Hype Cycle for Emerging Technologies, 2018

Published: 6 August 2018 **ID:** G00340159

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Our 2018 Hype Cycle reveals five emerging technology trends that profoundly shift experiences in our spaces, blur the lines between human and machine, and enable AI ubiquity that will propel organizations to connect into new business ecosystems to become competitive over the next decade.

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What You Need to Know

This document was revised on 16 August 2018. The document you are viewing is the corrected version. For more information, see the Corrections page on gartner.com.

As a technology leader, you will continue to be faced with rapidly accelerating technology innovation that will profoundly impact the way you deal with your workforces, customers and partners. The trends exposed by these emerging technologies are poised to be the next most important priorities of your executive teams.

To survive and thrive in the digital economy, CIOs, CTOs and other technology innovation leaders who are focused on driving business transformation must leverage this research to stay abreast of the emerging technologies landscape. Leading organizations are encouraged to leverage this Hype Cycle to understand what are the must-watch emerging technologies in the market, their maturity and what to expect from the technologies' expectations, along with the impact and value potential. These successful organizations are able to create new models for competitive advantage, identify new sources of revenue, create mitigation plans to overcome legal and regulatory hurdles, and reduce operating costs.

This year, five trends stand out (in alphabetical order):

- Democratized artificial intelligence (AI)
- Digitalized ecosystems
- Do-it-yourself biohacking
- Transparently immersive experiences
- Ubiquitous infrastructure

Business and technical decision makers who are focused on business transformation must consider the rapid advancements in technology innovation, and must evaluate these technologies and trends to assess the impact potential (value and risk) and strategic relevance on their businesses. In addition to the potential impact on businesses, these trends provide a significant opportunity for business and technology leaders to help senior executives respond to the digital business opportunities and threats by creating fit-for-purpose educational materials and ideation workshops that will guide investment decisions.

The Hype Cycle

The Hype Cycle for Emerging Technologies is unique among most Gartner Hype Cycles because it distills insights from more than 2,000 technologies that Gartner profiles into a succinct set of must-know emerging technologies and trends. This Hype Cycle specifically focuses on the set of technologies that is showing promise in delivering a high degree of competitive advantage to organizations over the next five to 10 years.

Emerging Technologies Trends

The emerging technologies on the 2018 Hype Cycle reveal five distinct trends that profoundly create new experiences, with unrivaled intelligence, and offer platforms that allow organizations to connect with new business ecosystems.

To find immediate actions and hone the long-term vision for your organization, CIOs, CTOs, enterprise architects, technology innovation leaders and other IT leaders should track the five emerging technology trends:

- **Democratized AI.** Along with being the most disruptive class of technologies, AI technologies will be virtually everywhere over the next 10 years. While these technologies will enable early adopters to adapt to new situations and solve problems that no one has ever encountered previously, we will also see these technologies available to the masses or democratized. Cloud computing, open source and a growing "maker" community further propel AI into everyone's hands. Although it is early, CIOs and IT leaders should encourage developers to experiment with AI developer toolkits and AI PaaS, as well as plan developers' upskilling to get this contingent ready for its new role in AI strategies.

  Enterprises that are seeking leverage in this theme should consider the following technologies: AI PaaS, artificial general intelligence, autonomous driving Level 4, autonomous driving Level 5, autonomous mobile robots, conversational AI platform, deep neural nets, flying autonomous vehicles, smart robots and virtual assistants.

- **Digitalized ecosystems.** Emerging technologies require revolutionizing the enabling foundations that provide the volume of data needed, advanced compute power and ubiquity-enabling ecosystems. The shift from compartmentalized technical infrastructure to ecosystem-enabling platforms is laying the foundations for entirely new business models that are forming the bridge between humans and technology. Within these dynamic ecosystems, organizations must proactively understand and redefine their strategy to create platform-based business models, and to exploit internal and external algorithms in order to generate value.

  Key platform-enabling technologies to track include: blockchain, blockchain for data security, digital twin, IoT platform and knowledge graphs.

- **Do-it-yourself biohacking.** Over the next decade, humanity will begin its "transhuman" era, where biology can be hacked, depending on one's lifestyle interests and health needs. Biohacking falls into four categories: technology augmentation, nutrigenomics, experimental biology and grinder biohacking. However, questions remain about how far society is prepared to accept these kinds of applications and what ethical issues they create.

Extending humans will wildly vary in scope and power, from simple diagnostics to neural implants. Emerging technologies to watch include: biochips, biotech — cultured or artificial tissue, brain-computer interface, exoskeletons, augmented reality, mixed reality, and smart fabrics.

- **Transparently immersive experiences.** Technology has and will continue to become more human-centric to the point where it will introduce transparency between people, businesses and things. These technologies extend and enable smarter living, work and other spaces we encounter.

  Critical technologies to be considered include: 4D printing, connected home, edge AI, self-healing system technology, silicon anode batteries, smart dust, smart workspace and volumetric displays.

- **Ubiquitous Infrastructure.** Infrastructure is no longer in the way of obtaining an organization's goals. The advent and mass popularity of cloud computing and the many variations have enabled an always-on, available and limitless infrastructure compute environment. These emerging technologies are the key to enabling this future.

  The emerging technologies to track includes: 5G, carbon nanotube, deep neural network ASICs, neuromorphic hardware and quantum computing.

Major Hype Cycle Changes

Understanding the new emerging technologies that are being introduced on the Hype Cycle for the first time in 2018 provides business and technology leaders with the leading indicators of what technology trends will be strategic in the decade. This year, we introduce the following new technologies to the Hype Cycle for Emerging Technologies:

- **AI PaaS —** This new innovation profile shows how the AI PaaS hype is heating up, with the leading cloud service providers' competition using AI PaaS as a lure to their clouds and as a tool to attract developers and data scientists.

- **Autonomous driving Level 4 —** While this innovation profile is new to our emerging technologies Hype Cycle, it did take on another form in previous years as "autonomous vehicles." For this year, we felt that there is enough of a difference to separate out the various level of autonomy to properly reflect the market movement and set reasonable expectations of the technologies.

- **Autonomous driving Level 5 —** While this innovation profile is new to our emerging technologies Hype Cycle, it did take on another form in previous years as "autonomous vehicles." For this year, we felt that there is enough of a difference to separate out the various level of autonomy to properly reflect the market movement and set reasonable expectations of the technologies.

- **Autonomous mobile robots —** This innovation profile was added given how next-generation AMRs are poised to transform warehouse operations over the coming decades, as these truly become more autonomous and intelligent.

- .**Biochips —** While the current market growth is limited due to regulations, high costs and complexity, we see a long-term cross-industry impact due to the many different applications across the board.
- **Biotech — cultured or artificial tissue —** We see enormous potential in this technology being used in the future in soft robots or artificial muscle for more complex robots, medicine, medical treatment, welfare equipment, military, toys and smart structures. Biotechnology is still at the lab development stage and at least 10 years away.
- .**Blockchain for data security —** Blockchain-enabled data security applications offer alternative methods to establish trust and resiliency with minimal reliance on centralized arbiters, and track digital assets.
- **Carbon nanotube —** This technology has the potential for a huge impact, particularly when silicon devices reach their minimum size limits, as it offers the promise of low electrical resistance that can be applied to the interconnections within integrated circuits. Individual nanotubes can be readily fabricated, but problems remain with their interconnection and the fabrication of arrays of transistors.
- **Conversational AI platform —** This new innovation profile is on many corporate agendas, spurred by the worldwide success of Amazon Alexa, Google Assistant and others represented by virtual-assistant-enabled wireless speakers at the pinnacle.
- **Deep neural network ASICs —** This innovation profile was added due to the significant benefits of DNN ASICs in performance and energy consumption when accelerating neural networks.
- **Edge AI —** This technology has been identified and profiled for the first time this year by Gartner. Gartner profiles this new edge device AI model, which solves challenges around latency issues, enhancing security, addressing privacy issues and improving the customer experience.
- **Exoskeletons —** This technology has been profiled based on the need to become more specific and decompose human augmentation into exoskeletons and other supporting technologies, rather than a broad category of technologies. Exoskeletons have been the bulk of market adoption for human augmentation technology.
- **Flying autonomous vehicles —** The development of flying autonomous vehicles is accelerating rapidly, with prototypes already available and real-world product launches projected for as early as this year.
- **Knowledge graphs —** This technology has been identified and profiled for the first time this year by Gartner. Gartner finds that organizations can expect significant value from knowledge graphs in many areas such as: reporting, interoperability, collaboration/sharing, audits and data reuse.
- **Mixed reality —** These solutions are poised to enable businesses to bridge their physical and real worlds with virtual and digital ones using sophisticated multichannel and multimodal human-centered visual experiences. Mixed reality could be the immersive solution that will provide the ultimate user experience for everyone.

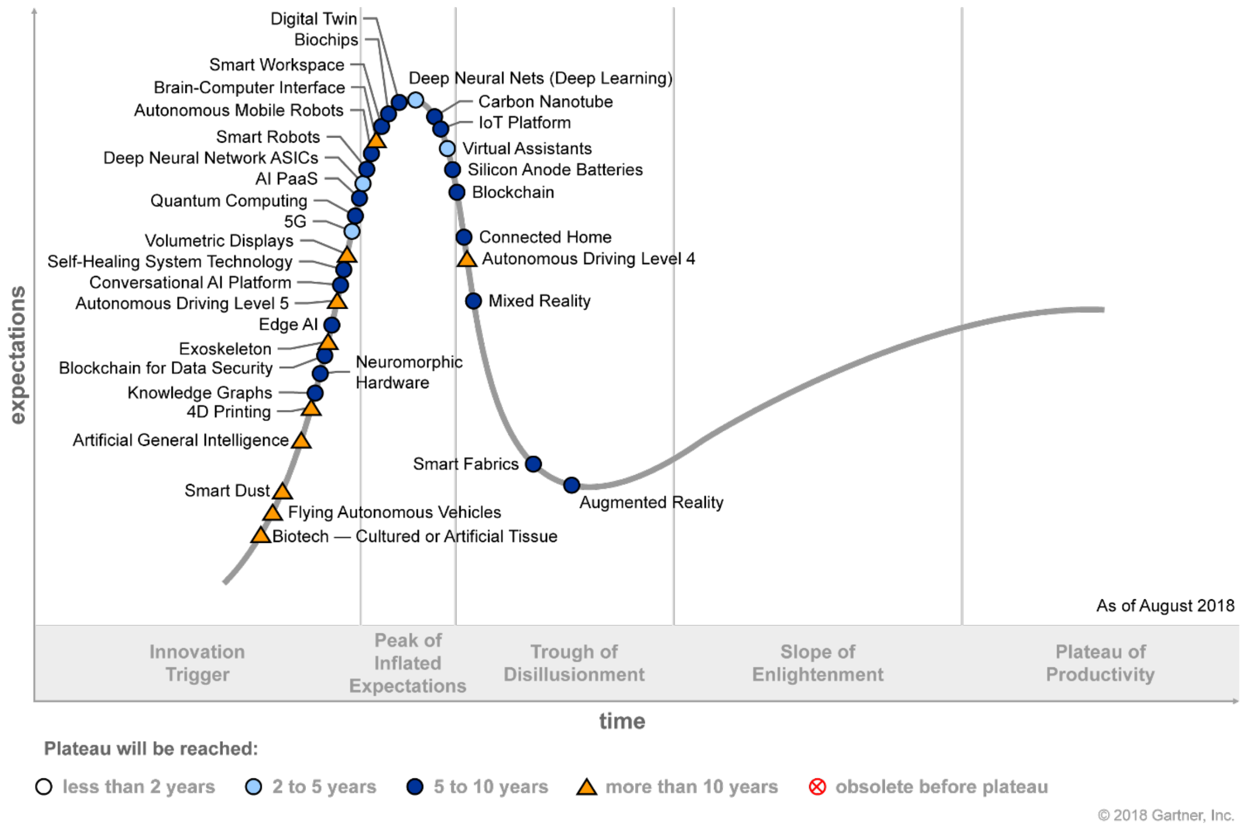
- **Self-healing system technology —** Emerging SHS technology includes print platforms and connected home solutions. We expect to see accelerating adoption of this technology as it becomes more widely leveraged by providers, and users in the enterprise and consumer markets.
- **Silicon anode batteries —** This technology could increase the energy density of batteries from three to 10 times than current battery technology. This could provide a significant volume and weight savings, and a longer operating lifetime.
- **Smart fabrics —** Smart fabric technology continues to improve with developments in sensor miniaturization and integrations with fabric. Technological advances allow new types of smart fabric every day. While many of the current products are still in testing, we expect use cases of smart fabric to extend beyond sports, professional athletes, healthcare and personal care to wider industries, including automobiles, manufacturing, military, emergency services and engineering.

In addition, technology innovation leaders should play close attention to the technologies that have moved forward along the Hype Cycle since 2017:

- **Brain-computer interface —** Brain-computer interfaces are maturating due to gains made in large commercial-scale deployments, VR headsets natively embedding the technology, a richer vendor landscape and leveraging AI technologies.
- **Connected home —** Adoption of computer vision, multimodal sensors and AI techniques is delivering intelligent, autonomous experiences to the connected home. However, the advancement is somewhat sluggish and not at the speed consumers and technology vendors would like to see.
- **Digital twin —** The emergence, adoption and hype around digital twins continues to grow. With widespread confusion about how to exploit the business value of digital twins in IoT and digital business initiatives, leaders must temper their expectations.
- **IoT platform —** As companies continue to add IoT capabilities to their products, many large vendors are responding to market demand by evolving their IoT business offerings and market strategy.
- **Quantum computing —** Quantum computers are still in the very early stages, but advancing steadily. The technology continues to attract significant funding, and a great deal of research is underway at many university and corporate labs.
- **Smart dust —** Gartner believes smart dust (also called neural dust) will have a transformational benefit, so should be tracked within innovation teams. Tracking should look at both smart dust research activity and the trajectories of the associated technologies within industry.
- **Smart workspace —** Adoption rates vary, based on organizations' requirements to support flexible work models that optimize the physical and interactive aspects of places and things to create a work environment that allows employees to intelligently interact with their physical surroundings.

