Looking Glass

Bringing tech-led business changes into focus

thoughtworks

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Technology's pace of change can be dizzying; the impact on your business hard to fathom. Here's where Thoughtworks Looking Glass comes in.

As a digital transformation consultancy, it's important for Thoughtworks to stay ahead of technology trends so we can help our clients create a strategic advantage for their business. Our global network of consultants and clients ensures that we see a broad picture of what's coming, how soon, and the likely impacts. In this report we share our insights, giving the outside world a glimpse into part of what allows us to transform businesses through leading-edge technology.

The Looking Glass includes over 120 individual technology trends; to make sense of these we've created "lenses" through which to view them. Our lenses help you focus on what these trends mean for your enterprise and how you need to prepare. The lenses can be used individually, or combined to create additional perspectives and prompt new avenues of investigation and lines of thinking.

The report highlights the opportunities that can be seen through each lens, as well as signals you can use to gauge how fast something is approaching. We categorize each of the 120 trends in two dimensions: the time horizon, and our recommended strategic response — adopt, analyze, or anticipate. We hope this report can help you to identify the most important trends impacting your business today and in the future.

Lens one

Humanity, augmented

Powerful new data-based tools are revolutionizing the way businesses make decisions and deploy talent, with broadly positive results. But these technologies also come with ethical and organizational challenges that responsible enterprises need to bear in mind.

Through the Looking Glass

As machine learning (ML) and artificial intelligence (AI) gain more industry adoption, they are enhancing — rather than replacing — human talent by automating data processing tasks and freeing people up to use their experience, creativity, and intuition. These systems enhance productivity in two main ways: making predictions to assist humans in making decisions, and automating decision-making completely.

The trend towards autonomous, machine-made decisions can have a significant impact on our lives and needs to be considered from an ethical perspective. This is driving research and industry interest in explainable AI (XAI) and stronger AI governance processes.

Signals include:

- Burgeoning investment in AI research and applications. **Bloomberg estimates** civilian spending on AI in the United States grew 22% in fiscal 2019, while government spending grew almost 70%
- Massive demand for ML, AI, and data specialists in the job market. According to **LinkedIn** AI specialist was the fastest-growing job category in 2020.
- Growth in ML/AI start-ups, specialized products, and acquisitions. As of this writing **Angel.co** lists 5,711 companies and 2,790 investors in the 'machine learning startups' category
- Existing jobs and roles changing. Rote tasks are being automated, human workers pairing with machine counterparts, and people freed to use their experience and intuition to provide value. For example, **Amazon announced** that it will spend $700 million to help about 100,000 workers in the US move into more highly skilled jobs by 2025

The Opportunity

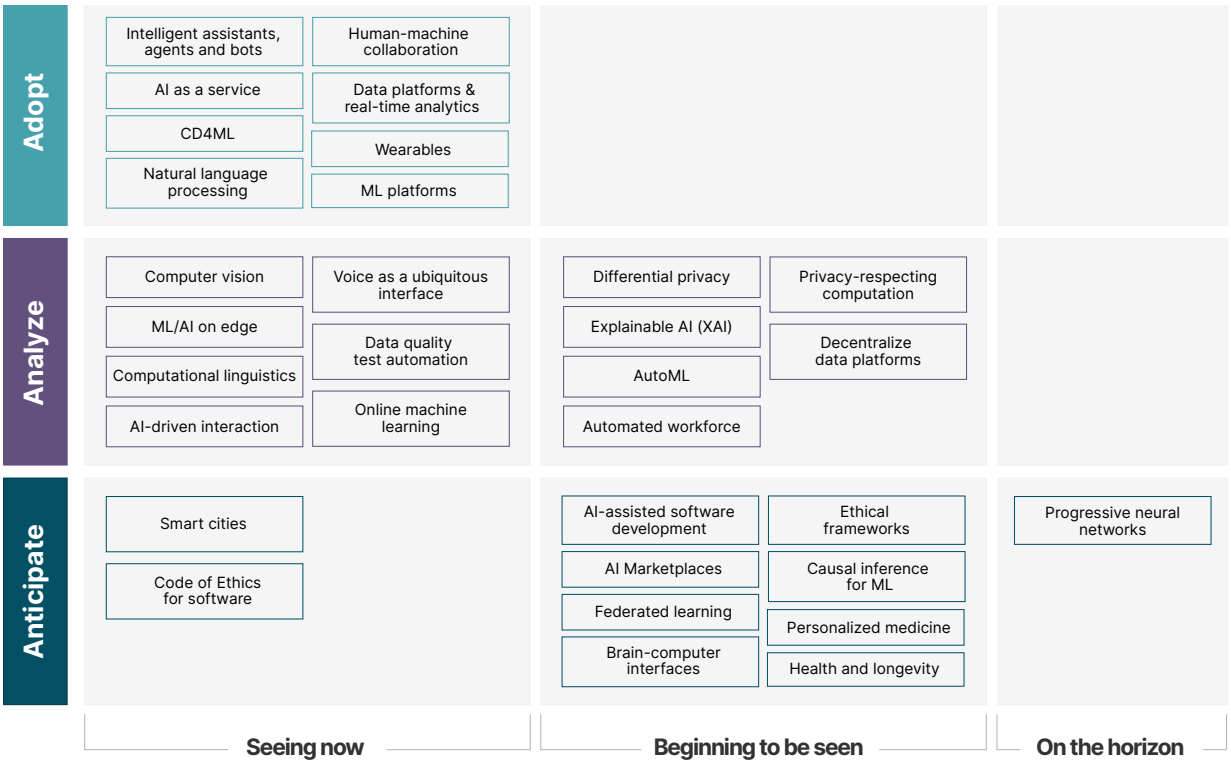
The rapid advance of AI and ML-based tools will benefit businesses on two main fronts. For workforces, automating repetitive and mundane tasks will enhance productivity, leading to gains in efficiency and output. Employees will also be freer to focus on higher-value activities that require more human creativity and ingenuity, such as developing the next product or service innovation. This will have positive consequences for employee morale and overall business performance.

Applying AI and ML to reduce inconsistencies and the probability of human error, and reduce turnaround times in delivering products or services, could significantly enhance customer satisfaction and ultimately retention. Companies can also draw on data-based solutions to learn more about and accurately anticipate customer needs, though caution needs to be exercised to ensure this is done in a way that respects privacy and security.

What we've seen

We've seen AI and ML have a huge impact on everything from marketing and customer service, to employee engagement and recruitment. One of the most promising applications is to improve predictive maintenance in manufacturing. By collecting and analyzing data from connected devices, AI and ML systems can help companies flag problems with an assembly line or product before they occur, avoiding potentially costly (and customer-alienating) defects or downtime. We partnered with one manufacturer to build an AI-enabled application that predicts when repairs or maintenance of the heavy equipment it sells may be needed, and alerts customer-facing teams to follow up. By paving the way for more anticipatory after-sales service, the solution has contributed to customer satisfaction and new sales opportunities.

Trends to watch



Adopt

Technologies that are here today and are being leveraged within the industry.

Continuous delivery for machine learning (CD4ML)

CD4ML is a software engineering approach in which cross-functional teams produce ML applications based on code, data and models in small increments that can be reproduced and released anytime, with short adaptation cycles. CD4ML allows enterprises to build the capabilities and processes needed to govern, release and update ML models in a reliable and safe way, while remaining able to respond to changes and evolutions in the ML landscape.

Analyze

Technologies that are beginning to gain traction, depending on industry and use-case.

XAI

Explainable AI (XAI) refers to a set of tools and approaches to understand the rationale used by an ML model in reaching a conclusion. These tools generally apply to models that are otherwise opaque in their reasoning. Explainable AI is becoming increasingly important as ML models are applied in areas that directly impact the health, rights, and economic well-being of individuals, such as healthcare, criminal justice and credit decisioning. XAI will likely play an even greater role as the implications of AI for privacy and regulations such the EU's General Data Protection Regulation (GDPR) are better understood.

Anticipate

Still lacking in maturity, these technologies could have an impact in a few years.

Brain-computer interfaces (BCI)

BCI interfaces enable users to interact with computers by means of brain activity only, generally measured by electroencephalography (EEG). Advances in the use of machine learning to interpret electrical signals from the brain have created new use cases where this could be applied to **help people make split-second decisions**, and vastly decreased the costs of technology in this space.

Advice for adopters

Develop trust in your data.

The AI models that support your teams will be created based on the data made available to them. That means the data must be transparent, accurate and reliable enough that you and your people can generally trust any decisions resulting from it will be sound and well-informed.

Understand and communicate where machine-made decisions are subject to bias and ethical concerns.

Create a framework to track what sensitive decisions will be made, describe how you expect these to affect any stakeholders involved and set out how you will detect potential unintended consequences. Ensure these decisions can be sufficiently explained and traced back to the 'source.'

Create quantitative baseline measurements of your current processes

Create quantitative baseline measurements of your current processes using techniques such as value stream analysis to identify areas with significant opportunities for automation, where AI and ML may produce the biggest potential gains. Refer to and update these on a regular basis to measure the effectiveness of AI/ML rollouts, and ensure automation remains targeted rather than the default solution for every problem.

Empathize with staff fearful that "the robots will take our jobs"

Empathize with staff fearful that "the robots will take our jobs" and support them as they learn to work alongside algorithms, making it clear the ultimate aim is freeing them up for more rewarding work. Develop clear transition and career progression plans for your employees to grow into roles enabled by automation handling repetitive tasks.

Consider whether human-machine collaboration can help you enhance customer value

Consider whether human-machine collaboration can help you enhance customer value, rather than seeing automation purely as a way to replace headcount and reduce costs. Existing staff have a wealth of knowledge about your business and customers, and these insights should be applied to effectively boost customer experience as they people spend less time on mundane functions. Any AI or ML solution should be judged not by the efficiencies it creates internally, but by the additional customer value it enables teams to deliver.

By 2022, business will...

"... move beyond using AI and ML in standalone solutions to bring them into more core business functions as confidence in these technologies grows. We also see companies being more conscientious and selective in the way they apply data, considering the impacts on their staff, customers and society at large, and taking steps to ensure these systems are more transparent."

