Fresh

The Future of Autonomous Systems

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Automated Versus Autonomous

Historically, machines have been pre-programmed to complete "deterministic" instructions: rote tasks free from randomness or variation. In other words, they've been automated to carry out relatively simple jobs like lifting objects, carrying materials on a direct path from Point A to Point B, or completing basic computations.

But as we progress to the new frontier of Industry 4.0 – an era defined by the "infusion of intelligence, connectivity, and automation into the physical world" – machines and systems must progress to advanced levels of autonomy to match novel demands and requirements.[1] Currently, machines and interconnected systems can make decisions independent of human operation. In the future, these systems will be able to do so with greater accuracy and sophistication, operating independently based on pattern recognition in data, setting goals for themselves, and adapting to changing environments.

In a sense, as humans evolve in consciousness and capability, so too will autonomous systems. It's our charge as innovators to ensure that it happens in a way that mirrors and complements us.

In this white paper, we'll discuss:

1. What defines an autonomous system
2. A vision for the future
3. The myriad benefits of creating autonomous systems
4. What's holding us back and what's required to advance
5. Human design considerations and principles

Understanding what autonomous systems are and how they'll change work and everyday life will help individuals and companies be part of the future. While it's natural to fear change, we believe that by making intentional decisions about how these systems are designed and engineered, we can ensure that human ingenuity is fostered, and advanced to levels once considered speculative – or even impossible.

Automated Systems	Autonomous Systems
Perform Efficiently (both)	**Perform Efficiently** (both)
Complete Complex Tasks (both)	**Complete Complex Tasks** (both)
Require expert setup (both)	**Require expert setup** (both)
Improve with new programming by humans	**Learn from operational experience**
Perform pre-defined tasks in a static environment	**Adapt to changing real-world conditions**
Programmed with predictable instructions	**Programmed with complex Machine Learning systems**
Require human supervision to ensure safety	**Operate alongside humans safely**

An Evolution of Self-Optimizing Systems

Consider the simple act of walking down the street from your office to meet a friend for lunch. Humans process gigabytes of data in a matter of milliseconds. We absorb and digest information coming from every angle, and our human brain collects, synthesizes, and comprehends it. After choosing the ideal route from a building to a cafe, we embark, but along the way, we make imperceptible adjustments:

Perceptions that drive direct action:

- Seeing a rain cloud, we take shelter under an awning to avoid getting wet
- Smelling pastries at the local patisserie, we stop by for a closer look

Perceptions that trigger indirect action based on prior experience:

- Sensing a car approaching down the street, we look both ways, even though the sign indicates that it's our turn to cross
- Hearing construction around the corner, we make a decision to choose a different route to stay on time for lunch

As we progress from Point A to Point B, we make choices – even if they happen at the subconscious level – to optimize and adjust based on the data at our disposal.

Comprehending the real world is much more complex than it appears on the surface. If you consider all the real data a machine needs to make a decision, let alone the *right* decision, it becomes clear how much sophistication and intelligence is required.

Now that robots and machines can observe the world with advanced sensors and large data sets, how do we enable them to use that information and make smart, safe decisions that increase productivity and efficiency? That's where the creation of autonomous systems comes into play. Think of autonomous systems as AI brains that help machines decipher clues about the world, learning, adjusting, and making real-time decisions from real-time input.

Machine Teaching: A Step Beyond Machine Learning

Once computers were only able to carry out simple instructions and make basic calculations. Now, thanks to a profound technological evolution, computing power gives systems and machines an awareness of their environment, with the ability to be smart about solving tasks. Under the hood, the technology is more simple than you might imagine. Using **machine learning**, we can create complex algorithms that look for patterns in data, improving and optimizing their behavior automatically through experience.[2] The more data and information a machine collects, the more patterns it recognizes and the better it becomes at performing its functions.

Machine teaching, a paradigm developed by Microsoft in **Project Bonsai**, takes things a step further.[3] In their white paper "**Bringing Autonomy to Industrial Control Systems**," Microsoft's authors write:

Machine teaching is a new, complementary approach to machine learning that can be used by those without AI expertise. With machine teaching, people break a complex problem into individual skills and give the AI brain important clues about how to learn faster. [4]

With machine teaching, non-data scientists can equip machines with the ability to collect data and act on a desired goal in simple, auditable ways. We can teach machines to find optimal behaviors through trial-and-error, learning how to handle varying inputs and still produce a desired outcome, often in more efficient ways we might not have initially seen or expected.

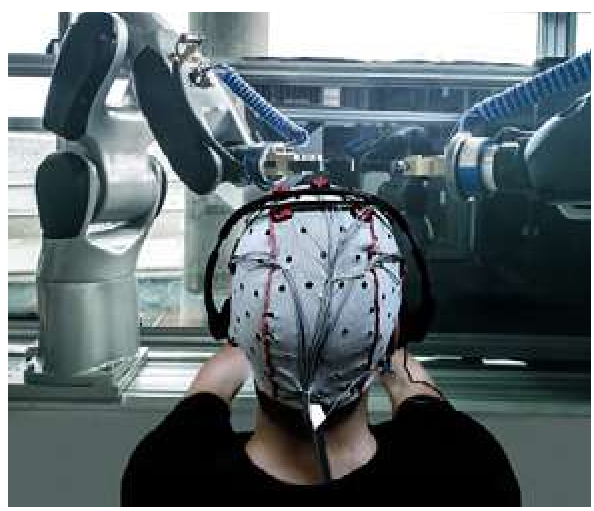
A Vision for the Future

Imagine a scenario where cobots ("collaborative robots") work alongside human scientists, engineers, and operators to harvest garbage from the ocean. The project is driven forward by Human-Centered AI, or intelligent systems that collaborate with humans in a deep, meaningful way. Thousands of tons of hazardous waste are collected from the ocean efficiently, the process evolving and optimizing as it continues.

Consider autonomous systems constructing landing pads for starships that touch down on planets once thought unreachable. The scientific research centers on the planets operate independently thanks to CPPS, or *cyber-physical production systems*, where cooperative elements within the facility are smart, interconnected, and capable of operating without intervention 100 million miles from Earth.

Picture a fleet of drones conducting direct air capture of carbon dioxide. They reduce Earth's atmospheric concentration of CO2 and thanks to identifying continuing opportunities to operate efficiently, they consume less than 25 thousand kilowatt-hours per tonne.

