Technology Vision 2024

Human by design

How AI unleashes the next level of human potential

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Foreword

Human by design

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Welcome to our Technology Vision for 2024. This year's Vision is grounded in two realities. First, technology is driving a wave of reinvention that is impacting every part of every business. Second, this emerging technology is becoming more "human" in its nature, creating unprecedented capabilities that in essence give people superpowers. Collectively these two realities stand to reshape the way we work and live.

Consider the possibilities. Where once we adapted to technology – such as changing our habits for a new app or computer interface – technology is beginning to adapt to us. Gen AI applications create realistic scripts and images as if created by people. New spatial computing mediums have begun to close the physical-digital divide to enable simultaneous activities in multiple spaces. Body-sensing technology like brain-computer interfaces and ambient computing are beginning to read and understand us like never before.

This year's Technology Vision comes at a time of expansive innovation in technology that is creating massive opportunities for leaders – from new ways to drive productivity to entirely new ways of doing business and tackling grand challenges. We identify actions to take today and also chart the steps to a future where technology transitions from a passive proxy to an active collaborator that engages with us through more natural interaction.

This move to more human-like technology raises questions about the impact on people. In this year's Vision, we explore this issue from all dimensions, centering on the importance of shaping technology that is human by design. Technology amplifies human creativity and productivity so we can create a positive impact for the most important part of any enterprise. People.

Step boldly into this future with us, and together we can shape our use of technology. We believe it's **Human by design.**

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The relationship between humans and technology is at an inflection point.

Have you ever seen dystopian pictures of humans in 1,000 years? Hunched backs, sallow skin, big and sensitive eyes – the hallmarks of people who spend too much time indoors, detached from the physical world. These images reflect how the artists see our relationship with technology today. They're visceral and striking, and based on true fears. People worry about screentime and the cognitive impact of technology, and increasingly we hear concerns about technology controlling our lives or about losing control of technology – despite using it more than ever.

But the future doesn't need to be what these artists imagine. Not if we recast the relationship between people and technology and design technology to amplify, rather than change, the things that make us human.

It's time to make technology human by design.

Hasn't technology always been human?

This is a moment for reinvention. In the coming years, businesses will have an increasingly powerful array of technologies at their disposal that will open new pathways to unleash greater human potential, productivity, and creativity. Autonomous agents that can act on our behalf; intelligent interfaces that transform the way we interact with information and software; spatial technologies that blend the digital world into our physical one, or instantly transport us from our desk to a factory to a mountain top; and even technologies like brain-computer interfaces that once sounded like science fiction are starting to find relevant, approachable, enterprise use cases. Early adopters and leading businesses have kick-started a race toward a new era of value and capability. And their strategies are underpinned by one common thread – the technology is becoming more human.

It sounds counterintuitive. After all, hasn't technology always been human? Humans invent technology, we build it, we scale it. We use it to overcome limitations and do more. In fact, creating tools that extend our physical and cognitive abilities is so unique to humanity that some argue it defines us as a species.[1]

Yet, by nature, the tools we build are often distinctly unhuman. They don't look or act "human," which has always been the point of creating them. As humans we had aspirations, but limitations: we wanted to plant a field, but couldn't till the ground; we wanted to reach the stars, but we were earthbound; we wanted to solve problems, but couldn't always crunch the numbers. Tools filled the gaps by doing and being what we couldn't, and in the process radically transformed our lives. Automobiles expanded our freedom of mobility. Cranes let us build skyscrapers and bridges. Machines helped us create, distribute, and listen to music.

95% of executives agree that making technology more human will massively expand the opportunities of every industry.

Technology's unhuman nature can also be its drawback, though. Extended use of hand tools can lead to arthritis. Years of looking at screens can accelerate vision problems. We have amazing navigational tools, but they still distract us from driving. The discordance can even go beyond our physical bodies and permeate the environments we live in: homes or offices are often designed to get the best bandwidth, combustion engines may be a need for some but generate pollution for others. Granted, there have been efforts to create tools that are more ergonomic or easier to use. But even so, time and again we see and make decisions about our lives based on what is best for a *machine* rather than optimizing human potential. This is why artists imagining the future of human evolution envision a world where we are at conflict with the technology we use. Technology amplifies our abilities and lets us do more, but its unnaturalness is just as likely to leave its mark.

Now, for the first time in history we see strong evidence that we are reversing course – not by moving away from technology, but rather by embracing a generation of technology that is more human. Technology that is more intuitive, both in design and its very nature, demonstrates more human-like intelligence, and is easy to integrate across every aspect of our lives.

Our world is becoming a fusion of atoms and bits, and if we want to help people better live in it, we need to design technology in ways that amplify these human-like traits. It's not an entirely new trend: the invention of the graphical user interface (GUI) created images that were friendly and more intuitive than lines of code; the smartphone miniaturized compute to reflect the mobility intrinsic to humans' lives; one of AI's most impactful uses was translating across languages. But now this slow trickle is about to become a torrential river of deliberate design.

Consider the impact generative AI and transformer models are having on the world around us. What began as chatbots like ChatGPT and Bard has become a driving force in making technology more intuitive, intelligent, and accessible to all. One example is Adobe Photoshop's Generative Fill and Generative Expand features, powered by Adobe Firefly.[2] These innovations let anyone add, expand, or remove content from images non-destructively, using simple text prompts. Users can now experiment with their ideas, ideate around different concepts, and produce dozens of variations faster than ever before. Where AI once focused on automation and routine tasks, it's now shifting to augmentation, changing how people approach work, and is rapidly democratizing the technologies and specialized knowledge work that were once reserved for the highly trained or deep-pocketed.

For more on the evolution of AI, see A new era of generative AI for everyone from Accenture Research.

And generative AI has the potential to impact much more than just the task at hand. It's also starting to profoundly reshape organizations and markets. Google Cloud, for instance, recently announced a generative AI search tool meant to help doctors and nurses rapidly find patient information that may be stored across multiple systems and in different formats – a major challenge that has plagued healthcare systems for years.[3] FrameDiff, a generative AI computational tool created by MIT CSAIL researchers, is crafting synthetic protein structures that go beyond what exists in nature to open new possibilities in drug development.[4] And for software companies, tools like GitHub's Copilot (a generative AI assistant that helps write code) are demonstrating potential to make software engineers more satisfied with their jobs.[5] In fact, in many cases generative AI tools are so intuitive to use and employees are adopting them so rapidly, they are permeating workplaces from the bottom up – faster than organizations can create formal programs.

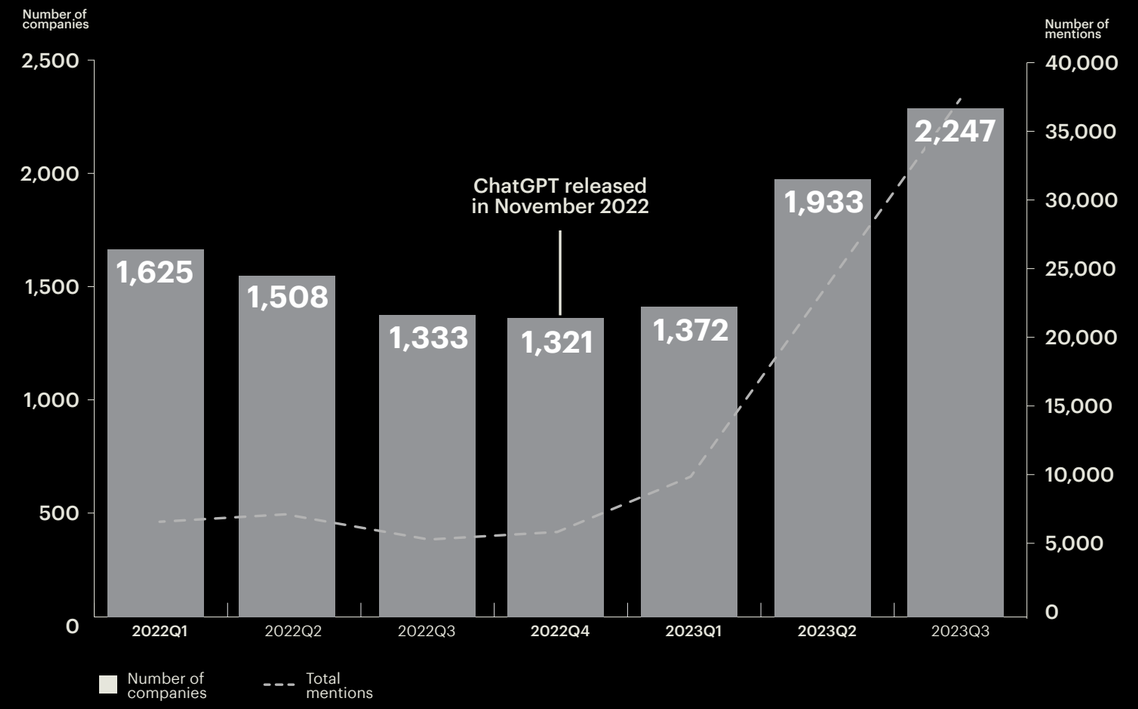
Generative AI has the potential to impact much more than just the task at hand.

To learn more about how our interaction experience is changing, go to Accenture Life Trends 2024.

Can AI have your attention?

The number of mentions of AI in earnings call transcripts has increased by **6x** since the release of ChatGPT in November 2022.

Number of companies mentioning AI, along with total number of mentions in earnings call transcripts, 2022Q1 – 2023Q3



Source: Accenture Research NLP analysis on earnings call transcripts (S&P Global Transcripts) across 10,452 companies and over 70K transcripts; Jan 2022 – Sep 2023

When technology is more human, it's more accessible.

Of course, the advent of more human technology is happening across many more dimensions than AI alone. And in the process, it's starting to solve many of the pain points that exist between us and technology, paving the way for greater human potential.

To solve challenges innate to digital work, like video fatigue, Microsoft made major updates to Microsoft Mesh, their platform for creating immersive spaces that blend digital and physical.[6] The company is trying to use immersion to solve pain points today, as well as drive new collaborative ways of working. Recognizing the importance social media plays in many people's lives, but also the friction it can create, social media newcomers Discord and Mastodon built social networks not driven by a centralized recommendation algorithm, but one more reflective of the types of communities and relationships we build in our personal lives. And Boston Dynamics has long been at the forefront of making robotics more human, promising a smoother integration between robotics and the world around us. For instance, their bipedal robot Atlas has been trained on diverse tasks, allowing it to mimic human movement and physical intuition.[7] What's more is these robots no longer just mirror humans physically, but socially too. Humans will usually interact with robots through complex lines of code and puzzling machine logic, leaving an impasse between people who don't speak that language and the robots next to them. However, researchers found a way to put ChatGPT onboard a Boston Dynamics robot, allowing people to use natural language to command the robot or ask it about its previous tasks and receive a clear response in plain English.[8]

This is why it's so important for businesses to build and use technology that's human by design. When technology is more human it's more accessible and makes people more productive and connected. And how often do we want to do *more*? Manufacture more custom products. Expand to more markets. Work with more partners.

We are about to see a massive expansion of every industry. Think of it like this: in the 1700s, the industrial revolution made creating physical things easier, and in turn refaced the way our world works and how we live in it. Now, as technology becomes more human, it becomes easier to work with – and will spark an infusion of technology through every dimension of the business. We are already seeing its impact on our ability to create. Recent innovations have led to an explosion of digital art, music, and product designs. And technology that is human by design is also introducing brand-new possibilities – digital helpers like AI agents, or digital spaces where we can build and create even in ways that break the laws of physics. By building fundamentally intuitive bridges between people and the most advanced technologies of our age, productivity and value creation are poised to grow exponentially across every industry. It's an entire universe of new ideas and new actions for businesses and consumers alike.

Technology that is human by design will also reach new people and knowledge that has never been digitized before. While this will create more of what we have, it will also enable the creation of things and ideas to which enterprises have never had access. Think of all the people historically alienated by technology who will be able to contribute to the digital revolution. As technology becomes more intuitive, we can tap into these people as new customers and new employees.

In doing so, their wealth of knowledge will become enterprise-actionable for the first time. And when every person can be part of the digital transformation, on-going efforts to modernize things like data, products, workforce, and more will only accelerate. Companies leading the shift to more human technologies will be injected with innovation opportunities as they both buoy and are buoyed by a flood of new people with the tools to affect change in the digital world.

Yet the world we will shape from this expansion of economic growth and empowerment of entire populations is still undecided – and enterprises have a responsibility to shape it into a world we want to live in. Leaders will be faced with familiar questions: Which products and services are ripe for scaling? What new data is at your disposal? What transformative actions can you take? But they will also be at the center of answering questions they may have never expected: What kind of oversight does AI need? Who will be included in the digital transformation? What responsibilities do we have to the people in our ecosystem?

Human by design is not just a description of features, it's a mandate for what comes next. As enterprises look to reinvent their digital core, human technology will become central to the success of their efforts. Every business is beginning to see the potential emerging technologies have to reinvent the pillars of their digital efforts. Digital experiences, data and analytics, products, all stand to change as technologies like generative AI, spatial computing, and others mature and scale.

In this moment of reinvention, enterprises have the chance to build a strategy that maximizes human potential, and erases the friction between people and technology. The future will be powered by artificial intelligence but must be designed for human intelligence. And as a new generation of technology gives enterprises the power to do more, every choice they make matters that much more too. The world is watching. Will you be a role model or a cautionary tale?

Make it human: The 2024 trends

Think about the things that make us human: the way we think, act, feel, and understand one another. Now technology is starting to reflect that range of human experience. It's a transformation that will reset our relationship with technology and completely change how we use it and what we do with it.

Last year's Technology Vision explored how the convergence of atoms and bits is building the foundations of our new reality. We described a world where the dissolving barrier between our digital and physical realities was opening up brand new innovations in nearly all dimensions of technology, from artificial intelligence, to identity and science tech – and importantly how each of these pieces would become a critical part of the enterprise core moving forward.

In this year's Technology Vision we investigate where the impact of that foundation matters most: people.

The advent of more human technology is both a highly concentrated example and the direct result of the broader trend towards a world where atoms meet bits. The four trends this year outline to enterprise leaders the key dimensions where technology is becoming human by design, and how organizations will need to prepare.

First: I think, therefore I am. The way we collect, store, and access information has always been a deeply rooted part of the human experience.

In **A match made in AI** we explore how technology is starting to imitate how we process information. These are not just superficial changes to the way we interact with technology, but rooted in memory structures designed and organized in a similar fashion to people's brains. The earliest changes are starting in search and will come to disrupt the way we approach knowledge and knowledge management.

Autonomy and the ability to act is even more innate to the human experience – before people could write or build, we were hunting and gathering, making decisions, and engaging the world around us. Now, in **Meet my agent** we are tracking the evolution from AI that can perform singular tasks to AI agents that, with appropriate oversight, can work with one another and act as proxies for people and enterprises alike. Today we might think of it as automated assistants for individual interactions, but tomorrow the agent ecosystem has the potential to underpin the entire business-to-business landscape.

In **The space we need**, we're watching the emergence of a new spatial computing medium, and the applications taking advantage of its capabilities to pierce the physical-digital divide. The metaverse struggled under the weight of ever-expanding definitions and expectations, but the value in the technology behind it has never been in doubt. In the end we are physical beings, and the digital world has always been a strange environment. Now spatial computing is letting the digital world reflect what it means to be human and in a physical space.

And lastly, it's always been a challenge to understand people. While technology can track and observe what people do, it often lacks the specificity of what was intended. **Our bodies electronic** looks at an emerging suite of technology that is starting to sidestep the unnatural technology interactions of the past to read and understand people more closely than has ever been possible.

To think, act, feel, and understand – these are human qualities. But by surrounding ourselves with tools that mirror us, we make it easier to connect to the world on a deeper level, and we empower people to take a larger role in shaping it. Individuals, companies, and governments – all empowered to do more.

Positive engineering: Our technology crossroads

Human by design technologies can deliver profound benefits to people and enterprises alike, but the path forward isn't so simple. The world is arriving at what might be technology's biggest inflection point in history, and enterprises – and the decisions their leaders make – are at the heart of shaping how we move forward.

As we experience more growth and innovation, it won't all be for the better. There will be more (and new) opportunities for fraud, misinformation, and breaches of security. If we engineer tools with human capabilities but without human intelligence – or even human conscience – we can create in a way that deteriorates both the bottom line and the greater good.

More human technology means more ethical questions, and many of these questions require answers before we can proceed. We made agents that could talk and act indistinguishably from humans, expanding human capabilities in impressive ways. But as quickly as ChatGPT was released, we also started seeing fear-laden headlines. Will machines devolve human creativity? Will they take our jobs? Will they try to destroy us? This isn't merely luddite speculation, many leading AI researchers have (controversially) raised concerns and halted research over the potential dangers of AI.[9,10] When the metaverse was introduced, it challenged us to question the impact it would have on people. Would the allure of the metaverse cause us to cocoon in our homes, potentially impacting our mental health?[11] Now brain scanning can be used to decode what people are thinking.[12] Will that potential be used for or against us?

None of these questions have a clear resolution, but enterprises *will* be on the front lines of answering them. While some may seem implausible, borderline unfathomable, they are quietly creeping out of science fiction books and into boardroom conversations. In the era of human tech, every product and every service that enterprises bring to market holds the potential to transform lives, empower communities, and ignite change – for better or for worse. And, invariably, enterprises will face the delicate balancing act of needing to act fast versus needing to act carefully, as well as the expectation that competitors or other countries may not share the same concerns or impose the same guardrails.

More human technology means more ethical questions, and many of these questions require answers before we can proceed.

93% of executives agree that with rapid technological advancements, it is more important than ever for organizations to innovate with purpose.

The choices enterprise leaders make, the values they uphold, and the priorities they set will reverberate far beyond profit margins and shareholder returns – which makes it more important than ever that enterprises innovate with purpose. As we strive to make technology human by design, we need to think of security as an enabler – an essential way to build trust between people and technology – rather than as a limitation or requirement. And we need to build technology without overshadowing or upending what it means to be human. It's a concept we call "positive engineering." Over the last few years, ethical questions have entered the technology domain from a number of different directions. Inclusivity, accessibility, sustainability, job security, protection of creative intellectual property, and so much more. Each of them roots back to one single question: how do we balance what we can achieve with technology with what we want as people?

As some humans enter the digital world for the first time, and others dive deeper and deeper in, companies must prioritize their well-being, privacy, and security. Companies that strive for technological inclusivity will bridge both societal gaps and the voids that exist between the organization, its employees, and its customers. As technologies become more human and expand opportunities for enterprise growth, they must also create new paths for humans to thrive.

This is a transformative moment for technology and people alike, and the world is ready for you to help shape it.

A match made in AI

Reshaping our relationship with knowledge

1665

The first scientific journal is printed.[1]

1768

Encyclopedia Britannica publishes its first edition.[2]

1873

The Dewey Decimal System is developed for Amherst College Library.[3]

1967

The "Ask NYPL" (New York Public Library) hotline opens.[4]

1967

ORBIT launches as a database search service for research abstracts.[5]

1975

Ohio State University implements the first major digital catalog.[6]

1990

Three McGill University students build Archie, the first search engine.[7]

1996

Ask Jeeves is founded.[8]

1998

Google goes online with its PageRank algorithm.[9]

2001

Wikipedia launches.[10]

2008

Stack Overflow begins crowdsourcing programming questions and answers.[11]

2010

Microsoft introduces SharePoint for enterprises.[12]

2012

Google announces its knowledge graph, a significant step toward semantic search.[13]

2019

Researchers propose K-BERT, a knowledge graph-enabled LLM.[14]

2022

OpenAI releases ChatGPT.[15]

2023

Bing Chat is unveiled by Microsoft.[16]

2025

A leading airline will announce that customers are just as satisfied with chatbot agents as human agents.

2027

Data poisoning (adding malicious data to ML models) will be a top cybersecurity threat to enterprises.

2028

Major corporations will have proprietary chatbots to assist with knowledge management, research, and task completion.

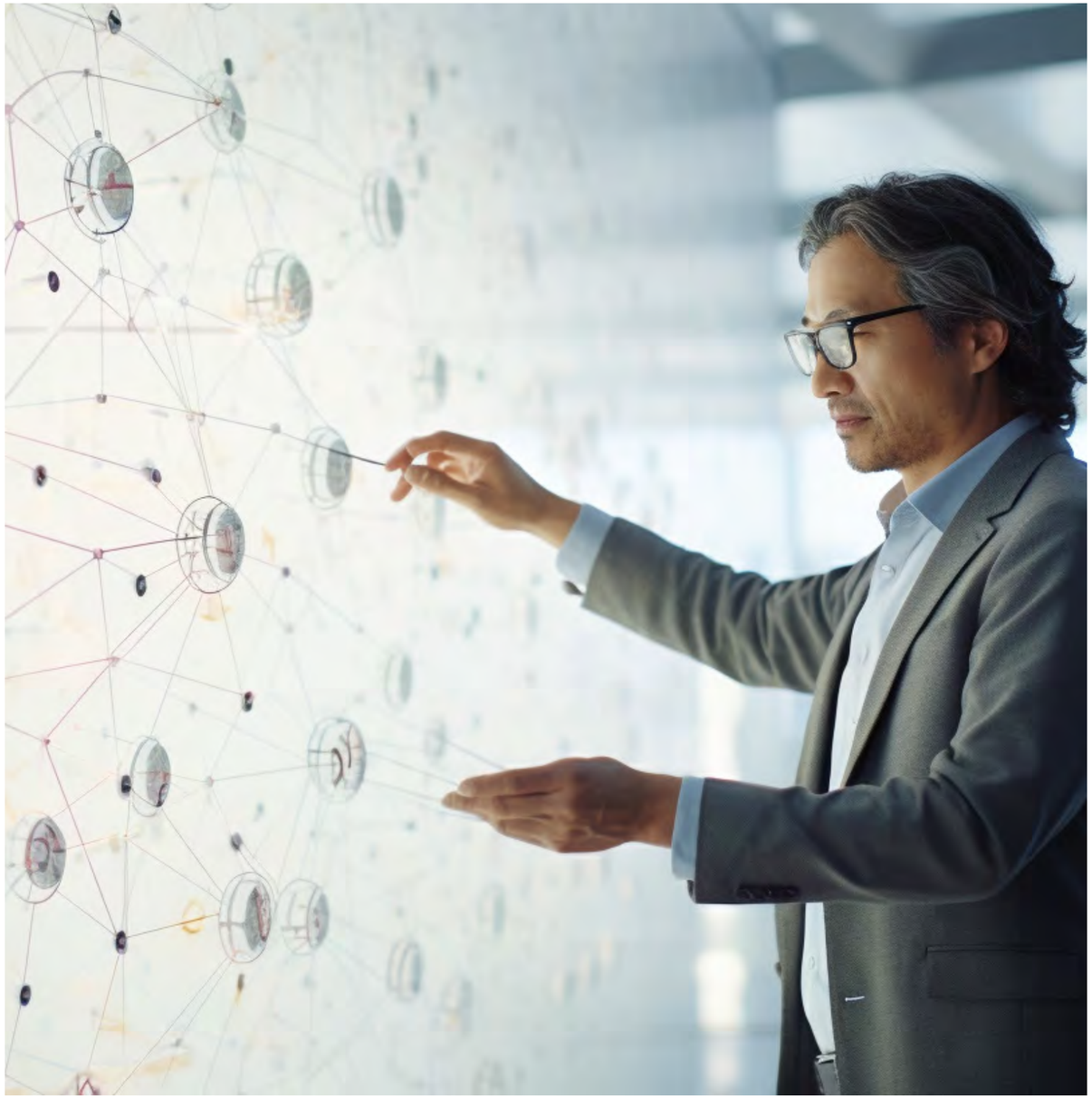
2029

AI advisors will receive more search traffic than traditional search engines.

2031

A smartphone will launch that replaces the app-based interface with an agent-based one.

The big picture



Our relationship with data is changing –
and with it, how we think, work, and interact with technology. The entire basis of the digital enterprise is getting disrupted.

This is no exaggeration. Think back about 15 years, to when the July cover story of *The Atlantic* asked, "*Is Google Making Us Stupid?*" Writer Nicolas Carr claimed that internet search was changing how his mind worked, transforming how he concentrated and how deeply he read.[17] Today, we can answer his question with an unequivocal "*No*." Using Google hasn't diminished our intelligence.

One point, though, was true – how we access information does shape our behaviors. Search changed nearly everything it touched. It became a primary way for people and businesses to interact with data. It wildly expanded the knowledge people can access and reduced research time from hours to minutes. And it had the same transformative effect on enterprises. It created new inroads into customers' lives via ads and search engine optimization (SEO), created new methods of serving and discovering products, and became intrinsic to the employee experience. We're so used to it that most people don't even realize how much search has permeated their lives. But almost 70% of all website traffic begins with search.[18] The web made every piece of information part of a vast library. And for over 20 years, search has been our librarian.

Then at the end of 2022, leaders in search went into high alert.[19] For the first time in years, people's relationship with data was in flux. The "librarian" model was giving way to a new "advisor" model. Rather than run a search to curate results, people were starting to ask generative AI chatbots for *answers*.

It started in November 2022 when OpenAI launched ChatGPT, which became the fastest-growing app of all time.[20] Large language models (LLMs) had been around for years, but ChatGPT's ability to answer questions in a direct and conversational manner made the difference. Microsoft, OpenAI's partner, quickly recognized what was happening and released Bing Chat in February 2023.[21] They positioned it not just as a search tool but as a "copilot for the web." The next month, Salesforce announced Einstein GPT – a generative AI CRM technology that leverages all the customer data a company stores in Salesforce applications to generate content like personalized marketing materials or knowledge articles.[22] By June, the electronic health record software company Epic was integrating GPT-4 into its products to allow clinicians to speedily generate summaries of patient charts.[23]

We're so used to it that most people don't even realize how much search has permeated their lives.