Danilo Sato

Lens two

Accelerating towards sustainability

As consumers, governments and investors demand greater environmental accountability from companies, going green has gone from optional to a business imperative. Technology will present both challenges and opportunities in the drive to embed sustainability in more activities and practices.

Through the Looking Glass

The concept of sustainability — using natural resources that are renewable, or in a way that will not lead to their depletion; reducing the ecological footprint of the business; and avoiding contributing to outcomes such as global warming — is gathering unprecedented mindshare in political, economic and market circles. Making sustainable choices is something an increasing number of consumers do as a matter of course, and that businesses are incorporating directly into commercial strategies.

Technology is a major contributor to climate change and a large number of tech companies are attempting to address this, whether by building energy-efficient data centers, adopting renewable energy sources, or developing applications that consume less in both their creation and ongoing operation. Technology can also help make our everyday lives more sustainable, by for example supporting smart cities that optimize traffic to reduce pollution.

The move to a sustainable world is accelerating, and the trend has wide business implications.

Signals include:

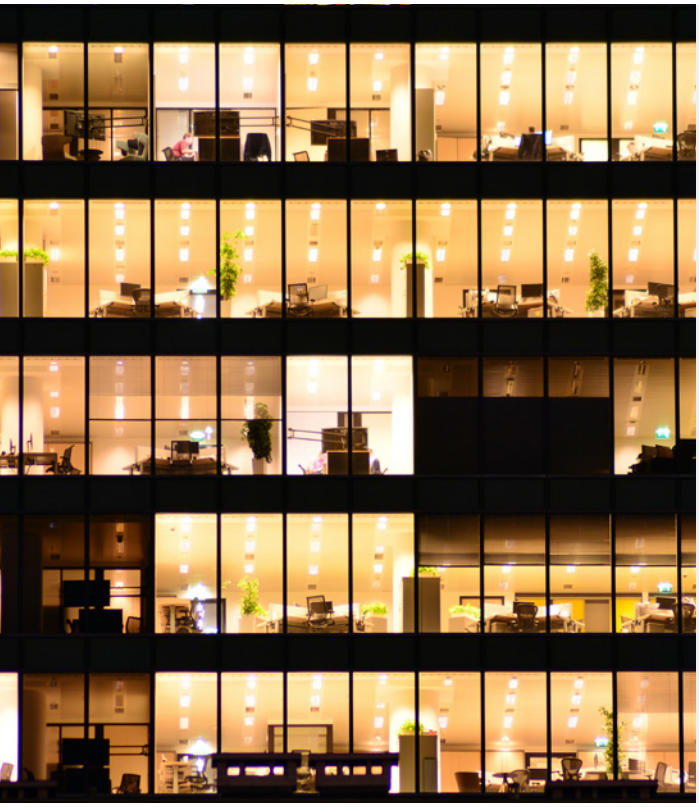
- The emergence of sustainability in government policies, for example the **Green New Deal** or the **European Green Deal**
- The increasing prominence of **ESG** standards within organizations, and the movement of funds into 'ethical' investments and away from companies that pollute or have a negative sustainability posture
- Technology providers touting their 'greenness' or other sustainability characteristics

- Organizations adopting carbon neutral or similar environmental impact reduction pledges. For example, upon winning the naming rights to Seattle's rebuilt sporting arena, Amazon dubbed the facility "**Climate Pledge Arena**," aiming to make it the first net-zero carbon building of its kind in the world. Microsoft has set the goals of being both water positive and **carbon negative by 2030**

The Opportunity

Consumers want to feel good about their impact on the world and will increasingly factor sustainability into their decision making when choosing a brand or supplier. That will require businesses to examine the environmental costs of their products and operations, and adopt more sustainable strategies and technologies in response.

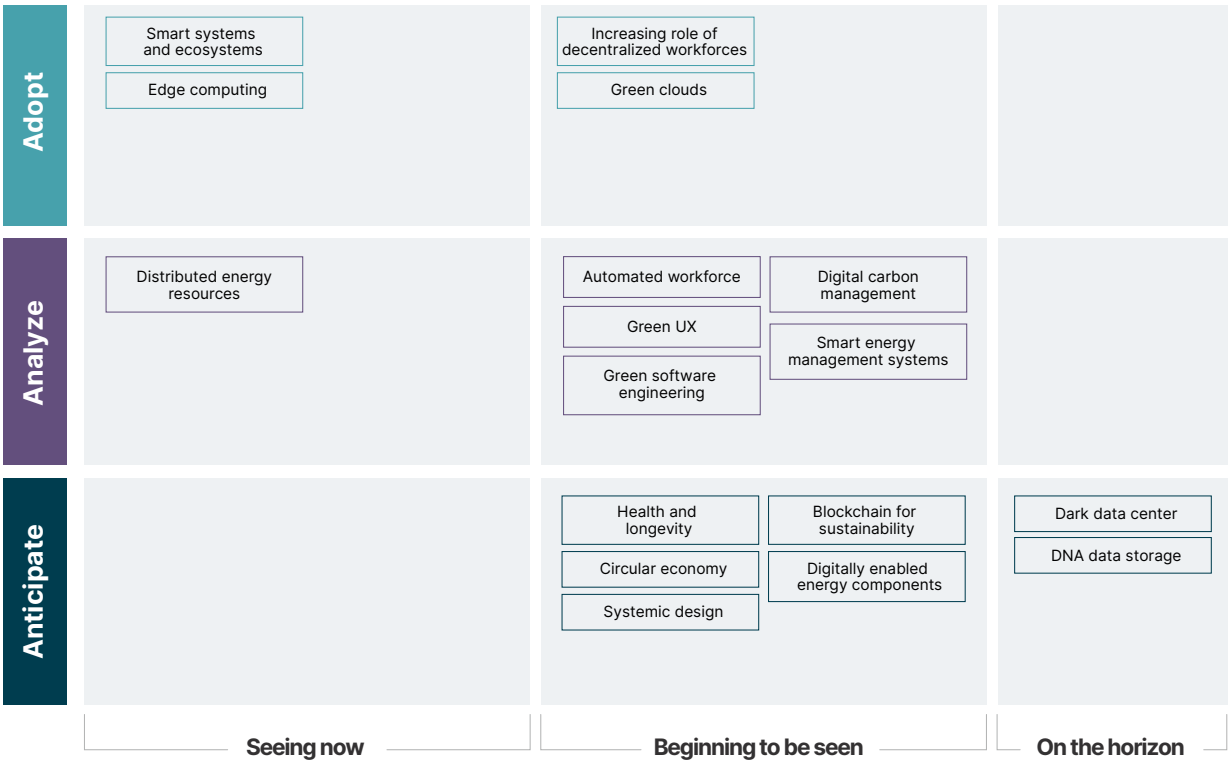
Rather than a box-ticking or compliance issue, sustainability should be understood as a contributor to business goals. Advances in sustainability such as reducing energy consumption often lower costs and can be a win-win for a business's bottom line. Sustainability has also gained considerable momentum in equity markets under the environmental, social and governance (ESG) banner, with many major investors and portfolio managers instituting ESG targets or requirements. Green credentials can therefore ultimately enhance a company's valuation and ability to attract quality investment.



What we've seen

Through our **Cleantech, Energy and Utilities** practice, we work with clients to tackle inefficiencies that lead to waste and overconsumption. A case in point is **Fresh Energy**, Germany's first digital electricity supplier, which drew on our expertise in platform development to create a versatile and scalable ecosystem that combines smart meters, a mobile app and machine learning to give customers complete visibility and control over their electricity usage. Greater availability and transparency of data provides the basis for both Fresh Energy and its customers to make more responsible electricity consumption decisions.

Trends to watch



Adopt

Technologies that are here today and are being leveraged within the industry.

Green clouds

One of the best sustainability steps a business can take is adopting a greener approach to data centers, which models predict could take up **over 10% of the global electricity supply** by the next decade. Encouragingly more cloud and data center providers are documenting and reporting sustainability metrics and practices. Take advantage of this and establish an environmental impact baseline for your data center infrastructure, by actively measuring and considering criteria such as carbon emissions and water consumption. Pursue resource conservation goals by creating collaborative environmental initiatives with cloud, colocation, edge and hosting service providers.

Analyze

Technologies that are beginning to gain traction, depending on industry and use-case.

Green software engineering

Awareness is growing that programming languages and practices have a direct bearing on energy consumption and the environment. Choose where possible languages and technology stacks as well as algorithms that reduce the amount of carbon produced by software. The **Green Algorithms website** can help developers estimate the costs of their code in "tree months" of carbon. Consider using Approximate Computing, a more energy-efficient technique that aims to produce 'good enough' rather than 100% accurate results.

Anticipate

Still lacking in maturity, these technologies could have an impact in a few years.

Blockchain for sustainability

The adoption of blockchain by more industries is beginning to provide unique sustainability opportunities by increasing transparency and traceability throughout supply chains. This promises to enable companies to improve their sourcing and recycling practices, and to give consumers greater visibility over the environmental inputs of the products they buy, supporting the shift to more sustainable lifestyles.

Advice for adopters

Measure, monitor and move to reduce your environmental impact.

An accurate and regularly updated reckoning of the energy consumption and carbon footprint of your operations, including the technology aspects, will make it clear where action can produce 'quick wins' in terms of controlling resource consumption and lowering costs. Practices like **green cloud optimization** can produce real-world improvements to energy usage, efficiency and by extension the balance sheet.

Consider sustainability throughout the tech supply chain.

With most enterprises depending more than ever on a vast network of external providers for data center, cloud and other technology solutions, it's important to take a close look at your suppliers to ensure they share your sustainability commitments. Many leading tech companies are making sustainability a priority, and the amount of competition in the space means there's no reason to choose providers with environmentally questionable practices.

As a leader, model the change you want to see in the world.

Ensure sustainability goes beyond rhetoric or far-off targets, and becomes a first-class concern in the things that you build and the services you offer to customers today. Communicate this regularly throughout the organization, so everyone from developers to customer-facing staff understand it's a key strategic consideration.