In Industry 4.0 – a world powered by the capabilities of machine learning, machine teaching, and fully independent, self-optimizing autonomous systems – all of the above is possible. As we explore the concrete ins and outs of autonomous systems and the technology's current state, we can also keep an eye toward the future, one that we can consciously and intentionally build.



The Future State

While there's justifiable fear that the future will be less human due to the proliferation of autonomous systems, we believe that **human potential can be magnified, similar to** how computers advanced the human race. Consider, for example, Digital Twins. In the white paper **Symbiotic Autonomous Systems**, the authors write:

A Digital Twin represents, in bits, an aspect of the real entity. In a human it might represent the health status, the knowledge, the set of relationships, and so on. In the context of Symbiotic Autonomous Systems, the functional area of a Digital Twin allows for the possibility of augmenting human capabilities and entering into a symbiotic relationship with other entities by creating a link through cyberspace. [5]

Take, for example, the Digital Twin of Singapore. In **a post for Tomorrow Mag**, Patricia Liceras writes that *"Large cities are usually characterised by a dynamism that conceals highly complex social structures and services. One only has to think of the millions of people living in large cities, or of schools, offices, shops, hospitals or transport systems. Any changes to these aspects affect many others. That is why the work of urban planners is so complicated."* [6]

The jobs and livelihoods of building tenants, teachers, government officials, business owners, healthcare workers, and transportation specialists aren't at stake when operating in a simulation. Rather, Digital Twins give humans the ability to create and improve solutions to complex problems. An autonomous system support tool like a Digital Twin makes the invisible infrastructure of a complex organism like a modern city visible. Human planners can use that information to understand inefficiencies and make changes that optimize all areas of city life. Paired with the capabilities of machine teaching – an autonomous system evolving and learning as it processes more data – you can imagine the vast possibilities.

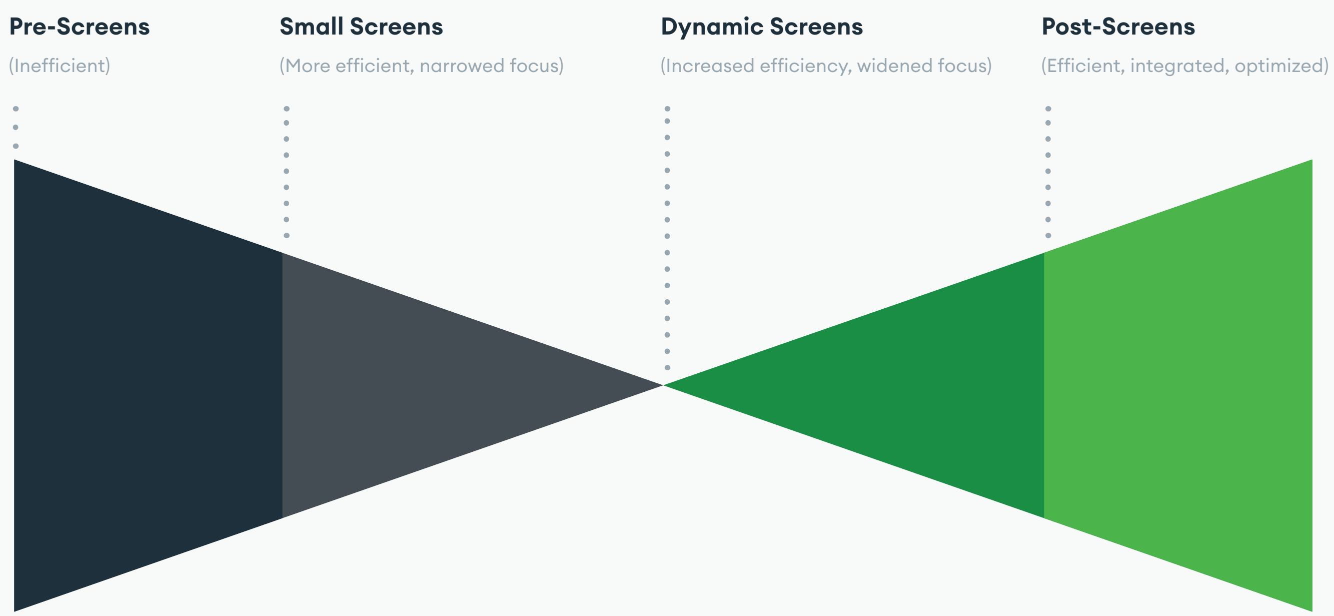
The conversation about Digital Twins is continued in a **related post** on their power to amplify human potential:

A good example would be its use by first responders like firefighters. In the case of fire they could have access to the 3D model of the building. With the companion aid of Augmented Reality and AI, firefighters could know where people are and how to predict fire's behavior. [7]

This use case illustrates a symbiotic relationship between humans and autonomous systems. With something like machine teaching, firefighters – subject matter experts in the area of first response and fire science, but not data scientists – can provide autonomous systems with relevant information. The system uses that information, teaching itself to complete important tasks dangerous for human beings to carry out. It's not a case of an automated robot replacing a worker; rather, it's an example of autonomous systems making firefighters better informed in a safe, simulated environment that makes use of vast wells of data that would otherwise remain untapped. Additionally, it empowers them to be more effective in what they do, with the byproduct of saving lives and using resources as efficiently as possible.

Integration: A New Way of Connecting

While screens have gotten progressively smaller in mobile forms, there's always been a reliance on humans staring at a self-contained display of data and information. In a sense, it's had the effect of partially disconnecting us from others. Autonomous systems provide the potential for us to reconnect in new ways by making computers more embedded in our machines and environment.



Before screens existed, we may not have faced the distraction of staring at them, but we were also less efficient. Even regulating temperature in a building was once a manual, unoptimized process. With the advent of more sophisticated heating units and display screens, we could see fluctuations in temperature and route heat or cooling to different areas as needed. Dynamic screens (sophisticated UI with various modes of input) allow us to do so with even greater accuracy and efficiency, but still, we're confined to an interface.

What if the intelligence was embedded in the human experience, making computer interaction so natural that it becomes unnoticeable? We now have the option of voice authentication – free from typing or any sort of manual input – which is a significant advancement. But using an autonomous system, like a Digital Twin with machine learning experience, will allow buildings to be completely self-regulating and self-optimizing, using a continuous stream of data to seamlessly support real-time human needs.

The same logic applies to virtually any system requiring manual operation of technology, which yields exciting possibilities for innovators across industry verticals.