- **Virtual assistants —** Advancements in technical capability and availability over the past year has enabled much greater traction within the enterprise and the home alike. With VAs expanding in scope and capability, they are becoming a key part of the workforce by reducing operational costs through automation of high-volume, low-complexity tasks.

Figure 1. Hype Cycle for Emerging Technologies, 2018



Source: Gartner (August 2018)

The Priority Matrix

Emerging technologies are disruptive by nature, but the competitive advantage they provide is not yet well-known or proved in the market. Most will take more than five to 10 years to reach the Plateau of Productivity. These examples illustrate the impact of key emerging technologies in the near term and the longer term.

Figure 2. Priority Matrix for Emerging Technologies, 2018

Priority Matrix for Emerging Technologies, 2018

benefit	years to mainstream adoption: less than 2 years	2 to 5 years	5 to 10 years	more than 10 years
transformational		**Deep Neural Nets (Deep Learning)** **Virtual Assistants**	Autonomous Mobile Robots Blockchain Carbon Nanotube Conversational AI Platform Digital Twin Edge AI Neuromorphic Hardware Smart Workspace	4D Printing Artificial General Intelligence Autonomous Driving Level 4 Autonomous Driving Level 5 Biotech — Cultured or Artificial Tissue Brain-Computer Interface Smart Dust
high		5G Deep Neural Network ASICs	AI PaaS Augmented Reality Biochips Blockchain for Data Security Connected Home IoT Platform Knowledge Graphs Mixed Reality Quantum Computing Self-Healing System Technology Silicon Anode Batteries Smart Fabrics Smart Robots	
moderate				Exoskeleton Flying Autonomous Vehicles Volumetric Displays
low				

As of August 2018

ID: 340159

Source: Gartner (August 2018)

Off the Hype Cycle

Because this Hype Cycle pulls from such a broad spectrum of topics, many technologies are featured in a specific year because of their relative visibility, but are not tracked over a longer period of time. This is not intended to imply that they are unimportant — quite the opposite. In many cases, these technologies are no longer "emerging," but rather are becoming more integral to business and IT (such as big data and cloud computing). In other cases, technologies have been removed from the Hype Cycle in order to highlight other new emerging technologies.

Technology planners can refer to Gartner's broader collection of Hype Cycles for items of ongoing interest. Some of the technologies that appeared in the "Hype Cycle for Emerging Technologies, 2017," but do not appear in this year's report, are:

- **Autonomous vehicles —** This innovation profile covered a very broad range and we felt it wasn't specific enough. This was replaced with autonomous driving Level 4 and Level 5.
- **Cognitive computing —** We find that this innovation profile is still valid and there is high potential for the technology over the next few years; however, it's transformational impact over the next 10 years is in question.
- **Cognitive expert advisors —** This year's Hype Cycle does not include this technology because it is represented by higher-level concepts like virtual assistants.
- **Commercial UAVs (drones) —** This technology is rapidly approaching a much more mature state, which moves it off the emerging technology class of innovation profiles.
- **Conversational user interfaces —** This technology is rapidly approaching a much more mature state, which moves it off the emerging technology class of innovation profiles.
- **Deep reinforcement learning —** Reinforcement learning is a specific, narrow case — at least for now. Training a DNN model by providing real-time feedback requires a huge number of iterations. Furthermore, it has only been demonstrated for cases with a single outcome to iteratively optimize for, and it inherits all current limitations of DNNs in general, including narrowness, lack of transparency and delivering probabilistic (not deterministic) results — that is, it can make errors.
- **Edge computing —** While there are very interesting things happening in this space, we find that this technology is shifting to an edge AI model, where it's not just about providing solutions at the edge, but also enabling them with intelligence at the edge.
- **Enterprise taxonomy and ontology management —** This technology is rapidly approaching a much more mature state, which moves it off the emerging technology class of innovation profiles.
- **Human augmentation —** Human augmentation has now morphed into exoskeletons, where the bulk of market adoption for this technology has been.
- **Machine learning —** This technology is rapidly approaching a much more mature state, which moves it off the emerging technology class of innovation profiles.
- **Serverless PaaS —** This technology is rapidly approaching a much more mature state, which moves it off the emerging technology class of innovation profiles.
- **Software-defined security —** This technology is rapidly approaching a much more mature state, which moves it off the emerging technology class of innovation profiles.

- **Virtual reality —** This technology is rapidly approaching a much more mature state, which moves it off the emerging technology class of innovation profiles.

Even though these profiled technologies were removed from the emerging technologies Hype Cycle, it doesn't mean that they are not going to have a high or transformative impact on your organization — quite the contrary. However, this Hype Cycle identifies the 30 to 40 technologies poised to have the most impact over the next decade, with less of a focus over the next three years. Every year, this will evolve to give clients the latest market movements and technology shifts. Given this long view of trends, expect that this Hype Cycle could change materially every year.

On the Rise

Biotech — Cultured or Artificial Tissue

Analysis By: Annette Jump

Definition: Biotech or biorobotics is artificial/cultured biologically inspired tissue, muscles or robots that could emulate some human response due to external stimulators, like current, pressure, temperature or voltage. Biotech tends to have greater mobility, flexibility and often can include some sensory abilities.

Position and Adoption Speed Justification: Biotechnology is still at the lab development stage. It is based on multiple streams of knowledge such as mechanical engineering, electronics, bioengineering and information engineering, and positioned at the cross-section between robotics, neural engineering and medicine. Biotechnology includes a variety of different future applications and could be used to make biologically inspired robots or highly advanced prosthetics as well as medical treatments. In robot arena, some research is being focused around developing artificially sensing skin, others on artificial muscles. Artificial sensing skin, via tactile sensors, will be able to detect pressure as contact is made with an object. This can help robots sense objects around them. Artificial muscle (often called actuator) is often used in soft robots, but it tends to respond slowly and is difficult to store. Recent research in Harvard University had a breakthrough in developing a dielectric elastomer with a broad range of motion that requires relatively low voltage and no rigid components. That could help address two main technical challenges in biotech, as many current robots rely on conventional electromagnetic rotary motors.

Ultimately, if it will be possible to grow skin and tissue over the robot exterior, then technology will achieve what soft robotics has been about since its conception. In addition, tissue could be grown to simulate muscles that might be used in propulsion of the robot and, in the case of nanobots and microsized robots, insect biology could be mimicked.

However, there is a lot of caution and skepticism about how quickly biotech and artificial muscle will develop in the new few years. The biggest challenge in this technology innovation is around electroactive polymers that enable creation of actuators.

User Advice: We are at least 10 years away from robots playing a part in our society. Therefore, for companies interested in biotech, it is worth getting in touch with specific universities and research labs to learn more about this technology and identify potential future usage scenarios.

Business Impact: This technology is still in very early development, but it could potentially be used in future in soft robots or artificial muscle for more complex robots, medicine, medical treatment, welfare equipment, military, toys and smart structures.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Recommended Reading: "Forecast: Internet of Things — Endpoints and Associated Services, Worldwide, 2017"

"Top 10 AI and Sensing Technology Capabilities for Personal Assistant Robots in 2020"

Flying Autonomous Vehicles

Analysis By: Michael Ramsey

Definition: Flying autonomous vehicles encompass self-operating aircraft that sometimes are referred to as "flying cars" or personal drones and are designed to operate without a human pilot either in the vehicle or remotely operating. These vehicles could include commercial delivery drones as well as air taxi services. They are distinguished by their ability to complete complex decision making in addition to handling normal vehicle operations as an "autopilot" function might do in a standard aircraft.

Position and Adoption Speed Justification: More than a dozen companies are working on new aircraft that are piloted by artificial intelligence and designed to create a more agile, less expensive and quicker way to execute air travel, primarily in congested areas. The goals of the projects include:

- Faster travel in densely populated areas
- Speedy delivery of goods and services in a three-dimensional context
- Economical air travel over short distances
- Logistics too difficult to reach, rural locations with poor infrastructure

The ambitions around these vehicles have primarily expressed themselves in the form of advanced air taxis that would fly over congested megacities, reducing transit time. There are efforts underway by companies such as Airbus and Uber Technologies to develop self-flying vehicles. In most cases, the designs are multiple rotor, vertical takeoff and landing devices. They are similar in capability to traditional helicopters, but look similar to much smaller drones.

While the prospect of direct flights over congested areas is tantalizing, these vehicles face significant challenges to implementation. The technology is not currently validated by federal authorities and ensuring safety of such a system could take years. In addition, regulations are such that distances of a mile or more may be required between the vehicles over urban areas, limiting the usefulness. In addition, infrastructure in cities is not currently available for landing areas to accommodate large numbers of vehicles. Finally, most versions of the vehicles are battery-powered, limiting their range significantly when compared with standard helicopters. All that said, the prospect of fast, economical and, ideally, safe flight point to point in urban areas is certain to attract significant interest and investment.

User Advice: For CIOs in organizations dependent on transportation and logistics, add these vehicles to the long-term technologies that may need to be obtained or used in your processes. While it may be decades before these vehicles proliferate, they are nearly certain to grace the skies at some point. Assess what problems in logistics, both human and parts, might be solved by using these vehicles. Consider how systems might need to be altered internally to allow for use of the vehicles.

Business Impact: The business impact of flying autonomous vehicles is likely to be moderate for most companies, though it could be quite high in a limited set of businesses around mobility services and logistics. For instance, if Amazon can use autonomous drones for package delivery at scale, it could reduce its costs and speed up delivery of packages. For most people, these vehicles will be an extra convenience, and not the primary way they will travel. In the end, they are mostly going to be the equivalent of robot-piloted helicopters, which lowers the cost and perhaps increases the availability of a service that already exists. It is likely that special use cases in remote areas or difficult topography will lead to much faster adoption on a regional or special use basis, as helicopters already serve locations like this in special circumstances.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Airbus; Lilium; Terrafugia; Uber; Volocopter

Recommended Reading: "Changing Drone Regulations Are a Major Market Opportunity for Technology and Service Providers"

"Maverick* Research: Flying Autonomous Vehicles — The Next Big Thing That Isn't"

Smart Dust

Analysis By: George Brocklehurst

Definition: Smart dust is composed of self-contained sensing systems called motes, targeting the size of a grain of sand, about 1 cubic millimeter. These systems have the capability to sense, compute, communicate and power their own activities. They are used to support a distributed sensing network, such as temperature, pressure and environmental sensing, potentially using mesh to achieve communication coverage.

Position and Adoption Speed Justification: Due to the aspired size of these motes, the two key challenges are power and communication. Self-powering motes using energy harvesting will be key in reaching the full potential of smart dust, but available space will limit the energy that can be recovered. Similarly, wireless communications face transmission range challenges due to available space for antennas. Technologies exist with the potential to solve these issues, but will require considerable time and investment to adapt to smart dust scale.

The University of Michigan has developed various cubic-millimeter computers, "micro-motes." In 2017, the researchers demonstrated a breakthrough 20-meter wireless communication range in a 9-cubic-millimeter mote. They are working to increase embedded memory to process AI algorithms. Meanwhile, in 2017, researchers at the University of California, Berkeley presented neural dust, a greatly simplified mote design for surgical implants, making use of an ultrasonic transducer for both communication and energy harvesting. Among other medical applications, the research provides avenues toward brain-computer interface technologies.

Recent activities in commercialization include Intel Capital funding in 2016 for CubeWorks, spun out from the University of Michigan. Also in 2016, MonoLets, led by a member of the original smart dust research team, was spun out from the University of California, Berkeley.

User Advice:

- Research into smart dust should be viewed as a vehicle for innovations that will also benefit other market activities. Near-term return on investment will come from commercialization of these innovations, including transfer to the somewhat larger IoT endpoint technologies.
- Smart dust is embryonic and should be tracked within innovation teams. Tracking should look at both smart dust research activity and trajectories of the associated technologies within industry.
- Lead adopters should invest in equity stakes in university commercialization efforts. Early successes and adjacent commercialization opportunities will be enabled by hardware innovations where IP protection will create barriers.
- Smart dust is only one piece of the puzzle. Consideration must be given to the complexity of low-latency mass data processing. This, in itself, will generate new use cases for the application of AI and associated technologies.
- Alongside the technological advances, interested parties should consider the legal, ethical, security and privacy challenges of this type of technology. Factors that have presented significant resistance to adoption of the IoT are orders of magnitude greater for smart dust.

Business Impact: The potential benefits of smart dust are wide-ranging, compelling and transformational. The concept of this technology transitions the Internet of Things into the Internet of Everything, which carries profound implications for the architecture of collecting, processing and interpreting data. A world with widespread adoption of smart dust will require radical innovations in all the systems that would convert captured data into some useful action. A further generational step, with innovations such as neural dust, will transform the way humans interact with their surroundings, emerging initially through medical advancements, such as prosthetic control, and then into broader possibilities.

In the medium term, the breakthroughs from pursuing this research will also have high impact and will help the IoT to meet its potential for lowering cost and power while increasing local processing and endpoint intelligence.