Be explicit with your customers

Be explicit with your customers about the specific measures you're taking to accelerate sustainability in your own organization. This is an important step in presenting your values as an enterprise and fostering dialogue with your customer base. What's more, using descriptive norms **has been shown** to have a positive effect on purchasing decisions.

By 2022, business will...

"...put sustainability at the heart of their strategy, so it's manifested not just in what they say, but how they create products and services, and interact with suppliers and their customers. As the urgency around climate change grows, visible and consistent commitment to sustainability will be a leading indicator of business performance; one that can't be sacrificed for the sake of profitability or short-term returns."

George Earle

Lens three

Evolving interactions

Consumers aren't just demanding availability and accessibility — they expect interactions to be seamless, and richer. Enterprises can deliver this experience through evolving interfaces that blend speech, touch and visuals.

Through the Looking Glass

Voice and touch interfaces, and virtual and augmented reality continue to evolve at a startling pace. We have higher expectations — we're no longer amazed by voice recognition and AI-based responses on our phones; instead we're annoyed when the technology fails or does something unexpected.

Consumers expect to be able to interact with technology in whatever manner fits their current context, and to switch between interaction styles in a way that makes sense.

Signals include:

- Growing adoption of voice in multiple use cases: shopping, ordering food, and booking travel
- VR and AR used beyond specialized, safety-critical cases such as police or military training
- Large platform players such as Google, Amazon and Microsoft creating new offerings including interaction technologies
- Apple set to announce its widely-rumored "Apple Glass," an augmented reality device

The Opportunity

Consumers want low-friction interactions, and often choose services and products accordingly. You'll need to be ready or risk being shut out by more proactive competitors.

Evolving interactions can also contribute directly to the bottom line. According to **IBM**, businesses spend $1.3 trillion on 265 billion customer service calls each year, but chatbots can speed up response times and answer up to 80% of routine questions, allowing agents to focus on higher-value customer service.

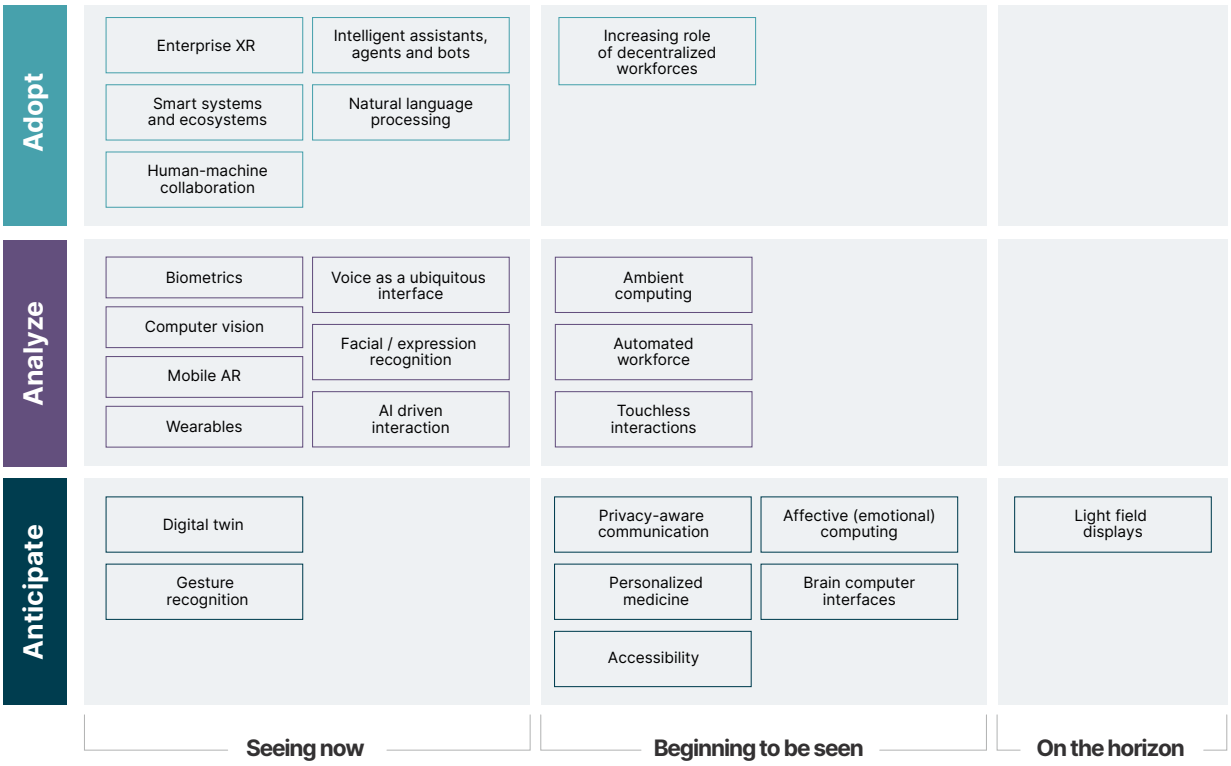
Consumers are eager to use voice interfaces, and make purchasing decisions based on other smart home devices (such as thermostats) that work with their existing voice assistants. According to **Invesp** voice shopping is expected to reach US$40 billion by 2022. Elsewhere, **Juniper Research** predicts that consumers will interact with voice assistants on over 8.4 billion devices by 2024.

Interaction with voice assistants devices by year — Juniper Research

What we've seen

We helped an automotive manufacturer use eye tracking technology to develop a new gesture interface for their in-car entertainment system. The team was able to obtain quantitative measures and to experiment with non-traditional gestures to help maintain driver attention on the road — for example, it turned out the best 'change volume' gesture was not twiddling an imaginary volume knob. While the solution hasn't yet been deployed to a finished vehicle, this is a good example of two interaction technologies working together to produce a strong, and measurable, outcome.

Trends to watch



Adopt

Technologies that are here today and are being leveraged within the industry.

Intelligent agents, assistants and bots

The technology behind intelligent assistants and chatbots is developing rapidly. Enterprises should watch this trend carefully, invest in capability building, and start to put this technology to use, as it has clear potential to enhance customer satisfaction and accessibility, cost savings, and product development. Depending on what market they are in, businesses should be prepared to spend more than they would anticipate on content and dialog design. It's important to treat a chatbot as another user experience channel, not a technical feature.

Analyze

Technologies that are beginning to gain traction, depending on industry and use-case.

Wearables

Wearables such as smart watches have become commonplace, but the technology is rapidly expanding in terms of both feature sets and interactions. For example, the new Apple Watch announced in late 2020 includes technology for measuring blood oxygen levels, a clear response to the COVID-19 crisis. Apple is also known to be in the later stages of developing its own augmented reality glasses. While it's still unclear how far we are along the path to wearables being a "must have" instead of a "want to have," fitness and medical monitoring are likely to drive the process.

Anticipate

Still lacking in maturity, these technologies could have an impact in a few years.

Gesture recognition

Machine understanding and interpretation of human gestures such as waving or making "up" or "down" motions is an ongoing and promising research area, with tech at varying levels of maturity. Leap Motion and Kinect made hand, finger, and body tracking relatively useful, but fine-grained hand and finger tracking using only cameras — as for example in the Oculus Quest — is still developing. In future we may be able to approach "natural" gesture recognition with machines able to recognise gestures such as pinches and finger taps, or two-handed gestures such as resizing, dragging, dropping, or zooming in and out.

Advice for adopters

Monitor opportunities to leverage these technologies.

Many are moving beyond the experimentation phase to the exploitation phase, and are attracting heavy investment from big tech companies such as Facebook and Microsoft.

Invest in the skills to succeed with new interfaces.

Many organizations are looking at hiring people from industries such as gaming who already have been working with things like XR for years. But you might be better served by training your existing development teams — the people who already know your business, products and customers — in the new technologies.

Bear in mind that consumer expectations are extremely high.

If you're going to offer an interface using voice, gesture, or XR, make sure it works well and is a compelling experience.

Understand that these technologies change the user journey and design process.

In XR for example, design must be done keeping spatial three-dimensional environments in mind, and that has deep implications. It's not simply about replicating reality — there is significant opportunity for innovative interaction design in these environments.

Beware vendor-lock in.

When developing with these interfaces, you will often have to choose a vendor — Google, Apple, Amazon, Microsoft, Oculus or others — in order to take advantage of the acceleration their platform can offer. But intense competition also encourages slow support of 'rival' vendors' ecosystems.

By 2022, business will...

"... see greater bottom-line impact from a wider adoption of VR/AR technologies. The lower cost of headsets has made it cost-effective for industries from manufacturing to healthcare to communications to use XR for everything from training doctors to treating patients to reducing time-on-task in industry. You should be exploring how to harness the power of this technology in your ecosystem."

Margaret Plumley

Lens four

Morphing of the computing fabric

The boundaries of computing are expanding, pushing the edges of what's possible for enterprises. The emerging computing environment not only provides the opportunity to tap into unprecedented data analysis and processing power, but also to structure computing architecture to better serve the needs of the business.

Through the Looking Glass

The computing landscape is changing to accommodate the future of the internet and all its users. No longer just centralized in cloud services, processing now occurs on the edge, in devices, across multiple clouds and in managed services. The future is potentially even more exciting, with the rise of quantum and biological computing, even DNA-based storage.

In the past, large-scale data processing was only needed by big enterprises. Since the advent of smartphones and the proliferation of IoT devices we've seen a massive increase in the amount of data produced. Analysis of data is no longer the domain of corporate data warehouses; data can be anywhere in the vast interconnected web of people, devices, cars, factories, and cities. With more data comes the requirement for more computing power.

Alongside changes in the location of data and computing, there's a continuing evolution of computer architecture. The push to mobile has driven high efficiency chips and even designs that include "big/little" computing cores optimized for high performance and efficiency depending on workload.

