she says. "I learned to code on the side, during my PhD. [My coding] isn't the most efficient or glamorous, but it's about seeing what you have to do computationally and making it happen."

In response to these needs, undergraduate degrees have been changing in the last few years. Newcastle University, for instance, now has a bioinformatics module in its biology undergraduate course, and Reading's final-year research projects involve computational biology, although the earlier optional computing modules have a low take-up, so students in their final year are learning the skills last-minute. Imperial College London, which already has bioinformatics courses, is planning to add programming for first- and second-years. "I think there's a recognition that biology involves more data than we used to have," says Wheeler, "so people need to have the skills to process it."

But the change is slow, and sometimes opposed by students, not all of whom got into biology to code. "I'd say some undergrad courses are catching up," says Corcoran. "But in general they have not, as exemplified by the proliferation of post-degree Master's courses teaching these skills."

The change is necessary, though. Even the most wet-lab-oriented scientists interviewed said they spend less than 50 per cent of their time doing experiments; some said it was as little as 10 per cent or even, in Cai's case, none at all since she has become a full-time bioinformatician.

The shift towards being data-driven, says Wheeler, can be seen as a move from science that's hypothesis-testing to one that's hypothesis-generating. One scientist, who preferred not to put their name to the concern, worried that it had reduced the creativity in science, but according to Wheeler that's not the case. "It's moved the creativity around," she says. "In some ways there's more room for creativity. You can really try out some crazy ideas at relatively low cost."

This has other advantages. "You can become attached to hypotheses," says Matt Bawn, a bioinformatician at the Earlham Institute, a computational biology research centre in Norfolk, UK. "It's better to be a disinterested observer with no preconceptions, to look at the blank canvas and let the picture emerge."

But the greatest benefit is that data-driven studies are throwing up fascinating new findings all the time, in complex areas that were previously impossible to study.

Stefan Schoenfelder, another researcher at the Babraham Institute, studies the 3D shapes of chromosomes and how they affect gene expression. When the Human Genome Project was completed, it was discovered that there were far fewer genes than previously expected – about 24,000, roughly a quarter of what scientists thought was the minimum. The rest of the DNA didn't code for proteins at all.

What has since been realised is that part of what those non-coding areas do is regulate the expression of the genes: they turn them on in some cells, off in others. And part of how they do that is by folding themselves into different shapes in different cells.

Chromosomes are usually depicted as X-shaped. But that's only when a cell is dividing. The rest of the time, the two metres of DNA inside almost every cell is coiled up in a complex tangle. So a length of DNA can be located a vast distance away from a gene on the chromosome but still be able to regulate it because in practice the two have close physical contact, says Schoenfelder. "That's why it's important to study this in 3D context: if you just look at the sequences and assume they will regulate the gene next door, that's often incorrect.

On top of this, genomes fold very differently, Schoenfelder says. "The same genome in a T cell will have a different conformation to in a liver cell or in a brain cell, and that's linked to different genes being expressed and the cells acquiring different functions."

Working out the 3D shape in each context is incredibly difficult. It involves sequencing cell types and seeing how they differ from other cell types, as well as which bits of DNA are interacting in that context. But the DNA first has to be treated using a complex technique known as cross-linking and ligation in order to allow the sequencing to see which bits are near each other. If two distant points are found together, it might be that they have been folded that way in order for one to affect the other. But – much more often – it's just the product of random jiggling.

Finding the real correlations among the noise requires looking at billions of data points and seeing which links keep coming up slightly more often than others. It's then that the algorithms really come into play. Once you know which bits of the chromosome are regularly in contact with which other bits, you can use other algorithms to build 3D models based on those points of contact.

"This whole field is only about 15 years old," says Schoenfelder. Before that, he says, "I didn't think of the genome's shape at all, I just thought of it as a ball of spaghetti crushed into the nucleus. I thought it was just a logistical problem, stuffing it into a nucleus that's maybe 5 microns across.

"What's blown me away is the fine level of regulation that exists, despite the extreme compaction, that still allows for this fine-tuning." The 3D shapes of chromosomes, and which regulatory elements interact with which genes on that shape, will be a large part of the story of how the 200 cell types in the human body arise.

Meanwhile, McVean says that genomic research has forced clinicians to reclassify the disease multiple sclerosis entirely. "We've found more than 250 bits of the genome which light up in terms of risk for the disease," he says. "That's let us make quite strong statements about the risk for the individual. But it's also allowed us to see overlaps with diseases like rheumatoid arthritis: some of the genes that raise your risk of MS decrease your risk of arthritis.

"So we've learned it's an autoimmune disease, even though it presents as a neurodegenerative disease," says McVean. "There are four or five companies with new therapeutic programmes coming out of this."

And Wolf Reik at the Babraham Institute has a thrilling, almost science-fiction story to tell. His work is in the field of epigenetics, looking at how the chemical environment of a cell affects the expression of genes; he sequences RNA, the messenger molecule that allows DNA to be read and proteins made, to see how it differs from cell to cell. His group is especially interested in ageing.

Five years ago, it was discovered – and Reik's work has since confirmed – that there is an ageing clock in all our cells. It's called DNA methylation. There are four letters in the DNA alphabet: C (cytosine), A (adenine), G (guanine) and T (thymine). As we get older, more and more of the Cs on our DNA gain a little chemical marker called a methyl group. To read this clock, the work is simple – just counting the methyl groups up – but, again, the sheer number of data points returned is so enormous that they absolutely have to be counted by algorithm.

"Reading that clock, we can predict your age, and my age, to within three years," says Reik. "Which is surprisingly accurate: the most accurate biomarker of ageing that we have."

All of which is very interesting, of course: it's "either a readout of an underlying ageing process, or our programmed life expectancy". But Reik says the implication is that we could interrupt it: "I'm sure there will be drugs and small molecules that can slow this ageing clock down."