Equal to smart dust's transformational potential are its legal, ethical, security and privacy ramifications.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: CubeWorks; HP Inc.; MonoLets; University of California (Berkeley); University of Michigan

Artificial General Intelligence

Analysis By: Tom Austin

Definition: Artificial general intelligence (AGI) — also known as "strong AI" and "general-purpose machine intelligence" — would handle a very broad range of use cases, if it existed. It does not, though it is a popular subject of science fiction. Current AI technologies do not deliver AGI. Despite appearing to have human-like powers of learning, reasoning and adapting, they lack commonsense, intelligence, and extensive means of self-maintenance and reproduction. Special-purpose AI — "weak AI" — does exist, but only for specific, narrow use cases.

Position and Adoption Speed Justification: Tangible progress on AI has been limited to weak AI. AGI's position and adoption speed on this Hype Cycle therefore remain unchanged. (We changed this entry's name from "general-purpose machine intelligence" in 2017 to reflect the popularity of the term "AGI.")

Today's AI technology cannot be proven to possess the equivalent of human intelligence (the lack of agreement about a test to prove such intelligence is itself a problem). It may, at some point, be possible to build a machine that approximates human cognitive capabilities, but we are likely decades away from completing the necessary research and engineering.

The subject of AGI often arises in discussions of "cognitive computing" — a term that means different things to different people. For some it denotes a set of AI capabilities, for others a specialized type of hardware (as in neuromorphic or other highly parallel, short propagation path processors). It can also describe the use of information and communication technology to enhance human cognition, which is how Gartner uses the term.

User Advice: Focus on business results enabled by applications that exploit special-purpose AI technologies, both leading-edge and older.

Leading-edge AI is enabling what are currently considered "amazing innovations," including deep-learning tools and related natural-language processing capabilities. These innovations are doing what we previously thought technology could not do. They are, however, typically research tools that are only just emerging from research labs, undergoing turbulent changes in direction, and not fully understood in terms of engineering principles. Over time, we will learn their limitations and develop workable engineering guidelines. As the amazement wears off and ennui sets in, we will treat them as "aging innovations."

Look for business results enabled by applications that exploit aging innovations (including expert systems and other symbolic AI approaches, as well as simpler forms of machine learning), amazing innovations (typically more powerful but less understood technologies), or both. Examples of such applications include autonomous means of transportation, smart advisors and virtual assistants focused on various goals (such as improved wealth management) and responsibilities (such as sales or budget management). Most use both amazing and aging innovations.

Special-purpose AI will have a huge and disruptive impact on business and personal life. End-user organizations should ignore AGI, however, until researchers and advocates demonstrate significant progress. Until then, ignore any suppliers' claims that their offerings have AGI or artificial human intelligence — these are generally illusions created by programmers.

Business Impact: AGI is unlikely to emerge in the next 10 years, although research will continue. When it does finally appear, it will probably be the result of a combination of many special-purpose AI technologies. Its benefits are likely to be enormous. But some of the economic, social and political implications will be disruptive — and probably not all positive.

There are currently no vendors of systems that exhibit AGI, but many companies are engaged in basic research. Examples are DeepMind (owned by Google), OpenAI and Vicarious.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Recommended Reading: "Smart Machines See Major Breakthroughs After Decades of Failure"

"How to Define and Use Smart Machine Terms Effectively"

4D Printing

Analysis By: Michael Shanler; Miriam Burt

Definition: Four dimensional printing (4DP) is a technique where the materials are encoded with a dynamic capability — either function, confirmation or properties — that can change via the application of chemicals, electronics, particulates or nanomaterials. The printing technology has extra functionality to sequence, mix and place specific materials that will have a calculated effect.

Position and Adoption Speed Justification: 4DP is an emerging technology that remains in the embryonic stage. This technology adds another dimension to the 3D printing process by creating an object designed to change shape after it leaves the print bed. The concept of this "shape shifting" technology was triggered a few years ago and is being developed through collaborative efforts between academia and technology firms.

While 4DP is on the radar for technologists, smart materials have actually been around for several decades. Recent scientific advancements in biology, chemistry, electronics and 3D printing will accelerate the discipline. Over the next few years, 4DP research will generate interest and hype.

Challenges persist with bringing precision to objects' transformations. Material science research for 3DP is still an underserved market. Software is still a niche for both nanoscale and human-scale programmable materials with self-assembly characteristics. Modeling the geometries, determining interactions for changing states and calculating the energy (from heat, shaking, pneumatics, gravity, magnetics and so on) is no easy task. Software vendors are just beginning to get interested.

Over 2017-2018, advances in the newest frontier of 4DP to grow tissues and organs in a laboratory setting have pushed this technology up the hype curve. These include:

- Harvard team's method to print transformable tissue engineering scaffolds to support cell growth.
- Wake Forest Institute of Regenerative Medicine printing 3D-printed structures made of living cells that could replace human tissue, where the scaffolds change shape over time.
- NASA has leveraged 4DP to print "space chain mail."
- Singapore Centre for 3D Printing and the Swiss Federal Institute of Technology in Zurich are addressing the durability of 4D printed parts and their predictability as it relates to load-bearing.
- Concordia University published findings on manufacturing curved composite pieces more quickly and economically than 3DP.
- Morphing Matter Lab at Carnegie Mellon has also evolved fused-filament fabrication (FFF) "Thermorph" research on self-folding materials and interfaces.

Academic and industrial labs are investigating pattern-driven 4D-printing, fiber architectures, hydro-reactive polymers/hydrogels, cellulose composites, thermos-reactive polymers/hydrogels, and a variety of "digital" stress-relaxation techniques. For this reason, the technology will not be in the mainstream for another 10 years.

User Advice: 4DP offers not only tremendous opportunities for designers as many new applications will arise. Smart materials will solve engineering problems, which often arise from the limitations of current materials.

Business and R&D IT leaders with science, technology and engineering responsibilities for new product innovation should explore the business and technical opportunities for 4D printing, and begin to educate peers on how 4D printing can add new functions. Building 4DP capabilities will initially present significant computer, scientific and engineering hurdles. Focus on strategic partnerships to advance the technique and develop proofs of concept.

Material science is a complicated space, and there are an immense number of scientific and formulation-based patents that may impact business cases. Explore relationships to further improve 4DP processes through R&D partnerships with material companies to develop and improve specifications for 4D-suitable materials. There are also opportunities for engaging via open innovation or consortium approaches.

Business Impact: 4DP, where using FFF or other modalities, is an opportunity to create future technology-based products that could disrupt your industry. Shape-shifting materials have already been leveraged in the automotive, aerospace, defense and medical industries. Dynamic and self-assembling materials have already begun to disrupt the way engineers think about designing components and delivering value.

Initially, the examples of "what's possible" will be technology-focused, but will have unclear revenue impacts:

- Shape-shifted materials that can reduce the drag coefficient of an airplane or vehicle during different environments might help optimize efficiency.
- The sole of an adaptive running shoe may adjust to wet versus dry pavements and improve grip.
- A self-assembling medical stent may reduce surgery times and improve patient outcomes.
- Implants will be able to change shape once they come into contact with body heat to conform with wound areas and lead to better surgical outcomes.
- A dynamic valve in an irrigation system could improve irrigation on a farm. A roof on a house could change form to facilitate draining, and walls could increase or decrease in thickness during the winter or summer to improve insulation values.

While 4DP POCs accelerate, don't be fooled by the growing hype. The technology is still in its infancy. However, now is the time for innovators to evaluate the possibilities the technology presents, to build into longer-term technology development roadmaps.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Autodesk; Geosyntec Consultants; HP Inc.; MIT; Stratasys

Recommended Reading: "The 2018 Top 8 Supply Chain Technology Trends You Can't Ignore"

"Toolkit: My Supply Chain Emerging Technologies"

Knowledge Graphs

Analysis By: Stephen Emmott; Svetlana Sicular; Alexander Linden

Definition: Knowledge graphs encode information ("knowledge") as data arranged in a network ("graph") of nodes and links ("edges") rather than tables of rows and columns. *Nodes* hold data or their labels; *edges* link nodes together, representing relationships between them. This results in sequences of "triples" — i.e., node-edge-node, or Mary-manages-John — which can accommodate, throughout the graph's life cycle, multiple and varied data schemas without the need for redesign. Once encoded, information can be recalled, or synthesized, in response to queries.

Position and Adoption Speed Justification: The rising role of content and context in delivering insights through the use of AI technologies has pulled knowledge graphs to prominence Google's Knowledge Graph and Microsoft Graph are examples of the knowledge graph's growing popularity due to its promise to enrich your data with missing data. Specialist vendors are offering graph-based products to new markets and well-known vendors are accommodating the technology in their platforms and products.

Knowledge graphs are ideally suited to storing data extracted from the analysis of unstructured sources, such as documents, using natural-language processing (NLP) and related text analysis techniques. They are also capable of storing structured data, including metadata that implicitly provides structure and context. For this reason, graphs enable the storage of data, the means to structure and contextualize this by building relationships within the data, and the ability to subject the information it encodes to processing in support of varied use cases.

User Advice: Application leaders should employ knowledge graphs to connect disparate concepts and enrich their data with missing information. Using graph analysis, organic and dynamic relationships between digital assets, data sources, processes, people and interactions can be discovered and exploited automatically. A key aspect in this respect is entity extraction, whereby entities — people, events, etc. — can be identified through analysis of unstructured data prior to ingestion, and subsequent disambiguation within the knowledge graph once contextualized.

Knowledge graphs silently accrue "smart data" — i.e., data that can be easily read and "understood" by AI systems. Although available as stand-alone products from niche vendors, the knowledge graphs' benefits are typically realized through the wider platforms and applications they service. Application leaders should evaluate how vendors apply knowledge graph concepts to determine how vendor solutions could benefit their digital business platform.

For example, Microsoft and Google embed knowledge graphs in their cloud office environments — Office 365 and G Suite respectively. By capturing signals from the usage of these environments, their graphs are able to ingest data about the use of applications, enabling working relationships between employees, as well as thematic connections between digital assets to be gathered. This supports collaboration and sharing, search and discovery, and the extraction of insights through analysis. Other platforms and applications — such as text analytics and insight engines — also include the underlying graph technology upon which to build knowledge graphs and enhance functionality. In contrast, stand-alone products are graph-based applications dedicated to the management of data using a graph-based approach in support of other products — see "Magic Quadrant for Data Management Solutions for Analytics," for an example.

Business Impact: Organizations can expect significant value from knowledge graphs in many areas, with the following being prominent:

- **Collaboration/sharing —** Interrelated data is contextualized data, thereby aiding its discovery and findability via implicit and indirect connections.
- **Investigation and audit —** With the capability to capture and disambiguate entities that map to entities in the real world, relationships can be explored to identify fraud, supply chain risks or patterns of collaboration.
- **Analysis/reporting —** Once structured in the form of a knowledge graph, unstructured data can be queried, thereby preprocessing it for analysis.
- **Interoperability and automation —** Autonomous reading and "understanding" of data supports integrating and operationalization of data for different enterprise applications.
- **Data reuse/cross-industry collaboration —** Being linked conceptually chunks data and metadata, which can be shared more easily and hence foster reuse.

However, it is too early to tell whether knowledge graphs will deliver on the broader promise.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Facebook; Google (Cloud Platform); Intelligent Views; Maana; Microsoft (Microsoft Graph); Mindbreeze; Neo4j; Semantic Web Company (PoolParty); TopQuadrant

Recommended Reading: "Magic Quadrant for Data Management Solutions for Analytics"

"Magic Quadrant for Insight Engines"

"Magic Quadrant for Operational Database Management Systems"

"Hype Cycle for Data Science and Machine Learning, 2017"

"Automate Knowledge Management With Data Science to Enable the Learning Organization"

"Digital Workplace Graphs Promise to Improve Productivity and Collaboration, but Risks Exist"

Neuromorphic Hardware

Analysis By: Chirag Dekate; Martin Reynolds

Definition: Neuromorphic hardware comprises semiconductor devices conceptually inspired by neurobiological architectures. Neuromorphic processors feature non-von-Neumann architectures and implement execution models that are dramatically different from traditional processors. They are characterized by simple processing elements, but very high interconnectivity.

Position and Adoption Speed Justification: Neuromorphic systems are at the very early prototype stage. IBM has delivered a TrueNorth-based system to Lawrence Livermore National Laboratory. BrainChip's Spiking Neuron Adaptive Processor technology and Hewlett Packard Enterprise's Labs Dot Product are other early entries, Intel's "Loihi" chip tackles a broader class of AI workloads: Loihi offers a higher degree of connectivity than competing implementations. Qualcomm, an early exponent of neuromorphic processors, has shifted its focus to conventional processors.

There are three major barriers to the deployment of neuromorphic hardware:

- GPUs are more accessible and easier to program than neuromorphic silicon.
- Knowledge gaps: Programming neuromorphic hardware will require new tools and training methodologies.
- Scalability: The complexity of interconnection challenges the ability of semiconductor manufacturers to create viable neuromorphic devices.

At the moment, these projects are not on the mainstream path for deep neural networks (DNNs), but that could change with a surprise breakthrough in programming techniques.

User Advice: Neuromorphic computing architectures can deliver extreme performance for use cases such as deep neural networks because they operate at very low power and are potentially capable of faster training than the GPU-based DNN systems deployed today. Furthermore, neuromorphic architectures can enable native support for graph analytics. Most of the neuromorphic architectures today are not ready for mainstream adoption. However, these architectures will become viable over the next five years, and will deliver new opportunities. I&O leaders can prepare for neuromorphic computing architectures by:

- Creating a roadmap plan by identifying key applications that could benefit from neuromorphic computing.
- Partnering with key industry leaders in neuromorphic computing to develop proof of concept projects.
- Identifying new skillsets that need to be nurtured for successful development of neuromorphic initiatives.