Signals include:

- The proliferation of devices capable of computing, like wearables, autonomous/smart cars or in-home "hubs"
- Application specific integrated circuits (ASICs) such as Google's **Tensor Processing Unit (TPU)**, which is designed specifically for neural network machine learning, becoming widely available

- Processor advancements for mobile devices, for example low-power chips such as Apple's M1
- Proliferation of on-premise hybrid cloud offerings such as Amazon Outposts, which offers low-latency solutions with consistent cloud APIs
- Development of practical applications for quantum computers. Examples are likely to include cryptography, medical research, and certain complex optimization problems such as those found in finance and supply chain management

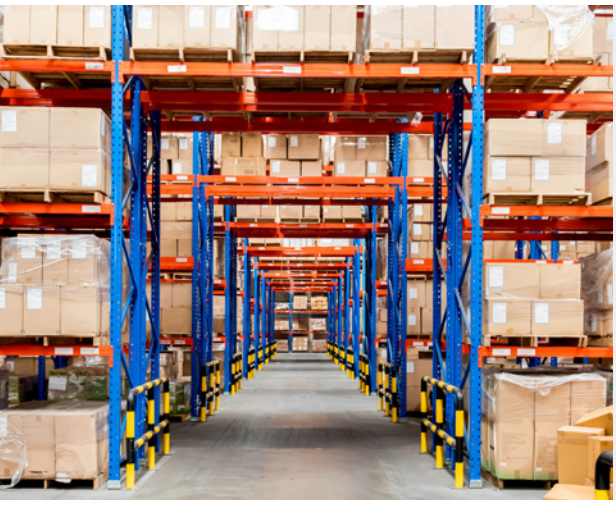
The Opportunity

Making informed computing choices enables businesses to optimize IT costs as well as provide more responsive services to consumers. In the enterprise context, all deployment options are not equal.

Despite the easy availability of cloud computing, where your data actually lives and how you process it *matters*. Innovative network technologies can't overcome fundamental physics; a data center halfway round the world will always have worse latency than one local to a region or even distributed to a home or workplace.

This means there can be significant cost and customer experience implications depending on where you choose to locate your data, how you move it around and how you compute with it. Selecting the most appropriate hardware, including chip type, size, and memory, will have a direct impact on the number of instances or virtual machines you need. Some use cases — healthcare, financial services, telecommunications and industrial IoT— require lower latency than can be obtained with a centralized platform, and therefore more local computing resources.

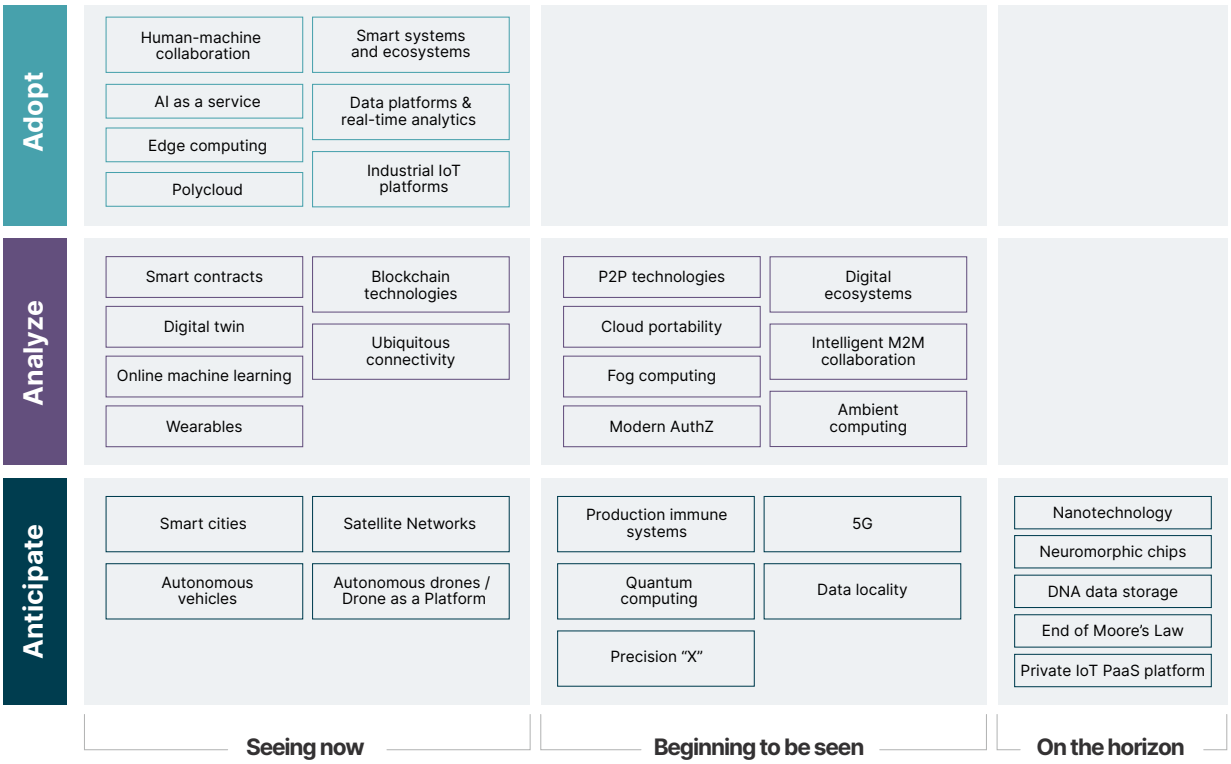
Regardless of how resources are structured, it's important to remember they will be seen by end-customers as your responsibility. Consumers expect their connected devices to work, and if they can't ring their doorbell or unlock their connected car due to a cloud provider's downtime, they'll blame the doorbell or car vendor — not the company providing the underlying computing.



What we've seen

We worked with Jungheinrich, a world leader in material handling and warehousing equipment, to create a custom IoT platform and operating system for their iconic line of forklift trucks that has made it easy to add applications that create differentiation and customer value. The platform has improved safety for customers by enhancing the monitoring of operators and has also reduced costs by enabling predictive maintenance for entire vehicle fleets, based on the intelligent integration of data such as operating hours and capacity utilisation.

Trends to watch



Adopt

Technologies that are here today and are being leveraged within the industry.

Edge computing

Autonomous vehicles, medical monitoring, smart homes and cities, and augmented reality all rely on powerful cloud-based computing and data storage, but need low latency to be safe and effective. Edge computing brings data storage and processing closer to devices rather than relying on a central location that may be thousands of miles away. Plan for more diverse and complex deployment scenarios. Consider the management, monitoring, and testing challenges associated with complex and remote architectures carefully.

Analyze

Technologies that are beginning to gain traction, depending on industry and use-case.

Digital twins

A digital twin is a virtual model of a process, product or service that allows both simulation and data analysis. 3D visualization can be used together with live data so you can understand what's happening to pieces of equipment you can't actually see. For example, **GE**'s jet engines contain around two dozen physical sensors, but their digital twins compute several hundred virtual sensors, improving maintenance, safety and efficiency. If this concept fits your use case, the efficiency gains can be enormous.

Anticipate

Still lacking in maturity, these technologies could have an impact in a few years.

Neuromorphic chips

Neuromorphic chips are made up of artificial neurons and synapses that replicate the way the brain works, handling processing entirely in the chip. They use significantly less energy because, like the human brain, they don't require the processor to be idle as data moves to and from memory. They also exploit parallelism to a much greater extent than even GPUs and other specialized systems. This computing strategy could result in both faster processing and significant energy savings.

Advice for adopters

Evaluate the full range of hardware options for the deployment of your software

Evaluate the full range of hardware options for the deployment of your software, and be open to using a non-obvious choice. While cloud platforms make it easy to provision servers, the hardware configuration of those servers can and should be tuned to the applications running on them.

Invest in software architecture patterns that allow components to be independently deployable

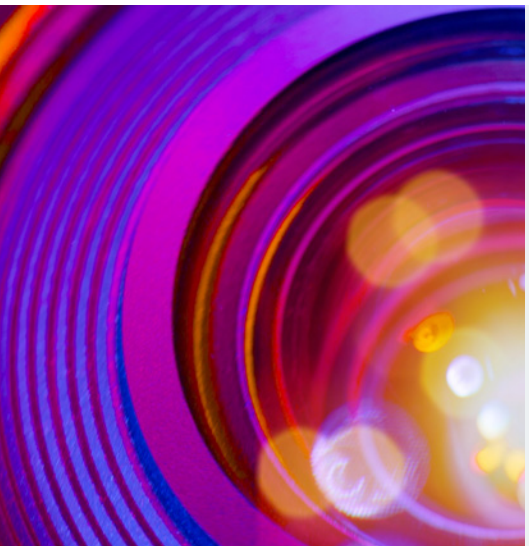
Invest in software architecture patterns that allow components to be independently deployable, even if you won't be deploying them in separate clusters or data centers initially. This means including decentralized authentication, authorization, and data. Doing so will allow you to move services to edge computing as needed to support your system's evolution.

When using distributed computing, carefully measure your network costs

When using distributed computing, carefully measure your network costs to identify services which could benefit from being moved closer to their users. Be sure to include the increased cost of maintenance in this calculation.

Invest in improving your distributed systems capabilitie

Most organizations default to centralized or monolithic applications, and the skills to build modern systems are sometimes lacking.



By 2022, business will...

"... realize computing is no longer confined to certain machines or locations, or subject to centralization or the old constraints. With more choice comes the ability to set up systems and devices so they contribute directly to the responsiveness of the organization, and bring services closer to customers so they can be delivered at speed."

Dave Elliman

Lens five

Coopetition forces platforms into ecosystems

The platforms created by businesses are increasingly only a starting point. Meeting rising customer expectations often requires joining up with or being open to other participants, turning platforms into ecosystems of related products and services that evolve dynamically as constituents cooperate and compete.

Through the Looking Glass

Ecosystems are the reality of the market today — whether organizations want them or not. Organizations set out to build platforms that they control and expand, but the messy reality of modern interconnected businesses is that often an ecosystem of diverse participants will emerge, and an organization will be forced to participate or lose its place in the market. The better you acknowledge that reality, the better placed you are to compete.

The key difference between a platform and an ecosystem is control. An organization can create and run a platform, which gives them control over who can participate. But a company can only loosely set standards for an ecosystem, and participants may emerge spontaneously. Like a biological ecosystem, a technology ecosystem involves competition and 'survival of the fittest.' This means symbiotic, parasitic and predatory behavior, as well as a continuing need to adapt or perish. There are limited resources — often economic, but sometimes something such as "consumer attention" — and the struggle for these fuels interaction, innovation and evolution.