It may be too much to hope that big data will help us all live for ever. But every scientist I spoke to agreed that the rise of algorithm-led, data-intensive genomic research has transformed the life sciences. It has left senior scientists sometimes unsure what their junior colleagues are doing, and left modern research centres with too much laboratory and not enough space for a laptop. The pace of change can be “disorienting”, says Schoenfelder.

“Life is a lot more complex now,” he says. “The skill set I had when I did my PhD, only 13 years ago, is absolutely not sufficient to keep up with today’s science.” But this change has brought an optimism back into genomic research. When the Human Genome Project neared completion, people were excited, believing that many diseases would fall quickly as their genetic components were revealed. But most of them turned out to be complex, polygenic, impossible to understand by looking at single genes. Now, though, it is possible to look at those diseases through the power of next-generation sequencing and tools that can sift the data it provides.

“Now when I run an experiment, I get 100 million, 200 million data points back,” says Schoenfelder. “I didn’t think that was possible in my lifetime, but it’s happened over the course of a few years. We can address questions that were completely off-limits 10 years ago. It’s been an extraordinary revolution.”

Adapted from Mosaic Science

Cloud Gaming Is Big Tech’s New Street Fight – Fortune

For nearly two decades, scenes like this one have unfolded in living rooms across the globe, thanks to Microsoft’s long-running video game franchise , playable on the tech giant’s ever-popular Xbox home console. But the rich gameplay described above, which Fortune witnessed during a recent visit to the company’s headquarters in Redmond, Wash., needed no brawny consumer electronics to run with the speed and splendor expected of a modern first-person shooter, as such computationally intensive games are known. It required only a smartphone—in this case, paired with a conventional Xbox controller.

Have smartphones become that good? Not quite. But their tremendous proliferation—more than 5 billion people across the globe own mobile phones, according to 2019 Pew estimates, and more than half of those devices are Internet-connected smartphones—has dramatically changed the way media is consumed. Music, portable since the days of Sony’s Walkman, is now streamed on the go. Movies and television, once limited to larger fixed screens, are now delivered to people’s pockets over the air.

Now video games are preparing to take their turn. If you’re not a gamer, you may not realize just how monumental a metamorphosis streaming promises to be. Today’s video game industry is a behemoth expected to generate $152 billion worldwide this year, according to market researcher Newzoo. That’s 57% more than the $97 billion generated by the global theatrical and home-movie market last year, and eight times the $19.1 billion generated by the global recorded music market. Like those industries, video game makers are grappling with the seemingly boundless potential of streaming, and the race is on to see who gets it right first.

The secret sauce powering all of this media streaming is a technology concept every executive is now familiar with: cloud computing. The off-loading of "compute" to staggeringly large server farms in remote locations, linked to our personal devices with persistent Internet connections, affords each of us on-demand access to supercomputer-level number-crunching power. This capability—plus forecasts that the global gaming industry could reach $196 billion in annual sales by 2022, per Newzoo—is why Microsoft, a gaming-industry stalwart that also happens to be a leading provider of cloud services, is so intrigued by so-called cloud gaming.

It's also why Halo 5 on a Samsung Galaxy smartphone can still manage such impressive visual pyrotechnics. The demonstration on view in Redmond is really running on the "racks" in a Microsoft data center in Quincy, Wash., 160 miles away. The Quincy facility is one of 13 the company plans to use to host its ambitious Project Xcloud game-streaming service when it begins a public trial this fall.

The last big breakthrough in gaming came a decade ago, when the birth of the smartphone gave rise to rudimentary but wildly popular mobile-first titles like Candy Crush and Angry Birds. "Ultimately the appeal of cloud gaming is the same thing," says Newzoo analyst Tom Wijman. "You can reach all of this audience without them needing to have a high-end gaming PC or expensive console."

The folks in Redmond are not alone in their interest. Google, which has fervently expanded its cloud division, announced a cloud-gaming platform called Stadia that it promises to launch by year's end. Meanwhile, crosstown rival Amazon, the leading cloud-services company by a country mile, is evaluating how to take its viewing platform Twitch, a top destination for people who watch other people play games, to even greater heights. Behind the big boys, a motley crew of lesser challengers—from Fortune 500 peers like Apple, Nvidia, Walmart, and Verizonto gamemakers like Electronic Arts and Valve to startups like Blade and Parsec—are developing or said to be investigating game-streaming subscription services of their own.

But none of them have cloud-computing muscle like the Big Three, which otherwise use their infrastructure to power the software and services they're best known for. Whether Amazon, Google, or Microsoft succeeds in crafting the next great console in the sky is almost immaterial. In any case, they'll all stand to benefit.

Satya Nadella has grown used to the naysayers. For years, Wall Street analysts questioned why Microsoft, the company famous for its Windows operating system and Office business suite, would waste money on something so seemingly trivial as video games. The calls grew louder when Nadella took the company's helm in July 2014. Still smarting from his predecessor's missteps in mobile devices, Nadella promised to steer Microsoft away from consumer distractions and toward its highly lucrative business services. Some even urged Microsoft to exit the gaming business altogether. "Four to five years ago, we and others were calling for them to divest that piece of the business," says Daniel Ives, managing director of Wedbush Securities and a longtime Microsoft observer. That tune has changed: Last year, Microsoft's gaming revenue—which includes Xbox, Windows games, and a cut of third-party gaming sales—topped $10 billion for the first time.

When I ask Nadella why the company didn't drop gaming, he chuckles. "There were a lot of things that a lot of people said Microsoft should be doing," he says. "If I listened to everything that everybody else on the outside asks me to do, there would be very little innovation in this company."

To be fair, in years past, Nadella had been hesitant to call gaming business core to Microsoft's overall strategy. Despite its success, gaming represents about a tenth of Microsoft's annual revenue. Cloud-computing growth is a big reason that the company's market capitalization topped $1 trillion this year; its "intelligent cloud" unit, which includes its Azure cloud-computing service, generates as much revenue in a quarter as the gaming group generates in a year. (Hasta la vista, Halo!)

