# Looking Glass

**Bringing tech-led business changes into focus**

/thoughtworks

2022

# Bringing tech-led business changes into focus

**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 100 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 100 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**

# Partnering with AI

Machine learning (ML) and artificial intelligence (AI) continue to gain traction across industries. We are seeing rapid adoption in use cases that range from automating everyday operational processes, to augmenting strategic decision-making. By better understanding the respective strengths and limitations of humans and machines, businesses can develop balanced and productive partnerships between their people and AI to extract maximum value from emerging technologies, while remaining mindful of the potential ethical implications.

## Through the Looking Glass

To truly partner with AI, we can't view it as a tool to solve every business problem. Instead, we must understand where it excels, where it requires human agency to fulfil its potential and where it might prove ineffective.

Some business problems — for example those that necessitate leveraging historical data or fast digital feedback loops — can be addressed by applying AI to completely automate processes or decision-making. However for others — especially those that require creativity, intuition and slower strategic feedback loops — AI's role is best structured as augmenting human talent.

As AI-supported techniques become more mainstream, they can touch on more areas of our lives and their impacts need to be considered from an ethical perspective. This is driving research and tooling to support **explainable AI (XAI)** and more robust governance processes, including **automated compliance**.

**Signals include:**

- A continued surge of investment in AI research and applications. Research firm IDC estimates the **worldwide AI market will exceed US$500 billion by 2024**
- Continued high demand for ML, AI and data specialists in the job market. According to **LinkedIn**, AI specialist was the fastest-growing job category in 2020, while **Glassdoor** ranked data scientist as the number two best job in the United States in 2021
- Increased growth in ML/AI start-ups, specialized products, IPOs, and acquisitions. In October 2021, Exscientia — a UK company that put the world's first three AI-designed drugs into phase one human testing — went public on the NASDAQ with a **valuation of US$3 billion**

- Changes in existing jobs and roles. The World Economic Forum estimates that **by 2025, 85 million jobs may be displaced by a shift in the division of labour** between humans and machines, while 97 million new roles may emerge
- Increased public awareness of situations where AI had unintended consequences. For example, **facial recognition has repeatedly been in the news** due to privacy concerns, and **racial bias** has been found in Twitter's image cropping AI. Despite that, **there are concerns** that ethical AI design will not be the norm within the next decade
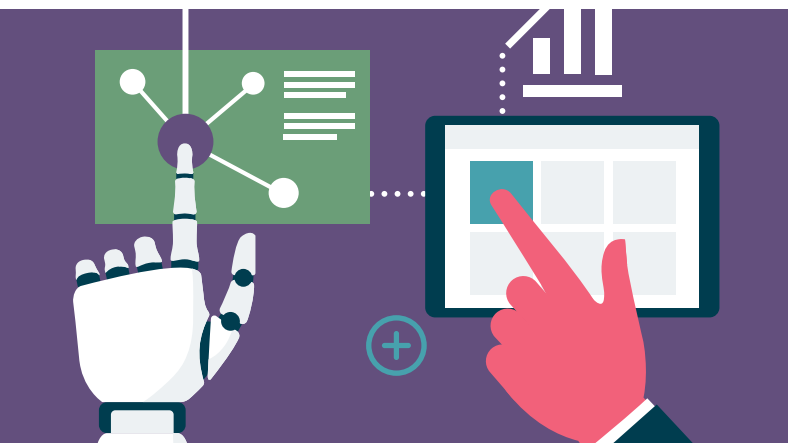
**The work of humans will benefit from AI/ML augmentation, with human and machine performing combined or complementary roles**

## The opportunity

Most enterprises understand automation can improve workforce productivity, by automating repetitive, mundane and data-crunching tasks. This can fundamentally change or even remove the need for some jobs, but new roles will also be created where people are shifted to higher value activities that require judgement and creativity. Typical areas that can benefit from automation include dynamic pricing, recommendation systems, anomaly detection and supply chain optimization.

In other cases, the work of humans will benefit from AI/ML augmentation, with human and machine performing combined or complementary roles. These tend to address problems that require creativity, intuition, experience and holistic thinking. They involve important strategic decisions that don't get made very frequently — e.g. "What product should we sell next?" or "How can we achieve net-zero emissions?" — but can benefit from machines helping simulate and explore different outcomes, or even to generate ideas that humans can then evaluate. Examples include AI-first drug or product development and dynamic simulations for planning complex scenarios like climate change.

All these applications demonstrate how AI can deliver value across the entire organization: by improving internal operations and informing better business decisions, all the way to product innovation and improving customer experience.

## What we've seen

**Forenom** is a rapidly growing serviced apartment provider offering thousands of rooms in all major Scandinavian cities. Over 200,000 guests stay at Forenom locations every year. Their revenue management team had to spend hours of manual labor to update prices in their old system. To improve operational efficiency and maximize revenue per room, we replaced the older pricing system with an online reinforcement learning model that implements a dynamic pricing strategy. The AI solution delivered a 13% increase in revenue and proved that automating operational decisions can deliver significant business results.

We have also seen a successful partnership with AI using computational creativity for product R&D. We worked with **Mackmyra**, a Swedish distillery, to launch the first AI-created whisky, employing machine learning to create hundreds of different recipes that the human master blender could choose to produce. This was not designed to replace the master blender, but to help them explore the full range of possibilities. The whisky was generated by AI, but curated by a human. Intelligens has received numerous awards, ranging from American Distilling Institute's Gold Label and Best International Malt Whisky trophies to the world-renowned ADC Silver Cube in Product Design.
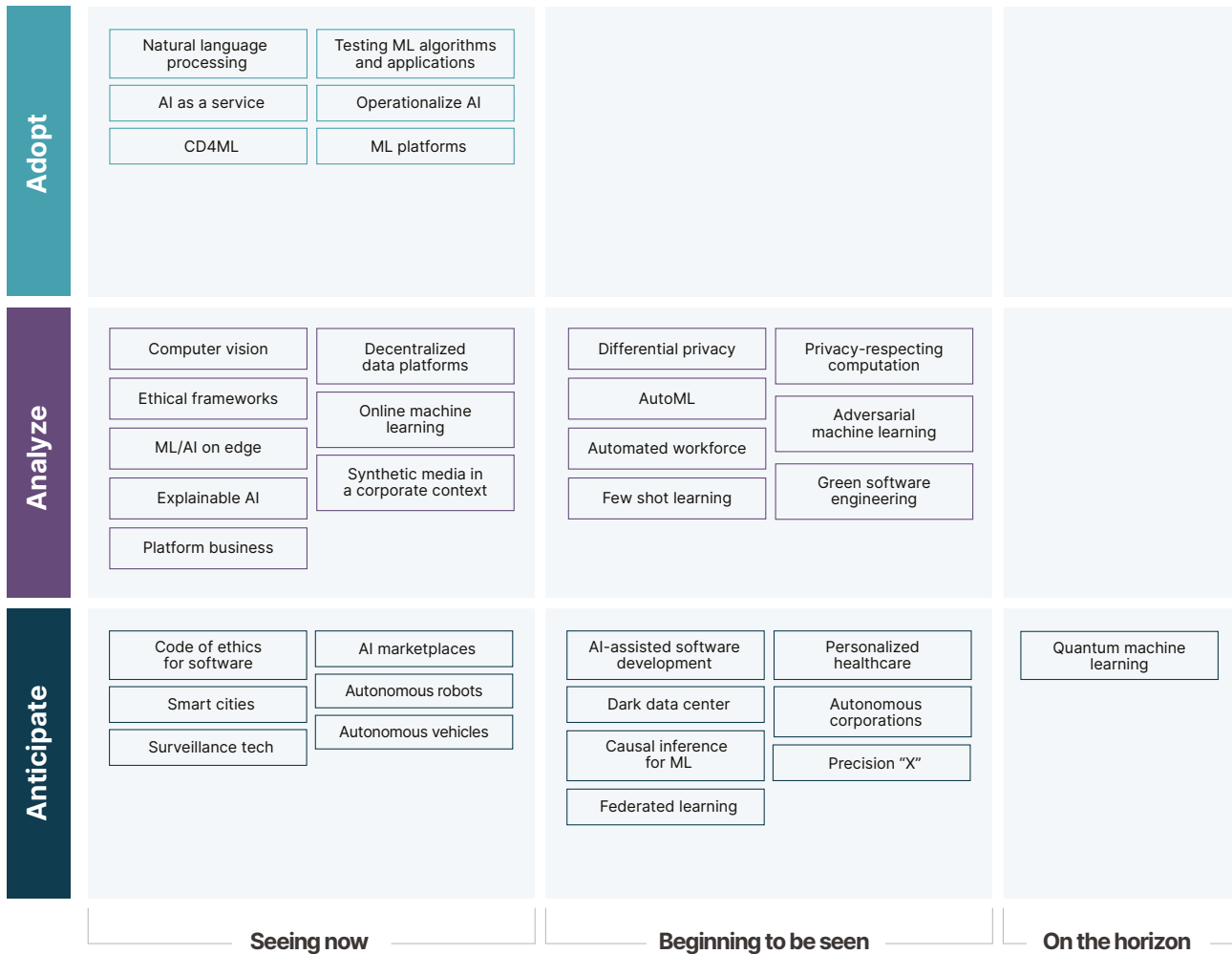
**By 2023, businesses will...**