How people access and interact with data is changing. Fast. And this change is a code red – not just for traditional search companies, but for every company. It's not just web search engines but search in the very broadest sense that is being impacted by generative AI – everything from searching for an email or a file to looking up customer details in a CRM database.

Data is one of the most important factors shaping today's digital businesses. And these chatbots – that can synthesize vast amounts of information to provide answers and advice, use different data modalities, remember prior conversations, and even suggest what to ask next – are disrupting that undercurrent. Many long-standing enterprise functions like digital marketing, advertising, and product discovery all stand to change. And beyond the open web, companies are also chock full of valuable information that wants to be found and used by customers, employees, partners, and investors. But whether it's because we don't recall the right search terms, we can't write the query, the data is siloed, or the documents are too dense, a lot of that information is hard to access or distill. For the data-driven business of today, that's serious untapped value that generative AI could bring in.

However, the true disruption here isn't just in how we access data – it could also transform the entire software market. What if the interface to every app and digital platform became a generative AI chatbot? What if that became the way we read, write, and interact with data, as a core competency of all platforms? The evolution happening in search is inevitably changing software, the role it plays in the enterprise, and the digital world at large.

Companies have the chance today to reimagine how information works throughout their organization, and in doing so, invent the next generation of data-driven business.

Customer experiences and interactions will look different as companies position themselves not just as a search result, but as a trusted advisor. Internal workflows will transform when employees are powered with the information and answers they need, when they need them. As businesses deliver novel products and services, their entire value propositions may shift.

It's a huge opportunity. Yet more than that, it's absolutely necessary. As an example, consider how a car manufacturer today can all but guarantee their new makes and models appear in the search results for "New Cars 2024." Could they say the same if a potential customer was asking an AI what new car they should buy? The attention mechanism that made transformer models so powerful is now suggesting what *people* should pay attention to as well. If enterprises fail to act, this transformation in our relationship with data could have consequences ranging from losing out on seamless internal information sharing, to losing direct access to customers, all the way to losing control of their brand.

Every enterprise has an information strategy. It's defined through the software they use, how they market information externally, and how they use it internally. Search, broadly speaking, has underpinned these strategies for decades. But every day, consciously or not, more people shift from search to asking, and more companies look to meet them where they are, using generative AI chatbots as the UI for enterprise platforms and a new access point for customers. Already there are multiple options to implement LLMs and generative AI chatbots in the enterprise, but it's far from a simple technology rollout. To truly reap the benefits of generative AI and build the data-and-AI powered enterprise of the future, businesses need to radically rethink their core technology strategy. How they gather and structure data, their broader architectures, and how they deploy technology tools and the features they include need to be rethought. And new practices like training, debiasing, and AI-oversight must be built in from the start.

It's a lot, but enterprises can't afford to be the last to move. People *want* the simplicity of asking questions and getting answers. Who else remembers Ask Jeeves from the 90s? The desire to ask was there, but the backend to support it wasn't. Now with generative AI, a digital butler is finally in the cards. The way we interact with data, and how we live, work, and think, is all changing. Enterprises need to be just as pliable – or a new generation of data-driven business will rise without them.

The technology: Unlocking your data-driven enterprise

Data powers digital business; there's no question about that. Across every industry and in more ways than we can count, enterprises have worked to build data-driven practices. And yet people still struggle with the most basic part: *finding* the data they need. This is why people are gravitating towards asking – it offloads and automates the mental burden of hunting for data.

According to a recent Gartner® survey, "47% of digital workers struggle to find information or data needed to effectively perform their jobs."[24] And employees are always looking for information. They look for documents in their team's file share, search the company knowledge base for policy or benefits information, and search their CRM to better understand customers and sales. What's more, other stakeholders are always trying to find information about the enterprise, too: customers browsing for products or searching help forums, shareholders looking for ESG filings, or partners trying to validate licensing. For all these people in need of information, many enterprises have failed to build sufficient search capabilities.[25]

It makes sense that the shift from search to asking is so alluring. It's shaking things up in a way enterprises desperately need. Putting an LLM-advisor with the breadth of enterprise knowledge at every employee's fingertips could unlock the latent value of data and finally let enterprises tap into the promise of data-driven business. Of course, it's not as simple as turning the knob to something new. Generative AI will be the interface that rests on top of enterprises' vast data architectures, but if businesses want to capture its many benefits and transform how people access their information, they need to finally get that foundation right.

95% of executives believe generative AI will compel their organization to modernize its technology architecture.

Shoring up your data foundation

The good news? New technologies and techniques can help enterprises shore up their data foundation and prepare for the future of data-driven business. In fact, some enterprises have already taken steps to modernize their data strategy. But the hard truth is that many others are still struggling, and their knowledge management systems are severely lacking. Wherever companies start from, LLM-advisors will demand a data foundation that's more accessible and contextual than ever.

The knowledge graph is one of the most important technologies here. It's a graph-structured data model including entities and the relationships between them, which encodes greater context and meaning. Not only can a knowledge graph aggregate information from more sources and support better personalization, but it can also enhance data access through semantic search.[26]

To demonstrate just how powerful a knowledge graph and semantic search can be, consider a use case from Cisco Systems. Like many large global enterprises, Cisco's sales team had tons of content to leverage. But they struggled to find relevant documents through their index-driven search due to a lack of metadata. So, they turned to Neo4j to help create a metadata knowledge graph. While they did not use LLMs, they relied on natural language processing to create an ontology and a machine tagging service to assign document metadata, which was then stored in a graph database. Now, finding information takes half the time, and Cisco saves its salespeople over four million hours per year with its boosted knowledge management capabilities.[27]

In addition to knowledge graphs, other data management strategies will be important. Data mesh and data fabric are two ways to help map and organize information that businesses should look into as they update their overall architecture. And vector databases are essential to represent high-dimensional data for inferring relationships and similarity. What's more, while building up an enterprise's data foundation is critical to enabling an LLM-advisor interface, LLMs are also a tool to support the creation and maintenance of this foundation.

The first step in creating a knowledge graph, for instance, is to determine its ontology, or the relevant entities and their relationships to each other. LLMs can extract that data from raw texts to automate this process.[28] LLMs can also accept natural language text prompts to generate the associated schema and database structure based on the ontology, as well as to populate the graph database. So, as complex data foundations become ever more critical, they're also becoming easier to maintain and keep up-to-date.[29]

Garbage in, garbage out has been enduring truth of machine intelligence. And in today's age of asking LLMs for answers, it's more acute than ever. As enterprises start to bring LLM-advisors into their businesses, their success or failure here will make all the difference.

Exploring LLMs as your new data interface

On their own, knowledge graphs, data mesh, and data fabric would be a huge step up for enterprise knowledge management systems. But there's a lot of value to be gained in taking the next step and shifting from the librarian to advisor model. Imagine if instead of a search bar, employees could ask questions in natural language and get clear answers – across every website and app in the enterprise. With an accessible and contextual data foundation, enterprises can start to build this – and there are a few different options to explore.

First, companies can train their own LLM from scratch, though this approach is rare given the significant resources required. Some of the leaders here are AI powerhouses, including Amazon, OpenAI, Google, Meta, AI21, and Anthropic. Bloomberg also took this approach, using its own massive knowledge base of financial data, along with a public dataset, to train a 50-billion parameter LLM for the financial industry called BloombergGPT.[30] It will be made available to customers on the Bloomberg Terminal.[31] For large companies with vast resources, however, self-training an LLM from scratch may be an appealing approach to secure a competitive advantage.

A second option is to "fine-tune" an existing LLM. Essentially, this means taking a more general LLM and adapting it to a domain by further training it on a set of domain-specific documents. OpenAI's GPT-3.5, for instance, can be fine-tuned using a business's own data, to hone it into a more custom or efficient model for certain tasks.[32] And major cloud providers like Amazon AWS, Microsoft Azure, and Google Cloud all provide services to help their customers fine-tune a private version of a foundation model with their own data.[33,34,35] These models can then be integrated and deployed in company applications. While this takes considerably fewer resources than training an LLM from scratch, it does not ensure that the model has the latest up-to-date information. This option makes the most sense for domain-specific cases when real-time information is not necessary, like for creative outputs in design or marketing.

A slight variation on this is also gaining traction. Enterprises are beginning to fine-tune smaller language models (SLMs) for specialized use cases. SLMs like DeepMind's Chinchilla and Stanford's Alpaca have started to rival larger models while requiring only a fraction of the computing resources.[36] These SLMs are not only more efficient, running at lower cost with smaller carbon footprints, but they can be trained more quickly and used on smaller, edge devices.

Lastly, one of the most popular approaches to building an LLM-advisor has been to "ground" pre-trained LLMs by providing them with more relevant, use case-specific information, typically through retrieval augmented generation (RAG). As suggested by the name, this combines an information retrieval system with a generative model, which can be either self-trained or used out-of-the-box and accessed through an API.

At a high level, RAG works something like this: First, a user will type in their request. Next, that input is used to search for and retrieve relevant documents – whether unstructured data like text from Word documents, chats, or PDFs, or structured data like CSVs or database tables – as vector embeddings. Then, these documents, along with a prompt, are sent to the LLM. The LLM is, of course, trained on a huge amount of data initially, but only uses the specific information it receives to generate its response to the user.

Grounding an LLM through in-context learning and RAG takes much less time and compute power, and furthermore, requires far less expertise than training LLMs from scratch or fine-tuning. In fact, this approach is built into Microsoft 365 Copilot, an AI assistant for Microsoft 365 applications and services.[37] And Salesforce's Einstein GPT uses this approach to ground generative AI chatbot responses too, when connected to one of OpenAI's LLMs or any other external LLM.[38] This option works best for use cases that require up-to-date information, though verifying for accuracy may still be necessary.

The field of generative AI and LLMs is moving fast, so by the time you read this report, there may already be new best practices for building generative AI advisors. But whatever way you choose to explore, one thing will stay constant: your data foundation needs to be solid and contextual, or your LLM-advisor will never live up to its promise.

The implications: The future of enterprise knowledge

Now that we've explored people's changing relationship with information, and how enterprise data practices can evolve to meet the moment, we need to discuss what it will let enterprises do. After all, it's one thing to say LLM-advisors will launch a new generation of data-driven business. It's another thing to build it.

Understanding and mitigating risks

First and most importantly, as businesses begin to explore the new possibilities LLM-advisors bring, they need to understand the associated risks. In March 2023, a lawyer submitted a brief to a New York judge.

In it, he cited multiple prior court decisions, indicating that his client's case should not be dismissed.[39] But there was a problem. None of those court decisions, or related quotations and citations, could be found – ChatGPT had created fictitious cases. According to the lawyer, he was not aware that ChatGPT could fabricate information, but the judge was not pleased. Not only did the judge fine that lawyer and others involved, but he required them to notify the real judges who were identified as having written the fake cases.[40] Most embarrassing: the colossal mistake wound up on the front page of *The New York Times*.[41]

What this lawyer experienced was an almost intrinsic characteristic of LLMs: "hallucinations." Because LLMs are trained to deliver probabilistic answers with a high degree of certainty, there are times when these advisors confidently relay incorrect information. And as LLM applications start to take a bigger share of how we access and relay information, or interact with and integrate software, there can be serious consequences. Any way you slice it, when you don't know if what you're reading is true, that's a major issue.

And while hallucinations are perhaps LLMs' most notorious risk, other issues come up when we think about using these chatbots in the enterprise. If using a public model, proprietary data must be carefully protected so that it cannot be leaked. And for private models too, data cannot be shared with employees who should not have access. The cost of computing is something that needs to be managed. And underlying everything, few people have the relevant expertise to implement these solutions well.

All that said, these challenges shouldn't be taken as a deterrent, but rather as a call to implement the technology with appropriate controls. And we're not starting from zero. The governance that matters most for LLMs is important for any AI implementation, especially when it comes to data security, accuracy, and ethical issues.

The data going into the LLM – whether through training or the prompt – should be high quality data. That means it should be fresh, well-labeled, and unbiased. Training data should be zero-party and proactively shared by customers, or first-party and collected directly by the company.[42] And security standards should be implemented to protect any personal or proprietary data. Finally, data permissions must also be in place to ensure that the user is allowed to access any data retrieved for in-context learning.

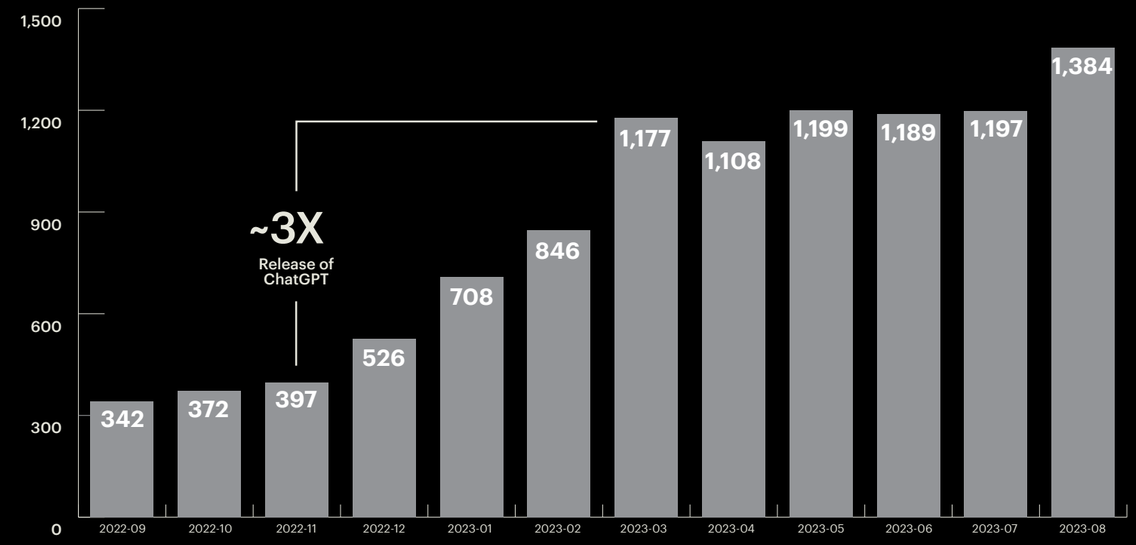
Beyond accuracy, the outputs of the generative AI chatbot should also be explainable and align with the brand. There are multiple ways to help achieve this. Guardrails can be put in place so that the model does not respond with sensitive data or harmful words, and so that it declines questions outside its scope. Moreover, responses can convey uncertainty and provide sources for verification. One company that does this today is Writer, a generative AI writing platform. It leverages a knowledge graph to highlight the AI-generated content that should be fact-checked, and it also suggests a replacement which may be more accurate, along with its source, based on the relevant information in the knowledge graph.[43]

Finally, generative AI chatbots should be subject to continuous testing and human oversight. Companies should invest in ethical AI and develop minimum standards to adhere to. And they should gather regular feedback and provide training for employees as well. Of course, given the power of generative AI chatbots, more associated risks are sure to arise – but these are some of the best ways to start mitigating those risks today.

Developer interest in generative AI surged in 2023

Following the launch of ChatGPT, there was a threefold surge in generative AI-related posts on Stack Overflow. This indicates a substantial ongoing trend among developers who are integrating and adopting generative AI into their workflow.

Total posts mentioning generative AI tools by month: September 2022 - August 2023



Source: Accenture Research analysis on Stack Overflow Data, timeline: Sep 2022 - Aug 2023

What the shift from search to asking will let us do

At last, it's time to start capitalizing on today's new age of LLM-advisors. Data and software are so intrinsic to businesses today, in how they operate and in what they fundamentally offer, that enterprises have a huge range of opportunities to change and improve what they do now.

Starting with opportunities inside the enterprise – equipped with generative AI chatbots, employees and customers will have newfound access to not just knowledge but answers in context, in a way that they've never had before. This new interface connecting them with the information they need will amplify internal knowledge sharing, customer service, product capabilities, and much more.

Morgan Stanley, for instance, has a vast internal knowledge library, including hundreds of thousands of documents ranging from investment strategies to market research and other insights.[44] These documents can be found across various internal sites, mostly in PDF form, so it can require significant time and energy for advisors to scan those documents and find the answers they're looking for. Now, however, with the help of GPT-4, Morgan Stanley has created a generative AI chatbot that can harness this wealth of internal knowledge and help advisors get the insights they need, instantly.

Toyota is another company leveraging generative AI to scour vehicle owner's manuals and provide more direct answers to people's car questions.[45] Currently, they have a proof-of-concept that allows a driver to ask aloud a question like, "How do I disable the VSC?" The Toyota AI will respond with clear instructions, as well as with the pages in the manual where the driver can find the answer. In addition, research shows that customer service workers can benefit from generative AI chatbot assistance too, likely through the dissemination of more tacit knowledge.[46] The findings showed that the AI assistant not only helped workers become more productive, resolving 14% more issues per hour on average, but it also improved customer sentiment and employee retention, while reducing requests for the manager.

Companies are finding ways to add generative AI chatbots to their products too. The social platform Discord, for instance, has launched AI-generated conversation summaries so that users can quickly catch up on what they've missed.[47] And its moderation tool AutoMod now uses OpenAI LLM technology to inform moderators when rules may have been broken, while also considering the context of the conversation. In addition, Snap has created one of the largest consumer chatbots, My AI, available through Snapchat, which has already received more than 10 billion messages from more than 150 million people.[48] Users can use My AI to learn more about their interests and hobbies, as well as to help foster connections with their friends.

These are just a few examples of opportunities businesses can capture when they combine their droves of data with the power of generative AI. And while the value we already see is vast – providing the answers employees and customers want in a more accessible way, saving countless hours and frustrations, and enabling better decision-making across the business – there's still a lot more to discover.

Moving to opportunities outside the enterprise: how do generative AI chatbots change the way information *about* the enterprise is found, say, by customers who are looking to potentially purchase the company's products or services?

If people's relationship with data is changing, then these questions are urgent. Already, people are replacing traditional search engines with generative AI internet search-bots like Microsoft Bing Chat, or augmenting the search experience with Google SGE, which can provide AI-powered overviews and responses to people's searches.[49,50] They're getting direct answers to their queries in natural language. And while sources are cited and search results are also provided on the page, the question is, will anyone actually visit those links?

If they don't, what does that mean for websites – and what does that mean for business websites in particular? How can businesses ensure that their customers get the right information that they are looking for and need, or the most up-to-date information with the appropriate sources linked?

This might sound less like an opportunity and more like a problem, but these are open questions everyone will be tackling in the coming years. Enterprises still have time to get ahead and reimagine how they reach customers.

Some companies are looking at plugins to give explicit access to external data and improve the outputs of generative AI chatbots like ChatGPT and Bard. For instance, Edmunds.com and CarGurus.com – websites providing car inventory, pricing, and reviews – both launched ChatGPT plugins to help prospective car-buyers.[51] This way, customers can get up-to-date information and explore cars in their own terms and language, without being constrained by the limited search fields. Today, companies with Bard plugins include Redfin, Instacart, and Spotify.[52]

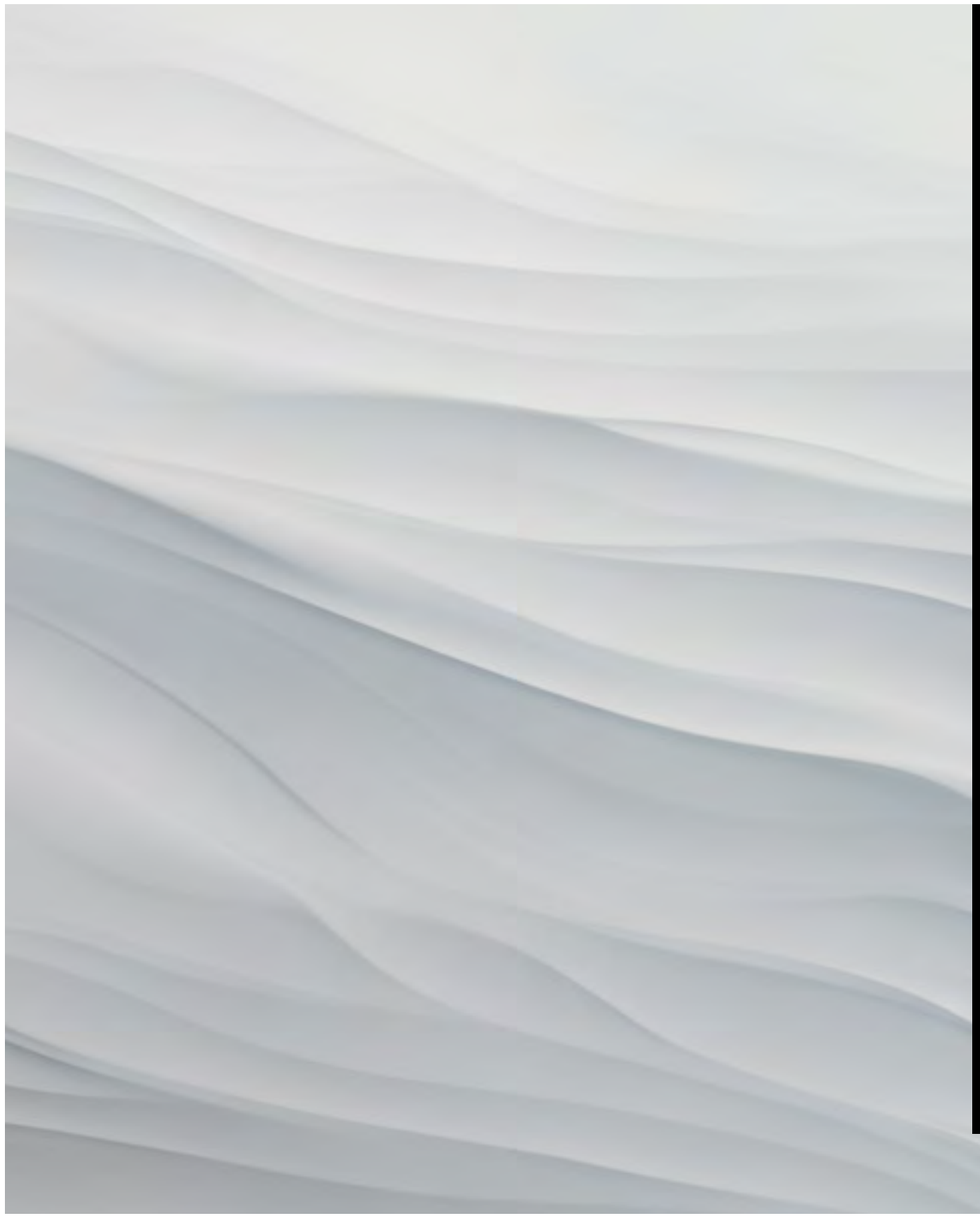
While plugins are one option for now, new trends are sure to gain steam in coming years, and businesses will need to be willing and ready to try new things. Those that do may find themselves at the cutting edge of change. The shift from search to asking is heralding a new era of data-driven business, and its impact on enterprises' marketing and content approaches, as well as how current and potential customers find them, might just decide the winners from the losers in this new age.

Security implications

Among the many other security implications already discussed in this trend, companies should also think about how LLM-advisors may change user data dynamics.

Historically, search providers have held all the power, storing a treasure trove of data about both companies and their customers, and often leaving people wary of how their information was used and who even had access to it.

Now we have an opportunity to reinvent the ethos of search and restore trust between businesses and their customers. Companies can now act as stewards of their own information – storing, securing, analyzing, and disseminating their data and institutional knowledge directly to customers through digital advisors. This is a big responsibility: your company must ensure that your data remains secure while yielding high-confidence responses in your advisory services. It's an even bigger opportunity: without search providers mediating the exchange of information, companies can serve as a direct source of reliable insight and win back their customers' trust.



Conclusion: A match made in AI

Generative AI is a game-changer for data and software. Just as search did decades ago, LLMs are changing our relationship with information, and everything from how enterprises reach customers to how they empower employees and partners stands to transform. Leading companies are already diving in, imagining and building the next generation of data-driven business. And before long, it won't just be leaders – it'll be the new way digital business works.

If you're starting to think differently about information, then you're on the right track.

Meet my agent

Ecosystems for AI

>

1770

The Mechanical Turk, an “autonomous” chess player, is built.[1]

1892

The first automatic telephone exchange is installed.[2]

1961

GM successfully integrates the Unimate robotic arm in their manufacturing process.[3]

1995

BargainFinder becomes the first comparison-shopping agent.[4]

1996

Microsoft releases Clippy.[5]

1997

NASDAQ uses an agent-based model to simulate the stock market.[6]

1999

eSnipe, a tool to automatically place eBay bids, launches.[7]

2001

The National Academy of Sciences hosts a colloquium on agent-based modeling.[8]

2011

Apple releases Siri.[9]

2015

Schwab Intelligent Portfolios, an autonomous investment advisor, is launched.[10]

2017

Research shows that humans working with software agents reach solutions 55.6% faster.[11]

2019

DeepMind’s AlphaStar becomes a Grandmaster in StarCraft II.[12]

2022

Amazon announces Proteus, its first fully autonomous mobile robot.[13]

2023

Update allows ChatGPT to receive speech and image inputs.[14]

2023

Auto-GPT and BabyAGI are launched.[15]

2025

A new code repository will launch for open-source code written by agents.

2026

Three-fourths of knowledge workers will use copilots every day.

2028

The first truly lights-out car manufacturing plant will open.

2030

One half of home mortgages will be approved and serviced by agents.

2032

Authorities will dismantle an insider trading ring that was using intelligent agents to collect protected information.

The big picture

Can an AI agent launch your next product?

96% of executives agree that leveraging AI agent ecosystems will be a significant opportunity for their organizations in the next three years.

It might sound futuristic, but it could happen sooner than you think. Already, enterprises are embedding AI across business operations. Generative AI has transformed industry leading creative tools at Adobe and propelled product ideation at Volkswagen.[16,17] Siemens and Fanuc have reimagined manufacturing by embedding AI across robotics and industrial processes.[18,19] And in the last few years, the advent of foundation models has radically expanded the deployment of AI to departments like marketing and sales to rapidly create new content and expedite time to market.[20]

With all this intelligence at their fingertips, enterprises need to start asking these kinds of questions: "Can AI launch my next product?" "Can it run my warehouse?" "Can it restructure my organization?" Otherwise, they're at risk of thinking too small.