But what if you could hitch gaming's fortunes to Microsoft's potent cloud engine? Well, now you're talking. Nadella's blockbuster $2.5 billion acquisition of the enormously popular world-building game Minecraft in 2014 was a "bit of a head-scratcher" when it was first announced, says analyst Ives, but it's now clear that the CEO was "planting the seed of how he viewed gaming as part of the broader business." Microsoft wouldn't just retain video games. Much as the company managed with Windows and Office, it would use the flywheel of its cloud-computing infrastructure to dramatically boost the scale of its gaming business—and the fortunes of every video game publisher it works with—far beyond what was previously possible.

Today, gaming is unquestionably "core"; in late 2017, Nadella elevated gaming lead Phil Spencer to the company's executive leadership team to underscore the point. And executives are bullish on the prospects of cloud-driven gameplay. Julia White, who leads product management for Microsoft's cloud platform, estimates that the business of selling Azure services to video game publishers is worth $70 billion—about as much as publicly traded transportation darling Uber. Most of today's Internet-connected video games are developed in, and operated from, private data centers run by game publishers, she says. Technology trends in other industries suggest that won't last. "Even though game developers are in a very different business," she says, "they face the same trials and tribulations of a commercial bank or a retail company going to the cloud."

To the cloudmaster go the spoils: In January, the Xbox maker shocked the gaming world by landing longtime console adversary Sony (of PlayStation fame) as an Azure customer with a promise to collaborate on future unspecified gaming projects. It was as if General Motors and Ford had announced a partnership to take on Tesla—an unmistakable sign that the competitive landscape would rapidly and dramatically change.

It was also an indication that Nadella's mission for Microsoft would be more expansive than it originally appeared. When I ask him why Microsoft is working so hard to build a consumer entertainment service when it has positioned itself as an enterprise software company, he replies, "It's a bigger business, right? It's bigger than any other segment. Why would I not do gaming? It fits with what we do. It has connective tissue to the common platform. We have a point of view that what we can do is unique." The problem: so does every other player in this game.

For 39,000 viewers tuned into Twitch, Elvis might as well have entered the building. Richard Tyler Blevins, the 28-year-old celebrity "streamer" known to fans by his moniker Ninja, has logged on to the service to play a few public rounds of the popular "battle royale" game Fortnite with his buddy. As his avatar runs and leaps through the game's virtual environment, weapon in hand, Blevins barks commands like an NFL quarterback at the snap—and his Twitch viewers hang on every mundanity. Their comments rush by in the chat window accompanying Ninja's feed. Some viewers respond to every move Blevins's character makes ("get that delay ninja"); others practically ignore the show to talk among themselves. (One thread of conversation among many: Why Finding Nemo was a "pretty good" Pixar movie.)

In other words, just another day on Twitch. Viewers—overwhelmingly male and mostly 34 or younger—watched a breathtaking 9.36 billion hours of gameplay on the platform last year, according to estimates by production company StreamElements. Twitch launched in 2011 as a spinoff of streaming video site Justin.tv, a pioneer in user-generated content. In 2014, Amazon reportedly spent $970 million to acquire the site, besting YouTube-owner Google in a bidding war. Wedbush analyst Michael Pachter estimates that Twitch brought in $400 million in revenue last year.

Twitch, which is housed in Amazon Web Services, the online retailer's cloud-computing unit, has rapidly become a cornerstone of the company's broader video gaming strategy. AWS, as Amazon Web Services is known, is already selling computing resources and developer tools to video game publishers. It's also rumored to be working on a service that would allow it to stream video games themselves rather than merely video of people playing them. (The company declined to comment, though recent job listings for technical roles for "an unannounced AAA games business" suggest its intentions. Like minor league baseball, "AAA" denotes the highest level of play in terms of budget and production.)

Two major milestones in the gaming industry set the stage for a cloudy future. The first: The massive success of Epic Games' Fortnite, which brought in an estimated $2.4 billion in sales last year and now claims 250 million registered players. Fortnitedemonstrated that "cross-platform" games, playable across competing devices from Microsoft, Sony, Apple, and others, could amass audiences far larger than those of the previous era, when titles were limited to specific ecosystems. "Fortnite was critical in getting the message across to all platforms that they have to lower the barrier of entry to their respective walled gardens," says Joost van Dreunen, head of games for market researcher SuperData.

The second? Twitch. The service demonstrated that people were just as happy to watch and cheer people playing games—call it the kid-sibling phenomenon—as they were to play the games themselves. That kind of interactivity proved that engagement and gameplay were not one and the same. The dynamic expands the addressable viewership for a given title. “Viewing is eclipsing gaming, and a lot of youth of today would say they played the game when they really viewed the game,” says Bonnie Ross, head of 343 Industries, the Microsoft studio that develops Halo.

For Microsoft’s part, the company never saw the spectatorship aspect coming. “Amazon has Microsoft on a treadmill,” a former executive says. Two years after Amazon bought Twitch, Microsoft acquired competing service Beam for an undisclosed amount. Rechristened Mixer, it has become the means by which Xbox customers can watch one another play games, logging 39.6 million hours of viewing in 2018, per StreamElements—a whopping 179% more than the previous year but still a distant third to Amazon’s Twitch and Google’s YouTube Live.

The summer sun blazes above the thousands of coders assembled for Google’s annual I/O developer conference in Mountain View, Calif., but the anxiety on display in the long line has little to do with the weather. The event’s attendees, who base their livelihoods on building software for as many users as possible, are keen to hear Google’s sales pitch for why they should create games for Stadia, an experimental cloud-gaming service that the search giant promises to debut in November.

Like most Silicon Valley presentations, the executives onstage overwhelm with ambitious assurances of technical prowess. Stadia’s complex cloud architecture will prevent the nasty networking hiccups that cause online gamers to throw down their controllers in frustration, Google’s representatives say. All gamers will need to do is open a tab in the Chrome web browser; with just a few clicks, they can play a high-speed, high-resolution title such as Assassin’s Creed Odyssey.

