Technology Vision 2023

When Atoms meet Bits

The foundations of our new reality

Voices of Change

From insights to action, the path to extraordinary value starts here.

accenture

Foreword

Businesses must embrace the foundations of our new reality

While standing at the edge of the next great technological era, enterprises must navigate economic and geopolitical uncertainty. The natural inclination of many organizations is to pull back. We have a different perspective. Now more than ever is the time for leaders to lean into strategies powered by technology to create differentiation. In fact, 10 years ago we predicted every business is a digital business, and this could not be more accurate today.

We've talked about the five key forces of change that companies must harness over the next decade, including the need for total enterprise reinvention. Cloud, AI, and the metaverse, in particular, have accelerated to such degrees that they dramatically speed up change, bend the innovation curve and create more and more value for every business and organization.

Yet our research shows that only 8% of companies are adopting a strategy of total enterprise reinvention. These are the Reinventors, and we believe every company must aspire to be one. Among that backdrop, our Technology Vision provides insights to enable leaders and their organizations to act now to embrace technology and use the foundations of a new reality as a path towards reinvention.

With this vision, we examine our movement between two types of worlds, physical and digital. Over the years, enterprises and individuals have taken many steps to create their presence in the digital space, consciously moving back and forth between physical reality and the digital ones they created. We believe the time has come to change that. The next wave of business transformation will erase the demarcation between those worlds to fuse them into a new reality.

The goal is not incremental improvement, but a step change towards total reinvention. Not everyone may be ready for this change, but leaders must prepare now for the future where the movement between worlds is seamless and often simultaneous.

We look forward to sharing our latest Technology Vision and building the foundations of a new reality with you.

Technology is the answer. The time is now.

Julie Sweet
Chief Executive Officer

Paul Daugherty
Group Chief Executive -
Technology & Chief Technology Officer

Contents

When Atoms meet Bits: The foundations of our new reality

We live in two parallel realities, one of atoms and one of bits.

When we shop, we either go into a store or pull up a webpage. We work in person or remote. We collaborate with people and computers, but usually not at the same time. We live our lives split between the digital and the physical, and, frankly, moving across these separate realities is exhausting and inefficient. Transitioning between them can be challenging, confusing, or impossible, and while it can be easier to focus on just one or the other, doing so is fundamentally limiting.

So, it's time to change that. The next wave of business transformation will shift from creating isolated digital capabilities to creating the foundations of a new reality—a shared reality that seamlessly converges the physical lives we've been leading with the digital ones we've been rapidly expanding. The goal is not incremental improvement, but a step change. An online store here or a smarter object there may have been good enough in the past, but we are now realizing that the true value of combining digital and physical together goes much further. Look at generative AI. Interest in generative AI is surging, with new tools capturing the world's attention faster than any other recent technology. But how people are using them right now—to create digital images and content—is just the beginning. We can already see that this technology is poised to shape the future of science, enterprise data, how we design and manufacture products, and so much more.

Is it challenging? Yes. But even at a time when the world faces an uncertain economic climate and is still in the shadow of recovery from COVID-19, we are seeing enterprises make some of their most ambitious bets yet. They are fueling a new wave of digital-physical convergence that's pushing us closer to a seamlessly shared reality—leveraging the best of atoms and bits to drive novel possibilties.

In healthcare, this shared reality is pushing us towards personalized care. With funding from the European Union, a consortium of hospitals, researchers, and startups have joined the Neurotwin project, an effort to build digital twins of individual human brains.[1,2] Each twin would be used to help healthcare providers understand and predict triggers for neurological diseases and improve preventative interventions. The project is set to launch two studies on individuals suffering from Alzheimer's and epilepsy in 2023.[3]

Even problems as big as sustainability are being re-examined through the lens of what we can do when we combine physical sciences and digital technology. In 2022, AB InBev expanded production facilities for its barley upcycling company, EverGrain, which uses technology and science to find new applications for byproducts of the beer-making process.[4,5] The company created a new barley milk-based coffee drink with Airship Coffee, is developing snacks with barley-based ingredients with Post Holdings, and even developed barley straw-based packaging for Corona, turning a traditionally discarded byproduct into paper board boxes that take 90% less water to fabricate.[6,7,8]

But not everyone is ready for this step change. For many years the guiding pillar of enterprise innovation has been taking processes, even whole parts of the organization, and digitizing them—from how the factory floor is run, to loyalty programs, advertising, supply chains, and recently the entire workforce. For people, the story has been no different. People have spent years building a digital life: from how we do our banking, to establishing ourselves on social media, to choosing streaming over cable—which the relative majority of TV watchers did for the first time this past summer.[9]

96%

of executives agree that the convergence of digital and physical worlds over the next decade will transform their industry.

Given how disconnected and disjointed our digital and physical worlds can feel, it's no wonder that the next decade of innovative efforts is starting to be defined by how we fuse the two together.

While we have built a rich and meaningful digital world, we haven't really reconciled it with the physical one. Challenges with digital identity and data interoperability leave people overwhelmed with technology and exposed to new dimensions of fraud and risk. Many enterprises watched their entire workforce go digital and are now suffering attrition as they struggle to figure out how to hybridize a remote workforce. We haven't even really accounted for the direct impact our digital efforts have had on the physical world, like how an estimated five billion mobile phones will be thrown out in 2022 alone, or how for all of cloud computing's efficiency benefits, it has surpassed commercial airlines in its contributions to global CO_2 emissions.[10,11]

Given how disconnected and disjointed our digital and physical worlds can feel, it's no wonder that the next decade of innovative efforts is starting to be defined by how we fuse the two together. The foundations of this new reality are already being put in place, so the time to make your own mark is *now*.

Last year, in Accenture's 2022 Technology Vision, we called out the Metaverse Continuum as the next big step after digital transformation. Though some may see the metaverse as the culmination of the last wave of digital disruption, it's better viewed as the beginning of the next. The metaverse is a watershed moment for the convergence of atoms and bits, accelerating the path to a singular shared reality. Across the metaverse continuum we are making the digital world behave more like how we experience the physical, and conversely we are using metaverse technologies to reimagine what we do in the physical world. It is the nexus between digital and physical—which is why some of the most powerful ways we have seen the metaverse used are ways in which we fuse the two.

For example, the very first 3D-printed steel bridge in the world was built in Amsterdam and was designed with this kind of digital-physical hybridization in mind.[12] Not only was the bridge created with 3D-printing and robotic arms, but it was also designed specifically to coexist with a digital twin. It was embedded with a cutting-edge sensor network that now feeds a digital twin with real-time data on vibration, strain, weather conditions, and more. The twin can predict how the bridge will behave, such

that maintenance needs can be quickly resolved and engineers can better understand how 3D-printed steel might be used in future projects.

Other companies are endeavoring to thread digital back into physical. Google has been slowly integrating a new wayfinding feature into Google Maps called Live View. It creates an overlay of details about, or directions around, users' environments via geolocators and smartphone cameras.[13] And Snap has been expanding its AR technology far beyond filters, partnering with companies like Amazon, Puma, and Ralph Lauren to integrate 3D product modeling and augmented reality try-on features into the shopping experience.[14,15] This blurring of the digital-physical boundary is now exposing new modes of commerce: the company is rolling out a new "Dress Up" feature where users can discover, try on, and shop for new products directly in the app, and the company reported 250 million people had used its AR shopping lenses over five billion times in just one year alone.

While the budding metaverse continuum is the most attention-grabbing frontier on the path to our new reality, it's hardly the only one. OpenAI open-sourced one of the most powerful Automatic Speech Recognition (ASR) neural networks, called Whisper, which was trained on nearly 700,000 hours of speech-related data and approaches human-like levels of accuracy.[16] ASR and natural language processing are fusing the digital and physical by doing away with today's abstractions like keyboards and gestures and allowing people to engage the digital world in one of the most human ways possible: speech.

Or consider the growing trend of cobots (collaborative robots), a market that is set to expand to $16.3 billion by 2028.[17] These machines let the power of machine intelligence and automation bleed into the physical world, allowing people to work more naturally and unearth new efficiencies. In one example, Moxi, a cobot designed for hospitals, was able to save healthcare workers at one hospital 3,200 hours by taking care of routine tasks like deliveries and allowing the staff to spend more time giving care to patients.[18]

> ... what becomes clear is that merging digital and physical is the path to truly new possibilities.

We've arrived at an exciting frontier of technology innovation for businesses, one where we're not just digitizing but starting to put that digital foundation to work. Fusing digital and physical is not only generating new products and services, it's the force behind a new era of scientific research. Leaders are creating the next set of tools and disruptions poised to rewrite how the world works. And what's become clear is that when atoms and bits collide, truly new possibilities emerge.

2023 Technology Vision:

The foundations of our new reality

The convergence of our parallel realities will evolve over the next ten years. Enterprises will first find opportunity from it in specific, narrower circumstances. It might begin as a digital twin for a single bridge, a robotics deployment in a hospital, or pairing a product designer with generative AI. But as these innovations proliferate, we will see them grow into entirely new physical environments, new ways of working in the metaverse, and more. Ultimately, the fusion of atoms and bits will disrupt the fabric of our worlds, where materials and living things are interlaced with technology and technology's capabilities expand exponentially—leading us to a new frontier.

This year's 2023 Technology Vision explores the technology trends driving this new reality, and the steps enterprises will need to take to thrive in it. We chart the path that begins with blurring physical and digital, continues through the intractable problems companies are starting to be able to solve, and concludes with the science technology revolution that's bringing true novelty to businesses and the world.

In **digital identity** we discuss how identity is the quiet catalyst of this next generation of innovation. Our biggest technological ambitions are being held back by old models of identity. The physical-digital convergence will only be sparked when people and things have identity that can traverse both sides. And emerging forms of digital ID are finally breaking down the walls that divide enterprises and people's physical and digital lives, sparking a torrent of change.

Your data, my data, our data explores how transparency will be a precious resource for enterprises looking to lead these changes. Supply and demand for data among all enterprise stakeholders is dramatically increasing. Enterprises will need to rethink their data collection and architecture design to begin exposing the data that matters. Leaders have an unprecedented opportunity to build trust with partners and customers by proactively becoming more transparent—or risk having someone else do it for them.

But the task of building this new reality won't just be for humans. **Generalizing AI** explores how a new category of AI—spurred on by foundation models and large language models—is becoming table stakes for any business operating in tomorrow's market. With the sheer volume of data and insights needed to drive solutions for the problems enterprises face, business leaders will need to lean on the full capabilities that generative AI and the next generation of AI advances provide.

And finally, **our forever frontier** gives enterprises a window into what lies farther down the line: the science technology revolution. It explores how the feedback loop between science and technology is getting faster, with each accelerating the advancement of the other, in ways that begin to unlock the world's grand challenges.

Bringing Atoms and Bits together:

From IT and OT to ST

Igniting a science technology revolution is the inevitable result of enterprises bringing atoms and bits together. As our digital and physical realities converge into one shared reality, physical science and digital technology are increasingly used to amplify one another, fundamentally reshaping the world around us. Companies already have a technology strategy that encompasses managing their information (IT) and controlling their physical systems (OT). To fully unlock the opportunity of our new reality, enterprises need to extend that strategy to a third dimension—Science Tech (ST).

Take AlphaFold, a recent innovation out of DeepMind. While other efforts like AlphaGo and AlphaStar explored AI's ability to win different types of games, AlphaFold turned to a far more practical and significant application: protein folding.[19] Proteins are the building blocks of biology, and their unique three-dimensional structures determine what function they will perform. So, for instance, if a pharmaceutical company were developing a new drug, understanding various protein shapes would be critical to understanding how the drug will interact with the person it is being administered to. The problem is, historically, these are extremely labor intensive to study, or computationally intensive to simulate. But in the summer of 2022, DeepMind publicly released a database of 200 million different protein structures —which covers nearly every protein known to human beings—now available to all companies and researchers around the world.[20]

The takeaway goes beyond protein folding. AlphaFold unlocked a grand challenge, and for enterprise leaders in all industries, that signals a brand-new world of *possibility*. The field of biology has always been limited by the time it took to perform operations related to protein folding—a restriction eliminated by AlphaFold. In the short time since its creation, AlphaFold has become a critical tool in the field of biology, accelerating activities like drug discovery and the study of novel bacteria and plant structures, and deepening our understanding of deadly diseases.[21] This is the true power of bringing science and technology together, not just efficiency or even acceleration—but how it completely reframes the horizon of possibility, shattering what were once considered insurmountable constraints.

Leaders need to reorient around this mindset shift. It is subtle, but profound. When enterprises approach digital *transformation*, it is often inward looking. It is about disrupting the enterprise, its partnerships, and its relationship to the market, and even demonstrating new models to the market that force others to react. The focus is on gaining advantage in the competitive landscape. But enterprises that look to science technology are going one step beyond: They aren't getting a leg up in the same competition, they are redefining the rules of the game.

As our digital and physical realities converge into one shared reality, physical science and digital technology are increasingly used to amplify one another, fundamentally reshaping the world around us.

Computational chemistry researchers at the University of New Mexico used high performance computing to accomplish in just four years research that would have taken 7,257 years on a single laptop.[22] Solugen, a biotech startup, used science and technology to develop a new method of fabricating industrial chemicals out of sugar instead of fossil fuels, and is already partnering with water treatment providers.[23] And Nokia is partnering with AST SpaceMobile to enable direct-to-cell phone connectivity from space to rural or otherwise underserved communities.[24]

This is the next generation of technology disruption—not just digitizing the present but accelerating towards a previously unimaginable future. The path forward will be challenging. There is no one clearly defined technology to invest in. Though there are some likely contributors like quantum computing, artificial intelligence, and extended reality, the point is that this generation of disruption is no longer about devising a technology strategy alone, it is about designing an innovation strategy that targets digital-physical convergence. The companies that succeed will find themselves at the center of the science technology revolution, and for better or worse, enterprises aren't hurting for areas to make their play.

This is the next generation of technology disruption—not just digitizing the present but accelerating towards a previously unimaginable future.

Grand Challenges:

Taking action in our new shared reality

Becoming a leader in building a shared reality and investing in the science and technology tools to get ahead of disruption are no small tasks. Understandably, every enterprise leader might wonder what the imperative is. Why try to get ahead, and why do we need to start now?

Think about some of the biggest challenges facing enterprises today: a global labor realignment; supply chain disruptions; misinformation; mounting pressure from customers and governments for more sustainable solutions; a growing cyberthreat landscape. These problems are top of mind for every executive, but importantly, they are fundamentally different from the problems of the past. These are massively interlocked problems, with numerous dimensions and a multitude of different partners and stakeholders at play.

Port delays and labor shortages across the food service industry are impacting the bottom line for food suppliers.[25,26] 52% of companies have supply chain partners that have been impacted by ransomware.[27] And enterprises are poised to feel the impacts of climate change, even if they are managing to avoid them today. In August 2022, for instance, companies in China's Sichuan province were forced to shut down factories making solar panels, cement, and more, after a worsening drought caused hydropower reservoirs to run low.[28] Is it conceivable that any enterprise could solve even one of these alone? Of course not.

This is the urgency. The problems enterprises are most affected by today are ones they are not yet equipped to solve. Yesterday's strategies and technologies are proving to not be enough to overcome the grand challenges enterprises are starting to stare down. Building a shared reality of atoms and bits is the necessary path to start tackling new problems in new ways. Technology has always risen to meet the needs of the time, and now the challenges we face are bigger than any one company alone. It's time to start forging the tools to fix them, together.

Think about sustainability. Environmental impact is one of the most pressing grand challenges that companies and the world face today, and increasingly more companies are eager to be part of the solution. Though despite their eagerness, many risk still missing their targets.[29] When shared solutions are built, however, the future starts to become much more attainable. Take Mango Materials. The renewable bioproducts startup collaborated with researchers around the world to

83%

of executives believe science tech capabilities could help address societal grand challenges of health-related issues and diseases, while 75% believe science tech capabilities could also help address poverty/inequality.

develop a bacteria-produced bioplastic designed to decompose in the ocean.[30] So far, five oceanographic equipment manufacturing partners have committed to replacing all their traditional plastic with this new degradable bioplastic once it's ready, with commercialization and other product applications being explored as the collaboration evolves.[31]

Or look at the grand challenge of delivering better healthcare. When it comes to using data to improve treatment, hospitals are typically limited to their own datasets for patient privacy reasons. But in a recent study published in *Nature Medicine*, 20 hospitals from around the world participated in training a federated learning model called EXAM, which predicted future oxygen requirements of COVID-19 patients.[32] The model leveraged data, including patient vital signs, laboratory data, and chest X-rays, from all of the participating hospitals—but each hospital trained their own copy of the AI model and periodically shared updates with a centralized server, which then aggregated them to train the global model. In this case, the hospitals created a shared reality that they couldn't have before, using federated learning to safely share digital data on physical information to improve AI predictions.

Foundations for a new reality

Mounting challenges on the global stage are forcing enterprises to reorient their business objectives and imagine how they can best contribute to solving these collective problems. Some of today's problems might have been considered unsolvable before—but as the convergence of atoms and bits continues to grow, the bounds of possibility expand. Digital identity gives us a foundation to traverse digital and physical worlds; transparency builds the trust and unlocks the data insights necessary to expose and tackle collective problems; generalizing AI provides us with the machine power to aid us in doing so; and our forever frontier is rapidly expanding as we bring physical sciences and information technology closer together. These foundations of our new reality are the path to taking action.

The world is watching.
What will you do next?

Our Four Technology Trends for 2023

Digital identity

ID for everyone and everything

Digital identity is quietly becoming the key to enterprises' technology aspirations, and efforts to reimagine it are underway—not just for people but for all things.

Your data, my data, our data

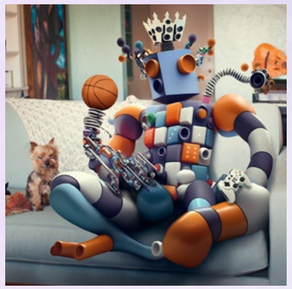
Why transparency will become your most precious resource

Data ecosystems are being reshaped by radical transparency as enterprises leverage their troves of data to offer unprecedented insight into their business.

Generalizing AI

The radical edges—and possibilities—of intelligence

Foundation models are driving one of the biggest step changes in AI history. Now, enterprise leaders can shift from building their own AI to building *with* AI.



Our forever frontier

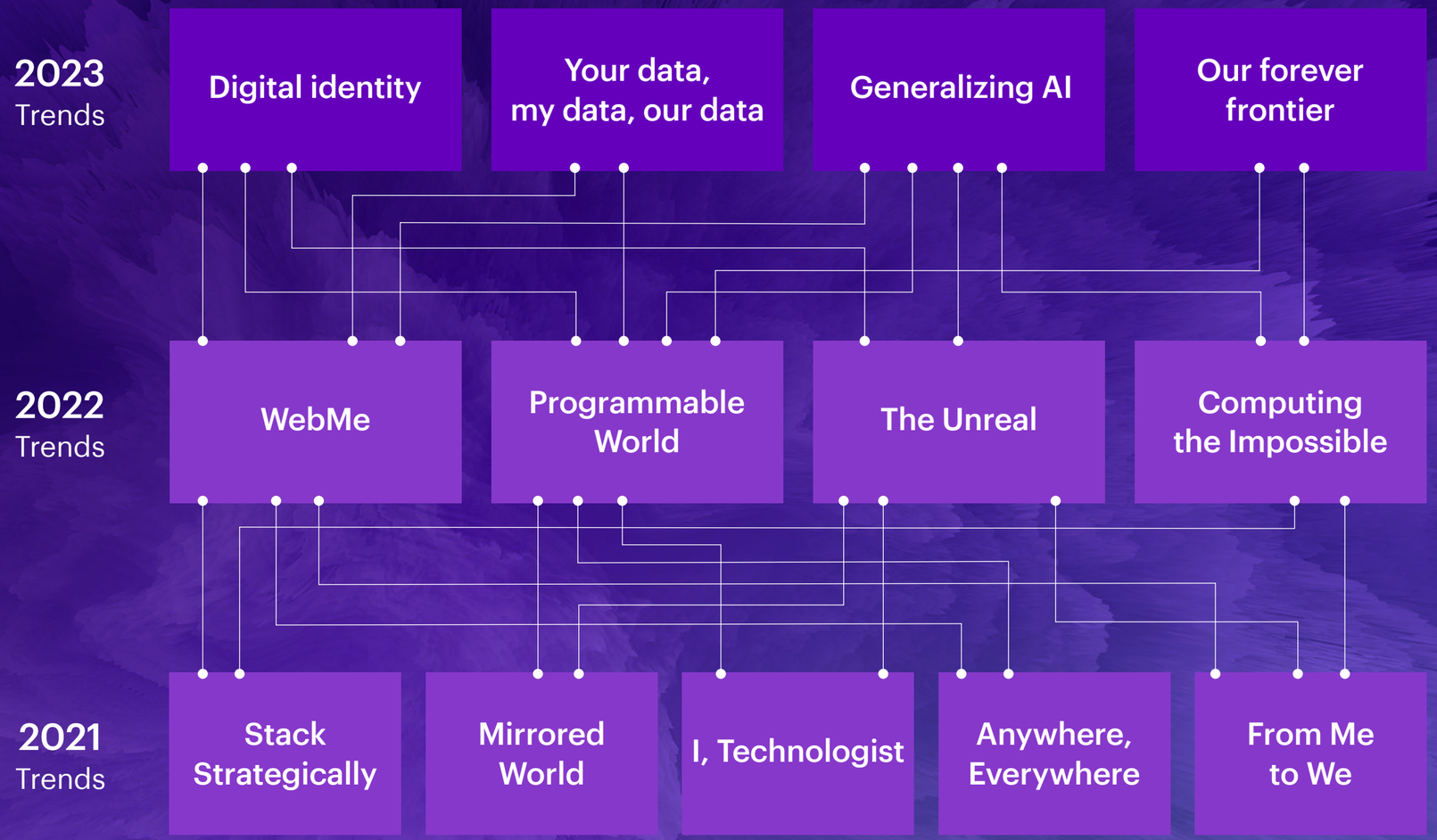
The big bang of computing and science

After decades of hyper focus on digital technology, science is leaping back to the top of enterprises' agendas.

Completing the picture

Accenture's Technology Vision report comprises a three-year set of technology trends, currently including trends from 2021 and 2022.

It's important to recognize that each year's trends are part of a bigger picture. Tracking how they evolve over time offers a glimpse into how they may continue to grow in the future.



2022 Trends

WebMe

Putting the Me in Metaverse

The internet is being reimagined as metaverse and Web3 efforts transform the underpinning and operation of the virtual world.

Programmable World

Our Planet, Personalized

Control, customization, and automation are being enmeshed into the world around us, making the physical as programmable as the digital.

The Unreal

Making Synthetic, Authentic

As AI-generated data and synthetic content convincingly mimic what is "real," authenticity is the new north star.

Computing the Impossible

New Machines, New Possibilities

A new generation of computers are solving some of the world's most intractable problems, leading to one of the biggest technological disruptions of our time.

2021 Trends

Stack Strategically

Architecting a Better Future

A new era of industry competition is dawning – one where companies compete on their architecture.

Mirrored World

The Power of Massive, Intelligent, Digital Twins

Growing investments in data, AI, and digital twin technologies are giving rise to a new generation of business and intelligence: the mirrored world.

I, Technologist

The Democratization of Technology

Natural language processing, low-code platforms, robotic process automation, and more are democratizing technology, putting powerful capabilities into the hands of people all across the business.

Anywhere, Everywhere

Bring Your Own Environment

It's time for enterprises to transform remote work from an accommodation, to an advantage.

From Me to We

A Multiparty System's Path Through Chaos

The global disruption of COVID-19 ignited a scramble for enterprises to reimagine their partnerships – and multiparty systems gained newfound attention.

A day in our new reality

It's 2035, and old college friends Miriam, Alex, and Ben are grabbing a quick coffee before work. Ben's favorite coffee chain has just opened a new café in his office building, so he and Miriam meet there.

"Alex texted—something hectic is going on at the farm, but she says she's ready when we are." Ben says as he gets in line to order. "I hope everything's okay," says Miriam, "I actually ordered ahead—I'll go pick up my drink and grab a table."

When Ben gets to the front of the line, he greets the barista and touches his thumb to the fingerprint sensor on the counter. "Oh! Trying out the personalization program today?" says the barista. "Yeah! I've been hearing about it —I'm excited to see what the fuss is about," Ben says. The screen in front of him springs to life with dozens of his preferences—ideal caffeination level, flavor affinities, milk content, exact temperature, and more. "You got all this from me talking to an AI for five minutes?" he asks, eyes widening. "Wild, right?" says the barista. "These are your default preferences, but you can tweak them in the app, and each time you check out it'll confirm what you want just to be sure. Hit 'OK' when you're ready—looks like we're already connected to your wallet for payment."

Ben's feeling a bit tired, so he raises his caffeine level, then taps the 'OK' button. "That's it?" he asks. "That's it," says the barista. "Our bean dispenser will give us a custom blend of our 18 coffee varieties—tailored just for you. Then I'll make your drink and have it out in a few minutes."

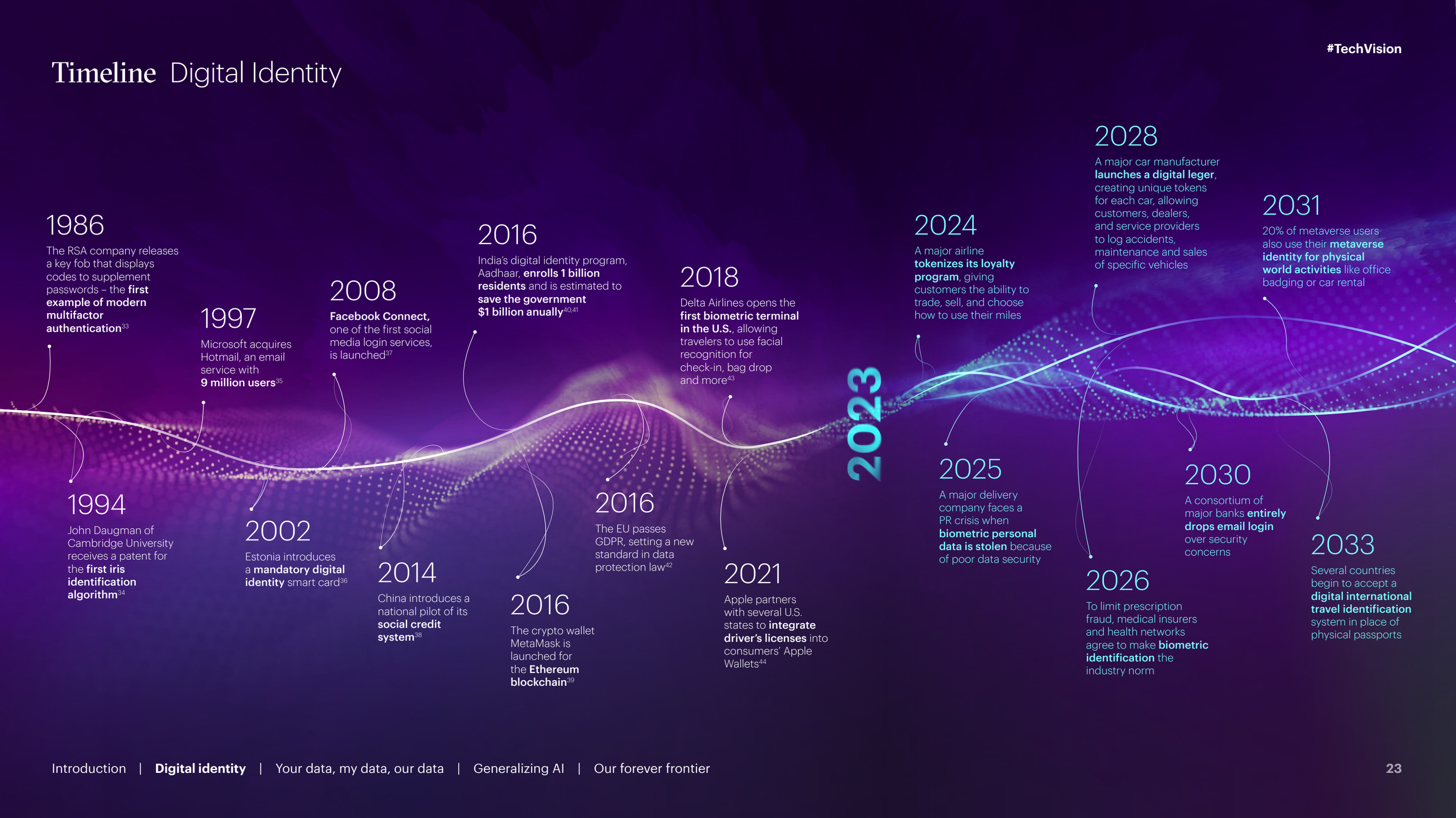
As Ben turns to find Miriam, his watch vibrates with a notification, letting him know he's been airdropped an NFT for trying the personalization program. Miriam is sitting at a table for three. "We're just about ready," she says as he sits down. They put on their AR glasses—and finally they can see Alex, sitting in the empty seat beside them.