Business Impact: Neuromorphic hardware faces the largest barriers in advancing DNN, but also may unlock the most powerful results. There are likely to be major leaps forward in hardware in the next decade, if not from neuromorphic hardware, then from other radically new hardware designs.

Neuromorphic systems promise lower power, but will likely operate across smaller input sets. As such, they will likely first appear in edge devices, where they will process images and sound. These devices may also execute lower levels of a DNN at the edge, reducing bandwidth and central processing constraints.

We are in the midst of an extremely rapid evolution cycle, enabled by radically new hardware designs, suddenly practical DNN algorithms and huge amounts of big data used to train these systems. Neuromorphic devices have the potential to drive the reach of DNNs further to the edge of the network, and potentially accelerate key tasks such as image and sound recognition inside the network. They will require significant advances in architecture and implementation to compete with other DNN architectures.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: BrainChip; Hewlett Packard Enterprise; IBM; Intel; Micron

Recommended Reading: "Cool Vendors in Novel Semiconductors for Neural Networks, 2016"

"Market Guide for Compute Platforms"

"Three Elements of a Scalable Enterprise Machine Learning Infrastructure Strategy"

Blockchain for Data Security

Analysis By: David Anthony Mahdi; Jonathan Care

Definition: A blockchain is an expanding list of cryptographically signed, irrevocable transactional records shared by all participants in a network. Each record contains a time stamp and reference links to previous transactions. With this information, anyone with access rights can trace back a transactional event, at any point in its history, belonging to any participant. A blockchain is one architectural design of the broader concept of distributed ledgers.

Position and Adoption Speed Justification: Awareness is growing across academia, government and industry that blockchain has the potential to enhance a number of approaches to data security, and to disrupt others. In lieu of common standards, proven implementations and the choice between different blockchain technologies (such as bitcoin, Ethereum and Hyperledger), the market will take time to reach a steady state. Additionally, since blockchain-based solutions differ dramatically from legacy technology, paradigm shifts (and in some cases, political changes) may be required. The ramifications of this can vary dramatically. For many, the nontechnical aspects of blockchain will likely pose as a greater impediment to the adoption over technical implementation. However, development and innovation are increasing at a rapid pace, actively supported by financial institutions, government and industry. A growing number of data security applications are integrating blockchain technology into their architectures.

User Advice: To illustrate a blockchain-based approach to data security, one application is ensuring data integrity with a dataset. By storing a representation of the dataset (i.e., a hash) in the blockchain, all nodes will now be aware of the status. Any attempt to change the data will require consensus among the nodes. Therefore, any data logged in the blockchain becomes a part of the immutable decentralized ledger. Common data security approaches that may benefit from a blockchain-based approach, such as PKI, key management and tokenization, can all gain resilience, reliability, transparency and trust.

Data security leaders should familiarize themselves with blockchain through early stage research. One such approach is by following publicly known proofs of concept (see "Toolkit: Overview of Blockchain Use Cases"). In doing so, leaders can gain insight into new ideas and approaches that may be relevant. A number of new and well-established vendors are experimenting with data security applications in areas such as:

- Ensuring the integrity of data and/or devices (including things in the IoT)
- Data transparency (e.g., smart contracts or land registries)
- Mitigating trust issues (e.g., distributed/decentralized authority)

As the excitement around blockchain continues to build, data security leaders should expect that varying business units, executives and/or investors might encourage the business to consider using blockchain. Data security leaders should work with developers/architects to establish at least a high-level position on its relevance and a vision for the future adoption. Blockchain-based data security initiatives differ dramatically from legacy business technology and processes. Therefore, data security leaders should take a bimodal approach and experiment with blockchain-based initiatives as Mode 2 projects.

Business Impact: With the backing of a significant number of financial institutions and enterprises, development and innovation with blockchain continue at a rapid pace. One aspect being examined is how blockchain can be applied to a range of data security applications. An example is in securing and sharing public records, such as a land registry digital document. The traditional approach is to host the document in a central database maintained by a select number of administrators. This model potentially suffers from weaknesses with resilience and transparency. What is to stop a malicious actor from modifying the land registry? In contrast, if the document or a pointer to the document was stored in a blockchain, then availability, transparency and integrity are maintained via the distributed cryptographic nature of blockchain. Any change or attempt to change the document is evident and requires consensus among the nodes. Most importantly, all of these transactions are made public via the nature of blockchain. Similar to bitcoin, the blockchain, in theory, is not controlled by a central authority, thus providing transparency, community control and data integrity. While this is one specific example of ensuring data integrity, there are a number of other data security applications that stand to benefit from blockchain.

Blockchain has the potential to increase resilience, reliability, transparency and trust in a variety of common data security functions that hinge on centralization, such as PKI, key management and tokenization. Finally, due to the absence of meaningful regulation or standards, governance must be exercised to limit risk within organizational tolerance, and also must ensure that enterprise risk appetite will allow for experimentation and eventual adoption of the new technology.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Acronis (GroupLogic); Factom; Guardtime; IBM; Schedule1 (DataPassports)

Recommended Reading: "Innovation Insight for Blockchain Security"

"Blockchain Technology: How Security Relates to Use Cases"

"Evaluating the Security Risks to Blockchain Ecosystems"

Exoskeleton

Analysis By: David Glenn

Definition: An exoskeleton is a wearable device powered by actuators that is worn on the entire body, or on just the upper or lower extremities. It uses sensors and mechanical or hydraulic systems to assist, enable or enhance human movement such as walking, lifting and repetitive work tasks.

Position and Adoption Speed Justification: Exoskeletons are highly customized to specific use cases and operating environments. Without increased interoperability to drive multiuse applications for single devices, mass commercial or military adoption by target markets is still 10 years away. Devices intended to treat people rehabilitating from the effect of strokes or spinal cord injuries are an exception. Several such devices have received approval as medical devices from U.S. and European regulators, including Cyberdyne's HAL for Medical Use and the lower-body exoskeleton from Indego. However, because exoskeletons are worn, matching the size of the device and wearer matters for most applications, and often requires at least a semicustom fit. This limits scalability, keeping costs high. Adjustable or fabric-based systems that provide a one-size-fits-most, mass-market approach remain years away from being available.

Rapid advancements in robotics and battery technology will drive growth in exoskeletons, especially for manufacturing, military, construction, healthcare and warehousing environments. Cost and battery life are two limiting factors to broader adoption. Advances in 3D printing promise to reduce unit costs on devices that act as human prosthetics. Low-cost customization is key.

User Advice: Logistics and warehouse managers should review exoskeleton use cases for greater worker safety or for job functions involving extreme repetitive motions that can create health issues. Worker safety, not productivity, will drive exoskeleton use in construction, manufacturing and warehousing environments. Exoskeletons used to provide industrial solutions will augment worker strength and endurance. Aerial arms, vests or full-suit-type exoskeletons can be used for tasks such as heavy or overhead loads, or high-frequency and long-duration lifting. Making hard tasks easy, saving time, and improving quality and motivation will reduce turnover and improve economic returns and outcomes.

Exoskeletons could help chief safety officers manage safety in better and more efficient ways, especially for rehabilitation use cases and for workers who repeatedly lift heavy objects. The ROI will often be a reduction in worker injuries, which in turn saves on medical expenses.

Health insurance and related companies should test exoskeletons that reduce rehabilitation times for customers as next-generation prosthetics and in assistive-living environments.

Business Impact: Product usability and market success vary based on application. Military device adoption estimates are hard to verify, but exoskeleton use will likely follow robotics and drone adoption as all three are related to trends in higher-tech battlefields, medical evacuation and military logistics operating environments.

Exoskeletons used in medical applications range from prosthetics that mitigate permanent mobility loss to wearable training devices for temporary injury rehabilitation. More modern prosthetics using electromyography (EMG) for control mechanisms and built on a 3D printer may be the biggest near-term business impact areas. Prosthetics of this type can reduce costs from $20,000 to $200.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: ATOUN; Cyberdyne; Ekso Bionics; Honda; Indego; ReWalk Robotics; ROAM; Sarcos; US Bionics (suitX)

Recommended Reading: "Hype Cycle for Human-Machine Interface, 2018"

"Maverick* Research: From Disability to Superability, Society and the Workplace Are Changing"

Edge AI

Analysis By: Mark Hung; Martin Reynolds; Erick Brethenoux

Definition: Edge AI refers to the use of AI techniques embedded in IoT endpoints, gateways, and other mobile and edge devices, in applications ranging from autonomous navigation to streaming analytics. In this context, AI techniques refer to probabilistic reasoning (e.g., machine learning, deep neural networks), computational logic (e.g., rule-based, fuzzy logic), optimization (e.g., constraint-based reasoning) and agent-based techniques.

Position and Adoption Speed Justification: As complementary technologies, IoT and AI can work together in three different ways:

- IoT Data as the Input to the AI System: In this architecture, the IoT system is a peripheral to the AI system. IoT acts as a data gatherer that feeds this data to the AI system. An example of this is environmental sensors deployed for a smart agriculture application.

- AI Technique as the Application in the IoT System: In this architecture, the AI technique is one of (many) applications in the IoT system. Specifically, the AI technique serves as the IoT system's inference engine, interpreting the data generated by the IoT endpoints and driving some of the endpoints' functions. An example is a medical wearable that leverages sensor data and AI to help visually impaired people navigate the world in their daily lives.
- IoT and the AI Technique as a Two-Way System: In this architecture, both the IoT and the AI technique interact with each other to their mutual benefit — the IoT system provides data to the AI system on an ongoing basis, the data is used to train the AI system on a periodic basis, and as the output of the AI technique improves over time (through new training), a new production system is created and deployed to the IoT system. An example is autonomous navigation.

The applications that are starting to see increasing adoption of edge AI include those that are latency sensitive (e.g., autonomous navigation), network availability (e.g., remote monitoring), and data intensive (e.g., video analytics). Currently, most of these applications are still in R&D or trial phases, and widespread adoption is at least a few years away.

User Advice: Enterprise architecture and technology innovation leaders should:

- Evaluate when to consider AI at the edge vs. a centralized solution. Applications that have high-communications costs are sensitive to latency, or ingest high volumes of data at the edge are good candidates for AI at the edge.
- Determine whether the new AI breakthroughs in deep learning are applicable to their IoT deployments, or whether traditional data analytics and AI methodologies are adequate.
- Deploy analytics across the key IoT system elements — IoT edge, IoT platform and enterprise — so that the processing is closer to the data source, the communications overhead is reduced, and meaningful insights are extracted more quickly. It will be key for some deployments of data aggregation and transformation, as well as event-based architecture.

Use the IoT gateway as the aggregation and filtering point to perform most of the edge analytics functions. Make an exception for compute-intensive endpoints, where AI-based analytics can be performed on the devices themselves.

Business Impact: By incorporating AI techniques at the edge, enterprises may be positively impacted as follows:

- Improved operational efficiency, such as enhanced visual inspection systems in a manufacturing setting
- Enhanced customer experience, through the use of conversational platforms with inferencing performed at the edge
- Reduced latency in decision-making, with the use of streaming analytics and migration to an event-based architecture
- Communication cost reduction, with less data traffic between the edge and the cloud
- Increased availability even when the edge is disconnected from the network

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Amazon; Baidu; Google; Huawei; Intel; Microsoft; NVIDIA; Qualcomm

Recommended Reading: "AI on the Edge: Fusing Artificial Intelligence and IoT Will Catalyze New Digital Value Creation"

"Innovation Insight for Artificial Intelligence of Things — Machine Learning in the IoT Era"

"Managing the Data Tsunami: How AI and Edge Computing Will Enhance IoT Analytics"

Autonomous Driving Level 5

Analysis By: Jonathan Davenport

Definition: Level 5 or "full" automation is a definition established by the SAE International that refers to self-driving vehicles that can operate without human intervention in every situation and condition. As a result, there is no longer any requirement for a vehicle to be fitted with pedals, brakes or a steering wheel. The autonomous vehicle system controls all driving tasks.

Position and Adoption Speed Justification: There is great excitement surrounding fully autonomous vehicles. However, achieving fully autonomous vehicles is incredibly complex, with some that believe that Level 5 autonomy is not possible and certainly won't be possible for a decade or more. Level 5 vehicles will further the reach of mobility as a service (MaaS). MaaS vehicles will no longer be limited to certain geofenced areas, and instead will be capable of taking passengers anywhere they want to go. It will have even farther-reaching consequences for the transport and logistics industries, which will no longer require human drivers.

Technology advancements necessary for Level 4 vehicles will be developed further for Level 5 use cases. For an autonomous vehicle, monitoring its environment is core to the technology that allows it to function independently. In order to gather situational data, vehicles such as those Waymo is developing are fitted with an array of sensors that provide a 360-degree field of view using lidar, camera, radar and other supplementary sensors. These sensors need to be capable of gathering data around the vehicle as it moves to create a 3D picture of the vehicle's surroundings. The ability for the artificial intelligence to understand what it sees through these sensors, along with lowering costs, is where a lot of the investment is being made.

This picture needs to build effectively across a variety of conditions from daytime and at night, in different weather and light conditions to identify dynamic and static objects including pedestrians, cyclists, other vehicles, traffic lights, construction cones and other road features. So, the improvement between Levels 4 and 5 will be incremental, but nonetheless significant.

Disengagements identify where the vehicle is not capable of dealing with a situation on a road and requires a human to take control. While much testing is done in virtual simulations, a linear decline in disengagements is not necessarily expected, as the more challenging the testing, the higher the likelihood of a disengagement. However, over time, disengagements will decline to a point where companies can prove that their vehicle is safe to operate without human oversight in all conditions.