Like their counterparts at Microsoft and Amazon, Google brass believe their vast data center empire gives them an edge on the technical demands of streaming high-end video game titles without interruption. Like its peers, Google has encouraged its consumer gaming and enterprise cloud groups to work together to ensure Stadia launches without the problems that have traditionally plagued online games.

Thomas Kurian, a longtime Oracleexecutive who is now chief executive of Google’s cloud business, says the company’s enterprise engineers built the networking technology that powers Stadia. Cloud gaming is a way for Google to penetrate a multibillion-dollar industry, Kurian says. “Our hope is that it’s expanding the market, not just being a replacement market,” he says. “For every person in the world that games on a professional desktop, there are probably three who can’t afford one.”

In other words: Why fight over a quarter of the market when the rest is greenfield? John Justice, a Microsoft veteran who now leads product development for Google Stadia, agrees. Gamers no longer want to “buy an expensive box every few years,” he says. Stadia, and services like it, are more accessible destinations to engage with games without the high barriers of entry found in the traditional console market.

Even the pricing plays a part: Though Stadia’s $129 bundle plus $9.99 monthly subscription has already been announced, Google says it is also evaluating a free version, with lower-quality graphics, that would debut later. Though the technological trajectory is clear, it's still "early days" for the business model behind cloud gaming, Justice says. "Some people really do want transaction models, and some people want subscription models," he says. "I don't think we will say we will only go with one."

It could take years to iron out the details. Though consumers would love a gaming model akin to Netflix or Spotify—pay a monthly fee, play titles to your heart's content—it's not yet clear that cloud providers have the leverage over game publishers to make that happen. Publishers have seen how platform pressures have changed the business of movies, music, magazines, and more. They don't want to give up a share of their sales unless they're certain that there are many more to be had in the long run.

Ubisoft, the French publisher best known for the Assassin's Creed series, isn't terribly concerned. "That's less interesting to us," says Chris Early, an Ubisoft executive who manages partnerships and revenue. The company in June revealed its own subscription service, called Uplay+, that is playable on personal computers and spans more than 100 titles in its own catalog, including Far Cry and Prince of Persia.

It costs $14.99 a month and will also be available on Stadia next year. At this moment, "it makes less sense for a publisher to be part of an aggregated subscription model," says Early. There are many proposals for how to sustainably monetize cloud gaming, he adds, but it remains unclear "who is going to pay whom."

For now, publishers are focused on figuring out whether today's successful titles make sense in the cloud—or whether all-new titles, native to the format, will replace familiar franchises. The interactivity of Twitch and the novelty of so-called freemium mobile games, like Candy Crush, showed that technological leaps could open new paths to gaming engagement. The possibilities that could emerge from running games on the same infrastructure that supports today's artificial intelligence are something that technologists can only fathom.

"There will probably be evolutions of game design that we can't even imagine yet," says Early, "and they're going to take advantage of the increase of cloud compute."

Back in Redmond, I stop by Microsoft's 343 Industries game studio, where employees welcome me to a visitor center—a shrine, really—celebrating the company's Halofranchise, which has racked up $6 billion in sales since its debut. Statues depicting its heroes and villains tower over my head—a gallery of Greek gods, so to speak, for the gaming set. There are glass museum cases everywhere packed with memorabilia. On one wall is a rack of replicas of the virtual weaponry from the game, as intimidating in person as they appear on the screen. Bright orange tags with the word "prop" hang from their triggers in case someone takes the "incineration cannon" a little too seriously.

Founded in 2007 and named after a Halo character, 343 Industries is one of the older members of the Microsoft game portfolio. Last year alone, Microsoft acquired six game studios; at this year's E3 industry confab, the company announced that it had picked up one more. Today, its Xbox Game Studios division is a federation of 15 semiautonomous studios that the company believes will be a key asset in the cloud-gaming wars—particularly against Amazon and Google, which lack strong titles of their own.

Not everyone sees it that way. Though Microsoft has won plaudits for successive editions of Halo and the Forza car-racing series, analysts have pointed to the titles' relative age—Halodebuted in 2001; Forza first appeared four years later—as evidence that Microsoft's homegrown studios have run out of ideas. "We have work to do there," acknowledged Spencer, the Microsoft gaming chief. "We haven't done our best work over the last few years with our first-party output."

Frames from Halo Infinite, the forthcoming edition of the sci-fi game series, and Forza Horizon 4, a popular car-racing series. Both are published by Microsoft.

Courtesy of Xbox Game Studios

That must change if Microsoft, the only video game veteran among the Big Three consumer cloud companies, hopes to maintain its natural advantage against Amazon and Google. After all, in video games, as in other parts of the media industry, content is king—which is why Microsoft's rivals have moved to hire gaming veterans from top shops such as Electronic Arts (Madden NFL, Need for Speed) and 2K Games (Civilization, NBA 2K20) in an effort to build their own franchises. It is an uncanny echo of the moves by Amazon and Google to build their own premium programming, for Prime and YouTube, respectively, to compete with Netflix.

But Rome wasn't built in a day. Seven years after establishing a gaming group in 2012, Amazon laid off dozens of game developers as it reorganized itself for a cloud-based future. (Amazon downplayed the news. "Amazon is deeply committed to games and continues to invest heavily in Amazon Game Studios, Twitch, Twitch Prime, AWS, our retail businesses, and other areas within Amazon," a spokesperson tells Fortune.)

Van Dreunen, the SuperData analyst, believes it will take up to five years before cloud-driven efforts by the Big Three will significantly affect the traditional gaming industry. Until then, look for cloud computing's leaders to continue investing in their data center infrastructure to support the "gradual rollout" of cloud-gaming services, he says.

Why would Amazon, Google, and Microsoft make so much noise about a future that's so far away? It's all a part of the "land and expand" business model familiar to the technology industry, says analyst Pachter: Give a speech, plant a flag, hope that early momentum snowballs into an insurmountable competitive advantage. After all, "Facebook wasn't a billion-dollar idea until it was," he says. "Uber wasn't a billion-dollar idea until it was."