Signals include:

- Organizations with more than one 'platform,' and cooperation across and between those platforms. For example, we helped restaurant chain Sonic build a **flexible digital platform** that enables it to integrate to and experiment with interaction platforms such as voice, delivering more convenience to customers.

- Dynamic introduction and removal of participants within an ecosystem
- More “peer” relationships between components as opposed to relationships between “platforms” and “consumers” — this implies no central ownership of information, such as user accounts.

The Opportunity

Consumers make purchasing decisions based on how your product fits in their ecosystem. Misunderstanding your position in the ecosystem can lead to poor business outcomes, while knowing when to share or ‘let go’ can create a source of competitive advantage.

For example, for years car manufacturers were investing to build proprietary platforms, These platforms failed for two reasons. First, drivers don’t think about their car as a closed platform; they just want their maps and music playlists to work. Second, auto manufacturers don’t have the specialization required to build world-class entertainment or mapping experiences, and always provided worse alternatives to the Spotify and Google Maps of the world. Consumers ultimately don’t care about their car manufacturer’s proprietary platform, they just want to be able to extend their most important and personal ecosystem — their phone — into the car.

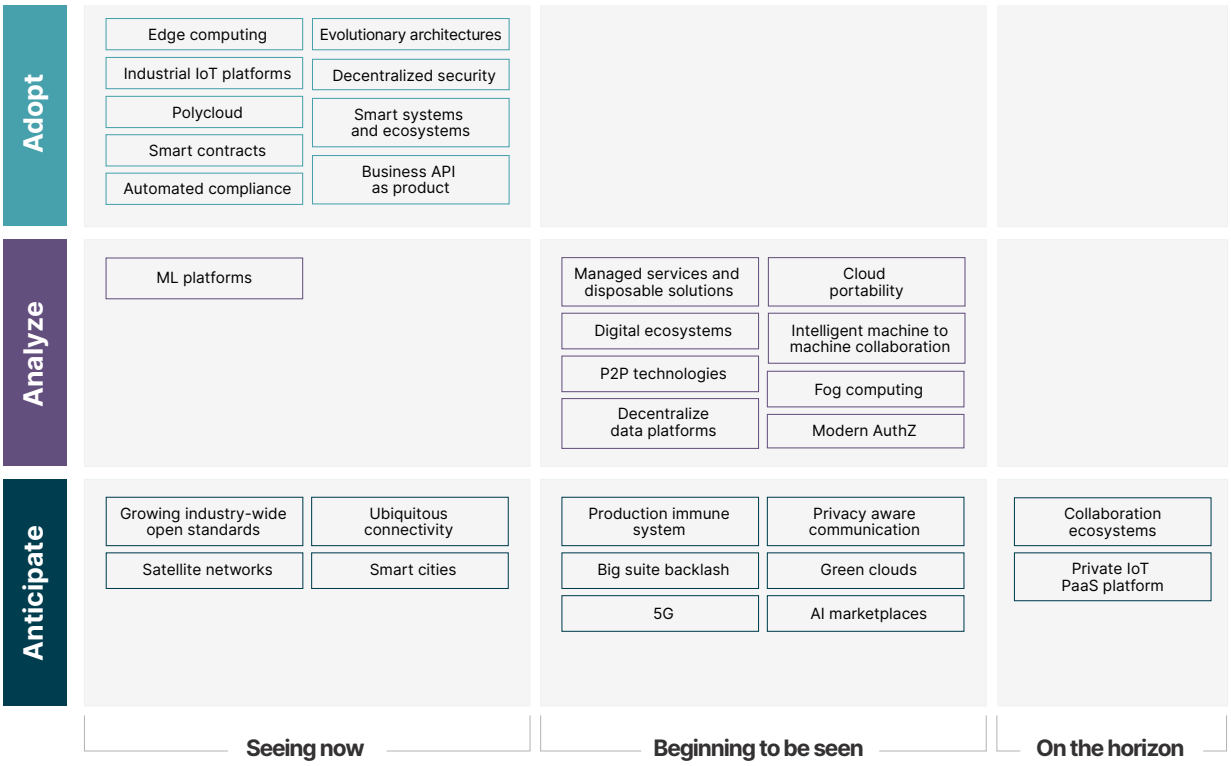
The lesson here is that enterprises that play to their core strengths, and make sure their offerings are built to interact with surrounding ecosystems that are evolving holistically, will be best placed to win over customers and succeed in the emerging business environment.

What we’ve seen

A good example of an ecosystem is the online travel industry, comprising travel aggregator sites, airlines, hotels, lodging, and ground transport providers. Airlines would prefer that consumers book travel directly on their platforms where they can control branding and offer other products such as credit cards — but consumers often prefer to use aggregators so they can compare prices between airlines and work out details such as the entire cost of their trip. Airlines have responded by incorporating more of the overall ecosystem into what they provide — for example, the Delta Airlines mobile app now allows you to book an Uber or Lyft directly.

While the aggregator might label itself a ‘platform business,’ we would argue that aggregators actually enable ecosystems in which an airline can derive a lot of business value from being a participant. Airlines are now learning how important it is to provide accurate data to other ecosystem participants, especially corporate travel management services. To take one example, one airline’s prices were not being correctly loaded into the Thoughtworks corporate booking system. Rather than driving fliers to book on the airline’s website directly, it simply caused them to choose another airline!

Trends to watch



Adopt

Technologies that are here today and are being leveraged within the industry.

Business API as Product

Having a product focus, which includes deliberate thinking about how others will consume your APIs, will be key to competing for a spot in both existing and emerging ecosystems. Treating an API as a product requires the creation of other assets such as documentation and support offerings in order to encourage other organizations to adopt it. Like any other product, APIs require investment in understanding and responding to customer needs to keep them relevant and high-quality.

Analyze

Technologies that are beginning to gain traction, depending on industry and use-case.

ML Platform

To speed deployment of machine learning into production, and to accelerate the training and management of ML models, many companies are creating ML platforms that can provide end-to-end capabilities such as data management; feature engineering; model training, evaluation, and governance; explainability; AutoML; and promotion between environments.

Anticipate

Still lacking in maturity, these technologies could have an impact in a few years.

Proliferation of industry-wide open standards

We're seeing a growing number of industry-specific standards that can help drive better interoperability between companies. Examples are GS1 barcode standards like Global Trade Item Numbers (GTIN) for product IDs, and the Fast Healthcare Interoperability Resources (FHIR) standard for the healthcare industry. There are also government-wide initiatives to encourage interoperability to give consumers more portability, such as the Open Banking initiative in the UK.

Advice for adopters

Think beyond platforms.

In most organizations today 'platforms' have momentum, mind share and often significant investment. But it's important while creating and building on platforms to also think about the ecosystems that are taking shape in your space, and to ensure the platforms and products that you build can be peers in something larger.

Act fast, and be flexible.

As with a biological ecosystem, the worst thing for participants in a technology ecosystem to do is stand still — they must continually compete and evolve. It's important to be somewhat opportunistic with your participation in ecosystems, and recognize other participants are likely doing the same. Participants may cooperate when it is clearly beneficial to them, but only until one party feels they can out-compete a rival or choose a better partner.

Consider the ecosystems of your customers.

Beyond technology, consider ecosystems from a go-to-market perspective. Ask yourself: are there opportunities to integrate better with your customers' ecosystems? Should you partner with other companies in order to create or extend an ecosystem of complementary products?

Look for new connections.

Challenge your existing notions of how your products interact with the outside world, as well as the scope of those interactions. Look for opportunities in those interactions to deliver more value to your customers, and to make your products and services more valuable by nature of them being part of an ecosystem.

By 2022, business will...

"... actively strive to build systems that are part of larger ecosystems, which will allow them to reach customers that they couldn't access otherwise. Combined with the fact that enterprises will be able to leverage technology created by others instead of struggling to build everything themselves, the evolving nature of platforms is a win-win proposition."

Zhamak Dehghani

Lens six

The expanding impact of hostile tech

'Hostile' technology is commonly associated with criminal activity such as ransomware, breaking into a system to steal data or creating computer viruses — but this misses the complete picture. The landscape is evolving in a way that the definition of hostile tech should be broadened to include legal, even widely accepted, acts which ultimately threaten societal well-being.

Through the Looking Glass

As technology grows more complex, the ways in which it can be misused rise. And as people rely more on technology in daily activities, they are increasingly subjected to unintended — even hostile — consequences. Add in a high level of automation — taking humans 'out of the loop' and making decisions at machine speed — and the possibility for things to go wrong rapidly escalates.

'Hostile' tech by our definition can encompass not just criminal tech such as malware and hacking tools, but also use cases like advertising and customer targeting. Whether a technology is hostile can be a matter of perspective. Some people don't find internet advertising, tracking cookies or social media influencing campaigns intrusive, and are happy to trade their data for what they perceive as personalized offers or special value. Others install ad blocking software in their browsers and eschew Facebook completely. Consenting to tracking or the collection of personal data is for some basically automatic; for others, a carefully considered choice.

What's more, not all hostile behavior is malicious or intended. One example is bias in algorithms or machine learning systems. These may exhibit hostile tendencies towards certain customer groups without ever having been compromised or deliberately designed that way.