We are beginning to see AI break out of its limited scope of *assistance* to engage more and more of the world through *action*. Over the next decade, we will see the rise of entire agent ecosystems – large networks of interconnected AI that will push enterprises to think about their intelligence and automation strategy in a fundamentally different way.

A useful analogy for the progression of AI agents is the advancement of self-driving cars. For many years, drivers were entirely responsible for the operation of the vehicle (no AI). But then semi-automated systems like cruise control or lane assist came into play (AI that assists). After that, automated driving became available to drivers in limited conditions, and then fully self-driving cars requiring no driver at all (agents with increasing action). And if you extrapolate this trend, we can imagine a future with self-driving cars that all work together on the road (an ecosystem of agents). For cars, these advances have not come as precise step changes but as progress on a continuum. The evolution of AI agents will be the same.

Today, most AI strategies are narrowly focused on assisting in task and function. To the extent that AI acts, it is as solitary actors instead of an ecosystem of interdependent parts. We might use AI to participate in design, find manufacturing flaws, or pull insight from consumer feedback – but it usually recommends rather than takes action, and is generally siloed, not threaded across an entire operation.

But now things are beginning to change. As AI evolves into agents, automated systems will make decisions and take actions on their own. Agents won't just advise humans, they will act on humans' behalf. AI will keep generating text, images, and insights, but agents will decide for themselves what to do with it.

Look at DoNotPay, a company designed to help consumers save money – from contesting parking tickets to identifying unused subscriptions. Until recently, DoNotPay identified these issues and prompted customers to take action – but then the company integrated GPT-4 and AutoGPT into its software.[21] The first user of these new features was DoNotPay's CEO. He gave the agent access to his financial accounts and prompted it with a concise yet complex task: *find me money*. The agent identified $81 in unnecessary subscriptions and an unusual $37 in-flight Wi-Fi fee. Then, it offered to automatically send cancellations to the subscription providers, drafted a letter to contest the Wi-Fi charges, and checked in with the CEO for review. As icing on the cake, it even drafted and sent emails that negotiated a 20% reduction in the CEO's cable and internet bill.

Today, AI can detect manufacturing flaws, but agents could enable true lights-out manufacturing.

But even as this agent evolution begins, companies already need to start thinking about what's next. Because if agents are starting to act today, it's not long until they start acting *with each other*. Tomorrow's AI strategy will require the orchestration of an entire concert of actors: narrowly trained AI, generalized agents, agents tuned for human collaboration, and agents designed for machine optimization. These agents will build on each other's efforts, forming an ecosystem that will transform both how and what companies are capable of producing.

Instead of using AI to optimize an isolated business process, agents could command entire chunks of the value chain. Today, AI can detect manufacturing flaws, but agents could enable true lights-out manufacturing. AI is already processing orders, yet agents could sell your product and then get it to the customer's door. Just as the moving assembly line allowed Ford to reimagine what the automobile market could be, agent ecosystems will let companies reinvent what they offer and how they offer it. With markedly greater efficiency across multiple departments, will your prices become accessible to a new demographic? With greater insights and ideas across the enterprise, will you create a product that captures an entirely new market? With comprehensive access to your organization's information, agent ecosystems could generate opportunities and solutions that neither siloed AI nor siloed humans could conceive.

But there's a catch: there's a lot of work to do before AI agents can truly act on our behalf, or as our proxy. And still more work before they can act in concert with each other. The fact is, agents are still getting stuck, misusing tools, and generating inaccurate responses – and these are errors that can compound in a hurry. Without the appropriate checks and balances, agents could wreak havoc on your business.

Innovative leaders will build the scaffolding that agents need to gradually earn their organization's trust and fulfill their explosive potential – and they will turn to human employees as the first test pilots, deciding when and where internal agents should be allowed to fly solo. In other words, *people* will create the support systems that turn agents into reliable actors, and success here will determine if agents work for or against the organization.

Humans and agents are co-dependent; if you want to reinvent your AI strategy to tap into agent ecosystems, you need to reinvent your people strategy, too. Already, 40% of all working hours across all industries could be impacted by large language models (LLMs) like GPT-4.[22] And that number is likely to grow. While we've discussed pairing humans and machines at the task-level before, we have never prepared for AI to operate our businesses – until today. As agents are promoted to be our colleagues and our proxies, we will need to reimagine the future of tech and talent together. It's not just about new skills, it's about ensuring that agents share our values and goals. Agents will help build our future, and it's our job to make sure they build a world we want to live in.

The technology: From assistance to actions to ecosystems

Companies are kicking off their most important transformation of the next decade. Every step in this AI evolution will introduce discrete technologies that, on their own, hold enormous innovative potential. But it is critical that leaders also recognize these pieces as part of something greater: the agent ecosystem.

AI assistants are maturing into proxies that can act on our behalf. As these agents emerge, the resulting business opportunities will depend on three core capabilities: access to real time data and services; reasoning through complex chains of thought; and the creation of tools – not for human use, but for the use of the agents themselves. Along with humans to guide and oversee them, these advancements will allow agent ecosystems to complete tasks in both the physical and digital worlds, generating immense value for every enterprise that takes part – and risking obsolescence for those who don't.

Starting with access to real time data and services – when ChatGPT first launched, a common mistake people made was thinking the application was actively looking up information on the web. In reality, GPT-3.5 (the LLM upon which ChatGPT was initially launched) was trained on an extremely wide corpus of knowledge and drew on the relationships between that data to provide answers. In fact, at that point, if you looked closely (or even asked it), it would tell you that the knowledge it held only went up to September 2021. But we live in the present.

For any tool to become a meaningful agent, it will need to combine the skills developed from a carefully cultivated historical record with the current information that comes from a rapidly expanding dataset of current events and knowledge.

In March 2023, OpenAI announced the first plugins for ChatGPT. "Plugins" allow LLMs to look up information, use digital software, execute code, call APIs, and generate outputs beyond text by allowing the model to access the internet. Instead of relying solely on the weights and tokens that make up the model's intelligence, ChatGPT can now search Expedia to get travel information, access Instacart for ordering groceries, and engage Wolfram (a computational intelligence platform) to perform complex mathematical calculations.[23] After just a few months, ChatGPT had access to hundreds of plugins.[24] By the time you read this, those numbers may be higher.

These plugins transform foundation models from powerful engines working in isolation to agents with the ability to navigate the current digital world.

While plugins have powerful innovative potential on their own, they'll also play a critical role in the emergence of agent ecosystems. Today, plugins give AI access to our most relevant digital tools, but tomorrow plugins could allow agents to engage powerful AI models, enabling far more than AI has ever done alone.

The second step in the agent evolution is the ability to reason and think logically – because even the simplest everyday actions for people require a series of complex instructions for machines. Imagine walking across the room to get a glass of water. You don't have to think too hard about it, but a machine needs to understand what a glass is, where to find it, how to get there, how to pick it up, how to fill it, and where the sink is before water even enters the glass.

Some may argue that AI has been doing complex tasks for some time now, such as playing chess or packing boxes. But these are relatively specific tasks, in which any deviation from the pre-trained instructions often results in failure. If we can't find a cup where we thought we left it, we adjust and go look for it. If a narrow AI is faced with a similar disruption, it's usually programmed to abort or restart the task. Even today's LLMs face similar limitations. With no internal memory, the ability to manage complex sequences has been a problem. It may not abort the request, but it could do something like confidently provide a false answer.

But AI research is starting to break down barriers to machine reasoning. Chain-of-thought prompting is an approach developed to help LLMs better understand steps in a complex task.[25] It started with researchers realizing they could provoke better outcomes by breaking down prompts into explicit steps, or even prompting the model to "think about this step by step." Further research showed that by utilizing few-shot techniques and providing the model with several chained-reasoning examples, the model would adapt to follow a similar sequence in other tasks.[26]

This style of prompting can initially require human input, but research continues to reveal that models can be engineered to self-critique and file information into their working memory – opening the door to automating this type of reasoning.[27] AutoGPT and BabyAGI are two open-source applications that leverage LLMs and automate chain-of-thought prompting. These applications will take broad queries or instructions, and then prompt themselves to think through the steps and ways to accomplish their goals, articulating for themselves a detailed set of instructions that they will then use to accomplish the original ask.[28,29]

Between chain-of-thought reasoning and plugins, AI has the potential to take on complex tasks by using both tighter logic and the abundance of digital tools available on the web. They imbue AI with the potential to navigate more uncertainty and with more solutions, opening up far greater opportunities for businesses. But what happens if the required solution isn't yet available?

When humans face a challenge that exceeds our equipment, we acquire or build the tools we need.

We run out to the hardware store, write a piece of code, or otherwise find what we can use to overcome the challenge. AI used to rely on humans exclusively to grow its capabilities. But the third dimension of agency we are seeing emerge is the ability for AI to develop tools for itself.

Take Nvidia, which along with researchers from several universities, explored the possibility of developing an "embodied agent." They built their agent – Voyager – in Minecraft, a popular game about survival and exploration that takes place in a 3D world.[30] To navigate this world, players acquire resources that allow them to forge new tools, like a pickaxe or lantern, which let them further traverse and shape their environment. Voyager was given the instruction to explore, and it was equipped with a skill library it could add to over time. As Voyager met new barriers, it would learn which tools were needed to overcome the obstacle, then store that information in its library. When encountering further obstacles, it would increasingly draw from its skill library – effectively, actions it taught itself – to overcome them faster.[31] The game has a hierarchy of skills and tools, where players can only move up by mastering the lower-level skills. Researchers were able to confirm Voyager's learning ability by watching it move up this skill tree.

Tool-building agents aren't just confined to simulations, they have real world potential. Researchers from Google, Stanford, and Princeton are working on generalizing this tool-making ability.[32]

In their paper "Large Language Models as Tool Makers" (LATM), the research team took a novel approach to how AI can create new, reusable tools to solve problems. They developed a closed-loop system comprised of two distinct AI models: the tool maker and the tool user. Instead of relying on a single model to accomplish an entire request, LATM takes a collaborative approach. As the model receives requests, the "tool maker" creates Python functions that accomplish the objective. But rather than executing the function itself, the maker hands it off to the "tool user" – a separate, more lightweight AI model. Over time, the tool user can respond to requests that fit its growing set of tools, and the tool maker improves tools over time by learning from similar requests.

Not only does Google's research demonstrate the rapidly expanding capabilities of AI to act, but it signals the beginning of multiagent interaction, as well as the opportunity that comes with it. LLMs today require immense computing resources, making them expensive to develop and run. LATM proposes a specialization strategy, where requests that have already been solutioned become more routine – and therefore executable by lightweight models. The "tool maker" does the heavy lifting, reducing the computational costs required.

And LATM isn't the only time Google has explored multi-agent interaction. In 2023, Google ran an experiment where they put 25 distinct agents, each with their own perspectives and backstories, into a virtual town.[33] The agents were given the freedom to interact with one another and the ability to store those interactions as memories, which they could reference later. What Google found were emergent social behaviors. When they prompted one agent to throw a Valentine's Day party, it invited other agents to the party, who in turn asked each other to go as dates.

Tool-building agents aren't just confined to simulations – they have real world potential, too.

Social behaviors in agents can enhance outcomes for the entire ecosystem. In another example, researchers from the Allen Institute for AI simulated negotiations between a buyer agent and a seller agent, with a third-party critic agent that provided feedback to improve bargaining.[34] The buyer and seller models incorporated feedback from the critic to improve future negotiation rounds. This diversity of perspectives could serve several purposes: a system of checks and balances to strengthen decision making; a productivity mechanism; or divergent inspiration to create novel solutions.

From real-time information to reasoning, tool creation, and multiparty interaction, valuable agent breakthroughs are happening fast.

But this is why it is so critical to maintain focus on the evolution of the whole ecosystem – because as independently valuable as each of these developments are, their combination will spark a revolution in how we apply artificial intelligence.

Agents, for example, can already automate entire tracts of scientific research by looking for information on the web, consulting scientific documents, and using scientific equipment in a cloud lab.[35] Google's PaLM-E can take a command in natural language, break it down into a series of subtasks, then generate and execute commands to control physical robots.[36] It's not difficult to imagine such an agent leading an entire manufacturing plant. And MetaGPT can automate an entire software development stream by acting as a product manager, architect, project manager, and engineer all rolled into one, delegating tasks to its array of GPTs. From one line of text, MetaGPT can generate user stories, competitive analyses, requirements, data structures, APIs, documents, and beyond.[37]

The agent ecosystem may seem overwhelming. After all, beyond the three core capabilities of autonomous agents, we're also talking about an incredibly complex orchestration challenge, and a massive reinvention of your human workforce to make it all possible. It's enough to leave leaders wondering where to start.

The good news is existing digital transformation efforts will go a long way to giving enterprises a leg up. Data modernization and creating libraries of APIs will be key to integrating enterprises' systems into the AI ecosystem. It's important to remember, though, that these models are not without their own drawbacks. Faulty responses remain inherent to LLMs. And much more research is needed on the risk and cybersecurity implications of leveraging these models. How enterprises balance the division of work between human and machine will be a delicate process that must, above all, prioritize human needs and benefits, not just what's possible with the technology.

But make no mistake: the next decade will see the emergence of the agent ecosystem and the enterprises who embrace it will effectively outpace their competition.

The implications: Aligning tech and talent in the workforce

What happens when the agent ecosystem gets to work? Whether as our assistants or as our proxies, the result will be explosive productivity, innovation, and the revamping of the human workforce.

As assistants or copilots, agents could dramatically multiply the output of individual employees. For the enterprise processes that will always depend on humans, agents will act as collaborators. Diagnosing a medical condition? Agents could help, but they won't share the diagnosis with the patient. Need to inspire your team? Agents could write the speech, but they won't deliver it. As copilots, agents and humans will complement each other, each playing to their own strengths.

In other scenarios, we will increasingly trust agents to act on our behalf. As our proxies, they could tackle jobs currently performed by humans, but with a giant advantage – a single agent could wield all of your company's knowledge and information. Their knowledge base would far surpass that of your most senior human employees, and agents could act on this knowledge everywhere, all at once. When they don't have the information they need, they could create it. When they don't have the proper tools, they could build them.

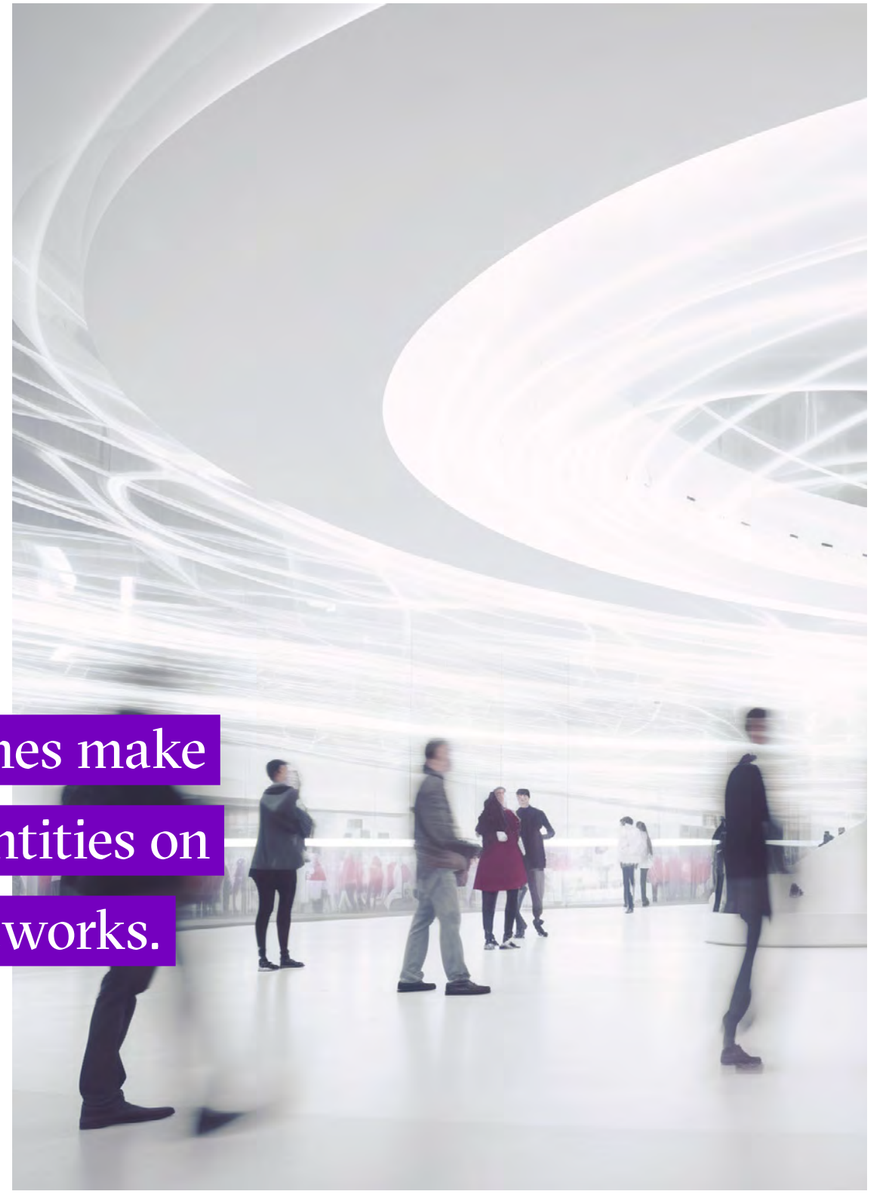
Humans have limits on their knowledge and their ability to take action. For agents, many of those limits won't apply.

So, what happens when agents work together? Imagine you need to boost sales for a struggling product. Your Product Management Agent works with your Finance Agent to set a growth target. Your Business Development Agent identifies new potential customers, and your Marketing Agent creates aligned campaigns. Such a network of agents could act and iterate continuously, pivoting after a missed target and doubling down when they hit the mark. The agent ecosystem is an inexhaustible source of productive innovation.

The companies that promote trusted agents to positions of power will discover new products, services, and capabilities. The more power we give agents over the value chain, the more value they can create. When we arm agents with information and tools, many of their abilities will transcend ours – meaning every company and every person will be empowered to do and create more than they ever could before. No digital market will ever be the same.

Businesses will need to think about the human and technological approaches they need to support these agents. From a technology side, a major consideration will be how these entities identify themselves. Today, machines make up 43% of identities on enterprise networks.[38] But they don't act alone, and we have an existing security framework for how they connect. As agents take more actions on their own, with behaviors that may mimic their human counterparts, technologies like Web3, decentralized identity, or other emerging solutions will become critical to making sure these agents can properly identify and authenticate themselves.

Yet while the framework of technology is a core consideration, the impacts on human workers – their new responsibilities, roles, and functions – demand even deeper attention. To be clear, humans aren't going anywhere. Yes, your people will have extra capacity, but they are going to need it. As agents take over enterprise functions, it won't be a purely machine operation. Humans will make and enforce the rules for agents. It's time to rethink your talent strategy to prepare your people for this new reality.



Today, machines make up 43% of identities on enterprise networks.

In the era of agent ecosystems, your most valuable employees will be those best equipped to set the guidelines for agents.

Rethinking human talent

What brave new world will agents inspire for your organization? The answer should come from your humans, not from your agents.

In the era of agent ecosystems, your most valuable employees will be those best equipped to set the guidelines for agents. As agents build their autonomy, humans must make and enforce the rules to ensure that their proxies act for the betterment of the company and the people within it. As humans are empowered by these agents to do more than they ever could before, both must have the company's North Star in mind. Whatever choices and decisions your employees make, for better or worse, are about to be amplified.

A company's level of trust in their autonomous agents will determine the value their agents can create. Your human talent is responsible for building that trust. Agent ecosystems will take actions without humans, but they won't always take the right actions. Before unleashing agents, humans need to embed rules, knowledge, and reasoning skills, and then rigorously test agents to ensure their readiness. As agent ecosystems evolve, humans have two primary responsibilities to engender trust in semi-autonomous systems: building agent support systems and refining machine reasoning.

Employees at frontier organizations are already driving autonomous AI toward accurate actions by curating their agent support systems. Existing LLMs are trained on massive amounts of information, which allows tools like ChatGPT to answer a range of questions with moderate accuracy. But if an agent controls your supply chain, for example, it first and foremost requires expertise on your supply chain – and extraneous information could lead your agent astray. As your employees embed your enterprise knowledge, proprietary data, and external tools into autonomous AI, these support systems can dictate the information the AI systems prioritize.

Investment research company Morningstar has successfully focused its GPT-3.5-embedded chatbot "Mo" on relevant proprietary information by providing such a support system.[39] Prompt-tuned on more than 10,000 pieces of proprietary research, Mo serves as an advisor to Morningstar's financial advisors and customers – and it's able to do this because Morningstar's human workforce set the stage in the background. Specifically, one Morningstar team created rules for what Mo can and can't answer, and Morningstar's lawyers ensured that none of Mo's capabilities violated ethical or regulatory bounds.[40] Morningstar proactively deployed their humans to put bounds on Mo because reactive trial-and-error isn't an option when you're dispensing financial advice.

Enterprise knowledge can no longer exist solely inside your employees if it's to be any value to agents. Now, your human talent must be able to extract their knowledge and skills so that it can be transferred to and used by your digital agents, too.

As agents get access to the right information, humans must also teach agents how to reason about that information.

In its simplest form, humans will test and correct agent reasoning. This is already happening at some companies today. For example, Morgan Stanley fine-tuned GPT-4 on 100,000 internal documents, creating an agent that answers questions for their financial advisors.[41] Their employees regularly ask the agent a series of "golden questions" to make sure its "thinking" stays sharp. When the system answers incorrectly, these knowledge managers go back into the training documents to figure out what needs to be fixed.

But it isn't enough to just think logically, agents also need to understand their limits. When does an agent have enough information to act alone, and when should it seek support before taking action? The specifics will vary agent to agent, company to company, and industry to industry. But across the board, humans will decide how much independence to afford their autonomous systems. Humans need to teach agents how to determine what they know, and more importantly what they don't know, so that agents can gather the information and certainty needed to keep working.

Self-examining agents won't hit the workplace in the immediate future, but the seeds of a reflective generation of agents are already being sown. LLM-based planners are now capable of determining their level of certainty for an action and reaching out for human support when confidence is low.[42] When the stakes aren't high, a lower confidence level may suffice. An agent creating marketing material is unlikely to face life-or-death decisions. But when the stakes *are* high, the only options are to act with certainty or not at all. The human knowledge and reasoning skills that an agent absorbs will determine the agent's competitive edge in the broader ecosystem. In other words, agents are only as valuable as the humans who teach them.

Agents are only as valuable as the humans who teach them.

What sort of human talent will give you an advantage? In the agent ecosystem era, your talent must have an intricate understanding of your company's values and mission and the ability to affect that vision to the agent ecosystem. If employee, agent, and company goals fall out of alignment, your actors will move fast in different directions. When this happens, the best-case scenario is stalled growth, the worst-case scenario is organizational destruction. When your actors are aligned, however, their actions will compound to accelerate your company towards its far-reaching goals.

With that potential acceleration of action, productivity, and value, businesses will need to decide what to do with it all. Will you create new products and enter new markets? Will you pay your employees more or embrace a four-day work week? In fact, all of these choices can be beneficial. Think again of Ford and the introduction of the moving assembly line. Ford was able to increase wages and decrease working hours, which not only attracted workers but afforded them the time and wages to drive the very cars that they were building. This new era could usher in the paradigm shift for work that many have been waiting for. Even better, everyone could benefit.

What companies can do now

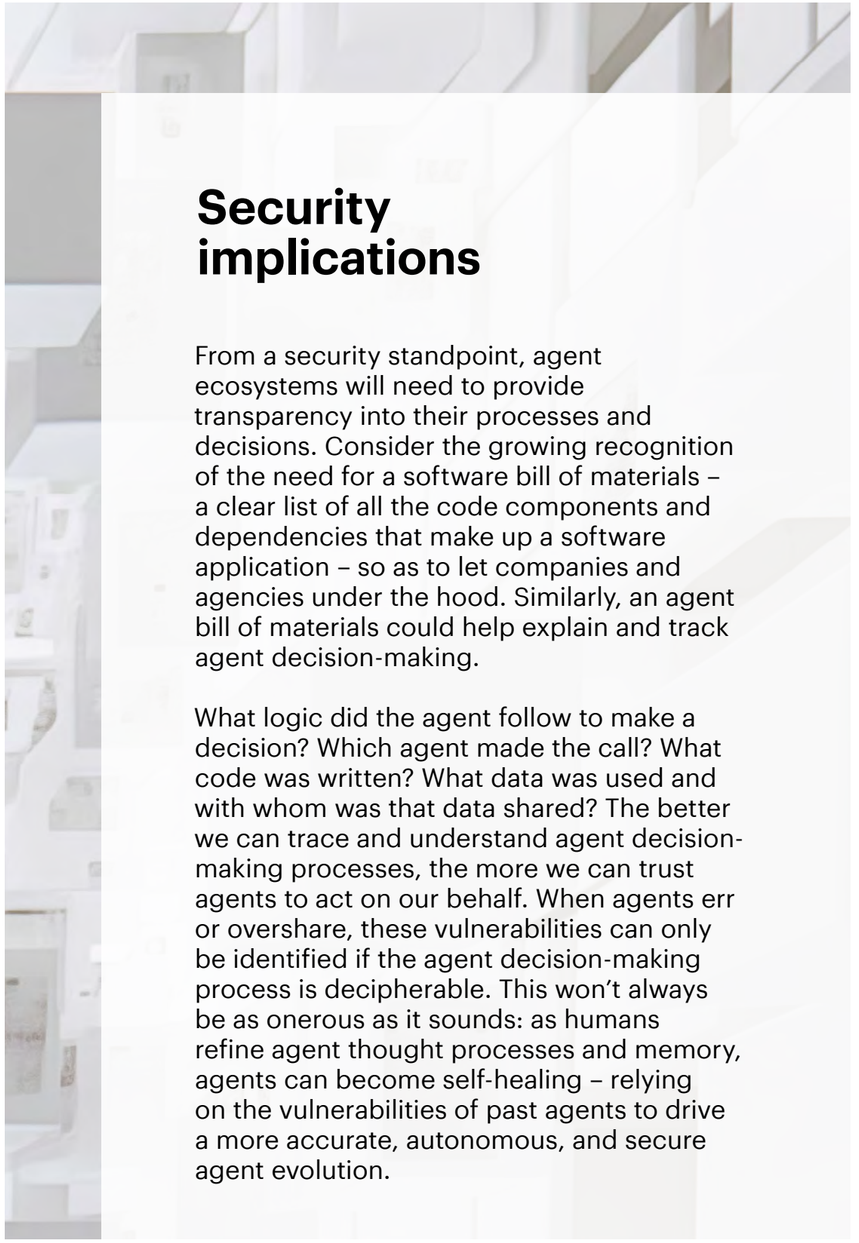
What can you do now to set your human and agent workforce up for success? Give agents a chance to learn about your company, and give your company a chance to learn about agents.