User Advice: The design of Level 5 vehicles will need to differ from their Level 4 counterparts, which were typically focused on geofenced urban and suburban transportation. Level 5 vehicles must be capable of transporting people long distances, allowing the provision of intercity MaaS offerings for the first time.

Trucks should no longer be designed with a cab for a human occupant. Thought will need to be given as to how the change in design will impact aerodynamics and associated fuel economy.

To deliver full autonomous driving functionality, Gartner assumes Level 5 autonomous driving ECU must have:

- More than 120 TFLOPS of processing capability
- More than 20GB of DRAM
- More than 500GB of nonvolatile storage
- Faster than 1 Gbps data link interface

Business Impact: Fully autonomous vehicles have the potential to radically affect lives. Different activities can be undertaken while the vehicle is in motion, while road safety will improve. This may lead to a relaxation of certain safety laws, allowing the vehicle interior to be rethought. As a result, people will seek to utilize their time in a vehicle more productively. This will lead to the vehicle becoming the third living space where people engage with family and friends, watch video, play computer games and work. There is even the potential for autonomous vehicles to lead to services such as haircuts or massages being delivered while in transit between locations, and workouts being undertaken in a vehicle as part of a daily commute.

Industries such as logistics will utilize fully autonomous fleets. This will radically change the distance that vehicles can travel in a single day (as they are no longer limited by driver safety hours). Trucks will look very different to how they do today as they start to be designed without a cab for the driver to sit in.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Apple; BMW; Bosch Group; nuTonomy; NVIDIA; Tesla Motors; Uber; Waymo

Recommended Reading: "Automotive and Smart Mobility CIOs Must Play a Crucial Role in the Autonomous Driving Technology Stack"

"Market Insight: Autonomous Driving Creates Opportunities for AI-Enabled Personal Technologies"

"Use Scenarios to Plan for Autonomous Vehicle Adoption"

"Market Insight: Prepare for Surging Semiconductor Business Opportunities Driven by Autonomous Vehicles"

Conversational AI Platform

Analysis By: Tracy Tsai; Adrian Lee

Definition: Conversational AI (CAI) platforms can be used by developers to build conversational user interfaces, chatbots and virtual assistants for a variety of use cases. They offer integration into chat interfaces like messaging platforms, social media, SMS, websites or similar. A conversational platform has a developer API so third parties can extend the platform with their own customizations.

Position and Adoption Speed Justification: CAI platforms in China were initially used for messaging-style chatbot, which are mostly rule-based. However, the use of CAI platform is evolving to handle more complex customer assistance such as travel booking. The rule-based approach is not able to support the task with satisfying user experiences. The approach is being shifted to natural-language processing (NLP) approach including recurrent neural network (RNN) or specific long- or short-term memory RNNs as an example to better understand users' intent. In addition to NLP, localized relevant content, domain knowledge graphs, business logic for dialogue management are also critical to support a CAI platform. Most Chinese speech-to-text (STT) vendors such as Baidu and iFLYTEK can support up to 20 Chinese dialects and accents. However, the mature use cases of STT are more limited to human machine command type applications, such as smart speakers. The Chinese NLP-based CAI platform will require at least five to 10 years to mature as STT; also, NLP, domain knowledge graph and training models based on localized language will take time.

User Advice: Enterprise architecture and technology innovation leaders planning to build CAI platforms should consider the following factors in evaluating and selecting vendors:

- Identify your business objectives and what kind of value the CAI platform will bring to support the organization objectives.
- Discuss with line of business stakeholders how to define your CAI platform, requirement, features and experiences.
- State your requirements with vendors to do preliminary vendor qualification if vendors can offer STT, TTS, NLP, domain knowledge graphs and ease of use. Only STT and keyword/rule based approach does not provide natural-language experiences.
- Request vendors to provide inference model for testing at least 30 or up to 90 days with your own company data. Each model needs to be trained and optimized with the new set of data.
- Be prepared to change to or add new providers of CAI platform product. Make sure the data prepared and business logic can be retrained and transferred seamlessly to next vendor.

Business Impact: The initial business value of CAI platform to enterprises was more about operation efficiency such as cost reduction from call center or increase in sales transactions. We have seen more requests for CAI platforms to support enterprise employees to improve employee productivity in China. There are also new revenue models created by the voice-enabled digital commerce platform through apps, smart speakers or home appliance. However, voice-enabled conversation platform remains an obstacle for most use cases, especially for smart speakers, as consumers' questions are too unstructured and general. In addition, the lack of relevant services to support revenue-generating use cases for speakers is another issue. If Chinese enterprises are not taking action to build the CAI platforms for customers or employee, they would face the risk of losing their relevance in the market as well as operational competitiveness.

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Sample Vendors: AISpeech; Alibaba Group; Baidu; Emotibot Technology; iFLYTEK; IBM; Microsoft; Tencent

Recommended Reading: "Market Guide for Conversational Artificial Intelligence in China"

Self-Healing System Technology

Analysis By: Kristin Merry Von Manowski

Definition: Self-healing systems (SHS) automatically detect issues and, using onboard or remote intelligence, determine the most appropriate course of action to initiate response and repair entirely without user intervention. This could include dynamic reconfiguration or the ability for a system to reboot or should key services fail.

Position and Adoption Speed Justification: SHS are relatively new to the IoT market. Emerging SHS technology includes print platforms and connected home solutions; however, few example products are available on the market today. However, due to the promised benefits of SHS, we expect to see accelerating adoption of this technology as it becomes more widely leveraged by providers, and users in the enterprise and consumer markets. As the printing market is one of the more mature IoT markets with a vast global installed base and deep engineering resources, print solutions may be an early adaptor of SHS capabilities.

User Advice: The promise of SHS is that they will enable users, whether enterprise or consumer, to drive high levels of system performance, reduces system downtime and at a lower total cost. However, few available products lead to limited market feedback as to the true effectiveness and value of SHS. Early adaptors of SHS should include those enterprises with large fleets of IoT devices (whether for internal use, or as provided to consumers), including fleets that are highly distributed and costly to support. Other consideration is the value of SHS relative to security policy management practices and the ability to reduce costs by making complex management activities automated and more efficient. Enterprises with existing complex IoT security practices will find value in the new opportunity offered by SHS. While few providers will be able to offer self-healing platforms, including SHS as part of any solution evaluation process in order to weigh in on the value of this emerging capability relative to solution strengths. More mainstream availability of SHS is expected within five years.

Business Impact: SHS benefits providers by differentiating their technology and decreasing costs to deliver services in the field so SHS provide excellent opportunity from the provider perspective. Enterprises and consumers benefit from SHS in terms of improved solution value and performance. When an SHS platform is implemented, SHS offer the potential of immediate benefits for industries with vast IoT networks. However, it is more likely that the impacts of SHS on any single enterprise will be limited until more SHS products are available, and until enterprises are able to refresh to the new SHS-enabled platforms. SHS will be a welcome new capability for those industries that invest in and prioritize highly secure systems. To that end, SHS will not be the first or only step that an enterprise takes toward managing IoT device security; it is a more advanced step that will benefit enterprises with a sophisticated approach to IoT security. Therefore, large enterprises with a strong focus on advanced security features will benefit from the availability of SHS prior to SMB and consumer market, where security still remains a lower priority. Finally, SHS help providers deliver a better user experience to consumers in the connected home supporting complex technology that is now easier to maintain.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: HP Inc.

Recommended Reading: "Predicts 2018: Print Solutions Become Intelligent, but Customers Struggle to Become Secure"

Volumetric Displays

Analysis By: Brian Blau

Definition: Volumetric displays create visual representations of objects in three dimensions, with a 360-degree spherical viewing angle in which the image changes as the viewer moves. Unlike most 3D planar displays, which create the illusion of depth through a stereoscopic or autostereoscopic technique, volumetric displays create lifelike images in 3D space.

Position and Adoption Speed Justification: Volumetric displays have emerged from the laboratory, but are often thought of as the iconic volumetric image of Princess Leia created by R2-D2 in the first Star Wars movie. Volumetric displays remain an elusive, yet aspirational goal.

Volumetric displays fall into two categories: swept volume and static volume. Swept volume uses the persistence of human vision to recreate volumetric images from rapidly projected 2D "slices." Static volume displays rely on a 3D volume of active elements. Swept and static volumetric displays suffer from the significant dangers of rapidly moving parts or ionized particles in the vicinity of people. The volumetric nature of the generated image convinces the brain that it is solid and "real" and, therefore, can be touched. In all cases, the physical volume of data required to generate a volumetric image is considerable, which will limit its overall advancement in the coming years.

User Advice: Outside of specialized areas where budgets are not significant constraints, with few exceptions, this technology remains firmly in lab rather than in commercial applications. Current technologies limit the size of volumetric space that can be displayed, and the mechanical solutions create potentially dangerous, rapidly moving parts. Until alternative approaches can be delivered, which seems unlikely in the near future, volumetric displays will remain an extremely niche product. However, eventually, they could be used as a product display, or to view objects or people that are not at the same location.

Businesses interested in experimenting with volumetric displays should investigate Kino-mo, a swept volume device used as a retail logo or ad display. Looking Glass, a new entrant in the holographic display market, announced a small desktop-based volumetric display device in 2016, which is shipping to developers.

Alternative devices, such as the HoloLamp, or even simple mirrors, such as the ones used in the Tupac Shakur performance art display at Cochella 2012, could provide quality volumetric experiences using projectors compared to swept or static volume displays.

Business Impact: General applications are not well-developed for business use with volumetric displays. To date, simple applications in marketing have been deployed — usually targeted at high-end retail environments. There are some specialized applications for geospatial imaging to enhance 2D maps and for architectural rendering. However, most of these applications can be achieved at much lower costs using other more commercialized technologies, such as 3D displays. Concurrently, the rapid growth and continuing development of head-mounted displays and light field displays threaten to overwhelm the continuing development of volumetric displays outside of specialized markets. Potential application areas include medical imaging, consumer entertainment, gaming and design. However, the price-to-value ratio will need to improve, including technology-based features, for these to be viable options for using true volumetric displays.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: HoloLamp; Kino-mo; Leia; Looking Glass; MDH Hologram; Realfiction; Voxon Photonics

Recommended Reading: "Market Insight: Mixed-Reality Immersive Solutions Are the Ultimate User Experience for Everyone"

"Top 10 Strategic Technology Trends for 2018: Immersive Experience"

5G

Analysis By: Sylvain Fabre; Mark Hung

Definition: 5G is the next-generation cellular standard after 4G (Long Term Evolution [LTE], LTE Advanced [LTE-A] and LTE-A Pro). It has been defined across several global standards bodies — International Telecommunication Union (ITU), 3GPP and ETSI. The official ITU specification, International Mobile Telecommunications-2020 (IMT-2020) targets maximum downlink and uplink throughputs of 20 Gbps and 10 Gbps respectively, latency below 5 milliseconds and massive scalability. New system architecture includes core network slicing as well as edge computing.

Position and Adoption Speed Justification: Gartner expects that by 2020, 4% of network-based mobile communications service providers (CSPs) will launch the 5G network commercially.

The Third Generation Partnership Project's (3GPP's) Release 15 is scheduled to be frozen mid-2018, with commercial network infrastructure based on the earlier New Radio (NR) specification launched by the end of 2018. NR allows CSPs to launch 5G with only new radio access network (RAN) deployments, leaving the existing core intact. 5G core and edge topology also need to be added to realize the full benefits of 5G, this may occur later toward 2022 to 2025.

Examples of early CSPs' 5G plans include:

- China Mobile, China Telecom and China Unicom all plan launching 5G in major cities during 2019.
- Verizon plans to launch fixed wireless access in high band in three selected markets during 2019 and will further expand this.
- In South Korea — kt builds out in main cities in 2019 using both midband and high-band frequencies.
- NTT DOCOMO — showcasing deployment for the 2020 Summer Olympic Games in Tokyo, with a potential launch commercially in early 2020. Japan is planning to establish 5G frequency strategy by summer 2018 and allocate spectrums by March 2019. Japanese CSPs are trialing 4.5 gigahertz (GHz) and 28GHz 5G, with their commercialization scheduled to be possible in 2020.

A driving factor for 5G adoption is the global competitive landscape of next-generation broadband access. For example, the EU's digital agenda has a target to realize 100% broadband coverage of 30 Mbps (at a minimum) by 2020 — that includes 50% of households having subscriptions of 100 Mbps available (or higher) by 2020. Whether 5G could be part of that agenda remains to be determined, as spectrum allocation and network economic limitation may apply.

From 2018 through 2022, organizations will mainly utilize 5G to support IoT communications, high-definition video and fixed wireless access (see "Emerging Technology Analysis: 5G.").

Use of higher frequencies and massive capacity, will require very dense deployments with higher frequency reuse. As a result, Gartner expects the majority of 5G deployments to initially focus on islands of deployment, without continuous national coverage, typically reaching less than full parity with existing 4G geographical coverage by 2022 in developed nations.

In addition, slower adoption of 5G by CSPs (compared to 4G) means less than 45% of CSPs globally will have launched a commercial 5G network by 2025. Uncertainty about the nature of the use cases and business models that may drive 5G is currently a source of uncertainty for many CSPs.

