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# Pervasive intelligence

Smart machines everywhere

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Everything is getting smarter, as new AI technology empowers an ever-widening range of devices to learn from experiences, adapt to changing situations, and predict outcomes. Companies are already exploring opportunities.

**A**DVANCES IN ARTIFICIAL intelligence (AI) software and hardware are giving rise to a multitude of smart devices that can recognize and react to sights, sounds, and other patterns—and do not require a persistent connection to the cloud. These smart devices, from robots to cameras to medical devices, could well unlock greater efficiency and effectiveness at organizations that adopt them. That’s only part of the story. In some industries, they may also change how profits are divided.

- Chip manufacturers are increasingly embedding support for AI directly into devices<sup>2</sup>
- AI chips are being developed that can perform complex computations but consume minute amounts of power in some cases, measured in microwatts<sup>3</sup>
- Machines with embedded AI are beginning to appear in many industries, including logistics, manufacturing, agriculture, transportation, and health care
- Annual shipments of devices with embedded AI are projected to increase from 79 million last year to 1.2 billion in 2023<sup>4</sup>



## Advanced hardware is propelling AI out of the data center

Advances in software and hardware are propelling AI outside of the data center into devices and machines we use in our work and our everyday lives.

Processors designed to execute machine learning algorithms efficiently while using minimal power—essential for use in mobile devices—are already coming to market.<sup>5</sup> And dozens of companies working on new generations of AI chips—for use both in and outside of data centers—are attracting significant investment. These companies raised more than US\$1.5 billion in funding last year, nearly twice the amount they raised the year before.<sup>6</sup>

The innovation in AI chips is impressive. For instance, MIT researchers unveiled a chip earlier this year that can perform inference using neural network computations three to seven times faster than previous chips, and with up to 95 percent less power consumption. Performance such as this makes these chips suitable for running algorithms

## Signals

- AI software providers are tailoring their AI models and algorithms for deployment on machines and devices outside the data center<sup>1</sup>

directly on low-power Internet of Things (IoT) devices such as sensors.<sup>7</sup>

AI chips are already beginning to appear in smartphones and other devices in large numbers: Deloitte predicts there will be more than half a billion mobile chips running machine learning on smartphones, tablets, and other devices in 2018.<sup>8</sup> And continued innovation in AI hardware and software will lead to a growing number of devices and machines with built-in AI capabilities.<sup>9</sup> One research study predicts that 43 percent of all AI inference (or analysis) globally will occur at the edge—meaning outside of data centers, on machines and devices—by 2023, up from just 6 percent last year.<sup>10</sup>

All this is to say that AI is not just getting better—it is becoming more pervasive. As new generations of hardware and software endow all manner of both consumer and enterprise devices, appliances, machines, and other equipment with AI capabilities, we are poised to enter an era of *pervasive intelligence*.<sup>11</sup>

## From connected to pervasive

The era of pervasive intelligence will be marked by a proliferation of AI-powered smart devices able to recognize and react to sights, sounds, and other patterns. Increasingly, machines will learn from experiences, adapt to changing situations, and predict outcomes. Some will infer users' needs and desires and even collaborate with other devices by exchanging information, distributing tasks, and coordinating their actions.

With AI embedded, rather than confined solely to the cloud, the intelligence in these devices will not depend on internet connectivity. And they will not suffer the latency entailed by transmitting data to the cloud for analysis. Lower latency and connectivity independence will enable all kinds of applications—such as vehicle navigation and augmented reality and some health care applications—that require instantaneous response and robust performance even when connectivity is poor or not available.

## PERVASIVE INTELLIGENCE TAKING ROOT ACROSS INDUSTRIES

A wide range of industries will likely benefit from the arrival of smart devices. The examples cited below—most still in development or in pilot offer a glimpse of how pervasive intelligence may well reshape not only company operations but, in some cases, industry dynamics.<sup>12</sup>

**Manufacturing.** Robots are increasingly being equipped with sensors and AI, dramatically boosting their utility on the factory floor by allowing them to work safely alongside humans.<sup>13</sup> Early iterations of this new generation of collaborative robots or *cobots* relied primarily on cloud-hosted intelligence, but chipmakers and robotics companies are partnering to embed intelligence in computing resources on the factory floor or in robots themselves.<sup>14</sup> This could allow robots on the assembly line to calculate the motion of their arms over a thousand times faster or respond immediately to disruptive events, such as taking up the task of another robot that fails in order to keep production running and prevent downtime.<sup>15</sup>