Companies can start by weaving the connective fabric between agents' predecessors, LLMs, and their support systems. There are many mature generative AI models and a few digital copilots ready to be linked up to the humans, data, tools, and robots that are already critical to your company. By fine-tuning LLMs on your company's information, you are giving foundation models a head-start at developing expertise. The sooner you prepare your infrastructure and information to be acted upon by agents, the sooner your future agents will be ready to fulfill their potential: acting as human proxies within and outside of your organization. For now, this introduction will require rethinking some of your data management practices, such as vectorizing databases, providing new APIs for accessing data, and expanding your tools to interface with corporate systems.

It's also time to introduce humans to their future digital co-workers. Companies can lay the foundation for trust with future agents by teaching their workforce to reason with existing intelligent technologies. Challenge your employees to discover and transcend the limits of existing autonomous systems. Help your people develop well-defined rules for when they can and cannot trust the autonomous systems at their disposal. In other words, train and upskill your human workforce such that they are ready and excited to take the reins – and know just how tightly to hold them – when agent ecosystems hit mainstream.

Finally, let there be no ambiguity about your company's North Star. Every action your agents take will need to be traced back to your core values and a mission, so it is never too early to operationalize your values from the top to the bottom of your organization. When your proxies start accelerating and amplifying the work of your human workers, they won't stop until they reach their goals. It's time to get crystal-clear about what those goals are.

By fine-tuning LLMs on your company's information, you are giving foundation models a head start at developing expertise.



Security implications

From a security standpoint, agent ecosystems will need to provide transparency into their processes and decisions. Consider the growing recognition of the need for a software bill of materials – a clear list of all the code components and dependencies that make up a software application – so as to let companies and agencies under the hood. Similarly, an agent bill of materials could help explain and track agent decision-making.

What logic did the agent follow to make a decision? Which agent made the call? What code was written? What data was used and with whom was that data shared? The better we can trace and understand agent decision-making processes, the more we can trust agents to act on our behalf. When agents err or overshare, these vulnerabilities can only be identified if the agent decision-making process is decipherable. This won't always be as onerous as it sounds: as humans refine agent thought processes and memory, agents can become self-healing – relying on the vulnerabilities of past agents to drive a more accurate, autonomous, and secure agent evolution.

Conclusion: Meet my agent

Agent ecosystems have the potential to multiply enterprise productivity and innovation to a level that humans can hardly comprehend. But they will only be as valuable as the humans that guide them; human knowledge and reasoning will give one network of agents the edge over another.

Today, artificial intelligence is a tool. In the future, AI agents will operate our companies. It is our job to make sure they don't run amok. Given the pace of AI evolution, the time to start onboarding your agents is now.

The space we need

Creating value in new realities

1957

Morton Heilig invents the Sensorama, a multisensory immersive movie experience.[1]

1973

The first tactile telephone is patented.[2]

1975

Xerox PARC releases the graphical user interface (GUI).[3]

1992

Louis Rosenberg creates the first interactive AR system.[4]

1999

The first camera phone is released.[5]

2003

Simon Greenwold coins the term Spatial Computing.[6]

2006

Roblox officially launches.[7]

2008

BMW runs the first AR advertisement.[8]

2011

Microsoft's Kinect, for Xbox gesture and voice control, becomes the fastest-selling consumer device.[9]

2012

Oculus VR is founded.[10]

2013

Google Glass sales begin.[11]

2016

Pokémon Go reaches 228 million downloads in its first quarter.[12]

2017

Apple announces ARKit for developing AR apps.[13]

2018

Not Impossible Labs creates a haptic suit to let people feel music.[14]

2019

Snapchat launches Landmarkers - AR overlay technology.[15]

2020

Nvidia releases the Omniverse platform.[16]

2021

Microsoft Mesh, an immersive collaboration platform, is released.[17]

2023

Apple announces the Apple Vision Pro spatial computer.[18]

2026

A professional sports league will launch an immersive 3D replay and highlight platform.

2027

A major city will add spatial entertainment, directions, and information to public spaces.

2028

A state public school system will announce offering physics courses taught entirely in an immersive spatial environment.

2030

The gaming market will be dominated by VR and spatially immersive games.

2031

A news site specializing in spatially immersive content will become the fastest growing new media company.

The big picture

When the original Macintosh launched in 1984, it was met with skepticism. The mouse was called "useless" and "awkward."[19] In 2001, when Apple launched the iPod, it was criticized for entering a crowded market at too high a price point. The iPad? It was scoffed as a glorified iPod touch, an absurdity because “how could anyone get serious work done without a mouse?”[20,21]

Apple got the last laugh. Today the Macintosh is considered a revolutionary product, as is the iPod, iPhone, and iPad. They each shaped the world of computing in unique and transformative ways. Still, in 2023 when Apple launched the Vision Pro, its mixed reality glasses, it seemed the critics hadn't learned their lesson.

This was Apple's entry into spatial computing – an already growing market – and should signal to every enterprise leader that a new technology medium has arrived. Yet few are recognizing the moment for what it is.

Spatial computing is about to change the course of technology innovation and the ways people work and live. Whereas desktop and mobile used screens as portals to the digital world, spatial will finally combine our disparate realities, fusing digital and physical together. Apps built for this medium will let people immerse themselves in digital worlds with a physical sense of space, or layer content on top of their physical surroundings.

It's a huge moment. Distinct technology eras are shaped and defined by the computing mediums we use. Desktop introduced consumers to the information world. Then mobile untethered the digital world, letting us take computers everywhere. And throughout the explosive technology innovation of the past decades, desktop and mobile were the foundation of it all. The fact is, computing mediums don't change very often, and it's a big deal when they do.

So, why doesn't it feel like we're at the beginning of a new technology era? Why are we inundated instead with talk of a "metaverse slump"? The metaverse is one of the best-known applications of spatial computing. But just look at the price of digital real estate, booming in 2021 and 2022, down 80-90% in 2023.[22] While some early endeavors are succeeding, why are so many others falling flat?

This is why we need to remember the Macintosh. New mediums don't come very often, and when they do, the uptake is slow. But the payoff for diving in early is nearly immeasurable.

Some companies are holding off, content to say metaverse hype outpaced technology maturity. But others are racing ahead, building the technology capabilities themselves. Meta has been rapidly developing its Reality Labs VR and AR products, and introduced Codex Avatars, which use AI and smartphone cameras to create photorealistic avatars.[23,24] Epic's RealityScan App lets people scan 3D objects in the physical world with just their phone and turn them into 3D virtual assets.[25] Underlying it all, advancing technologies like generative AI continue to make it faster and cheaper to build spatial environments and experiences. And, perhaps quietly, these technologies are already being proven out in industrial applications. Digital twins for manufacturing, the growth of VR/AR in training and remote operation, and the establishment of collaborative design environments are all already having practical – and valuable – impacts on industry.

Across the board, forward-thinking companies acting today recognize a core truth: expecting immediate, mass adoption of a new medium is unrealistic, but wait too long and you'll spend the next five or ten years trying to catch up.

But while the supporting technology is radically improving, it's only the first hurdle.

Spatial computing is about to change the course of technology innovation and the ways people work and live.

Enterprises that fail to see the significance of a new computing medium will struggle to get the applications right, too. Think back to the move from desktop to mobile. Google Maps debuted in 2005 as a desktop app, and it changed how people navigated the world.[26] But people still printed out their routes to take them on-the-go. Then the smartphone arrived. Google met the moment by unveiling a mobile Google Maps, which drew on real-time user data to refine its accuracy at staggering speed. Now, nearly wherever you and your phone go, you can get from Point A to Point B. More than one billion people today use mobile Google Maps.

This success happened because Google didn't just put Google Maps on the phone – it changed what the product was to meet the new medium's advantages. And that's exactly how enterprises need to approach spatial computing. Existing concepts of what an app is no longer apply. If enterprises want to build enriching experiences that truly improve on what we had before, their designs must match the new medium.

92% of executives agree their organization plans to create a competitive advantage leveraging spatial computing.

It sounds simple, but it isn't. Spatial computing, with its ability to blend physical and digital, is still mostly uncharted territory. Think about your first website or mobile application. Did your company get it right immediately? Or did it take time to learn from mistakes? Just as before, it will take time for enterprises to build the skills, infrastructure, and experience necessary to deliver new experiences to customers. If enterprises delay, waiting for spatial computing to hit some imagined saturation, they are committing to being too late.

Spatial is quickly becoming a key part of the enterprise fabric. Already, early adopters are finding ways to unlock its unique advantages, and those that follow can rapidly benefit from these learnings. Successful spatial computing deployments in industrial settings have shown it can be used to better convey massive amounts of complex information by tapping into multiple senses and communication avenues at once. Other experiments have found that when we see applications as "spaces," we can mold experiences to the individual's environment and gestures, or give them freedom to self-direct. Mobile and desktop users, in contrast, could only click or swipe where the design let them. And with spatial computing able to augment our physical environments, it can lessen our need for bulky office equipment and to repeatedly update physical spaces.

A new computing medium is exceptionally rare, and so a tipping point lies ahead. Spatial computing could grow to be as groundbreaking as desktop and mobile, ushering in a new era of technology innovation. But to succeed, enterprises need to rethink their position on it, starting today. They need to get out of the slump and recognize this moment for what it is. The tools are more ready every day – how you apply them is what matters now.

The technology: Today's spatial technology landscape

There's no doubt that delving into the world of spatial computing is a tall order for enterprises. 3D assets are notoriously difficult to develop. Questions around interoperability and design best-practices are still being answered. And even if a company invests in building a spatial app, one of that app's most important features will be to feel lived in and shared. The same way walking into an empty office can be eerie, metaverse worlds without a population feel empty, with few users wanting to return. Despite all this, and despite critics saying it's too early, spatial computing continues to grow.

The truth is: the time to start is now.

The market is rapidly shifting from a space where enterprises feel they can safely lag, to one where they will quickly need to catch up. We are reaching a turning point with the technology where the cost to create *and* adopt is coming down, and major advancements are being made in how to build spatial apps, make them feel real, and ultimately live up to their potential. And capitalizing on these technologies will take new skills, investments, and the institutional knowledge necessary to execute successfully.

First, new standards, tools, and technologies are making it easier – and cheaper – to build spatial apps and experiences. It's essential to understand just how important this is.

Building spatial apps

First, new standards, tools, and technologies are making it easier – and cheaper – to build spatial apps and experiences. It's essential to understand just how important this is.

Think about every website you've visited or your favorite apps on your phone. Even if their purposes are different, something feels undeniably familiar across even the most disparate experiences. Why? They all used the same foundation.

That consistency came through languages like HTML and the TCP/IP protocol that gave websites a common look and feel, as well as uniform ways for us to access sites. For mobile apps, the app stores provided design guidelines, ensuring apps held to uniform principles. This not only made the experience stickier for users, but easier for enterprises to design because they had a general understanding of what something should look like. This improved the ecosystem, too, since contributors knew what types of apps or websites to expect to support.

For a long time, spatial never had such a foundation. And when trying to build worlds that feel real, that lack of consistency is a major roadblock. Builders of digital spaces have to consider dozens more factors beyond what a web designer would weigh. Textures, shapes, lighting, and physics are just a few critical components for a space's look and feel. And because 3D modelling came into spatial computing out of disparate tracts – ranging from game design to film animation to industrial-type applications like architectural drawing or CAD modelling – there was a wide array of languages, file types, vendors, and design approaches. The ecosystem was fractured.

Enter Universal Scene Description (USD), or what can best be described as a file format for 3D spaces. Developed by Pixar, USD is a framework that lets creators map out aspects of a scene, including specific assets and backgrounds, lighting, characters, and more. Since USD is designed around bringing these assets together in a scene, different software can be used across each one, enabling collaborative content building and non-destructive editing.[27] USD might sound like its main use is in entertainment applications, but it is quickly becoming central to the most impactful spatial applications, notably within industrial digital twins.

Nvidia currently uses USD within its Omniverse platform for designing digital twins, as well as within Isaac Sim, its platform for developing and testing robotics in physically accurate digital environments.[28] And critically, companies that are driving forces in the spatial revolution are adopting it as well. Apple included it as part of the VisionOS SDK, and in 2023 Pixar, Nvidia, Apple, Autodesk, and Adobe all helped launch the Alliance for OpenUSD in an effort to standardize the 3D ecosystem and help the world of spatial computing flourish.[29,30]

With some companies working on making spatial worlds look and feel similar, others are focused on standardizing how we access those experiences. OpenXR is an open API standard that has now been adopted by most major device manufacturers.[31] It ensures applications can guarantee uniformity in head and hand position, controls, visual display, and more across most devices by using a single API (rather than testing and designing for all of them independently).

Critically, enterprises need to understand they will not be operating spaces in isolation. Just as no webpage or app exists on the internet alone, the next iteration of the web promises to bring these parallel experiences even closer together. Digital identity and Web3 will play a major role underpinning these spaces, from how to move a pair of digital pants or our payment information from one space to another, to how we identify the entities operating within those spaces. Today these technologies might not seem intrinsic to developing a successful space, but they will soon inform the long-term viability and value of the space to the customer.

Some are already taking this into account. The Open Metaverse Alliance for Web3 (OMA3) is building a standard for how we move across experiences. Today, if you want to move from one metaverse world to another, you need to quit one application and move to the next, almost like quitting and relaunching your browser every time you want to go to a new website. In 2023, OMA3 launched a project called the Inter-World Portaling System, an effort to develop a protocol that would let developers move users from one space to another without breaking the immersion, like how an address bar sits at the top of whatever website you visit.[32]

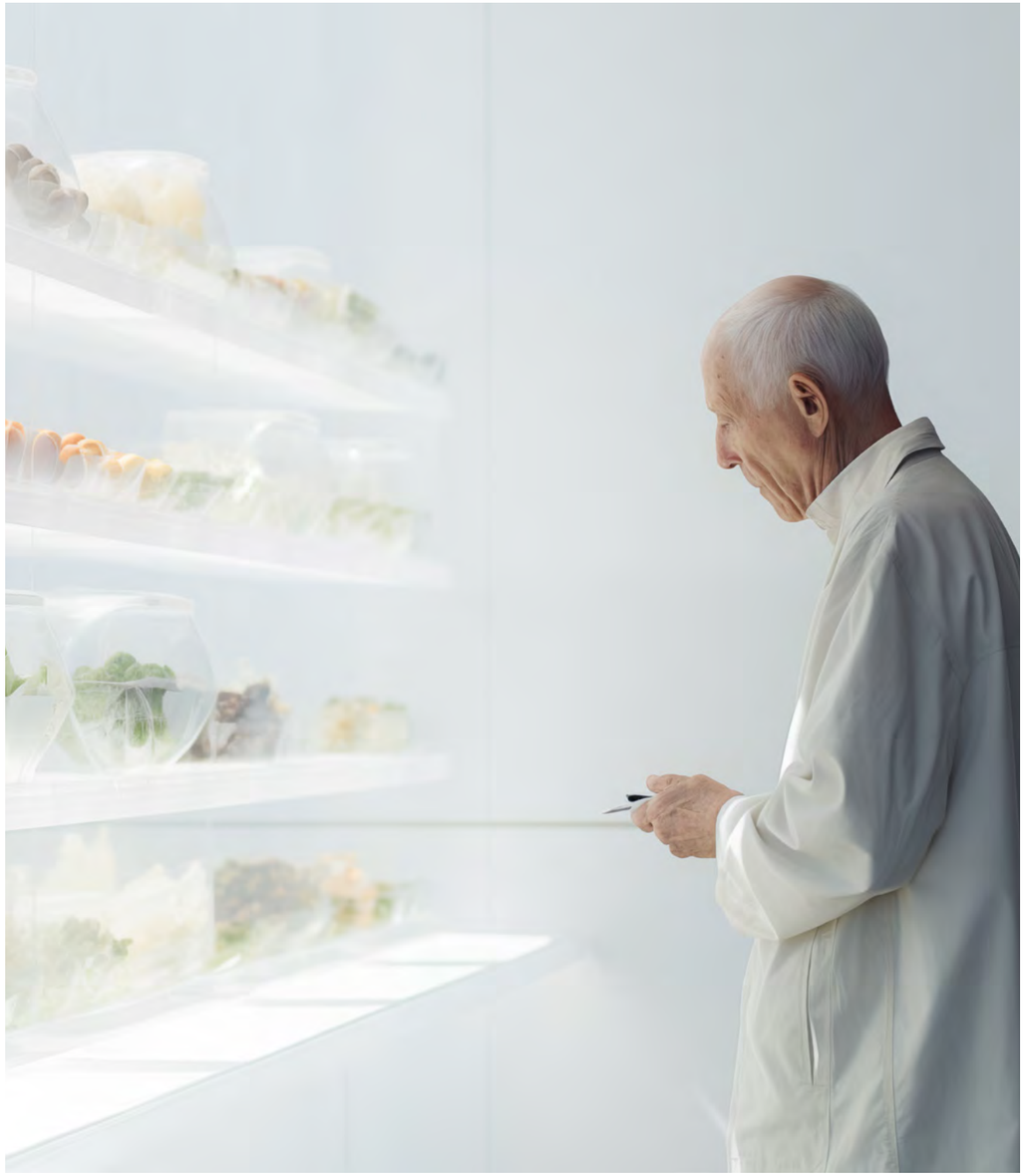
But as important as interoperability is, it still doesn't help if developing 3D assets is very expensive – which, historically, it has been. One estimate from 2020 had the average cost of 3D models anywhere from $40 to thousands of dollars per asset. And 3D scenes will require *a lot* of assets.[33] Yet this is one area where the cost pressure is beginning to break.

Generative AI is speeding up the creation of 3D digital content. Take Nvidia's Neuralangelo, a generative neural network. It can rapidly turn 2D video clips into 3D digital objects or structures.[34] Those assets can be imported into VR or AR spaces, digital twins, or video games. And Intel's LDM3D AI model can churn out 360-degree 3D images from simple text prompts.[35]

Other examples are cutting out the need to create a 3D model in the first place. Qualcomm's Snapdragon Spaces is leaning into realism by letting people blend digital content with their physical environment. The AR SDK is allowing developers to rapidly create new applications that blend the digital and physical by using semantic scene understanding, hand tracking, object detection, and more.[36] And Google's TryOnDiffusion uses generative AI to let online shoppers see how clothes would realistically drape or fold over their unique bodies.[37]

Not only is the financial cost starting to break, so is the time investment as well. Some tools are making it simple enough for anyone to build spatial environments. Google's Geospatial Creator, powered by the Google Maps Platform and ARCore (Google's AR Software Development Kit), lets you create an immersive experience in just minutes. You can build 3D digital content to layer onto real-world locations and it integrates with design engines like Unity and Adobe Aero.[38] The best part? Little to no coding skills are needed.

But building a world isn't the only hard part – you also need to fill it.



Enterprises need to go beyond just making spaces look real, to making them feel lived in.

Populating spaces

"Where is everybody?" famously said physicist Enrico Fermi when contemplating life in the universe. Math told him our universe should be teeming with life. Yet looking at the stars, space seemed desolate – a feeling that often exists in metaverse spaces we visit today. Well-crafted but empty spaces can turn users away, which is why to be successful, enterprises need to go beyond just making spaces look real, to making them feel lived in.

One obvious way to populate spaces is by bringing in other users. The metaverse's promise has always been a shared vision, where people could work or talk together. But with an estimated 400 million people engaging in metaverse experiences, these spaces could get crowded quickly. It's one thing in the physical world to walk into a local retailer that has multiple locations. It's another when everyone in the world can access the same virtual store at once.

This is why part of Meta's training and guides for developers building 3D spaces includes proxemics as a topic.[39] Proxemics is the study of how we use space, including how population density or physical proximity impacts how we act, communicate, and relate to each other. Meta recognizes that spatial awareness is key to making these experiences work.

A user's experience in a crowded space may well be an important factor in figuring out when an enterprise needs another instance of a digital store or world to combat overcrowding.

Another strategy is creating AI people. These AI characters can populate spatial apps, making interactive and tailored experiences. It's not a new concept: non-player characters (NPCs) have been in video games for almost as long as they have existed. But historically, they've brought a different slew of challenges, like feeling hollow and impersonal. The software company Inworld AI found that 52% of gamers disliked repetitive NPC dialogue.[40] But making higher quality NPCs usually took more time and money without quite enough pay-off.

Inworld AI points to a new direction. It creates AI characters with personalities, that can communicate verbally as well as non-verbally.[41] These characters are context-aware, so they don't hallucinate or refer to content outside their set world, mitigating misinformation risks.[42] And they offer a sense of interpersonal realism that will ground the spatial apps of tomorrow.

Sense of place

Finally, one emerging capability that differentiates spatial computing from its digital counterparts is engaging our senses. New technologies are letting engineers design experiences that address all types of senses, like touch, smell, and sound.

In past VR attempts, adding haptics, or touch, could be bulky or underwhelming. But University of Chicago researchers recently proposed using electrodes to better mimic touch.[43] They built an electrode system with 11 controllable tactile zones on a person's fingers, so they could "feel" digital content. Imagine a meditation spatial app that took you to a virtual beach where you could "feel" the grains of sand.

Scents can make digital spaces lifelike, too, by evoking memories or triggering the all-important fight-or-flight response. Scentient, a company trying to bring olfactory senses to the metaverse, believes scent can be the key to overcoming the "uncanny valley" – when a scene feels almost believable, but not quite enough, turning users away. Scentient's leaders think scent brings realism and dimension to a digital space, and they have been experimenting with the technology for training firefighters and emergency responders, where smells, like the presence of natural gas, can be critical for evaluating an emergency.[44] At first glance, the idea of scent may seem gimmicky, but it can have real impact, and be a key part of a successful space.

Of course, sound, or spatial audio, is also critical to realistic digital scene-building. *The New York Times* recently used web-based spatial audio to immerse readers in the sonic landscape of the Cathedral of Notre Dame in Paris. On mobile or desktop, users could "walk" in the cathedral to hear how a choir sounded depending on where they "stood" in the space.[45,46]

Lastly, immersive spatial apps will need to respond to how we naturally move. Apple's Vision Pro tracks eye movements to better place low-latency content in its display.[47] And Meta's Direct Touch feature explores how tracking hand motions in VR could replace hand controllers for experiences where natural movement would be better.[48]

Today's spatial computing technology landscape is rapidly growing with exhilarating potential. Design foundations and standards are being set, and more tools appear every day. Enterprises can mix-and-match these technologies to find their own way to meet this spatial moment. And once you can build spatial apps, the next challenge is *what* to build.

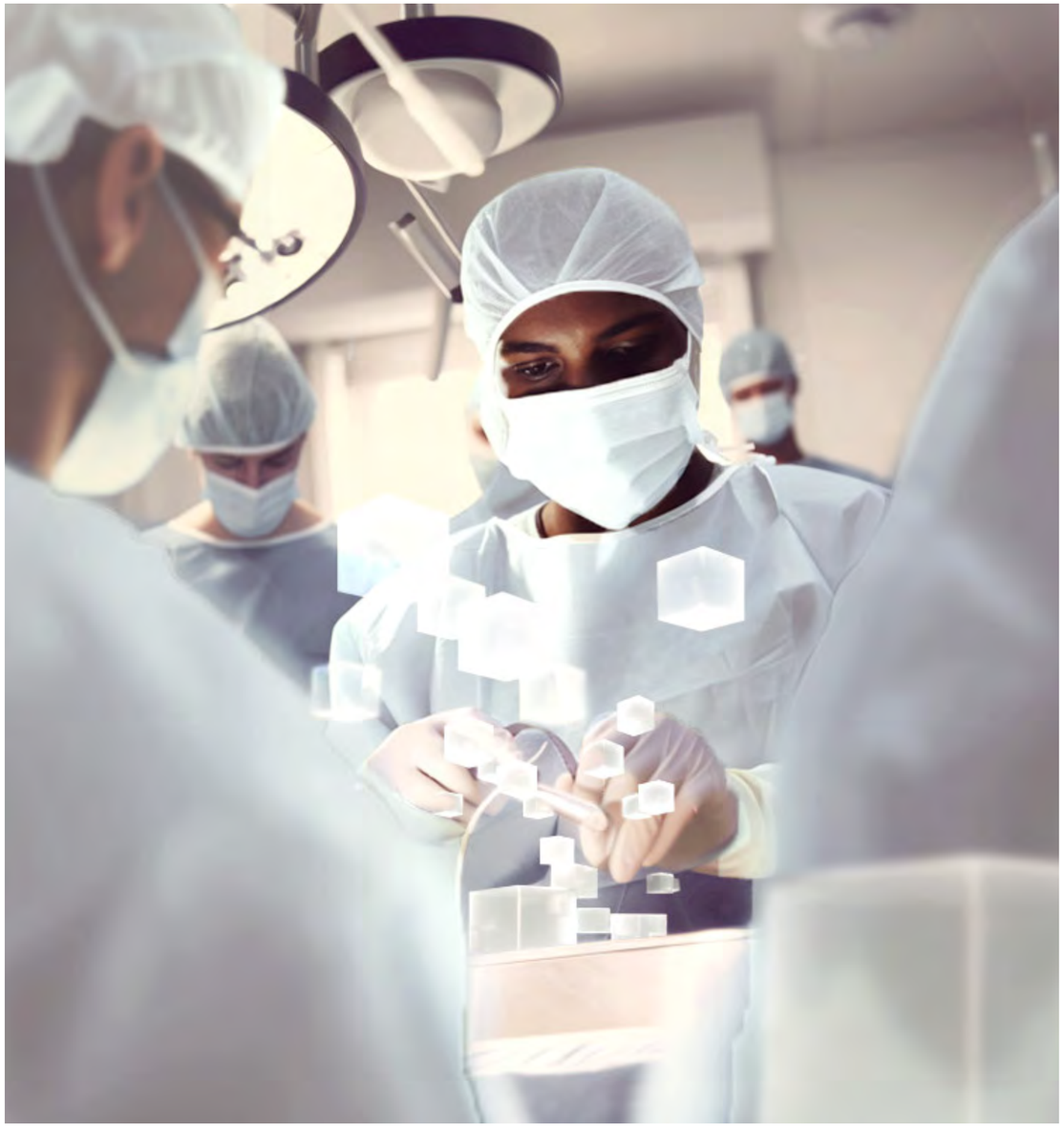
The implications: Spatial's killer applications

Spatial computing is not coming to replace desktop or mobile computing – but it is becoming an important piece of the computing fabric that makes up enterprise IT strategy.