Our Technology Vision 2023 trends are driving a new reality—one where our physical and digital worlds converge. As we progress through the report, we will continue Ben, Miriam, and Alex's stories to illustrate what this reality could look like, and how our trends could impact businesses and people's lives.

Digital identity

ID for everyone and everything

Timeline Digital Identity



1986

The RSA company releases a key fob that displays codes to supplement passwords – the **first example of modern multifactor authentication**[33]

1994

John Daugman of Cambridge University receives a patent for the **first iris identification algorithm**[34]

1997

Microsoft acquires Hotmail, an email service with **9 million users**[35]

2002

Estonia introduces a **mandatory digital identity** smart card[36]

2008

Facebook Connect, one of the first social media login services, is launched[37]

2014

China introduces a national pilot of its **social credit system**[38]

2016

India's digital identity program, Aadhaar, **enrolls 1 billion residents** and is estimated to **save the government $1 billion anually**[40,41]

2016

The crypto wallet MetaMask is launched for the **Ethereum blockchain**[39]

2016

The EU passes GDPR, setting a new standard in data protection law[42]

2018

Delta Airlines opens the **first biometric terminal in the U.S.**, allowing travelers to use facial recognition for check-in, bag drop and more[43]

2021

Apple partners with several U.S. states to **integrate driver's licenses** into consumers' Apple Wallets[44]

2023

2024

A major airline **tokenizes its loyalty program**, giving customers the ability to trade, sell, and choose how to use their miles

2025

A major delivery company faces a PR crisis when **biometric personal data is stolen** because of poor data security

2026

To limit prescription fraud, medical insurers and health networks agree to make **biometric identification** the industry norm

2028

A major car manufacturer **launches a digital leger**, creating unique tokens for each car, allowing customers, dealers, and service providers to log accidents, maintenance and sales of specific vehicles

2030

A consortium of major banks **entirely drops email login** over security concerns

2031

20% of metaverse users also use their **metaverse identity for physical world activities** like office badging or car rental

2033

Several countries begin to accept a **digital international travel identification** system in place of physical passports

The big picture

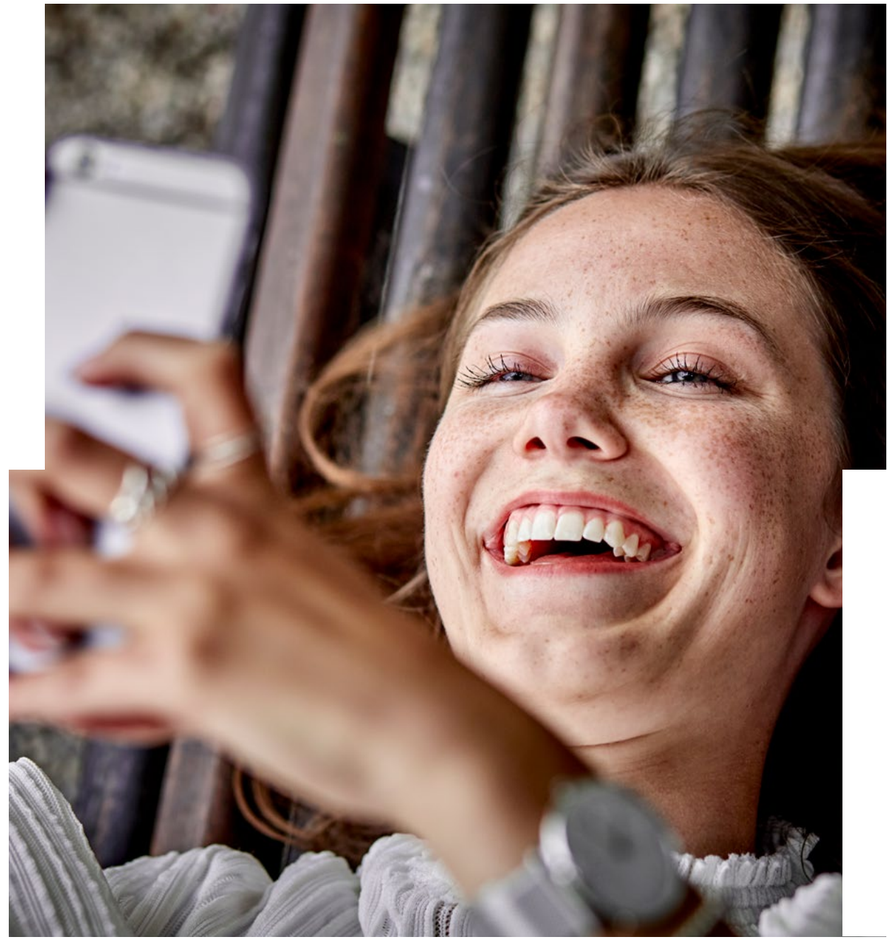
Digital identity is quietly catalyzing the next generation of technology disruption, and the world's leading innovators are starting to act.

In August 2022, Microsoft launched Microsoft Entra Verified ID, a new product based on decentralized identity standards. The company's vision is to build a new future for digital identity, where instead of widely spreading identity data across countless apps and platforms, people and organizations can have greater trust in and control over what information is accessed, by whom, and for how long.[45,46] And already, proof of concepts and pilot programs are underway with two universities, a healthcare system, and a government service.[47]

And other companies are also innovating in this space. Early Warning Services and seven banks including Capital One, Wells Fargo, Chase, and Bank of America launched Authentify—an identity verification product that lets users log into their online banks from participating websites and apps, streamlining the process for sharing sensitive banking data.[48] Apple has expanded its Wallet app, moving beyond payment information to let users store and share government-issued IDs like driver's licenses.[49] And while not an example of innovation itself, the Bill & Melinda Gates Foundation committed $200 million to digital public infrastructure projects, including digital ID.[50] These are only a fraction of the initiatives underway, and the market for digital identity is expected to swell from $27.9 billion in 2022 to $70.7 billion by 2027.[51]

Digital identity is ever evolving and notoriously challenging, but what these leaders have recognized is a simple truth: Today's identity efforts will directly shape tomorrow's most innovative businesses. What's more, the entire C-suite needs to pay attention. While digital identity gives the illusion of being a technical challenge suited for the CIO's or CTO's purview, the truth is it underpins many of our greatest business ambitions.

Imagine what the next decade of your enterprise could look like. Does it include the metaverse, where people traverse a persistent digital environment for work, socialization, and recreation? Maybe it involves the programmable world, where the physical environment is threaded with technology such that people can command their surroundings with a word or gesture. Or perhaps it entails the growing intersection of science and technology, where possibilities like personalized medicine can be



85%

of global executives agree that **digital identity is no longer just a "technical issue"**; it's becoming a strategic business imperative for their organizations.

realized. Whatever your preferred vision is, the next decade of technology disruption is being shaped by how our digital and physical worlds intersect—and the very epicenter of that exchange is digital identity.

Look at what b.well is doing to improve healthcare experiences.[52] For many patients, there is critical data that could improve outcomes; medical records, family history, genomic data, financial information, even wearables that track sleep, exercise, and diet could be used by providers and payers to deliver better, more personalized care. But this data exists across a multitude of platforms and hosts, forcing patients to repeatedly validate who they are. This can mean going in person to offices to request data, providing physical ID to prove who they are, and then taking data to the relevant party just to go through ID verification all over again. There's too much friction that frequently leaves this critical information untapped.

b.well saw this as an identity challenge, and partnered with Mastercard to build a new intelligent identity platform for healthcare systems. Their platform replaces emails and passwords with mobile-native biometrics and provides secure document scanning and storage, giving users greater control over their medical information and letting them seamlessly share it with providers and payers.[53] Moreover, it opens the possibility of integrating other data, like proof of income, to ease the approval process for insurance policies or financial relief programs. And on the healthcare side, it gives providers access to standardized and high-fidelity information about those in their care, all while reducing fraud and risk.[54]

Although this example is contained to a single ecosystem, it sends a strong message. Emerging digital identity solutions are precisely, if unsuspectingly, the answer to creating the types of multi-partner value people and enterprises have long been desperate for.

Every business leader needs to recognize that digital identity isn't a technology question—it's a strategic business imperative. The web was never built with an identity layer, and as companies have increasingly relied on digital technology to run their businesses, the challenges resulting from that gap have

continued to grow. People, assets, services and the data we have access to are all predicated on strong identity (knowing exactly who or what something is). How businesses ensure resilience, security, privacy, consent and trust is inextricably dependent on the quality of digital identity—and these are challenges that continue to plague enterprises today. While patchwork solutions have gotten us to this point, achieving any further ambitions will require solving the underlying problem. Only secure and trusted digital identity will let people frictionlessly authenticate themselves across any digital or physical environment, maintain firmer control over the data they store and how it is shared, and alleviate concerns around security, privacy, and human factors like password fatigue. And for enterprises it could eliminate red-tape and reduce risk by having a more secure ecosystem for human and non-human entities alike.

But importantly, early innovators in this space are now finding that digital identity isn't just about shoring up oversights of the past but also future-proofing the enterprise for a world where data sharing and ownership is dramatically different.

The concept of a trusted, portable digital identity across the web disrupts many of the conventions we've come to accept. Tokenization, for instance, is one of the most innovative technology trends that is transforming how we authenticate ourselves, share data, own digital assets, and track physical things, and it's entirely predicated on the ability to reliably identify any person—or any *thing*—in a trusted and secure manner.

> Every business leader needs to recognize that digital identity isn't a technology question—it's a strategic business imperative.

> Digital identity may not be a significant part of your innovation agenda today—but it needs to be.

Look at how Wien Energie, an Austrian energy provider, recently tokenized one of the largest photovoltaic (PV) solar plants in the country.[55] The company created unique identifying tokens for each individual PV module in the plant, which were then sold to customers. Token holders receive an annual payment relative to the amount of energy produced by the plant. Right now, it's a closed system, so payment is made in the form of discounts on electric bills. But the company envisions a future where these tokens can be used to fund new plants, used as proof of origin for energy sources, or traded to fuel things like electric vehicles. By giving the plant and solar cells a unique digital ID, the company was able to expose innovative new business models, ones that turned customers into stakeholders.

However, the time to seize the opportunity and become an early leader is now, and it won't last long. Gaining advantage with single solutions and one-off disruptive new efforts today is only part of the story. Enterprise leaders must grasp the full scale and speed at which identity is changing our digital and physical landscapes. What we are truly witnessing is nothing short of digital transformation at a societal level.

The UN calls for the creation of a legal ID for all people by 2030 as part of its Sustainable Development Goals, so it's no surprise governments around the world are beginning to make digital identity a top priority.[56] As one of the first digital identity adopters, Estonia has 98% of its citizens registered with its electronic identity system (e-ID) that is used for public services like voting, health insurance, taxes, and more.[57] India's Aadhaar, with a 93% adoption rate, ties biometric information to a 12-digit pin and has been used for offline and online purposes like COVID-19 vaccinations and contact tracing, as well as banking and financial services—and it is now being adopted by Sri Lanka too.[58,59,60,61,62] And the European Union plans to roll out a digital identity system in 2023.[63] Soon enough, it won't just be early adopters creating digital identities. Businesses may soon be required to do so to integrate with state-level programs.

Digital identity may not be a significant part of your innovation agenda today—but it needs to be. The imperative is two-fold: while there is opportunity to explore, find value, and innovate around digital identity right now, there is also a speeding torrent of change coming that will inevitably shape what all businesses can do, and how they do it, across the web. Some will experiment with their own digital identity projects. Others will investigate and prepare for how changes to digital identity will demand business transformation. And for everyone, regulations are sure to come, so the last thing you want is to be caught off guard and left behind. It's time to stop overlooking digital identity. Let it catalyze your future.

The technology

The emergence of new digital identity solutions is both opening the door to new forms of value creation and challenging enterprises of all sizes and industries to rethink how identity is used across the organization. Grasping the significance of this trend is key to recognizing the opportunity that lies ahead.

To start, it helps to consider two basic categories of identity: The first is core identity, or the primary identifier of who or what something is. These are created for general purpose, like a national ID or legal name logged in a registry. The second category is functional identity, which is created for a specific purpose to convey certain characteristics or data about a particular thing—like the way a driver's license number is created to convey someone is legally allowed drive, or the way internet cookies are used to manage sessions and your activity when traversing the web.

Of course, internet cookies and (in some countries) driver's licenses aren't used exclusively for those dedicated purposes. In practice, all too often we take functional pieces of information intended for a specific purpose and, in lieu of a better option, use them as core identity.

Consider what is happening to phone numbers. Mobile phone numbers are a functional piece of contact information. Yet, our phone numbers have increasingly become the gateway to our digital lives, such that they are being used like core identifiers.

When our bank, work, or social apps want us to prove who we are, what do they do? Send us a text message. We've taken a number we share publicly, for those who want to communicate with us, and turned it into proof of who we are—and now we are starting to see the consequences. In one type of attack called SIM-swapping, hackers use social engineering tactics to convince mobile carriers to re-route a target's phone traffic to a new SIM card. At that point, any messages, calls, or verification codes sent to the target number are received by the attacker instead. In 2021, the FBI logged 1,611 of these attacks—this was 5x growth over the previous three years combined and amounted to an astounding $42,000 in average damages per attack.[64] At this point, if a hacker has your phone number, they may as well be you.

Digitally, we see this happen all the time because the internet was not built with core identity in mind. The entire ecosystem has become overly reliant on leveraging functional data, like email addresses or social logins, to access services or identify people across the web. But now the legacy of never having built a system for core digital identity is catching up

76%

of global executives agree issues with authenticating customers' identity are negatively impacting their bottom line (e.g., abandoned transactions, customer frustration, fraud).

with us, opening the door to fraud and fractured experiences. A recent study showed that over half of consumers have abandoned a purchase or booking online because they forgot their password and retrieving it would take too long.[65] Invalid traffic (the traffic comprised of bots and fake users) accounts for 40% of all web traffic, which is a major issue for security and marketing teams.[66] And ad fraud, including click fraud (when invalid traffic engages an online ad), is costing businesses between $35-40 billion dollars annually, surpassing losses from global credit card fraud.[67]

As the significance of our digital lives has grown, the problems have only become more acute. For instance, customers may inadvertently use multiple email addresses for a single service, and barring an onerous reconciliation process, this means multiple profiles for the same customer or vendor may exist, leading to billing issues, frustration with loyalty programs, problems processing returns and deliveries, and more. In essence, the absence of strong core digital identity has become an artificial limit on what we can do with technology, as well as a downside to business.

This is why digital identity is attracting such significant investment. At a time when we are reimagining the relationship between our digital and physical lives, we want to avoid the mistakes of the past. Leading innovators are creating this base layer of identity that has long been missing and forging solutions that will become nothing short of our new on-ramp to the web.

At a time when we are reimagining the relationship between our digital and physical lives, we want to avoid the mistakes of the past.

Core digital identity: centralized vs. decentralized

Already, digitally-born core identities are starting to emerge. Unsurprisingly, many of the biggest efforts are spearheaded by governments, though there are a number of public-private partnerships and grassroots efforts as well. It's a complicated landscape, but every enterprise needs to take note of these evolutions as they will quickly become a primary way to engage customers.

The best way to make sense of these efforts is to look at them across a spectrum of centralized to decentralized, each with advantages and disadvantages.

The Modular Open Source Identity Platform (MOSIP) is an example of a centralized effort. It is based off India's Aadhaar system, but is completely open source and modular, meant to fit various countries' requirements. Governments can leverage the code as a starting point to build digital identity systems which they then have complete control over. MOSIP is intended to help countries—particularly in regions where physical institutions are weak (or lacking entirely)—fast track into the digital era by implementing identity capabilities built digitally from the ground up. It is currently being used in Ethiopia and the Philippines, and there is a planned inter-country effort across West Africa too.[68,69]

Centralized efforts tend to be easier to deploy and to build for purpose, and for those reasons may come to dominate much of the core identity ecosystem. However, as with any centralized system, challenges include concerns over a single point of failure and privacy fears over who controls the centralized platform.

The other, increasingly popular, approach to core identity has been to create decentralized, or distributed, platforms. These efforts, sometimes known as Self-Sovereign Identity (SSI), are based on blockchain and distributed ledger technology, so rather than one central authority, they rely on consensus mechanisms from multiple parties to validate identity. In late 2022, the World Wide Web Consortium (W3C) published a specification for

79%

of executives report their organizations' preferred strategy leans toward centralized solutions, and 54% as partnership-led solutions, to address challenges faced by the lack of standardized digital identity.

Decentralized ID (DID), signifying an important step forward for decentralized identity efforts.[70] Also in fall 2022, the Linux Foundation announced the OpenWallet Foundation (OWF). Instead of publishing identity credentials or standards, OWF wants to create open-source software that will democratize the process, allowing any organization to develop their own digital wallet.[71]

Early efforts are already demonstrating how decentralized core identities could radically transform our experiences on the web. For example, Microsoft's ION is an identification service that runs on the Bitcoin network. Users of ION can replace email and password logins with a unique identifier authenticated by blockchain.[72] Any other personal data exists off-chain, making this purely a core identity solution. And Web3 wallets, like MetaMask and Trust Wallet, are increasingly being positioned as core IDs as well. They provide users with a unique non-custodial ID (the individual holds the private key to the ID), which can be used to access a whole slew of next-generation digital services, like storing NFTs, transferring cryptocurrency, or interacting with distributed apps (dApps).[73]

The advantages to distributed approaches are enhanced safety, security, and trust—but the nature of decentralization leaves things harder to build for purpose. Usability, interoperability, and fears over account recovery are challenges that can end up hurting adoption.

Importantly though, enterprises don't have to wait for tomorrow's standards or apps to start benefiting from this technology. The government of British Columbia (BC) built OrgBook BC, a blockchain-based publicly searchable directory for the 1.4 million organizations registered in the province.[74] Countrywide every year, Canadian companies waste an estimated C$10 billion on administrative red tape, like vetting permits.[75] Now, with OrgBook, a unique digital identity is created for every registered business in BC, which is then associated with the various licenses and permits the business has qualified for. This allows OrgBook BC's public-facing website to automatically validate a company's ID and credentials against the blockchain every time its name appears in a search, providing users a trusted record of companies' registration status and selected licenses and permits.

As it stands, the core identity ecosystem is messy—a testament to the rapid innovation happening today. But the amount of change bubbling beneath the surface is enough that every enterprise should take note. From large state-led projects to novel methods of authentication, how enterprises engage people—whether customer or employee—is starting to change on a foundational level. What's more, while that alone would be enough to re-engineer systems, an even bigger change is yet to come: how the use of those identities is starting to evolve.

Early efforts are already demonstrating how decentralized core identities could radically transform our experiences on the web.

The implications

Parallel to the wellspring of effort to introduce core digital identity is an equally large push to rethink the function of those identities: how we create and associate data about those identities, how that data is shared and managed, and the balance of ownership across the ecosystem.

Each new effort for core digital identity is like a stone cast into water, and the underlying changes to the data ecosystem are the rippling, lingering results—and this is where the real opportunity begins.

Today these changes are just starting to manifest, so leaders have a chance to pull ahead, lead their competitors, and shape what comes next. But new forms of digital identity and the subsequent data paradigms are growing in popularity by the day, so left unaddressed, businesses leaders will quickly find themselves racing to catch up to a future they are unprepared and ill-equipped to engage with. Already, some are experimenting with how digital identities allow them to approach data differently, devising and executing new strategies that lean into the novel capabilities the technology presents.

Take Starbucks, which is exploring how digital wallets can transform their loyalty program with a new NFT effort called Starbucks Odyssey. Based on a proof-of-stake blockchain built by Polygon, Starbucks customers will be able to collect unique tokens, store them in digital wallets, and exchange them for benefits like virtual classes, unique merchandise, or a trip to one of the company's coffee farms.[76] The customer owns their tokens outright, so if they don't want one of the benefits, they are free to sell it on Odyssey's open marketplace to another customer. It transforms the standard loyalty program into a community in which the customer is also a stakeholder and has much more control over what they own. Starbucks knows its pilot is experimental but believes it's an important first step to "[potentially] create an expanded, shared-ownership model for loyalty"—and to build upon in future collaborations as well.[77]

While Starbucks is more of a contained ecosystem for now, Permission.io is looking to introduce a similar paradigm across the web. Permission.io allows advertisers to allocate a dedicated amount of the company's cryptocurrency ($ASK) to a given ad campaign.[78] Consumers can then earn varying amounts of the currency by opting into data sharing or engaging with content. Consumers have the freedom to do what they want with their earned currency—either hold it, sell it on an open exchange, or be immediately rewarded by trading it in on Permission.io's website for gift cards to major brands like Domino's Pizza and Nordstrom.[79] Whereas Starbucks allows consumers to own a share in their loyalty, Permission.io gives consumers a new ability to own their data and attention.

Permission.io and Starbucks are leveraging tokenization, one of the leading ways enterprises are starting to innovate around identity. Tokenization is the process of taking a "thing" and creating an associated digital asset, often stored on a blockchain. Importantly, these examples also show how identity innovation isn't limited to people. Starbucks and Permission.io are tokenizing loyalty and attention. The "thing" can be any asset from a shipping container to a piece of art or financial securities.

In essence, tokenization is the process of creating an immutable, functional identity for anything: physical, digital, unique, or not. And once those identities are created, enterprises can start to transform what they do with them. Unilever and SAP are using a blockchain system where tokens are created at the source for batches of palm oil.[80] The tokens allow Unilever to trace specific crops through their supply chain and connect them directly back to the farms they were sourced from. The Industrial and Commercial Bank of China (ICBC) created Icago, a tokenization system that allows public transit operators to issue NFT "carbon credits" to riders, who can then exchange those tokens for China's central bank digital currency.[81] And Goldman Sachs is building an end-to-end tokenization solution for assets in its portfolio.[82]

What's clear is that the disruptive impact of these changes to digital identity is going to be huge: it is bringing forward a new paradigm for data and ownership. And soon enough, it won't just be leaders capitalizing on early opportunities and upsides—every business will be forced to think about identity and data differently.

Tokenization is the process of taking a "thing" and creating an associated digital asset, often stored on a blockchain.

> It is crucial that enterprise leaders understand the inflection point digital identity is in right now.

In early 2021, Apple introduced a number of privacy changes to iOS that turned all third-party app tracking and data sharing into an opt-in experience; by 2022, on average only 25% of users opted-in to app tracking.[83,84] And Google intends to kill cookie tracking in its Chrome browser.[85] It's new planned system, called Topics, will categorize activity into 350 predetermined general "topics."[86] Every week users' top five "topics" plus an additional randomized sixth topic will be calculated and stored by Chrome—and only a random subset will be shared with third parties.[87] After three weeks the topics refresh, and no history of past topics is saved or stored. And if there is skepticism around how much enterprises will drive this trend forward, regulators aren't far behind them. Gartner predicts that by 2024, 75% of the global population will have its personal data covered under privacy regulations.[88]

Stated bluntly, by no choice of their own, enterprises may no longer have access to the data they're used to having. The third party and consumer data they currently rely on is starting to disappear, and with no preparation to rotate to the new models, the trickledown effect could be massive. It is crucial that enterprise leaders understand the inflection point digital identity is in right now: it is not just that new doors of opportunity are being opened, but many of the old ones that enterprises rely and depend on are starting to close.

While these changes are often welcomed by consumers, enterprises are understandably nervous. 69% of U.S. marketers believe the elimination of third-party tracking will have a greater impact than GDPR.[89] And GDPR left businesses scrambling to comply. While data collection and use was largely a CIO activity before, GDPR requirements for explaining how data was used, user control requirements, and downstream data sharing quickly roped every part of the business into the discussion.[90] Failure to comply has been met with steep fines—and not just to tech companies, but to hotel chains and airlines as well.[91] In short, GDPR changed the risk proposition, guardrails, and requirements for how enterprises around the world use data—and subsequently, how they innovate. With digital identity poised to be a deeper and more seismic shift than GDPR, enterprises need to start preparing with the same urgency.

This is why experimenting with new forms of identity, digital wallets, and tokenization isn't all about chasing upside—it's about exploring and preparing for the pivot tomorrow will require. Onyx, an identity solution being developed by JPMorgan, for instance, could be used as a way to credential people across the metaverse, Web3, and decentralized finance.[92] The solution will allow people to bind digital assets to a decentralized ID and then pick and choose which data they want to share to access services across

the web—such as opting to use one's credit score to leverage a "buy now, pay later" option.[93] While the solution is still in development, the underlying takeaway is that one of the largest investment banks in the world, accustomed to having deep access to customer data, is envisioning (and building!) a world where customers decide what data businesses have access to and when.

As we shift towards a consent- and value-based data ecosystem, rather than the track and surveil one that exists today, businesses need to be prepared for disruptions to their data pipeline. Exploring tomorrow's solutions will help enterprises navigate those disruptions, but the technology alone is only half the solution. Enterprise leaders need to be asking themselves: How will we gain—and earn the right to maintain—access to a person's data, when they are the ones who own it?

With digital identity poised to be a deeper and more seismic shift than GDPR, enterprises need to start preparing with the same urgency.

The bottom line

Core identities, biometrics, tokenization, and other emergent technologies are beginning to alleviate digital identity's past shortcomings—but will also challenge businesses in ways they are unprepared for, like shifting access to critical data and needing to integrate new technologies. But the enterprises that rise to the challenge and shape the future of digital identity will enjoy enhanced security and resilience to changes in the wider marketplace and build renewed confidence with their customers and partners. Most importantly, they will have a head start on the future—and push us ever closer to a better web, and a better world.

A day in our new reality: Miriam

After coffee with Alex and Ben, Miriam decides to walk to work. Her company's office is only 20 minutes away, but before long she's lightheaded, short of breath, and feels a sharp pain in her chest. Panicking, she calls an ambulance.

Miriam's call automatically triggers an app on her phone, which grants emergency services access to her medical records. When paramedics arrive a few minutes later, they've already checked her allergy and medical history, and give her a shot to ease her breathing. Once it takes effect, the paramedic in charge updates her medication history and signs with a thumbprint. Then, their access to her records ends.