**"... understand that AI is not the art of trying to force value out of historical data, but actually the art of creating new data and insight by interacting with the world."**

**Jarno Kartela**, Global Head of AI Advisory, Thoughtworks

# Trends to watch

| | Seeing now | | Beginning to be seen | | On the horizon |
|---|---|---|---|---|---|
| **Adopt** | Natural language processing | Testing ML algorithms and applications | | | |
| | AI as a service | Operationalize AI | | | |
| | CD4ML | ML platforms | | | |
| **Analyze** | Computer vision | Decentralized data platforms | Differential privacy | Privacy-respecting computation | |
| | Ethical frameworks | Online machine learning | AutoML | Adversarial machine learning | |
| | ML/AI on edge | Synthetic media in a corporate context | Automated workforce | Green software engineering | |
| | Explainable AI | | Few shot learning | | |
| | Platform business | | | | |
| **Anticipate** | Code of ethics for software | AI marketplaces | AI-assisted software development | Personalized healthcare | Quantum machine learning |
| | Smart cities | Autonomous robots | Dark data center | Autonomous corporations | |
| | Surveillance tech | Autonomous vehicles | Causal inference for ML | Precision "X" | |
| | | | Federated learning | | |

## Adopt
*Technologies that are here today and are being leveraged within the industry*

## Analyze
*Technologies that are beginning to gain traction, depending on industry and use-case*

**Operationalize AI** — At many enterprises, AI and ML adoption is shifting from experimentation to production, growing closer to the customer. On top of developing the technical capabilities to train, deploy, and monitor ML systems (such as CD4ML), there are also process and operational issues that need to be considered. First of all, the governance process to deploy AI and ML needs to take into account audit, explainability, ethics, bias and fairness concerns. Secondly, the business needs to be willing and ready to adopt AI and ML solutions once they are released, which might require change management — especially when roles are impacted.

**Online machine learning** — Machine learning models are usually trained as an offline batch activity, performed over a static data set that doesn't evolve over time. The need to re-train models more frequently is exacerbated when the data itself changes at a fast pace. Online machine learning techniques enable solutions to continuously learn based on the sequential arrival of data. Reinforcement learning is an example of such techniques, which are less dependent on historical data and is being applied in areas like content placement, personalization and dynamic pricing.

## Anticipate

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

**Causal inference for ML** — Many machine learning techniques use statistical methods to learn, by finding correlations between variables. This works well when the data used for inference has not changed much from the training data. However, correlation doesn't imply causation. Causal inference studies techniques to draw cause and effect relationships between input data and the outcomes. If machine learning models can learn causal relationships, they become more generally applicable and require less training data to perform well. We are beginning to see research trying to apply causal inference-informed ML to real world problems, especially in medical diagnosis scenarios.

## Advice for adopters

**Understand when to use automation vs. augmentation.** There are processes or roles that AI and ML can automate completely, and others where they can assist humans to make better decisions, and it's critical to understand the difference.

**Operationalize AI experiments, taking a holistic approach.** Consider the business readiness for adoption and the change management required, and build a robust technical and governance process to deploy your AI/ML solutions.

**Consider the ethical implications of AI/ML and take the responsibility seriously throughout.** AI and ML are extending into complex and sensitive areas such as financing, sentencing and medical diagnostics, where the impact of decisions can have unintended consequences. Bring any potential implications into consideration early on to assess and catch any issues before it's too late.

**Prepare your staff for changes to their roles.** Don't underestimate the effort required to support and empower employees that can be affected by AI impacting their jobs. Automation can free them up to perform higher-level tasks, while augmentation can help them be more productive. Develop clear transition and career progression plans for them to grow and thrive.

**Choose your KPIs carefully.** Understand the metrics you are trying to move with AI and ML; measure the current process to capture your starting baseline; and use KPIs to evaluate if AI and ML are delivering real business benefits. With the appropriate benchmarks in place, even if a particular AI/ML approach does not work, you can experiment with different techniques to achieve the desired outcome.

**Invest in robust data governance and data management practices.** AI/ML techniques still require access to data, and if your data is siloed and hard to access, progress will be painstaking. Consider where data ownership sits within your organization as data quality problems tend to emerge from organizational structures and architectures that don't incentivize teams to produce and share the data resources they have.
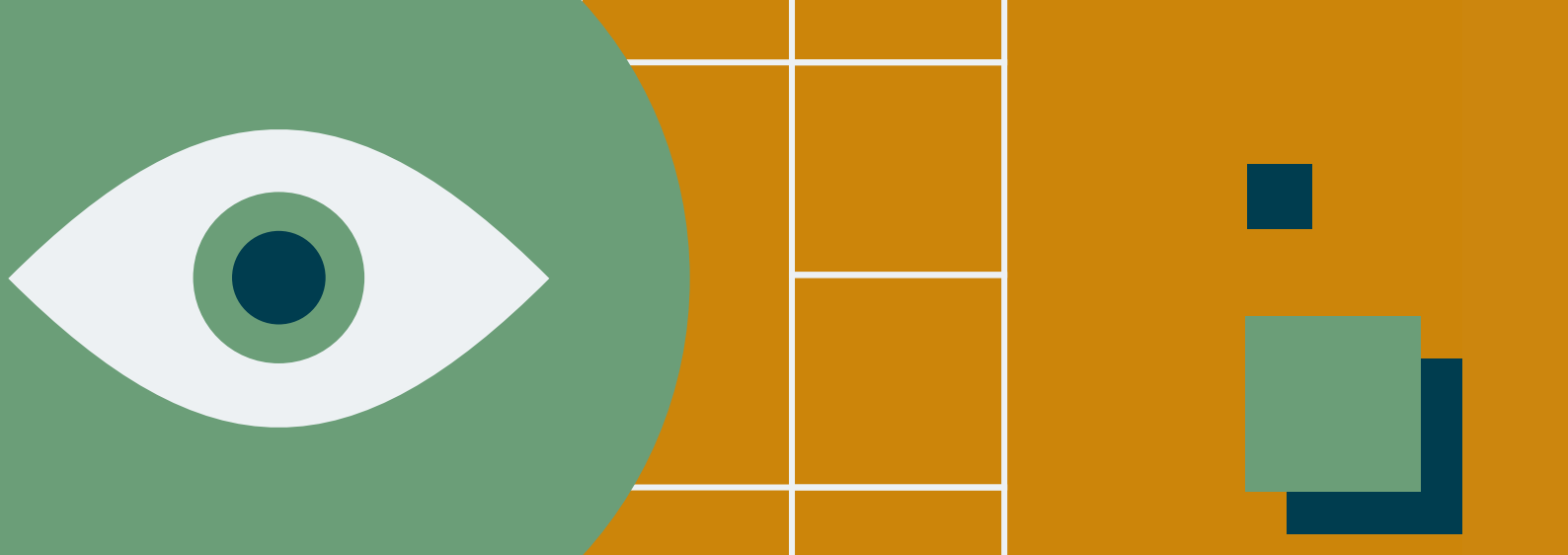
# Evolving the human-machine experience

We are changing the way that we interact with the digital world and what we expect from it. Traditional devices are extending their reach with gestures and voice interaction and real-world scenarios are being tested through the use of digital twin simulations that guide consumers and model results. In moving with some inevitability toward the **metaverse**, the physical and digital worlds will further converge in a way that will open new possibilities for businesses.