Signals include:

- The increasing ubiquity of technology and concurrent expansion of the potential threat surface. One simple example is the sheer number of connections: IDC predicts the number

of active Internet of Things (IoT) devices will **grow to 55.7 billion by 2025**. Each of these comes with potential security breaches that could be exploited
- Evolving consumer sentiment and behavior towards ad and marketing tech, and increasing bifurcation between those who accept broad uses of their data and those who are more concerned about privacy
- Rising anxiety about the use and impact of social media in political campaigns, and how social media channels are shaping political and other societal debates
- Unintended consequences arising from increased use of AI and machine learning, such as bias in algorithms. Concerns about hostile impacts are prompting attempts to control the use of AI in **processes like hiring**
- Increased regulation around data collection, retention and use, such as the European General Data Protection Regulation (GDPR), the California Privacy Rights Act (CPRA), and equivalents in other jurisdictions

The Opportunity

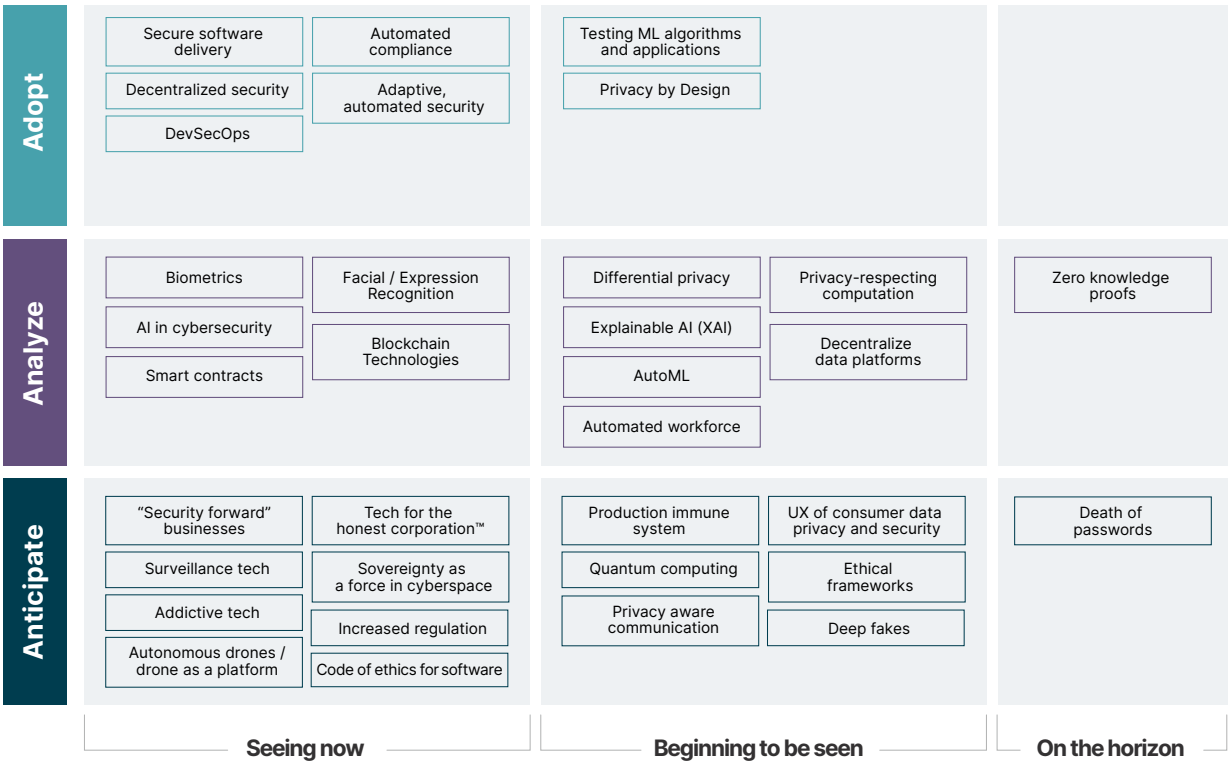
Protection against deliberate hacking and malware is increasingly important. Companies must invest in defending a wider range of touchpoints against well-funded and organized adversaries. Yet as the potential for danger rises, other dimensions of hostile tech also have to be considered. We believe that being respectful of customer wishes, avoiding 'spooky' targeting, and rooting out bias within algorithmic systems is not only inherently the right thing to do, but conducive to trust, positive public perceptions, and ultimately the health of the business.

According to **IBM**, the average global cost of a data breach in 2020 was US$3.86 million. In the first half of 2020 alone, European supervisory authorities **issued fines** totalling over €50 million for GDPR violations. With consumers placing a higher value on their privacy, robust privacy practices have become a strong differentiator for some companies. A recent **survey by McKinsey** found a clear majority of consumers will not do business with a company if they have concerns about its security practices, or believe it gives out sensitive data without permission.

What we've seen

In a seven-year partnership, we set out to help the UK government transform the way it interacted with and delivered public services to citizens, making trust and security a priority from the very beginning. The project united disparate government websites into a single robust and user-friendly platform, enhancing citizen experience and substantially accelerating deployment cycles. Importantly, the platform was backed by an online identification assurance system that allowed citizens to submit applications for services while meeting all necessary data protection requirements and respecting individuals' privacy rights. Minimizing the potential for negative outcomes and fostering confidence in the platform encouraged its rapid adoption.

Trends to watch



Adopt

Technologies that are here today and are being leveraged within the industry.

Secure software delivery

Treat delivery pipelines as the high-risk production systems that they are, since by design they are used to deploy software to your production environments. Understand security implications for data in-flight and at rest. Generate audit trails, and learn about and integrate anomaly detection solutions to help detect security incidents. Stay abreast of compliance laws that affect your region and the effect they have on your systems.

Analyze

Technologies that are beginning to gain traction, depending on industry and use-case.

Modern AuthZ

A combination of increased cyber-threats and liability, coupled with decentralized microservices architecture, have stretched traditional authorization (AuthZ) solutions. With the boundaries of network perimeter trust fading, authorization based on network location loses its effectiveness. Consider adopting approaches like **Zero Trust**, **BeyondCorp**, **BeyondProd**, and **Vectors of Trust** to modernize your AuthZ processes and incorporate a broader spectrum of factors in authorization decisions.

Anticipate

Still lacking in maturity, these technologies could have an impact in a few years.

Quantum computing

Quantum computing is a proven concept, but hasn't scaled and may take a long time to approach maturity. Though the full scope of its potential applications is not yet clear, it bears close watching as there is a threat that the encryption of many systems, and indeed the entire internet, could be easily broken using quantum algorithms such as Shor's.

Advice for adopters

Make security 'everyone's problem'.

Security is fast-moving and can't be the responsibility of just one person or department; people throughout the organization need to make it a priority. Similarly, you can't simply buy a security solution, install it, and consider yourself protected. Security considerations should be built into your product lifecycle from idea to production. Combine audits with monitoring so you can proactively discover breaches and respond quickly when they occur.

Promote your positive privacy stance.

Establish and communicate clear policies, such as promising customer data will never leave a device, as a business differentiator. Make sure these policies are fully understood by your employees and customer base.

Capture only the data needed to provide service to your consumers

Capture **only the data needed** to provide service to your consumers, rather than simply collecting everything possible. Gathering and storing data that is not business-critical only adds to the organization's technology and compliance burden, and creates a bigger target for hackers or other bad actors.

Create an explicit framework outlining your policies for detecting and avoiding bias in your systems

Create an explicit framework outlining your policies for detecting and avoiding bias in your systems, and promoting ethical technology practices. Brookings Institution's Algorithmic bias detection and mitigation: **Best practices and policies to reduce consumer harms** is an example.

By 2022, business will...

"... consider a wider range of negative implications than privacy and security breaches when developing and deploying customer-facing systems and products, and understand that robust action to minimize unintended 'hostile' outcomes can be a source of competitive advantage. For forward-looking companies, rather than a set of policies, security and ethics will be a practice evident in everything teams do."

Dr. Rebecca Parsons

Glossary

A

Accessibility
Digital accessibility is about ensuring that products, services, apps and web sites are properly available to everyone, including those who may need to use screen readers, larger fonts, or high-contrast modes.

Adaptive, automated security
As the arms race between attack and defense in computer security intensifies, there is an increasing need for sophisticated tools and techniques that can dynamically adapt to changing conditions.

Addictive Tech
Our ability to instrument user behavior at a very granular level, combined with psychological research and fierce competition for eyeballs and "engagement", has led to applications that are specifically designed to be addictive. While this might be good for companies in the business of selling advertisements to audiences, there is a growing societal and environmental harm from addictive tech.

Adversarial Machine Learning
The ubiquity of machine learning models has opened up the possibility of new types of cyber attacks. These attacks might involve tampering with training data, using brute force to identify specific inputs that a model classifies poorly and so on. When combined with opaque ML models, these attacks can become particularly insidious.

Affective (emotional) Computing
Systems and devices that can recognize, interpret, process, simulate and respond to human emotions are collectively called "affective computing."

AI as a service
The big cloud providers are increasing their offering of "ready-to-go" AI solutions as a service on their cloud platforms. Even as Cloud providers try to make it as easy as possible to use AI-as-a-service functionality, you still need a thorough understanding of how to apply different models to different problems and the engineering disciplines to do it well.

AI driven interaction
Chatbots, digital assistants and conversational AI technologies are here and we see an increasing trend to rely more and more on those engines.

AI in cybersecurity
AI is increasingly being deployed both defensively, to respond to threats more dynamically, and offensively, to probe for weaknesses in a system.

AI Marketplaces
AI solutions marketplaces such as AWS Marketplace, Google TensorFlow Hub, and MS Azure Marketplace enable smaller developers and companies to sell their models to a huge global market, and allows consumers to quickly leverage those models to create value.

AI-assisted software development
Artificial Intelligence is being used increasingly in all areas of software development, such as as code completion in IDEs, AI-created automated tests, or even AI that can detect bugs.

Alternative Currencies
Currencies other than money, such as cryptocurrencies or reputation-based currency. Increasingly this includes vendor specific reward based currency such as Starbucks Stars or Amazon Coins.

Ambient Computing
Ambient computing is the convergence of hardware, software, user interface, and human-machine interactions which allow a computer or device to be used "in the background" rather than explicitly.

Automated workforce
Automation has always been a trend in industry, and the COVID-19 crisis has accelerated some industries moving towards automating their workforce. Automation doesn't necessarily mean completely replacing humans. For example, human-machine 'teaming' may produce better results than either working alone.

AutoML
AutoML is an approach to partly automate the work of data scientists and Machine Learning Engineers, by automatically selecting and training machine learning models for specific tasks.

Autonomous corporations
A decentralized autonomous organization (DAO), also called a decentralized autonomous company (DAC), is an organization defined by rules encoded as a computer program that is transparent, governed

by the organization members, and not regulated by a central government. A DAO's financial transaction record and program rules are stored on a blockchain.