The fear of technology replacing us or being too invasive is real and worth recognizing. But there's a possibility for a future where technology is invisible. Paired with human ingenuity, autonomous systems can supplement workflows, acting symbiotically in a way that benefits us and equips us for the challenges of an ever-changing world.

Proactivity is Essential to Innovation

Innovation is not passive; at its core, it involves developing new methods, ideas, and products. The danger lies in a lack of intention. If we create new systems without purpose or vision, we risk creating technology that is useless, or worse yet, harmful.

We believe in AI and technology used for good:

- Integrating systems with human beings to augment our capabilities
- Intentionally and strategically connecting humans, systems, and machines
- Thinking progressively about how tech affects our lives
- Creating systems that allow us to be our best selves and live more fulfilling lives
- Investing early because there is a demand, and we have the potential to shape the future

Image source: Unsplash

The Benefits: Human-System Integration

As discussed in previous sections, the most powerful implementations of autonomous systems will be ones intentionally designed with human beings in mind: those that magnify our potential as a species. While autonomous systems themselves are intelligent and independent, the most impactful ones will also be symbiotic, benefiting us in direct and indirect ways.

In discussing the benefits that autonomous systems carry, it's helpful to understand the core ways they can improve our lives.

Smarter Work

In the late 90s, world champion chess player Garry Kasparov played a number of matches against IBM's Deep Blue computer. Initially skeptical of the technology, comparing its sophistication to that of an alarm clock, Kasparov eventually came to appreciate what machines can teach us by opening up new possibilities – in the case of chess, new moves, of which there are 10 variations.[45]

Human-System Integration Benefits

- Complex Pattern Recognition
- Enhanced Safety
- Smarter Work
- Self Optimization
- Intentional Innovation

In the article **Don't try and beat AI, merge with it says chess champ Garry Kasparov**, the author writes, regarding Kasparov's change of heart:

The same thing happened when DeepMind beat the Go champion Lee Sedol. Although Sedol was thrashed, the moves made by the machine taught him new methods and strategies that were unexplored before.

"AI will help us to release human creativity. Humans won't be redundant or replaced, they'll be promoted." [. . .] Kasparov imagines machines will [eventually] reach what he calls the third "Type C" stage.

Type C is an augmented intelligence, where machines and humans work together to create smarter tools. Jobs will evolve and adapt, opening up new careers and industries. He envisions a future where humans don't have to become expert coders to work with AI, since machines will be advanced enough to understand and take instructions by listening to the human voice. [8]

Humans can – and should – "set the aim" of autonomous machines. In giving them direction, we make machines and systems smarter and more compatible with us. With the power of machine learning and machine teaching, we can now put actual AI brains on top of subsystems, still maintaining control over their ultimate aim, but giving them the freedom to teach us new possibilities, moves, and approaches that go far beyond games like Chess or Go.

With the dawn of Industry 4.0, autonomous machines can open up possibilities that we otherwise would not have been able to imagine.

Image source: **Unsplash**

Self-Optimization

With Project Bonsai, Microsoft has created the possibility for AI agents, or small "brains," to self-optimize through machine teaching, reinforcement learning, and simulation.[9] They describe a use case for silicon epitaxy wafer manufacturing:

The PID controller provides error correction in order to manage consistent temperature. The controller is only focused on heat distribution and doesn't consider other optimization goals like speed or energy usage. [. . .] This company built an AI brain to automatically control reactors–speeding up the process and saving costs. Ultimately, the AI brain minimized the time and cost of growing wafer substrate above a target quality consistency.

PID (proportional integral derivative) controllers require continuous moderation. But with a new AI brain, a formerly *automated* system becomes *fully autonomous*. It has the flexibility to do the task but self-adapt for efficiency. It has the reliability to optimize its behavior, setting "optimization goals," and continue operations without pause.

The end result is a system that frees human operators to do other work, handling formerly manual tasks in a more efficient manner.

Complex Pattern Recognition

Demis Hassabis, co-founder of DeepMind, posits that AlphaGo – originally created to imagine possible moves in the game Go – can be thought of as a thinking engine for all types of scientific research. In an article about DeepMind's Go exploits, the author dives deeper into the possibilities this presents for other industries and use cases:

Hassabis explains that you can think of AlphaGo as essentially a very good machine for searching through complicated data. In the case of Zero, that data is comprised of possible moves in a game of Go. But because Zero was not programmed to understand Go specifically, it could be reprogrammed to discover information in other fields: drug discovery, protein folding, quantum chemistry, particle physics, and material design.

Hassabis suggests that a descendant of AlphaGo Zero could be used to search for a room temperature superconductor – a hypothetical substance that allows electrical current to flow with zero lost energy, allowing for incredibly efficient power systems. (Superconductors exist, but they only currently work at extremely cold temperatures.) As it did with Go, the algorithm would start by combining different inputs (in this case, the atomic composition of various materials and their associated qualities) until it discovered something humans had missed. [10]

Autonomous machines are extremely fast and efficient in addressing real-world tasks involving a surplus of data. These capabilities can be applied in small but important ways; for instance, improved collision avoidance for cars. The same principle applies to fleets of autonomous machines working to make an industrial site more safe and predictable, drones planting trees together while surveying the land for feasibility, and systems working on surveying, indexing, and cleaning the ocean.

We create the machines and set the initial aim, but the machines themselves have the unparalleled ability to process stores of data and make decisions based on patterns they find.

Intentional Innovation

In our Technology Landscape for Innovation white paper, we discuss a number of autonomous systems and a few of the seemingly infinite number of use cases across industries.[11] It's a virtually endless frontier:

- **Autonomous Things** are devices that can function as a part of an interrelated system and carry out the same tasks as people. Examples include self-driving cars, capable of operating without the possibility of human error, or self-navigating drones that can aid with dangerous tasks like disaster relief and scientific exploration in environments that were once thought inaccessible.
- **Smart, machine learning-powered robots** collaborate with us, learn from their environment, and modify their actions accordingly. Consider surgical assistants operating as a part of an autonomous system in a medical facility, providing a deep understanding of a patient's needs by interpreting historical medical data, and giving additional layers of insight.
- **Artificial focused neural networks** are modeled on how human brains process information, and can eventually become auto-didactic, or self-teaching, without the need to be programmed. A use case would be automated medicine discovery, expediting the process of researching, developing, and testing new medicines. Operating as a part of an autonomous laboratory system, these networks could form hypotheses, run tests, analyze and record data, and assist scientists in pharmacological studies.