Just as people aren't going to write an essay on a mobile device, and tablets freed retail associates from stationary POS systems, spatial will have its own killer use cases that will leave us wondering how we ever managed without it.

We've already seen the early stages. Digital twins make more sense when you walk through them. Training is more impactful when you can live the experience rather than watch a video. While these were often standalone pilots, a careful consideration of the unique advantages of spatial computing can help shape and guide enterprise strategy. The market is still maturing, but it is quickly becoming clear that spatial apps thrive when applied in three ways: conveying large volumes of complex information; giving users agency over their experience; and, perhaps counterintuitively, allowing us to augment physical spaces.

When it comes to conveying complex information, the advantage of the spatial medium over the alternatives is probably clearest. Since a space can let users move and act naturally, information can be conveyed in more dynamic, immersive ways. We've already seen it in action. Some of the earliest examples of successful spatial apps were industrial digital twins, virtual training scenarios, or real-time remote assistance – all use cases where lots of information may need to be shared, and where conventional methods can cause information overload, leading to confused or ill-trained employees.



Surgical training, for instance, is an extremely information-heavy task. Research from the University of California Los Angeles found that medical students performed two and a half times better on surgical skills assessments when they learned new procedures in virtual reality versus the standard guides.[49] And importantly, including more spatial information can improve results even further. Haptic feedback – the sensation of touch – helped surgical trainees achieve proficiency in cortical bone drilling roughly seven times more often than those operating without it.[50]

Going forward, this ability to convey information in a realistic setting, and through different senses, could reinvent many tasks. Like virtual training, surgeons operating remotely need to simuntaneously digest information and perform delicate procedures. Teleoperating through a spatial environment, however, could help by displaying information more clearly, conveying it in a realistic environment when and where it's needed. Already, a surgeon in China has successfully removed a patient's gallbladder from 4,600 KM away, operating a surgical robot in the distant operating room.[51]

Airports are also complex, information-dense operations. And Vancouver Airport is working to optimize its efficiency with a spatial application that unifies real-time and historic flight data, passenger counts, and security wait times.[52] The interactive app is layered with live video and can be viewed in 2D, 3D, or from a bird's-eye view. Employees can collaboratively simulate passenger flows, test new facility layouts, and run virtual trainings – reducing costly errors and improving resource allocation.

The second advantage spatial has over older mediums is the ability to give users agency to shape their in-app experiences. Because spatial computing lets us build digital experiences that embody a physical sense of space, we can design experiences that give users more flexibility to move and explore. And for some applications, putting users in the driver's seat will make experiences more personal, organic, and useful.

Paris's Centre Pompidou capitalized on this ability to personalize a museum experience through a collaboration with Snapchat and artist Christian Marclay.[53] Marclay overlayed Centre Pompidou's façade with a colorful digital instrument that users could play in many ways through Snapchat AR. Visitors could also record and share how they "played" the museum. Rather than an experience exclusively shaped by the museum's curators, visitors were able to infuse their own creativity and discovery into the space.

And Fiat, the automotive brand, is showing how user self-driven discovery can help with sales conversion.[54] Typically, when people are buying a car they are able to test drive one model, but then have to look at a different model or a bunch of advertising pamphlets to see the customization options. They don't necessarily get to drive the exact car they want to buy. Fiat built the Fiat Metaverse Store to challenge this paradigm. Within the virtual store, users are able to customize their

car model with all the various body types, colors, interiors, and infotainment options.[55] Users can then take the car out on a virtual test drive to experience what it would be like and see the features up close. Throughout the experience they are accompanied by "Product Genius" – a connection to a live expert who can answer any questions.

And finally, greater user agency can even be brought to shaping the experience itself. Researchers from UC Berkeley recognized that as people adopt spatial computing there will be a range of asynchronous situations as people attempt to collaborate and interact across devices. For instance, an instructor may be on a laptop, while a trainee will be wearing a VR headset. They recognized that trying to force content into one mode or the other will result in a worse experience for all involved, so they proposed a model for "Interactive Mixed-Dimensional Media" – a way to seamlessly shift information streams between 2D and 3D. It allows users a greater degree of control over their own experience, allowing them to decide how information is presented to them across spatial and dimensional levels of detail.[56]

Lastly, spatial applications bring advantages to physical spaces; they can augment, enhance, and extend physical places without materially changing them. Imagine a future office where physical monitors, projectors, and displays are replaced by spatial computers and apps. People will have the flexibility to design simpler spaces, lowering overhead costs, and to change their surroundings more easily.

Gap and Mattel leveraged this when launching their Barbie clothing line.[57] Using Google's Geospatial Creator, they transformed New York City's Times Square with lifelike 3D Barbie dolls, massive digital billboards, and floating neon-pink signs. This launch event showed the spatial medium as a captivating, scalable alternative to building expensive new infrastructure.

Spatial applications bring advantages to physical spaces; they can augment, enhance, and extend physical places without materially changing them.

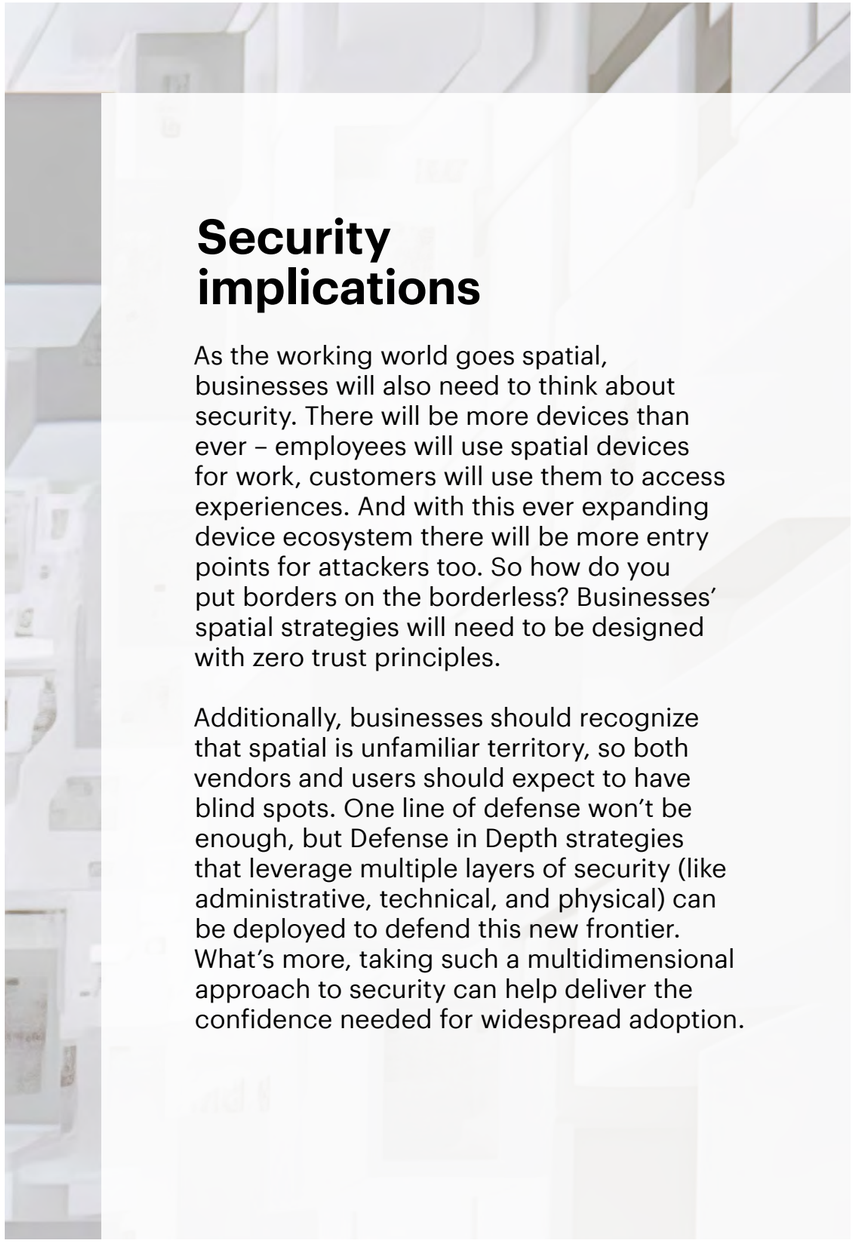
Accenture, Google, and Telstra, Australia's leading telecommunications firm, also harnessed spatial computing in a pilot app to improve the stadium experience – without significant physical changes.[58] In the app, fans could find their seats with immersive wayfinding and enjoy augmented reality experiences.

The technology also has the potential to enable multi-user AR games and enhanced player analytics and performance statistics. By tapping into spatial technology, future event spaces could be designed in a simpler manner, requiring less hardware and fewer displays.

This evolution to our spaces will let enterprises rethink operations and workflows entirely, promising benefits like efficiency, safety, and more.

In one cross-industry collaboration at CHRISTUS MUGUERZA Hospital Conchita in Mexico, a renowned orthopedic surgeon was equipped with a Microsoft HoloLens during surgery.[59] The technology transformed the surgical environment, allowing the doctor to access patient records, X-rays, scans, and 3D models during a procedure. Importantly, digitally accessing this information mid-surgery let the operating team preserve a sterile field for the patient. When the team needed to refer to patient information, they could do so and overlay it while still in the operating room – without stepping out, removing scrubs, finding the record in question, recalling what they needed to know, changing back into scrubs, and re-sterilizing upon return – so there was no need to delay.

As companies begin experimenting with spatial, it is paramount that they appreciate what sets it apart from desktop and mobile. Understanding these differences is the key to designing applications that capture and unlock this medium's promise and value.



Security implications

As the working world goes spatial, businesses will also need to think about security. There will be more devices than ever – employees will use spatial devices for work, customers will use them to access experiences. And with this ever expanding device ecosystem there will be more entry points for attackers too. So how do you put borders on the borderless? Businesses' spatial strategies will need to be designed with zero trust principles.

Additionally, businesses should recognize that spatial is unfamiliar territory, so both vendors and users should expect to have blind spots. One line of defense won't be enough, but Defense in Depth strategies that leverage multiple layers of security (like administrative, technical, and physical) can be deployed to defend this new frontier. What's more, taking such a multidimensional approach to security can help deliver the confidence needed for widespread adoption.

Conclusion: The space we need

Spatial computing is about to hit its stride, and the race is on for leaders to get ahead. To position themselves at the top of the next era of technology innovation, enterprise leaders will need to rethink their position on spatial and recognize the effect recent technology advances are about to have.

New computing mediums are few and far between, and they can have immeasurable impact on businesses and people for decades. Are you ready to immerse yourself in the moment?

Our bodies electronic

A new human interface

1924

The first electroencephalogram (EEG) recording is made.[1]

1947

Pilots' eye movements are monitored to improve instrument design.[2]

1952

Bell Labs develops the initial speech recognition system.[3]

1964

Early research on facial recognition begins.[4]

1990

fMRI technology is developed.[5]

1994

Netscape invents web browser cookies.[6]

1998

The first invasive BCI is implanted in a human.[7]

2007

Volvo introduces a distracted driver alert system.[8]

2009

Fitbit releases the Fitbit Tracker.[9]

2012

Samsung announces voice and gesture control for TVs.[10]

2013

The White House launches the BRAIN initiative.[11]

2015

Oura introduces its first smart ring.[12]

2016

Neuralink is founded.[13]

2017

Apple launches Face ID.[14]

2021

A study finds that Kaiser Permanente's COVID-19 Home Monitoring is safe and effective.[15]

2021

Chile passes the world's first neurorights legislation.[16]

2023

Using AI and a BCI, researchers partially return a stroke survivor's speech.[17]

2026

A racing simulator will feature cars that are controlled by brain activity and eye movement.

2027

A major retailer will launch a BCI pilot program for employee training and skill retention.

2029

A major bloc of nations will pass legislation protecting citizens' neurorights.

2032

A large insurance provider will offer in-home gait analysis to detect early signs of Parkinson's and ALS.

2035

A consumer neurotech device will transcribe dreams into visualizations and text.

The big picture

Ask your smart home to turn on the lights, and there's a decent chance it'll play "Lights," Journey's 1978 single. Or it might turn on the lights in the wrong room. Smart homes can't read our minds, after all, so the onus to be understood is on us.

Did we enunciate? Did we specify which lights?

Misunderstanding people is a limiting factor for a lot of technologies we use today. Just think about robots and drones that we can only control if we translate what we want into commands they recognize. Or how digital products can't be as successful if we don't understand how they make customers feel. Even in VR, people get dizzy when there's a disconnect between what they expect to see and what the device shows them. We try to close the gap – learning new gestures, running focus group and A/B tests, taking motion sickness pills, and training employees on new tech. Large companies in 2022 spent about $1,689 *per employee* for overall training.[18] But the fact is, when tech struggles to connect with us, it's often because people – what they want, expect, or intend – are a black box.

Now innovators are trying to change that. Across industries, they're building technologies and systems that can understand people in new and deeper ways. They're creating a "human interface" – and the ripple effect will go far beyond improving smart homes.

Look at how neurotech is beginning to connect with people's minds. Recently, two separate studies from researchers at the University of California San Francisco and Stanford University demonstrated using neural prostheses – like brain-computer interfaces (BCI) – to decode speech from neural data.[19,20] This could help patients with verbal disabilities "talk" by translating attempted speech into text or generated voices. Interest in neurotech has reached enterprises, too. Researchers in Meta's AI lab experimented with decoding speech from brain activity in 2022, using non-invasive brain recordings and an AI model to decode sentences and stories that patients heard out loud.[21]

Or look at technologies that read body movement, like eye and hand tracking. In 2023, Apple's Vision Pro introduced visionOS, which lets users navigate and click with just their gaze and a simple gesture, bypassing the need for a handheld controller.[22] The highly precise eye tracking acts as a targeting system; users can pinch their index finger and thumb together to click on what they're looking at. Even more impressive eye tracking could also be coming. Apple has filed a patent that describes using pupil dilation to predict if a user intends to do something – like select a button – even before they do it.[23]

Innovations like these are shifting the rules and the limits that have guided human-machine interaction for decades. So often today, we bend over backwards, adapting and changing what we do to make technologies work. But the "human interface" will turn that on its head; when technologies can better understand us – our behavior and our intentions – they will more effectively adapt to us.

Just think about how many business challenges hinge on exactly that. Customer service, products, and workplace experience, for a start. Across the business, we use a wide array of technologies to help us understand and adapt to people. And we're so used to today's limitations, to the way these technologies never fully "get" us, we might not even realize how much that gap constrains what we do. Now, advancing the "human interface" – from eye-tracking to posture recognition, computer vision to machine learning, brain sensing to reading muscle signals – is lifting that limit.

So often we bend over backwards, adapting and changing to make technologies work – the human interface will turn that on its head.

This collision between technology and our bodies may evoke futuristic, even far-fetched images. But a careful evaluation of the technologies already at hand shows us boundless opportunities for enterprise innovation. We could improve employee training, leading to safer workplaces with less miscommunication and fewer accidents. We could build digital products that, in better understanding and engaging people, reach a wider customer base. Imagine the productivity gains when we don't need to contort ourselves around technology, but when it can work around us instead. It's already starting with headsets that observe us to deliver smoother experiences. Soon we could see robots paying attention to us to contextualize our instructions, or digital experiences that track our engagement, picking up on the subtlest cues and reactions. These technologies – the ones that "get" us better – will transform what we do.

The "human interface" will be a major leap forward in technology capability, with widespread impact on businesses.

But to succeed, enterprises will also need to address growing issues around trust and technology misuse. Companies and individuals alike may balk at the idea of letting technology read and understand us in these new and more intimate ways. Biometric privacy standards will need to be updated. And new neuroethics safeguards will need to be defined – including how to appropriately handle brain and other biometric data that can be used to infer people's intentions and cognitive states. Until formal regulations catch up, it's on enterprises' shoulders to earn people's trust.

The "human interface" is a tricky field to dive into today. There's hesitation around the tech, and the full implications are still unclear. Even so, the tech is further along than many realize, and there's no doubt businesses need to get started. When technology can better understand people, every human-centric area of business – everywhere people and technology interact and everything dependent on understanding people's behaviors and intentions – will be disrupted. From the smallest tasks to the largest challenges, the "human interface" will raise the bar. You don't want to be left behind.

The technology: A more human-centric view of people

Attempting to understand people – as individuals, target groups, or populations – is a centuries' old business challenge. And in recent decades, using digital technology to do this has been the ultimate differentiator.

Digital platforms and devices have let businesses track and quantify people's behaviors with enormously valuable impact. Now, the "human interface" is changing the game again, making it possible to understand people in deeper, more human-centric ways.

How digital technology "understands" people

Consider the leading strategies companies use to understand human behavior today. They generally fall into two categories: data collection on the web and physical sensors out in the world.

On the web, businesses' ability to understand behavior is a major factor shaping digital experiences. Platforms rely on user data to personalize experiences and improve the product. According to Statista, the global revenue of customer experience personalization and optimization software is projected to reach $11.6 billion by 2026.[24] Not only that but many companies today spend more than half of their marketing budgets on personalization.[25] Newsfeed rankings, content recommendations, ad targeting, and more all stem from this.

Out in the physical world, a lot of recent technology innovation has also centered around understanding what people do. Devices have long collected data on people physically – letting businesses build products and services around health and location. In-store sensors to analyze foot traffic, or facial recognition with sentiment analysis, are tools to better understand people to steer them toward various outcomes. And voice and gesture recognition are ways for people to interact with technology more naturally.

These are important technologies. But they're based on tracking and observing patterns that still lack specificity. People may read or watch familiar content, but they may actually want something new. They may try to command robots or devices with unclear gestures or the wrong phrases. We're very good at recognizing what people do, but we don't always understand intent. Many frustrations stem from this: technology misinterpreting our instructions, or platforms trapping us in recommendation doom loops. It's no surprise – people also can struggle to express themselves in a world with both technology limits and human constraints.

That's what the "human interface" promises to change. As algorithms get ever more precise, more comprehensive sensor arrays are built, and new technologies emerge that can make the leap to intent, we are starting to understand people in a more human-centric way.

Nearly one in three consumers agree they are often frustrated that technology fails to understand them and their intentions accurately.

How the “human interface” measures intent

The “human interface” isn’t any one technology. Rather, it encompasses a suite of technologies that are deepening how innovators see and make sense of people. Identifying intent – people’s state of mind or what they really want or mean – is one of the most important factors here. And across industries, leaders are finding ways to predict or observe it.

Some are using wearable devices to track biosignals that can help predict what people want or understand their cognitive state. For instance, researchers at the University of Washington Seattle explored ways gaze-centered eye tracking in VR can grant users more control over a prosthesis.[26] Here, following a person’s eye movements could help predict intent, like if they wanted to move in a certain direction or pick up a particular object. As another example, Immersion Neuroscience is a company using smartwatches and fitness sensors to measure subtle changes in people’s heart rate to predict their cognitive state.[27]

Others are building more detailed ways to understand people’s intent in relation to their environments. Researchers at Tongji University’s School of Automotive Studies, for instance, wanted to find out how to reduce human-vehicle collisions.[28] Where most crash prevention efforts focus simply on detecting pedestrians, these researchers conducted a study that went further. They captured details including the distance between the vehicle and the pedestrian, the speed of the vehicle, and the pedestrian’s physical posture – like the angle between their thighs and calves or between their calves and the ground. Grasping a person’s posture while walking on a street can be a clue to discern where they are likely to move next, potentially making the roads safer for everyone.

Waymo, the self-driving car subsidiary of Alphabet, is doing something similar. In addition to watching everything happening around the car – like traffic signs and signals, pedestrians, construction, cyclists, and other cars – the Waymo Driver autonomous system also makes predictions about other road users’ intent.[29] Understanding that pedestrians, cyclists, and others all move differently, it predicts the many possible paths each might take, all in real-time.

Another approach to human intent is through AI. Consider human-robot collaborations. People's state of mind, like if they're feeling ambitious or tired, can impact how they approach a task. But while humans tend to be good at understanding these states of mind, robots aren't. So, researchers at the University of Southern California tried to teach robots to identify these states to help them better assist people.[30] Typically, training a robot to fit an individual's work style takes a lot of time. But the researchers proposed a transfer learning system, where the robot observes someone performing a small, canonical task, then creates a preference model that it continuously updates as the robot and person interact.[31]

Similarly, a 2023 research paper from Accenture and Cornell University describes a way human-robot collaborations can benefit when robots can identify when they've made an error based on implicit reactions from humans they interact with – much like how people use social cues to recognize their own mistakes.[32] The authors built a dataset of bystander responses to human and robot errors and used it as input to a deep-learning model to predict failures. By creating these systems that are sensitive to human social signals, they are efficiently using the expertise of human perception and action as a marker for mitigating robotic errors.

Lastly, perhaps one of the most exciting "human interface" technologies is neurotech: neuro-sensing and BCI.

Many new neurotech companies have appeared in the last decade, and the field holds clear potential to read and identify human intent.

Look at how prosthetic limbs could act and feel more natural, as companies start to use neural prostheses to strengthen the connection between a person's intent and their robotic limbs.

Blackrock Neurotech and Phantom Neuro, for instance, have partnered to build advanced prosthetic limbs and exoskeletons.[33] By implanting a prosthetic at the amputated site, they can detect neural signals through muscle activity, and use that to control the robotic arm. The companies hope to build devices that can move in response to a person's intentions much like an intact limb would.

These are just a few of the "human interface" technologies starting to emerge. In coming years, we expect to see a wide range of devices and systems that can better understand human intent, ranging all the way from fully external, to skin-touching, to invasive implants in our bodies. While we focus primarily on external and skin-touching technologies here, it's worth noting that invasive devices are also advancing. Across the board, what's clear is that we're already starting to understand human intent to a previously impossible degree, and we're only getting better.

There has been an uptick in consumer-oriented development in recent years, a strong signal that the "human interface" is heading for the mainstream.

Neurotech highlights the pace of "human interface" advances

Progress towards the "human interface" and a new generation of business built on human-centric tech is happening fast – and neurotech is a great example of this. Many may think neural-sensing and BCI are years from commercial use, but recent advances tell a different story. In fact, there has been an uptick in consumer-oriented development in recent years, a strong signal that the "human interface" is heading for the mainstream.

First off, skeptics tend to believe that neurotech will stay limited to the healthcare industry. Many high-profile neurotech devices, after all, are centered around highly invasive implants as a course of medical treatment. In 2022, Galvani Bioelectronics, a joint venture from GlaxoSmithKline and Google's Verily, implanted its first neurostimulator in a patient with rheumatoid arthritis.[34] And in early trials, Synchron's partially-invasive brain implant hopes to restore communication and other functions to severely paralyzed individuals.[35]

The invasiveness is justified by the medical need, making it unlikely anyone today would opt in to using this technology without a necessitating condition. But there are a lot of approaches to building these devices. They can be invasive, partially invasive, or fully external. They can be massive systems in medical offices, or small and portable. With the range of technology options available, the right solution can be found to match the need and comfort level of the intended user – and commercial initiatives and use cases grow by the day.

Two key advances are driving this. The first is decoding brain signals. For decades, it's been possible to sense brain signals, yet the leap to commercial products is a giant one.[36] It's very difficult to identify common signals and patterns across different people's brains. But advances in AI pattern detection, as well as greater availability of brain data, is making a big difference.

Take this example. In a 2023 paper in the *Neural Networks* journal, researchers used a deep learning model based on a transformer architecture to make it easier to recognize brain signals across multiple subjects, without needing to recalibrate for each person's brain.[37] They described how conventional systems for classifying SSVEP (steady-state visual evoked potential) – a type of brain signal – need to be specifically trained for every individual. And though previous studies have used deep learning to improve inter-subject SSVEP recognition, this paper demonstrated that a transformer architecture could achieve even better results in classification accuracy, potentially alleviating the need for individual BCI calibration.

Fueling this research is an industry-wide shift toward open-source data. Transformer models (and machine learning models in general) require huge amounts of training data, and brain signal datasets are still relatively rare. But more institutions are starting to publish their brain data, so a wider community of researchers can build on each other's work.[38] And at Accenture Labs, researchers tested how AI can efficiently generate synthetic brain signals to train detection models, without needing to rely on people's original brain signals.[39] This capability demonstrates the potential to develop novel AI health solutions that make use of synthetic proxies, rather than depending on sensitive patient bio-signals.