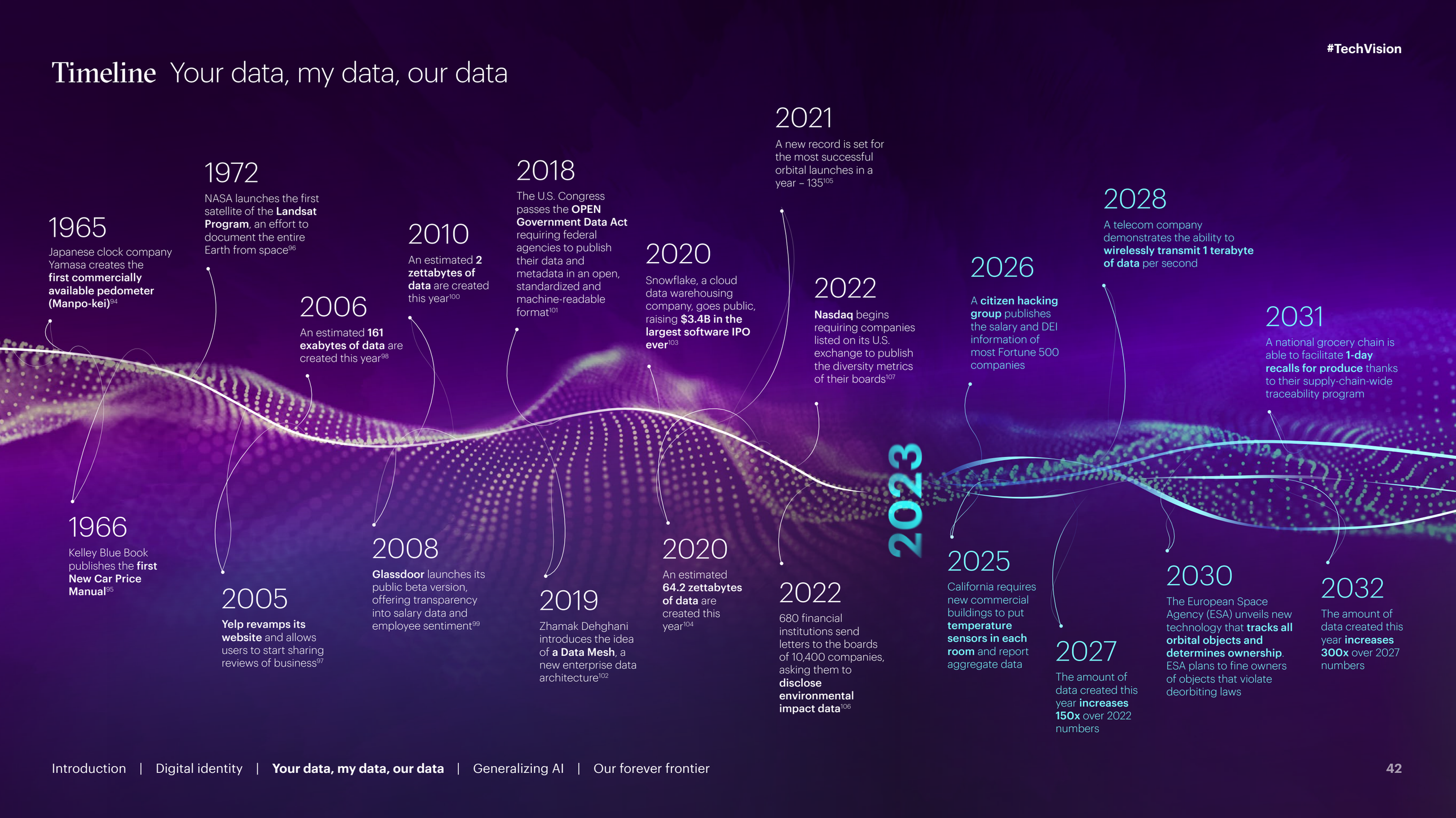
Later, Miriam's doctor wants to dig deeper into the issue, so Miriam uses her app again to grant the doctor access to her records—specifically health and fitness wearables data. Using this information, as well as city-wide air quality data, the doctor sees that spikes in Miriam's heart rate and blood pressure are correlated with upticks in pollution. She's diagnosed with severe environmental asthma and recommended for an experimental drug trial.

As part of the trial, she'll record the frequency of her asthma attacks and her adherence to the drug regimen in her app. The information will be anonymized, and then uploaded to a public database for researchers and doctors to analyze. Someday when the study concludes and her test group is revealed, the app will automatically update so her medical history is always complete.

Your data, my data, our data

Why transparency will become your most precious resource

Timeline Your data, my data, our data



1965
Japanese clock company Yamasa creates the **first commercially available pedometer (Manpo-kei)**[94]

1966
Kelley Blue Book publishes the **first New Car Price Manual**[95]

1972
NASA launches the first satellite of the **Landsat Program**, an effort to document the entire Earth from space[96]

2005
Yelp revamps its website and allows users to start sharing reviews of business[97]

2006
An estimated **161 exabytes of data** are created this year[98]

2008
Glassdoor launches its public beta version, offering transparency into salary data and employee sentiment[99]

2010
An estimated **2 zettabytes of data** are created this year[100]

2018
The U.S. Congress passes the **OPEN Government Data Act** requiring federal agencies to publish their data and metadata in an open, standardized and machine-readable format[101]

2019
Zhamak Dehghani introduces the idea of **a Data Mesh**, a new enterprise data architecture[102]

2020
Snowflake, a cloud data warehousing company, goes public, raising **$3.4B in the largest software IPO ever**[103]

2020
An estimated **64.2 zettabytes of data** are created this year[104]

2021
A new record is set for the most successful orbital launches in a year – 135[105]

2022
Nasdaq begins requiring companies listed on its U.S. exchange to publish the diversity metrics of their boards[107]

2022
680 financial institutions send letters to the boards of 10,400 companies, asking them to **disclose environmental impact data**[106]

2023

2025
California requires new commercial buildings to put **temperature sensors in each room** and report aggregate data

2026
A **citizen hacking group** publishes the salary and DEI information of most Fortune 500 companies

2027
The amount of data created this year **increases 150x** over 2022 numbers

2028
A telecom company demonstrates the ability to **wirelessly transmit 1 terabyte of data** per second

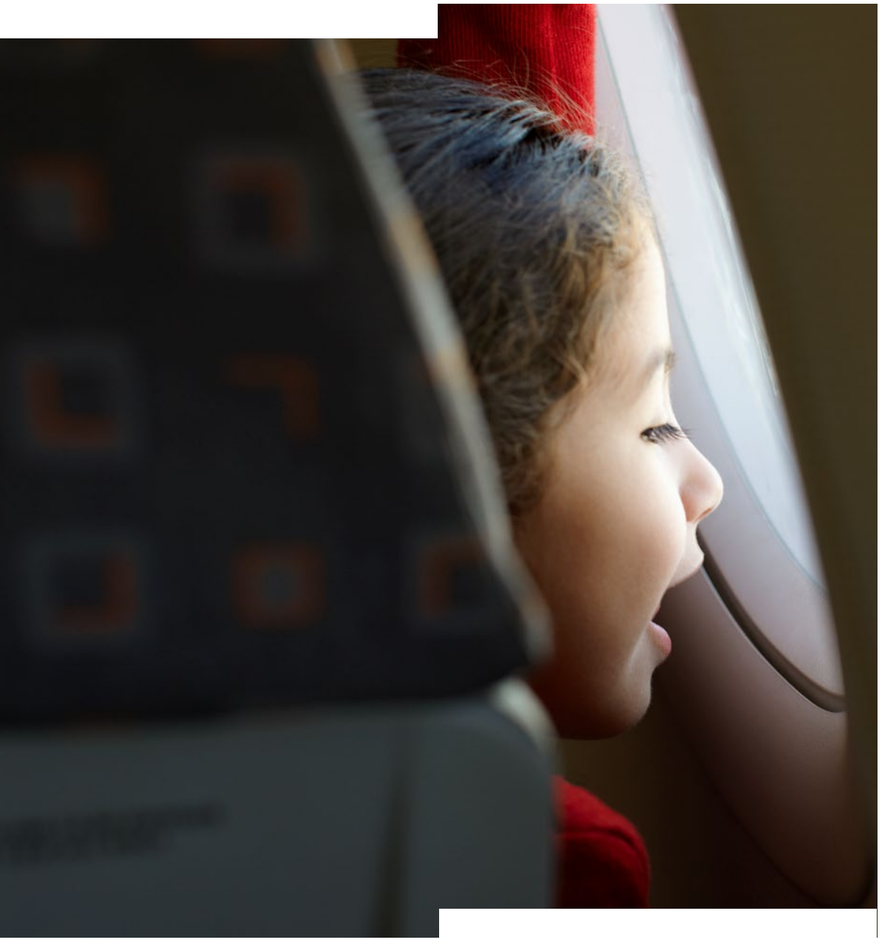
2030
The European Space Agency (ESA) unveils new technology that **tracks all orbital objects and determines ownership**. ESA plans to fine owners of objects that violate deorbiting laws

2031
A national grocery chain is able to facilitate **1-day recalls for produce** thanks to their supply-chain-wide traceability program

2032
The amount of data created this year **increases 300x** over 2027 numbers

The big picture

In the not-so-distant past when you were deciding where to eat, you might rely on word-of-mouth or the occasional expert guide. Then in 2005, Yelp changed everything.[108]



The company created a digital service for customers to share reviews of businesses—which is now a go-to website for foodies, based on millions of restaurant ratings and reviews from fellow diners.

It was an industry-altering move. Yelp changed how people find restaurants, how restaurateurs get publicity, and how customers voice their experiences at restaurants and other businesses too. Research shows that a restaurant can increase its revenue by 5% to 9% if its Yelp rating goes up by one star—and even a half-star bump can help a restaurant sell out 49% more frequently.[109,110] And it's all based on data that was already out there—customers always had opinions, they just weren't recorded or made accessible to this degree before.

What Yelp did is create a "window of transparency"—a clear, detailed, and expansive view into a piece of the world around us. Beyond pure data, these windows can provide real insights into business processes, consumers, market shifts, investments, corporate leaders, and entire industries. And today, they're shaking up more than just dinner plans.

As businesses and governments around the world continue to invest in digital transformation, these windows are popping up everywhere. Look at the airline industry. For years, industry-wide data on flying was scattered. But Cirium, an aviation-data marketplace, figured transparency could improve the way the industry is run. The company now quantifies and aggregates aviation data from 97% of scheduled flights worldwide, so customers can track an aircraft's usage and part wear, see real-time flight schedules of about 880 airlines, and even find a specific flight's CO_2 emissions.[111,112,113]

Similarly, due to countless shippers, forwarding agents, and transportation companies behind the scenes, the freight industry has long struggled with black-box costs and price volatility. But the company Xeneta tackled this problem by aggregating millions of data points on ocean and air freight rates as well as shipping lanes. Xeneta today analyzes more than 300 million freight rates, 160,000 port-to-port lanes, and 40,000 airport-to-airport connections.[114] It uses that data to define benchmark rates at market value and shares those rates on its platform. Overcharging is easier to spot and stop as a result. Associated

British Foods, for example, used Xeneta's benchmark rates to negotiate a 30% decrease in their shipping spending.[115] With a clear window into the industry—one that anyone can see through—stakeholders can leverage this information to make their operations more efficient.

So why is this level of transparency only coming to freight, aviation, and other industries now, when Yelp has been functioning for many years? It comes down to maturing digital strategies and how they've changed the way people and enterprises think about data. As businesses built robust data practices, they drove major shifts in the data ecosystem, from the skyrocketing volume of data to transformations in how data can be shared and managed. Subsequently, enterprises today have more precise insight into their operations than ever before. But that's not all. As the appetite for data grows, it's also changing. Now, it's not just businesses looking for this level of information, it's everyone: governments, consumers, employees, shareholders, watchdog groups, business partners, media, even curious individuals.

In successfully creating greater lines of sight into their business, companies have created a new expectation: People believe that this data exists (or should exist), and they want to see it too. From information about sourcing to climate impact, salaries, diversity hiring, and more, we have shifted from an information environment that accepts opacity to one that expects transparency. For example, when it comes to making grocery choices, one report found two-thirds of shoppers would switch from their usual brand to one that provides deeper information about products.[116] Another study found that 60% of people shopping for clothes want more information about how their clothes are produced so they can make more ethical purchasing decisions.[117] And this trend isn't restricted to consumers—the demand is being driven by all manner of stakeholders in an enterprise's ecosystem. They are no longer wondering if enterprises have the data they want, it's an assumption that they do.

We're moving from the historic reality where data was scarce (and often a proprietary secret) to a new reality where data is being systematically quantified

90%

of global executives agree data transparency is becoming a competitive differentiator for their organizations.

Before companies can even think about turning transparency into a resource, they need to be prepared to handle this quantity of data and manage it responsibly.

and made available—and it puts enterprises in a number of difficult positions. First, most corporate data architectures aren't built to handle this level of transparency. Even as many have built out data strategies, they are still not fully tapping into the data at their fingertips. Consider this: the world is being quantified at a historic and accelerating rate. 47 zettabytes of data were created in 2020 alone—and by 2035, it is predicted that 2,142 zettabytes of data will be created *each year*.[118,119] And the number of connected IoT devices worldwide is expected to reach 27 billion by 2025.[120] Before companies can even think about turning transparency into a resource, they need to be prepared to handle this quantity of data and manage it responsibly.

Second, even if your data architecture is leading edge, your strategies in a world of plentiful data need to change too. It's not enough just to have the data, your company needs to be able to assess the quality and integrity of it, as well as act on and share the insights it finds. Like the aviation and freight examples demonstrated, transparency can bring enterprises big advantages. It can offer industries growth, optimization, and efficiency. It can also bolster an enterprise's operations, improve customer experiences, and build a trusted reputation by driving accountability to values like fairness and sustainability.

The Swedish footwear brand Icebug illustrates how giving customers more information can drive loyalty and profits. Customer consciousness has been a major factor in purchasing decisions—in fact, 66% of customers want eco-friendly products.[121] Icebug recognized that footwear makes up 2% of global carbon emissions, so they bet that publishing sustainability information would make customers happier, ultimately boosting sales.[122] The brand partnered with fashion traceability firm TrusTrace to collect, store, and analyze sustainability metrics, such as the percentage of recycled material used in a shoe. Icebug made those figures public on the brand's website and in retail shops, and a year later, saw a 37.8% increase in its annual net profit.[123]

Spotify demonstrates another way to attract customers through information sharing. First introduced in 2016, Spotify Wrapped is a personalized summary of the music, artists, podcasts, and genres that a user listened to in the past year.[124] By packaging and presenting personalized data from an individual user back to them, it not only allows users to reflect on the year and learn about their listening habits, but it is also designed to be shared on social media, sparking engagement and surfacing content—with Spotify at the center. In 2021, Spotify Wrapped received mentions in 1.2 million Twitter posts, and during the week of its campaign, downloads of Spotify's mobile app increased 21%.

Lastly, you'll need to update your branding strategy, because once this kind of data exists you can't assume that it won't get out to the public. Skeptical? Most companies don't publish salary information, but you can find it on Glassdoor. Want to know who the biggest CO_2 emitters are? Check out the University of Massachusetts's Greenhouse 100 Polluters Index. Increasingly, when companies do not take the helm, gathering and sharing information within as well as beyond their walls, third parties can and will meet that demand first.

This is a generation-defining moment. We are beginning a business era driven by transparency rather than opacity. Enterprises are at the forefront of changes radically reshaping the world, and being a leader in this next era will depend on trust—making transparency your most precious resource. Yet to succeed, your company's data strategy—how you create and collect, manage, and use your data—likely needs a reboot. You'll need to look at your entire data lifecycle, rethinking what data you collect and how you collect it, looking at your data management approach and how it might fall short, and reassessing how you use data, who has access to it, and what business functions you want from it. It's a big undertaking, but the benefits that can be gained are too big to pass up.

We are beginning a business era driven by transparency, rather than opacity.

The technology

The expectations around transparency today are a direct function of the technology that has become an inextricable part of our world. To turn transparency into a strategic advantage, enterprise leaders first need to understand the technology shaping it, and why the conditions demanding transparency will only accelerate moving forward. Then, they need to design the data strategies that will let them generate, manage, and share their own data with ease.

Building the conditions for transparency

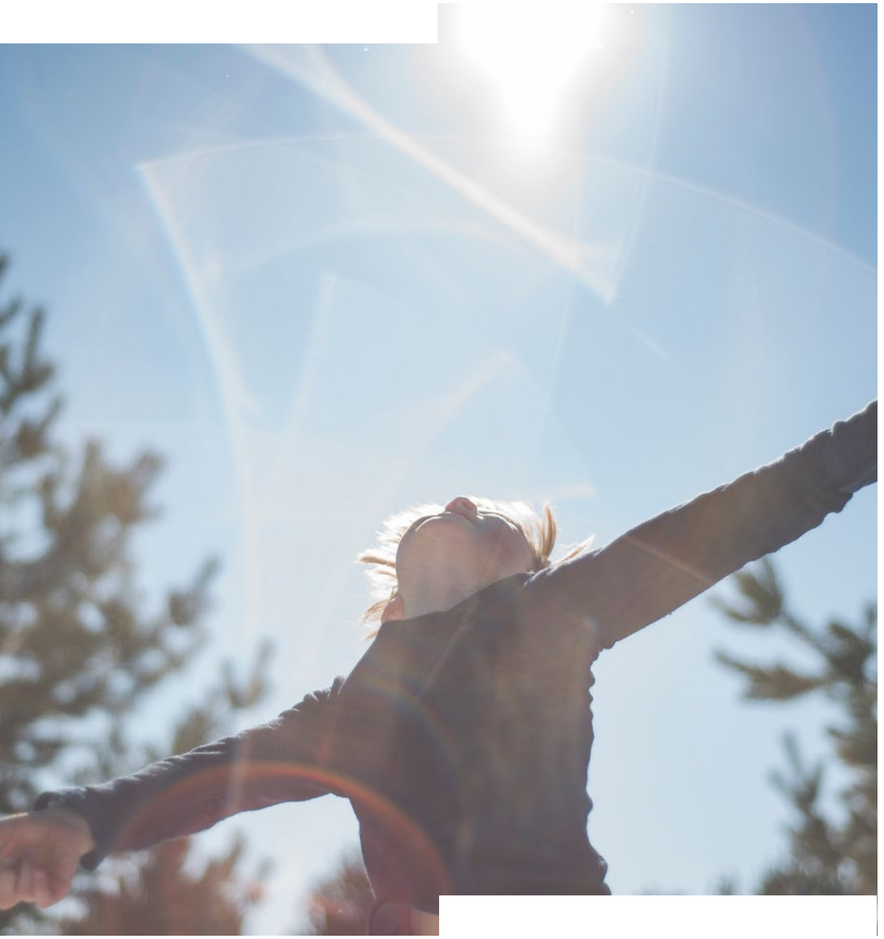
Back in 2013, Target made what was, at the time, considered an incredibly bold move. The company became one of the first retailers to announce a year-round price matching policy that included pricing found on popular e-commerce sites.[125] Target adopted this policy because they were grappling with a "window of transparency." Customers were coming into the company's stores, trying out and falling in love with a product, only to pull up their smartphone and find an online retailer with a cheaper price. Shoppers had nearly perfect information, instantly attainable at their fingertips, and so they acted on it.

> But data alone isn't enough. The availability of that data is key. That's where communications technologies come into play.

While price matching in the retail industry is old news, what it teaches us is more relevant today than ever: the conditions for transparency all come down to data and connectivity. In Target's case, what drove them to act was a combination of pricing information from online competitors (a new data source) and frictionless access to that data via their smartphones (connectivity). Today, we are seeing a rapid acceleration of both new types of data and our ability to transmit and access them with unprecedented speed. This confluence is creating incredible opportunity for "windows of transparency" to open, giving enterprises a stark choice: get ahead now or risk missing out.

Worldwide, the supply of data is growing fast. Much of it is being generated online—in the past year the internet had 5.07 billion users total, with an average of 6.5 hours spent online a day.[126] However, the contributor that is perhaps most influential on transparency is how advances in sensing technology are generating new types, and enhanced fidelity, of data about our physical world. From our health to our home, sensing technologies increasingly play an integral role in our daily lives. The new Apple Watch can calculate sleep cycles down to the minute and track heartbeat irregularities.[127] And in Sweden, researchers built a low-cost nano-sensor that can detect pesticides on fruit in a matter of minutes.[128]

While each of these new sensors operates on a small scale, they give clear, quantifiable lines of sight into increasingly larger systems. One research effort demonstrated how a low-cost microsensor can recognize and locate the distinct sound of a leaky water pipe with 100% accuracy.[129] Scientists at the



University of Washington created a self-powering sensor that can float in the air like a dandelion seed and measure the temperature, humidity, and other details of the surrounding environment.[130] And Climate Trace uses 300 satellites and over 11,100 sensors to track carbon emissions across global industrial sectors or even at a single power plant.[131]

As the cost of sensors drops and their capabilities grow, we are entering a time with extremely precise and expansive information about our bodies, environments, and world. When enterprises think about generating and pulling back the curtain on this data, it can be used to disruptive effect.

Take Planet Labs. Every day, satellites from Planet Labs capture 300 million square kilometers of images from space at a 3.7-meter resolution—a clarity so high that the naked eye can see individual animals.[132,133] The company partnered with King Abdullah University in Saudi Arabia to capture daily, cloud-free images from space of a Nebraska corn field. The images showed the crops' health, which helped farms tailor field irrigation, and better predict crop yields.[134,135]

But data alone isn't enough. The availability of that data is key. That's where communications technologies come into play. In addition to data volumes growing, we are seeing the ability to transmit data grow dramatically—over long distances, to places previously unconnected, and in nearly real-time.

For example, T-Mobile has been building out a 5G network and they are thinking bigger than connectivity just for phones. The company partnered with Pano AI and Portland General Electric to deploy 5G-connected cameras in remote, wildfire vulnerable areas. Pano AI placed its artificial intelligence enabled cameras in rural locations, then used T-Mobile's 5G network to quickly transmit the data.[136] This lets users access real-time observations and data—and has resulted in users reporting fires when they start and enabling authorities to respond more quickly. And now, T-Mobile and SpaceX have also announced a partnership to use Starlink's satellite constellation with the goal of providing near complete coverage in the U.S.—even in remote locations previously unreachable by traditional cell signals.[137]

Managing the data deluge

Data and connectivity generate the conditions for transparency—but they don't guarantee enterprises' ability to manage it. In a June 2022 study, *"Evolve Your Data Practices To Stay Ahead Of The Competition,"* Forrester found that 79% of enterprise decision-makers believed their enterprise struggles to "take insight-driven action in real time."[138] An underlying issue is that data within enterprises is often siloed—so it's no surprise that when respondents were asked to name the top challenge in better using customer data, 56% stated the lack of integration between data sources. If your data infrastructure is already struggling with the massive amounts of data it contends with, then it will only buckle under the greater data load that is on the horizon.

Enterprises need to start building their way out of this data deluge if they hope to turn transparency into trust. Emerging AI tools will likely play a big role in your enterprise's transition. They can autonomously aggregate, de-duplicate, and auto-tag data as well as do other key data preparation tasks.[139] Recently, for example, the restaurant reservation company OpenTable used Clarifai's auto-tagging feature to help employees moderate content in images uploaded to OpenTable's platform. After integrating this auto-tagging, OpenTable noticed its content moderation became 16 times more productive; on average, each moderator jumped from moderating 300 to 5,000 photos a day.[140]

From our health to our home, sensing technologies increasingly play an integral role in our daily lives.

95%

of global executives agree new data architectures and strategies are required to manage the dramatic changes to their organizations' data landscapes.

Another technology that can bolster your data strategy is a knowledge graph, which links related data points and visualizes those links. These graphs often include semantic layers, or text descriptions of the data, which make it easier to find what you need. Stardog partnered with NASA to build a knowledge graph out of various data sources about the manufacturing of NASA's Space Launch System rocket. So, instead of NASA engineers manually pulling in data, they could query a knowledge graph to get the data they sought, resulting in a ten-fold increase in their productivity.[141]

Importantly, emerging tools are allowing non-engineers to tap into technologies in the data management toolbox as well, allowing your enterprise to build a more data-forward company culture. For instance, self-service analytics can let employees, regardless of their technical background, explore your enterprise's data to find insights. This can both empower workers and help solve business problems. Take the Seattle Seahawks, a professional American football team.[142] For years, the National Football League (NFL) Voice of the Fan survey found that some Seahawks supporters had a hard time hearing games in the team's stadium. But the team's management did not know where those fans sat to fix the game's speakers there. So, the Seahawks turned to Tableau's heat mapping tool. After inputting their Voice of the Fan survey data, four corners of the team's stadium lit up in Tableau's visualization, showing where those fans who complained of poor sound quality sat. The Seahawks could reconfigure the stadium's audio system without buying a new one, saving money and improving fan experiences.

But isolated tools won't be enough. Enterprises need to think top to bottom about their data management. Fortunately, two emerging data management strategies, data mesh and data fabric, hold promise to revamp your enterprise. They each have unique benefits and differences, but underscoring both is streamlining and de-siloing data architectures.

With data fabrics, the goal is to defragment an enterprise's data architecture by leveraging automation and metadata to build a single source of truth across disparate data sources. It is a top-

down approach that installs a virtual layer on top of an organization's various data sources for tightly controlled, unified, data management. Metaphorically speaking, it is like building a zoo around your data. You aren't changing the underlying data, and in fact you're trying to preserve the environments—but at the same time you're building consistency across the enclosures, better descriptions about what's inside, and a map to where everything is so it's all readily accessible by everyone.

The major boon here is how the single source of truth and automation can dramatically increase productivity. One survey found data scientists spend 45% of their time on data preparation tasks, including data loading and data cleansing.[143] While these steps may be time-consuming and tedious, they are necessary to ensure data quality for things like data visualization or model development. A data fabric paradigm can automate data tasks, saving the enterprise and its employees' valuable time, thanks to an active metadata management system. Gartner predicts that by 2025, "active metadata-assisted automated functions in the data fabric will reduce human effort by a third, while improving data utilization fourfold."[144]

Data mesh is another emerging concept which tackles the problem in a different way. If data fabrics try to assert top-down management over data, data mesh treats each data source as an independent product. Coined by Zhamak Dehghani in 2019, data mesh stresses domain-specific expertise, management, and governance.[145] The owners of data sources are distributed and entrusted to manage data themselves, with the expectation that they are trying to reduce the friction to access that data (typically through the use of APIs).

This is particularly useful for businesses that have varied data needs across different environments. For instance, an oil and gas company may seek to understand offshore extraction data at one site, then pipeline efficiency data at another. So, instead of something like a data lake pooling information together, a data mesh paradigm can help a company access data across locations from multiple sources.

No matter which data strategy you end up with (and it can even be both), data mesh and data fabric, as well as the technologies behind them, can help your enterprise manage its data better—and having a solid data management strategy is necessary in this new era of transparency. That said, the ability to unlock "windows of transparency" is not the same thing as actually opening them. Indeed, many businesses will choose to keep their insights under lock-and-key—but as exemplified by Yelp, they may find their data out in the open anyway, and soon.

Data mesh is another emerging concept which tackles the problem in a different way.

The implications

The “windows of transparency” that are starting to emerge reflect the beginning of a new business landscape everyone will soon find themselves operating in. It will reshape customer and partner relationships and the value of data and how it’s gathered, creating a market with closer to perfect information than ever before.

To thrive in this landscape, enterprises need to quickly start revisiting their data technologies and build transparency as the demand (or opportunity) for it emerges. But technology is only half the story. Businesses also need to shift their mindsets towards embracing transparency, revisit how they calculate risk, and think more multidimensionally about the value of their data.

A "window of transparency" frees information—and under your management this can be a powerful thing. Does it mean to you should share *all* your data *all* the time? No, data must be collected and used responsibly—privacy and confidentiality are essential and should always come first in any decisions surrounding data. But companies also shouldn't be overly conservative. When it comes to transparency, there are valuable gains to be found for businesses' internal operations, for customers, and for the public, and you don't want to miss out.

Internal:

Transparent enterprises can see more clearly the gears that make their business turn. That clarity brings problems or inefficiencies to light, which can then pave the way to solutions. Until we know that a problem exists, we can't fix it. And transparency can be that illuminating force to strengthen internal operations.

Digital twins are "windows of transparency"—and they are one of the best ways to shine a light on a business's internal workings. While they may not be new, they are getting better in significant, more transparent ways. For instance, Bentley Systems' platform for building digital twins of critical infrastructure systems, iTwin, now includes iTwin Experience, which acts as a "single pane of glass" to integrate and overlay engineering, operations, and information technology data.[146] This allows owners and operators to more easily visualize, query, and analyze digital twins at different levels of granularity and scale, effectively empowering them to make better informed, more actionable decisions.

Actively generating transparency can also help satisfy new internal requirements. Increasingly, local regulations across a number of geographies are placing maximums on carbon emissions, and penalizing companies that pass that threshold.[147] It means companies have to be able to both measure and report their emissions to ensure compliance. To help building owners, Measurabl and Singularity Energy launched a tool that quantifies and monitors buildings' CO_2 emissions.[148] This tool can determine a building's compliance with local regulations, give building owners a financial risk report based on their carbon emissions, and create a decarbonization plan per building. Making carbon emissions visible will not only ensure a company's compliance and commitment to sustainability, but overall, it will take a city one step closer to being cleaner and healthier.