## Through the Looking Glass

Interfaces continue to evolve across gesture, voice and touch — engaging all the senses. Devices that work with us in our everyday lives are commonplace and a richer pairing of software and hardware. Devices themselves are becoming more ergonomic, designed to slot into everyday interactions with minimal disruption. We now see more intelligent devices, with local and cloud-based AI solutions supporting day to day decision-making.

Autonomous driving is not the only example of evolving interactions but provides powerful examples of this lens in action. We've moved very quickly from real-time, traffic-based mapping services, to self-driving cars that are constantly simulating all the possible future actions of the vehicles on the road to realize lower risk outcomes. In an autonomous vehicle, instead of focusing on making small adjustments to steering, you can concentrate on the bigger picture. Perhaps the car notifies you of a major traffic incident. It can route around it but you are also able to investigate and pursue completely alternative goals, such as stopping for a meal now instead of after arriving at your destination.

Facebook's plans for the metaverse have unleashed a torrent of hype and various big players are already jockeying for position. Yet the concept of a fully digital world is far from new. The first million-dollar virtual property was sold in Second Life 15 years ago. What has changed is that higher spec devices — such as phones and wearables — are in most people's possession, making it possible to access new digital worlds in some form almost instantly. Even more specialized devices are sure to follow. Enterprises and investors are realizing this is the new frontier and that the way we work and live our lives will again change via the medium of technology.

**Signals include:**

- A surge of investment in extended reality (XR) consumer solutions in readiness for the metaverse and related services
- Increasing numbers of players entering the metaverse market alongside Facebook and Microsoft. **Tencent** recently announced their intention to build a metaverse platform, while **Nike** is positioning itself to become a virtual apparel provider
- Rising investment from hardware vendors providing pre-rendered and streamed XR experiences as they move the heavy lifting to the cloud
- While we're still waiting for a consumer-grade augmented reality (AR) device from a player such as Apple, such an announcement could come at any time and will prompt the market to move quickly



**The global metaverse market is expected to grow at over 40% per year, reaching US$800 billion by 2028**

Analysis by Emergen Research

## The opportunity

People expect more from their interactions. It's not just about function over form anymore: we want devices to look good, feel good, understand our emotions and be more aware of our needs. Providing service of this kind is table stakes, doing it well is the goal.

New on the horizon this year is the metaverse. Consumers have demonstrated enthusiasm for new platforms driven by fundamental trends and the metaverse hopes to be one such example. We will see new devices, as well as extensions to existing devices such as phones, designed for this emerging environment. It is also likely that we will see different companies provide competing environments. As Second Life has already demonstrated, it's not just advertising revenue that will monetize these platforms; there are a myriad of possible products and services and it is already a proven model at a smaller scale.

The evolution of interactions can also contribute to the bottom line. The global metaverse market is expected to grow at over 40% per year, reaching US$800 billion by 2028, according to the latest analysis by **Emergen Research**.

> **"Thoughtworks contributed significantly, innovating in the areas of 3D apps, certification and compliance enabling Lenovo to establish ThinkReality as the preferred enterprise solution in the AR/VR space."**
>
> **Vikram Sharma, Engineering Director, Cloud Solutions & Platform, Lenovo**

## What we've seen

Lenovo was in the process of building their new ThinkReality Platform — a next-generation augmented reality (AR) solution that transforms work and enhances productivity in office and industrial settings both large and small. The platform is designed for remote assistance and collaboration, workflow support and 3D visualization while bringing existing enterprise applications into AR. ThinkReality encompasses smart glasses and head mounted displays, cloud technology and device support.

With the ThinkReality platform, Lenovo has established strong credibility in the Enterprise XR space, offering enterprise-ready products and quickly iterating on their platform.

### By 2023, businesses will

**"...begin to understand that the expanding frontiers of interaction don't just pave the way for richer customer experience but can actually drive business and process improvements, by pairing technology-based speed, scale and precision with human capabilities and ingenuity."**

**Kate Linton, Head of Design, Thoughtworks**

# Trends to watch

| | Seeing now | | Beginning to be seen | | On the horizon |
|---|---|---|---|---|---|
| **Adopt** | Smart systems and ecosystems | Intelligent assistants, agents and bots | | | |
| | Natural language processing | Increasing role of decentralized workforces | | | |
| | Enterprise XR | | | | |
| **Analyze** | Biometrics | Augmented reality | Ambient computing | Autonomous robots | |
| | Computer vision | Connected homes | Green UX | | |
| | Touchless interactions | Gaze tracking | | | |
| | Facial recognition | Synthetic media in a corporate context | | | |
| **Anticipate** | Digital twin | | Privacy-aware communication | Brain computer interfaces | Metaverse |
| | Gesture recognition | | Retinal projection | Data locality | |
| | Addictive tech | | Affective (emotional) computing | | |

## Adopt
*Technologies that are here today and are being leveraged within the industry*

**Natural language processing** — The ability to interpret human language — converting speech into text, and text into meaning — continues to improve, with impressive capabilities just a cloud API call away. The most obvious use-case for this technology is in customer service, where 85% of requests are customer initiated and an immediate response is preferred. But NLP can also be used to understand sentiment, create summaries of larger texts, interpret legal documents such as contracts, and much more. This makes NLP widely applicable, beyond the customer service department.

## Analyze
*Technologies that are beginning to gain traction, depending on industry and use-case*

**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.

## Anticipate

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

**Metaverse** — Seen by some as the future of the internet and others as the next stage in human evolution, the metaverse could offer compelling, integrated virtual environments to visitors. These virtual worlds have been around for a while but with progression in headset resolution and power, as well as the ability to create content in realtime in the cloud and stream to headsets, the experience promises to be more advanced. We are seeing large companies, retailers and governments all considering how to construct or participate in the metaverse.

## Advice for adopters

**Many of these emerging technologies require specialized knowledge which is not common in traditional enterprise software development.** For example, users will interact in a VR environment in completely different ways than they interact with web-based applications. This requires the application creators to think about user experiences in entirely new ways. Organizations wishing to leverage these new experiences need to start building capabilities now.

**Consider B2B opportunities.** Emerging interfaces will without question present a wealth of opportunities in the B2C world but many B2B possibilities will also be created that businesses should explore. Training, conferencing, gaming and virtual worlds are the classic examples but there are even more inventive ways in which devices and AI can partner with a human agent to produce better outcomes in the professional context, such as intelligent, self-piloted drones in agriculture or rescue.

**The rollout of solutions will be hampered by available capabilities and to some extent by the race of the dominant technology sets.** Relatively simple AR offerings are translating into available products and will become more commoditized over time.

**Bear in mind that these technologies change the user experience and design process.** In XR for example, working across multiple dimensions well is a challenge but emotional interactions also need to be considered. People represent differently in virtual worlds, which can have moral and ethical implications.

**Be prepared for change.** A certain degree of vendor lock-in is inevitable, whether in devices, digital worlds or the data that they generate. Accept this but also be prepared for change. Embracing one platform may be the best solution for your organization now but not necessarily over the longer term, depending on how the ecosystem and your needs develop.

**Lens three**

# Realizing the potential of platforms

Platform building is core to modern business strategy — yet also an area that's fraught with ambiguities. Even within a business, views on what a platform is and the purpose it's designed to serve can vary widely. The result is that for all the excitement around platforms, many organizations are disappointed in the results they get from their platform investments. This stems not just from the inherent difficulty of doing platform building well but often from fundamental misalignment on the kind of value the platform is designed to achieve. As platform failures mount we see a new focus on resolving the uncertainties around platforms and connecting platform building to clearly defined business goals.

## Through the Looking Glass

Recognizing that they're increasingly critical to competing in the digital economy and getting assets into production faster, most organizations have embarked on platform-building initiatives of some description, usually starting with technology or infrastructure. However research and our own observations demonstrate many of these efforts are ultimately unsuccessful. Not surprisingly there's a lot of disillusionment surrounding platforms as a result and organizations are asking themselves how they can achieve the benefits platforms seem to promise.