Microsoft, in particular, has no intention of missing out. The company still regrets losing the mobile war to Google and its Android operating system. (Microsoft "missed being the dominant mobile operating system by a very tiny amount," cofounder Bill Gates lamented earlier this year.) To underperform in an area where it has a head start of almost two decades would be, in a word, unconscionable.

Time to suit up, then. “We’re in gaming for gaming’s sake,” Nadella says. “It’s not a means to some other end.”

Adapted from Fortune

Seeking Big A.I. Advances, a Startup Turns to a Huge Computer Chip

Tucked in the Los Altos hills near the Stanford University campus, in a low-slung bunker of offices across from a coffee shop, is a lab overflowing with blinking machines putting circuits through their paces to test for speed, the silicon equivalent of a tool and die shop. Most chips you can balance on the tip of your finger, measuring just a centimeter on a side. Something very different is emerging here.

Andrew Feldman, 50, chief executive of startup Cerebras Systems, holds up both hands, bracing between them a shining slab the size of a large mouse pad, an exquisite array of interconnecting lines etched in silicon that shines a deep amber under the dull fluorescent lights. At eight and a half inches on each side, it is the biggest computer chip the world has ever seen. With chips like this, Feldman expects that artificial intelligence will be reinvented, as they provide the parallel-processing speed that Google and others will need to build neural networks of unprecedented size.

Four hundred thousand little computers, known as “cores,” cover the chip’s surface. Ordinarily, they would each be cut into separate chips to yield multiple finished parts from a round silicon wafer. In Cerebras’s case, the entire wafer is used to make a multi-chip computer, a supercomputer on a slab.

Companies have tried for decades to build a single chip the size of a silicon wafer, but Cerebras’s appears to be the first one to ever make it out of the lab into a commercially viable product. The company is calling the chip the “Wafer-Scale Engine,” or WSE—pronounced “wise,” for short (and for branding purposes).

“Companies will come and tell you, we have some little knob that makes us faster,” says Feldman of the raft of A.I. chip companies in the Valley. “For the most part it’s true, it’s just that they’re dealing with the wrong order of magnitude.” Cerebras’s chip is fifty-seven times the size of the leading chip from Nvidia, the “V100,” which dominates today’s A.I. And it has more memory circuits than have ever been put on a chip: 18 gigabytes, which is 3,000 times as much as the Nvidia part.

“It’s obviously very different from what anyone else is doing,” says Linley Gwennap, a longtime chip observer who publishes a distinguished chip newsletter, Microprocessor Report. “I hesitate to call it a chip.” Gwennap is “blown away” by what Cerebras has done, he says. “No one in their right mind would have even tried it.”

A.I. has become a ferocious consumer of chip technology, constantly demanding faster parts. That demand has led to a nearly $3 billion business almost overnight for the industry heavyweight, $91 billion Nvidia. But even with machines filled with dozens of Nvidia's graphics chips, or GPUs, it can take weeks to "train" a neural network, the process of tuning the code so that it finds a solution to a given problem. Bundling together multiple GPUs in a computer starts to show diminishing returns once more than eight of the chips are combined, says Gwennap. The industry simply cannot build machines powerful enough with existing parts.

"The hard part is moving data," explains Feldman. Training a neural network requires thousands of operations to happen in parallel at each moment in time, and chips must constantly share data as they crunch those parallel operations. But computers with multiple chips get bogged down trying to pass data back and forth between the chips over the slower wires that link them on a circuit board. Something was needed that can move data at the speed of the chip itself. The solution was to "take the biggest wafer you can find and cut the biggest chip out of it that you can," as Feldman describes it.

To do that, Cerebras had to break a lot of rules. Chip designers use software programs from companies such as Cadence Design and Synopsis to lay out a "floor plan"—the arrangement of transistors, the individual units on a chip that move electrons to represent bits. But conventional chips have only billions of transistors, whereas Cerebras has put 1.2 trillion of them in a single part. The Cadence and Synopsis tools couldn't even lay out such a floor plan: It would be like using a napkin to sketch the ceiling of the Sistine Chapel. So Cerebras built their own software tools for design.

Wafers incur defects when circuits are burned into them, and those areas become unusable. Nvidia, Intel, and other makers of "normal" smaller chips can get around that by cutting out the good chips in a wafer and scrapping the rest. You can't do that if the entire wafer is the chip. So Cerebras had to build in redundant circuits, to route around defects in order to still deliver 400,000 working cores, like a miniature internet that keeps going when individual server computers go down. The wafers were produced in partnership with Taiwan Semiconductor Manufacturing, the world's largest chip manufacturer, but Cerebras has exclusive rights to the intellectual property that makes the process possible.

In another break with industry practice, the chip won't be sold on its own, but will be packaged into a computer "appliance" that Cerebras has designed. One reason is the need for a complex system of water-cooling, a kind of irrigation network to counteract the extreme heat generated by a chip running at 15 kilowatts of power.

"You can't do that with a chip designed to plug into any old Dell server," says Feldman. "If you build a Ferrari engine, you want to build the entire Ferrari," is his philosophy. He estimates his computer will be 150 times as powerful as a server with multiple Nvidia chips, at a fraction of the power consumption and a fraction of the physical space required in a server rack. As a result, he predicts, A.I. training tasks that cost tens of thousands of dollars to run in cloud computing facilities can be an order of magnitude less costly.

Feldman's partner in crime, co-founder Gary Lauterbach, 63, has been working on chips for 37 years and has 50 patents on the techniques and tricks of the art of design. He and Feldman are on their second venture together, having sold their last company, SeaMicro, to AMD. “It’s like a marriage,” says Feldman of the twelve years they’ve been collaborating.

Feldman and Lauterbach have gotten just over $200 million from prominent venture capitalists because of a belief size matters in making A.I. move forward. Backers include Benchmark, which funded Twitter, Snap, and WeWork. It also includes angel investors such as Fred Weber, a legendary chip designer and former chief technology officer at Advanced Micro Devices; and Ilya Sutskever, an A.I. scientist at the well-known not-for-profit lab OpenAI and the co-creator of AlexNet, one of the most famous programs for recognizing objects in pictures.