Customer:

With customers, opening up greater transparency can help enterprises revitalize and enhance existing relationships – and even become an avenue for securing new ones. At a time when trust is top of mind for consumers, the value of transparency cannot be understated. Approach these new data demands head on, and you will build a trusted relationship with customers and see them become enthusiastic brand champions. Data about customers has long been valuable to the enterprise—now it is time to make it valuable to customers as well.

Being transparent with customers, however, is also about allowing feedback to be shared with you.

Wanting to emulate the success of Spotify Wrapped, many other companies from fitness trackers to news sites and delivery services explored ways to present data back to customers.[149] For example, The Washington Post launched its personalized annual year-in-review in 2022, summarizing a subscriber's reading habits to reveal their unique reading "personality."[150] It reminds readers of all the content they've enjoyed and the value they got from The Post—and the reader's unique "Newsprint" looks like a fingerprint, ready to be shared on social media. And other companies provide year-end data back to their customers in aggregate. For instance, according to Strava's 2022 Year In Sport, cyclists riding in groups rode both farther and faster, on average, than those who rode solo—hard proof that it really is beneficial to have a training partner.[151]

Being transparent with customers, however, is also about allowing feedback to be shared with you. Thinking back to Yelp, we know people's reviews can shape consumer behavior. It's understandable that enterprise leaders are reluctant to embrace reviews systems since bad ones can hurt the business—but now the assumption must be that people have that information. In an environment with increasing activity from fake or bot-generated reviews, it benefits enterprises to think about how they don't shy away from the conversation, but ensure it is a fair and accurate depiction. Trustpilot seeks to rekindle customer trust by requiring that reviewers share an email address and leave their reviews within one year of purchasing a product. Moreover, Trustpilot employs community flaggers, a paid human enforcement team, and algorithmic detection to get rid of fake reviews.[152] Trustpilot found that 74% of consumers are more likely to purchase from a website that shows Trustpilot reviews.[153] Verifiable reviews are key to building a credible brand and loyalty.

For years there have been calls for companies to be responsible and open about the data they collect on customers. Now the expectation is that it will be a two-way street. Enterprises are being given the unique opportunity to not just step away from practices that leave customers skeptical, but also actively embrace ones that reinforce trust.

Societal:

One of the biggest drivers in the demand for transparency is how both enterprises and people alike are starting to confront problems that are bigger than any one business. But tackling complex multivariate problems, once again, demands reliable and transparent data.

For example, as more enterprises begin to look beyond the limits of our planet and up towards space, the world is quickly running into the problem of "space junk." Debris from satellites, rocket launches, and more are starting to crowd the areas around our planet creating all manner of difficulty, from obstructing astronomers to interfering with future rocket launches. Normally, no enterprise would treat this as "their" problem, but Privateer, a space startup, decided to shed light on it.[154] The company built a publicly accessible object tracking platform to trace the orbits and velocity of all the objects crowding our planet. The hope is that by quantifying this problem, others can start working on a solution—or at least stop making the problem worse in the near term.

What's become clear is that transparency can drive significant benefits for a huge range of stakeholders. Whether companies are looking to improve their operational efficiency, transform their relationship with customers, or take part in solving some of the world's most challenging information-related problems, this new approach and mindset around data is key.

59%

of executives report accelerated innovation and 56% report greater trust with customers as the leading benefits of increased transparency for their organizations.

The bottom line

"Windows of transparency" are coming, whether you're the one opening them or not. The decision companies need to make today comes down to whether they seize this moment and find ways to take advantage of the changing data ecosystem, or if they'll resist these changes and miss the opportunities ahead.

We no longer operate in an environment that accepts opacity. Partners, customers, regulators, and more are all demanding greater insight into your business and industry than ever—and if you don't meet those demands, someone else will.

A day in our new reality: Alex

Alex is a farm manager, responsible for hundreds of acres of land in the Midwestern United States. It's a lot to keep track of—but she's not doing it alone. Every morning, she starts her day with a briefing from TerraWise, her AI assistant for all things agriculture.

TerraWise regularly aggregates and analyzes a massive stream of data, from soil sensors, drone footage, farm equipment, satellite images, weather forecasts, and more, and alerts Alex to the most important information.

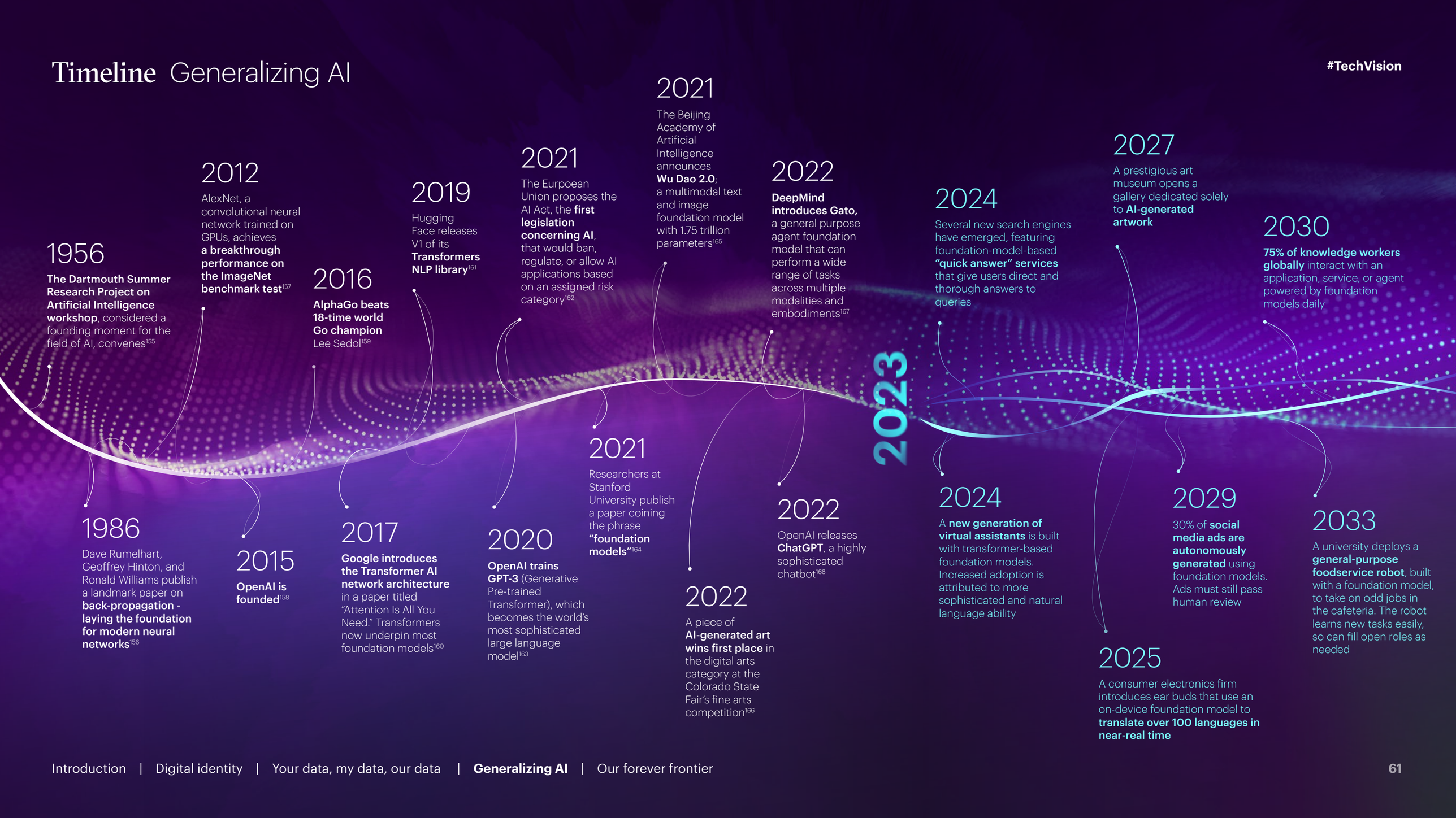
Today's news: satellite images show an anomaly in one of her soybean fields. Alex heads out to inspect the field, and to her dismay, finds discoloration on the crop leaves. She's pretty sure she knows what it is but takes a dozen photos and uploads them for TerraWise to confirm.

Later, during a coffee break with her friends, TerraWise pings her with the results. As she suspected—it's soybean rust. This can spread quickly, so they need to act fast. Using what it knows about the history of the field, as well as leading research on soybean rust, TerraWise generates a custom fungicide plan for the affected crop, as well as preventative treatment for surrounding fields. It also sends an alert to neighboring farms' AI assistants. With luck and her neighbors' help, they may all manage to avoid crop loss.

Generalizing AI

The radical edges—and possibilities—of intelligence

Timeline Generalizing AI



1956

The Dartmouth Summer Research Project on Artificial Intelligence workshop, considered a founding moment for the field of AI, convenes[155]

1986

Dave Rumelhart, Geoffrey Hinton, and Ronald Williams publish a landmark paper on **back-propagation - laying the foundation for modern neural networks**[156]

2012

AlexNet, a convolutional neural network trained on GPUs, achieves **a breakthrough performance on the ImageNet benchmark test**[157]

2015

OpenAI is founded[158]

2016

AlphaGo beats 18-time world Go champion Lee Sedol[159]

2017

Google introduces the Transformer AI network architecture in a paper titled "Attention Is All You Need." Transformers now underpin most foundation models[160]

2019

Hugging Face releases V1 of its **Transformers NLP library**[161]

2020

OpenAI trains GPT-3 (Generative Pre-trained Transformer), which becomes the world's most sophisticated large language model[163]

2021

The Eurpoean Union proposes the AI Act, the **first legislation concerning AI**, that would ban, regulate, or allow AI applications based on an assigned risk category[162]

2021

Researchers at Stanford University publish a paper coining the phrase **"foundation models"**[164]

2021

The Beijing Academy of Artificial Intelligence announces **Wu Dao 2.0**; a multimodal text and image foundation model with 1.75 trillion parameters[165]

2022

A piece of **AI-generated art wins first place** in the digital arts category at the Colorado State Fair's fine arts competition[166]

2022

DeepMind introduces Gato, a general purpose agent foundation model that can perform a wide range of tasks across multiple modalities and embodiments[167]

2022

OpenAI releases **ChatGPT**, a highly sophisticated chatbot[168]

2023

2024

Several new search engines have emerged, featuring foundation-model-based **"quick answer" services** that give users direct and thorough answers to queries

2024

A **new generation of virtual assistants** is built with transformer-based foundation models. Increased adoption is attributed to more sophisticated and natural language ability

2025

A consumer electronics firm introduces ear buds that use an on-device foundation model to **translate over 100 languages in near-real time**

2027

A prestigious art museum opens a gallery dedicated solely to **AI-generated artwork**

2029

30% of **social media ads are autonomously generated** using foundation models. Ads must still pass human review

2030

75% of knowledge workers globally interact with an application, service, or agent powered by foundation models daily

2033

A university deploys a **general-purpose foodservice robot**, built with a foundation model, to take on odd jobs in the cafeteria. The robot learns new tasks easily, so can fill open roles as needed

The big picture

AI is stirring up the internet.

When OpenAI revealed ChatGPT—a powerful new chatbot—in late 2022, people clambered to test it.[169] They asked complicated, open-ended questions, requested poems and essays with obscure topics and styles, and got impressive and sometimes humorous results: in one case, instructions for removing a peanut butter sandwich from a VCR written in the style of the King James Bible.[170]

Then, not even four months later, OpenAI released GPT-4, the greatly anticipated next generation of its AI software, which is even more creative, and can respond to both image and text inputs and even more nuanced instructions.[171,172]

And before all this, the internet was flooded with AI-generated art. Text-to-image generators like Stability AI's Stable Diffusion, Midjourney, and OpenAI's DALL-E 2, stunned people by responding to written prompts with photorealistic images. "Two capybaras waltzing in the style of Monet" would get you pretty much that.

In fact, this wave of AI-generated content is so advanced—and moving so quickly—that it's driving controversy. Arguments over fairness in art competitions, the ethics of mimicking artists' styles, legal risks, and the impact on people's livelihoods have flared. And yet, while relevance to the art industry is clear, businesses in other fields may still see it as mere novelty—and they're making a mistake.

This generated content is part of one of the biggest step changes in the history of AI: the introduction of pretrained models with remarkable task adaptability, which will revolutionize how and where enterprises across industries use AI.

It began with a landmark innovation in AI model architecture by Google researchers in 2017.[173] Since then, tech companies and researchers have been supersizing AI, increasing the size of models by 10,000 times and the size of training sets too. The result: powerful, pretrained models, often called "foundation models," that offer unprecedented adaptability within the domains they're trained on, be it language, images, or the structure of proteins. With this adaptability, foundation models can complete a wide variety of tasks without needing task-specific training. What's more, companies

96%

of global executives are either very or extremely inspired by the new capabilities offered by AI foundation models.

building foundation models are giving third parties access through APIs or by open sourcing them, putting these advanced models in anyone's hands.

This is no everyday technology advancement. While foundation models are not the only area of AI research that's growing, the magnitude of their potential impact and the speed at which they can be deployed is driving them to the top of companies' innovation agendas. With them, businesses can start to approach many tasks and challenges differently, shifting focus from building their own AI to learning to build *with* AI.

One company taking advantage of this is CarMax. CarMax is using GPT-3, a large language model and predecessor to GPT-4, to improve the car-buying experience.[174] Knowing that there's a massive amount of information potential car buyers may want to read through before making a purchase decision, CarMax used Microsoft's Azure OpenAI Service to access a pretrained GPT-3 model to quickly read and synthesize over 100,000 customer reviews for every vehicle make, model, and year that they sell. From these reviews, the model generated 5,000 easy-to-read summaries—a task that CarMax said would have taken its editorial team 11 years to complete.

Other organizations are also experimenting with foundation models, adapting them for tasks ranging from powering customer service bots, to generative product design, to automated coding. And the models are advancing fast, with companies across industries quickly discovering new ways to use them. As foundation models broaden and extend what we can do with AI, they are letting companies transform human-AI interaction and build an entirely new generation of AI applications and services.

It is imperative for every business to pay attention to foundation models. To be part of this new generation of AI applications and leverage these models to drive novel business solutions and offerings, companies need to understand their strengths and capabilities and track how they are advancing—starting today. The bedrock of AI is shifting. Will you lose your footing—or end up on higher ground?

The technology

To understand what's happening in this new era of AI and set yourself up to build a new generation of AI applications, we first need to explore what makes foundation models different.

A new category of AI

OpenAI's GPT-3, which was released in 2020, was the first foundation model to capture widespread public attention—for good reason. It was the largest language model in the world then and drove a breakthrough in the field. It demonstrated capabilities no one had seen before, teaching itself to perform tasks it had never been trained on, and outperforming models that *were* trained on those tasks. In the years since, many more supersized models have appeared. Companies like Google, Microsoft, Meta, and Baidu have created their own large language models.[175,176,177,178] And some have started building large *multimodal* models—like the aforementioned GPT-4 and text-to-image generators—which are trained on multiple types of data (like text, image, video, or sound) and to identify the relationships between them.[179]

In an effort to define this new class of AI, researchers from the Stanford Institute for Human-Centered Artificial Intelligence coined the term "foundation model" in August 2021.[180] They generally defined them as large AI models trained on a vast quantity of data with significant downstream task adaptability.

In practice today, these models typically leverage transformer machine learning models and have a massive number of parameters—ranging from hundreds of millions to trillions. What makes them so game changing, is that they're broadly trained across a data modality (or multiple modalities like language and image), rather than on a specific task, and can learn to complete new tasks within these data types with minimal or no extra training. In other words, they have generalist capabilities within their domains.

DeepMind's Gato is one of the most exciting examples to date. The company calls Gato a "generalist agent" because it is multimodal and can complete over 600 different tasks.[181,182] Using a single AI model with fixed weights, it can chat, caption images, play Atari video games, stack blocks with a robotic arm, and more. Additionally, it can learn these various tasks simultaneously and switch between them without having to forget previous skills. For context, AlphaZero—an older DeepMind model known for playing chess, Go, and shogi—had to unlearn how to play chess in order to play Go.

In an effort to define this new class of AI, researchers from the Stanford Institute for Human-Centered Artificial Intelligence coined the term "foundation model" in August 2021.

Foundation model workings

There are two key innovations making this new wave of AI possible. The first is transformer models, introduced by Google researchers in 2017.[183] One of the newest classes of AI models, transformers are neural networks that identify and track relationships in sequential data (like the words in a sentence), to learn how they depend on and influence each other. They are typically trained via self-supervised learning, which for a large language model could mean pouring through billions of blocks of text, hiding words from itself, guessing what they are based on surrounding context, and repeating until it can predict those words with high accuracy.[184] This technique works well for other types of sequential data too: some multimodal text-to-image generators work by predicting clusters of pixels based on their surroundings.

The second innovation is scale—significantly increasing the size of models, and subsequently, the amount of compute used to train them. The size of a model is measured in parameters, which are the values or weights in a neural network that are trained to respond to various inputs or tasks in certain ways.[185] Generally speaking, more parameters lets a model soak up more information from its training data and make more accurate predictions later. But what OpenAI demonstrated with GPT-3 is that vastly increasing the number of parameters in a transformer model, and the computational power put into training it, leads not just to higher accuracy but also the ability to learn tasks the model was never trained on.

This novel learning ability—also known as few-shot and zero-shot learning—means that foundation models can successfully complete new tasks given only a few or no task-specific training examples. DeepMind's Flamingo—an 80B parameter multimodal visual-language model—is especially good at this.[186] In a 2022 paper, DeepMind researchers demonstrated how Flamingo can conduct few-shot learning on a wide range of vision and language tasks, only being prompted by a few input/output examples and without the researchers needing to change or adapt the model's weights. In six of 16 tasks they tested, Flamingo surpassed state-of-the-art models that had been trained on much more task-specific data, despite not having any re-training itself.

One of the newest classes of AI models, transformers are neural networks that identify and track relationships in sequential data (like the words in a sentence), to learn how they depend on and influence each other.

Future advances in foundation models

While foundation models have already pushed technological boundaries, it's important to recognize that the field is changing quickly. Stanford's 2022 Artificial Intelligence Index Report found a significant uptick in the annual number of global AI publications since 2017.[187] According to CB Insights, 2022 saw record investments in generative AI startups, with $2.6 billion in funding across 110 deals.[188] And in early 2023, Microsoft announced the next phase of its partnership with OpenAI through a multibillion dollar investment.[189] To truly understand the impact foundation models will have on their industries and businesses, companies need to carefully track new developments.

One of the most significant ways foundation models are evolving has to do with the data types they're trained on—which right now are limited. Most of today's foundation models are large language models trained on natural language, and even multimodal models are typically language-and-image only. But some are working to expand to more data modalities.

This can mean building standalone foundation models for new kinds of data. Meta, for instance, developed a protein-folding model—a large language model that learned the "language of protein"—that accelerated protein structure predictions by up to 60x.[190] And a research team from the University of Texas at Austin, the Indian Institute of Technology Madras, and Google Research, proposed Generalizable NeRF Transformer (GNT), a transformer-based architecture for NeRF reconstruction.[191, 192] A NeRF (Neural Radiance Field) is a neural network that can generate 3D scenes based on only partial 2D views—and experimenting with transformers to generate 3D data like this could have big metaverse implications.

Other organizations are working to incorporate more data types into a single model. Take Microsoft's Florence, a foundation model built for general-purpose computer vision tasks.[193] While it was trained on a large data set of image-text pairs and has only a two-tower architecture, combining one language encoder and one image encoder, its creators

97%

of global executives agree AI foundation models will enable connections across data types, revolutionizing where and how AI is used.

> To truly understand the impact foundation models will have on their industries and businesses, companies need to carefully track new developments.

extended its learning ability to video tasks with a proposed video adapter built off the image encoder. Extending to this additional data type is a key step toward a computer vision foundation model that can generalize across real-world vision tasks—and could drive applications in security, healthcare, and more.

Another significant area to track is efforts to make building and deploying foundation models easier. Rapidly growing compute requirements, and the associated costs and expertise needed to handle this scale, are the biggest barriers today. The amount of compute needed to train the largest AI models has grown exponentially—now doubling anywhere from every 10 months to every 3.4 months, according to various reports.[194,195] And even after a model is trained, it's expensive to run and host all of its downstream variations as it gets fine-tuned to handle different tasks. In today's cloud computing setups, it's slow to load foundation models each time they're needed but expensive to keep many models online.

Anyscale—a unicorn that recently raised $199 million—is working to lower these barriers.[196] Anyscale was founded by a group of UC Berkeley researchers who developed Ray, an open-source framework that improves access to foundation models by making it easier to scale and distribute machine learning workloads. It's currently used to train the largest AI models coming out of OpenAI, like ChatGPT.[197] Cohere, a startup building an NLP developer toolkit, also uses Ray to train large language models.[198] And IBM is using it to implement zero-copy model loading, where they store model weights in shared memory, and use Ray to instantly load and redirect cluster resources to whatever model an application requires in the moment.[199] This frees users from needing to tune the number of model variations they keep loaded in memory, and is expected to lead to much simpler foundation model adaptation and deployment.

The novel capabilities of foundation models—and these ongoing advances in the technology—have led some in the community to see them as a step toward artificial general intelligence (AGI), an AI system capable of learning any intellectual task that a human can learn. Only time will tell if the technologies and methods behind foundation models are enough to achieve some form of truly general intelligence in the future. Nevertheless, the level of generalization foundation models have already achieved within certain data types is hugely significant and more than enough to revolutionize how and where enterprises use AI.

The implications

The question now for businesses shouldn't be whether these models will impact their industry, but *how*. Foundation models are widely adaptable and could technically be used for a wide variety of tasks—so the decisions companies make around where and how to deploy them, what problems to attempt to solve with them, and what problems to address with different technologies, are where competitive differentiation will be found.

Characterizing the benefits of foundation models

Using foundation models for the right purposes starts with understanding what they truly change. This goes beyond technical capabilities—it's about what these models let businesses do that they couldn't do before. There are two major benefits here.

First, they have the potential to deeply transform human-AI interaction. Look at how some are calling ChatGPT the future of search and knowledge retrieval.[200] It can write poems and essays, debug code, and answer complicated questions because it's trained on billions of examples of text pulled from the internet.[201] And it remembers previous conversations, so it can revise or elaborate on responses, making human-machine communication more sophisticated and natural.

This is important. Because many foundation models are (or contain) a large language model, they use natural language as their interface. It's a big part of why foundation models are giving rise to a new generation of AI applications: people can easily engage with them. Frame, for instance, is using a large language model capable of generating code to help teachers design 3D metaverse classrooms simply by describing what they want in the room out loud.[202] And they're not the only ones thinking along these lines. Jensen Huang, CEO of Nvidia, has also said he expects large language models to be a core technology for generating 3D images and shapes to populate the metaverse.[203]

Another way foundation models are changing human-AI interaction is by transforming how work is done. Google used a foundation model to develop a code completion tool, which over 10,000 engineers tested for a three-month period.[204] The results showed that coding iteration time was reduced by 6%. The potential of these models to transform workflows and improve productivity, even in highly complex tasks, is undeniable. And soon, companies may start to use them in much more varied ways, augmenting tasks all across product development, business processes, and more.

The second major benefit is that foundation models are opening the door to new AI applications and services that were difficult or impossible to build before. For instance, lack of training data is a major issue for most organizations looking to expand their use of AI. But with zero- and few-shot learning abilities, pretrained foundation models may help circumvent this limitation.

Foundation models require massive amounts of data upfront, which is handled by their creators. But once a model is trained, organizations can adapt it to a range of downstream tasks, building new capabilities with just a few examples or fine-tuning a model with just a small training set. Rather than every new AI application requiring months of effort and investment, organizations will be able to create and deploy them much more simply. IBM, for instance, has been transitioning some of its Watson portfolio to use foundation models.[205] They found that with pretrained language models, Watson NLP could train sentiment analysis on a new language with only a few thousand sentences, a training set a hundred times smaller than what previous models required. Over about a year, the company was able to expand Watson NLP from 12 languages to 25.

Sidebar: Synthetic data and foundation models

The intersection of data and foundation models presents an interesting irony. These models require huge amounts of data for training, but once trained, can generate limitless quantities of synthetic data.

This could be useful for many organizations constrained by the lack of real-world labeled data, the need for data from edge cases, or the need to preserve data privacy. Synthetic data is primed to play an important role in training and validating autonomous vehicles, systems that work with health records or financial data, and much more.

On the flip side, as companies develop new foundation models, they may also run out of training data. Most language and image models rely on huge amounts of web data, and organizations' ability to increase model size depends on finding new data sources. Additionally, developing foundation models for new modalities may require huge amounts of hard-to-obtain data. Synthetic data, perhaps even from early foundation models, could be a powerful tool for building these new models.

Multimodal foundation models' ability to recognize multiple data types and identify the relationships between them is also pushing the envelope of what AI is capable of, enabling powerful new systems. GPT-4, for example, is multimodal and accepts both image and text inputs, meaning that if someone were to show it a picture of the inside of their refrigerator, it could correctly identify the items inside, suggest meals that can be made with those ingredients, and then provide step-by-step cooking instructions.[206]

And Meta has long seen the value of an AI system that can interpret content on its platform—especially when it comes to detecting hate speech. But this is a task that's historically been difficult for machines because people tend to communicate in multimodal ways on these platforms (using text and image together to tell a joke, for instance). So Meta has launched a series of foundation and multimodal AI projects to help them analyze different types of communication—like text, image, and video—in conjunction. The company created the Hateful Memes dataset to address the shortage of publicly available training data for classifying memes; it developed FLAVA, a multimodal foundation model that works across dozens of tasks; and it built Omnivore, a model that can operate across images, video, and 3D data, doing things like detecting content in both videos and images.[207,208]

Though multimodal foundation models are still relatively few, and most of them are text-to-image generators, it's exciting to imagine the possibilities we'll have in the future. What will we be able to do when multimodal models connect text, sound, image, video, 3D spatial data, sensor data from industrial equipment, environmental data, or many other types of data? Early opportunities may start with generating marketing images and ad copy but could grow into sophisticated autogenerated code and new ways to search and access information. Analysts might use language to ask an AI system to describe patterns across thousands of satellite images. A piece of industrial equipment might use an AI system to translate data from dozens of sensors into a repair procedure for a mechanic. Or multimodal AI might help drastically improve the path planning and performance of robotic arms.

Though multimodal foundation models are still relatively few, and most of them are text-to-image generators, it's exciting to imagine the possibilities we'll have in the future.

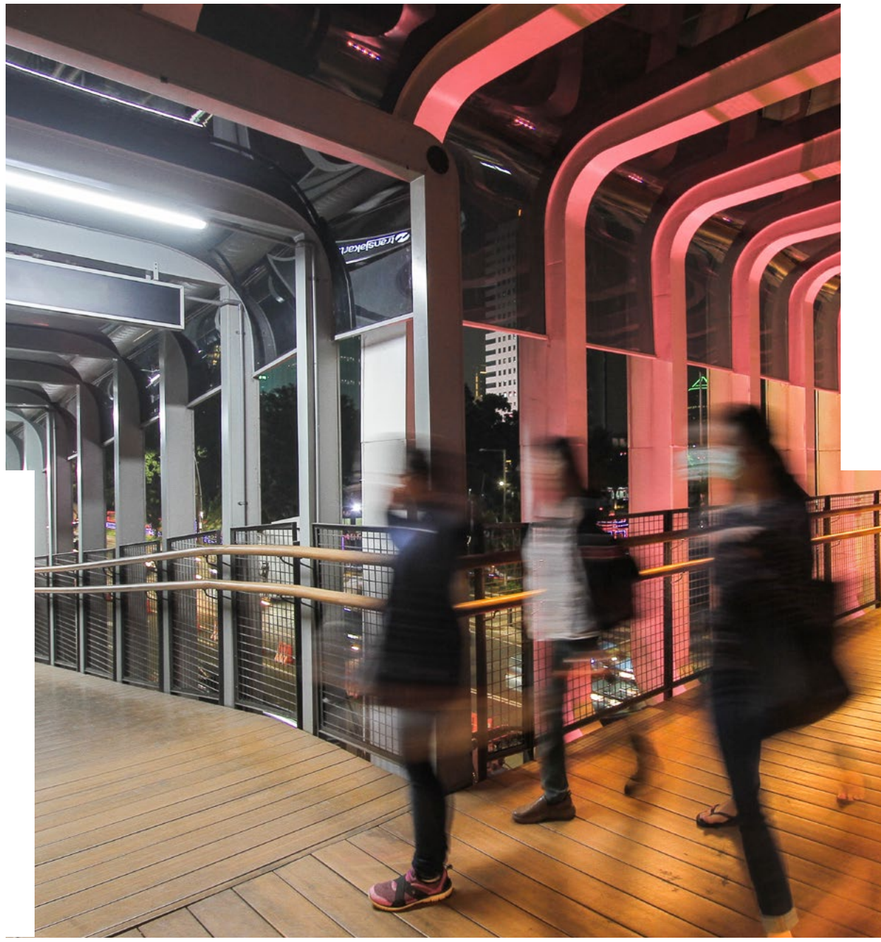
From building AI to building with AI

Once companies grasp the benefits of foundation models, the question shifts from where they drive value to how to deploy them—and one of biggest reasons foundation models are so exciting is that most companies won't need to build their own.