A successful platform approach depends on nailing down definitions. Platforms can drive various kinds of value and misunderstanding or misalignment among stakeholders regarding these will lead to subpar or wasted efforts. For example, if the goal of the platform is to extend the business's capabilities, little will be derived from a developer-focused infrastructure platform, even though this is an important foundation for building everything else.

When planning a platform it's important to not just put business value squarely in the frame but also to define precisely what kind of value you're trying to achieve and how it will be measured — and to ensure all key stakeholders understand and share these goals. Any uncertainties in platform building will weigh on performance and frustrate those who green-light such projects. We anticipate a shift from developing 'platforms for platforms' sake,' towards platform building with a laser focus on specific outcomes.

**Signals include:**

- 'Platform-enabled' businesses bringing new services and value to their customers faster than competitors — and sparking 'platform envy' as a result. The pandemic has highlighted the gulf between businesses with a robust, production-ready platform and those lacking practical platform capabilities, with some companies struggling and others (like Spotify with its recent shift to original content) adeptly pivoting in response to changing conditions. It's important to bear in mind these successes do not mean the platform-enabled business model should be the end-goal for every business or even for every platform-building initiative. Sometimes, just putting more resilient infrastructure in place is more important
- More organizations feeling dissatisfied with their platform building efforts. Platform initiatives that are seen as unsuccessful can lead to disjointed or competing efforts within a company, or even software being built outside the 'official' platform, as more people attempt to take matters into their own hands
- Cloud vendors packaging offerings and providing consulting services to help customers create platforms efficiently and in a way that reduces time to recognizable value

## The opportunity

By understanding there are various platform paths to pursue, then agreeing on what they're specifically building and how that advances their overall strategy, businesses can be confident their platform investments will enable them to explore new opportunities and deliver financial, operational or other benefits. Broadly speaking, there are three distinct types of platform commonly in development today:

- **Developer-focused infrastructure platforms** that provide a 'paved road' to production, increasing technical quality, improving time to market and mitigating risk through a common, validated approach to security and compliance
- **Business capability platforms** that accelerate new product development by providing a set of APIs (application programming interfaces) that capture existing business capabilities, making it easier to mobilize and combine these to create new products in response to customer demands, or to repurpose existing value in new ways. These platforms help an organization directly target outcomes like customer engagement and satisfaction and ultimately revenue
- **Platform business models** where a company creates value by facilitating interactions among consumers, peers and service providers, with all participants benefiting from a 'flywheel' effect as the platform grows and scales

Platform business models tend to hog the spotlight but most organizations really need a business capability platform, which will typically be built on top of an infrastructure platform. Separating these concepts — and their consumers — and creating clear measures of success for each are critical steps on a rewarding platform journey.

## What we've seen

**AvidXchange** is the industry leader in automating invoice and payment processes for mid-market businesses. They wanted to reduce complexity and adopt a microservices architecture in order support their growth goals and deliver additional value to their customer network.

Beginning in 2019, AvidXchange used our Digital Platform Strategy blueprint to evolve and accelerate a number of programs, including: a unified invoicing system; an agile transformation office; enabling continuous delivery by implementing core product practices; instituting leading tools and practices to increase developer effectiveness; establishing a delivery infrastructure; restructuring their engineering practices and architectures to host a microservices approach in order to create a strong, functional delivery infrastructure; and bringing alignment to their technology and product roadmaps.

The efforts have increased the capability, speed and efficiency of AvidXchange's production ability and technology operations. They increased releases by 250% versus the prior year and reduced solution architecture work cycle times by 65%.

### By 2023, businesses will...
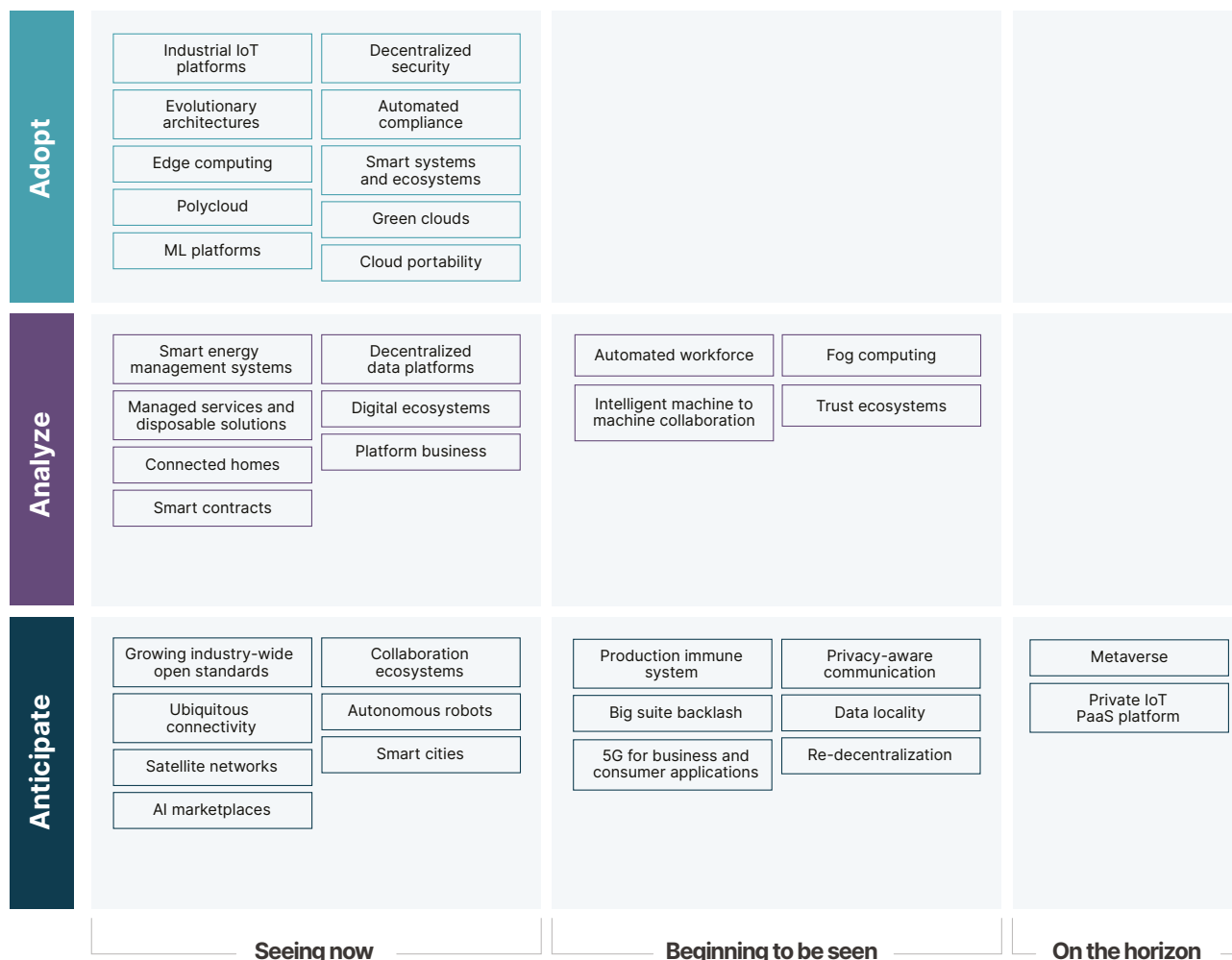
"...understand simply building a platform isn't necessarily enough to achieve their ambitions and that developing a strategy that clearly sets out how the platform connects to the organization's immediate and long-term priorities is just as critical as technology to peak performance."

**Rachel Laycock, Global Managing Director, Modernization, Platforms and Cloud, Thoughtworks**

# Trends to watch

| | Seeing now | | Beginning to be seen | | On the horizon |
|---|---|---|---|---|---|
| **Adopt** | Industrial IoT platforms / Decentralized security / Evolutionary architectures / Automated compliance / Edge computing / Smart systems and ecosystems / Polycloud / Green clouds / ML platforms / Cloud portability | | | | |
| **Analyze** | Smart energy management systems / Decentralized data platforms / Managed services and disposable solutions / Digital ecosystems / Connected homes / Platform business / Smart contracts | | Automated workforce / Fog computing / Intelligent machine to machine collaboration / Trust ecosystems | | |
| **Anticipate** | Growing industry-wide open standards / Collaboration ecosystems / Ubiquitous connectivity / Autonomous robots / Satellite networks / Smart cities / AI marketplaces | | Production immune system / Privacy-aware communication / Big suite backlash / Data locality / 5G for business and consumer applications / Re-decentralization | | Metaverse / Private IoT PaaS platform |

## Adopt
*Technologies that are here today and are being leveraged within the industry*

## Analyze
*Technologies that are beginning to gain traction, depending on industry and use-case*

**Cloud portability** — The ability to shift applications and data to new cloud computing environments quickly and relatively effortlessly will give organizations more freedom to choose providers with expertise or solutions that serve dedicated platform needs.