Today’s dominant form of artificial intelligence is called “deep learning” because scientists keep adding more layers of calculations that need to be performed in parallel. Much of the field is relying on neural nets designed 30 years ago, maintains Feldman, because what could fit on a chip up to now was limited. Still, even such puny networks improve as the chips they run on get faster. Feldman expects to contribute to a speed-up that will yield not just a quantitative improvement in A.I. but a qualitative leap in the deep networks that can be built. “We are just at the beginning of this,” he says.

“What’s really interesting here is that they have done not one but two really important things, which is very unusual, because startups usually do only one thing,” says Weber, the former AMD executive. There’s the novel A.I. machine, but also the creation of a platform for making wafer-scale chips. The latter achievement could itself be worth a billion dollars in its own right, Weber believes, if Cerebras ever wanted to design chips for other companies; in his view, “They have created two Silicon Valley ‘unicorns’ in one company.”

It remains to be seen, however, whether Cerebras can keep all of the 400,000 cores humming in harmony, because no one has ever programmed such a large device before. “That’s the real problem with this huge number of cores,” says analyst Gwennap. “You have to divide up a task to fit across them all and use them all effectively.”

“Until we see benchmarks, it’s hard to assess how good the design is for A.I.,” says Gwennap.

Cerebras is not disclosing performance statistics yet, but Feldman promises that will follow once the first systems ship to customers in September. Some have already received prototypes and results are competitive, Feldman asserts, although he is not yet disclosing customer names. “We are reducing training time from months to minutes,” he says. “We are seeing improvements that are not a little bit better but a lot.”

What gives Feldman conviction is not merely test results, but also the long view of a Valley graybeard. “Every time there has been a shift in the computing workload, the underlying machine has had to change,” he observes, "and that presents opportunity.”

The amount of data to be processed has grown vastly larger in the "Big Data" era, but progress at Nvidia and Intel has slowed dramatically in terms of performance improvements. Feldman expects in years to come that A.I. will take over a third of all computing activity. If he's right, just like in the movie "Jaws," the whole world is going to need a bigger boat.

Adapted from Fortune

Computer Scientists Make the Case Against an Expensive New Voting System

Georgia is preparing to spend $150 million on election technology. Experts worry it will be a security nightmare.

Earlier this year, Georgia's Secure, Accessible, and Fair Elections (SAFE) Commission held a public meeting at the state capitol to answer a pressing question: What should Georgia do to replace its aging touch-screen voting machines, as well as other parts of its election system? In the preceding years, security vulnerabilities in the state's election system had been repeatedly exposed: by Russian operatives, friendly hackers, and even a Georgia voter who, just days ahead of the 2018 midterms, revealed that anyone could go online and gain access to the state's voter-registration database. Computer scientists and election experts from around the country weighed in during the seven months of the commission's deliberations on the issue. They submitted letters and provided testimony, sharing the latest research and clarifying technical concepts tied to holding safe, reliable elections. Their contributions were underscored by the commission member Wenke Lee, a co-director of Georgia Tech's Institute for Information Security and Privacy and the group's only computer scientist.

Despite this, the commission ultimately did not recommend measures backed by Lee and his colleagues at places such as Stanford, Yale, Princeton, MIT, and Google—including the recommendation that the state return to a system of paper ballots filled out by hand, combined with what scientists call "risk-limiting audits." Instead, the commission recommended buying a system that included another, more expensive touch-screen voting machine that prints a paper ballot. Months later, Lee is at a loss to explain. "I don't understand why they still don't understand," he says.

With the decision, Georgia's counties remain among the 33 percent of counties nationwide that use either machines with no paper trail or machines that print paper ballots that are then scanned on separate machines. The majority of the rest of the counties use paper ballots filled out by hand, which are then scanned or counted by hand. With the passage of the Help America Vote Act in 2002, all polling places nationwide must also include at least one electronic voting machine for voters with disabilities. But with Texas, Ohio, Pennsylvania, Delaware, and New Jersey among the many states also overhauling their election systems before the 2020 presidential election, Georgia's decision has computer scientists and election experts worried that lessons learned during nearly two decades of computerized voting are being woefully ignored. Indeed, hundreds of millions of dollars have been or will soon be spent in these and other states on technology that experts say decreases election security and erodes election integrity. And this, they say, will only contribute to the sizable portion of the American public that already worries its votes are vulnerable to hacking and other threats.

The sentiments of many computer scientists were crystallized by Richard DeMillo, a colleague of Lee's at Georgia Tech, who recommends casting paper ballots filled out by hand for all voters, except those with disabilities who would benefit from using machines. "You simply can't construct a trusted paper trail," DeMillo says, "if you let a machine make a ballot for you."

Computer science's scrutiny of voting systems goes back several decades. The Federal Election Commission issued its first standards for computer-based voting as far back as 1990, but it wasn't until the 2000 presidential race between George W. Bush and Al Gore, which hinged on the shortcomings of punch-card voting, that states across the nation began to digitize their election systems to varying degrees. Just three years later, one of the first independent computer security analyses of electronic voting systems was already raising flags.

With the global spread of computer technology and the sophisticated tactics of nefarious actors, concerns have only multiplied since then—not least because many state voting systems have not been redesigned since shortly after Bush's election. Those systems are "vulnerable to nation-states now," says E. John Sebes, the chief technology officer of the Open Source Election Technology Institute, a nonprofit organization that researches and develops election technology, "and operated by county officials with no IT experience."

That was among the concerns raised in a 160-page report published last year by the National Academies of Sciences, Engineering, and Medicine. In that report, some of the nation's leading experts on computer science and elections concluded that there is no "technical mechanism currently available that can ensure that a computer application—such as one used to record or count votes—will produce accurate results." One reason the authors noted: Malicious software "can be introduced at any point in the electronic path of a vote—from the software behind the vote-casting interface to the software tabulating votes—to prevent a voter's vote from being recorded as intended."