A single foundation model's ability to complete many downstream tasks is creating a paradigm shift in the business of AI. Large tech companies and research organizations that have built pretrained foundation models are starting to position them as platforms to underpin new AI applications. They are making foundation models available via open-source channels or via paid access through APIs —meaning that downstream organizations don't need to build their own foundation models but can focus on building on top of existing ones. Just as the emergence of cloud platforms transformed conversations from "How do I build my own cloud data center?" to "What can I build with the public cloud?" foundation models are shifting conversations from "How do I build my own AI?" to "What can I build with AI?"

Going back to GPT-3—this foundation model is the most established as a platform today. OpenAI transitioned from a non-profit to capped-profit company in 2019 and released the OpenAI API as its first commercial product in 2020.[209,210] It grants customers access to GPT-3 and makes customizing or adapting the model for a new task as simple as showing it some new examples or prompts. Nine months after launching, the company reported over 300 applications using the API.[211] By 2022, that number was in the thousands, with GPT-3 powering features like copywriting, website building, chatbots, and more.[212,213]

Additionally, the startup Hugging Face is growing in popularity as a hub for foundation, transformer, and other machine-learning models. The community platform offers many pretrained models, allowing developers to work with new AI models without needing to collect data or train them themselves. The platform is popular with indie developers, but major companies—including Intel, eBay, Pfizer, and Bloomberg—are starting to use it as well.[214] Hugging



Face closed a $100 million funding round at a $2 billion valuation in May 2022 to help it become the premier location for building with pretrained AI models.

A "middle layer" is also starting to appear alongside foundation model platforms, offering services like fine-tuning the models for more custom use. Though foundation models are pretrained and highly adaptable, some downstream tasks may require more specific training, and fine-tuning means training it on new, task-specific data to change its output. Microsoft, for instance, is packaging and selling GPT-3 capabilities to customers, integrating it into its low-code app development platform Power Apps, and offering customers access to the model along with the enterprise-grade security, compliance, reliability, and data privacy assurance of Azure.[215]

The changes foundation models have brought to the AI landscape—and their expected impact on businesses—shouldn't be understated. With platforms making it increasingly simple to adapt pre-trained models for various AI needs, companies may deploy AI solutions far more readily than before. And with foundation models expanding into new data modalities, companies can build truly novel applications that wouldn't have been possible before. This is a fast-moving field, so it's time to start imagining how these models may transform—or disrupt—your business.

This is a fast-moving field, so it's time to start imagining how these models may transform—or disrupt—your business.

Constructing a new AI strategy

Every year AI plays a bigger role in companies' innovation agendas, operations, customer interactions, and more. But now, organizations' carefully constructed strategies need to be rethought with foundation models in mind. This means discovering the most appropriate applications for foundation models in your organization, planning to access the broader foundation model ecosystem, and building the talent pipeline that will be needed to create, maintain, or integrate these models.

First to identify the right role for foundation models in your organization, it's necessary to understand their best use cases. There are many AI applications that work with data types no foundation model can handle yet. Additionally, some use cases that a foundation model could feasibly attempt are still fundamentally better served by narrow AI, which is trained specifically for a task rather than across a modality.[216] Clearly defined problems like predictive maintenance and medical image analysis, for instance, are areas where narrow intelligence may be the better choice. Beyond that, some applications require special characteristics that other approaches are better suited to. On-device AI may require extreme low power operation or the ability to run an AI model fully offline so data can stay with the device rather than being sent to the cloud.

What's more, foundation models have some characteristics that—for now—make them questionable for certain situations. This is adding an entirely new dimension to enterprises' security efforts. For instance, bias in foundation models is a common concern due to homogenization as well as the fact that many are trained on large datasets from the internet. Historic datasets that excluded certain populations, people, and demographics can lead to undesirable outcomes. And some companies' early efforts even found misinformation was affecting the outputs of these algorithms. When the same few models are used as the basis for many downstream applications, then any issues in the original models may propagate throughout the rest. There have been efforts from the makers of foundation models to

98%

of global executives agree AI foundation models will play an important role in their organizations' strategies in the next 3 to 5 years.

correct for some of these biases. GPT-3, for instance, was given an extra round of training on a more curated dataset after religious bias was discovered.[217] But even so, businesses should carefully consider risks like this when determining not only if they can use a foundation model, but whether they should.

As businesses narrow down where to use foundation models, they next need to decide how they will access these models and where they will sit in the foundation model ecosystem. The base layer of this ecosystem consists of organizations with the expertise, access to data, and computing infrastructure to train new foundation models—but not everyone needs to function on this level. For many, decisions will be around how directly they work with pre-trained models.

For instance, another layer of the ecosystem will be companies that access foundation models via APIs or model repositories and build on them to create their own applications and services. For simple applications, developers will be able to leverage the transfer learning of foundation models by simply building the UI and interconnects around the model, while in more advanced cases, developers might leverage fine-tuning to hone the foundation model to a specific application. This approach creates the opportunity for wide experimentation throughout the organization, as well as the chance to develop B2B foundation model offerings.

But again, not everyone will want to do this. Even with natural language offering an easy-to-use interface, some software engineering knowledge is needed to successfully build applications around foundation models. Companies without those skillsets can still benefit from the technology though, and they make up the third layer of the ecosystem. In the wake of OpenAI and others turning their models into platforms, a wave of companies have started offering new B2B products and services. Whether they use foundation models to power B2B tools, enhance their own services, or build custom applications for clients, these companies are making it easier than ever for anyone to capitalize on foundation model capabilities.

Finally, a third way businesses can start reworking their AI strategies has to do with talent. As foundation models emerge and offer a powerful baseline for

building AI applications, AI operations will shift from building models to building on top of models. Talent with the skills to take foundation models, adapt them to business needs, and integrate them into applications will become increasingly important. Just as the adoption of the cloud shifted business needs from talent with data center expertise to cloud architects, foundation AI is likely to reshape the nature of AI operations too.

Your talent strategy adjustments shouldn't stop there, however. Some of the biggest challenges with foundation models will be discovering the new possibilities they can bring to your organization and then monitoring their output and behavior. And with these models evolving quickly, it's an ongoing challenge. This will need to be a cross-organization effort—and who better to discover how a process can be improved or how an experience can be elevated, and then supervise how a foundation model is used to solve those challenges, than the people working on them? Whether it means training every employee on foundation model capabilities, or creating teams dedicated to integrating these models into different parts of the business, bringing your wider organization into this new era of AI is critical.

Foundation models are in their infancy, but over the next decade their impact will grow to be overwhelming. They could drive new data practices, transforming the nature of knowledge sharing in the organization. They could be game-changing for digital strategies, writing sophisticated code and powering novel offerings. They could transform strategy and business planning, forecasting headcount needs or shifts in customer demand with greater ease and accuracy than we can imagine. And for those that build their own foundation models, they could bring industry-shifting advantages—new tools for scientific discovery, new methods for engineering, or new industry-specific AI agents. What if your business builds the model that changes everything?

Whether it means training every employee on foundation model capabilities, or creating teams dedicated to integrating these models into different parts of the business, bringing your wider organization into this new era of AI is critical.

The bottom line

The arrival of foundation models is one of the biggest step changes in AI history—and no enterprise can ignore them. These supersized models, with unprecedented adaptability to new tasks, are forcing enterprises to rethink their AI strategies—from how they access AI to what applications are even possible.

Already, companies can use models available today to experiment and build novel applications more easily than ever—and as the technology advances, the opportunities will only keep growing.

*** To learn more about the impact of generative AI on business, read Accenture's latest report, A new era of generative AI for everyone.**

A day in our new reality: Ben

Wearing his AR glasses, Ben examines a 3D diagram, rotating the image to see every side. He's a food scientist at Meat4All—a startup aiming to produce affordable synthetic protein. Right now, he's trying to design a new scaffold for their meat cultures, one that he hopes will improve the texture of their newest substitute meat product.

He's working with the company's AI system, which generates several novel protein structures, all of which could be used as scaffolding material, and have the potential to improve texture without overly compromising the flavor of the meat. After examining them, Ben selects the three best options. Then, he asks the AI system which of the three would have the lowest carbon impact. It's a broad question with a lot of contributing factors, from where materials are sourced to differences in the synthesis process. The AI system comes back with a carbon impact analysis for each one, and the differences are slight. But Ben knows that once Meat4All is producing these scaffolds at scale, slight differences can mean a lot.

Our forever frontier

The big bang of computing and science

Timeline Our forever frontier

1907

By combining formaldehyde and phenol, Belgian chemist Leo Baekeland creates the **first entirely synthetic plastic**[218]

1942

The Manhattan Project begins and draws attention to the impact of science on technology[219]

1946

Physicists at Bell Labs achieve a semiconductor breakthrough, leading to **the invention of the transistor** and transistorized computers[220, 221]

1973

The first **U.S. space station, Skylab,** launches. It will be the site of nearly 300 technical and scientific experiments[222]

1994

Peter Shor develops **an algorithm that could break traditional encryption**, if a powerful enough quantum computer existed[223]

2003

Bringing together expert computer scientists, engineers and biologists, **the Human Genome Project** successfully sequences 92% of the human genome[224]

2008

Boeing, Virgin Atlantic and GE Aviation conduct the first commercial flight with a mixture of **traditional and bio-derived aviation fuel**[225]

2010

DARPA launches the Living Foundries program which aims to harness biological systems to produce complex molecules for defense-relevant applications[226]

2013

NASA, Google, and the Universities Space Research Association purchase a D-Wave Two to **study the intersection of quantum computing and AI**[227]

2019

To create better automotive tires, Goodyear experiments on **silica particle formation aboard the International Space Station**[228]

2020

Computational immunology and mRNA technology lead to the COVID-19 vaccines - the fastest vaccines ever developed[229]

2022

Hosted at Oak Ridge National Laboratory, the Frontier supercomputer becomes the **first exascale computer**, according to the Top500 list[230]

2022

The average price to sequence a human genome reaches $600, down from $10,000 in 2012, thanks in part to **advances in molecular chemistry**[232]

2022

DeepMind releases over 200 million protein structure predictions derived from the **deep learning algorithm AlphaFold**[231]

2023

2025

A new quantum computing algorithm propels a **breakthrough in solid-state battery production**

2026

In a national sustainability push, India unveils a synthetically derived microbe which **increases efficacy of plastic breakdown**

2027

Using quantum computing, scientists create a new method to **speed up green hydrogen production**. Global hydrogen use grows 3x

2030

More than **50% of new cars sold are electric**, 20% have solid-state batteries

2031

A large agriculture company uses generative AI to **design a new bacteria that captures CO_2** and converts it into compounds for fertilizer

2032

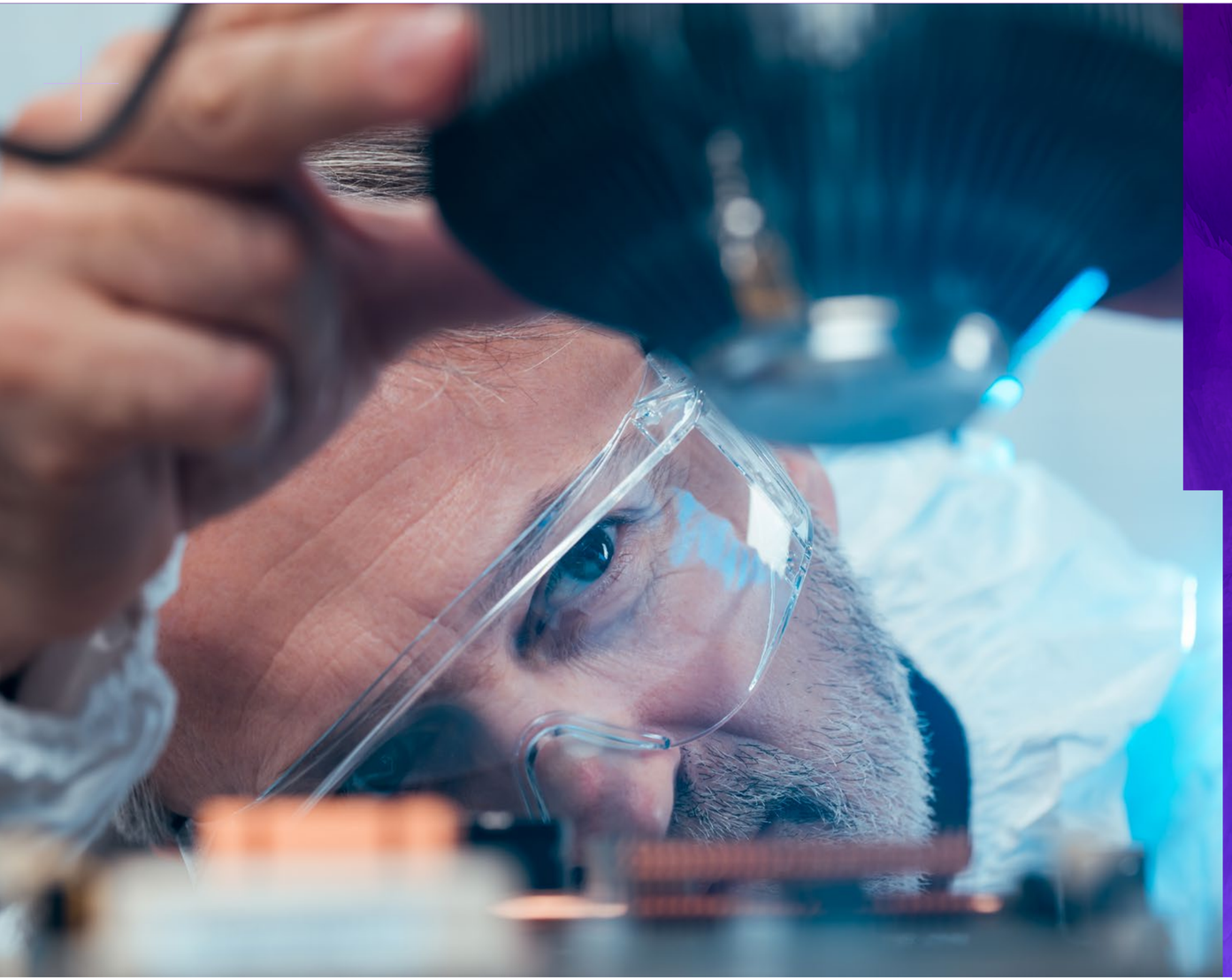
Q-Day arrives, and systems protected with **RSA encryption are no longer secure**

2033

1 billion people have at least 10% of their genome sequenced and now benefit from improvements in **personalized medicine**

2033

The **first private space station** is completed and will host both NASA and private scientific research



The big picture

World War II taught us an important lesson about the relationship between science and technology—one that guided innovation efforts for decades after.

During the war, science was having clear and significant impact on military success, through the creation of new tools and weapons like radar and the atomic bomb.[233] And near the end of it, a landmark report to the U.S. president, called "Science, the Endless Frontier," made the case that supporting scientific research would drive technologies critical to the national economy—and it led to significant government and corporate investments in science.

The period of innovation that followed all but proved this theory. Look at Bell Labs and the invention of the transistor. The first patent for a proposed field-effect transistor was filed in 1925, but a scientific breakthrough was needed to make a transistor that actually worked.[234] In 1946, Bell Labs physicists made that breakthrough, advancing critical understanding of electron mobility in semiconductors. They built the first working transistor in 1947, and seven years after that, the first transistor computer was made—forever changing technology and the world.[235]

But the "science drives technology" ethos wasn't the whole story. High investment in and focus on science during and after World War II certainly accelerated technological development—but technology also began to rapidly accelerate science. Rocket technology developed for military applications quickly became the first human-made objects to reach outer space and would send humanity to the moon less than two decades later.[236] Combat radar was adapted to focus on weather patterns, sparking the field of meteorology. And the hunt for cheap alternatives to rubber led to the development of new materials.[237]

The relationship between science and technology is a bi-directional feedback loop that can be exercised to powerful effect, pushing the bounds of the possible. But recently, with the growth of computing, (digital) technology took center stage, capturing the fascination of enterprises everywhere. While technology certainly still accelerated scientific discovery, enterprises were largely content to leave that in the hands of researchers and specific industries. We forgot the lessons from Bell Labs, the space race, and others.

96%

of global executives agree the combinatorial effect of science and technology driving each other is leading to compressed innovation in science tech.

Now that's starting to change. More enterprises are widening their innovation efforts to focus on the entirety of the feedback loop and are seeing just how powerfully disruptive the intersection of science and technology can be.

The COVID-19 pandemic created global pressure and urgency to innovate to a degree that we hadn't seen in decades, and leaders responded with high investment in emerging technologies to help them drive science and deliver new solutions at breakneck speed. It was a period of massive innovation compression, the impact of which will continue to be felt for a decade or more.

Consider the development of COVID-19 vaccines. In late December 2019, the first COVID-19 cases were reported by Chinese health officials. By January 10, scientists had published the genomic sequence of SARS-CoV-2, and by mid-March, vaccine trials had begun.[238,239] By the end of 2020, multiple mRNA vaccines for COVID-19 demonstrating over 90% efficacy had been created. These vaccines were developed at unprecedented speed (often, this process could take over a decade), largely due to advances in computational immunology used to develop vaccine candidates—and virtual communication and collaboration technologies proved critical as well.[240, 241]

What this achievement demonstrated is that certain technologies could accelerate the science-technology feedback loop faster than anyone knew. The digital technologies that had been amplifying business capabilities for years were focused on a new domain: science-led innovation. It radically reshaped our approach to scientific innovation, from how quickly we can achieve results to its potential impact on enterprises and our lives—a big bang of computing and science. Now, with the world largely emerging from the crisis, we're putting those lessons to work.

Every organization needs to start rethinking their innovation strategies with an eye to how technology is driving science, and how science will in turn drive technology in coming years. The speed of the science-technology feedback loop is one of the biggest variables setting the pace of innovation, and investments in the technologies to accelerate it are

only increasing, bringing new innovation possibilities —and new opportunity—to *everyone*.

It's a wide-ranging imperative, but already there are a few key domains where the science-technology feedback loop is having great impact and where businesses can start to focus their innovation efforts.

One such area is synthetic biology, and its origin is a prime example of just how powerful the science-technology feedback loop can be. Tom Knight is considered the godfather of synthetic biology, but he began as a computer scientist.[242] While designing one of the first silicon retinas for his PhD, he began investigating Moore's Law, or the observation that the number of transistors on an integrated circuit doubles every two years, making compute power grow exponentially. He saw that eventually Moore's Law would come to an end—because transistors would be so small that placing a dozen or so atoms correctly would be impossible in the silicon manufacturing process. This was what led Knight to biochemistry, because he recognized that if proteins naturally and accurately self-assemble, perhaps the right bio-molecules could too. At the same time, Knight realized the ways in which, conversely, biology could benefit from engineering principles, like using modularization and abstraction to build biological systems.[243] And indeed this approach has expedited the growth of synthetic biology—a field now poised to disrupt materials and manufacturing as we know them today.

Besides the emergent field of synthetic biology, other notable domains are also seeing major advances from the science-technology feedback loop. For instance, next-generation computing methods, enabled by the combination of increased computing power and new capabilities inspired by science, are starting to unlock new scientific possibilities in areas like computational chemistry for new materials and energy solutions. Advances in rocket and satellite technologies are also redefining the space economy, enabling more science experiments in space labs, as well as the study of deep space and Earth itself.

Advances in rocket and satellite technologies are also redefining the space economy, enabling more science experiments in space labs, as well as the study of deep space and Earth itself.

The power of technology is extending beyond IT (information tech) and OT (operational tech) to a new ST (science tech) domain. Everyone will be impacted by science tech, whether or not they work in the physical sciences or build the technologies to accelerate those fields. New technological advances in computing, rockets and satellites, and biotech will drive scientific advancements in materials and energy, Earth and space, and synthetic biology—which in turn will transform the technologies that enterprises can build, as part of a virtuous cycle. Everything from where companies can deliver solutions, to what their products and packaging and other physical assets are made of, could change. And beyond that, the societal need for a faster science-technology feedback loop has never been more crucial. The world faces unprecedented challenges in medicine, the supply chain, and climate change, and we need better and faster solutions from science and technology.

Reorienting for a new period of science and technology acceleration will not be easy. It will require deep understanding of how technology is accelerating the sciences, and how these changes will impact your business. And it will require fast action too—innovation compression has already been a challenge for the past few years, and the pace of innovation is only getting faster. Are you ready for it?

Everyone will be impacted by science tech, whether or not they work in the physical sciences or build the technologies to accelerate those fields.

The technology

Many of today's emerging technologies have the potential to accelerate the science-technology feedback loop—so it's critical for companies to start identifying which ones could have the biggest potential impacts on scientific advancement, and in turn, which scientific advancements could have the biggest impacts on future technologies.

The importance of this knowledge shouldn't be understated. Taking strategic advantage of these developments will be what lets enterprises transform their businesses in coming years, and ultimately the futures of their industries.

While there are many areas where science-technology feedback loops can drive innovation, we will discuss three early domains where the cycle is significantly accelerating and we are seeing its impact already: materials and energy, Earth and space, and biology.

Materials and energy

Major technological advances in computing are launching a new era of computational chemistry, a major driver behind material and energy innovation.[244] With access to greater compute power and new computing paradigms, chemists will be able to do more complex and more accurate molecular simulations than ever before, deepening scientific understanding and pushing the bounds of novel material development, energy solutions to address climate change, and more.

Consider this: performing more than one quintillion operations per second, a supercomputer in China appears to have been the first to break the exascale barrier in 2021.[245] And in May 2022, a supercomputer from the U.S. Oak Ridge National Laboratory became the first to officially demonstrate exascale performance, according to researchers for the Top500, a ranking of the world's most powerful high-performance computers.[246] With plans for more exascale machines around the world, this scale of compute power will transform science, and computational chemistry in particular.

Chemists will be able to run faster simulations over larger molecular systems and over longer lengths of time, providing needed insights into chemical theory to reduce the gaps between virtual simulations and real-world experimental findings. While the right code would still be needed to take advantage of this computing power, some programs like NWChemEx are already being developed—in this case to run complex molecular simulations to better use catalytic materials to more sustainably produce biofuels.[247]

The impact that powerful supercomputers are starting to have on the sciences is undeniable—but it's not limitless. There's the end of Moore's Law to keep in mind, meaning that the growth of compute power is slowing—and to the extent that it grows, costs may become prohibitively high. As such, methods to overcome these computing limits are also growing, including moving to entirely new computing paradigms like quantum computing.

95%

of global executives believe next-generation computing will be a major driver of breakthroughs in their industry over the next decade.

Quantum computers have a "natural" advantage (over classical computers) in simulating quantum mechanics, which governs the behavior of molecules, atoms, and electrons. As such, it is contributing to the field of chemistry, in perhaps the nearest-term application of quantum computers.[248] Though computational speedups may come with quantum computers, what they provide in this case is an advantageous level of accuracy in modeling distinct parts of a chemical reaction—and this enhanced understanding has many potential applications.

For instance, Hyundai is partnering with the quantum computing startup IonQ to analyze and simulate battery materials—in this case lithium oxide, contained in lithium-air batteries.[249] Using hybrid algorithms that leverage computing by both classical and quantum computers, they can improve the chemical makeup for greater efficiency and eliminate possible sources of waste.

Building supercomputers and quantum computers is not cheap, but experimenting with them is significantly cheaper than before, thanks to cloud platforms. Firefly Aerospace, for instance, is a startup that relies on cloud supercomputing to do advanced simulations to save massive amounts of money on prototyping, enabling them to build a rocket to go to the moon.[250] And while quantum computing still needs time to mature, it's clear that these computers have a major role to play helping companies effectively drive science technology feedback loops and accelerate materials and energy innovation.

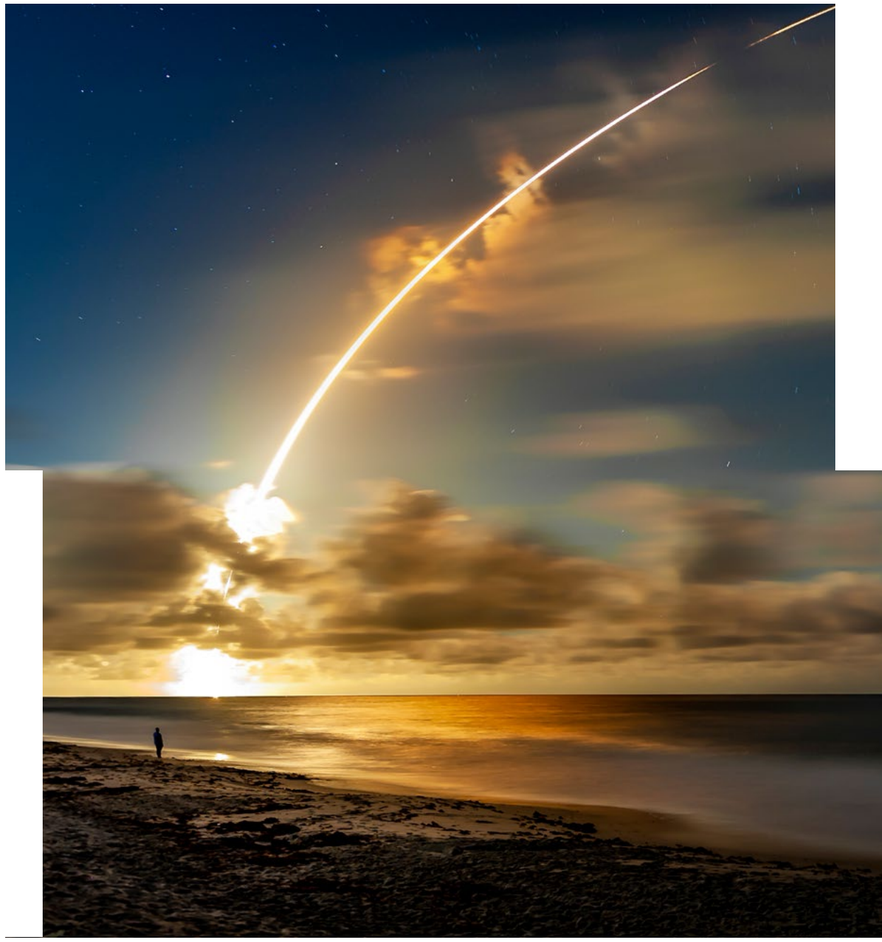
Earth and space

Moving over to Earth and space innovation—since the International Space Station (ISS) began to house its first astronauts, nearly 3,000 science experiments have been conducted in space, taking advantage of its unique conditions like microgravity to better understand how things work, or of its vantage point to look down at Earth or out into the depths of space.[251] Now, advances in rocket and satellite technologies are making space more accessible and useful for scientists—accelerating what we can learn about fluid physics, diseases, materials, climate change, and more, to improve life on Earth.