**Digital ecosystems** — Disparate participants, systems and even organizations that cooperate, collaborate, and compete to create an emergent ecosystem where the whole is greater than the sum of the parts. Examples include the travel industry, online marketplaces, and new "super apps" such as Gojek and WeChat.

## Anticipate

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

**Re-decentralization** — The internet and the World Wide Web were designed to be robust in the face of failure, but today a small number of companies — Amazon, Google, Facebook and others — host 75% of web traffic. Outages and security breaches now have a much greater impact due to this centralization. With the rise of blockchain and other distributed technologies we may see a return to a more decentralized 'net.

## Advice for adopters

**Before embarking on platform-building, get all stakeholders in the room and on board.** Ensure before the actual 'building' begins that key decision-makers agree on what's being created when you use the word 'platform' and set out the specific goals and outcomes the platform is designed to serve. Pay particular attention to the needs of the end-consumers of the platform and what you're trying to accelerate for them.

**Understand and be sensitive to the 'cognitive load' of your technology teams.** Technologists will inevitably bear much of the pressure from any platform building and may be preoccupied grappling with the mechanics, leaving little time or capacity to consider the project's end-goals. Ensuring projects are focused with minimal overreach and running regular check-ins can help ensure tech teams stay on track and don't lose sight of how platform performance will ultimately be measured.

**Pursue platforms in stages — and remember it's a journey, not a race.** Rather than instantly looking to build the kind of platform that enables revolutionary change, businesses should remember transformation doesn't happen overnight and that the best platform strategies are often iterative. Focusing on getting the infrastructure right first can provide a solid basis for the organization to get more adventurous with its platform strategies and construct platforms that contribute genuine innovations.
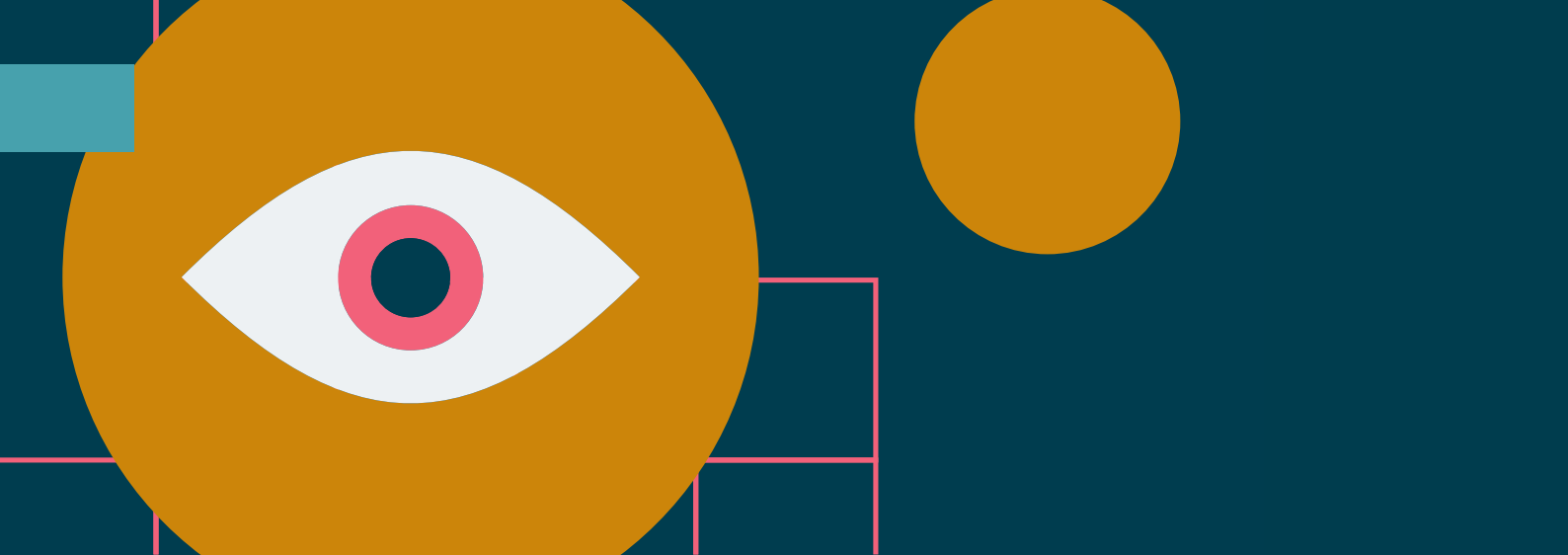
**Lens four**

# 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 that 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 — 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 technology is hostile can be a matter of perspective. Some people don't find internet ads, 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 track or the collection of personal data is for some basically automatic; for others, a carefully considered choice. That said, many people are oblivious to the fact that they have a choice in the first place, due to varying levels of access to and experience with technologies among different social and demographic groups, as well as discrepancies in the way information and options around consent are presented.

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 having been compromised or deliberately designed that way, because of unplanned and unnoticed distortions in the way they were constructed or developed.

**Signals include:**

- The increasing ubiquity of technology and concurrent expansion of the potential threat surface. One simple example is the sheer number of connections: Frost & Sullivan predicts **the number of active Internet of Things (IoT) devices will top 65 billion globally by 2026**. Each of these comes with potential security breaches that could be exploited

- Evolving consumer sentiment and behavior toward 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 misinformation campaigns and how social media channels are shaping health, political and other societal debates
- Unintended consequences from the increased use of artificial intelligence (AI) and machine learning (ML), such as bias in algorithms and in data sets collected. 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 **China's new Personal Information Protection Law**, the European General Data Protection Regulation (GDPR) the California Privacy Rights Act (CPRA) and equivalents in other jurisdictions

**Almost 80% of consumers** factor data protection into purchasing decisions and are open to paying more for products or providers with higher privacy standards.

Survey by Cisco

## The opportunity

With data breaches approaching **record levels**, 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 intrusive and self-serving targeting and rooting out bias within algorithmic systems and data sets is not only inherently ethical but conducive to trust, positive public perceptions and ultimately the health of the business.

According to media reports, the SolarWinds supply chain hack cost the company nearly US$20 million, with estimates for insurance claims reaching US$100 million, showing how easily the financial fallout from a hostile incident can spiral out of control. After a slow start GDPR fines have increased, with **total penalties surging 113.5% over the last year**. Most notably, Amazon's gigantic GDPR fine of US$877 million, announced in the company's July 2021 earnings report, is nearly 15 times bigger than the previous record. With consumers placing a higher value on their privacy, robust security practices have become a strong differentiator for some companies. A **recent survey by Cisco** found almost 80% of consumers factor data protection into purchasing decisions and are open to paying more for products or providers with higher privacy standards.