The second area to watch is neuro-hardware – specifically, the quality of external devices. Though invasive BCIs typically have higher resolution, external devices are expected to have wider market appeal.

Historically, EEG (electroencephalogram) and fMRI (functional magnetic resonance imaging) have been two of the most widely used external brain sensing techniques.[40] EEG measures the brain's electric activity and has better temporal resolution (capturing neural events as soon as they happen), and fMRI measures the brain's blood flow and has higher spatial resolution (pinpointing where the neural activity took place).[41] However, until recently, capturing either type of brain signal required a lab setting.

Now, that's starting to change.

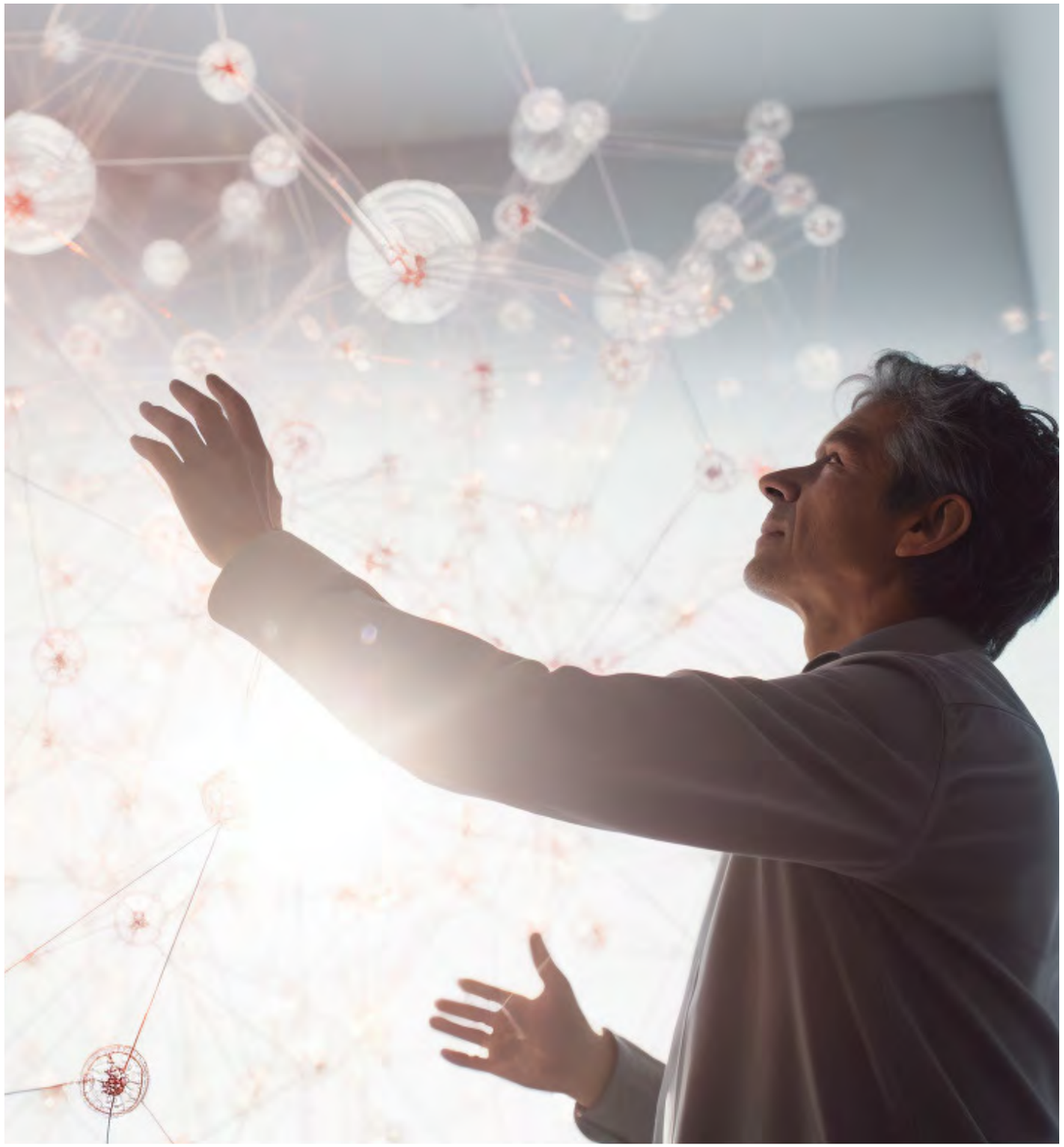
EEG devices were once very sensitive to environmental noise and muscle movement, requiring users to be very still. But new devices, like Wearable Sensing's DSI-24 headset that uses a dry electrode EEG system, are more resilient to motion and noise.[42] And while fMRI is likely to remain in medical settings, a newer technology called fNIRS (functional near-infrared spectroscopy) is making it possible to measure blood flow in the brain without people needing to be in a tube in a lab.[43] Kernel's Flow2 neuroimaging headset, for instance, combines fNIRS technology with EEG to gain a comprehensive view of brain activity in a portable headset.[44]

Portability is critical to commercialization, and some companies are already building products that depend on it. EMOTIV, a bioinformatics startup, and X-trodes, which builds wireless wearable tech, are collaborating on a wearable at-home solution for brain and physiological measurement.[45] They're building sticker-electrodes that conform to people's skin and enable use cases where larger EEG devices are not ideal – like sleep studies. And Apple has submitted a patent application for measuring biosignals and electrical activity from a user's brain through an AirPods Sensor System.[46]

Lastly, also related to portability, being able to quickly translate brain signals into action is very important. For certain use cases, sending raw brain data to the cloud could be unacceptably slow, creating usability frustrations and potentially preventing people from moving or communicating in a timely manner. But advances are happening here, too. In 2022, VC funding drove a boom in edge AI chip startups.[47] Established chip makers like Nvidia and Qualcomm continue to work on building smaller, more powerful edge chips.[48] And some are working to increase the computational efficiency of processing brain signals. In a 2022 paper, researchers from the University of California Merced and Ericsson proposed an efficient method for classifying EEG brain responses to song recordings, demonstrating that EEG data can be processed effectively through standard computer vision methods.[49] In fact, their classification model was small enough to fit on a floppy disc.

Connecting to people's minds like this would have seemed impossible just a few years ago – and that's why neurotech is such a powerful indicator of the "human interface." So many different technologies are starting to observe and understand people in deeper, more human-centric ways. Neurotech is one, while others are observing and learning people's moods and habits over time or grasping a person's environmental context to predict action and intention better. Across them all, technology is quickly changing what it means to understand people. And for enterprises, that is going to change a lot.

Technology is quickly changing what it means to understand people, and for enterprises that is going to change a lot.



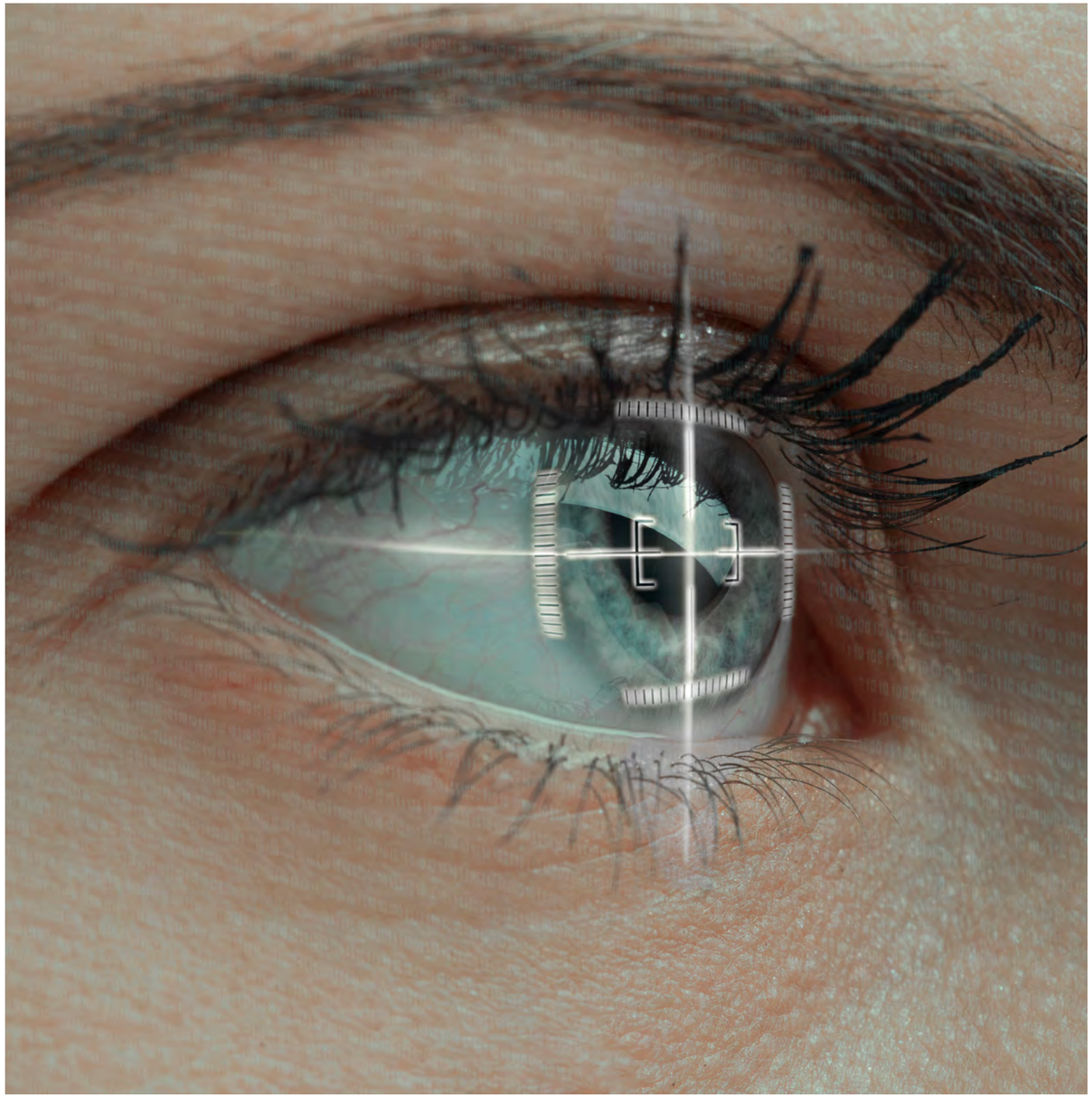
The implications: Getting started – the right way

It's time for enterprises to ask what the "human interface" means for them, and right now, it's an open-ended question.

These innovations and advances are closing the gap between people and technology, making it possible for technology to understand and adapt to people on a whole new level. They could drive huge transformations across the business, anywhere people and technology interact.

The breadth of opportunity is exciting. Already, leaders are diving in – and in very different ways. Some are exploring how these technologies can amplify the workforce. Accenture, for instance, is working with neurotech startup Mendi, to study how applications of neurofeedback can improve learning and training programs.[50] Still others are thinking about consumer products. In the video game industry, leaders are exploring everything from how eye tracking can control or influence VR experiences to how neurotech can help them better understand how players react to games.[51,52]

But widely distributed opportunities can also make it harder to see the big picture. As more enterprises start to build "human interface" strategies, they should begin by scoping out the different business areas and challenges that can be transformed.



The scope of the "human interface"

First, consider how "human interface" technologies are raising the bar when it comes to anticipating people's actions. This is something enterprises have tried to do for many years – but the "human interface" lets us combine the sophisticated behavior analysis we've been building with a novel ability to account for human complexity.

Some of the most promising use cases are in areas where people and machines operate in shared spaces. For instance, enterprises could create safer and more productive manufacturing systems if robots could anticipate what people were about to do. Or cars could monitor not just pedestrians but also drivers, nudging them to improve road safety, and potentially impacting the auto industry, supply chains, and more.

Other industries see the promise, too. Cornell University researchers are experimenting with algorithms that can predict athletes' moves during a sports game with about 80% accuracy.[53] Their algorithms use computer vision to interpret visual information about the player in real time, like their position on the court and their body posture, then combine that information with contextual data like the team's strategy or the player's role.

The Cornell team envisions these algorithms being used to help teams better prepare for competitions. And for enterprises, tools like this could change a lot more than sports. So much of what we do is influenced by our surroundings, so technologies that can capture what's going on and how it influences us hold a lot of promise. Training employees better, consumers getting more personalized and engaging digital experiences – these examples are only the beginning.

94% of executives believe human interface technologies will let us better understand behaviors and intentions, transforming human-machine interaction.

Another area that can be transformed is direct human-machine collaboration – how we use and control technology. As an example, think about how neurotech is letting us tap into our minds and connect with technology in new, potentially more natural ways.

Researchers at the University of Technology Sydney, for instance, have developed a BCI headset that uses a biosensor to pick up brainwaves and translate them into commands.[54] In a test with the Australian Army, soldiers were able to use the device to control a four-legged robot dog with just their minds – with up to 94% accuracy. And Snap has acquired NextMind, the maker of a mind-controlled headband that lets people interact with and command digital objects with their brain signals.[55]

Going forward, this could go beyond hands-free control to bring new capabilities or improved performance to certain technologies. WiMi Hologram Cloud, a Chinese AR and holographic services provider, is working to build a hybrid BCI system – one that would combine and analyze multiple types of complementary brain signals – for controlling humanoid robots.[56] The company believes that using a person's neural signals to deliver commands could let us control humanoid robots with greater precision.

And InnerEye, a neurotech startup, is transforming human-machine collaboration in yet another way. People's brains can process visual images very quickly but are slowed down by the cognitive and motor processes needed to decide and execute a response. InnerEye demonstrated that a BCI headset can take advantage of our brain's rapid response to patterns to enhance productivity.[57] The company had a test subject watch airport security X-ray scans rapidly appear and disappear on a computer screen – at about three images per second. This pace is normally way too fast for a person to properly look for things like hidden firearms. But after the stream of scans ended, almost all the images flagged for firearms were indeed correct.

Lastly, the "human interface" could drive the invention of new products and services. Brain-sensing, for instance, could help people "get" themselves better. L'Oréal is working with EMOTIV to help people better understand their fragrance preferences.[58] The companies are using EMOTIV's EEG-based headset to measure customers' neuro responses to various L'Oréal scent families. The headset's ML algorithm then interprets the EEG data to show customers how the different scents make them feel.

Still others are thinking about the "human interface" as a safety measure. Meili Technologies is a startup working to improve vehicle safety. It uses deep learning, visual inputs, and in-cabin sensors to detect if a driver has been incapacitated by a heart attack, seizure, stroke, or other emergency.[59,60] And SmartCap is a fatigue awareness product built into a hard hat.[61] It measures alertness and fatigue by analyzing EEG brain signals and provides early warning alerts. SmartCap Technologies first developed the product for the Australian mining industry to prevent safety hazards. The company was later purchased by Wenco International Mining Systems, a division of Hitachi Construction Machinery, which is expanding it into North America.

All these business areas and challenges demonstrate different uses for the "human interface." But underlying each of them is that age-old business challenge: whether we want to make sales, build customer loyalty, or give our employees the best workspaces and tools, success starts with how well we understand people.

Now, the "human interface" is letting us meet that challenge like never before.

Business competition is changing – and trust is more important than ever

As enterprises explore the possibilities and build their strategies, however, they will also need to address a growing challenge. The "human interface" will never live up to its potential – in products or in the enterprise – if people don't trust it.

Businesses need to start asking what risks come with these technologies, and what new policies and safeguards need to be put in place. Rather than wait for regulations to ramp up, responsible enterprises need to begin now. In particular, the field of neuroethics is already getting attention. Questions around the physical safety of neurotech devices are being raised, as well as the psychological risks around human autonomy and societal factors like brain data privacy, informed consent, and fairness.[62]

In 2021, Chile was the first country to pass a constitutional amendment to extend human rights to include neurorights.[63] And groups like the Neurorights Foundation are working to further the development of neuroethics guidelines and laws around the world. The Foundation's goal is to prevent the abuse or misuse of neurotechnology, which it defines as any technology that records or interferes with brain activity.[64]

In addition to promoting formal laws, they believe it is essential for companies, entrepreneurs, scientists, and more to collaborate and set a standard for self-governance and accountability, and to "proactively manage the societal impact of their innovations."[65] Whether or not you choose to work with a foundation like this, the point about self-governance and accountability stands. Any business exploring this area today is a first mover, and there's opportunity to set the tone for the future.

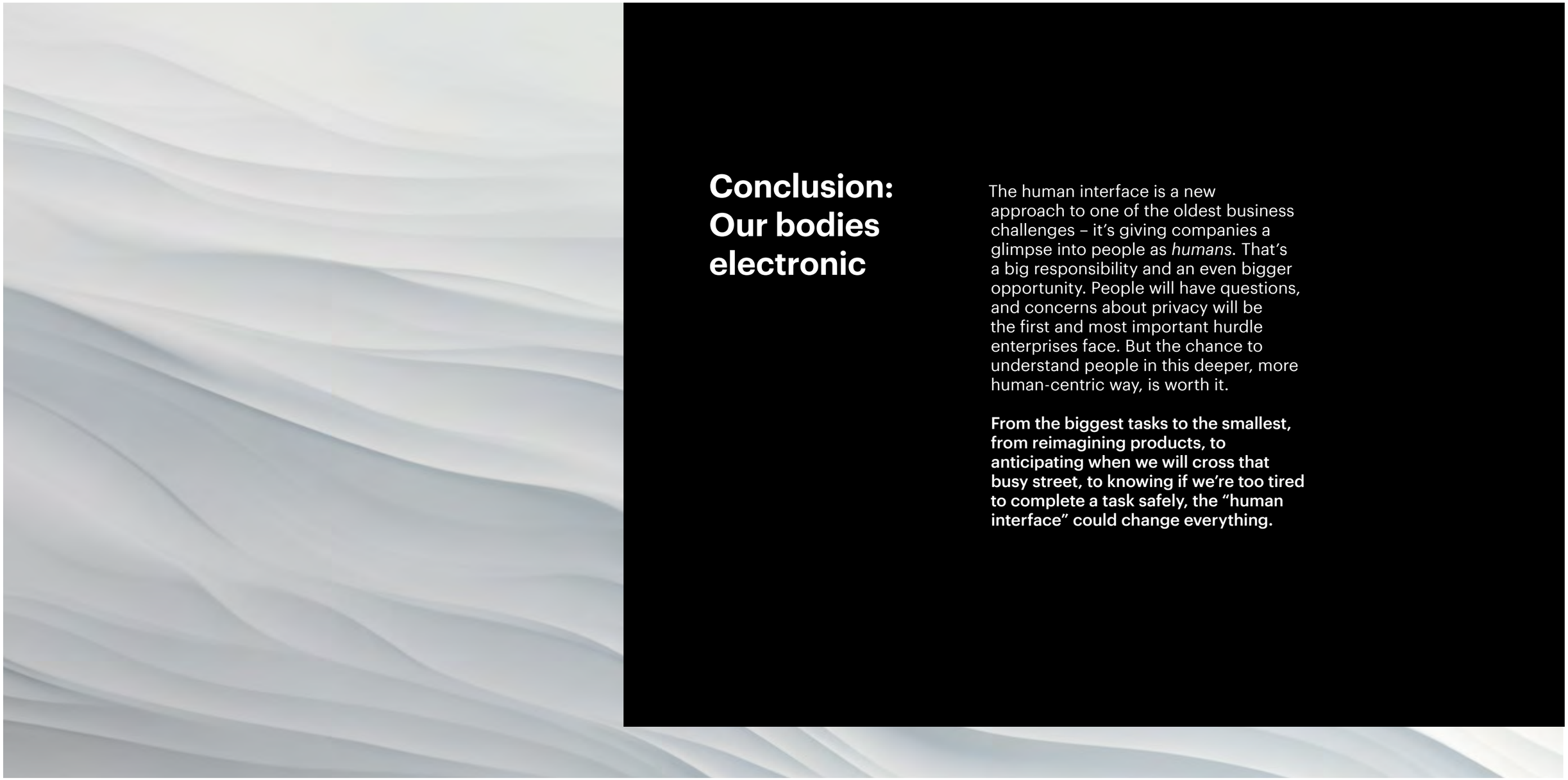
As enterprises get started with the wider suite of "human interface" technologies, they can look to existing biometric laws and to the medical industry for guidance. Many of the risks around this space are the same. Any collection of biometric data, for instance, comes with privacy concerns and questions about the right to refuse the technology. And with any biometric data, employees and customers will want transparency around what is being collected, what it's used for, and if it's saved anywhere. This extends to inferences made from that data, too. Care and due diligence here may make or break a business's successful adoption of this trend.

Security implications

If tin foil hats don't prevent mind reading, what will? More than any other trend this year, security will make or break enterprise and consumer adoption of the "human interface."

Acceptance of more perceptive and connected tools hinges on humans' ability to be the primary gatekeepers of what information gets shared, at a minimum. This practice needs be integrated into the design of the next generation of human-computer interface tools, letting people either opt into sharing data or telemetry relevant to the task at hand, or opt out of sharing extraneous or sensitive information.

Think of it like mobile device management for humans: we already know how to control what mobile device data stays local or gets sent to the cloud, but the stakes are higher and more complex for sharing humans' biological, behavioral, and sensory data. While rule-based approaches can lay the foundation for data sharing systems, humans will need more flexible and interpretable safeguards to maintain control of their own data. The data will also need to be interpreted for them, so that there is no ambiguity about what access they are granting.



Conclusion: Our bodies electronic

The human interface is a new approach to one of the oldest business challenges – it's giving companies a glimpse into people as *humans*. That's a big responsibility and an even bigger opportunity. People will have questions, and concerns about privacy will be the first and most important hurdle enterprises face. But the chance to understand people in this deeper, more human-centric way, is worth it.

From the biggest tasks to the smallest, from reimagining products, to anticipating when we will cross that busy street, to knowing if we're too tired to complete a task safely, the "human interface" could change everything.

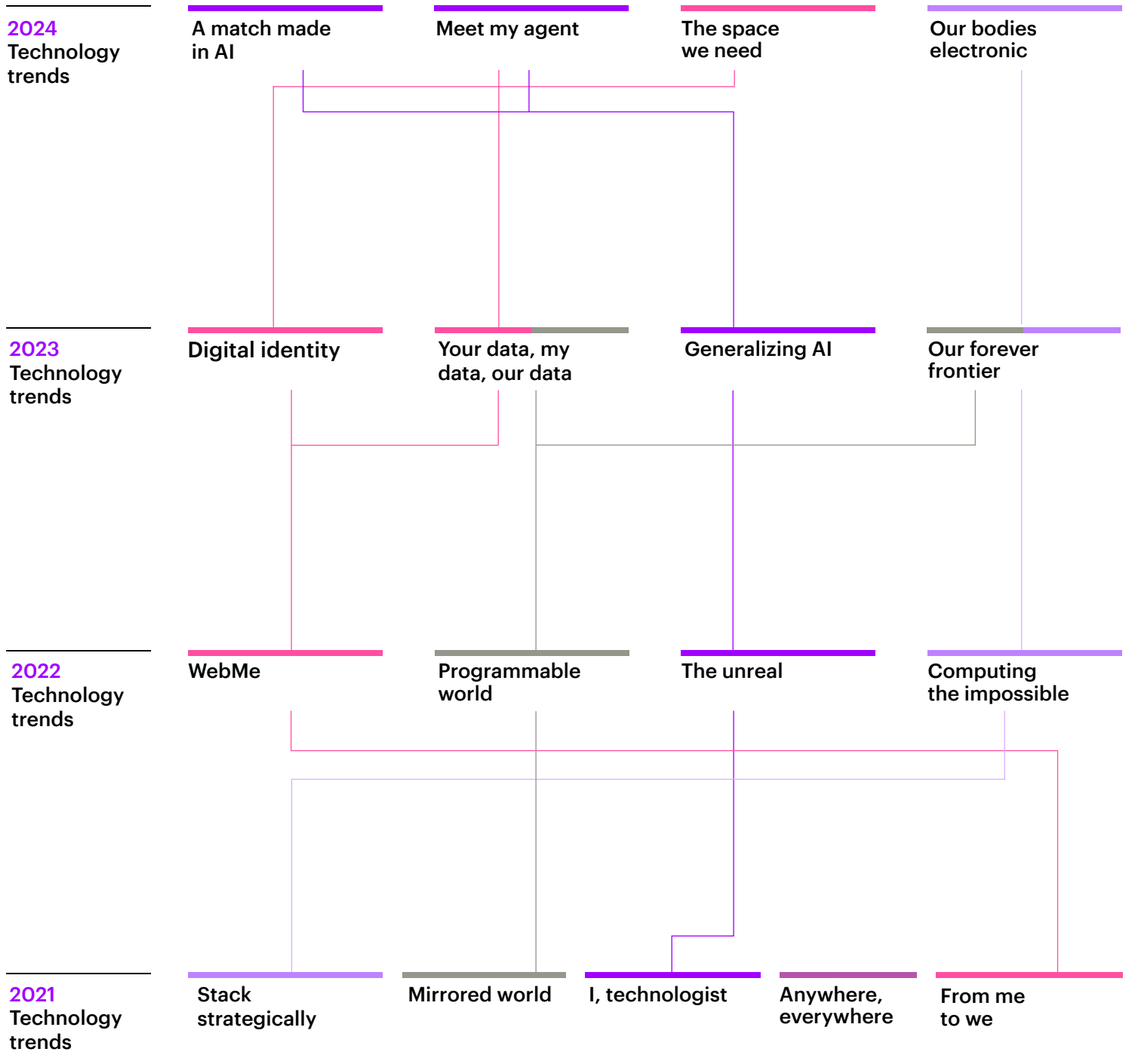
Epilogue

The ongoing story: Trend evolution

The Technology Vision trends represent some of the most impactful, exciting advancements in technology innovation. However, these are just a few of the trends making up a much broader technology revolution that is touching every dimension of businesses.