User Advice: CSP technology business unit leaders should:

- Focus mobile infrastructure planning on LTE, LTE-A, LTE-A Pro, small cells and heterogeneous networks (HetNets), as part of a planned transition toward 5G. Standards-compliant commercial network equipment could be available by 2018.
- Test backward compatibility to preceding generation (LTE) devices and networks. This is necessary because initial 5G coverage may be limited, so new devices need to be able to seamlessly transition the 4G infrastructure, at least, as a fallback. 3GPP is evaluating only 4G/5G interoperability; Internet Protocol Multimedia Subsystem (IMS) will be required to handle additional intergeneration interwork for 5G.
- Focus on related architecture initiatives — such as software-defined network (SDN), network function virtualization (NFV), CSP edge computing and distributed cloud architectures, as well as end-to-end security in preparation for 5G. 4G mostly follows a traditional cellular network architecture, but 5G will prove more complicated and a heterogeneous network (HetNet) will be commonly adopted, with a denser grid in hot spots, so topology changes must be planned. Operations need further automation and orchestration at scale as well, so self-organizing network (SON) frameworks need to be in place.
- New frequency allocations (preferably) should be used for the latest technology — 5G — to benefit from lower cost per byte, higher bandwidth and more capacity.
- CSPs should devote more of their focus into vertical solutions (B2B) for 5G.

Enterprise business leaders should:

- Identify use cases that definitely require the high-end performance of 5G; these may be few or even nonexistent for many verticals.
- Evaluate the multiple alternatives currently available that may prove adequate and more cost-effective than 5G for many use cases (for example, low-power wide-area [LPWA] such as NarrowBand Internet of Things [NB-IoT], long-range [LoRa], Sigfox, Wireless Smart Ubiquitous Networks [Wi-SUN]).

Business Impact: 5G requirements cover primarily three technology aspects which each support distinct new services, and possibly new business models (such as latency-as-a-service):

- Enhanced mobile broadband (eMBB)
- Massive Machine-Type Communications (mMTC)
- Ultrareliable and low-latency communications (URLLC)

URLLC and mMTC will be implemented after eMBB. Only eMBB addresses the traditional mobile handset requirement of ever higher throughput. URLLC addresses many existing industrial, medical, drone and transportation requirements — where reliability and latency requirements surpass bandwidth needs. Finally, mMTC addresses the scale requirements of IoT.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Cisco; Ericsson; Huawei Technologies; NEC; Nokia; Samsung; ZTE

Recommended Reading: "Market Guide for CSP Edge Computing Solutions"

"Market Trends: 5G Value Propositions for CSPs"

"Market Trends: Make Compelling 5G Technology Selections and Be First to Attain 5G Success"

"CSP 5G Revenue Depends on New Business Models for Enterprises"

"User Confusion About 5G Demands CSP Action"

"IT Market Clock for Communications Service Provider Infrastructure, 2017"

"Magic Quadrant for LTE Network Infrastructure"

Quantum Computing

Analysis By: Martin Reynolds; Matthew Brisse; Chirag Dekate

Definition: Quantum computing is a type of nonclassical computing that operates on the quantum state of subatomic objects (e.g., electrons, ions). The particles represent information as elements denoted as quantum bits (qubits). A qubit can hold all possible results simultaneously (superposition) until read. Qubits can be linked with other qubits, a property known as entanglement. Quantum algorithms manipulate linked qubits in their undetermined, entangled state. The qubits resolve to the solution when read.

Position and Adoption Speed Justification: Quantum computers are not general-purpose computers. Rather, they are accelerators capable of running a limited number of algorithms with orders of the magnitude of speedup over conventional computers. These problems fall into a broad category of search, where a traditional algorithm would take impossibly long to find a solution.

Hardware based on quantum technology is unconventional, complex and leading-edge. To date, the largest demonstration of entanglement is just a few qubits. Useful work demands perhaps 200 entangled qubits.

Quantum computing will not advance at a Moore's Law pace. Quantum computers already operate close to the lowest possible temperatures and physical dimensions.

The technology continues to attract significant funding, and a great deal of research is underway at many university and corporate labs.

User Advice: In the few known applications, quantum computers can operate exponentially faster than conventional computers. One example is known as Grover's algorithm, which can search data in the square root of the time taken by conventional computing. An early application will likely be routing optimization for delivery trucks.

Given the nature of quantum computing, our view is that general-purpose quantum computers will never be realized; they will instead be dedicated to solving a narrow, but important, class of problems. This suggests architectures where traditional computers offload specific calculations to dedicated quantum acceleration engines. Specific applications include route optimization; image analysis; biochemistry and drug discovery; materials science; and code breaking (as prime number factoring).

Quantum computers, in the distant future, will compromise today's cryptographic key exchange protocols. Quantum safe cryptography is emerging, implemented in software, and should be a medium-term strategic initiative for organizations where data must be protected over decades.

If a quantum computer offering appears, check its usefulness across the range of applications that you require. It will probably be dedicated to a specific application, and this is likely to be too narrow to justify a purchase. For those customers interested in quantum computing, Gartner recommends the use of quantum as a service (QaaS). QaaS providers such as IBM's Q cloud and Quantum Experience enable developers and programmers to have the ability to work with a quantum machine.

Business Impact: Quantum computing could have a huge effect, especially in areas such as optimization, machine learning, cryptography, DNA and other forms of molecular modeling, large database access, encryption, stress analysis for mechanical systems, pattern matching, image analysis and (possibly) weather forecasting. Analytics is likely to be a primary driver as the technology becomes useful, but this is outside the planning horizon of most enterprises.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: 1QBit; Alibaba Cloud; D-Wave Systems; Google; IBM; Microsoft; QC Ware; QinetiQ; Rigetti Computing

Recommended Reading: "Quantum Computing: A Research Project or a Practical Computing Architecture for Machine Learning?"

At the Peak

AI PaaS

Analysis By: Jim Hare; Bern Elliot

Definition: Cloud artificial intelligence and machine learning platform services are known collectively as AI platform as a service (PaaS). They provide AI model building tools, APIs and associated middleware that enable the building/training, deployment and consumption of machine learning models running on prebuilt infrastructure as cloud services. These cover vision, voice and general data classification and prediction models of any type.

Position and Adoption Speed Justification: The AI PaaS hype is rapidly increasing, with the leading cloud service providers, including Amazon Web Services (AWS), Google, IBM and Microsoft, clamoring to become the platform of choice. Over the last several years, AI applications utilizing cloud services have continued to gain traction and acceptance in the market both by data scientists and developers alike. AI PaaS offerings are primarily focused on the three key areas of machine learning, natural-language processing and computer vision. The AI cloud approach is beginning to disrupt the more established on-premises data science and machine learning platform market, especially as organizations experiment and build AI prototypes. The availability of specialized hardware instances with AI-optimized chips and large amounts of data storage makes the cloud an ideal environment for organizations to build and deploy AI applications without the risks, costs and delays of conventional on-premises procurement. Cloud service providers are also offering packaged APIs and tools that make it easier for developers to integrate AI capabilities into existing applications. The promise of using cloud services to more quickly and easily build and deploy AI solutions will push AI PaaS to the Peak of Inflated Expectations. This will be followed by some level of disillusionment as organizations experience and understand the limitations of AI PaaS offerings.

User Advice: Enterprise architecture and technology innovation leaders responsible for AI-enabled applications should take these steps:

- Consider AI PaaS over on-premises options to reduce the overhead of packaging and for easier deployment and elastic scalability.
- Improve chances of success of your AI strategy by experimenting with different AI techniques and PaaS providers, using the exact same dataset, and then selecting one that best addresses your requirements.
- Increase your organization's AI project success by selecting AI cloud services that balance your data science, developer and infrastructure expertise.

Business Impact: AI PaaS offerings are focused on the three key AI portfolio services of machine learning, natural-language processing and computer vision:

- Machine learning: Packaged ML services offered by the AI cloud service providers unify the end-to-end ML workflow. They extend the capabilities of an isolated ML engine by providing integrated access to all phases of the project — from data preparation to deployment in a managed training and execution environment accessible through APIs. For technical professional teams with little to no data science expertise, features like automated algorithm selection and training-set creation will offload some of the complexity of the project and leverage existing expertise on operating cloud services.

- Natural-language processing: Organizations can use pretrained NLP systems to create cloud-based chatbots for a variety of use cases. Major AI PaaS vendors provide a language-processing catalog as part of their conversational platform that can be used to deliver applications through a natural-language interface.
- Computer vision: This enables organizations to apply facial detection, recognition and analysis to unlock new sources of image-based data. Pretrained systems require no data science expertise and allow developers to gain unique and new insight by invoking an API.

The combination of the above as cloud services will accelerate digital business technology platform viability in the short term.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: Amazon Web Services; Google (Cloud AI); IBM (IBM Cloud); Microsoft (Azure AI Platform)

Recommended Reading: "Market Guide for AI Portfolio Cloud Service Providers"

Deep Neural Network ASICs

Analysis By: Chirag Dekate; Martin Reynolds; Alan Priestley

Definition: A deep neural network (DNN) application-specific integrated circuit (ASIC) is a purpose-specific processor that accelerates DNN computations.

Position and Adoption Speed Justification: Deep neural networks (DNNs) are statistical models that detect and classify patterns in input data such as sound and images, or text patterns such as sentences. There are two phases in DNN systems. In the training phase, the DNN iterates across a large dataset and distills it down to a small DNN parameter set. In the inferencing phase, the DNN uses this parameter set to classify an input such as an image, speech or text. Today, a vast majority of training and inferencing tasks use GPUs. DNN ASICs can deliver significantly higher performance and lower power consumption than CPUs or GPUs when accelerating neural networks.

Google has deployed DNN ASICs (known as Tensor Processing Units [TPU, TPU2, TPU3]), at scale, providing inferencing across its businesses for, for example, speech and image recognition. The TPU2 and TPU3 also accelerate the training process, a task formerly delegated to GPUs. Google does not make the TPU2 available other than through a cloud-based service. Other cloud vendors are following suit.

Other dedicated silicon is coming. Graphcore has developed a custom processor to deliver extreme performance for DNN-based applications and plans to launch the next-generation "Colossus" processor in 2018. Their marketing materials suggest close to an order of magnitude improvement over GPUs, although performance improvements move faster than presentations. Intel is also developing an ASIC code named "Lake Crest," optimized for DNN, based on the technology it acquired from Nervana Systems in 2016.

User Advice: The benefits of DNN ASICs in performance and energy consumption are significant. However, widespread use of DNN ASICs will require the standardization of neural network architectures and support across diverse DNN frameworks. Plan an effective long-term DNN strategy comprising DNN ASICs by choosing DNN ASICs that offer or support broadest set of DNN frameworks to deliver business value faster. Compare the return on investment of a GPU-based solution against an ASIC solution, and plan to retire the GPU solution if your business will perform better with a dedicated neural network processor.

Business Impact: Hardware acceleration will enable neural-network-based systems to address more opportunities in a business, through improved cost and performance. Use cases that can benefit from DNNs include speech-to-text, image recognition and natural-language processing.

IT leaders deploying deep neural network applications should include DNN ASICs in the planning portfolio. We expect this market to mature quickly, possibly within the three-year depreciation horizon of new systems.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Sample Vendors: Google; Graphcore; Intel

Recommended Reading: "Market Guide for Compute Platforms"

"Three Elements of a Scalable Enterprise Machine Learning Infrastructure Strategy"

"Find the Right Accelerator for Your Deep Learning Needs"

Smart Robots

Analysis By: Annette Jump; Kanae Maita

Definition: Smart robots are electromechanical form factors that work autonomously in the physical world, learning in short-term intervals from human-supervised training and demonstrations or by their supervised experiences on the job. They sense environmental conditions and recognize and solve problems. Some can interact with humans using voice language, while some have a specialized functional form, like warehouse robots. Others have general forms and/or humanoid appearances. Due to advanced sensory capabilities, smart robots may work alongside humans.

Position and Adoption Speed Justification: Smart robots have had significantly less adoption to date compared with their industrial counterparts (predefined, unchanged task) — but they received great hype in the marketplace, which is why smart robots are positioned climbing the Peak of Inflated Expectations. In the last 12 months, we have seen some of the established robot providers expanding their product line and new companies entering the market (particularly from China). Therefore, the market is becoming more dynamic, opening to new technology providers and technologies, and the barriers for entry are slightly dropping.

Hype and expectations will continue to build around smart robots during the next few years, as providers execute on their plans to expand their offerings and deliver solutions across the wider spectrum of industry-specific use cases and enterprise sizes. Hype is quickly building for smart robots as a result of several key vendors' actions during the past few years:

- Amazon Robotics (formerly Kiva Systems) deployed robots across Amazon warehouses.
- Google has acquired multiple robotics technology companies.
- Rethink Robotics launched Baxter and Sawyer, which can work alongside human employees.
- SoftBank Robotics introduced the humanoid Pepper and created the Pepper for Business Edition.
- In early 2018, LG introduced CLOi, a series of robots developed for commercial use in hotels, airports and supermarkets. Also, various hotels in the U.S. and two Shangri-La hotels in Singapore now use robots for delivering room service.

User Advice: Users in light manufacturing, distribution, retail, hospitality and healthcare facilities should consider smart robots as both substitutes and complements to their human workforce. Begin pilots designed to assess product capability, and quantify benefits. Examine current business- and material-handling processes into which smart robots can be deployed; also, consider redesigning processes to take advantage of the benefits of smart robots with three- to five-year roadmaps for large-scale deployment. Smart robots could also be a quality control (QC) check at the end of the process, rejecting product with faults and collecting data for analysis.