Autonomous drones / Drone as a Platform
A solution designed to manage drone fleets, providing services for the control and autonomous navigation of these devices. Drones can be used in different contexts including agriculture, delivery, inventory, inspection, and more.

Autonomous vehicles
Self-driving cars, trucks and public transport are under development and likely to be available soon, at least in limited deployment scenarios. While the headline focus may be on self driving cars, autonomous vehicles also have high potential for specialized industrial and business applications.

Addictive Tech
Our ability to instrument user behavior at a very granular level, combined with psychological research and fierce competition for eyeballs and "engagement", has led to applications that are specifically designed to be addictive. While this might be good for companies in the business of selling advertisements to audiences, there is a growing societal and environmental harm from addictive tech.

B

BCI - brain computer interfaces
The ubiquity of machine learning models has opened up the possibility of new types of cyber attacks. These attacks might involve tampering with training data, using brute force to identify specific inputs that a model classifies poorly and so on. When combined with opaque ML models, these attacks can become particularly insidious.

Big Suite Backlash
With a big suite of packaged software, the vendor owns all your data and has the keys to your solution. There is a growing worry of being held to ransom in the future despite current 'race for the bottom' pricing.

Biometrics
The use of human physical characteristics for authorization or access, for example fingerprint, facial recognition, or iris scanning.

Blockchain for sustainability
Blockchain is beginning to provide unique sustainability opportunities in fostering transparent collaborations between consumers and producers, by assisting people in adopting more sustainable lifestyles and helping companies improve their sourcing and recycling practices.

Blockchain Technologies
Blockchain is a nuanced term. Sometimes it's just used to refer to any technology that provides some mechanism to record digital transactions and facts with some level of trust. We can also speak of blockchain as an architectural pattern. Depending on your industry, it might be key to pay close attention to how blockchain technologies evolve and what kinds of applications start to emerge.

Business API as Product
Rather than building an API as a technical feature, treat it as a product that has customers and creates value, and that is supported by a long-lived product team.

C

Causal Inference for ML
Causal Inference studies techniques to draw cause and effect relationships between the input data and the outcomes. If Machine Learning models can learn causal relationships they become more generalizable and require less training data to perform well.

CD4ML
Continuous Delivery for Machine Learning (CD4ML) is a software engineering approach in which a cross-functional team produces Machine Learning applications based on code, data, and models in small and safe increments that can be reproduced, retrained, and reliably released at any time, in short adaptation cycles.

Circular Economy
According to the Ellen Macarthur Foundation:
A circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment. In contrast to the 'take-make-waste' linear model, a circular economy is regenerative by design and aims to decouple growth from the consumption of finite resources gradually.

Cloud portability
The ability to easily convert an application from one cloud to another, and in some cases the ability to leverage more than one cloud at once.

Code of Ethics for Software
With the increased use of AI and data in software, as well as the potential negative aspects of addictive tech, privacy, and user tracking, it may be time for software developers to create and adhere to a code of ethics for the software they create.

Collaboration ecosystems
The global move to remote working in 2020 has brought into sharp focus the need for better collaboration. Development teams will increasingly need the ability to start a remote environment, share a workspace with a colleague, and effectively pair on hard problems remotely.

Computational Linguistics
Natural Language Processing combined with Deep Learning has made a quantum leap in the last few years, with breakthroughs including new unsupervised training methods like Transformers which take advantage of the vast amount of text available on the internet.

Computer Vision
Computer Vision is the ability of machines to interpret visual inputs and continues to improve via deep learning applied to vast data sets. Increasingly, computer vision can be applied to existing video feeds such as security camera footage.

D

Dark Data Center
A dark data center is designed to run without lighting or direct human intervention in all but extraordinary circumstances. This brings energy savings, power usage effectiveness, reduced staffing costs and provides more flexibility for the site choice (away from population centers, for example).

Data locality
The mechanics of how we analyze data are changing. Sometimes due to data volumes or network speeds, computing needs to move to the data and not the other way around.

Data platforms & real-time analytics
Unlike traditional data warehouses, modern cloud-based data platforms or data lakes can provide real-time analytics and enable broad data discoverability.

Data Quality Test Automation
Data Quality Test Automation is the practice of automatically detecting data quality issues within a dataset, and the associated practices to manage and fix such issues. This automated process is an important aspect of the broader need for Test Data Management.

Death of Apps
As Siri and other intelligent digital assistants become more useful, consumers may stop using specific apps. There is also a rise in mini-apps, smaller versions of applications which might be part of a larger offering. Applications such as iMessage, WeChat and WhatsApp are including this capability.

Death of Passwords
Apple and Google have both added face recognition for unlocking devices and authentication for many applications. Biometric devices such as fingerprint readers are slightly more common than in the past. This may lead to the end of passwords as we know them.

Decentralized data platforms
There is a new trend towards building decentralized data platforms. One approach is the "data mesh" where the platform is organized around the domain and data is treated as a product, with each data product owned by a team. To enable speed and drive standardization, infrastructure teams provide tools that allow data product teams to self-serve.

Decentralized Security
Rather than using traditional security perimeters that are a single point of failure, techniques such as Zero Trust Networks instead decentralize security checks across the network.

Deep Fakes
Deepfakes (a portmanteau of "deep learning" and "fake") are synthetic media in which a person in an existing image or video is replaced with someone else's likeness, and represent a serious threat with their ability to spread disinformation.

Deep Learning Transformer Networks
Transformers are learning language models including text language syntax and semantics, powered by deep neural networks. Capable of unsupervised training on billions of pieces of text they can reach state-of-the-art results on multiple NLP tasks with only minor re-training.

Differential Privacy
Differential privacy aims to introduce noise in the dataset in such a way as to provide individual privacy while still allowing insights to be drawn or machine learning models to be built on top of the data.

Digital Carbon Management
A Digital Carbon Management program measures organizational green house gas (GHG) emissions and efforts to mitigation those emissions. Establishing a carbon footprint and a program to determine it is an essential component on the journey towards net zero and is the first building block towards any sustainability strategy.

Digital Ecosystems
In a digital ecosystem, each component can be considered an 'agent', with ecosystem participants cooperating as peers. These components range in size from small edge devices to large business or development platforms. An ecosystem may include multiple platforms exchanging information with each other and gaining value from the ecosystem as a whole.

Digital twin
A digital twin is a virtual model of a process, product or service that allows both simulation and data analysis. 3D visualization can be used together with live data, so you can understand what is happening to pieces of equipment you can't actually see.

Digitally enabled energy components
Digitally enabled energy components and products, such as electrified transport, are completely different from non-electrified alternatives, for example, petrol-powered vehicles. The software architecture of new and advanced electric vehicles surpasses petrol vehicles due to opportunities found when the whole vehicle is electric.

Distributed energy resources
Distributed Energy Resources (DERs) are a category of electrical power generation, such as solar panels, that are "behind-the-meter". DERs generate power for the utility scale grid and create credits for that generation to the DER owner (e.g. home owner).

DNA data storage
DNA — which consists of long chains of the nucleotides A, T, C, and G — is life's information-storage material. Data can be stored in the sequence of these letters, turning DNA into a new form of information technology. DNA is incredibly stable, as has been demonstrated by the complete genome sequencing of a fossil horse that lived more than 500,000 years ago.

E

Edge Computing
Edge computing brings data storage and processing closer to the devices where it is stored, rather than relying on a central location that may be thousands of miles away. This is done to prevent data, particularly real-time data, from suffering latency issues that can affect the performance of an application.

End of Moore's Law
Moore's Law predicts that the number of transistors on a chip will double every 18 months. While we can't say that Moore's Law is dead yet, the rate of change is slowing and the cost of change is increasing.

Enterprise XR
Extended Reality — an umbrella term for virtual and augmented reality and related technologies — is now being used in the Enterprise in places where the advantages can bring cost reductions or efficiency or safety improvements.

Ethical Frameworks
Any decision has consequences. In the tech world as AI decision making has started to emerge into the mainstream, ethicists have been discussing ethical decision-making frameworks to attempt to bring transparency and clarity into the decision making process.

Explainable AI (XAI)
Explainable AI refers to a set of tools and approaches to understand the rationale used by an ML model in reaching a conclusion. These tools generally apply to models that are otherwise opaque in their reasoning.

F

Facial / Expression Recognition
Detection of a human face, matching against a database of faces for identification purposes, and further, recognition of a person's emotional expression: happy, sad, frightened, etc.

Federated learning
An approach that downloads a machine learning model and then computes or trains a specific, modified model using local data on some other device. The approach helps multiple organizations to collaborate on model creation without explicitly exchanging protected data.

Few shot learning
A machine learning technique where models can be trained from only a few examples. It is used in computer vision and more recently in natural language tasks.

Fog Computing
Fog computing is a decentralized computing infrastructure where data, computation, storage, and applications are somewhere between the data source and the cloud.

G

Gaze Tracking
Monitoring a person's eyes to see where they are looking. Can be used to determine what a person is looking at on a retailer's shelf, for example, or even as a mouse-pointer replacement input device. In HMDs (Head Mounted Devices) gaze tracking can be enabled by including inward facing cameras and sensors.

Gesture Recognition
Machine understanding and interpretation of human gestures such as waving, making an "up" or "down" motion, hand positioning, and so on.

Green clouds
Green cloud computing at its best is a remote data centre, fed by renewable energy, running software and systems designed and optimized for efficient processing while also minimizing energy consumption.

Green software engineering
Software engineers have a responsibility to consider not just the ethical implications of the code they write, but the environmental sustainability too. Choice of language and technology stack as well as algorithm can alter the amount of carbon produced by software.

Green UX
Green UX is about designing user interfaces and prompts that help people understand the environmental consequences of the choices they make. This kind of UX could include an airline website displaying carbon emissions for flights or a mapping tool showing the carbon output for driving a particular route.

Growing Industry-wide open standards
Industry-specific standards can help drive better interoperability between companies, for example the GS1 standards like GTIN for product ids, the FHIR standard for the healthcare industry and the Open Banking initiative in the UK.