Two years ago we asked businesses to "Meet us in the Metaverse," and last year we demonstrated how our digital and physical lives are converging with "When Atoms Meet Bits" – messages that are still as topical and impactful as ever. While some trends may garner more excitement or progress more than others year over year (just look at the breakneck pace of AI innovation), innovation is still happening across all these areas – and it remains critical for enterprises to consider the entire scope of change taking place when planning their long-term strategy.

New this year we present the ongoing story: major themes that have been raised in the Technology Vision and are underpinning enterprise strategy, the market, and the future of technology.



Science tech

The convergence of science and technology continues to influence innovation at large. Technologies such as AI are accelerating scientific advancements, which are proliferating into industry faster than ever. New domains like energy, materials, space, and biology will increasingly take a primary role in the innovation strategy of the world's most disruptive companies. This feedback loop between science and technology is expanding the horizon of what we can compute, creating tools that will allow us to solve bigger problems, and fundamentally transforming industries and marketplaces.

Sustainability

From regulatory requirements to customer pressure to the desire to be more efficient, sustainability remains top of mind among executives across industries. And technology innovation continues to play a vital part in creating truly circular economies. Emerging technologies at enterprises can build cleaner energy systems, which can offset or diminish negative environmental impacts. While the short-term costs of sustainability efforts may concern some executives, enterprises must not lose sight of the long-term gains – and how leveraging technologies can help.

Digital ownership

The emergence of digital ownership driven by technologies like blockchain and digital ledgers continues to completely upend long held conventions around data, identity, customer relationships, and online ecosystems. Distributed computing lets us create unique identities for an array of people and things, allowing for once-impossible ownership across digital domains. But ownership itself is not the point – it is what this can support. Digital ownership can excitingly spur new forms of customer engagement, of raising capital, and of interoperability between digital environments.

The unreal

While generative AI has seized the attention of boardrooms around the world, conversations on deepfakes, doctored images, and falsified videos have inevitably followed. Enterprises are in the middle of debates over what is real, what is not, and whether people really care. The "unreal," however, can be incredibly advantageous to enterprises under the right circumstances. Synthetic data can help us identify and prepare for edge events. Talking to a "fake" sales assistant could be a better, more judgement-free customer interaction. Yet to navigate these possibilities, enterprises will still need to monitor their "unreal" solutions' impact on people, all while bolstering security and risk practices.

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About the Technology Vision

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

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

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

Primary research, including a global survey of 20,027 consumers to capture insights into their use of, familiarity with, and perceptions about technology in their daily lives. In addition, Accenture conducted a survey of 3,450 C-level executives across 21 industries to understand their perspectives and organizational priorities regarding emerging technologies. The surveys were fielded from October to November 2023 across 20 countries.

Research and data science to analyze technology developments and advancements; and generative AI-led interviews of 50 developers, industrial workers, and advanced users of spatial computing.

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

Survey demographics

Countries	Consumer survey (N=20,027)	Business survey (N=3,450)
Australia	5%	4%
Brazil	5%	3%
Canada	5%	4%
China	5%	8%
France	5%	4%
Germany	5%	4%
India	5%	5%
Ireland	5%	3%
Italy	5%	3%
Japan	5%	4%
Netherlands	5%	3%
Saudi Arabia	5%	2%
Singapore	5%	3%
South Africa	5%	3%
Spain	5%	3%
Sweden	5%	3%
Switzerland	5%	3%
United Arab Emirates	5%	1%
United Kingdom	5%	4%
United States	5%	32%

Business survey industries	
Aerospace & Defense	3%
Airline, Travel & Transport	5%
Automotive	5%
Banking	7%
Biopharmaceuticals	3%
Capital Markets	3%
Chemicals	4%
Communications, Media & Entertainment	8%
Consumer Goods	5%
Energy	5%
Health	6%
High Technology	4%
Industrial Goods & Equipment	8%
Insurance	8%
MedTech	3%
Natural Resources	4%
Private Equity	1%
Public Service	3%
Retail	5%
Software & Platforms	5%
Utilities	5%

Business survey roles	
Chief Analytics Officer	2%
Chief Customer Officer	2%
Chief Data Officer	2%
Chief Executive Officer	32%
Chief Experience Officer	2%
Chief Financial Officer	11%
Chief HR Officer	9%
Chief Information Officer	5%
Chief Innovation Officer	5%
Chief Marketing Officer	6%
Chief Operating Officer	4%
Chief Production Officer	2%
Chief Sales Officer	1%
Chief Strategy Officer	8%
Chief Supply Chain & Operations Officer	3%
Chief Technology Officer	7%
R&D Lead	1%

Business survey revenues (USD)	
$50 billion or more	1%
$30 to $49.9 billion	1%
$10 to $29.9 billion	23%
$5 to $9.9 billion	31%
$1 to $4.9 billion	43%
$500 to $999 million	1%

References

Introduction: Human by design

1. Choi, C. (2009, November 11). Human Evolution: The Origin of Tool Use. Live Science: https://www.livescience.com/7968-human-evolution-origin-tool.html

2. Edwards, B. (2023, May 23). Adobe Photoshop's new "Generative Fill" AI tool lets you manipulate photos with text. Ars Technica: https://arstechnica.com/information-technology/2023/05/adobe-photoshops-new-generative-fill-ai-tool-lets-you-manipulate-photos-with-text/

3. Capoot, A. (2023, October 9). Google announces new generative AI search capabilities for doctors. CNBC: https://www.cnbc.com/2023/10/09/google-announces-new-generative-ai-search-capabilities-for-doctors-.html

4. Gordon, R. (2023, July 12). Generative AI imagines new protein structures. MIT News: https://news.mit.edu/2023/generative-ai-imagines-new-protein-structures-0712

5. Kalliamvakou, E. (2022, September 7). Research: quantifying GitHub Copilot's impact on developer productivity and happiness. GitHub: https://github.blog/2022-09-07-research-quantifying-github-copilots-impact-on-developer-productivity-and-happiness/

6. Finnegan, M. (2023, May 24). Microsoft advances mixed-reality plans with Teams avatars, Mesh update. Computerworld: https://www.computerworld.com/article/3697316/microsoft-advances-mixed-reality-plans-with-teams-avatars-mesh-update.html

7. Boston Dynamics Atlas. (2023): https://bostondynamics.com/atlas/

8. Diaz, J. (2023, May 2). Boston Dynamics robodog just got a ChatGPT brain. May it have mercy upon our souls. Fast Company: https://www.fastcompany.com/90889271/boston-dynamics-spot-chatgpt-brains

9. Metz, C. (2023, May 3). 'The Godfather of A.I.' Leaves Google and Warns of Danger Ahead. The New York Times: https://www.nytimes.com/2023/05/01/technology/ai-google-chatbot-engineer-quits-hinton.html

10. Anderson, M. (2023, April 7). 'AI Pause' Open Letter Stokes Fear and Controversy. IEEE Spectrum: https://spectrum.ieee.org/ai-pause-letter-stokes-fear

11. Hanlon, A. (2022, June 1). Metaverse – together alone? LSE Blogs: https://blogs.lse.ac.uk/businessreview/2022/06/01/metaverse-together-alone/

12. Airhart, M. (2023, May 1). Brain Activity Decoder Can Reveal Stories in People's Minds. The University of Texas at Austin College of Natural Sciences: https://cns.utexas.edu/news/podcast/brain-activity-decoder-can-reveal-stories-peoples-minds

A match made in AI

1. Swoger, J. (2012, July 27). The (mostly true) origins of the scientific journal. Scientific American: https://blogs.scientificamerican.com/information-culture/the-mostly-true-origins-of-the-scientific-journal/

2. Levy, M., Hardy Wise Kent, C., et al. (n.d.). Encyclopædia Britannica. Brittanica.com: https://www.britannica.com/topic/Encyclopaedia-Britannica-English-language-reference-work

3. The Editors of Encyclopaedia Brittanica. (n.d.). Dewey Decimal Classification. Brittanica.com: https://www.britannica.com/science/Dewey-Decimal-Classification

4. Xu, S. (n.d.). Fact check with the "Ask NYPL" librarian hotline at the New York Public Library in NYC. Untapped New York: https://untappedcities.com/2016/10/24/fact-check-with-the-ask-nypl-librarian-hotline-at-the-new-york-public-library-in-nyc/

5. White, M. (2022). A history of enterprise search 1938-2022. University of Sheffield: https://sheffield.pressbooks.pub/eshistory1/chapter/1960-1969-the-pioneers/

6. Borgman, C. (1996, July 1). Why Are Online Catalogs Still Hard to Use? Journal of the American Society for Information Science: https://escholarship.org/content/qt3mz7h8hr/qt3mz7h8hr.pdf?t=p7cad8

7. Nguyen, J. (2020, September 10). Archie, the very first search engine, was released 30 years ago today. Mashable: https://mashable.com/article/first-search-engine-archie

8. Williams, N. (2023, August 10). The Real Reason Ask Jeeves Failed Spectacularly. History-Computer: https://history-computer.com/the-real-reason-ask-jeeves-failed-spectacularly/

9. Broderick, R. (2023, August 28). The end of the Googleverse. The Verge: https://www.theverge.com/23846048/google-search-memes-images-pagerank-altavista-seo-keywords

10. The Editors of Encyclopaedia Brittanica. (n.d.). Wikipedia. Brittanica.com: https://www.britannica.com/topic/Wikipedia

11. Hanlon, J. (2013, September 16). Five years ago, Stack Overflow launched. Then, a miracle occurred. Stack Overflow Blog: https://stackoverflow.blog/2013/09/16/five-years-ago-stack-overflow-launched-then-a-miracle-occurred

12. Lutkevich, B., Scardina, J., et al. (n.d.). Microsoft SharePoint. TechTarget: https://www.techtarget.com/searchcontentmanagement/definition/Microsoft-SharePoint-2016

13. Knowledge Graph. (2022, December 2). Scholarly Community Encyclopedia: https://encyclopedia.pub/entry/37713

14. Liu, W., Zhou, P., et al. (2019, September 17). K-BERT: Enabling Language Representation with Knowledge Graph. arXiv: https://arxiv.org/abs/1909.07606

15. Stringers, A., and Wiggers, K. (2023, September 28). ChatGPT: Everything you need to know about the AI-powered chatbot. TechCrunch: https://techcrunch.com/2023/08/10/chatgpt-everything-you-need-to-know-about-the-open-ai-powered-chatbot/

16. Warren, T. (2023, August 7). Microsoft's AI-powered Bing chat is coming to mobile browsers. The Verge: https://www.theverge.com/2023/8/7/23822773/microsoft-bing-ai-chat-mobile-browsers-google-chrome-safari

17. Carr, N. (2008, July/August). Is Google Making Us Stupid? The Atlantic: https://www.theatlantic.com/magazine/archive/2008/07/is-google-making-us-stupid/306868/

18. Organic Search Improves Ability to Map to Consumer Intent: Organic Channel Share Expands to 53.3% of Traffic. (2019). BrightEdge Research: https://videos.brightedge.com/research-report/BrightEdge_ChannelReport2019_FINAL.pdf

19. Metz, C., and Grant, N. (2022, December 21). A New Chat Bot Is a 'Code Red' for Google's Search Business. The New York Times: https://www.nytimes.com/2022/12/21/technology/ai-chatgpt-google-search.html

20. Hu, K. (2023, February 2). ChatGPT sets record for fastest-growing user base – analyst note. Reuters: https://www.reuters.com/technology/chatgpt-sets-record-fastest-growing-user-base-analyst-note-2023-02-01/

21. Mehdi, Y. (2023, February 7). Reinventing search with a new AI-powered Microsoft Bing and Edge, your copilot for the web. Official Microsoft Blog: https://blogs.microsoft.com/blog/2023/02/07/reinventing-search-with-a-new-ai-powered-microsoft-bing-and-edge-your-copilot-for-the-web/

22. Salesforce Announces Einstein GPT, the World's First Generative AI for CRM. (2023, March 7). Salesforce News & Insights: https://www.salesforce.com/news/press-releases/2023/03/07/einstein-generative-ai/

23. Landi, H. (2023, June 27). Epic, Nuance bring ambient listening, GPT-4 tools to the exam room to help save doctors time. Fierce Healthcare: https://www.fiercehealthcare.com/health-tech/epic-nuance-build-out-more-gpt4-tools-ehrs-help-save-doctors-time

24. Gartner Press Release. Gartner Survey Reveals 47% of Digital Workers Struggle to Find the Information Needed to Effectively Perform Their Jobs. (2023, May 10). Gartner: https://www.gartner.com/en/newsroom/press-releases/2023-05-10-gartner-survey-reveals-47-percent-of-digital-workers-struggle-to-find-the-information-needed-to-effectively-perform-their-jobs GARTNER is a registered trademark and service mark of Gartner, Inc. and/or its affiliates in the U.S. and internationally and is used herein with permission. All rights reserved.

25. Hilger, J. (2022, February 17). The Top 5 KM Technologies. Enterprise Knowledge: https://enterprise-knowledge.com/the-top-5-km-technologies/

26. Hilger, J. Top 5 KM technologies.

27. CXOtoday News Desk. (2022, August 29). Real-Time Graph Analysis of Documents Saves Company Over 4 Million Employee Hours. CXO Today: https://www.cxotoday.com/case-studies/real-time-graph-analysis-of-documents-saves-company-over-4-million-employee-hours/

28. Trajanoska, M., Stojanov, R., et al. (2023, May 8). Enhancing Knowledge Graph Construction Using Large Language Models. arXiv: https://arxiv.org/abs/2305.04676

29. Rao, D. (2023, April 15). How to use large language models and knowledge graphs to manage enterprise data. VentureBeat: https://venturebeat.com/ai/how-to-use-large-language-models-and-knowledge-graphs-to-manage-enterprise-data/

30. Introducing BloombergGPT, Bloomberg's 50-billion parameter large language model, purpose-built from scratch for finance. (2023, March 30). Bloomberg: https://www.bloomberg.com/company/press/bloomberggpt-50-billion-parameter-llm-tuned-finance/

31. Shah, A. (2023, April 6). Bloomberg Uses 1.3 Million Hours of GPU Time for Homegrown Large-Language Model. HPC Wire: https://www.hpcwire.com/2023/04/06/bloomberg-uses-1-3-million-hours-of-gpu-time-for-homegrown-large-language-model/

32. Davis, W. (2023, August 22). OpenAI opens GPT-3.5 Turbo up for custom tuning. The Verge: https://www.theverge.com/2023/8/22/23842042/openai-gpt-3-5-turbo-fine-tuning-enterprise-business-custom-chatbot-ai-artificial-intelligence

33. Sivasubramanian, S. (2023, April 13). Announcing New Tools for Building with Generative AI on AWS. AWS Blog Home: https://aws.amazon.com/blogs/machine-learning/announcing-new-tools-for-building-with-generative-ai-on-aws/

34. Hawk, J. (2023, May 23). Build next-generation, AI-powered applications on Microsoft Azure. Azure Blog: https://azure.microsoft.com/en-us/blog/build-next-generation-ai-powered-applications-on-microsoft-azure/

35. Customize and deploy generative models. (n.d.). Google Cloud: https://cloud.google.com/generative-ai-studio

36. Wang, Z. (2023, May 17). The Underdog Revolution: How Smaller Language Models Can Outperform LLMs. Deepgram: https://deepgram.com/learn/the-underdog-revolution-how-smaller-language-models-outperform-llms

37. Berger, E. (2023, June 9). Grounding LLMs. Microsoft Blog: https://techcommunity.microsoft.com/t5/fasttrack-for-azure/grounding-llms/ba-p/3843857

38. How to Request Technical Support for Einstein GPT Products. (2023, July 19). Salesforce Product Support: https://help.salesforce.com/s/articleView?id=000395674&type=1

39. Mata v. Avianca, Inc. (2023, June 22). Casetext: https://casetext.com/case/mata-v-avianca-inc-2

40. Claburn, T. (2023, June 22). Lawyers who cited fake cases hallucinated by ChatGPT must pay. The Register: https://www.theregister.com/2023/06/22/lawyers_fake_cases/

41. Moran, L. (2023, May 30). Lawyer cites fake cases generated by ChatGPT in legal brief. Legal Dive: https://www.legaldive.com/news/chatgpt-fake-legal-cases-generative-ai-hallucinations/651557/

42. Baxter, K., and Schlesinger, Y. (2023, June 6). Managing the Risks of Generative AI. Harvard Business Review: https://hbr.org/2023/06/managing-the-risks-of-generative-ai

43. Miller, R. (2023, May 11). Writer introduces product that could help reduce hallucinated content in its LLMs. TechCrunch: https://techcrunch.com/2023/05/11/writer-introduces-product-that-could-help-reduce-hallucinated-content-in-its-llms/

44. Morgan Stanley wealth management deploys GPT-4 to organize its vast knowledge base. (2023, March 14). OpenAI: https://openai.com/customer-stories/morgan-stanley

45. Wheeler, R., and Stone, J. (2023, May). Using Large Language Models and Generative AI to Build a Digital Owner's Manual. Toyota Connected: https://www.toyotaconnected.com/insights/using-large-language-models-and-generative-ai-to-build-a-digital-owners-manual

46. Brynjolfsson, E., Li, D., et al. (2023, April). Generative AI At Work. National Bureau of Economic Research: https://www.nber.org/system/files/working_papers/w31161/w31161.pdf

47. Malik, A. (2023, March 9). Discord updates its bot with ChatGPT-like features, rolls out AI-generated conversation summaries and more. TechCrunch: https://techcrunch.com/2023/03/09/discord-updates-its-bot-with-chatgpt-like-features-rolls-out-ai-generated-conversation-summaries-and-more/

48. Early Insights on My AI. (2023, June 11). Snapchat Newsroom: https://newsroom.snap.com/early-insights-on-my-ai

49. Bing Chat. (n.d.). Microsoft Edge: https://www.microsoft.com/en-us/edge/features/bing-chat?form=MT00D8

50. Reid, E. (2023, May 10). Supercharging Search with generative AI. The Keyword: https://blog.google/products/search/generative-ai-search/

51. Lee, M. (2023, June 27). Looking for help buying a car? Ask ChatGPT. How new plugins can save you time (and money). USA Today: https://www.usatoday.com/story/money/personalfinance/2023/06/27/chatgpt-car-buying-purchasing-research-details/70358652007/

52. Ahmad, F. (2023, May 17). Bard Plugins: How to Add New Features and Functionality. Tech Craving: https://www.techcarving.com/bard-plugins-how-to-add-new-features-and-functionality/

Meet my agent

1. Josić, K. (2012, January 11). The Mechanical Turk. The Engines of our Ingenuity: https://engines.egr.uh.edu/episode/2765

2. Almon Brown Strowger. (n.d.). National Inventors Hall of Fame: https://www.invent.org/inductees/almon-brown-strowger

3. Marsh, A. (2022, August 30). In 1961, the First Robot Arm Punched In. IEEE Spectrum: https://spectrum.ieee.org/unimation-robot

4. Anker, A. (1995, October 1). BargainFinder. Wired: https://www.wired.com/1995/10/bargainfinder/

5. Meyer, R. (2015, June 23). Even Early Focus Groups Hated Clippy. The Atlantic: https://www.theatlantic.com/technology/archive/2015/06/clippy-the-microsoft-office-assistant-is-the-patriarchys-fault/396653/

6. Bonabeau, E. (2002, May 14). Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences: https://www.pnas.org/doi/pdf/10.1073/pnas.082080899

7. About Us. (n.d.). eSnipe: https://www.esnipe.com/about

8. Berry, B., Kiel, L., et al. (2002, May 14). Adaptive agents, intelligence, and emergent human organization: Capturing complexity through agent-based modeling. Proceedings of the National Academy of Sciences: https://www.pnas.org/doi/epdf/10.1073/pnas.092078899

9. Siri. (n.d.). SRI International: https://www.sri.com/hoi/siri/

10. Charles Schwab Launches Schwab Intelligent Portfolios. (2015, March 9). BusinessWire: https://www.businesswire.com/news/home/20150309005290/en/Charles-Schwab-Launches-Schwab-Intelligent-Portfolios

11. Shirado, H., and Christakis, N. (2018, April 23). Locally Noisy Autonomous Agents Improve Global Human Coordination in Network Experiments. Nature: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5912653/

12. The AlphaStar Team. (2019, October 30). AlphaStar: Grandmaster level in StarCraft II using multi-agent reinforcement learning. DeepMind Research: https://www.deepmind.com/blog/alphastar-grandmaster-level-in-starcraft-ii-using-multi-agent-reinforcement-learning

13. Wessling, B. (2022, June 22). A decade after acquiring Kiva, Amazon unveils its first AMR. The Robot Report: https://www.therobotreport.com/a-decade-after-acquiring-kiva-amazon-unveils-its-first-amr/

14. Fried, I. (2023, September 25). We tested ChatGPT's new support for images and voice search. Axios: https://www.axios.com/2023/09/25/testing-chatgpt-support-images-voice-search

15. Sullivan, M. (2023, April 13). Auto-GPT and BabyAGI: How 'autonomous agents' are bringing generative AI to the masses. Fast Company: https://www.fastcompany.com/90880294/auto-gpt-and-babyagi-how-autonomous-agents-are-bringing-generative-ai-to-the-masses

16. Adobe Firefly: Your imagination's new best friend. (n.d.). Adobe.com: https://www.adobe.com/sensei/generative-ai/firefly.html

17. Greenfield, D. (2019, August 1). Volkswagen Applies Generative Design. Automation World: https://www.automationworld.com/products/software/blog/13320039/volkswagen-applies-generative-design

18. Deslandes, N. (2023, July 4). Siemens and Intrinsic to make AI-based robotics accessible to SMEs. Tech Informed: https://techinformed.com/siemens-and-intrinsic-to-make-ai-based-robotics-accessible-to-smes/

19. Micropsi Industries' AI Software MIRAI Now Compatible with FANUC Robots. (2022, November 30). Automation.com: https://www.automation.com/en-us/articles/november-2022/micropsi-industries-ai-software-mirai-fanuc-robots

20. Dencheva, V. (2023, June 7). Generative AI in marketing – statistics & facts. Statista: https://www.statista.com/topics/10994/generative-ai-in-marketing/#topicOverview

21. Bastian, M. (2023, April 30). How GPT-4 and AutoGPT could save you money. The Decoder: https://the-decoder.com/how-gpt-4-and-auto-gpt-could-save-you-money/

22. Daugherty, P., Ghosh, B., et al. (2023). A new era of generative AI for everyone. Accenture: https://www.accenture.com/content/dam/accenture/final/accenture-com/document/Accenture-A-New-Era-of-Generative-AI-for-Everyone.pdf

23. ChatGPT plugins. (2023, March 23). OpenAI: https://openai.com/blog/chatgpt-plugins

24. Peterson, J. (2023, July 31). A Beginner's Guide to Using ChatGPT Plugins. Lifehacker: https://lifehacker.com/a-beginners-guide-to-using-chatgpt-plugins-1850578719

25. Wei, J., and Zhou, D. (2022, May 11). Language Models Perform Reasoning via Chain of Thought. Google Research: https://ai.googleblog.com/2022/05/language-models-perform-reasoning-via.html

26. Wei, J., Wang, X., et al. (2022, Janurary 28). Chain-of-Thought Prompting Elicits Reasoning in Large Language Models. arXiv: https://arxiv.org/abs/2201.11903

27. Shinn, N., Cassano, F., et al. (2023, March 20). Reflexion: Language Agents with Verbal Reinforcement Learning. arXiv: https://arxiv.org/abs/2303.11366

28. CyberNews. (2023, June). What is AutoGPT? Explained in 2 minutes. YouTube: https://www.youtube.com/watch?v=-N5Rhx-1K7w

29. Parthasarathy, S. (2023, May 10). Meet BabyAGI – The Autonomous AI Agent to Streamline Your Tasks. TowardsAI: https://pub.towardsai.net/meet-babyagi-the-autonomous-ai-agent-to-streamline-your-tasks-f44cb9de5503

30. Suki. (2023, June 2). VOYAGER: Revolutionizing Lifelong Learning in Minecraft with LLM Technology. Medium: https://medium.com/@SukiLLM/voyager-revolutionizing-lifelong-learning-in-minecraft-with-llm-technology-ec99a1bf867b

31. Wang, G., Xie, Y., et al. (2023, May 25). Voyager: An Open-Ended Embodied Agent with Large Language Models. arXiv: https://arxiv.org/abs/2305.16291

32. Tool up! DeepMind, Princeton & Stanford's LATM Enables LLMs to Make Their Own Tools. (2023, May 31). Synced: https://syncedreview.com/2023/05/31/tool-up-deepmind-princeton-stanfords-latm-enables-llms-to-make-their-own-tools/

33. Pejcha, C. (2023, April 13). Google put 25 AI agents together in a Sims-inspired virtual town, and told them to go about their lives. Document Journal: https://www.documentjournal.com/2023/04/google-ai-study-creates-chatgpt-generative-agents-that-simulate-artificial-human-society/

34. Fu, Y., Peng, H., et al. (2023, May 17). Improving Language Model Negotiation with Self-Play and In-Context Learning from AI Feedback. arXiv: https://arxiv.org/abs/2305.10142

35. Boiko, D., MacKnight, R., et al. (2023, April 11). Emergent autonomous scientific research capabilities of large language models. arXiv: https://arxiv.org/abs/2304.05332

36. Driess, D., and Florence, P. (2023, March 10). PaLM-E: An embodied multimodal language model. Google Research: https://ai.googleblog.com/2023/03/palm-e-embodied-multimodal-language.html

37. Xing, P. (2023, August 5). MetaGPT: a Multi-Agent Framework to Automate Your Software Company. DataDrivenInvestor: https://medium.datadriveninvestor.com/metagpt-a-multi-agent-framework-to-automate-your-software-company-4b6ae747cc36

38. Machines make up 43% of digital identities on enterprise networks. (n.d.). Security Magazine: https://www.securitymagazine.com/articles/98401-machines-make-up-43-of-digital-identities-on-enterprise-networks