## 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 identity 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.
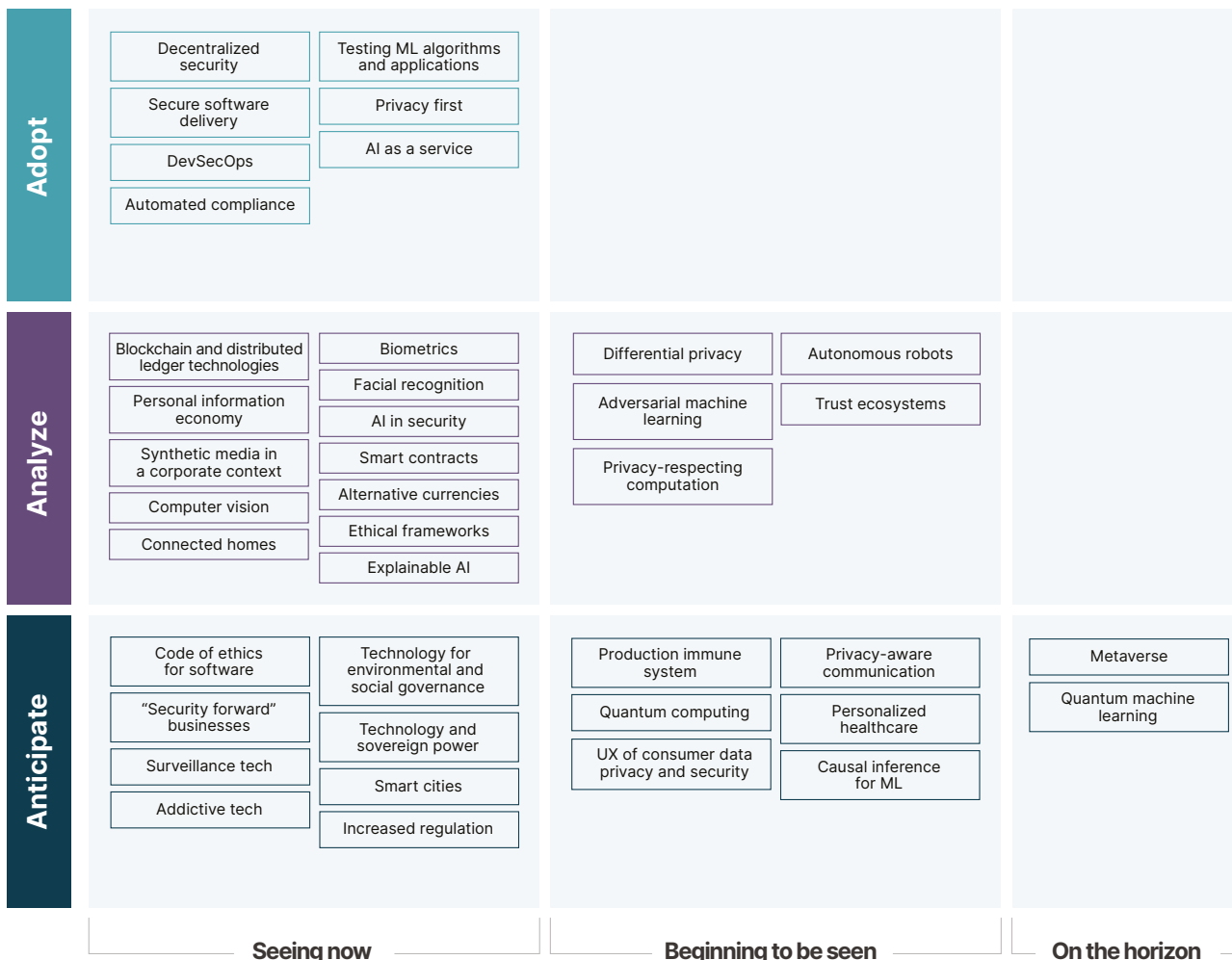
### By 2023, businesses will...

"...recognize, and work to seize the opportunity to stand out in the race for customers and talent by adopting holistic strategies incorporating social consequences as well as secure and ethical technology."

Harinee Muralinath, Global Security Community Lead, Thoughtworks

# Trends to watch

| | Seeing now | | Beginning to be seen | | On the horizon |
|---|---|---|---|---|---|
| **Adopt** | Decentralized security / Secure software delivery / DevSecOps / Automated compliance | Testing ML algorithms and applications / Privacy first / AI as a service | | | |
| **Analyze** | Blockchain and distributed ledger technologies / Personal information economy / Synthetic media in a corporate context / Computer vision / Connected homes | Biometrics / Facial recognition / AI in security / Smart contracts / Alternative currencies / Ethical frameworks / Explainable AI | Differential privacy / Adversarial machine learning / Privacy-respecting computation | Autonomous robots / Trust ecosystems | |
| **Anticipate** | Code of ethics for software / "Security forward" businesses / Surveillance tech / Addictive tech | Technology for environmental and social governance / Technology and sovereign power / Smart cities / Increased regulation | Production immune system / Quantum computing / UX of consumer data privacy and security | Privacy-aware communication / Personalized healthcare / Causal inference for ML | Metaverse / Quantum machine learning |

## Adopt
*Technologies that are here today and are being leveraged within the industry*

## Analyze
*Technologies that are beginning to gain traction depending on industry and use-case*

**Secure software delivery** — In the past year we've seen a significant rise in attacks on the "software supply chain" — not the software itself, but the tools, processes and libraries that help us get software into production. The US White House even issued an executive order on cybersecurity, including specific directives to improve supply chain security such as requiring a software "bill of materials" for all government systems. Secure software delivery emphasizes that security is everybody's problem and should be considered throughout the software lifecycle.

**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**.**
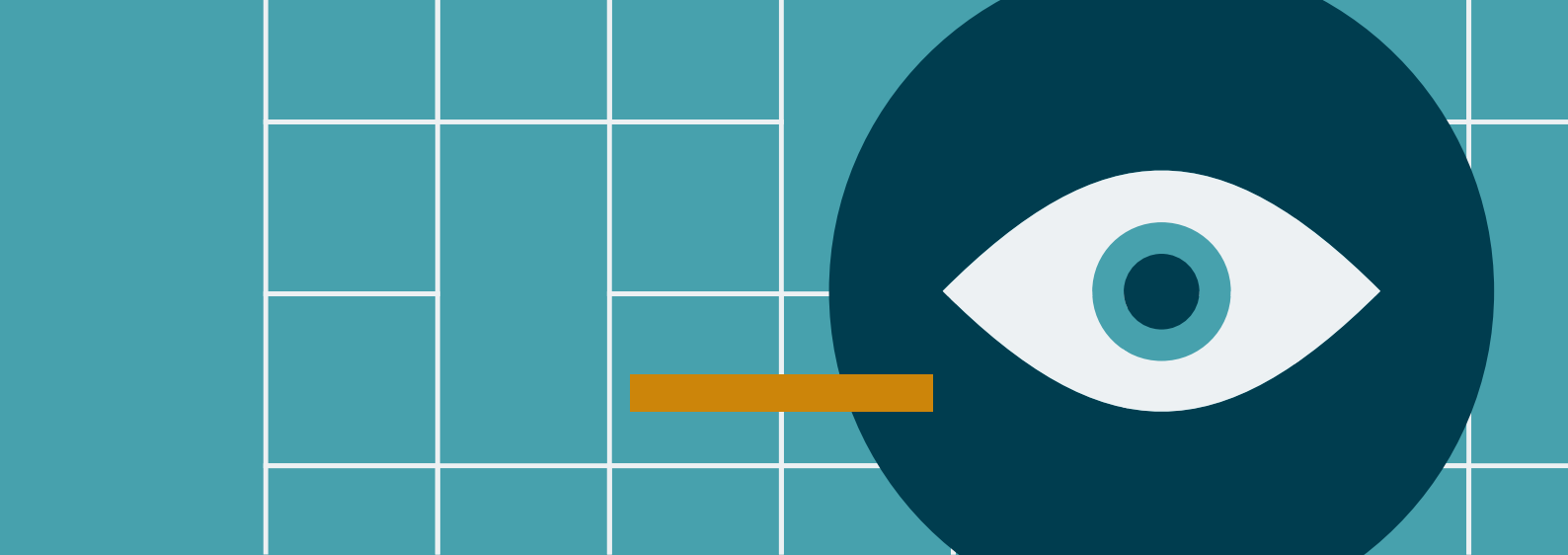
## Anticipate

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

**Quantum machine learning** — While likely a force for good, solving complex chemical and materials science problems, quantum ML could also create further challenges in the ethical use of data.

## Advice for adopters

**Cybersecurity is a game of cat and mouse with your adversaries.** AI is fast becoming a popular tool to help organizations fight security threats, with a wide variety of products emerging to meet rising demand. The aim is to level the playing field by automating manual detection tasks, providing intelligence such as intrusion alerts and scrutinizing network traffic to detect odd behavior, policy breaches or bad bots. Perhaps the most critical asset of AI-enabled approaches is their ability to not just limit the attack surface and plug gaps but also to help predict where future attacks might occur, thus allowing the appropriate risk mitigation strategy to be adopted in advance.