H

Health and longevity
Average human lifespans have been extending due to healthcare, science, and lifestyle improvements. New technology in editing DNA and using custom medicines and nutrition designed specifically for the individual is entering the commercial world. Furthermore, we see hybrid cell robots as the object of experimentation intended to work inside the body without rejection to support diseased organs.

Human-Machine Collaboration
The concept of "teaming" humans and machines is gaining traction. Rather than completely replacing humans, ML and AI applications are assisting us to better perform our jobs.

I

Intelligent agents and assistants disintermediate business & their customers
Intelligent agents, bots, natural language and machine learning allow us to complete tasks via a more convenient interface, such as talking to our phone. But if the primary interface between a customer and a business is a digital agent, rather than an app that the business directly controls, businesses and brands may become separated or 'firewalled' off from their customers.

Intelligent assistants, agents and bots
Intelligent assistants, agents, and chatbots are ubiquitous technology today, found on your mobile phone, TVs, computers, and smart home devices. These agents use natural language processing and speech recognition to interact with users.

Intelligent machine to machine collaboration
Machine-to-Machine (sometimes referred to as M2M) relates to the technologies enabling direct interaction of devices and information sharing between them, usually in a very autonomous fashion and leading to decision making - and acting - with little or no human intervention.

M

Managed Services and disposable solutions
Organizations can now access a range of building blocks as managed services, allowing them to create systems faster and with better capabilities. Because they're accessed as a service, they can be disposed of equally quickly.

ML Platforms
Many companies are creating ML Platforms that can provide the end-to-end capabilities such as: data management, feature engineering, model training, model evaluation, model governance, explainability, AutoML, model versioning, promotion between environments, model serving, model deployment, and model monitoring.

ML/AI on edge
IoT and mobile devices are becoming more powerful through specialized chips, enabling advanced ML algorithms to be run and trained on the devices themselves.

Mobile AR
Augmented Reality combines the physical world with a purely digital space. A limited form of AR is now ubiquitous, delivered via Apple and Android cell phones, which are capable of overlaying virtual objects to a camera view of the world. More advanced AR is delivered via a dedicated headset such as Microsoft's Hololens or Google Glass.

Modern AuthZ
Industry concepts like Zero Trust, BeyondCorp, BeyondProd, and Vectors of Trust suggest that we should move from AuthZ based on few rules to do with users and their locations and instead consider a whole spectrum of factors in authorization decisions.

N

Nanotechnology
Nanotechnology is the creation and application of things at the scale of 1-100 nanometers, and can can be used across fields such as biotechnology, chemistry, physics, biology, materials science, and engineering.

Neural Architecture Search
Neural Architecture Search automates neural network architecture engineering. It aims to learn a network topology that can achieve the best performance on a specific task.

Neuromorphic Chips
Neuromorphic chips use chip designs and algorithms, different from conventional chips, that are much more like how the human brain works. They use significantly less energy because, like the human brain, they don't require the processor to be idle as data moves to and from memory. They also exploit parallelism to a much greater extent than even GPUs and other specialized systems.

O

Online Machine Learning
Machine learning models are usually trained as an offline batch activity, performed over a static dataset. Online Machine Learning is technique where algorithms continuously learn based on the sequential arrival of data.

Operationalize AI
AI has proven itself in the lab, but organizations must now work to integrate AI and ML into their core processes, products, and IT environments, to truly operationalize it and reap the benefits.

P

P2P Technologies
In computer systems, peer-to-peer (or P2P) refers to a distributed systems architecture in which participants interact directly with each other, without centralized control.

Personal Information Economy
Personal Information Economy refers to the business model that aims at extracting business value (or valuation) from the possession and or use of large amounts of personal information.

Personalized Medicine
Much of the research and active work in personalized medicine is around understanding an individual patient's genetic profile to identify potential issues before they happen and provide more effective treatments in response to existing conditions. In the past several years we've seen this expanded to devices and applications that do things like monitor glucose levels in order to provide personalized recommendations on diet and other contributing factors.

Precision "X"
Precision technologies can now be applied to a wide range of applications and domains. Such technologies provide highly customized responses based on inputs from sensors.

Privacy aware communication
Increasingly, consumers are concerned about their privacy, and communications software now directly advertises its security stance and features. Examples include various providers offering end-to-end encryption, consumer concern around Zoom privacy and the company's response, or TikTok's 'malware' concerns and government responses.

Privacy by Design
Privacy by Design advocates that privacy assurance must become part of the organization's mode of operation. Privacy considerations should not be a siloed concern, but present throughout the whole system development and operational process and owned by all the development team.

Privacy-respecting Computation
With the obvious rise in importance of privacy for user data, new techniques have been developed that allow stronger guarantees for privacy even when personal data is used in computations.

Private IoT PaaS Platform
While public clouds can provide scalable solutions for IoT, the 'per-message' costs can be high. Some organizations instead choose to build a private platform for their IoT devices.

Production Immune Systems
Production Immune Systems monitor metrics and take corrective action if a problem is detected. They are often used for security, but increasingly also for resilience and recovery in the face of an outage.

Progressive Neural Networks
Neural Networks have great learning abilities, but when trained on a new task they often 'forget' how to perform a previously learned skill. Progressive Neural Networks may offer an approach that avoids this drawback.

Q

Quantum Computing
Quantum computing uses probabilistic states of photons, rather than binary ones and zeros, to run algorithms. Although proven to work in the small, quantum computing has yet to scale to broadly useful applications.

R

Retinal projection
Retinal projection creates a visual image by scanning a low power laser beam directly onto the retina. For AR applications, the method has some big advantages, such as producing high contrast, bright, high resolution images, working well in bright sunlight and eliminating focus concerns.

S

Satellite Networks
SpaceX and Amazon's satellite systems provide high-speed, low-latency broadband for places where traditional fiber or wireless network providers won't spend the money to connect. The systems comprise ground-based transceiver stations that fiber-connect to the Internet, end-user terminals, and satellite operations centers. Starlink will also provide backhaul solutions for wireless carriers to broaden coverage of LTE and 5G service to new regions.

Secure Software Delivery
The requirement to include security earlier must include the entire system, which in modern architectures means it includes the delivery pipeline used to build, test, and deploy applications and infrastructure.

"Security Forward" Businesses
We're increasingly seeing an emphasis on being trustworthy custodians of customer data, albeit primarily as a PR strategy. Apple in particular has taken a pro-privacy stance in a number of high profile cases.

Shared tenancy for container clusters
Shared Tenancy for this trend is the practice of many teams or applications sharing a compute resource such as a Kubernetes cluster. Often this is done with the goal of reducing the management overhead and opportunity cost related to working on cluster management instead of core software, but comes with several trade offs.

Smart cities
A smart city is an urban area that uses different types of IoT sensors to collect data coupled with platforms to integrate and act on the data, advising or commanding digitally enabled systems to perform some response. Insights gained from the data are used to manage assets, resources and services efficiently; in return, that data is used to improve the operations across the city.

Smart Contracts
A smart contract is a programmable business agreement that allows for automatic execution of actions according to agreed terms.

Smart Energy Management Systems
Ubiquitous availability of energy usage data via measurement equipment, APIs and tools gives a range of energy players (generators, distributors, suppliers, vendors) and customers more ability to understand and analyze their energy usage.

Smart Systems and Ecosystems
Smart Systems and Ecosystems are networks of networks. With ML and AI, an ecosystem can become more than the sum of its parts, for example in a smart city where networks of cars and roadside sensors help speed the flow and safety of traffic.

Sovereignty as a Force in Cyberspace
The internet has largely remained one freely connected network since its inception. However there are rising forces leading to internet balkanization — the splintering of the internet — many led by nation states. Privacy legislation — such as GDPR — also accelerates this process, as it enforces data rights, data sovereignty, and strongly impacts how companies deploy and distribute systems and data on the Internet.

Surveillance tech
From smartphone apps that deliberately gather data and "phone home" with their owners' secrets to cheap machine vision systems that create databases of car license plates as they drive past, surveillance is everywhere.

Systemic Design
The emergent field of systemic design integrates systems thinking and human-centered design with the intention of helping designers cope with complex design projects. Systemic design is a response to the increased complexity caused by globalization, migration and sustainability, that has rendered traditional design methods insufficient.

T

Tech for the Honest Corporation™
There is an increasing need for corporate transparency. If companies were open by default — with appropriate privacy built in — they would gain trust and increase brand strength.

Testing ML Algorithms and applications
Machine Learning models are usually non-deterministic, and their overall accuracy is heavily dependent on the quality of the data and the data science approach used while building them. Testing ML algorithms and applications therefore requires a unique approach.

Touchless interactions
There may be an increased desire to interact with devices without touching, at least partially as a result of the COVID-19 pandemic. Technologies such as Ultraleap and Soli promise to accurately track hand movements and enable touchless interactions.

U

Ubiquitous Connectivity
"Providing connectivity to everyone and everything, everywhere, every time" — this is the promise of ubiquitous connectivity. Futurists talk of innovation springing up from currently resource-limited parts of the planet, whilst critics say that it is an unnecessary set of functional privileges that only some will be able to use and afford.

UX of consumer data privacy and security
An increase in consumer demand and regulation related to privacy requires new thinking about the user experience around management of data. Multiple disclaimers and notifications may result in users agreeing to policies they don't understand.

V

Voice as a ubiquitous interface
Voice — both speech recognition and speech synthesis by machines — increases its position as the dominant interface. Increasingly, this is true not only for computing devices like smartphones and home assistants but also things like television remote controls.

W

Wearables
Wearables like smart watches are commonplace now, but the technology is rapidly expanding in both feature sets and interactions. For example, the latest Apple Watch includes technology for measure blood oxygen levels, in clear response to the COVID-19 crisis.

Z

Zero Knowledge Proofs
A zero-knowledge proof is a method by which one party (the prover) can prove to another party (the verifier) that something is true, without revealing any information apart from the fact that this specific statement is true.

#

4D Printing
4D printing adds the dimension of transformation over time to 3D printing, utilizing a type of programmable matter.

5G
Fifth generation cellular networks promise increased bandwidth, lower latency, and higher device density. This will allow much deeper interaction with IOT devices.

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