39. Davenport, T., and Alavi, M. (2023, July 6). How to Train Generative AI Using Your Company's Data. Harvard Business Review: https://hbr.org/2023/07/how-to-train-generative-ai-using-your-companys-data

40. Davenport, T. (2023, June 26). Fast, Cheap, And In Control: Generative AI In Morningstar's Mo. Forbes: https://www.forbes.com/sites/tomdavenport/2023/06/26/fast-cheap-and-in-control-generative-ai-in-morningstars-mo/?sh=651146f716ae

41. Davenport, T. (2023, March 20). How Morgan Stanley Is Training GPT To Help Financial Advisors. Forbes: https://www.forbes.com/sites/tomdavenport/2023/03/20/how-morgan-stanley-is-training-gpt-to-help-financial-advisors/?sh=6184710c3fc3

42. Ren, A., Dixit, A., et al. (2023, September 4). Robots That Ask For Help: Uncertainty Alignment for Large Language Model Planners. arXiv: https://arxiv.org/pdf/2307.01928.pdf

The space we need

1. Morton Heilig: Inventor VR. (n.d). USC School of Cinematic Arts: https://www.uschefnerarchive.com/morton-heilig-inventor-vr/

2. Laidlaw, Z. (2020, November 15). What are haptics, and why are they such an important part of your smartphone? Android Police: https://www.androidpolice.com/2020/11/15/what-are-haptics-and-why-are-they-such-an-important-part-of-your-smartphone-sponsored/

3. PARC History. (n.d.). PARC: https://www.parc.com/about-parc/parc-history/

4. Rosenberg, L. (2022, April 7). How A Parachute Accident Helped Jump-Start Augmented Reality. IEEE Spectrum: https://spectrum.ieee.org/history-of-augmented-reality

5. Physical, Elecrical, Digital. (n.d.). NYU: https://kimon.hosting.nyu.edu/physical-electrical-digital/items/show/1518

6. Greenwold, S. (1995, June). Spatial Computing. MIT: https://acg.media.mit.edu/people/simong/thesis/SpatialComputing.pdf

7. Dredge, S. (2019, September 28). All you need to know about Roblox. The Guardian: https://www.theguardian.com/games/2019/sep/28/roblox-guide-children-gaming-platform-developer-minecraft-fortnite

8. Javornik, A. (2016, October 4). The Mainstreaming of Augmented Reality: A Brief History. Harvard Business Review: https://hbr.org/2016/10/the-mainstreaming-of-augmented-reality-a-brief-history

9. Warren, T. (2017, October 25). Microsoft kills off Kinect, stops manufacturing it. The Verge: https://www.theverge.com/2017/10/25/16542870/microsoft-kinect-dead-stop-manufacturing

10. Kumparak, G. (2014, March 26). A Brief History of Oculus. TechCrunch: https://techcrunch.com/2014/03/26/a-brief-history-of-oculus/

11. Leswing, K. (2023, March 15). Google ends enterprise sales of Google Glass, its augmented reality smartglasses. CNBC: https://www.cnbc.com/2023/03/15/google-discontinues-google-glass-enterprise-end-to-early-ar-project.html

12. Clement, J. (2023, August 7). Global Pokémon GO app downloads as of Q2 2023. Statista: https://www.statista.com/statistics/641690/pokemon-go-number-of-downloads-worldwide/

13. Robertson, A. (2017, June 5). Apple is launching an iOS 'ARKit' for augmented reality apps. The Verge: https://www.theverge.com/2017/6/5/15732832/apple-augmented-reality-arkit-ar-sdk-wwdc-2017

14. Christian, J. (2018, September 27). Make Music A Full Body Experience With A "Vibro-Tactile" Suit. Futurism: https://futurism.com/the-byte/vibro-tactile-suit-music

15. Newton, C. (2019, April 4). Snapchat's new Landmarkers will make the Eiffel Tower puke rainbows. The Verge: https://www.theverge.com/2019/4/4/18294062/snapchat-landmarkers-ar-lenses-filters-eiffel-tower-rainbows

16. Takahashi, D. (2020, May 14). Nvidia launches early access for Omniverse computer graphics and simulation platform. VentureBeat: https://venturebeat.com/business/nvidia-launches-early-access-for-omniverse-computer-graphics-and-simulation-platform/

17. Roach, J. (2021, November 2). Mesh for Microsoft Teams aims to make collaboration in the 'metaverse' personal and fun. Microsoft: https://news.microsoft.com/source/features/innovation/mesh-for-microsoft-teams

18. Introducing Apple Vision Pro: Apple's first spatial computer. (2023, June 5). Apple: https://www.apple.com/newsroom/2023/06/introducing-apple-vision-pro

19. Apple's long history of lousy first reviews. (2015). The Week: https://theweek.com/articles/496303/apples-long-history-lousy-first-reviews

20. Slattery, B. (2010, January 28). Apple iPad Reviews: The Critics Weigh In. PC World: https://www.pcworld.com/article/516566/apple_ipad_reviews-2.html

21. Pogue, D. (2010). Looking at the iPad From Two Angles. The New York Times: https://www.nytimes.com/2010/04/01/technology/personaltech/01pogue.html

22. Young, M. (2023, May 26). Metaverse 'Virtual Land Barons' Down Bad in 2023 as Prices Decline Further. Be(in)Crypto: https://beincrypto.com/metaverse-virtual-land-barons-down-2023-prices-decline/

23. Hatmaker, T. (2023, February 3). Meta's Reality Labs lost $13.7 billion on VR and AR last year. TechCrunch: https://techcrunch.com/2023/02/03/metas-reality-labs-lost-13-7-billion-on-vr-and-ar-last-year/

24. Joseph, S. (2023, May 1). Meta Introduces Codex Avatars, Life-Like Avatars that can be Created Using a Smartphone. The Tech Outlook: https://www.thetechoutlook.com/news/innovation/meta-introduces-codex-avatars-life-like-avatars-that-can-be-created-using-a-smartphone/

25. Peters, J. (2022, December 1). Epic's free app that turns real-life items into 3D models is available now on iOS. The Verge: https://www.theverge.com/2022/12/1/23488421/epic-games-reality-scan-ios-app-scan-objects-3d-models

26. Reid, E. (2020, February 5). A look back at 15 years of mapping the world. Google: https://blog.google/products/maps/look-back-15-years-mapping-world/

27. Introduction to USD. (n.d.). OpenUSD: https://openusd.org/release/intro.html

28. Universal Scene Description. (n.d.). Nvidia: https://www.nvidia.com/en-us/omniverse/usd/

29. Pixar, Adobe, Apple, Autodesk, and NVIDIA form Alliance for OpenUSD to drive open standards for 3D content. (2023, August 1). Apple: https://www.apple.com/newsroom/2023/08/pixar-adobe-apple-autodesk-and-nvidia-form-alliance-for-openusd/?1690894762

30. Loder, C. (2023, June 22). Getting started with Apple Vision Pro developer software. Apple Insider: https://appleinsider.com/articles/23/06/22/getting-started-with-apple-vision-pro-developer-software

31. OpenXR. (n.d.). Khronos Group: https://www.khronos.org/openxr/

32. Takahashi, D. (2023, July 3). OMA3 offers way for users to travel between blockchain gaming worlds in the metaverse. VentureBeat: https://venturebeat.com/games/oma3-offers-way-for-users-to-travel-between-blockchain-gaming-worlds-in-the-metaverse/

33. Deltombe, A. (2020, October 20). How Much Does it Cost to Create 3D Models? Sketchfab: https://sketchfab.com/blogs/enterprise/create-3d-models-cost

34. Salian, I. (2023, June 1). Digital Renaissance: NVIDIA Neuralangelo Research Reconstructs 3D Scenes. Nvidia: https://blogs.nvidia.com/blog/2023/06/01/neuralangelo-ai-research-3d-reconstruction/

35. Intel Labs Introduces AI Diffusion Model, Generates 360-Degree Images from Text Prompts. (2023, June 21). Intel: https://www.intel.com/content/www/us/en/newsroom/news/intel-introduces-3d-generative-ai-model.html

36. Qualcomm Accelerates an Open, XR Developer Ecosystem with Snapdragon Spaces Milestones. (2023, May 31). Qualcomm: https://www.qualcomm.com/news/releases/2023/05/qualcomm-accelerates-an-open--xr-developer-ecosystem-with-snapdr

37. Kemelmacher-Shlizerman, I. (2023, June 14). How AI makes virtual try-on more realistic. Google: https://blog.google/products/shopping/virtual-try-on-google-generative-ai/

38. Silva, S. (2023, May 10). Create world-scale augmented reality experiences in minutes with Google's Geospatial Creator. Google: https://developers.googleblog.com/2023/05/create-world-scale-augmented-reality-experiences-in-minutes-with-google-geospatial-creator.html

39. Designing the future: How we prototype in AR and VR. (2023, January 19). Meta: https://design.facebook.com/stories/designing-the-future-how-we-prototype-in-ar-and-vr/

40. Inworld AI: 99% of gamers are excited by the potential of smart NPCs powered by advanced artificial intelligence. (2023, February 15). PR Newswire: https://www.prnewswire.com/news-releases/inworld-ai-99-of-gamers-are-excited-by-the-potential-of-smart-npcs-powered-by-advanced-artificial-intelligence-301747635.html

41. Gibbs, K. (2023, July 18). Feature Release Week 1: Our Improved Character Brain. Inworld: https://www.inworld.ai/blog/improved-character-brain

42. Contextual Mesh. (n.d.). Inworld: https://www.inworld.ai/#contextual-mesh

43. Ackerman, E. (2023, April 22). Haptic System Creates Finger-Touch Sensations Hardware-Free. IEEE Spectrum: https://spectrum.ieee.org/finger-haptics

44. Kersley, A. (2023, April 11). Smell Your Way Out of the Uncanny Valley. Wired: https://www.wired.com/story/scentient-smell-virtual-reality/

45. McKeague, M., Cohrs, J., et al. (2023, March 16). Adapting Spatial Audio for Browser-Based 3D Storytelling. New York Times: https://rd.nytimes.com/projects/adapting-spatial-audio-for-browser-based-3d-storytelling

46. Schwartz, M., Khurana, M., et al. (2023, March 3). The Quest to Restore Notre Dame's Glorious Sound. The New York Times: https://www.nytimes.com/interactive/2023/03/03/magazine/notre-dame-cathedral-acoustics-sound.html

47. Lesiv, A. (2023, June 28). The Dawn of Spatial Computing. Every: https://every.to/p/the-dawn-of-spatial-computing

48. Peters, J. (2023, February 21). Meta is improving Quest hand tracking so you can touch buttons and type on virtual keyboards. The Verge: https://www.theverge.com/2023/2/21/23609001/meta-quest-pro-hand-tracking-direct-touch-v50

49. Blumstein, G., Zukotynski, B., et al. (2020, February 5). Randomized trial of a virtual reality tool to teach surgical technique for tibial shaft fracture intramedullary nailing. National Library of Medicine: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7351249/

50. Validation study: Haptic feedback is proven to improve surgical education (2022, October). Fundamental Surgery: https://fundamentalsurgery.com/validation-study-haptic-feedback/

51. Zhenhuan, M. (2023, February 12). Gallbladder surgery done at long distance with 5G. China Daily: https://www.chinadaily.com.cn/a/202302/18/WS63f0223ea31057c47ebaf7e9.html

52. Unity, Vancouver Airport Authority Partner to Leverage Digital Twins. (2023, June 19). XR Today: https://www.xrtoday.com/virtual-reality/unity-vancouver-airport-authority-partner-to-leverage-digital-twins/

53. "Playing Pompidou": Christian Marclay and Snap's AR Studio transform The Centre Pompidou into a musical instrument. (2022, November 16). Snap: https://newsroom.snap.com/playing-pompidou

54. Purdy, M. (2023, April 3). Building a Great Customer Experience in the Metaverse. Harvard Business Review: https://hbr.org/2023/04/building-a-great-customer-experience-in-the-metaverse

55. FIAT Metaverse Store, the world's first metaverse-powered showroom, a revolution in customer experience. (2022, December 1). Stellantis: https://www.media.stellantis.com/uk-en/fiat/press/fiat-metaverse-store-the-world-s-first-metaverse-powered-showroom-a-revolution-in-customer-experience

56. Kumaravel, B. T. and Hartmann, B. (2022, May 12). Interactive Mixed-Dimensional Media for Cross-Dimensional Collaboration in Mixed Reality Environments. Frontiers: https://www.frontiersin.org/articles/10.3389/frvir.2022.766336/full

57. Gap x Mattel: Barbie's Times Square Takeover powered by Google's Geospatial Creator. (n.d.). Unit9: https://www.unit9.com/project/gap-x-mattel-barbies-times-square-takeower-powered-by-googles-geospatial-creator

58. Telstra, Google, and Accenture develop 5G powered augmented reality wayfinding experience at Marvel Stadium. (2022, May 11). Accenture: https://newsroom.accenture.com/news/telstra-google-and-accenture-develop-5g-powered-augmented-reality-wayfinding-experience-at-marvel-stadium.htm

59. Augmented for surgical success—a reality now. (n.d.). Accenture: https://www.accenture.com/fi-en/case-studies/technology/microsoft-hololens-surgery

Our bodies electronic

1. Kawala-Sterniuk, A., and Browarska, N., et al. (2021, January 3). Summary of over Fifty Years with Brain-Computer Interfaces—A Review. National Library of Medicine: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7824107/

2. Di Stasi, L., and Diaz-Piedra, C. (2021, January 14). Re-examining the Pioneering Studies on Eye Movements in Aviation: Connecting the Past to the Present. ResearchGate: https://www.researchgate.net/publication/346675919_Re-examining_the_Pioneering_Studies_on_Eye_Movements_in_Aviation_Connecting_the_Past_to_the_Present

3. Spicer, D. (2021, June 9). Audrey, Alexa, Hal, and More. Computer History Museum: https://computerhistory.org/blog/audrey-alexa-hal-and-more/

4. A brief history of Facial Recognition. (2022, May 12). NEC: https://www.nec.co.nz/market-leadership/publications-media/a-brief-history-of-facial-recognition/

5. Glover, G. (2011, April). Overview of Functional Magnetic Resonance Imaging. National Library of Medicine: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3073717/

6. Singleton, S. (2000, July 11). How Cookie-Gate Crumbles. Cato Institute: https://www.cato.org/commentary/how-cookie-gate-crumbles

7. Kawala-Sterniuk, A., and Browarska, N., et al. Summary of over Fifty Years with Brain-Computer Interfaces.

8. Volvo Cars introduces new systems for alerting tired and distracted drivers. (2007, August 31). Volvo Cars: https://www.media.volvocars.com/us/en-us/media/pressreleases/12130

9. Ewalt, D. (2010, June 11). Getting Fitbit. Forbes: https://www.forbes.com/2010/06/11/fitbit-tracker-pedometer-lifestyle-heatlh-lifetracking.html

10. Katzmaier, D. (2012, April 9). Samsung Smart Interaction: Hands-on with voice and gesture control. CNET: https://www.cnet.com/tech/home-entertainment/samsung-smart-interaction-hands-on-with-voice-and-gesture-control/

11. DARPA and the Brain Initiative. (n.d.). DARPA: https://www.darpa.mil/program/our-research/darpa-and-the-brain-initiative

12. Wong, J. (2023, June 15). Oura. Contrary Research: https://research.contrary.com/reports/oura#

13. Revell, T. (2023, May 26). Elon Musk's brain implant firm Neuralink gets approval for human trial. New Scientist: https://www.newscientist.com/article/2375886-elon-musks-brain-implant-firm-neuralink-gets-approval-for-human-trial/

14. Brandom, R. (2017, September 12). iPhone X will unlock with facial recognition instead of the home button. The Verge: https://www.theverge.com/2017/9/12/16270352/apple-iphone-x-home-button-removed-unlock-touch-id

15. Huynh, D., Millan, A., et al. (2021, July 28). Description and Early Results of the Kaiser Permanent Southern California COVID-19 Home Monitoring Program. National Library of Medicine: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8784054/

16. Neurorights in Chile. (n.d.). The Neurorights Foundation: https://neurorightsfoundation.org/chile

17. Belluck, P. (2023, August 23). A Stroke Stole Her Ability to Speak at 30. A.I. Is Helping to Restore It Years Later. The New York Times: https://www.nytimes.com/2023/08/23/health/ai-stroke-speech-neuroscience.html

18. Freifeld, L. (2022, November 16). 2022 Training Industry Report. Training: https://trainingmag.com/2022-training-industry-report/

19. Metzger, S., Littlejohn, K., et al. (2023, August 23). A high-performance neuroprosthesis for speech decoding and avatar control. Nature: https://www.nature.com/articles/s41586-023-06443-4

20. Willett, F., Kunz, E., et al. (2023, August 23). A high-performance speech neuroprosthesis. Nature: https://www.nature.com/articles/s41586-023-06377-x

21. King, J. (2022, August 31). Using AI to decode speech from brain activity. Meta: https://ai.meta.com/blog/ai-speech-brain-activity/

22. Heaney, D. (2023, June 9). Here's How You Control Apple Vision Pro With Eye Tracking And Hand Gestures. UploadVR: https://www.uploadvr.com/apple-vision-pro-gesture-controls/

23. Crispin, S., Yildiz, I., et al. (2021, November 11). Biofeedback Method of Modulating Digital Content to Invoke Greater Pupil Radius Response. Google Patents: https://patents.google.com/patent/US20210349536A1

24. Dencheva, V. (2023, January 6). Customer experience personalization and optimization software and services revenue worldwide from 2020 to 2026. Statista: https://www.statista.com/statistics/1333448/cx-personalization-optimization-revenue-worldwide/

25. Navarro, J. (2023, January 6). Marketing personalization worldwide – statistics & facts. Statista: https://www.statista.com/topics/4481/personalized-marketing/#topicOverview

26. Karrenbach, M., Boe, D., et al. (2022, January). Improving Automatic Control of Upper-Limb Prosthesis Wrists Using Gaze-Centered Eye Tracking and Deep Learning. ResearchGate: https://www.researchgate.net/publication/358291275_Improving_Automatic_Control_of_Upper-Limb_Prosthesis_Wrists_Using_Gaze-Centered_Eye_Tracking_and_Deep_Learning

27. The Science of Immersion. (n.d.): https://www.getimmersion.com/v4/why-it-works

28. Ma, J., and Rong, W. (2022, July 31). Pedestrian Crossing Intention Prediction Method Based on Multi-Feature Fusion. MDPI: https://www.mdpi.com/2032-6653/13/8/158

29. Waymo Driver. (n.d.): https://waymo.com/waymo-driver/

30. Dawson, C. (2023, April 5). Robots predict human intention for faster builds. ScienceDaily: https://www.sciencedaily.com/releases/2023/04/230405090242.htm

31. Nemlekar, H., Dhanaraj, N., et al. Transfer Learning of Human Preferences for Proactive Robot Assistance in Assembly Tasks. ACM Digital Library: https://dl.acm.org/doi/10.1145/3568162.3576965

32. Bremers, A., Pabst, A., et al. (2023, January 27). Using Social Cues to Recognize Task Failures for HRI: A Review of Current Research and Future Directions. arXiv.org: https://arxiv.org/abs/2301.11972

33. Blackrock Neurotech and Phantom Neuro Partner to Enable Prosthetics and Exoskeletons that Mimic Human Movement in Real-Time. (2022, April 26). PR Newswire: https://www.prnewswire.com/news-releases/blackrock-neurotech-and-phantom-neuro-partner-to-enable-prosthetics-and-exoskeletons-that-mimic-human-movement-in-real-time-301532495.html

34. Bardin, E. (2022, February 7). Galvani Bioelectronics implants first neurostimulator for splenic nerve stimulation in rheumatoid arthritis patient. MedCity News: https://medcitynews.com/2022/02/galvani-bioelectronics-implants-first-neurostimulator-for-splenic-nerve-stimulation-in-rheumatoid-arthritis-patient/

35. Capoot, A. (2023, February 18). Brain implant startup backed by Bezos and Gates is testing mind-controlled computing on humans. CNBC: https://www.cnbc.com/2023/02/18/synchron-backed-by-bezos-and-gates-tests-brain-computer-interface.html

36. Stripe, S. (2021, August 14). Brain-computer interfaces are making big progress this year. VentureBeat: https://venturebeat.com/business/brain-computer-interfaces-are-making-big-progress-this-year/

37. Chen, J., Zhang, Y., et al. (2023, July). A transformer-based deep neural network model for SSVEP classification. ScienceDirect: https://www.sciencedirect.com/science/article/abs/pii/S0893608023002319

38. Agarwal, M. (2023, May 31). EEG-Datasets. GitHub: https://github.com/meagmohit/EEG-Datasets

39. Accenture. (2023). Internal Interview.

40. Gonfalonieri, A. (2018, November 25). A Beginner's Guide to Brain-Computer Interface and Convolutional Neural Networks. Towards Data Science: https://towardsdatascience.com/a-beginners-guide-to-brain-computer-interface-and-convolutional-neural-networks-9f35bd4af948

41. Warbrick, T. (2022, March 15). Simultaneous EEG-fMRI: What Have We Learned and What Does the Future Hold? National Library of Medicine: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8952790/

42. Wearable Sensing DSI-24. (n.d.): https://wearablesensing.com/dsi-24/

43. Karim, H., Schmidt, B., et al. (2012, March). Functional Near-infrared Spectroscopy (fNIRS) of Brain Function During Active Balancing Using a Video Game System. National Library of Medicine: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3294084/

44. Kernel Introduces Flow2: Revolutionary Advanced Neuroimaging Technology Enabling Precision Neuromedicine. (2023, July 31). Business Wire: https://www.businesswire.com/news/home/20230731933400/en/Kernel-Introduces-Flow2-Revolutionary-Advanced-Neuroimaging-Technology-Enabling-Precision-Neuromedicine

45. EMOTIV and X-trodes collaborate on brain and physiological measurement. (2022, November 22). Med-Tech News: https://www.med-technews.com/news/ai-and-vr-in-healthcare/emotiv-and-x-trodes-collaborate-on-brain-and-physiological-m/

46. Purcher, J. (2023, July 20). Apple Invents a next-generation AirPods Sensor System that could measure Biosignals and Electrical Activity of a user's Brain. Patently Apple: https://www.patentlyapple.com/2023/07/apple-invents-a-next-generation-airpods-sensor-system-that-could-measure-biosignals-and-electrical-activity-of-a-users-brain.html

47. Ray, T. (2022, February 11). The AI edge chip market is on fire, kindled by 'staggering' VC funding. ZDNET: https://www.zdnet.com/article/the-ai-edge-inference-chip-market-is-raging/

48. Clark, A. (2023, June 7). Qualcomm, Mobileye, Other AI Chip Stocks That Can Thrive. It's Not All About the Cloud. Barron's: https://www.barrons.com/articles/qualcomm-mobileye-nvidia-ai-chip-stocks-497a0ab7

49. Ramirez-Aristizabal, A., Ebrahimpour, M., et al. (2022, January 31). Image-Based EEG Classification of Brain Responses to Song Recordings. arXiv.org: https://arxiv.org/pdf/2202.03265.pdf

50. Accenture. (2023). Internal Interview.

51. Knight, S. (2023, February 20). Switchback VR uses eye tracking to make the game scarier every time you blink. TechSpot: https://www.techspot.com/news/97667-switchback-vr-uses-eye-tracking-make-game-scarier.html

52. Porter, J. (2021, January 25). Gabe Newell has big plans for brain-computer interfaces in gaming. The Verge: https://www.theverge.com/2021/1/25/22248202/gabe-newell-valve-brain-computer-interface-bci-meat-peripherals

53. Kacapyr, S. (2022, October 5). Algorithms predict sports teams' moves with 80% accuracy. Cornell Chronicle: https://news.cornell.edu/stories/2022/10/algorithms-predict-sports-teams-moves-80-accuracy

54. McClure, P. (2023, March 21). New graphene sensors make for better brain-machine interface. New Atlas: https://newatlas.com/technology/graphene-sensor-interface-thought-controlled-robot/

55. Heater, B. (2022, March 23). Snap buys mind-controlled headband maker, NextMind. TechCrunch: https://techcrunch.com/2022/03/23/snap-buys-mind-controlled-headband-maker-nextmind/

56. WiMi to Design A Hybrid BCI-Based Humanoid Control System. (2023, June 23). PR Newswire: https://www.prnewswire.com/news-releases/wimi-to-design-a-hybrid-bci-based-humanoid-control-system-301860836.html

57. Radic, N. (2022, November 19). Are You Ready for Workplace Brain Scanning? IEEE Spectrum: https://spectrum.ieee.org/neurotech-workplace-innereye-emotiv

58. Loréal, in partnership with global neurotech leader, EMOTIV, launches new deivce to help consumers personalize their fragrance choices. (2022, March 21). Emotiv: https://www.emotiv.com/news/loreal-in-partnership-with-emotiv-neurotech-leader/

59. Meili Technologies. (n.d.). LinkedIn: https://www.linkedin.com/company/meilitech/about/

60. Meili Technologies. (n.d.). AutoSens: https://auto-sens.com/organisation/meili-technologies/

61. Doyle, M. (2021, June 15). One Smart Hard Hat: How This Device Keeps Your Workers Awake. Equipment World: https://www.equipmentworld.com/technology/article/15066019/how-smart-cap-keeps-workers-awake

62. Shipman, M. (2023, April 28). The Future Is Now: Wrestling with Ethics, Policy and Brain-Computer Interfaces. NC State News: https://news.ncsu.edu/2023/04/ethics-brain-computer-interfaces/

63. Strickland, E. (2021, December 18). Worldwide Campaign for Neurorights Notches Its First Win. IEEE Spectrum: https://spectrum.ieee.org/neurotech-neurorights

64. The Neurorights Foundation. (n.d.): https://neurorightsfoundation.org/

65. Policy. (n.d.). The Neurorights Foundation: https://neurorights-foundation.org/policypage

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