While autonomous systems can hunt for a solution, we need human effort to leverage expert wisdom into pointing those systems in the right direction. That's where human ingenuity is essential.

Enhanced Safety

The ability for autonomous systems to make decisions quickly leads to greater levels of safety in workplaces and everyday life. Systems can make sense of disparate datasets in real-time, developing novel or predictive solutions in response. For example, an autonomous system can determine the likelihood of material loss or theft within a security monitoring use case. An autonomous, self-driving vehicle can calculate the required degree of brake depression to avoid a collision from in front and behind.

Safety is one of the biggest concerns in an industry like construction. Autonomous systems can be used to actively monitor the collaboration between people and machines, acting on early indicators to avoid accidents. Safety benefits have a massive range, from collision avoidance to optimized fleets working in tandem on site to decrease traffic.

Our charge as innovators is to provide machines with the data and opportunity to help us optimize for safety, but also to "set the aim" as suggested earlier. We have decades of wisdom and experience, and these systems have an opportunity to learn from us as well.

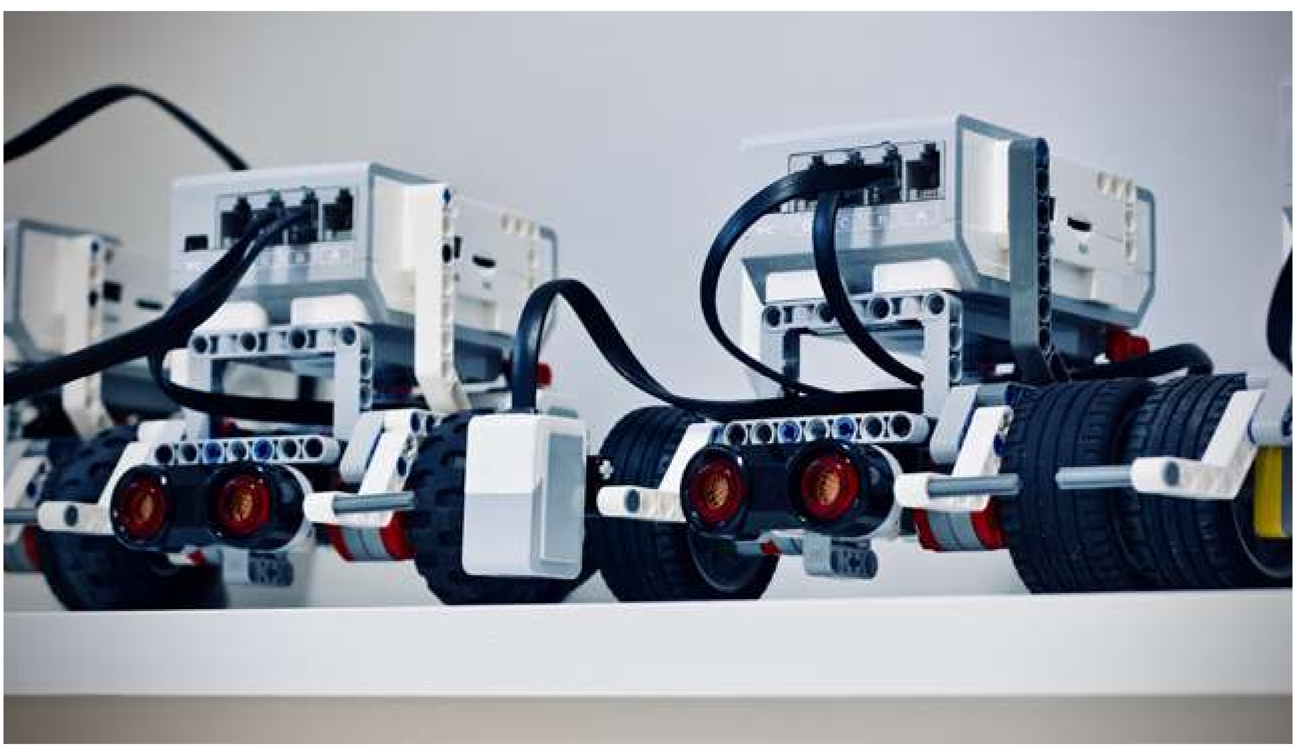


Image source: Unsplash

A Short History of Autonomous Systems

Historical evolutions of systems technology give us a sense of where things started and where they're going. The creation of more sophisticated autonomous systems has been the result of trial and error, using our experience to set intentional aims that benefit us and solve problems. To be successful, autonomous systems will need to continue to focus on connectivity, with other systems and humans involved directly or indirectly in their operation.

Power Grid

ML is a great fit for managing complex parts of power generation and delivery systems, including the addition of renewables, as they all require strategic, tactical, and technical decisions at a regional scale, often in real-time:

"Smart grid" technologies are made possible by two-way communication technologies, control systems, and computer processing. These advanced technologies include advanced sensors known as Phasor Measurement Units (PMUs) that allow operators to assess grid stability, advanced digital meters that give consumers better information and automatically report outages, relays that sense and recover from faults in the substation automatically, automated feeder switches that re-route power around problems, and batteries that store excess energy and make it available later to the grid to meet customer demand. [12]

Voice Systems

Phone system technology has evolved substantially, with voice recognition being one of the most significant gains. Earlier digital phone system technology has grown into **sophisticated voice recognition in automated systems**:

Thanks to ongoing data collection projects and cloud-based processing, many larger speech recognition systems no longer struggle with accents. They have, in a way, undergone a series of "brain transplants" that have improved their ability to "hear" a wider variety of words, languages, and accents. [13]

This is a prime example of an autonomous system. AI analyzes, filters, and digitizes language, using complex algorithms to process the vast amount of data and provide, in some cases, technology that can recognize speech patterns with the **same degree of sophistication** as human beings.[14]

Healthcare

Robotics in surgical applications were at one time automated, requiring involved operation. Not only has surgery become more automated, but prescribing has as well, with real-time interaction monitoring and diagnostic decision-making support.