With such realities in mind, Lee tried to explain to the Georgia committee, early in its deliberative process, just what it would take to build a more secure electronic voting system. He drew on a concept that had been kicking around computer science for more than a decade called "software independence." The idea, introduced in a 2008 paper, refers to the ability to verify computerized election results without depending on the software used in the system. Examples provided by the authors included paper ballots filled out by hand and scanned, and touch-screen machines that print out paper ballots. That might seem like a straightforward solution, but a series of studies since 2008 has tested the notion that voters using a touch-screen or other electronic machine will or can verify their votes on a printed ballot. The answer is mostly no. Last year, DeMillo collaborated on a study of voter interaction with one such system used during the 2018 Tennessee primary elections.

The analysis came to two troubling conclusions: Most voters don't bother to verify paper-ballot summary cards, and a significant percentage can't recall the selections they made on the computer touch screen anyway—even when they had cast their votes just moments before.

Andrew Appel, a computer-science professor at Princeton and one of the authors of the National Academies report, says DeMillo's research "has strong implications about how we assess voting technology." If voters don't and can't verify ballots printed by machines, he says, then "the average voter can't notice if the machine is cheating."

Lee had DeMillo's results in mind when he tried, near the end of the Georgia commission's last meeting, to alert his fellow members to questions he had asked the voting-machine vendors that had submitted proposals to the state. "Have you done [a] study to show that the voters can actually clearly verify the contents?" he recalls asking the companies. Their answer, according to Lee: "We don't deal with that."
Katina Granger, a spokeswoman for Elections Systems & Software, the nation's largest election-technology company, according to the National Academies report, confirms that her company doesn't do such research. Instead, she says, the research "should be conducted by a third party, across jurisdictions and over time, and the research should be peer reviewed."

As it happens, the Tennessee system DeMillo studied uses the same technology Georgia is now preparing to buy for $150 million. Georgia will then have one of the nation's most expensive election systems.
The decisions Georgia and other states are making on updating their election systems are not regulated by the federal government. Instead, since the Help America Vote Act passed, the Election Assistance Commission and the National Institute of Standards and Technology have worked together to develop voluntary guidelines for election systems. Most states use these guidelines in some way, but DeMillo and other computer scientists have criticized the guidelines for being vague and unenforceable.

Georgia and other states are not only changing their voting machines. They are also looking at how to ensure the validity of election results through audits. And if experts insisted to Georgia policy makers that ballots marked by hand are the only way to produce reliable paper trails for any audit, the National Academies report was clear about what kind of audit should be used: "States should mandate risk-limiting audits" before certifying election results, the authors wrote.

For decades, many states performed audits by hand-counting ballots in a fixed percentage of precincts. But a fixed percentage "may not provide adequate assurance with regard to the outcome of a close election," the National Academies–report authors wrote. Risk-limiting audits, however, examine "randomly selected paper ballots until sufficient statistical assurance is obtained." The so-called risk limit refers to the largest possible chance that the audit will not correct an inaccurate result. For example, a 10 percent risk limit means an audit has a 90 percent chance of identifying the correct result of an election.

Philip B. Stark, a statistics professor at UC Berkeley, developed the idea of risk-limiting audits more than a decade ago. He says that pilots of the technique have been conducted in a handful of states. But he cautions that risk-limiting audits should not be conducted with machine-printed ballots: "If the paper trail is not reliable, all you're doing is confirming what the papers show."

Georgia State Senator William T. Ligon Jr. doesn't agree that touch screens are a less reliable method for casting votes. He was a sponsor of the bill, now signed into law, overhauling Georgia's election system. (State Representative Barry Fleming, the bill's lead sponsor and a co-chair of the SAFE Commission, did not respond to multiple requests for comment.) Ligon says he isn't familiar with Lee and his advice to the commission. Instead, Ligon cites the testimony of former Georgia Secretary of State Cathy Cox as one of the reasons he chose to back a system based on touch-screen voting machines that print out a paper ballot.

Cox told the legislature about "under votes, over votes, and stray votes. They all come with hand-marked paper ballots," Ligon says. It is clear to him that printed ballots bring more certainty. When asked about research demonstrating that voters don't or can't verify their ballots when printed, Ligon said, "Voters have to take some responsibility for verifying their ballots."

"In my opinion, we've built in as many systems to protect the vote as possible —and that's the goal," Ligon concluded.

Meanwhile, in Europe, countries such as the United Kingdom, Germany, and the Netherlands all use paper ballots marked by hand. The Netherlands has recently taken computers out of vote tallying as well.

Until such standards are reached in the United States, Lee says, he will not be dissuaded from speaking up on the issue of election security and integrity, and he hopes that other scientists will do the same: "I would urge all scientists and engineers, when they have the opportunity … to educate about what technologies should be used, and not stay in our ivory towers."

Adapted from The Atlantic

Our Bots, Ourselves

How the descendants of Siri and Alexa could change our daily lives, thoughts, and relationships

In the coming decades, artificial intelligence will replace a lot of human jobs, from driving trucks to analyzing X-rays. But it will also work with us, taking over mundane personal tasks and enhancing our cognitive capabilities. As AI continues to improve, digital assistants—often in the form of disembodied voices—will become our helpers and collaborators, managing our schedules, guiding us through decisions, and making us better at our jobs. We'll have something akin to Samantha from the movie Her or Jarvis fromIron Man: AI "agents" that know our likes and dislikes, and that free us up to focus on what humans do best, or what we most enjoy. Here's what to expect.