Space programs were historically very expensive, limiting access to only a few nations and their governments. Recently however, due to cheaper components and growth in the private sector, costs have fallen precipitously.[252] According to a 2022 Citi report, between 1970 to 2010, the average launch cost remained relatively steady at $16,000/kg for heavy payloads and $30,000/kg for light payloads.[253] Then in 2010, SpaceX launched Falcon 9 with a payload cost of $2,500/kg, roughly ten times cheaper—and getting cheaper still.[254] Relatedly, the cost of satellites has also decreased drastically. Now, rather than cost hundreds of thousands of dollars to get into orbit, it can take only a couple thousand—also thanks to their smaller size.[255,256]

All these lowered costs are fueling the space industry.[257] In 2021, space infrastructure companies saw record high private investments at $14.5 billion (up 50% from 2020), and the industry overall is expected to generate over $1 trillion in annual sales by 2040.[258,259]

With this level of growth and investment, there will only be cheaper and more frequent flights to space, leading to more people and more scientific research there as well.[260] Already, the startup Titan Space Technologies is sending "both code and crew" on space missions to conduct experiments in their digital space labs, essentially enabling "space-as-a-service" for companies that want to perform their own experiments in space.[261] This is exciting for those who might want to take advantage of the

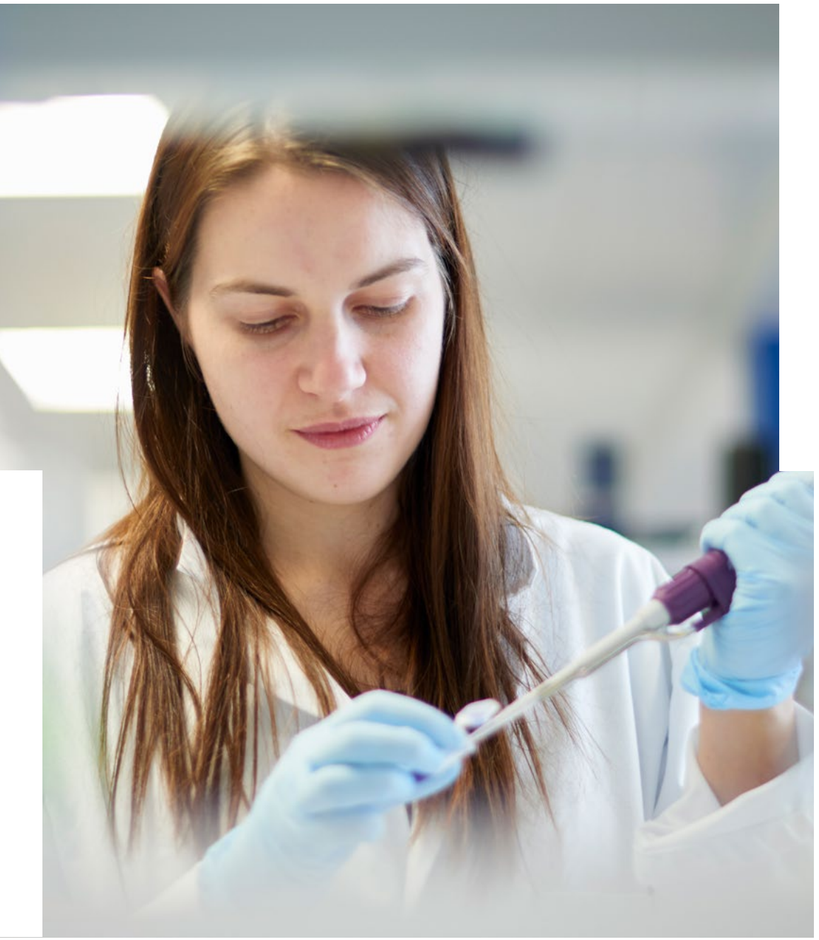


unique properties of space—including microgravity, extreme temperatures, or a vacuum—for research into advanced materials, pharmaceuticals, and much more. This has historically been key to gaining greater scientific knowledge—since the early days of space experimentation, scientists have been able to learn much more about insulin, for instance, because it was crystallized in space (in microgravity, protein crystals grow larger and more uniformly).[262]

Satellite advances are pushing science forward too. Launched in 2018 aboard a SpaceX Falcon 9, NASA's Transiting Exoplanet Survey Satellite (TESS) is expanding scientists' knowledge of the galaxy.[263] By 2020, TESS had imaged 75% of the sky and, in so doing, found 66 new exoplanets and 2,100 candidates.[264] Now on an extended mission, its imaging cadence has been increased to better find Earth-like habitable planets near red dwarf stars—and it has found one of particular interest (TOI 700 d) already.[265] Turning our attention to Earth, satellites like Jason-3 take ocean surface topography measurements for scientists to better understand sea level rise and climate change, as well as to predict severe weather events.[266] And new business models like "satellite-as-a-service" and "space data-as-a-service" are providing even greater access to space, which could be leveraged by researchers too.[267]

Rocket and satellite technology advances have driven down the cost barriers to space, fueling a burgeoning space economy that is having real and significant impact on the sciences, opening the doors to space labs for conducting novel experiments and satellites for finding new worlds and understanding more of our own. As history has shown us before, science discoveries in space lead to technological progress on Earth—and perhaps now in space as well—as part of a productive science-technology feedback loop.

Now, advances in rocket and satellite technologies are making space more accessible and useful for scientists —accelerating what we can learn about fluid physics, diseases, materials, climate change, and more, to improve life on Earth.



Biology

Lastly, this "big bang" of computing and science is giving life to an entirely new field: synthetic biology. Driven forward by technological advances in DNA sequencing and synthesis and technology-inspired best practices, synthetic biology combines engineering principles with biology to create new organisms or enhance existing ones. Its promise lies in what those organisms are then able to do or produce, from new foods to pharmaceuticals, fuels, and more—thereby changing manufacturing processes and products as we know them today.

A recent article published in *Scientific Report* predicts that synthetic biology may be the next major advancement following microelectronics and the internet, and one of the main reasons for this is that the cost of both DNA sequencing and DNA synthesis (the "reading" and "writing" of genetic code) is halving roughly every two years.[268] To get a sense, in 2001, the cost to sequence a human genome was $100 million, and it is roughly $600 today (and could be as little as $100 next year); ten years ago, gene synthesis cost about $10/base pair and is now about $0.10/base pair today.[269,270]

These falling costs have had a significant impact on synthetic biology—because both DNA sequencing and DNA synthesis are critical to the process. To illustrate, let's imagine a company wants to produce synthetic vanilla. First, they go through their (now much larger) database of DNA sequences to determine which might be most likely to generate that flavor.[271] Next, the most promising are (more cheaply) synthesized and put into cells, like yeast cells. The new organisms start producing chemicals, and whichever is best is increased in production. With this manufacturing process determined, the company is set to produce synthetic vanilla flavoring.

Of course, most businesses cannot do this on their own—but they could work with a company like Ginkgo Bioworks, a one-stop-shop for synthetic biology, to do so. Ginkgo provides the technology

Driven forward by technological advances in DNA sequencing and synthesis and technology-inspired best practices, synthetic biology combines engineering principles with biology to create new organisms or enhance existing ones.

platform, including both its codebase and foundries (labs), for its customers.[272] Its codebase consists of cells, enzymes, and genetic programs, which organism engineers can use to start projects. And the foundries are its factories, which combine automation, analytics, and software to automate and scale organism engineering. Not surprisingly, Ginkgo's website draws many parallels to software engineering, and its platform has been likened to cloud platforms like AWS.

Another example of synthetic biology being driven by technology-inspired practices comes from the BioBricks Foundation. The organization is attempting to establish an open-source synthetic biology movement, inspired by the open-source software movement, through programs like bionet, which is an open technology commons for scientists to share their materials in the name of collaboration, standardization, and sharing for science.[273, 274] In short, synthetic biology as we know it today has clear computer science- and engineering-inspired origins.

Though a relatively new field, synthetic biology is being used already. It's well-known for aiding in the development of the COVID-19 vaccine, but it's also used by Bolt Threads to make bio-based leather and Upside Foods to produce synthetic meat like duck, beef, and chicken.[275, 276, 277] Synthetic biology techniques can also be used to make dyes, cosmetics, and spices. Not only are these new and innovative products, but they are more environmentally friendly and sustainable than their alternatives.

From materials and energy to Earth and space and bio-innovation, these three domains are just a few early ways the science technology feedback loop is already at work. And each of them has huge potential impact on the futures of companies and industries. As more companies start to recognize that and take advantage of technology-driven scientific advances, the building blocks of innovation will start to change, and stragglers will quickly be left behind.

The implications

Now that we've covered some of the most significant science-technology feedback loops today, we need to think about how these advances will impact our world—and what is newly possible in it.

It's critical that businesses understand the scope of this new frontier, or they risk failing to set a competitive innovation strategy and pace for the next years. While the accelerated feedback loop will not be the sole driver of new innovations—purely technology-driven IT, OT, and digital projects are still very important—ST is still too big for anyone to ignore. The impact will be felt by everyone.

To double down on exactly how big this impact could be, consider what it could mean for some of the world's biggest problems, like pandemics, climate change, and the supply chain. If they're not already, these will be some of businesses' biggest problems in coming years too, meaning they should have a vested interest in science technology and the vast innovation opportunities that come with it.

In 2020, of course, businesses learned that pandemics are a serious threat to people and themselves. We've discussed how the COVID-19 pandemic prompted swift action to develop a vaccine—and computational approaches vastly increased the speed at which this was possible.[278] Still though, new COVID-19 variants continue to emerge. While our vaccines can be updated, researchers at Penn State College of Medicine are working on a better solution—a vaccine that could protect against all existing and future variants of the virus—and science tech is at the heart of their efforts.[279] Unlike existing vaccines that target the receptor binding domain (RBD), these researchers are targeting the virus through immunogens—designed using computational biology to identify regions of the spike protein that remain the same despite mutations, and tested for stability using computer simulations. Given that pandemic-capable diseases are increasing in frequency, the speed of vaccine development and the breadth of immunity those vaccines provide will be of critical importance throughout the world.[280]

Moving on to climate change, of all the challenges the world faces today, this may be the biggest. Sustainability is certainly on most businesses' radars, and all of the areas we've discussed, from materials and energy to space innovations and synthetic biology, have the potential to contribute to sustainability in a significant way. For example, Accenture, the Irish Centre for High-End Computing (ICHEC), and IonQ collaborated to create a scalable software platform for chemistry simulation on quantum computers. It is used to calculate the energy needed to break chemical bonds in molecules like PFAS—helping to find mechanisms to destroy PFAS, which are human-made carcinogenic "forever chemicals" that pollute the environment.[281] And LanzaTech is using synthetic biology to make microbes that take carbon emissions and turn them into valuable raw materials like fuels and chemicals.[282]

> ... of all the challenges the world faces today, climate change may be the biggest.

And consider how synthetic biology facilities can be strategically placed near fossil fuel plants or other

83%

of executives believe science tech capabilities could help address societal grand challenges of health-related issues and diseases, while 75% believe science tech capabilities could also help address poverty/inequality.

waste heavy sites for fuel—this would make their raw material sources abundant and no longer potentially vulnerable to global supply chain issues. In addition, because these facilities produce unique materials, a product like vanilla no longer has to come almost entirely from Madagascar but can be made synthetically anywhere in the world. Finally, relatively small-scale manufacturing of things like synthetic protein sources is economically viable (no need for years of animal farming)—meaning that again, demands on global supply chains are reduced, as are transportation emissions.[283]

Our world faces immense challenges, many of which have been difficult and painfully slow to address in the past. But this is the ultimate promise of science tech—as more companies invest in the technologies needed to accelerate science, more companies will be able to use those scientific developments to create new solutions faster and more effectively than ever before. It won't happen overnight, but the benefits are necessary and worthwhile, and have the potential to be invaluable for the businesses that get involved.

Getting started today

Still, getting involved in the science technology revolution is easier said than done. Many new technologies are already at work accelerating the science-technology feedback loop, and the changes this will bring to our innovation landscape are coming fast.

Compounding the challenge is that unlike the digital revolution, companies are starting at wildly different levels of maturity. Some enterprises, like those in pharmaceuticals or chemicals, have long-standing science-led innovation practices. These companies will know the value of maintaining their position on the leading edge, explore and invest in emergent digital technologies that will accelerate their practices, and jump on the opportunity that science tech poses to build partnerships and bridges into brand new industries. Other companies have never considered themselves involved in the sciences at all. For them, there are three high-level actions to take today to set themselves up for success in this next phase of innovation compression.

First, businesses that want to be more active participants in developing these next-generation technologies, and the sciences they drive, should recognize that collaboration is the key.

Next-generation computing technologies like quantum computing are not only advanced and complex but require skills that are hard to find and in high demand. Therefore, organizations across industries and sectors are pursuing quantum computing goals together through consortiums. For example, in Japan, the Quantum Innovation Initiative Council (QIIC) aims to accelerate Japan's quantum leadership and consists of members from academic institutions, government, and businesses like IBM, Toyota, and Toshiba.[284] And this sort of collaboration can also be achieved through strategic partnerships. For instance, the quantum algorithm design platform Classiq has partnered with ColdQuanta for its cold atom technology, NVIDIA for its cuQuantum software development kit, and NTT DATA for a specific application of quantum computing to credit risk analysis.[285]

In the emerging field of synthetic biology, there are many partnerships as well. For instance, the synthetic biology company Codexis has partnerships with pharmaceutical companies like Merck, GSK, and Novartis who use its CodeEvolver® protein engineering platform to develop enzymes to enhance their pharmaceutical manufacturing processes.[286] And Ginkgo Bioworks is working with Motif FoodWorks to develop novel dairy, meat, and plant-based proteins—and bring these new food products to market faster.[287]

The second way businesses can prepare themselves is to find ways to start experimenting with new science-driven innovations. Fortunately, this is getting easier with the many advanced technology and science platforms being created. As an example, Microsoft is working with NASA's Jet Propulsion Laboratory (JPL) to develop scheduling solutions using quantum-inspired optimization algorithms on Azure Quantum, available in the cloud.[288] And Google has created a Quantum Virtual Machine that anyone can use and that is specifically intended for research and education.[289] Given there are many new and exciting potential applications for quantum computing yet to be explored, this sort of experimentation is beneficial to businesses and the field as a whole.

And in terms of trying new things in space, Amazon recently partnered with the Italian satellite company D-Orbit and the Swedish intelligent automation company Unibap to conduct a "first-of-its-kind" experiment in space—running a suite of AWS software on a satellite in low Earth orbit.[290] The AWS software was trained to review images and send only the most useful to Earth, improving the productivity of the satellite in space and reducing the amount of time to get insights on the ground.

Finally, businesses also need to be aware of and prepare for the risks in this new frontier. Advances and increased access to synthetic biology could lead to dangerous laboratory leaks or biological weapons abuse, for instance.[291] This highlights the need for substantial biosecurity strategies. And while clearer legal regulations are still needed, companies can take their own steps now to implement policies and governance plans and view biosecurity as an investment rather than a burden.

Next-generation computing technologies like quantum computing are not only advanced and complex but require skills that are hard to find and in high demand.

Companies are going to want to get involved in this compressed innovation, and soon. There's no longer time to sit back and wait, the big bang of computing and science is happening now.

Another serious security issue for every business stems from quantum computing. Shor's algorithm provides a quantum-theoretical solution to prime factorization, which can break public-key encryption that we rely on today. Quantum computers simply aren't advanced enough yet to do so, but they're getting there at a breakneck pace.[292] While some believe quantum computers will break encryption in the next 10 to 20 years, the reality is that smaller, more targeted attacks will happen soon, and companies will need to have plans to address this in the next two years. Already, there are serious concerns that hackers are collecting data now to decrypt later once quantum computing is ready, also referred to as "store now, decrypt later" schemes.

Currently, NIST has identified some quantum-resistant algorithms, but predictions on their viable lifecycle vary. What we know is that these algorithms will not last 20 years and we have to be agile with cryptographic methods, ready to upgrade at any time. In the meantime, companies should prepare to transition to post-quantum cryptography and potentially invest in countermeasures to reduce the immediate threat from "store now, decrypt later" threats. One of these countermeasures is to protect the distribution of keys, and here, quantum computing becomes our security ally. For example, in early 2022, researchers from JPMorgan Chase, Toshiba, and Ciena demonstrated the full viability of a Quantum Key Distribution (QKD) network, supporting 800 Gbps data rates—showing that under real-world environmental conditions, this network could enable secure communications and successfully defend against quantum computing-based attacks.[293]

As the positive feedback loop between science and technology accelerates, understanding both the risks and the opportunities ahead is critical. Companies are going to want to get involved in this compressed innovation, and soon. There's no longer time to sit back and wait, the big bang of computing and science is happening now.

The bottom line

Science tech needs to be on everyone's radar. Advances in next-generation computing, space technologies, and biotech will drive progress in materials and energy innovation, science in space for Earth, and synthetic biology in an incredibly exciting time for people, businesses, and the world.

Indeed, as challenges like pandemics and climate change are ever more present, it's time to invest in and fully unleash the promise of compressed innovation and accelerated science and technology cycles, as they evolve and revolve over time, driving each other forward into the future.

About the Technology Vision

For more than 20 years, Accenture has developed the Technology Vision report as a systematic review across the enterprise landscape to identify emerging technology trends that will have the greatest impact on companies, government agencies, and other organizations in the coming years. This year the trends look a decade into the future, while remaining relevant across industries and actionable for businesses today.

Accenture Labs and Accenture Research collaborate on the annual research process, which this year included:

- Input from the Technology Vision External Advisory Board, a group of more than two dozen experienced individuals from the public and private sectors, academia, venture capital, and entrepreneurial companies. In addition, the Technology Vision team conducts interviews with technology luminaries and industry experts, as well as many Accenture business leaders from across the organization.

- Accenture conducted a survey of 4,777 C-level executives and directors across 25 industries to understand their perspectives and use of emerging technologies across their organizations. The surveys were fielded from December 2022 through January 2023 across 34 countries.

- Experiential research and data science to analyze technology developments and advancements.

As a shortlist of themes emerges from the research process, the Technology Vision team works to validate and refine the set of trends. The themes are weighed for their relevance to real-world business challenges. The Technology Vision team seeks ideas that transcend the well-known drivers of technological change, concentrating instead on the themes that will soon start to appear on the C-level agendas of most enterprises.

Technology Vision 2023 Editorial & Research Team

Michael Biltz

Ari Bernstein

Julian Dreiman

Maria Fabbroni

Naomi Nishihara

Krista Schnell

David Strachan-Olson

Accenture Research

Renee Byrnes

Prashant Shukla

Gerry Farkova

Donovan Griggs

Ammar Mohammed

Abira Sathiyanathan

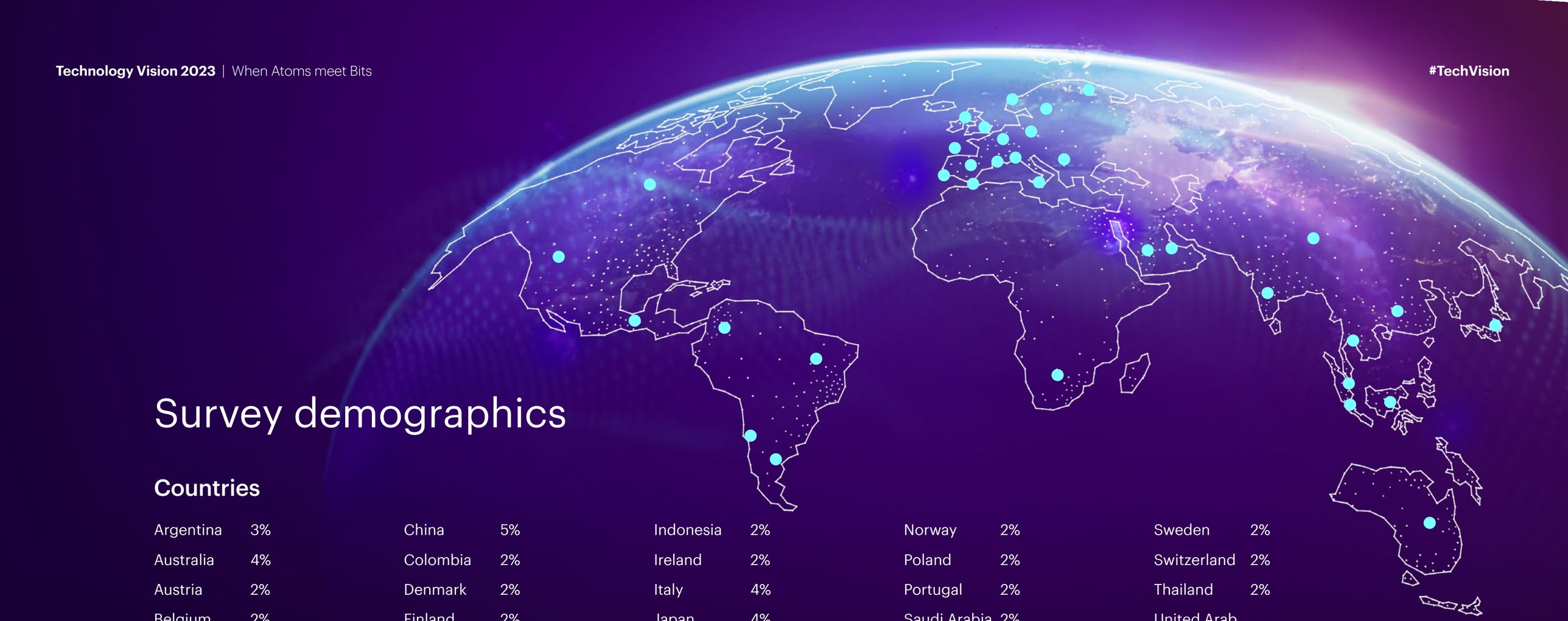
Vincenzo Palermo

Tal Roded

Mariusz Bidelski

Laura Converso

Selen Karaca-Griffin



Survey demographics

Countries

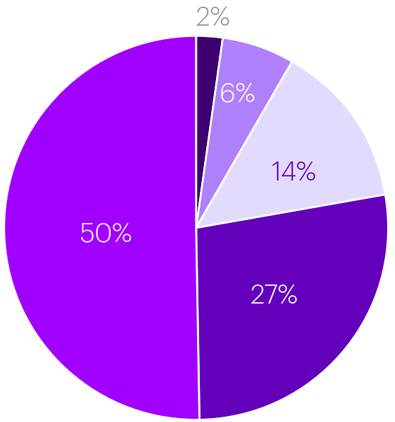
Argentina	3%
Australia	4%
Austria	2%
Belgium	2%
Brazil	4%
Canada	5%
Chile	2%
China	5%
Colombia	2%
Denmark	2%
Finland	2%
France	3%
Germany	4%
India	4%
Indonesia	2%
Ireland	2%
Italy	4%
Japan	4%
Malaysia	2%
Mexico	2%
Netherlands	2%
Norway	2%
Poland	2%
Portugal	2%
Saudi Arabia	2%
Singapore	2%
South Africa	3%
Spain	4%
Sweden	2%
Switzerland	2%
Thailand	2%
United Arab Emirates	2%
United Kingdom	4%
United States	16%

Industries

Aerospace and Defense	1%
Automotive	5%
Banking	6%
Biopharma	1%
Capital Markets	3%
Central Government (CA)	1%
Chemicals	5%
Communications	4%
Consumer Goods and Services	6%
Energy	4%
Federal Government (US)	4%
Healthcare Payor (US)	2%
Health Provider	6%
High Tech	4%
Higher Education (US)	4%
Industrial Goods and Equipment	6%
Insurance	6%
Media and Entertainment	2%
MedTech	1%
Natural Resources	4%
Public Service	6%
Retail	6%
Software and Platforms	4%
Travel	3%
Utilities	4%

Revenue (USD)

$50 billion or more	2%
$20 to $49.9 billion	6%
$10 to $19.9 billion	14%
$5 to $9.9 billion	27%
$1 to $4.9 billion	50%



Roles

Chief Digital Officer	1%
Chief Executive Officer	5%
Chief Finance Officer	10%
Chief Human Resources Officer	12%
Chief Information Officer	5%
Chief Information Security Officer	8%
Chief Innovation Officer	2%
Chief Marketing Officer	13%
Chief Operating Officer	9%
Chief Purchasing Officer	1%
Chief Risk Officer	2%
Chief Security Officer	4%
Chief Strategy Officer	4%
Chief Supply Chain Officer	2%
Chief Sustainability Officer	2%
Chief Technology Officer	4%
Chief Transformation Officer	1%
Director of Business Function	6%
Director of Technology	8%

References

Executive summary

1. Neurotwin. (n.d.): https://www.neurotwin.eu/
2. Consoritum. (n.d.) Neurotwin: https://www.neurotwin.eu/consortium
3. Browne, G. (2022, February 15). The Quest to Make a Digital Replica of Your Brain. Wired: https://www.wired.com/story/the-quest-to-make-a-digital-replica-of-your-brain/
4. Anheuser-Busch & EverGrain Celebrate Opening Of The First Major Site Of U.S. Operations. (2022, June 30). Anheuser-Busch: https://www.anheuser-busch.com/newsroom/2022/06/evergrain-opening/
5. Shoup, M. E. (2022, July 7). Anheuser-Busch & EverGrain Celebrate Opening Of The First Major Site Of U.S. Operations. FoodNavigator-USA: https://www.foodnavigator-usa.com/Article/2022/07/07/EverGrain-starts-commercial-production-of-upcycled-barley-protein
6. Meet the Airship Barley Milk Latte – the delicious, nutritious cold-brew coffee that almost wasn't. (2022, March 18). Evergrain: https://evergrainingredients.com/news/meet-the-airship-barley-milk-latte-the-delicious-nutritious-cold-brew-coffee-that-almost-wasnt/
7. Best, D. (2021, April 27). Post Holdings in snacks tie-up with A-B InBev-backed EverGrain. Just Food: https://www.just-food.com/news/post-holdings-in-snacks-tie-up-with-a-b-inbev-backed-evergrain/
8. Arthur, R. (2021, March 18). Corona Launches Six-pack Beer Packaging Made from Barley Straw. BeverageDaily https://www.beveragedaily.com/Article/2021/03/18/Corona-launches-beer-six-packs-made-from-barley-straw#
9. Forristal, L. (2022, August 18). Streaming viewership surpassed cable TV for the first time, says Nielsen. TechCrunch: https://techcrunch.com/2022/08/18/streaming-viewership-surpassed-cable-tv-for-the-first-time-says-nielsen/
10. Gill, V. (2022, October 14). E-waste: Five billion Phones to Be Thrown Away in 2022. BBC: https://www.bbc.com/news/science-environment-63245150
11. Lavi, H. (2022, April 21). Measuring Greenhouse Gas Emissions in Data Centres: The Environmental Impact of Cloud Computing. Climatiq: https://www.climatiq.io/blog/measure-greenhouse-gas-emissions-carbon-data-centres-cloud-computing
12. Walker, A. (2021, July 16). World's First 3D-printed Steel Smart Bridge Opens in Amsterdam. Infrastructure Intelligence: http://www.infrastructure-intelligence.com/article/jul-2021/world%E2%80%99s-first-3d-printed-steel-smart-bridge-opens-amsterdam
13. Hall, C. (2022, May 6). What is Google Maps AR Navigation and Live View and How Do You Use It? Pocket-lint: https://www.pocket-lint.com/apps/news/google/147956-what-is-google-maps-ar-navigation-and-how-do-you-use-it
14. Hutchinson, A. (2022, November 2). Snapchat Announces New Virtual Try-On AR Partnership with Amazon. Social Media Today: https://www.socialmediatoday.com/news/Snapchat-partners-with-Amazon-on-new-AR-Try-On-initiative/635643/
15. McDowell, M. (2022, April 28). Why Snapchat is Giving Away its AR Try-on Shopping Tools. Vogue Business: https://www.voguebusiness.com/technology/why-snapchat-is-giving-away-its-ar-try-on-shopping-tools
16. Introducing Whisper. (2022, September 21) OpenAI: https://openai.com/blog/whisper/
17. Collaborative Robots Market Size, Share & COVID-19 Impact Analysis, By Payload Capavity, By Application, By Industry, and Regional Forecast, 2021-2028. (2022, January). Fortune Business Insights: https://www.fortunebusinessinsights.com/industry-reports/collaborative-robots-market-101692
18. Moxi Case Study, Shannon Health. (n.d.) Dilligent Robotics: https://static1.squarespace.com/static/606f1bb0f7e05e3329035ff8/t/636adf13f00ad670c037d49d/1667948329711/ANCC+Magnet+Case+Study+-+Shannon.pdf
19. Walsh, B. (2022, August 3). Finally, an answer to the question: AI — What is it Good For? Vox: https://www.vox.com/future-perfect/2022/8/3/23288843/deepmind-alphafold-artificial-intelligence-biology-drugs-medicine-demis-hassabis
20. Lewis, T. (2022, October 31). One of the Biggest Problems in Biology Has Finally Been Solved. Scientific American: https://www.scientificamerican.com/article/one-of-the-biggest-problems-in-biology-has-finally-been-solved/
21. AlphaFold Reveals the Structure of the Protein Universe. (2022, July 28). DeepMind: https://www.deepmind.com/blog/alphafold-reveals-the-structure-of-the-protein-universe
22. Wenzl, T. (2022, July 2). Computational Chemistry Researchers Complete Millennia of Research in Four Years. University of New Mexico: https://news.unm.edu/news/releases-20220630
23. Kolodny, L. (2021, September 10). Solugen Raises $357 Million to Make Chemicals from Sugar, Not Petroleum. CNBC: https://www.cnbc.com/2021/09/09/solugen-raises-357-million-to-make-chemicals-and-plastic-from-plants.html
24. Nokia Radio Technology to Enable AST SpaceMobile's Direct-to-cell Phone Connectivity From Space (2022, July 28). Business Wire: https://www.businesswire.com/news/home/20220728005646/en/Nokia-Radio-Technology-to-Enable-AST-SpaceMobile%E2%80%99s-Direct-to-cell-Phone-Connectivity-From-Space
25. Williams, V. (2022, April 7). How Restaurants Are Managing Supply Chain Shortages and Inflation. DoorDash: https://get.doordash.com/en-us/blog/supply-chain-shortages
26. Maze, J. (2022, May 11). A Look Into the Impact of the Driver Shortage on Distributors. Restaurant Business: https://www.restaurantbusinessonline.com/financing/look-impact-driver-shortage-distributors
27. Global Supply Chains: An Ecosystem Under Threat. (n.d.) Trend Micro: https://www.trendmicro.com/explore/glrans/01589-tm1-en-ifg#page=1
28. Chinese factories close as drought hits hydropower (2022, August 17). Al Jazeera: https://www.aljazeera.com/economy/2022/8/17/chinese-factories-close-as-drought-hits-hydropower
29. Accelerating global companies toward net zero by 2050. (2022) Accenture: https://www.accenture.com/content/dam/accenture/final/capabilities/strategy-and-consulting/strategy/document/Accenture-Net-Zero-By-2050-Global-Report-2022.pdf