Business Impact: Smart robots will make their initial business impact across a wide spectrum of asset-centric, product-centric and service-centric industries. Their ability to do physical work, with greater reliability, lower costs, increased safety and higher productivity, is common across these industries. The ability for organizations to assist, replace or redeploy their human workers in more value-adding activities creates potentially high — and occasionally transformational — business benefits. Typical and potential use cases include:

- Medical materials handling
- Disposal of hazardous wastes
- Prescription filling and delivery
- Patient care
- Direct materials handling

- Stock replenishment
- Product assembly
- Finished goods movements
- Product pick and pack
- E-commerce order fulfillment
- Package delivery
- Shopping assistance
- Customer care
- Concierge

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Aethon; Amazon Robotics; ARxIUM; Google; iRobot; Panasonic; Rethink Robotics; Savioke; SoftBank Robotics; Symbotic

Recommended Reading: "How Virtual Assistants, Immersive Experiences and Robots Will Impact Your Organization"

"10 Critical Components Driving the Robot and Drone Revolution"

"Five Ways Vendors Can Grow Their Personal Assistant Robot Business Opportunity"

"Top 10 AI and Sensing Technology Capabilities for Personal Assistant Robots in 2020"

"Top 10 Strategic Technology Trends for 2018: A Gartner Trend Insight Report"

Autonomous Mobile Robots

Analysis By: C. Dwight Klappich

Definition: Autonomous mobile robots (AMRs), formerly called smart automated guided vehicles (AGVs) in previous Gartner Supply Chain Execution Hype Cycles, add intelligence, guidance and sensory awareness to historically "dumb" AGVs, allowing them to operate independently and around humans. These new types of AGVs address the historic limitations of traditional AGVs, making them better suited to, and more cost-effective for, complex warehouses.

Position and Adoption Speed Justification: AGVs are not new. However, for most of their history AGVs were brainless and chiefly applicable for simple tasks. The lack of intelligence, guidance and sensory awareness has been the primary barrier to AGV growth, but as computing power has grown and the cost of sensors has declined, the potential for smart AGVs grew significantly. The capabilities of these units have evolved well beyond the simple use cases of traditional AGVs — thus the name change to autonomous mobile robots. AMR advancements beyond previous generations of AGVs address three areas:

- **Navigation** — Although wires, tracks or floor tags work, this rigid form of navigation is too limiting in the long term. New types of AGVs will use a variety of techniques to self-navigate.
- **Sensors** — AGVs are increasingly being outfitted with arrays of sensors, whether they are multiple cameras or motion or sound detectors.
- **Intelligence** — Things such as embedded analytics and use of agent-based technologies will enable the AGVs to navigate on their own, optimize work individually and across a group, and respond to unforeseen events, such as breakdowns or bottlenecks.

User Advice: Next-generation AMRs will transform warehouse operations over the coming decades, as these truly become more autonomous and intelligent. Costs and complexities will also come down, which will open up the market to more companies. Labor reductions seem the most likely drivers, but improvements in overall throughput and productivity will be the primary value, regardless of whether labor is reduced. Warehouse operations with a high volume of bulk (i.e., palette) product moves should consider some of the current generations of AMRs as an alternative or to supplement existing automation. Companies looking to build new automated facilities also should explore the potential value of these smart machines.

Some industries are further along in using this technology, such as the life sciences industry. Here we see extensive use of this technology in manufacturing facilities with the benefits of improved traceability and compliance. An example of use is in cleanroom environments where the technology is used to reduce contamination risks from humans.

Business Impact: AMRs will continue to gain traction in complex distribution centers. The same technologies will emerge and also have applications outside warehouses as the technology matures. For example, in retail stores there is the potential that an AMR could unload trucks and deliver palettes of goods to 98 specific departments in a store without human intervention. Smart AGVs will increasingly develop to take over functions such as product put-away or forward-picking replenishment with little to no human intervention. AMRs could also have a positive environmental impact as they reduce costs such as lighting, heating and air conditioning, because robots don't need any of that.

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Aethon; Amazon Robotics; Clearpath Robotics; Fetch Robotics; GreyOrange; Locus Technologies; Seegrid

Brain-Computer Interface

Analysis By: Anthony Mullen

Definition: A brain-computer interface (BCI) is a type of user interface whereby signals in the brain are interpreted, or written to, by a computer. Typically, data is either passively observed for research or used as commands to control an application or device. There are three approaches:

- Invasive, where electrodes directly connect to the brain.
- Partially invasive, where the skull is penetrated, but the brain is not.
- Noninvasive, where commercially available caps or headbands are worn to interact with signals from outside the skull.

Position and Adoption Speed Justification: Currently, the best BCIs are used for limb prosthetics, and use 100 channels to distill the neural signals of the brain. The Defense Advanced Research Projects Agency (DARPA) looks to improve this to a million channels with their Neural Engineering System Design (NESD) and in 4Q17 DARPA awarded five research organizations funding to move this project forward. This project also writes to the brain.

Noninvasive methods cannot use higher-frequency signals as the skull blocks and disperses electromagnetic waves meaning less fidelity of signal. A 2017 Stanford study showed that paralyzed patients could type via brain control with invasive methods but not with noninvasive approaches. While control today is not very smooth or continuous, it is possible to control virtual objects in multiple dimensions, play interactive games and control hardware. Latency is a major problem for BCI. Novel solutions by Ecole polytechnique fédérale de Lausanne in Geneva, Switzerland look to improve the human-computer interface (HCI) with a mutual learning approach, where users alter their own wave patterns as well as machine learning optimizing device learning provides marked performance improvements.

While invasive techniques provide better results, it is expected that the noninvasive BCIs will grow at a quicker rate as the method has no issues with infection and discomfort, and can be more easily accommodated by institutions, patients and consumers. Noninvasive methods make up the majority of research. Recently, computer vision researchers at Kyoto University, Japan mapped the brain signals of subjects focusing on an image to hierarchical features of a deep neural network allowing them to reconstruct the object being thought about.

In 2017, large technology organizations such as Facebook research group Building 8 (typing via the mind) and Elon Musk's investment in Neuralink (ultra-high bandwidth BCI) peaked interest but little news has come from these projects since. Microsoft in early 2018, showed a patent for a BCI device for application control.

Brain-computer interfaces have moved to an emerging level of maturity in recognition of the gains made in large commercial scale deployments in China, VR headsets natively embedding the technology, a richer vendor landscape and broader applications in conjunction with deep neural network technologies.

User Advice: Today, outside the medical domain, speech recognition, gaze tracking or muscle-computer interfaces offer faster and more flexible interaction than brain-computer interfaces. The need to wear a headband or cap to recognize the signals is also a serious limitation in most consumer or business contexts.

China began to use this technology on an industrial scale deploying noninvasive BCI technology inside headgear to detect changes in mental states of employees in military, transportation and manufacturing verticals. Outside of China, however, legislation is likely to slow the use of these devices for workers outside of high-impact safety scenarios. Ultimately, most users outside of the medical and rehabilitation domain should treat brain-computer interfaces as a research activity and experiment with noninvasive tools. Undertaking these projects will require a considered investment of time and expertise.

Hardware manufacturers developing drones, robotics, virtual reality headsets and professional sports devices should explore the benefits of noninvasive methods to improve performance and experience immersion.

Platform developers in the physical and mental wellness space should consider these devices as part of innovation programs to better understand contextual conditions that give rise to the state of mind such as attention, joy and frustration. Presence in China will provide a distinct data capture advantage.

Marketers, customer experience professionals and interaction designers can use these devices now to add more quantitative signals on the state of mind to better understand how consumers use products and view messaging.

Business Impact: The BCI market is typically segmented into neurogaming, neuroprosthetics, defense and neuroanalysis (psychology). Neuroanalysis and neuroprosthetics are the largest commercial segments driven by hospitals and rehabilitation centers. Psychological research centers and military applications are next, with neurogaming as mostly nascent. These relative market sizes are likely to persist for five to 10 years. New research by Grand View Research projects that the total BCI market will be worth $1.73 billion by 2022 with noninvasive BCI identified as the most profitable segment expected to grow at a rate of over 10.0% over the forecast period (2016 to 2024).

As wearable technology becomes more commonplace, applications will benefit from hybrid techniques that combine brain, gaze and muscle tracking to offer hands-free interaction. As predicted we are now starting to see virtual reality (VR) hardware developers incorporating this technology into headset designs. Over the next five years, as virtual reality (VR) hardware develops, it is likely that noninvasive versions of this technology will be included in VR headset designs.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: ANT Neuro; Blackrock Microsystems; EMOTIV; InteraXon; Looxid Labs; MindMaze; neurowear; NeuroSky; OpenBCI; Personal Neuro Devices

Recommended Reading: "The Future of Customer Feedback in Marketing"

"Alternative Channels for Engaging Customers of the Future"

"Market Insight: Disruptive Macro Trends for 2025 Personal Tech Market — Holistic Wellness"

Smart Workspace

Analysis By: Mike Gotta

Definition: A smart workspace exploits the growing digitalization of physical objects brought about by the Internet of Things (IoT) to deliver new ways of working, scheduling resources, coordinating facility services, sharing information and collaborating. The programmability of physical environments enables smart workspaces to work contextually with mobile devices, software applications, enterprise social graphs and smart machines to improve workforce efficiency and effectiveness. Any location where people work can be a smart workspace.

Position and Adoption Speed Justification: Digital workplace strategies that focus on facility modernization, more agile work environments, and employee experience value continues to shape interest in smart workspace technologies. Synergies between, six trends:

1. The IoT
2. Artificial-intelligence-related technologies
3. Digital signage/electronic whiteboards
4. Indoor mapping
5. Smart buildings (including trends in integrated workplace management systems)
6. IWMS platforms (as they move into IoT-based services).

A smart workspace is a key aspect of a digital workplace initiative, as it includes strategists involved in facilities and real estate as key stakeholders. It applies to physical environments such as:

- Building and campus environments, including in-building open spaces
- Office and desk spaces
- Conference rooms
- Huddle rooms (small spaces where people congregate)
- Retail and shop floors
- Manufacturing assembly lines

"Things" participate in a smart workspace. Examples include applications and devices such as electronic whiteboards, building interfaces (HVAC), large digital displays, smart badges, workstations, mobile devices and wearables.

Taking full advantage of a smart workspace will require organizations to revisit design strategies, to include methods for gaining a better understanding of how people participate in physical spaces. Such insight can create new capabilities related to seating and room allocation, access management, and wayfaring.

Adoption rates will vary, based on organizations' requirements to support flexible work models that optimize the physical and interactive aspects of places and things (as well as employees' privacy concerns).

Technological advances in nonenterprise environments — in consumer electronics and appliances, as well as in homes, cities, transportation, fashion, security and so on — will influence smart workspace innovation. Conversely, a lack of advances in these areas will constrain progression of smart workspace technologies.

User Advice: Enterprise strategists focusing on a digital workplace strategy and digitalized business processes should follow smart workspace trends and look for deployment opportunities, such as meeting rooms, huddle rooms and in-building open spaces. Emerging applications will expand beyond traditional productivity scenarios to include situations that are more industry- and process-specific, such as an insurance professional using a digital pen that interacts directly with back-end processing systems, or a patient being remotely monitored via a wearable interface in their home that interfaces with diagnostic systems and advises healthcare professionals to improve care delivery. IT organizations will need to work much more closely with real estate and facilities teams, and vice versa. Identity, access management, privacy and security teams will also play a critical role. Anonymizing data is key to safeguard privacy expectations and help promote adoption of new services.

Additionally, electronic whiteboards are becoming integrated with traditional collaboration and content software systems, providing more opportunities for experimentation. Meeting artifacts can be better captured and connected to digital workplace graphs, to become more widely searchable. Beacons and sensors placed in key locations within a workplace can interact with mobile apps to deliver personalized information to workers, based on proximity. These can be used to improve employee learning, provide relevant information on products, or communicate safety procedures based on employee location.

The smart workspace will emerge at an uneven pace as organizations prioritize potential solutions independently of one another. For instance, building upgrades may take longer than expected, and some market sectors will be laggards in terms of smart workspace adoption. Localization needs will also influence smart workspace adoption.

Business Impact: The business impact of smart workspaces will be diverse, ranging from improved employee productivity and cultural perception of the workplace by workers, to improved customer experience as employees make better use of smart workspaces to serve clients. The results of these changes will often be a reduction in cost, because office utilization data will guide decisions about what types of workspace are most conducive to employee effectiveness.

The digitalization and programmatic evolution of places and things will impact IT methodologies related to system design, requiring new skills for design teams to understand how people use places and things. Smart workspaces will also have organizational impacts as traditional software teams now need to work with facilities management teams in ways not previously envisioned. The digitalization and programmability of the workplace will create new integration opportunities. For instance, smart workspace activities will signal information to digital workplace graphs and smart machines, and vice versa. Finally, adoption of smart workspaces will trigger a form of consumerization — "bring your own thing" (BYOx) — as employees add their own objects to smart workspace environments. Organizations will need to formulate and adjust BYOx policies accordingly.

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: AgilQuest; Condeco; Estimote; MCS Solutions; Microsoft; Oblong Industries; Planon; Prysm; Trimble

Recommended Reading: "Market Guide for Integrated Workplace Management Systems"

"Create a Catalog of Activity-Based Spaces in the Digital Workplace to Improve the Employee Experience"

"Crafting Workspaces That Enhance the Employee Experience"

Biochips

Analysis By: Gaurav Gupta

Definition: Biochips relate to several technologies that combine semiconductor and biological sciences. The most common form is based on an array of molecular sensors on the chip surface — typically referred to as "lab-on-chip." The underlying mechanism utilizes microfluidic micro-electromechanical systems (MEMS) technology. Biochips are used to analyze biological elements, such as DNA, ions, ribonucleic acid and proteins, in addition to certain chemicals.

Position and Adoption Speed Justification: Current market growth is limited due to regulations and high costs/complexity in manufacturing of biochips. It limits the number of people who can afford to purchase them. Continuous innovation in technology in addition to increasing usage across applications will fuel market growth. Further, rising demand for miniaturization of clinical and biological test systems will be critical for growth of global biochips market. Today application is limited and that's why we have kept the same position in HC as last year.