**AI is not a silver bullet.** It is important to remember that any technology used for defense can also be used by attackers and that while the organization might benefit from AI, it's not a silver bullet. Enterprises need to move away from seeing AI, machine learning and data-oriented tools as 'one size fits all' solutions. Instead, any tool needs to be a part of a pervasive intelligence strategy embedded throughout the organizational structure. Machine learning, for example, can't support effective security in isolation; it requires managing the lifecycle of data and models and feeding back outcomes. What's more, security needs to be seen as everybody's problem. This enables the application of zero-trust architectural approaches to subdivide the physical network and overlay security and data access principles in a way that scales safely and makes information available as needed; no more than is necessary for privacy purposes but no less either.

**Adopt or construct a [data ethics framework](#) to make clear to your employees and customers how data is stored, used and kept safe.** We advise that you only keep the data you actually need and no more. Modern compliance and privacy laws demand high levels of scrutiny and with careful thought can be turned into a positive differentiator. A robust data ethics framework can also play an essential role in your overall data strategy by serving as the basis of retention policies and data set construction and usage.

**Even if it's not immediately apparent, bias is always present — so work at it constantly.** It's also hard to remove after the fact, so dealing with issues like unfairness upfront is essential. It's vital to record data in a way that allows for the actions, products or decisions based on it to be audited and analyzed in terms of their impact on certain groups. Specific thought needs to be applied to the representation of the source of the data, the demographics of samples extracted from it and choices of algorithms used. Our **[Responsible tech playbook](#)** provides guidance and best practices that can assist with this process. Never assume your data is free of bias. We're humans — bias is everywhere.

# Accelerating towards sustainability

As consumers, governments and investors demand greater environmental accountability from companies, going green has gone from being 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 push for 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 momentum in political, economic and market circles. Making sustainable choices is something an increasing number of consumers do as a matter of course, and businesses are incorporating sustainability considerations directly into commercial strategies. Technology is a major contributor to climate change and most tech companies are attempting to address this, whether by building energy-efficient data centers, adopting renewable energy sources, analyzing their vendors and supply chains, 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 growing emphasis on sustainability emerging in government policies, for example in the **Build Back Better Framework**, the **UK Green Financing bonds**, or in the wake of the **26th Annual Conference of the Parties — COP26**
- The increasing prominence of environmental, social and governance (ESG) standards within organizations, and the movement of funds into 'ethical' investments and away from companies that pollute or have a negative sustainability posture

- A growing focus on supply chain analysis to identify opportunities to reduce energy intensity and emissions throughout the production cycle, and more **consultancies and solutions** emerging to support this process
- Technology providers proclaiming their 'greenness' or other sustainability characteristics
- Organizations adopting ambitious carbon neutral or similar environmental impact reduction pledges. For example, HP **announced an extensive lineup of climate goals** in its quest to become the world's most sustainable technology company. Equinix has set itself a target of becoming **climate neutral by 2030**, a first for the data center industry

**ESG assets are expected to make up more than one third of total assets under management globally by 2025**

## 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. Choosing to understand and invest in sustainability through supply chain analysis, simulation and selection can increase profits through more efficient processes and can be a win-win for a business's bottom line.

Sustainability has also gained considerable momentum in equity markets under the ESG banner, with many major investors and portfolio managers instituting ESG targets or requirements. Based on analyst projections, ESG assets are expected to make up **more than one third of total assets under management globally by 2025**. Green credentials can therefore ultimately enhance a company's market valuation, competitiveness and ability to attract quality investment.

## What we've seen

Holaluz is a green energy technology company that has been listed on BME Growth since November 2019. The company has the goal of a world powered by 100% green energy. This objective is advanced by persuading people to switch to a green energy plan composed of 100% renewable energy sources. Even in an organization whose vision is to connect people to green energy, understanding energy resources being consumed by technology infrastructure is difficult. Using the open source **Cloud Carbon Footprint** tool created by Thoughtworks and the AWS Compute Optimizer service, Holaluz is now able to closely monitor their own carbon footprint to take appropriate action. This led to recommendations of up to 3% reduction in their cloud infrastructure costs.
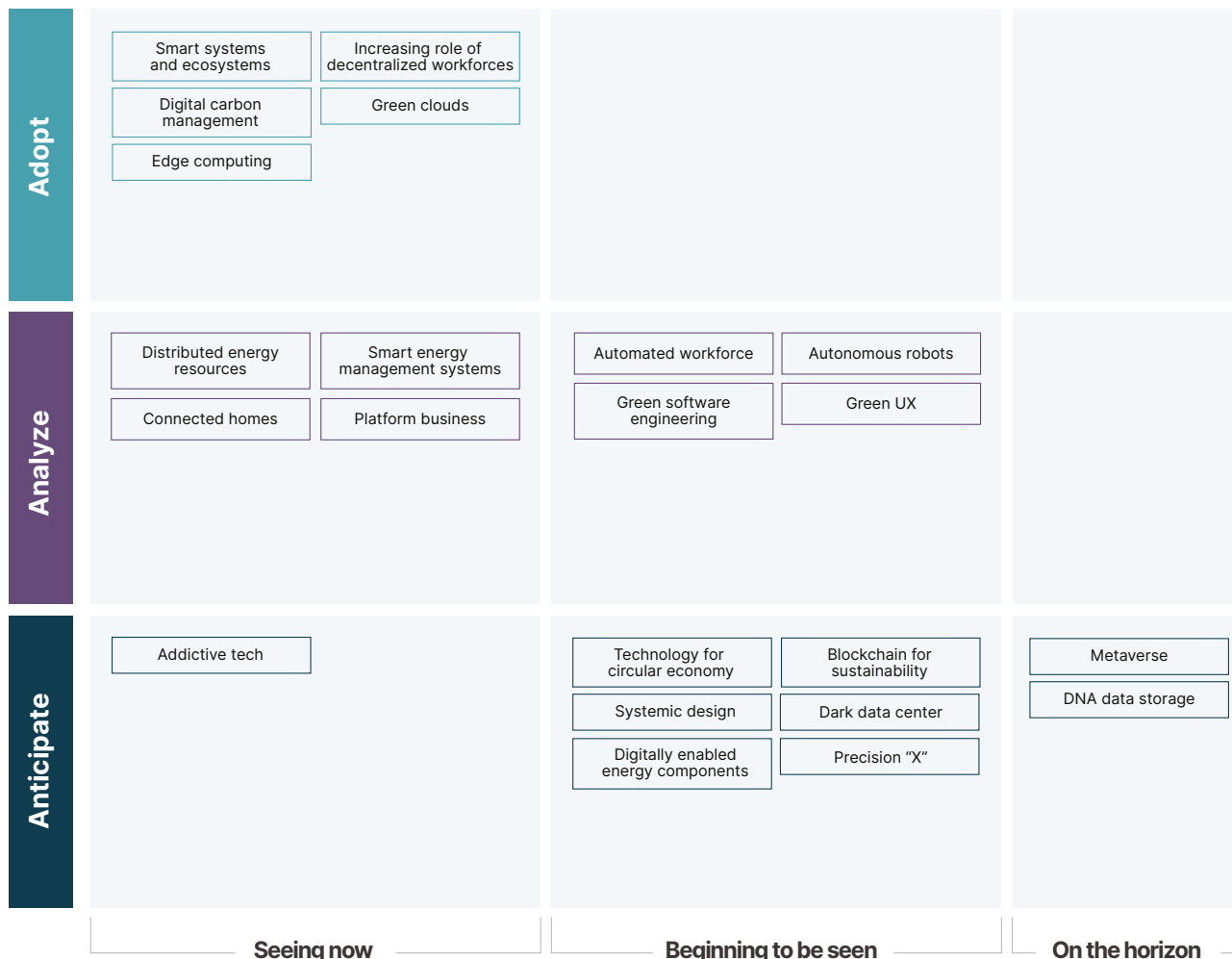
**By 2023, businesses will...**

"...recognize the urgency, advised by the investment community, policy makers and scientists, and not only commit to mitigation and conservation efforts, but become aware and take advantage of the opportunities to reduce costs, become more efficient, and drive profitability with sustainable metrics and technology early in project design and continuously throughout implementation.