30. Fernandez, S. (2022, October 5). Fantastic Bioplastic. UC Santa Barbara: https://www.news.ucsb.edu/2022/020733/fantastic-bioplastic
31. Bioplastics Made of Bacteria Can Reduce Plastic Waste in Oceans. (2022, October 6). University of Rochester: https://www.rochester.edu/newscenter/bioplastics-reduce-plastic-waste-in-oceans-536322/
32. Dayan, I., Roth, H.R., et al. (2021, September 15). Federated learning for predicting clinical outcomes in patients with COVID-19. Nature Medicine: https://www.nature.com/articles/s41591-021-01506-3

Digital identity

33. Case Study #2: Offering Two-Factor Authentication. (n.d.) New America: https://www.newamerica.org/in-depth/getting-internet-companies-do-right-thing/case-study-2-offering-two-factor-authentication/
34. History of Iris Recognition. (n.d.) University of Cambridge: https://www.cl.cam.ac.uk/~jgd1000/history.html
35. Gallagher, S. (2017, December 29). How Hotmail Changed Microsoft and Email Forever. Ars Technica: https://arstechnica.com/information-technology/2017/12/how-hotmail-changed-microsoft-and-email-forever/
36. Van de Poll, M. (2020, February 17). The History of Digital Identity in Estonia. Cybernetica: https://cyber.ee/resources/news/the-history-of-digital-identity-in-estonia/
37. Facebook Expands its Social Platform across the Web Through General Availability of Facebook Connect. (2008, December 4). Meta: https://about.fb.com/news/2008/12/facebook-expands-its-social-platform-across-the-web-through-general-availability-of-facebook-connect/
38. Kobie, N. (2019, June 7). The Complicated Truth About China's Social Credit System. Wired: https://www.wired.co.uk/article/china-social-credit-system-explained
39. Strachan, M. (2022, July 14). MetaMask Co-Founders: 'We Can't Stop People From Making Ponzis on Blockchains' Vice: https://www.vice.com/en/article/v7vea9/metamask-co-founders-we-cant-stop-people-from-making-ponzis-on-blockchains
40. Aadhaar enrollment crosses 1 billion mark: Ravi Shankar Prasad (2016, April 4). Business Standard: https://www.business-standard.com/article/current-affairs/aadhaar-enrollment-crosses-1-billion-mark-ravi-shankar-prasad-116040400863_1.html
41. Aadhaar ID saving Indian govt about $1 billion per annum: World Bank (2016, January 14). Economic Times: https://economictimes.indiatimes.com/news/economy/finance/aadhaar-id-saving-indian-govt-about-1-billion-per-annum-world-bank/articleshow/50575112.cms?from=mdr
42. The History of the General Data Protection Regulation (n.d.) European Data Protection Supervisor: https://edps.europa.eu/data-protection/data-protection/legislation/history-general-data-protection-regulation_en
43. Steele, K. (2018, November 29). Delta unveils first biometric terminal in U.S. in Atlanta; next stop: Detroit. Delta Air Lines: https://news.delta.com/delta-unveils-first-biometric-terminal-us-atlanta-next-stop-detroit
44. Apple announces first states signed up to adopt driver's licenses and state IDs in Apple Wallet (2021, September 1). Apple: https://www.apple.com/newsroom/2021/09/apple-announces-first-states-to-adopt-drivers-licenses-and-state-ids-in-wallet/
45. Tait, D. (2022, July 1). Microsoft Going Big on Identity with the Launch of Entra. Dark Reading: https://www.darkreading.com/omdia/microsoft-going-gig-on-identity-with-the-launch-of-entra
46. Alspach, K. (2022, May 31). Microsoft Wants Everything to Come With its Verified Check Mark. Protocol: https://www.protocol.com/bulletins/microsoft-verified-id-digital-privacy
47. Microsoft Entra Verified ID. (n.d.) https://www.microsoft.com/en-us/security/business/identity-access/microsoft-entra-verified-id
48. Early Warning Services, Big Banks Launch ID Service Authentify (2022, April 5). PYMNTS: https://www.pymnts.com/identity/2022/early-warning-services-big-banks-launch-id-service-authentify/
49. Peterson, M. (2022, May 25). Digital ID feature in Apple Wallet has expanded to Maryland. Apple Insider: https://appleinsider.com/articles/22/05/25/digital-id-feature-in-apple-wallet-has-expanded-to-maryland
50. Burt, C. (2022, September 27). Gates Foundation commits $200M to digital ID and other public infrastructure. Biometric Update: https://www.biometricupdate.com/202209/gates-foundation-commits-200m-to-digital-id-and-other-public-infrastructure
51. Digital Identity Solutions Market by Offering (Solutions and Services), Solution Type (Identity Verification, Authentication), Identity Type (Biometric and Non-Biometric), Deployment Mode, Organization Size, Vertical and Region - Global Forecast to 2027. (2022, September). Research and Markets: https://www.researchandmarkets.com/reports/5393866/digital-identity-solutions-market-by-offering
52. b.well Overview. (n.d.) Pitchbook: https://pitchbook.com/profiles/company/121691-08#overview
53. Landi, H. (2021, April 2). Mastercard Makes Healthcare Move with Digital ID Solution Patients Can Use on their Smartphones. Fierce Healthcare: https://www.fiercehealthcare.com/tech/mastercard-makes-healthcare-move-digital-id-solution-patients-can-use-their-smartphones
54. How ThedaCare powers population health with b.well's digital front end and Mastercard ID Verification service. (n.d.) Mastercard: https://www.mastercard.us/en-us/business/large-enterprise/healthcare-solutions/security-solutions/bwell-thedacare-case-study.html
55. Sonnenenergie für alle: Wien Energie Startet Neues BürgerInnen-Solarkraftwerk. (2021, June 6). Wien Energie: https://www.wienenergie.at/pressrelease/sonnenenergie-fuer-alle-wien-energie-startet-neues-buergerinnen-solarkraftwerk/
56. Sustainable Development Goals. (n.d) UN: https://unstats.un.org/sdgs/metadata/?Text=&Goal=16&Target=16.9
57. Kotkas, K. (2022, February 25). Following in Estonia's Footsteps: Blueprints for a Successful Digital ID. Security Magazine: https://www.securitymagazine.com/articles/97159-following-in-estonias-footsteps-blueprints-for-a-successful-digital-id
58. Aadhaar key ID layer for India-first innovations: UIDAI CEO Saurabh Garg. (2022, July 8). Economic Times: https://economictimes.indiatimes.com/tech/technology/aadhaar-key-id-layer-for-india-first-innovations-uidai-ceo-saurabh-garg/articleshow/92732142.cms

59. Weiss, E. (2022, July 19). India Unveils New Face-Based Aadhaar Authentication App. Find Biometrics: https://findbiometrics.com/india-unveils-new-face-based-aadhaar-authentication-app-071901/
60. AePS Product Overview. (n.d.) National Payments Corporation of India: https://www.npci.org.in/what-we-do/aeps/product-overview
61. Saini, S and Hussain, S. (2021, October 1). Leveraging India's Aadhaar platform to ease COVID-19 pain. East Asia Forum: https://www.eastasiaforum.org/2021/10/01/leveraging-indias-aadhaar-platform-to-ease-covid-19-pain/
62. Sharwood, S. (2022, February 9). Sri Lanka to Adopt India's Aadhaar Digital Identity Scheme. The Register: https://www.theregister.com/2022/02/09/sri_lanka_to_adopt_indias/
63. Hurd, D. (2022, December 12). A 'Trojan Horse' for Tyranny: Brussels Rolling Out a New 'Digital Identity' System for EU Citizens. CBN News: https://www1.cbn.com/cbnnews/world/2022/may/is-the-eu-undergoing-a-chinafication-brussels-will-be-rolling-out-a-new-digital-identity-nbsp
64. Tung, L. (2022, February 9). FBI Warns: SIM-swapping Attacks Are Rocketing, Don't Brag About Your Crypto Online. ZDNET: https://www.zdnet.com/finance/blockchain/fbi-warns-sim-swapping-attacks-are-rocketing-dont-brag-about-your-crypto-online/
65. Forgotten Passwords are Increasing Your Website's Abandonment Rate. (2021, May 6). iProov: https://www.iproov.com/blog/forgotten-passwords-increasing-websites-abandonment-rate
66. The Impact of Invalid Traffic on Marketing. (2022, May). Cheq: https://cheq.ai/wp-content/uploads/2022/05/The-Impact-of-Invalid-Traffic-on-Marketing-2.pdf
67. Digital Ad Fraud Costs Will Rise to $35B Globally This Year. (2020, October 28). University of Baltimore: http://www.ubalt.edu/news/news-releases.cfm?id=3621
68. MOSIP, Open-Source National ID System, Gains Momentum in Africa and Asia. (2020, December 20). Identity Review: https://identityreview.com/mosip-open-source-national-id-system-gains-momentum-in-africa-and-asia
69. Burt, C. (2022, September 6). MOSIP's Growth Examined as Asian Digital Identity Schemes Expand in Reach, Applications. Biometric Update: https://www.biometricupdate.com/202209/mosips-growth-examined-as-asian-digital-identity-schemes-expand-in-reach-applications
70. Vescent, H. (2022, July 5). Decentralized Identifiers 1.0 are Now a W3C Standard. Biometric Update: https://www.biometricupdate.com/202207/decentralized-identifiers-1-0-are-now-a-w3c-standard
71. Linux Foundation Announces an Intent to Form the OpenWallet Foundation. (2022, September 13). The Linux Foundation. https://www.linuxfoundation.org/press/linux-foundation-announces-an-intent-to-form-the-openwallet-foundation
72. Harper, C. (2021, March 5). Microsoft's ION Digital ID Network Is Live on Bitcoin. Coindesk: https://www.coindesk.com/markets/2021/03/25/microsofts-ion-digital-id-network-is-live-on-bitcoin/
73. Overview of Web3 Wallets. (n.d.) Alchemy. https://www.alchemy.com/web3-wallets-overview
74. HyperledgerIdentity Round-up: A Cross Section of Production Digital Identity Solutions Built Using Hyperledger Technologies. (2022, September 28). Hyperledger: https://www.hyperledger.org/blog/2022/09/28/hyperledgeridentity-round-up-a-cross-section-of-production-digital-identity-solutions-built-using-hyperledger-technologies
75. BC aims to cut government red tape with Hyperledger Indy. (n.d.) Hyperledger: https://www.hyperledger.org/learn/publications/orgbook-case-study
76. Starbucks Brewing Revolutionary Web3 Experience for its Starbucks Rewards Members. (2022, September 12). Starbucks: https://stories.starbucks.com/press/2022/starbucks-brewing-revolutionary-web3-experience-for-its-starbucks-rewards-members/
77. Starbucks: We're creating the digital Third Place. (2022, May 3). Starbucks: https://stories.starbucks.com/stories/2022/starbucks-creating-the-digital-third-place/
78. Permission.io to Launch Industry-First Demand Side Platform (DSP) Offering Crypto Rewards. (2021, October 11). Permission.io: https://www.prnewswire.com/news-releases/permissionio-to-launch-industry-first-demand-side-platform-dsp-offering-crypto-rewards-301396159.html
79. Permission.io: Redeem. (n.d.): https://redeem.permission.io/?_ga=2.245706951.257697819.1666984884-1674603746.1666843526
80. SAP, Unilever Pilot Blockchain Technology Supporting Deforestation-free Palm Oil. (2022, March 21). Unilever: https://www.unilever.com/news/press-and-media/press-releases/2022/sap-unilever-pilot-blockchain-technology-supporting-deforestationfree-palm-oil/
81. del Castillo, M., Schifrin, M., et al. (2022, February 8). The Blockchain 50 2022. Forbers: https://www.forbes.com/sites/michaeldelcastillo/2022/02/08/forbes-blockchain-50-2022/?sh=526ecf2d31c6
82. Goldman's Interest in NFTs Could Speed the Tokenization of Real Assets. (2022, April 28). PYMNTS: https://www.pymnts.com/nfts/2022/goldman-sachs-interest-could-speed-tokenization-real-assets-nfts/
83. Gartenberg, C. (2021, April 27). Why Apple's New Privacy Feature is Such a Big Deal. The Verge: https://www.theverge.com/2021/4/27/22405474/apple-app-tracking-transparency-ios-14-5-privacy-update-facebook-data
84. Lukovitz, K. (2022, May 5). Privacy Update: ATT IDFA Opt-In Rate At 25% Overall, But Varies By Vertical. Media Post: https://www.mediapost.com/publications/article/373613/privacy-update-att-idfa-opt-in-rate-at-25-overal.html
85. Burgess, M. (2022, January 27). Google Has a New Plan to Kill Cookies. People Are Still Mad. Wired: https://www.wired.com/story/google-floc-cookies-chrome-topics/
86. Titone, T. (2022, January 31). Topics API - The Google FLoC replacement explained. Ad Tech Explained: https://adtechexplained.com/google-topics-api-explained/
87. Nguyen, G. (2022, January 25). Google Kills FLoC, Introduces Topics API as its Next-gen Targeting Tech. Search Engine Land: https://searchengineland.com/google-kills-floc-introduces-topics-api-379120

88. Garner Researchers. (2022, May 31). Gartner Identifies Top Five Trends in Privacy Through 2024. Gartner: https://www.gartner.com/en/newsroom/press-releases/2022-05-31-gartner-identifies-top-five-trends-in-privacy-through-2024
89. Preparing for a World Without Third-party Cookies. (2020, October). Epsilon: https://www.epsilon.com/hubfs/3PC_Deprecation_Research_Exec_Summary_23Oct2020.pdf?hsCtaTracking=6eda0e9d-6c8d-4c52-922f-1e396ac75978%7C8c887de0-50d4-40c9-9ebe-93d1c26e8d29
90. Uzialko, A. (2023, January 23). How GDPR Is Impacting Business and What to Expect in 2023. Business News Daily: https://www.businessnewsdaily.com/15510-gdpr-in-review-data-privacy.html
91. GDPR Enforcement Tracker (n.d.): https://www.enforcementtracker.com/
92. Digital identity in Web3. (n.d.) J.P. Morgan: https://www.jpmorgan.com/onyx/content-hub/digital-identity-in-web3.htm
93. Fadilpašić, S. (2022, October 27). JPMorgan Exploring Digital Identity Wallets in Web3. Crypto News https://cryptonews.com/news/jpmorgan-exploring-digital-identity-wallets-web3.htm

Your data, my data, our data

94. Maldarelli, C. (2021, April 26). Why 10,000 steps a day isn't the secret to better health. Popular Science: https://www.popsci.com/story/health/10000-steps-evidence-study/
95. Kelley Blue Book Celebrates 80 Years of Trust. (n.d.). Kelley Blue Book: https://mediaroom.kbb.com/press-releases?item=105784
96. Coleman, J. (2022, July 22). Landsat Legacy: NASA-USGS Program Observing Earth from Space Turns 50. NASA: https://www.nasa.gov/feature/goddard/2022/landsat-legacy-nasa-usgs-program-observing-earth-from-space-turns-50
97. Canavan, H. (2014, August 5). Yelp Turns 10: From Startup to Online Review Dominance. Eater.com: https://www.eater.com/2014/8/5/6177213/yelp-turns-10-from-startup-to-online-review-dominance
98. Press, G. (2013, May 9). A Very Short History Of Big Data. Forbes: https://www.forbes.com/sites/gilpress/2013/05/09/a-very-short-history-of-big-data/?sh=1743b36665a1
99. Glassdoor.com launches public beta, opening doors to employee salaries, bonuses, reviews and ratings at any company for free. (2008, June 11). Glassdoor: https://www.glassdoor.com/about-us/glassdoorcom-launches-public-beta-opening-doors-employee-salaries-bonuses-reviews-ratings-company-free/
100. Armstrong, M. (2019, April 16). Global Data Creation is About to Explode. Statista: https://www.statista.com/chart/17727/global-data-creation-forecasts/
101. Open Government. (n.d.). Data.gov: https://data.gov/open-gov/
102. Dehghani, Z. (2019, May 20). How to Move Beyond a Monolithic Data Lake to a Distributed Data Mesh. MartinFowler.com: https://martinfowler.com/articles/data-monolith-to-mesh.html
103. La Monica, P. (2020, September 17). Snowflake shares more than double. It's the biggest software IPO ever. CNN Business: https://www.cnn.com/2020/09/16/investing/snowflake-ipo/index.html
104. Taylor, P. (2022, September 8). Amount of data created, consumed, and stored 2010-2020, with forecasts to 2025. Statista: https://www.statista.com/statistics/871513/worldwide-data-created/
105. Clark, S. (2022, July 6). World's rockets on pace for record year of launch activity. Spaceflight Now: https://spaceflightnow.com/2022/07/06/worlds-rockets-on-pace-for-record-year-of-launch-activity/
106. More than 680 financial institutions with US$130+ trillion in assets call on nearly 10,400 companies to disclose environmental data through CDP. (2022, March 14). CDP: https://www.cdp.net/en/articles/media/More-than-680-financial-institutions-call-on-nearly-10400-companies-to-disclose-environmental-data-through-CDP
107. Board Diversity Matrix Disclosure Requirments and Examples. (2023, January 26). Nasdaq: https://listingcenter.nasdaq.com/assets/Board Matrix Examples_Website.pdf
108. Canavan, H. Yelp Turns 10.
109. Luca, M. (2016). Reviews, Reputation, and Revenue: The Case of Yelp.com. Harvard Business School: https://www.hbs.edu/ris/Publication%20Files/12-016_a7e4a5a2-03f9-490d-b093-8f951238dba2.pdf
110. Anderson, M., and Magruder, J. (2013). Does Yelp Affect Restaurant Demand? Agricultural and Resource Economics: https://s.giannini.ucop.edu/uploads/giannini_public/9e/fe/9efe6100-005c-4b7c-aaa8-678a96a883cb/v16n5_1.pdf
111. Infinite horizons. (n.d.). Cirium.com: https://www.cirium.com/about/
112. Cirium. (2019, May 21). Cirium: A Smarter Way to Travel. YouTube.com: https://www.youtube.com/watch?v=wtRZrJijNNM
113. Cirium integrates the most accurate CO_2 emissions and flight tracking data with its unrivalled fleets database. (2022, October 18). Cirium.com: https://www.cirium.com/thoughtcloud/cirium-integrates-most-accurate-co2-emissions-and-flight-tracking-data-with-fleets-database/
114. Container Rates Alert: Calm before storm, as long-term ocean freight rates hold steady ahead of expected New Year pain. (2022, December 22). Xeneta.com: https://www.xeneta.com/news/calm-before-storm-as-long-term-ocean-freight-rates-hold-steady-ahead-of-expected-new-year-pain
115. ABF Uses Xeneta to Negotiate a 30% Decrease in Ocean Rates and Provide Category Leadership in Logistics Procurement. (n.d.). Xeneta.com: https://www.xeneta.com/abf-customer-case-study
116. Consumer demand for food transparency remains strong as omnichannel rises. (2022, January 25). NielsenIQ: https://nielseniq.com/global/en/news-center/2022/consumer-demand-for-food-transparency-remains-strong-as-omnichannel-rises/
117. Adams, H. (2021, December 13). Report shows shoppers want transparency in the supply chain. SupplyChain: https://supplychaindigital.com/sustainability/report-shows-shoppers-want-transparency-supply-chain
118. Armstrong, M. Global Data Creation is About to Explode.
119. Taylor, P. Amount of data created, consumed, and stored.
120. Hasan, M. (2022, May 18). State of IoT 2022: Number of connected IoT devices growing 18% to 14.4 billion globally. IoT Analytics: https://iot-analytics.com/number-connected-iot-devices/

121. Buonfantino, G. (2022, April 27). New research shows consumers more interested in brands' values than ever. Google Cloud Blog: https://cloud.google.com/blog/topics/consumer-packaged-goods/data-shows-shoppers-prioritizing-sustainability-and-values
122. Trust Has To Be Earned. (n.d.). IceBug: https://www.icebugitalia.it/en/segui-le-impronte
123. McGee, B. (2022, May 25). Icebug promotes sustainabile lifestyle as annual sales, profits rise. Outdoor Industry Compass: https://www.oicompass.com/financial-results/icebug-promotes-sustainable-lifestyle-as-annual-sales-profits-rise/96541.article
124. Tameez, H. (2022, November 30). The Washington Post launches a year in news a la Spotify Wrapped. NiemanLab: https://www.niemanlab.org/2022/11/the-washington-post-launches-a-year-in-news-a-la-spotify-wrapped/
125. Perez, S. (2013, January 8). Target Now Price Matching Amazon, Walmart.com, BestBuy.com & Toysrus.com Year-Round. TechCrunch: https://techcrunch.com/2013/01/08/target-now-price-matching-amazon-walmart-com-bestbuy-com-toyrus-com-year-round/
126. Kemp, S. (2022, October 20). Digital 2022: October Global Statshot Report. Datareportal.com: https://datareportal.com/reports/digital-2022-october-global-statshot
127. What's new in Apple Watch and watchOS 9. (n.d.). Apple Watch User Guide: https://support.apple.com/guide/watch/whats-new-apdb93ea3872/watchos
128. Nano-sensor detects pesticides on fruit in minutes. (2022, June 7). Science Daily: https://www.sciencedaily.com/releases/2022/06/220607121014.htm
129. Bild, N. (2022, July 26). Don't Be a Drip: A TinyML-Based Solution for Acoustic Pipe Leak Detecton. Edge Impulse: https://www.edgeimpulse.com/blog/dont-be-a-drip-a-tinyml-based-solution-for-acoustic-pipe-leak-detection
130. McQuate, S. (2022, March 16). Tiny battery-free devices float in the wind like dandelion seeds. UW News: https://www.washington.edu/news/2022/03/16/battery-free-devices-float-in-wind-like-dandelion-seeds/
131. Climate Trace: Independent Greenhouse Gas Emissions Tracking. (n.d.). ClimateTrace.org: https://www.climatetrace.org/about
132. WorldView-3 Satellite Sensor (30cm). (n.d.). Satellite Imaging Corporation: https://www.satimagingcorp.com/satellite-sensors/worldview-3/
133. Real-Time Satellite Monitoring with Planet. (n.d.). Planet.com: https://www.planet.com/products/monitoring/
134. Ziliani, M., Altaf, M., et al. (2022, February 15). Early season prediction of within-field crop yield variability by assimilating CubeSat data into a crop model. ScienceDirect: https://www.sciencedirect.com/science/article/pii/S0168192321004226?via%3Dihub
135. Ferreira, T. (2022, August 8). Planet Data Helps Advance The Promise Of Digital Agriculture And Enables Novel Water Dynamics Research. Planet.com: https://www.planet.com/pulse/planet-data-helps-advance-the-promise-of-digital-agriculture-and-enables-novel-water-dynamics-research/
136. Wooden, A. (2022, September 21). T-Mobile is providing the 5G goods to a new AI wildfire detection system. Telecoms.com: https://telecoms.com/517551/t-mobile-is-providing-the-5g-goods-to-a-new-ai-wildfire-detection-system/
137. T-Mobile Takes Coverage Above and Beyond With SpaceX. (2022, August 25). T-Mobile.com: https://www.t-mobile.com/news/un-carrier/t-mobile-takes-coverage-above-and-beyond-with-spacex
138. A commissioned study conducted by Forrester Consulting on behalf of Amperity. (2022, June). Evolve Your Data Practices To Stay Ahead Of The Competition. Forrester: https://assets.ctfassets.net/5vqt5w81x2im/1HOANJ4cyvHPd1w5WRSf5f/b95f310d796029d7619789c5a2b28dab/Data_Practices_Opportunity_Snapshot-Forrester.pdf
139. Cole, A. (2021, November 24). AI will soon oversee its own data management. VentureBeat: https://venturebeat.com/ai/ai-will-soon-oversee-its-own-data-management/
140. Build a Scalable Content Moderation Strategy using AI Automation. (n.d.). Clarifai.com: https://www.clarifai.com/customers/opentable
141. Case Study: NASA. (n.d.). Stardog.com: https://www.stardog.com/company/customers/nasa/
142. Data Culture is a team sport for the Seattle Seahawks – and their fans win every time. (n.d.). Tableau.com: https://www.tableau.com/solutions/customer/data-culture-team-sport-seattle-seahawks-and-their-fans-win-every-time
143. The State of Data Science 2020: Moving from hype toward maturity. (2020). Anaconda: https://www.anaconda.com/state-of-data-science-2020
144. Sallam, R., Friedman, T., et al. (2022, March 11). Top Trends in Data and Analytics, 2022. Gartner: https://www.gartner.com/document/4012385?ref=solrAll&refval=351999153
145. Dehghani, Z. How to Move Beyond a Monolithic Data Lake.
146. Bentley Systems Launches iTwin Experience, iTwin Capture, and iTwin IoT to Extend iTwin Platform. (2022, November 15). Bentley: Advancing Infrastructure: https://www.bentley.com/wp-content/uploads/bsy-11152022-itwin-experience-itwin-capture-itwin-iot-launch.pdf
147. Bock, E. (2023, January). Compliance Monitoring Methodology. Measurabl.com: https://support.measurabl.com/hc/en-us/articles/4831627362701-Compliance-Monitoring-Methodology
148. Product Spotlight: Compliance Monitoring. (2022, March 17). Measurabl.com: https://www.measurabl.com/resources/product-spotlight-compliance-monitoring/
149. Fried, I. (2022, December 21). Axios Login. Axios.com: https://www.axios.com/newsletters/axios-login-5f2df8f4-b28d-45a4-abf8-e89815ec4b35.html
150. Tameez, H. The Washington Post launches a year in news.
151. 2022 Year in Sport. (2022). Strava.com: https://www.strava.com/yis-community-2022
152. We work around the clock to safeguard our platform and combat fake reviews. (n.d.). Trustpilot.com: https://www.trustpilot.com/trust/combating-fake-reviews
153. Reviews in the right place at the right time. (n.d.). Trustpilot.com: https://business.trustpilot.com/features/trustbox-widgets
154. Alamalhodaei, A. (2021, October 12). Steve Wozniak and Alex Fielding's startup Privateer aims to be the Google Maps of space. TechCrunch: https://techcrunch.com/2021/10/12/steve-wozniak-privateer-space-company/