The bionics of today also represent advances in the field of prosthetics, integrating various autonomous systems:

A bionic leg provides a replacement of the missed limb leveraging sophisticated technology that emulates real limb movement and interfaces with the body capturing electrical signals arriving at the muscles on the stump and in today's most sophisticated bionic leg, by providing electrical stimulus that can be interpreted by the brain as sensations. A computer inside the bionic leg analyzes signals from the body and from sensors in the prosthetic leg and recreates the appropriate movement to match the normal movement of that person. The goal is to have bionic prosthetics that can seamlessly integrate with the body. [15]

The goal of seamless integration will necessitate incorporating machine learning and teaching so that the limb can self-optimize, reacting to the body and the owner's needs in real-time. You can find an extremely detailed survey of autonomous systems in **Future Healthcare Journal's The Potential for Artificial Intelligence in Healthcare**.[16]

Construction

The construction industry has myriad possibilities for automation. While in the past, manual operators have faced decision-making challenges around working in suboptimal weather conditions and preserving site resources, autonomous systems can identify new operational tactics for resource savings, all while operating safely alongside human co-workers.

Khari Johnson notes the advantages of self-deploying drones in **Robots, AI, and the road to a fully autonomous construction industry**:

Drones that can deploy automatically from a box are being developed for a variety of applications, from fire safety to security to power line inspection. Drones hovering above a construction site can track project progress and could eventually play a role in orchestrating the movement of people, robotic equipment, and heavy machinery. [17]

Manufacturing

Autonomous assembly line robots can work together – as a symbiotic ecosystem of cobots – to handle different volumes of goods based on changes in output, human team support, available supply chain material, and other historically manual tasks. Automated alternatives include assembly lines with simple, six-axis robots that don't collaborate, or "talk." Any changes in their rote behavior require input from a human operator.

A **partnership** between Ford VOME (Vehicle Operation Manufacturing Engineering), Dürr Assembly Products, and KUKA illustrates the value of an automated process for adjusting vehicle fog lights:

Two KUKA LBR iiwa cobots are already in use in four headlight/driver assistance system test stands for the Ford Focus C519 at the Ford plant in Saarlouis. There are several advantages to using this automated system. First are the aforementioned benefits of reduce strain on human workers from an ergonomically-unfriendly task and improving the quality of the fog light adjustments.

The automated system also creates valuable time savings for the entire light adjustment process. While the foglight on one side is being adjusted by the KUKA LBR iiwa cobot, a human is simultaneously adjusting the main headlight on the other side of the vehicle. [18]

The system has automated elements – cobots reduce their level of force by using servo controls to detect contours – but applying more self-teaching systems will help boost efficiency to even greater degrees.

A Promising Outlook for Innovation and Acceptance

The history of autonomous systems has allowed us to build to our current heights, but we're only just beginning to see what the future holds. For a detailed outlook, explore **Loup Ventures' Robotics Outlook 2025**. [19]

Where We're Going & How We'll Get There

The current developments in autonomous systems span a wide range of focus areas, from the technical rigor of purpose-built AI hardware to the human-driven design of products and interfaces. Tackling the major challenges ahead will require widespread collaboration and a consistently evolving vision of an autonomous world across industries and disciplines.

Existing Platforms

New technologies like machine learning are iteratively driving advances in the underlying platforms that enable their progress. In the near future, product and usability breakthroughs will be critical to advancing autonomous adoption in the real world. The following is a brief look at the current contributors driving towards a more integrated autonomous future.

IBM – Watson:

IBM was an early provider of AI-based solutions through their consulting services and platforms like Watson. While these applications are often targeted at large-scale corporate optimization, IBM has focused on generalizing the power of Watson and AI, especially with advances in Natural Language Processing, which can provide easy interaction through normal conversation.

"With Watson, you can create better, more personalized experiences for customers, scale the expertise of your best people across the organization, and make smarter decisions based on deep insights from data." [20]

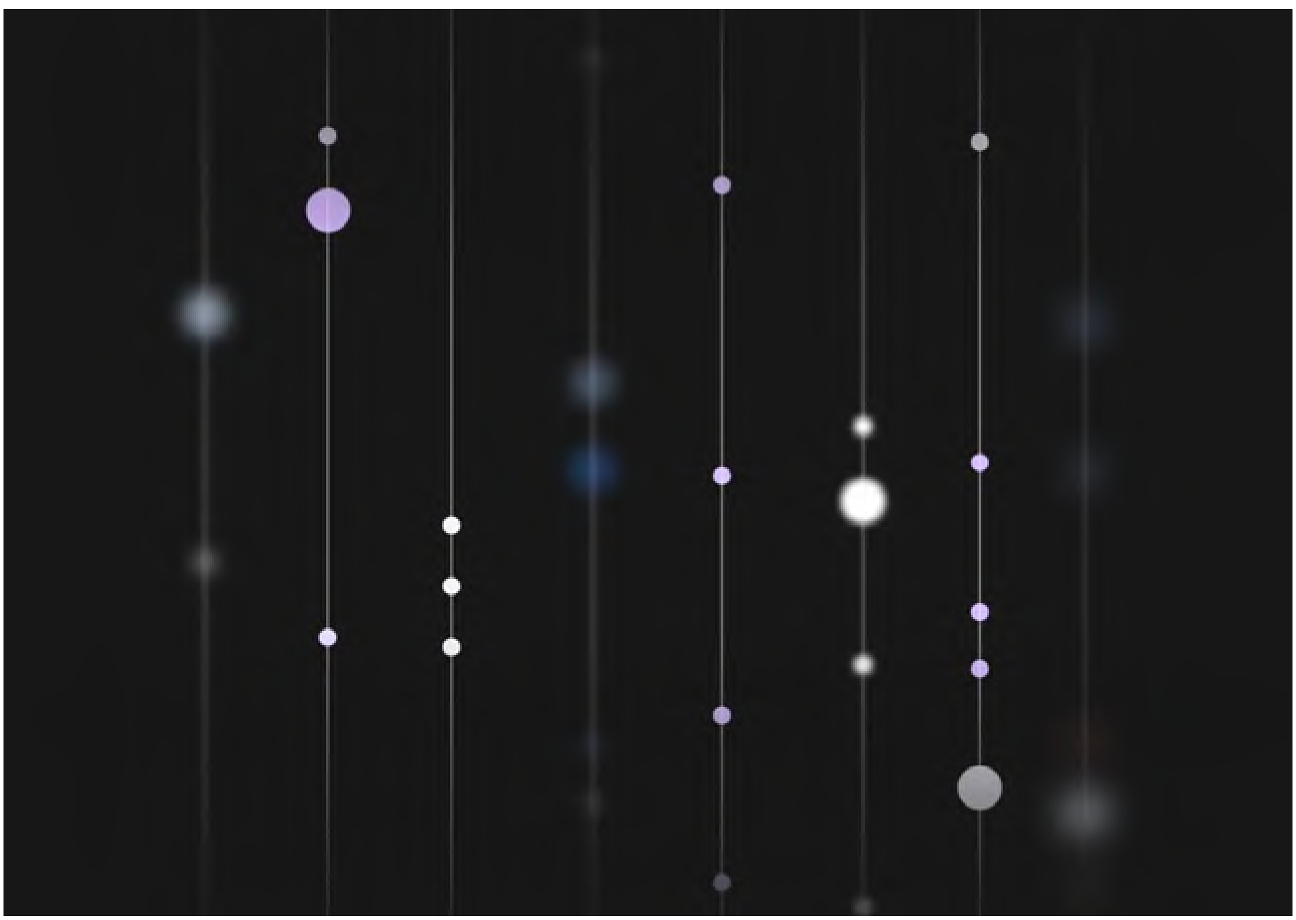


Image source: IBM

OpenAI – GPT-2:

OpenAI is one of the prominent companies driving the direction and development of artificial intelligence, focused on providing platforms and libraries to empower development across academia, industries, and applications. Their GPT-2 toolkit spurred a series of massive language-focused AI models, as well as a major ethical debate over AI's inevitable ability to interact with humans in an invisible way. [22]

"GPT-2 is a large transformer-based language model with 1.5 billion parameters, trained on a dataset of 8 million web pages. GPT-2 is trained with a simple objective: predict the next word, given all of the previous words within some text." [21]

Image source: OpenAi

Microsoft/OpenAI– AI Supercomputer:

Many cloud computing providers have created AI-focused platforms, with a growing set of tools that enable non-data scientists to quickly apply machine learning to their work. The Microsoft partnership with OpenAI represents a move toward this goal, matching the necessary cloud computing power with tools for developers across application areas to create novel and intelligent models for existing systems. [24]

"Microsoft has built one of the top five publicly disclosed supercomputers in the world, making new infrastructure available in Azure to train extremely large artificial intelligence models. Built in collaboration with and exclusively for OpenAI, ...it represents a key milestone in a partnership announced last year to jointly create new supercomputing technologies in Azure." [23]

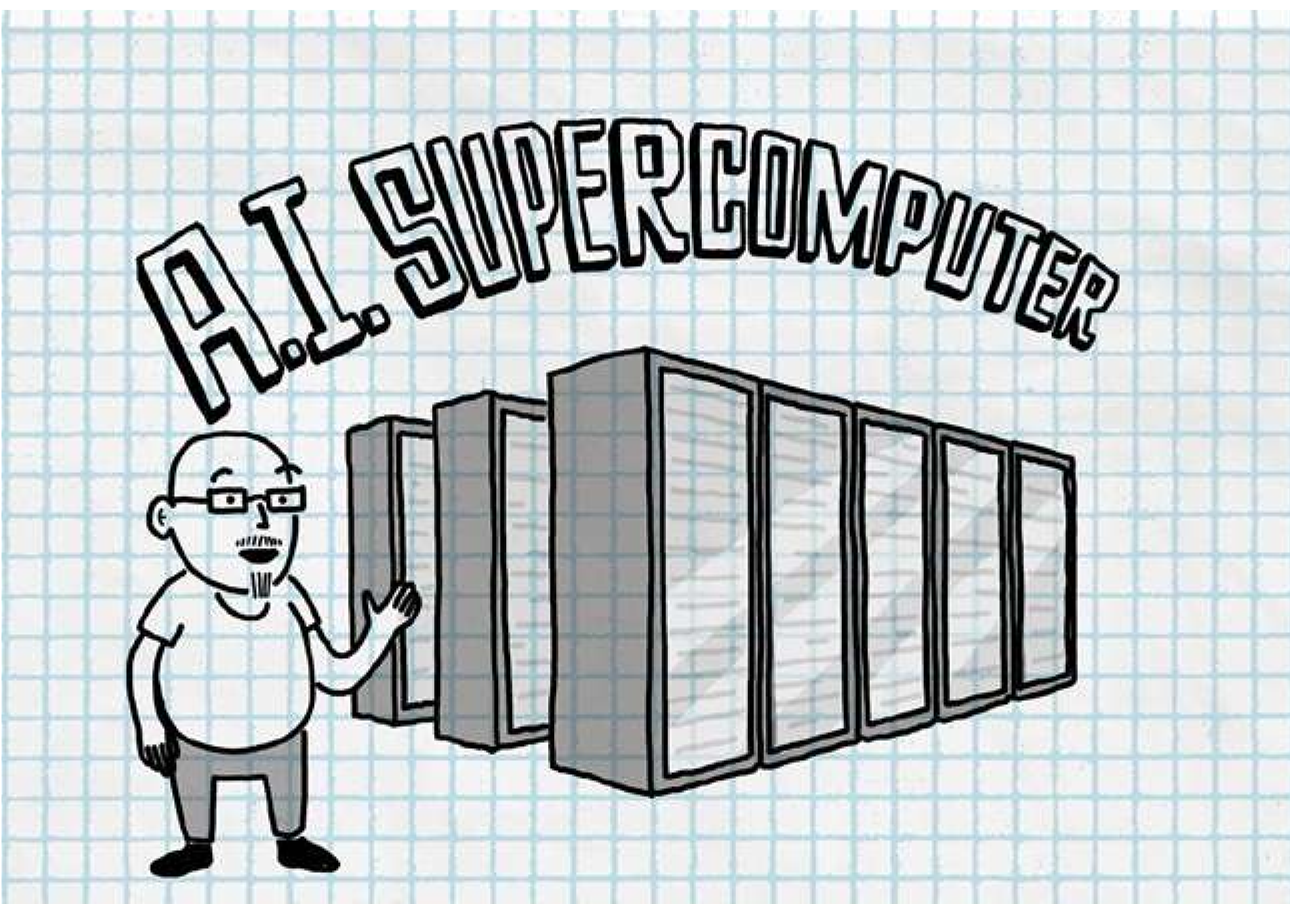


Image source: Microsoft

Microsoft – Project Bonsai:

Microsoft Project Bonsai is an AI platform that speeds the creation of intelligent decision support and industrial controls. Through leading AI training techniques and simplified authoring experiences, experts in control systems and processes can enable autonomous decision making or train AI agents to work alongside people. This helps experts scale their industry expertise while confidently deploying and managing explainable solutions. From wind turbine optimization to continuous machine calibration, these next-generation control systems inspire transformative innovation and produce significant improvements in throughput, efficiency, and quality.