**Lisa McNally, Head of Cleantech & Sustainability, Thoughtworks**

# Trends to watch

| | Seeing now | Beginning to be seen | On the horizon |
|---|---|---|---|
| **Adopt** | Smart systems and ecosystems · Increasing role of decentralized workforces · Digital carbon management · Green clouds · Edge computing | | |
| **Analyze** | Distributed energy resources · Smart energy management systems · Connected homes · Platform business | Automated workforce · Autonomous robots · Green software engineering · Green UX | |
| **Anticipate** | Addictive tech | Technology for circular economy · Blockchain for sustainability · Systemic design · Dark data center · Digitally enabled energy components · Precision "X" | Metaverse · DNA data storage |

## 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 IT (e.g. cloud providers), manufacturing, shipping and other supply chain components, 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 and possibly liable 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 about trends like sustainable consumption has been shown to have a positive effect on purchasing decisions.
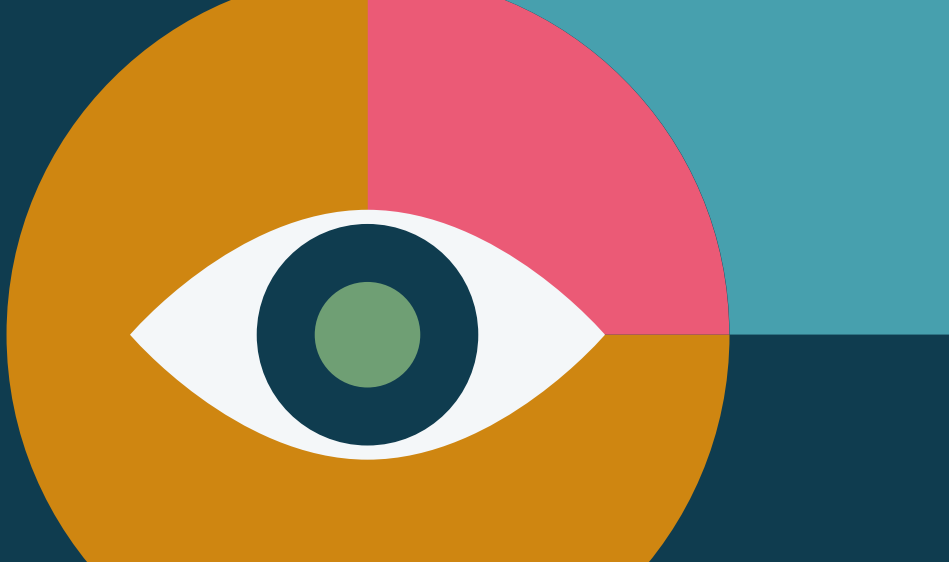
# Glossary

## A

### 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 or using brute force to identify specific inputs that a model classifies poorly. 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 in security
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. This 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.

### 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, 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.

### Automated compliance

The use of technology to make available all the data that is needed to satisfy compliance reports, checks and balances. In many cases the automation simplifies reporting by sifting through data, however AI is becoming more prevalent to replace manual decisionmaking.

### 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 robots

Smaller and cheaper than their industrial counterparts, robots with on-board AI are able to sense their environment, navigate, learn to complete tasks and even fix themselves and other things.

### 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.

## B

### 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 and distributed ledger 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.

### 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.

### Brain computer interfaces

A BCI is a device (hardware + software) that reads and analyzes signals from the brain (central nervous system) and turns them into

instructions to be carried out in another device. The human and the device, both after a period of training, work together to encode and decode intention to enhance human function.

## 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.

### 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 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.

### 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.

### Connected homes
Featuring smart hubs, voice activation, the ability to control lights, temperature and even cooking via an app, homes are now becoming 'smart'. Analytics can even guide or manage heat and energy supply and learn from individual habits or those in a neighborhood.

## 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.

### 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.

### DevSecOps
An abbreviated portmanteau for development, security and operations. A term we tend to eschew because it might suggest placing

security in the middle of development and operations. We prescribe shifting left security concerns so that they are considered, automated where possible, at every stage of the development and deployment process.

### 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 greenhouse 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
Disparate participants, systems and even organizations that cooperate, collaborate, and compete to create an emergent ecosystem where the whole is greater than the sum of the parts. Examples include the travel industry, online marketplaces, and new "super apps" such as Gojek and WeChat.

### Digital twin
A digital twin is a virtual model of a process, product or service that allows both simulation and data analysis. Live data can be combined with 3D vizualization, 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.

### 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.

### Evolutionary architectures
In contrast to traditional up-front, heavyweight enterprise architectural designs, evolutionary architecture accepts that we cannot predict the future and instead

provides a mechanism for guided, incremental change to systems architecture.

### 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 recognition
Detection of a human face, matching against a database of faces for identification purposes and even recognition of a person's emotional state.

### 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. It 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 center, 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.

## I

### Increased regulation
GDPR and others define new internet age privacy rules. Over the next decade we are going to have to instrument our supply chains for accurate carbon reporting — expect universal legislation requiring provable metrics.

**Increasing role of decentralized workforces**
Technology for remote working was given a radical boost in response to the COVID-19 pandemic. Combined with growth of the gig economy and casual work, this means the workforce will never be the same.

**Industrial IoT platforms**
Services and capabilities that connect, monitor, manage IoT assets in a scalable way. Vendors include tradtional industrial data collecion and telemetry manufacturers as well as cloud vendors, all of whom look to provide services that cover end-to-device installation, data collection, analytics and intelligence.

**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.

**Metaverse**
A version of the internet experienced as a 3D virtual world. Large companies, content providers and governments are all making investments to construct or participate in the metaverse.

**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.

## N

**Natural language processing**
Artificial intelligence and other modern technologies that help computers understand the intent and meaning of spoken or written language. Used for everything from dictation software to analyzing documents for meaning.

## 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

**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 healthcare**
Understanding an individual patient's genetic profile to identify potential issues before they happen and provide more effective treatments in response to existing conditions.

**Platform business**
A business model based on facilitating transactions between an ecosystem of participants, usually consumers and producers, and that creates value through these interactions.

**Polycloud**
Passing different types of workloads to different cloud providers based on their relative strengths, in contrast to a "one cloud fits all" approach.

**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 first**
Respect for an individual's privacy should be top priority and proactive rather than reactive. This is achieved by building security in from the beginning, and must be embedded into all aspects of the product creation lifecycle.

**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.

## 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.

**Quantum machine learning**
The coming together of machine learning algorithms adapted and executed on a quantum computing engine.

## R

**Re-decentralization**
A movement that challenges today's paradigm of central 'clouds' and 'platforms' that intermediate people's interactions, set the rules and lock them in. It aims to bring people together to learn and exchange and help bridge the gap between technology, media and politics. With the rise of blockchain and other distributed technologies we may see a return to a more decentralized 'net.

**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.

**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.

**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.

**Synthetic media in the corporate context**
AI-generated or manipulated news, images and content commonly referred to as deep fakes has many negative stories associated with it, but it can potentially be used for positive reasons as part of social media, chatbot responses or even art.

**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.

**"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.

**T**

**Technology and sovereign power**
Rising forces are leading to internet balkanization — the splintering of the internet — many led by nation states. Privacy legislation accelerates this process, as it enforces data rights, data sovereignty, and strongly impacts how companies deploy and distribute systems and data on the Internet.

**Technology for circular economy**
A circular economy is a closed economic system where raw materials and products are constantly shared so as to lose their value as little as possible. Technology that supports this includes reusable services, traceability, IoT and data mining.

**Technology for environment and social governance**
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 nondeterministic, 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.

### Trust ecosystems
A model where new decentralized ecosystems based on distributed ledgers allow trust to be suitably handled within the ecosystem in a mutually agreeable way to all parties. This includes consortia-based systems focused on specific domains such as energy emerging.

## 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, while 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.

## #

### 5G for business and consumer applications
The fifth generation technology standard for broadband cellular networks, which cellular phone companies began deploying worldwide in 2019, and the planned successor to the 4G networks which provide connectivity to most current cellphones.

Thoughtworks is a global technology consultancy that integrates strategy, design and engineering to drive digital innovation. We are 10,000+ people strong across 48 offices in 17 countries. Over the last 25+ years, we've delivered extraordinary impact together with our clients by helping them solve complex business problems with technology as the differentiator.

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