Generalizing AI

155. Veisdal, J. (2019, September 12). The Birthplace of AI. Cantor's Paradise: https://www.cantorsparadise.com/the-birthplace-of-ai-9ab7d4e5fb00
156. Geoffrey Hinton: a look at the prolific career of AI and deep learning pioneer behind backpropagation, unsupervised learning. (2022, May 19). Ai.nl: https://www.ai.nl/artificial-intelligence/geoffrey-hinton-a-look-at-the-prolific-career-of-ai-and-deep-learning-pioneer-behind-backpropagation-unsupervised-learning/
157. Krizhevsky, A., Sutskever, I., et al. (2012). ImageNet Classification with Deep Convolutional Neural Networks. NIPS 2012: https://papers.nips.cc/paper/2012/hash/c399862d3b9d6b76c8436e924a68c45b-Abstract.html
158. Olanoff, D. (2015, December 11). Artificial Intelligence Nonprofit OpenAI Launches With Backing From Elon Musk and Sam Altman. TechCrunch: https://techcrunch.com/2015/12/11/non-profit-openai-launches-with-backing-from-elon-musk-and-sam-altman/
159. AlphaGo: The Challenge Match. (n.d.). Deepmind.com: https://www.deepmind.com/research/highlighted-research/alphago/the-challenge-match
160. Vaswani, A., Shazeer, N., et al. (2017, June 12). Attention Is All You Need. arXiv: https://arxiv.org/abs/1706.03762
161. Johnson, K. (2019, September 26). Hugging Face launches popular Transformers NLP library for TensorFlow. VentureBeat: https://venturebeat.com/business/hugging-face-launches-popular-transformers-nlp-library-for-tensorflow/
162. The Artificial Intelligence Act. (n.d.): https://artificialintelligenceact.eu/
163. Brown, T., Mann, B., et al. (2020, May 28). Language Models are Few-Shot Learners. arXiv: https://arxiv.org/abs/2005.14165
164. On the Opportunities and Risks of Foundation Models. (2021, August 16). Stanford University: https://fsi.stanford.edu/publication/opportunities-and-risks-foundation-models
165. Zhavoronkov, A. (2021, July 19). Wu Dao 2.0 – Bigger, Stronger, Faster AI from China. Forbes: https://www.forbes.com/sites/alexzhavoronkov/2021/07/19/wu-dao-20bigger-stronger-faster-ai-from-china/?sh=35dcf4e26fb2
166. Gault, M. (2022, August 31). An AI-Generated Artwork Won First Place at a State Fair Fine Arts Competition, and Artists Are Pissed. Vice: https://www.vice.com/en/article/bvmvqm/an-ai-generated-artwork-won-first-place-at-a-state-fair-fine-arts-competition-and-artists-are-pissed
167. A Generalist Agent. (2022, November 10). Deepmind.com: https://www.deepmind.com/publications/a-generalist-agent
168. ChatGPT: Optimizing Language Models for Dialogue. (2022, November 30). OpenAI: https://openai.com/blog/chatgpt/
169. Roose, K. (2022, December 5). The Brilliance and Weirdness of ChatGPT. The New York Times: https://www.nytimes.com/2022/12/05/technology/chatgpt-ai-twitter.html
170. Kreitman, A. (2022, December 13). Why My Writing Career Is Just About Over. The Marketing Advocate: https://medium.com/the-marketing-advocate/why-my-writing-career-is-just-about-over-deece661eaa2
171. GPT-4 is OpenAI's most advanced system, producing safer and more useful responses. (n.d.). OpenAI: https://openai.com/product/gpt-4
172. Wiggers, K. (2023, March 14). OpenAI releases GPT-4, a multimodal AI that it claims is state-of-the-art. TechCrunch: https://techcrunch.com/2023/03/14/openai-releases-gpt-4-ai-that-it-claims-is-state-of-the-art/
173. Vaswani, A., Shazeer, N., et al. Attention Is All You Need.
174. Ho, V. (2022, May 24). Build: Azure OpenAI Service helps customers accelerate innovation with large AI models; Microsoft expands availability. Microsoft: https://blogs.microsoft.com/ai/azure-openai-service-helps-customers-accelerate-innovation-with-large-ai-models-microsoft-expands-availability/
175. Dai, A., and Du, N. (2021, December 9). More Efficient In-Context Learning with GLaM. Google Research: https://ai.googleblog.com/2021/12/more-efficient-in-context-learning-with.html
176. Alvi, A., and Kharya, P. (2021, October 11). Using DeepSpeed and Megatron to Train Megatron-Turing NLG 530B, the World's Largest and Most Powerful Generative Language Model. Microsoft Research Blog: https://www.microsoft.com/en-us/research/blog/using-deepspeed-and-megatron-to-train-megatron-turing-nlg-530b-the-worlds-largest-and-most-powerful-generative-language-model/
177. Alford, A. (2022, June 7). Meta Open-Sources 175 Billion Parameter AI Language Model OPT. InfoQ: https://www.infoq.com/news/2022/06/meta-opt-175b/
178. Introducing PCL-BAIDU Wenxin (ERNIE 3.0 Titan), the World's First Knowledge Enhanced Multi-Hundred-Billion Model. (2021, December 28). Baidu Research: http://research.baidu.com/Blog/index-view?id=165
179. Liang, J. (2022, May 1). Foundation Models and the Future of Multi-Modal AI. Last Week in AI: https://lastweekin.ai/p/multi-modal-ai
180. On the Opportunities and Risks of Foundation Models.
181. A Generalist Agent.
182. Heikkilä, M. (2022, May 23). The hype around DeepMind's new AI model misses what's actually cool about it. MIT Technology Review: https://www.technologyreview.com/2022/05/23/1052627/deepmind-gato-ai-model-hype/
183. Merritt, R. (2022, March 25). What is a Transformer Model? NVIDIA: https://blogs.nvidia.com/blog/2022/03/25/what-is-a-transformer-model/
184. Huge "foundation models" are turbo-charging AI progress. (2022, June 11). The Economist: https://www.economist.com/interactive/briefing/2022/06/11/huge-foundation-models-are-turbo-charging-ai-progress
185. Heaven, W. (2021, December 21). 2021 was the year of monster AI models. MIT Technology Review: https://www.technologyreview.com/2021/12/21/1042835/2021-was-the-year-of-monster-ai-models/
186. Alayrac, J., Donahue, J. et al. (2022, April 29). Flamingo: a Visual Language Model for Few-Shot Learning. arXiv: https://arxiv.org/abs/2204.14198
187. Announcing the 2022 AI Index Report. (2022). Stanford University Human-Centered Artificial Intelligence: https://hai.stanford.edu/research/ai-index-2022

188. The state of generative AI in 7 charts. (2023, January 25). CB Insights: https://www.cbinsights.com/research/generative-ai-funding-top-startups-investors/
189. Microsoft and OpenAI extend partnership. (2023, January 23). Microsoft Corporate Blogs: https://blogs.microsoft.com/blog/2023/01/23/microsoftandopenaiextendpartnership/
190. Daws, R. (2022, November 2). Meta's protein-folding AI reminds us it's not just a metaverse firm. AI News: https://www.artificialintelligence-news.com/2022/11/02/meta-protein-folding-ai-not-just-metaverse-firm/
191. IITM & UT Austin's Generalizable NeRF Transformer Demonstrates Transformers' Capabilities for Graphical Rendering. (2022, August 3). Synced: https://syncedreview.com/2022/08/03/iitm-ut-austins-generalizable-nerf-transformer-demonstrates-transformers-capabilities-for-graphical-rendering/
192. T, M., Wang, P., et al. (2022). Is Attention All NeRF Needs? arXiv: https://vita-group.github.io/GNT/
193. Yuan, L., Chen, D., et al. (2021, November). Florence: A New Foundation Model for Computer Vision. Microsoft: https://www.microsoft.com/en-us/research/publication/florence-a-new-foundation-model-for-computer-vision/
194. Sevilla, J., Heim, L., et al. (2022, March 9). Compute Trends Across Three Eras of Machine Learning. arXiv: https://arxiv.org/abs/2202.05924
195. AI and Compute. (2018, May 16). OpenAI: https://openai.com/blog/ai-and-compute/
196. Loten, A. (2022, August 23). AI Startup Anyscale Adds $99 Million to Andreessen Horowitz-Led Funding Round. The Wall Street Journal: https://www.wsj.com/articles/ai-startup-anyscale-adds-99-million-to-andressen-horowitz-led-funding-round-11661254200
197. Lynley, M. (2022, December 31). ChatGPT got all the buzz, but beneath it is a $1B developer framework that's quietly fueling the new era of lifelike AI and OpenAI and beyond. Business Insider: https://www.businessinsider.com/openai-chatgpt-trained-on-anyscale-ray-generative-lifelike-ai-models-2022-12
198. Zhang, Z., Stoica, I., et al. (2022, October 19). Four Reasons Why Leading Companies Are Betting On Ray. Anyscale.com: https://www.anyscale.com/blog/four-reasons-why-leading-companies-are-betting-on-ray
199. Chu, L., Reiss, F., et al. (2022, August 23). IBM Research unveils two key advances for foundation models. IBM Research: https://research.ibm.com/blog/ray-summit-codeflare-foundation-models
200. Metz, C. (2022, December 26). A New Chat Bot Is a 'Code Red' for Google's Search Business. The New York Times: https://www.nytimes.com/2022/12/21/technology/ai-chatgpt-google-search.html
201. Roose, K. The Brilliance and Weirdness of ChatGPT.
202. Microsoft Developer. (2022, May 27). The Future of AI Development Tools. YouTube.com: https://www.youtube.com/watch?v=GVf7A_sr3cM
203. Takahashi, D. (2022, September 23). The DeanBeat: Nvidia CEO Jensen Huang says AI will autopopulate the 3D imagery of the metaverse. VentureBeat: https://venturebeat.com/games/the-deanbeat-nvidia-ceo-jensen-huang-says-ai-will-auto-populate-the-3d-imagery-of-the-metaverse/
204. Tabachnyk, M., and Nikolov, S. (2022, September 6). ML-Enhanced Code Completion Improves Developer Productivity. Google Research: https://ai.googleblog.com/2022/07/ml-enhanced-code-completion-improves.html
205. Murphy, M. (2022, May 9). What are foundation models? IBM Research: https://research.ibm.com/blog/what-are-foundation-models
206. Wiggers, K. (2023, March 14). OpenAI releases GPT-4, a multimodal AI that it claims is state-of-the-art. TechCrunch: https://techcrunch.com/2023/03/14/openai-releases-gpt-4-ai-that-it-claims-is-state-of-the-art/
207. Fitzpatrick, C. (2021, January 7). Meet the Winners of the Hateful Memes Challenge. Driven Data Labs: https://drivendata.co/blog/hateful-memes-winners
208. Maaten, L., Misra, I., et al. (2022, March 16). Advances in multimodal understanding research at Meta AI. Meta AI: https://ai.facebook.com/blog/advances-in-multimodal-understanding-research-at-meta-ai/
209. Coldeway, D. (2019, March 11). OpenAI shifts from nonprofit to 'capped-profit' to attract capital. TechCrunch: https://techcrunch.com/2019/03/11/openai-shifts-from-nonprofit-to-capped-profit-to-attract-capital/
210. Wiggers, K. (2021, November 2). GPT-3 comes to the enterprise with Microsoft's Azure OpenAI Service. VentureBeat: https://venturebeat.com/ai/gpt-3-comes-to-the-enterprise-with-microsofts-azure-openai-service/
211. Pilipiszyn, A. (2021, March 25). GPT-3 Powers the Next Generation of Apps. OpenAI: https://openai.com/blog/gpt-3-apps/
212. Build next-gen apps with OpenAI's powerful models. (n.d.). OpenAI: https://openai.com/api/
213. Sinha, D. (2022, April 15). Top 10 GPT-3 Powered Applications to Know in 2022. Analytics Insight: https://www.analyticsinsight.net/top-10-gpt-3-powered-applications-to-know-in-2022/
214. Cai, K. (n.d.). The $2 Billion Emoji: Hugging Face Wants To Be Launchpad For A Machine Learning Revolution. Forbes: https://www.forbes.com/sites/kenrickcai/2022/05/09/the-2-billion-emoji-hugging-face-wants-to-be-launchpad-for-a-machine-learning-revolution/
215. Langston, J. (2021, November 2). New Azure OpenAI Service combines access to powerful GPT-3 language models with Azure's enterprise capabilities. Microsoft: https://blogs.microsoft.com/ai/new-azure-openai-service/
216. Joshi, N. (2019, June 19). 7 Types Of Artificial Intelligence. Forbes: https://www.forbes.com/sites/cognitiveworld/2019/06/19/7-types-of-artificial-intelligence/?sh=6f27cc37233e
217. Samuel, S. (2021, September 18). AI's Islamophobia problem. Vox: https://www.vox.com/future-perfect/22672414/ai-artificial-intelligence-gpt-3-bias-muslim

Our forever frontier

218. The Age of Plastic: From Parkesine to Pollution. (2019, October 11). Science Museum: https://www.sciencemuseum.org.uk/objects-and-stories/chemistry/age-plastic-parkesine-pollution
219. The Editors of Encyclopaedia Britannica. (2022, December 12). Manhattan Project. Britannica: https://www.britannica.com/event/Manhattan-Project

220. Transistor Invention & History – when was the transistor invented. (n.d.). Electronics Notes: https://www.electronics-notes.com/articles/history/semiconductors/when-was-transistor-invented-history-invention.php
221. 1953: Transistorized Computers Emerge. (n.d.). Computer History Museum: https://www.computerhistory.org/siliconengine/transistorized-computers-emerge/
222. Norman, S. (2020, July 14). Skylab: Remembering America's First Space Station. Coca-Cola Space Science Center: https://www.ccssc.org/skylab/
223. Chu, Jennifer. (2016, March 3). The beginning of the end for encryption schemes? MIT News: https://news.mit.edu/2016/quantum-computer-end-encryption-schemes-0303
224. Human Genome Project Fact Sheet. (2022, August 24). National Human Genome Research Institute: https://www.genome.gov/about-genomics/educational-resources/fact-sheets/human-genome-project
225. McElroy, P. (n.d.). Boeing pilots the birth of biofuel for aviation's sustainable growth. Boeing: https://www.boeing.com/features/innovation-quarterly/2019_q3/btj-sustainability.page
226. DARPA Successfully Transitions Synthetic Biomanufacturing Technologies to Support National Security Objectives. (2021, December 8). DARPA: https://www.darpa.mil/news-events/2021-12-08
227. Jones, N. (2013, May 16). Google and NASA snap up quantum computer. Nature: https://www.nature.com/articles/nature.2013.12999
228. Fifty Years After Going to the Moon, Goodyear Looks to Space to Enhance Tire Performance. (2019, July 12). Goodyear: https://corporate.goodyear.com/us/en/media/news/fifty-years-after-going-to-the-moon-goodyear-looks-to-space-to-enhance-tire-performance.html
229. Ball, P. (2020, December 18). The lightning-fast quest for COVID vaccines – and what it means for other diseases. Nature: https://www.nature.com/articles/d41586-020-03626-1
230. Larabel, M. (2022, May 30). AMD-Powered Frontier Supercomputer Tops Top500 At 1.1 Exaflops, Tops Green500 Too. Phoronix: https://www.phoronix.com/news/Top500-Green500-Frontier
231. Callaway, E. (2022, July 28). 'The entire protein universe': AI predicts shape of nearly every known protein. Nature: https://www.nature.com/articles/d41586-022-02083-2
232. Mullin, E. (2022, September 29). The Era of Fast, Cheap Genome Sequencing Is Here. Wired: https://www.wired.com/story/the-era-of-fast-cheap-genome-sequencing-is-here/
233. Brooks, H. 1994. The relationship between science and technology. Belfer Center: https://www.belfercenter.org/sites/default/files/files/publication/sciencetechnology.pdf
234. Transistor Invention & History – when was the transistor invented.
235. 1953: Transistorized Computers Emerge.
236. Howell, E. (2020, February 10). The History of Rockets. Space: https://www.space.com/29295-rocket-history.html
237. Three Famous Things Invented by Accident – Slinky, Silly Putty and the Popsicle. (n.d.). The Energy Credit Union: https://theenergycu.com/three-famous-things-invented-by-accident-slinky-silly-putty-and-the-popsicle/
238. Zheng, J. (2020, March 15). SARS-CoV-2: an Emerging Coronavirus that Causes a Global Threat. National Library of Medicine: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7098030/
239. Cohen, J. (2020, December 17). Shots of hope. Science: https://vis.sciencemag.org/breakthrough2020/#/finalists/2020-breakthrough-of-the-year
240. Arnold, C. (2020, July 15). How computational immunology changed the face of COVID-19 vaccine development. Nature: https://www.nature.com/articles/d41591-020-00027-9
241. Bernardo, T., Sobkowich, K., et al. (2021, February 9). Collaborating in the Time of COVID-19: The Scope and Scale of Innovative Responses to a Global Pandemic. National Library of Medicine: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7879722/
242. Bluestein, A. (2012, August 28). Tom Knight, Godfather of Synthetic Biology, On How To Learn Something New. Fast Company: https://www.fastcompany.com/3000760/tom-knight-godfather-synthetic-biology-how-learn-something-new
243. Hammerling, M., Gottel, N., et al. (2013, October 6). Open Sequence Initiative: a part submission standard to complement modern DNA assembly techniques. MIT Libraries: http://oastats.mit.edu/handle/1721.1/81334
244. Remmel, A. (2022, September 2). What exascale computing could mean for chemistry. Chemical & Engineering News: https://cen.acs.org/physical-chemistry/computational-chemistry/exascale-computing-mean-chemistry/100/i31
245. Trader, T. (2021, November 24). Three Chinese Exascale Systems Detailed at SC21: Two Operational and One Delayed. HPC Wire: https://www.hpcwire.com/2021/11/24/three-chinese-exascale-systems-detailed-at-sc21-two-operational-and-one-delayed/
246. Remmel, A. What exascale computing could mean for chemistry.
247. Barney, L. (2021, April 29). NWChemEx: Computational Chemistry Code for the Exascale Era. HPC Wire: https://www.hpcwire.com/2021/04/29/nwchemex-computational-chemistry-code-for-the-exascale-era/
248. Choi, C. (2021, March 2). Quantum Computing Makes Inroads Towards Pharma. IEEE Spectrum: https://spectrum.ieee.org/quantum-drug
249. Choi, C. (2022, January 20). How Quantum Computers Can Make Batteries Better. IEEE Spectrum: https://spectrum.ieee.org/lithium-air-battery-quantum-computing
250. Smith, C. (2021, May 25). Going to the Moon via the Cloud. The New York Times: https://www.nytimes.com/2021/05/25/technology/cloud-computing-simulations-startups.html
251. Witze, A. (2020, November 3). Astronauts have conducted nearly 3,000 science experiments aboard the ISS. Nature: https://www.nature.com/articles/d41586-020-03085-8
252. Chow, D. (2022, April 8). To cheaply go: How falling launch costs fueled a thriving economy in orbit. NBC News: https://www.nbcnews.com/science/space/space-launch-costs-growing-business-industry-rcna23488
253. Space: The Dawn of a New Age. (2022, May). Citi GPS: https://ir.citi.com/gps/o_tzvWOka8KtDtjaEWqxkaFlSijjTRjTrQv1J5Zpd-qNEd4M3mkhNRA858x6-9WCyx1cO1wh_WU%3D
254. Venditti, B. (2022, January 27). The Cost of Space Flight Before and After SpaceX. Visual Capitalist: https://www.visualcapitalist.com/the-cost-of-space-flight/
255. Chow, D. To cheaply go: How falling launch costs fueled a thriving economy in orbit.

256. Davenport, C. (2021, April 11). The revolution in satellite technology means there are swarms of spacecraft no bigger than a loaf of bread in orbit. The Washington Post: https://www.washingtonpost.com/technology/2021/04/06/small-satellites-growth-space/
257. Chow, D. To cheaply go: How falling launch costs fueled a thriving economy in orbit.
258. Sheetz, M. (2022, January 18). Investment in space companies hit record $14.5 billion in 2021, report says. CNBC: https://www.cnbc.com/2022/01/18/space-investing-q4-report-companies-hit-record-14point5-billion-in-2021.html
259. Space: The Dawn of a New Age.
260. Mann, A. (2020, May 20). SpaceX now dominates rocket flight, bringing big benefits—and risks—to NASA. Science: https://www.science.org/content/article/spacex-now-dominates-rocket-flight-bringing-big-benefits-and-risks-nasa
261. Titan. (2022): https://titanspace.co/
262. Kim, S. (2022, November 13). Pharma goes to space. Chemical & Engineering News: https://cen.acs.org/articles/100/i40/Pharma-goes-space-drug-development.html
263. TESS Exoplanet Mission. (2022, October 13). NASA: https://www.nasa.gov/tess-transiting-exoplanet-survey-satellite
264. Transiting Exoplanet Survey Satellite (TESS). (2021, March 22). NASA: https://exoplanets.nasa.gov/tess/
265. Mehta, J. (2021). TESS, finding new worlds. The Planetary Society: https://www.planetary.org/space-missions/tess
266. JASON-3. (n.d.). National Oceanic & Atmospheric Administration: https://www.nesdis.noaa.gov/current-satellite-missions/currently-flying/jason-3
267. Uppal, R. (2021, November 3). 'Space-as-a-Service', 'Satellite-as-a-Service' and 'Space Data as a Service' Are New Business Models of Space Industry. International Defense, Security & Technology: https://idstch.com/space/space-as-a-service-satellite-as-a-service-and-space-data-as-a-service-are-new-buisness-models-of-space-industry/
268. Riolo, J. and Steckl, A. (2022, February 18). Comparative analysis of genome code complexity and manufacturability with engineering benchmarks. Nature: https://www.nature.com/articles/s41598-022-06723-5
269. Snyder, A. (2022, October 2). There's a new competition for faster, cheaper DNA sequencing. Axios: https://www.axios.com/2022/09/29/competition-dna-sequencing-illumina
270. Gene Synthesis Cost. (n.d.). Synbio Technologies: https://synbio-tech.com/gene-synthesis-cost/
271. Lu, Y. (2021, November 24). The Gene-Synthesis Revolution. The New York Times: https://www.nytimes.com/2021/11/24/magazine/gene-synthesis.html
272. Ginkgo Bioworks: Our Platform. (2023): https://www.ginkgobioworks.com/our-platform/
273. Fitzpatrick, E. (2013). Open Source Synthetic Biology: Problems and Solutions. Seton Hall University: https://scholarship.shu.edu/cgi/viewcontent.cgi?article=1047&context=student_scholarship
274. BioBricks Bionet. (n.d.): https://biobricks.org/bionet/#
275. Rappuoli, R., Gregorio, E., et al. (2021, January 11). Vaccinology in the post-COVID-19 era. PNAS: https://www.pnas.org/doi/10.1073/pnas.2020368118
276. Bolt Threads Mylo. (n.d.): https://boltthreads.com/technology/mylo/
277. Candelon, F., Gombeaud, M., et al. (2021, August 6). Synthetic biology could help business save the planet. Fortune: https://fortune.com/2021/08/06/synthetic-biology-plant-based-meats-bioengineering-environmental-impact/
278. Arnold, C. How computational immunology changed the face of COVID-19 vaccine development.
279. Sweger, Z. (2022, October 18). New engineered proteins could be used to develop adaptation-proof COVID vaccine. Penn State: https://www.psu.edu/news/research/story/new-engineered-proteins-could-be-used-develop-adaptation-proof-covid-vaccine/
280. Tollefson, J. (2020, August 7). Why deforestation and extinctions make pandemics more likely. Nature: https://www.nature.com/articles/d41586-020-02341-1
281. Quantum PFAS Chemicals Remediation (QPFAS). (n.d.). Irish Centre for High-end Computing: https://www.ichec.ie/academic/research/quantum-pfas-chemicals-remediation-qpfas
282. LanzaTech. (2022): https://lanzatech.com/
283. Specht, L., and Stone, L. (2021, May 21). USDA AMS Comment on Supply Chains. Good Food Institute: https://gfi.org/wp-content/uploads/2021/05/Comment-from-the-Good-Food-Institute.pdf
284. Quantum Innovation Initiative. (n.d.): https://qii.jp/
285. Fein, R. (2022, April 11). Collaboration is Dominating Quantum Computing. The Quantum Leap: https://quantumtech.blog/2022/04/11/collaboration-is-dominating-quantum-computing/
286. Codexis: Our Partners. (2023): https://www.codexis.com/partnerships/our-partners
287. Ginkgo Bioworks: The Future of Food. (2023): https://www.ginkgobioworks.com/our-ecosystem/the-future-of-food/
288. Ramanan, A. (2022, January 27). NASA's JPL uses Microsoft's Azure Quantum to manage communication with space missions. Microsoft: https://cloudblogs.microsoft.com/quantum/2022/01/27/nasas-jpl-uses-microsofts-azure-quantum-to-manage-communication-with-space-missions/
289. Volgraff Heidweiller, C. (2022, July 19). Our new Quantum Virtual Machine will accelerate research and help people learn quantum computing. Google: https://blog.google/technology/research/our-new-quantum-virtual-machine-will-accelerate-research-and-help-people-learn-quantum-computing/
290. Sheetz, M. (2022, November 29). Amazon used AWS on a satellite in orbit to speed up data analysis in 'first-of-its kind' experiment. CNBC: https://www.cnbc.com/2022/11/29/amazon-aws-experiment-satellite-orbit.html
291. Sun, T., Song, J., et al. (2022, March 1). Challenges and recent progress in the governance of biosecurity risks in the era of synthetic biology. ScienceDirect: https://www.sciencedirect.com/science/article/pii/S2588933822000036
292. Xu, T. (2022, September 14). What are quantum-resistant algorithms—and why do we need them? MIT Technology Review: https://www.technologyreview.com/2022/09/14/1059400/explainer-quantum-resistant-algorithms/
293. JPMorgan Chase, Toshiba and Ciena Build the First Quantum Key Distribution Network Used to Secure Mission-Critical Blockchain Application. (2022, February 17). Toshiba: https://news.toshiba.com/press-releases/press-release-details/2022/JPMorgan-Chase-Toshiba-and-Ciena-Build-the-First-Quantum-Key-Distribution-Network-Used-to-Secure-Mission-Critical-Blockchain-Application/default.aspx

About Accenture

Accenture is a leading global professional services company that helps the world's leading businesses, governments and other organizations build their digital core, optimize their operations, accelerate revenue growth and enhance citizen services—creating tangible value at speed and scale. We are a talent and innovation led company with 738,000 people serving clients in more than 120 countries. Technology is at the core of change today, and we are one of the world's leaders in helping drive that change, with strong ecosystem relationshaips. We combine our strength in technology with unmatched industry experience, functional expertise and global delivery capability. We are uniquely able to deliver tangible outcomes because of our broad range of services, solutions and assets across Strategy & Consulting, Technology, Operations, Industry X and Accenture Song. These capabilities, together with our culture of shared success and commitment to creating 360° value, enable us to help our clients succeed and build trusted, lasting relationships. We measure our success by the 360° value we create for our clients, each other, our shareholders, partners and communities. Visit us at **www.accenture.com**.

About Accenture Labs

Accenture Labs incubates and prototypes new concepts through applied R&D projects that are expected to have a significant impact on business and society. Our dedicated team of technologists and researchers work with leaders across the company and external partners to imagine and invent the future. Accenture Labs is located in seven key research hubs around the world: San Francisco, CA; Washington, D.C.; Dublin, Ireland; Sophia Antipolis, France; Herzliya, Israel; Bangalore, India; Shenzhen, China and Nano Labs across the globe. For more information, please visit **www.accenture.com/labs**.

Accenture Research

Accenture Research creates thought leadership about the most pressing business issues organizations face. Combining innovative research techniques, such as data science led analysis, with a deep understanding of industry and technology, our team of 300 researchers in 20 countries publish hundreds of reports, articles, and points of view every year. Our thought-provoking research developed with world leading organizations helps our clients embrace change, create value, and deliver on the power of technology and human ingenuity. For more information, visit **www.accenture.com/research**.