Manufacturers could also benefit from leveraging on-site intelligence for other equipment. Smart valves tapping AI algorithms on nearby gateway devices can help reduce chemical leakages and costly downtime.<sup>16</sup>

**Health care.** Intelligent medical devices with embedded AI could change how health care is delivered and promise to cut costs and enhance patient well-being. Trials have shown, for instance, that AI-powered implants for epilepsy patients significantly reduced the frequency of seizures.<sup>17</sup> Similar implants that can sense and avert impending negative health events could deliver remote monitoring and treatments, along with cost savings in patient care.

**Construction.** Real-time monitoring of progress at construction sites with drones and smart cameras could prevent project delays and cut material waste, estimated at US\$160 billion annually.<sup>18</sup> One startup that makes AI-powered autonomous construction-site inspection vehicles claims that its system helped improve productivity by 38 percent

and helped a project come in 11 percent under budget.<sup>19</sup>

**Logistics and distribution.** Intelligent robots are cutting costs and increasing speed and efficiency in the logistics domain. A system of smart warehouse robots, leveraging a combination of AI hosted in the cloud and in on-site micro data centers, can communicate with each other to jointly tackle order-fulfillment assignments, slashing picking times for online grocery orders from hours down to minutes.<sup>20</sup>

**Automotive/transportation.** Autonomous vehicles, perhaps the most prominent example of machines with embedded intelligence, are expected eventually to reshape the transportation sector by offering a cheaper alternative to traditional car ownership through on-demand ride services. They could also make parking lots, traffic jams, and gas stations disappear, while upending traditional business models for auto insurers, logistics providers, and other companies.<sup>21</sup>

**Agriculture.** Robotic herbicide sprayers equipped with cameras and computer vision allow precise application of herbicide to weeds only, cutting the use of herbicide and associated costs for some farmers by up to 90 percent compared to prevailing methods.<sup>22</sup>

**Energy.** Networked wind turbines outfitted with sensors and tapping algorithms deployed on-premises at a wind farm can share information about changing wind conditions and make real-time adjustments to their speed and blade and rotor angle, allowing each individual turbine to maximize its power generation based on changing conditions and the actions of neighboring turbines. This could increase their collective output by as much as 4 to 8 percent while minimizing wear and tear.<sup>23</sup>

**Security.** Smart security cameras with embedded AI “will be able to know your name, what you’re holding, or that you’ve been loitering for exactly 17.5 minutes,” in the words of one journalist, making it possible to alert companies or law enforcement of suspicious activity in real time.<sup>24</sup>

## Strategic implications

Smart devices have the potential to help companies achieve new levels of efficiency and effectiveness: automating processes, cutting materials waste, reducing cost, and increasing output. But the impact of the age of pervasive intelligence goes beyond faster, better, and cheaper. Smart machines may well help expand existing markets, threaten incumbents, and shift how profits are divided. We explore each of these possibilities below.

### EXPANDING MARKETS

By cutting costs and increasing efficiency, smart machines may help expand certain markets. The adoption of the aforementioned warehouse picking robots, for instance, could help expand the online grocery market. Faster order fulfillment and delivery can help reduce the wait times that some cite

#### SWARM INTELLIGENCE

The examples of smart warehouse robots that work together to pick orders and smart wind turbines that collaborate to maximize power generation both demonstrate how distributed systems of connected, intelligent devices can cooperate to achieve greater speed and efficiency. In an example from the public sector, a system of smart traffic lights with embedded AI delivered a 25 percent reduction in travel times and a 40 percent reduction in idling times during a test pilot in Pittsburgh.<sup>25</sup> The lights make decisions based on traffic volumes at their individual intersections and then relay those decisions to nearby traffic lights, which then incorporate that information into their own decision-making. While these types of coordinated and decentralized systems are still mostly in early development, startups are working on similar systems for managing crop fields,<sup>26</sup> inspecting infrastructure,<sup>27</sup> and maintain physical security.<sup>28</sup>

as a top reason why consumers don't buy groceries online.<sup>29</sup> Smart wind turbines that work collaboratively (see sidebar, "Swarm intelligence") help operators simultaneously cut costs and increase output. In many geographies, they have increased demand for wind energy by helping to make wind price-competitive with more traditional energy sources.<sup>30</sup> Smart surveillance cameras that can automatically analyze and act on what they see may expand the market for surveillance cameras to uses in which people are unavailable to monitor the resulting video footage.