"Microsoft's machine teaching service to create and optimize intelligence for industrial control systems... With Project Bonsai subject matter experts can innovate their most dynamic physical systems and processes without needing a background in AI." [25]

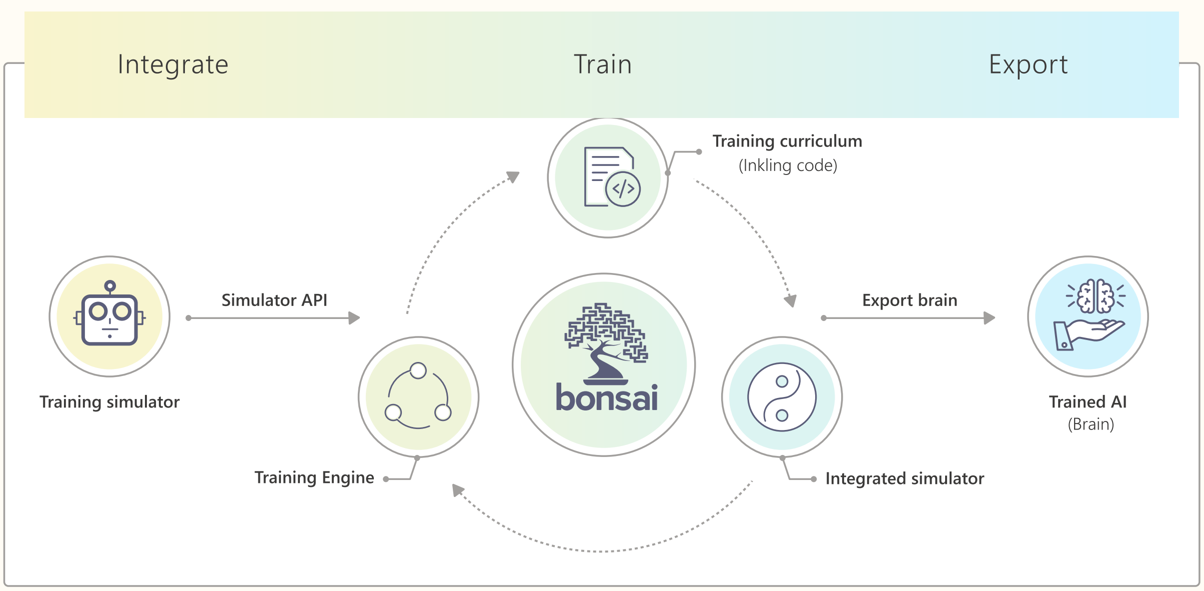


Image source: Microsoft

Microsoft – Project Moab:

As a hardware complement to Project Bonsai, Microsoft's Project Moab brings an approachable platform to developers new to the AI space. While the system itself is simple, Project Moab represents the open opportunity to add intelligence to systems in a way that humans can easily understand and manage.

"A new open-source balancing robot to help engineers and developers learn how to build real-world autonomous control systems with Project Bonsai. Customers can 3D print the robot, and availability for purchase will be announced later in [2020]. [26]

Image source: Microsoft

Amazon – Amazon Scout:

On the human-centric end of the technology spectrum, Amazon's Scout robots and future Prime Air drones can bridge the most difficult gap in the transportation industry: the last mile. Autonomous systems that can carry out complex missions in a world full of humans will help transform our cityscapes, driving visible automation far beyond manufacturing and e-commerce.

"A new, fully-electric delivery system – Amazon Scout – designed to safely get packages to customers using autonomous delivery devices. These devices were created by Amazon, are the size of a small cooler, and roll along sidewalks at a walking pace." [27]

Image source: Amazon

NASA Intelligent Systems – Autonomous Systems and Robotics:

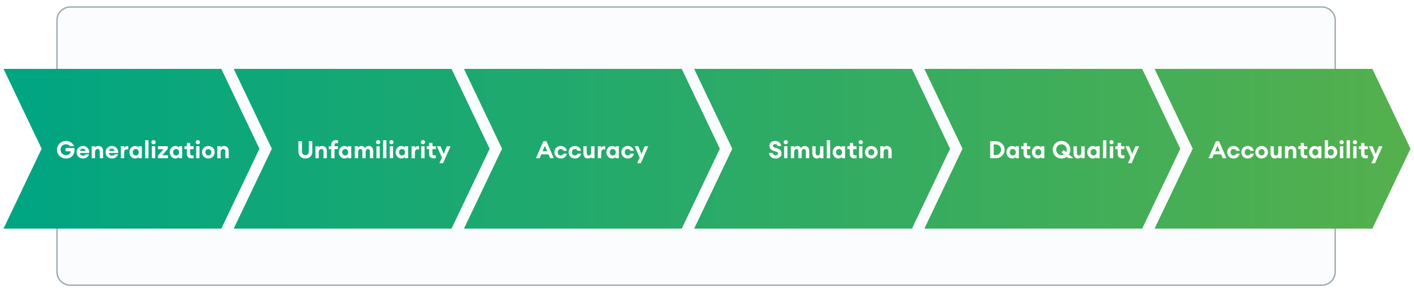
For decades, NASA has tackled challenges by innovating at the edge of human ingenuity and technology, and their efforts to pioneer autonomous systems are no different. The NASA Intelligent Systems division has researched and tested a number of autonomous system implementations, including the efficient interaction of humans with machine learning models during flight operations.

"As NASA prepares for unprecedented missions, our spacecraft, space habitats, aircraft, planetary and space exploration platforms, and operations are becoming progressively more complex. To sustain these future complex systems, the Autonomous Systems and Robotics (ASR) technical area is making critical advancements in novel system architectures, algorithms, and software tools." [28]

Image source: Margaux Olverd

What's Holding Us Back

While there have been many promising advances, autonomous systems are still far from reaching widespread adoption, in both implementation and acceptance. Below are six examples of the many challenges we must overcome to make autonomous systems an integral part of the industrial and consumer world.



Generalization

Autonomous system generalization – that is, transitioning use cases to commercial settings – is still in development. Simpler options used in automation limit the scope of control, increasing safety but reducing the impact of technology. While automated systems can perform defined tasks efficiently, humans are still more adaptable to even small changes in tasks or goals.