1 | A Voice in Your Head

Anyone who's used Siri (on Apple products) or Alexa (on Amazon Echo) has already spoken with a digital assistant. In the future, such "conversational platforms" will be our primary means of interacting with AI, according to Kun Jing, who oversees a digital assistant called Duer for the Chinese search engine Baidu. The big tech companies are racing to create the one agent to rule them all: In addition to Siri, Alexa, and Duer, there's Microsoft's Cortana, Facebook's M, and Google Assistant. Even Mattel is getting in on the action: It recently announced Aristotle, a voice-controlled AI device that can soothe babies, read bedtime stories, and tutor older kids. These voice systems might eventually go from something you talk to on a device to something that's in your head. Numerous companies—including Sony and Apple—have developed wireless earbuds with microphones, so your virtual helper might be able to coach you on dates and interviews or discreetly remind you to take your meds. You might even be able to communicate back without making a sound. nasahas developed a system that uses sensors on the skin of the throat and neck to interpret nerve activity. When users silently move their tongues as if speaking, the system can tell what words they're forming—even if they don't produce any noise and barely move their lips.

2 | Talking Cereal Boxes

Your main AI agent won't be the only new voice in your life. You'll likely confront a cacophony of appliances and services chiming in, since companies want you to use their proprietary systems. Ryan Gavin, who oversees Microsoft's Cortana, says that in 10 years you might select furniture at the mall and say, "Hey, Cortana, can you work with the Pottery Barn bot to arrange payment and delivery?" Consider this a digitally democratized version of the old power move: "Have your bot call my bot."

Nova Spivack, a futurist and entrepreneur who works with AI, says a wearable device like Google Glass might, for example, recognize a book and then connect you to an online voice representing that book so you can ask it questions. Everything in the world could be up for a chat. ("Hello, box of Corn Flakes. Am I allergic to you?") Your agent might also augment reality with visual overlays—showing you a grocery list as you shop or displaying facts about strangers as you meet them. All of which sounds rather intrusive. Not to worry, says Subbarao Kambhampati, the president of the Association for the Advancement of Artificial Intelligence: Future agents, like trusted friends, will be able to read you and know when to interrupt—and when to leave you alone.

3 | Smarter Together

In 1997, a reigning world chess champion, Garry Kasparov, lost a match to the supercomputer Deep Blue. He later found that even an amateur player armed with a mediocre computer could outmatch the smartest player or the most powerful computer working alone. Since then, others have pursued human-computer collaborations in the arts and sciences.

A subfield of AI called computational creativity forges algorithms that can write music, paint portraits, and tell jokes. So far the results haven't threatened to put artists out of work, but these systems can augment human imagination. David Cope, a composer at UC Santa Cruz, created a program he named Emily Howell, with which he chats and shares musical ideas. “It is a conversationalist composer friend,” he says. “It is a true assistant.” She scores some music, he tells her what he likes and doesn’t like, and together they compose symphonies.

IBM’s Watson, the AI system best known for winning Jeopardy, has engaged in creative collaborations, too. It suggested clips from the horror movie Morganto use for a trailer, for instance, allowing the editor to produce a finished product in a day rather than in weeks.

Eventually, digital assistants may co-author anything from the perfect corporate memo to the next great American novel. Jamie Brew, a comedy writer for the website ClickHole, developed a predictive text interface that takes examples of a literary form and assists in producing new pieces, by giving the user a series of choices for what word to write next. Together he and the interface have churned out a new X-Files script and mock Craigslist ads and IMDb content warnings.

4 | Mutual Understanding

Most machine-learning systems are unable to explain in human terms why they made a decision or what they intend to do next. But researchers are working to fix that. The military’s Defense Advanced Research Projects Agency recently announced a plan to invest significantly in explainable AI, or XAI, to make machine-learning systems more correctable, predictable, and trustworthy. Armed with XAI, your digital assistant might be able to tell you it picked a certain driving route because it knows you like back roads, or that it suggested a word change so that the tone of your email would be friendlier. In addition, with more awareness, “the robot would know when to ask for help,” says Manuela Veloso, the head of Carnegie Mellon’s machine-learning department, who calls this skill “symbiotic autonomy.”

Researchers are developing artificial emotional intelligence, or emotion AI, so that our agents can better understand us, too. Companies such as Affectiva and Emotient (which was bought by Apple) have created systems that read emotions in users’ faces. IBM’s Watson can analyze text not just for emotion but for tone and, over time, for personality, according to Rob High, Watson’s chief technology officer. Eventually, AI systems will analyze a person’s voice, face, posture, words, context, and user history for a better understanding of what the user is feeling and how to respond. The next step, according to Rana el Kaliouby, Affectiva’s co-founder and CEO, will be an emotion chip in our phones and TVs that can react in real time. “I think in the future we’ll assume that every device just knows how to read your emotions,” she says.

5 | Getting Attached

We already know that people can form emotional bonds with Roomba vacuum cleaners and other relatively rudimentary robots. How will we relate to AI agents that speak to us in human voices and seem to understand us on a deep level?

Spivack, the futurist, pictures people partnering with lifelong virtual companions. You’ll give an infant an intelligent toy that learns about her and tutors her and grows along with her. “It starts out as a little cute stuffed animal,” he says, “but it evolves into something that lives in the cloud and they access on their phone. And then by 2050 or whatever, maybe it’s a brain implant.” Among the many questions raised by such a scenario, Spivack asks: “Who owns our agents? Are they a property of Google?” Could our oldest friends be revoked or reprogrammed at will? And without our trusted assistants, will we be helpless?

El Kaliouby, of Affectiva, sees a lot of questions around autonomy: What can an assistant do on our behalf? Should it be able to make purchases for us? What if we ask it to do something illegal—could it override our commands? She also worries about privacy. If an AI agent determines that a teenager is depressed, can it inform his parents? Spivack says we’ll need to decide whether agents have something like doctor-patient or attorney-client privilege. Can they report us to law enforcement? Can they be subpoenaed? And what if there’s a security breach? Some people worry that advanced AI will take over the world, but Kambhampati, of the Association for the Advancement of Artificial Intelligence, thinks malicious hacking is the far greater risk. Given the intimacy that we may develop with our ever-present assistants, if the wrong person were able to break in, what was once our greatest auxiliary could become our greatest liability.

Adapted fron The Atlantic