## THREATENING INCUMBENTS

Product companies of all kinds may face competition from new entrants offering smart alternatives. Makers of traditional surveillance cameras, herbicide spraying equipment, and industrial valves, for instance, could see demand for their products shift toward smarter alternatives; they would be wise to consider adding smart options to their product lineup. While development and adoption of many smart devices may take time, incumbents must prepare for a tipping point when smart products could render traditional ones obsolete. Automakers are preparing for this shift by developing their own autonomous vehicles and technologies through partnerships and acquisitions.<sup>31</sup> Incumbents in other sectors should similarly explore partnerships and acquisitions with an eye toward introducing embedded AI into their product lines.

## SHIFTING REVENUES

Smart devices could lead to shifts in how revenue and profits are apportioned among industry players. Many industry experts expect that the advent of autonomous ride-hailing services will drive down vehicle ownership, shifting revenue from carmakers to autonomous fleet operators.<sup>32</sup> Other industries could see similar transformational shifts driven by the speed and efficiency of intelligent machines. The robotic herbicide sprayers mentioned above could drastically cut farmers' herbicide usage, shrinking

the US\$28 billion herbicide market, and could similarly dampen demand for other chemicals like fertilizer, a US\$150 billion global market.<sup>33</sup> Health care providers could see similar value shifts caused by AI-equipped medical devices such as the epilepsy implant cited earlier. Health care spending in this case could shift from emergency-room visits to devices and implant procedures, with technology potentially saving patients and insurers tens of thousands of dollars in annual emergency care costs per patient.<sup>34</sup>

## Implications for business and technology leaders

The era of pervasive intelligence will present professionals in a variety of roles with opportunities and challenges.

*Operations professionals* may need to consider how to select, integrate, and employ smart products to gain greater speed and efficiency for their organizations.

*Product marketers* may need to plan new generations of products with embedded intelligence. Smartphone manufacturers are already beginning to enhance their products with embedded AI capabilities, such as image or speech recognition, that don't rely on network connectivity to the cloud. One newly released smartphone, for instance, can turn users into better photographers by automatically capturing many images in rapid succession and recommending the best of them.<sup>35</sup> These devices will be able to offer new experiences like augmented and virtual reality and provide greater levels of personalization based on self-learning users' preferences. Gartner forecasts that 80 percent of smartphones shipped in 2022 will have embedded AI to enable these types of enhancements, up from 10 percent last year.<sup>36</sup>

*Market strategists* will need to understand how intelligent devices could change the dynamics in their industry. Where embedded intelligence can

yield improved products or better service delivery, companies should strive to identify how to capture greater value from expanding markets or product differentiation. Makers of inputs like pesticides or construction materials will need to consider how to hedge against declining demand for those goods if customers adopt smarter processes that use those inputs more efficiently.

Strategists should also consider how pervasive intelligence can create opportunities for new revenue sources and business models. Some telecom operators are already building computing infrastructure into their cellular base stations,<sup>37</sup> enabling them to provide services for analyzing data from nearby devices with AI or offer up that computing infrastructure itself as a managed service. Goods manufacturers can leverage the flexibility of collaborative robots to quickly produce and sell customized items for end consumers.<sup>38</sup> Media companies might benefit from on-device AI by offering premium services based on AI-powered, personalized recommendations or augmented reality.

*Risk leaders* will need to work with product marketers to analyze the potential risk implications of the proposed products, especially those deployed in sensitive settings such as cars, personal spaces, and

human bodies. In order for pervasive intelligence to deliver on its potential, risks around algorithm bias, decision accuracy and transparency, data privacy, and cybersecurity need to be identified, assessed, managed, and monitored through a combination of technical and operational measures. Ethics of pervasive intelligence applications should be considered as well, especially in circumstances where individuals' rights may be significantly affected.

## The coming era of pervasive intelligence

It will be several years before the pervasive intelligence trend has a significant impact on most industries. But as the examples above suggest, the impacts could ultimately be significant. Devices with embedded intelligence will eventually become ubiquitous in commercial settings and consumers' lives, enabling entirely new levels of performance and efficiency. Companies should begin now to game out the potential impact of pervasive intelligence on their business and their industry to position themselves to reap the benefits.

## Endnotes

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