Unfamiliarity

Autonomous systems have not reached human performance in dealing with unfamiliar situations. Experts often leverage complex experience and outside knowledge to make decisions, many of which are hard to program, train, or anticipate in the breadth needed for safe autonomous systems. Leveraging outside knowledge, something that humans and other natural systems do, is still far on the horizon for integrated artificial intelligence.

However, something natural like the swarm behavior of honeybees has a great deal to teach us about how to make artificial intelligence better at performing in unfamiliar situations.[29] Through a collection of actors, honeybee swarms create solutions that can be observed, reshaped, and reused by human experts. Translating these lessons onto a collection of autonomous actors is the challenging next step to making systems truly adaptable.

Transfer learning enables ML agents to apply trained behavior to new concepts or situations, but there have only been limited examples applied to hardware. [30]

Accuracy

Consider an autonomous system application in healthcare. Applying deep learning to cancer detection has shown high accuracy in some trials, but these are often dependent on specific conditions.

Google research models can make an accurate prediction based on a single image but do not comb through the hundreds of other images that would be examined by human experts, or accurately rate blurred or out-of-focus images.[31]

Deep learning and other technologies underlying autonomous systems require careful vetting and validation, which will continue to improve accuracy but take significant expert time.

Simulation

While evolving technology allows us to get closer and closer to a digital copy of the real world, there will always be differences. Physical autonomous systems will continue to need real-world experience and training to become effective, which can often be expensive, time-consuming, or impossible due to safety.

Simulators are now starting to implement autonomous features of their own. Rather than a digital world handcrafted by human designers or procedurally generated based on fixed rules, simulators learn from other smart systems. Computer vision powered by machine learning can provide granular details of an environment, exploring and adding to a simulator while coupled with a physical autonomous vehicle.

Machine learning control can also be applied to simulation elements, providing more realistic examples of behavior like human movement or advanced control responses. But the critical limitations of simulated behavior aren't yet fully understood, creating the need for more exploration and efficiency.

Data Quality

Data is available, but it isn't always usable. Similar to the challenges in simulation, applying machine learning to real-world situations requires massive amounts of data not typically collected for other applications. Thus, the creation of autonomous systems powered by machine learning necessitates the collection of unique data.

A promising advancement is companies pursuing synthetic data development, which will enable complex models to train on smaller data sets and improve their capabilities.[32] This effort to reduce the need for data mirrors a similar trend towards lower compute times for machine learning model training.

Accountability

With legitimate concerns about safety and a general fear of change, accountable AI is essential.[33] Some AI researchers express concerns about the flaws of burgeoning fields like deep learning, which will only be assuaged by continued research, testing, and validation.[34]

Unexplainable operation and vulnerability to errors or interference, in both data preparation and deployment, creates risks that are amplified by the consequences of hardware around humans. But combinations of automation – different types of systems – plus more humans in the loop can be used to mitigate these issues. We can use collaborative intelligence as a method of gaining widespread acceptance and implementation.[35]

Human Design Considerations

Just as the principles of human-centered design have influenced the creation of products that aid rather than inhibit us, a similarly codified approach must be used to create autonomous systems that augment and empower us, rather than stand in opposition. Here are five principles we believe are worth starting with, though the conversation should continue and evolve as more professionals enter the space and provide perspective based on their own experiences.

Preserve Human Autonomy

Machines and systems will become autonomous, but we should always maintain an emphasis on our own autonomy as well. As Creative, productive, social, and innovative creatures, we believe that any technology should aid our continued development and evolution, rather than forcing our species to be something it's not.

View AI as a Tool, Not an Equal

Stanford's Human-Centered Artificial Intelligence provides a noble vision for autonomous systems design: AI as a tool.[36] We believe that humans should still direct the intent of machines, working in tandem. An approach where systems that self-optimize are "amenable to human feedback" is the ideal, and with the great minds working in this field, it's entirely possible. Recommender systems, which provide the most relevant information to make a decision, will be a key component in this effort. [37]

Prioritize Ethics

AI and the hardware that powers it has reached a level where learning is happening fast. While machines can learn new use cases and better performance, they need humans to teach them about concepts outside their limited point of view, skills they would not otherwise comprehend. Common sense ethics are easy for us to understand but less simple for machines.[38] It's imperative that AI researchers and engineers make this a part of their practice.

Intelligent systems are constantly improving at learning *how* to interact with the world. But humans are central to answering the question *"Why?"*

Foster Safety and Transparency

Safety and transparency are also important to consider.[39] Only by proving that the systems we create are advantageous to our species – and are capable of co-existing in a meaningful way – will we achieve true mainstream acceptance.

With something like self-driving cars, **humans are still integral to the process**, even though significant advances have been made.[40] Neither the technology nor its public perception is mature enough to become a forgettable part of everyday life. But by providing studies and publishing research written in the common vernacular that everyday people can understand, acceptance is more likely.

Build Trust

Autonomous systems will continue to play an active role in our lives, making decisions that affect humans in countless physical and emotional ways. In order to create true collaboration and symbiosis, these systems must earn trust. As autonomous systems increase in everyday visibility, **humans need to be able to trust them.**[41]

Systems will need to favor predictability and gradual learning over pure performance. Humans build interpersonal relationships because we can generally understand why we behave the way we do. And though in many cases a machine's behavior is even more predictable, a deep level of general machine understanding must be created, especially as machines advance in sophistication.

Creating Tomorrow, Intentionally

In computer-aided design, there's a concept called **design intent**: "*a method that defines relationships between objects, so that a change to one propagates automatically to others*."[40] When it comes to the creation of autonomous systems, one of the most prevalent fears is that artificial intelligence will somehow get away from us, acting in unpredictable, disadvantageous ways. While it changes and evolves automatically, we don't, and will be left behind.

The fears that people have are real and should be addressed, but if the ideas explored in this paper continue to be discussed, deliberated, and expanded upon, then the creation of autonomous systems will happen with reasonable caution in mind. We're at the precipice of a unique opportunity to shape Industry 4.0, making gains once thought impossible and empowering people to live more fulfilled lives and be more present and engaged in their work.

At Fresh, we believe wholeheartedly that artificial intelligence is not adversarial, and that to help people understand that, we need to preserve human autonomy, use AI as a tool, prioritize ethics, create safe, transparent practices, and earn trust. The work begins with honest conversations about what autonomous systems are, respecting that we're still learning about the underlying technology as it grows in sophistication.

Just as designers exercise intent with CAD, we should also prioritize understanding the relationship between humans, systems, and machines, so that when something changes, other actors are aware and can respond intentionally, making the field, ideally, more human.

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