User Advice: Players in the global biochips market must:

- Focus on strategic collaborations, technological advancements, and M&A to strengthen their product portfolio.

- Find application areas which are not price sensitive, while research continues to create more cost-effective and efficient ways of preparing biochips.
- Target areas for initial introduction into market which can make them popular like medicine.

Business Impact: Biochips because of its multiuses promises to have a strong impact on business across the board:

- Impact on medical field — biochips can detect cancer even before the body develops symptoms of it. They can also be used to detect various other diseases such as smallpox, anthrax and plague.
- Impact on biotechnology- there are biochips for pH detection, oxygen detection and genetic decoders.
- Impact on drug discovery — biochips for pharmacogenomics, where it is currently in initial stage, but expected to grow.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Abbott; Agilent; Cellix; imec; Illumina; Mitsubishi Chemical; Owlstone; PerkinElmer; Thermo Fisher Scientific

Digital Twin

Analysis By: Alfonso Velosa; Marc Halpern; Benoit J. Lheureux

Definition: A digital twin is a virtual representation of a real object. Digital twins are designed to optimize the operation of assets or business decisions about them, including improved maintenance, upgrades, repairs and operation of the actual object. Digital twins include the model, data, a one-to-one association to the object and the ability to monitor it.

Position and Adoption Speed Justification: The idea of modeling the operational behavior of things and processes continues to gain traction.

- For operators of assets (aircraft, buildings, power plants, windmills), digital twins are starting to gain adoption. Their primary near-term use is lowering maintenance costs and increasing asset uptime.
- For product OEMs, digital twins are beginning to proliferate for connected products (cars, lights, stereos). The primary near-term use of digital twins is differentiation and to help the enterprise manage warranty costs, support channel partners and better understand customer experiences.

Hundreds of millions of things will have digital twins within five years.

The digital twin profile has moved closer to the Peak of Inflated Expectations, in part due to heavy promotion by technology and service providers. Although about 5% of enterprises have started implementing digital twins, less than 1% of assets have digital twins.

User Advice: CIOs should identify and prioritize opportunities to use digital twins for business outcomes. To do this, consider the following:

- Business outcomes: Determine with business leaders the outcomes (financial, innovation, productivity) they hope to realize by exploiting digital twins. Leverage design thinking to identify potential business models.
- Objectives: Work with IoT teams to review your strategy and establish an IT vision for digital twins. Align it with the enterprise's digital transformation strategy.
- Technology: Start with asset models based on key business uses. Build the system representation, applying physics and function features as appropriate. Determine what data is necessary to "feed" the models and the types of analytics needed. Use standards where possible, but don't let their dearth limit innovation.
- Stakeholder engagement: Engage the business unit to build their business twin strategy. This may require discussions on the nature of digital twins, their value, and issues such as the cost of software asset life cycle management. Use design thinking exercises to help develop the models and user experience.
- Digital ethics: Work with business and legal teams to establish a policy on ownership of the digital twin models and data, as well as who may participate. Ensure this digital ethics policy helps engage partners and customers about what data may be shared and monetized.
- Business case: Align with business objectives, to identify a portfolio of digital twin initiatives that provide short (~1 year) and midrange (~5 year) paybacks.
- Risk analysis: Create a threat and opportunity analysis of the current business ecosystem, incorporating digital twin development by competitors or partners.

Business Impact: Digital twins are transformational as they enable business to optimize or transform their current business models. In the next decade, digital twins will become the dominant design pattern for solutions.

For example, they enable superior asset utilization, service optimization and improved customer experience. They create new ways to operate, such as consumption of physical outcomes instead of the capital expenditure acquisition of industrial assets. And they will open up new ways to monetize data.

Digital twins will challenge most enterprises to change their thinking from a hardware-centric to a hardware-plus-software-centric perspective. This includes the implications on operating business models, product management costs, and risks on unethical data use.

Finally, digital twins' impact will extend beyond assets. People within the supply chain are currently being modeled and analyzed. The digital twin of organizations has been used to optimize the business decisions for customer experience, cost optimization and portfolio management.

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: ANSYS; Cognite; Dassault Systèmes; Flutura Decision Sciences and Analytics; GE Digital; IBM; Microsoft; Particle; PTC; Siemens PLM Software

Recommended Reading: "Five Approaches for Integrating IoT Digital Twins"

"Exploiting Digital Twins to Drive Ecosystem Strategies"

"Four Best Practices to Avoid Digital Twin Failures"

"Digital Twins Will Impact Economic and Business Models"

"Innovation Insight for Digital Twins — Driving Better IoT-Fueled Decisions"

"Top 10 Strategic Technology Trends for 2018: Digital Twins"

Deep Neural Nets (Deep Learning)

Analysis By: Alexander Linden; Chirag Dekate

Definition: Deep neural nets (DNNs) are large-scale neural networks, often with many processing layers. They underpin most recent advances in artificial intelligence (AI) by enabling computers to process much more complex data than before, such as video, image, speech and textual data.

Position and Adoption Speed Justification: The internet giants deploy systems based on DNNs across their businesses. Examples of well-developed DNN systems underpin Amazon Alexa's speech-to-text capability, Google's search capability, image recognition and self-driving cars, and Facebook's face-tagging technology.

DNNs are, however, tricky to build and train. To achieve consistently good results, you need large quantities of labeled data, data science expertise and special-purpose hardware. Most enterprises struggle to obtain enough labeled data to support their DNN initiatives. Furthermore, data science experts are scarce, as the IT and internet giants have hired aggressively. Additionally, optimized computational resources for DNNs require a great deal of capital expenditure.

The most widely implemented DNNs are convolutional neural networks (CNNs) and recurrent neural network (RNNs). CNNs are used, for example, for image classification and speech to text. RNNs are good for, among other things, extracting meaning from snippets of speech. Additionally, hyperscalers are developing generative adversarial networks (GANs), a technology that is most useful in gameplay situations, but that will no doubt be pressed into service for business applications.

The level of hype about DNNs is not very different from last year.

User Advice: Data and analytics leaders of modernization initiatives should:

- **Explore DNNs:** These technologies could help them solve previously intractable classification problems, especially relating to images, video and speech.
- **Start with tools from cloud providers:** Wherever possible, begin by using tools available from the major cloud providers. They have enormous resources invested in image, speech and facial classification systems, and in training and data. Their systems will likely outperform almost anything you build and deploy yourself.
- **Develop and acquire skills:** Improve your machine learning experts' skills through training. Engage with academic teams. Use crowdsourcing providers like Algorithmia, Experfy, Kaggle and TunedIT. Although it's currently difficult to compete with the big cloud companies, there is a good stream of graduates skilled in this area, and talent will become easier to acquire.
- **Focus on data for deep learning as a long-term investment:** DNNs are within your field of competency, and the value of the right data will grow over time. Don't assume that DNNs will derive insights from any type of data through unsupervised learning. So far, results have mostly been achieved using supervised learning.

Business Impact: DNNs have transformational, and therefore disruptive, potential for all industries. The challenge for those wanting to realize this potential is to identify the business problems to solve, and to secure availability of enough experts and reasonably good datasets. DNNs demonstrate superior accuracy to past state-of-the art algorithms in detecting fraud, determining quality, predicting demand and other classification problems that involve sequences (using, for example, video, audio or time series analysis).

The basis of a DNN's potential is its ability to produce granular representations of highly dimensional and complex data. A DNN can, for example, give promising results when interpreting medical images in order to diagnose cancer early; help improve the sight of visually impaired people; enable self-driving vehicles; colorize black-and-white photographs; add missing elements to photographs; and recognize and understand speech (which, in time, may make most devices conversational devices).

Completely new product categories are likely in fields such as personal assistance and surveillance.

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Amazon; Baidu; deepsense.ai; Google; H2O.ai; Intel; Microsoft; NVIDIA; Skymind

Recommended Reading: "Innovation Insight for Deep Learning"

"Cool Vendors in AI Core Technologies"

"Cool Vendors in Data Science and Machine Learning, 2017"

"Artificial Intelligence Primer for 2018"

"Predicts 2018: Analytics and BI Strategy"

"Preparing and Architecting for Machine Learning"

"Magic Quadrant for Data Science and Machine-Learning Platforms"

Carbon Nanotube

Analysis By: Amy Teng

Definition: Carbon nanotubes are tiny cylinders of carbon atoms that can be used for a wide variety of purposes. Properties can include high electrical conductivity, great mechanical strength and thermal insulation. Carbon nanotube finds their applications in many different fields but we only focus at electronics.

Position and Adoption Speed Justification: Carbon nanotubes with semiconductor properties offer the promise of small transistors with high switching speeds in future semiconductor devices. Carbon nanotubes with metallic (conducting) properties offer the promise of low electrical resistance that can be applied to the interconnections within integrated circuits. Other nanotube materials being evaluated include silicon and compound semiconductor materials and printed and flexible electronics. Silicon versions (often referred to as silicon nanowires) are actively being researched for use in silicon anode batteries.

During the past year, CNT showed significant technology advancement in flexible electronics and in interposers. IBM research demonstrated a nearly 1000X improvement on the CMOS ring oscillator made on a polyimide substrate, and a CNT TFTs fabricated on flexible substrates which is capable of wrapping on a finger with no performance degradation. Mei Fujitsu Semiconductor announced plan to mass produce NRAM (a type of emerging memory based on forming a film of CNTs onto silicon substrate to interface the NRAM switch). As a result we moved CNT slightly forward on the Hype Cycle curve.

User Advice: Interested parties should monitor the developments of this technology closely to decide when to enter for what applications. Do not expect all advancements to occur during the same period, recognize that utility (and therefore the value) will be different for different application. Pursue advances in energy-related applications first, such as batteries, solar cells and conducting materials in printed electronics. Semiconductor-related opportunity will take place CMOS integration circuits in flexible substrate or next-generation transistors beyond 5nm.

Business Impact: There is potential for a huge impact, particularly when silicon devices reach their minimum size limits — expected during the next 5 to 10 years and regarding to next-generation transistors. Understand the factors that will affect this technology adoption within your target application and what you try to achieve to nurture the impact.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: GLOBALFOUNDRIES; IBM; Imec; Intel; Nano-C; Samsung Electronics; TSMC

Recommended Reading: "Emerging Technology Analysis: Carbon Nanotubes Will Drive the Next Generation of Semiconductor Devices"

"Emerging Technology Analysis: Carbon Nanotubes and Graphene Are Indispensable for Future Electronic Products, So Act Now"

IoT Platform

Analysis By: Alfonso Velosa; Eric Goodness; Benoit J. Lheureux

Definition: An Internet of Things (IoT) platform is software that enables development, deployment and management of solutions that connect to and capture data from IoT endpoints. It is a suite of functional capabilities:

- Device management
- Integration
- Data management
- Analytics
- Application enablement
- Security

It may be delivered as a hybrid combination of edge software platform and/or cloud IoT platform as a service.

Position and Adoption Speed Justification: Enterprises continue to add IoT capabilities to assets and products, seeking benefits such as asset optimization, better interactions with customers, and new business opportunities such as product as a service. The sophistication, scale and business value of these interactions call for specialized technology resources, resulting in the IoT platform. The IoT platform may be deployed in a hybrid cloud or edge fashion to meet technical or business objectives. The edge software is further distributed between the endpoints and gateways.

Continued vendor hype, along with culture, schedule, security and technical challenges for IoT projects, has pushed IoT platforms past the Peak of Inflated Expectations. 2018 sees many large vendors reorganizing their IoT businesses and evolving their offerings and market strategy. A further complication is the rise of embedded solutions by OEMs using them as part of existing business operations. These issues also lead us to push out the time to plateau to five to 10 years.

User Advice: CIOs should factor in the following for their IoT platform strategy:

- Project strategy: Identify the range of IoT projects for your enterprise, and segment them by their complexity and business objectives. This will help you establish a flexible, multivendor architecture. Start with smaller initiatives to build momentum, test business hypothesis and acquire implementation lessons, while limiting enterprise and career risk.
- Skills: IoT projects will require new capabilities for your organization. Build an IoT capabilities gap analysis, a skills migration plan, and training program for your developers and business analysts. In parallel, perform an assessment of IoT skill sets within your enterprise. Plan to leverage a service partner to ramp up as you train internal resources.
- Platform customization: Understand that an IoT platform is a starting point. No IoT platform will work straight off the shelf. Customize the platform to build a solution for your unique circumstances (for example, adding third-party security or device support or analytics to meet special needs).
- Vendor selection: Evaluate candidate IoT platforms in terms of their fit-to-your-business objectives and technology, but expect roadmaps to evolve quickly in the fast-changing IoT market. Key criteria will be vendor capabilities to scale from proofs of concept to operational-scale deployments, vertical market expertise, their partner ecosystem and customer references.

Business Impact: There is a significant opportunity from IoT-enabled business moments to achieve greater business value. This includes making better decisions from the insights, information and data that are generated by instrumented assets, and providing better control of things distributed across the enterprise and its external stakeholders. Unfortunately, this data has been largely locked in the assets — mostly due to lack of connectivity, but also because of lack of systems and governance processes to obtain and share this data systematically.

IoT platforms act as the intermediary between the "thing" and the IT and OT systems and the business processes. Therefore, they facilitate the introduction of a new potentially transformative wave of digital business innovation and digital transformation to enterprises. IoT platforms provide the middleware foundation to implement asset-centered business solutions — and are part of a broader technology solution to manage multiple IoT applications in an agile/flexible fashion.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: ABB; Atos Origin; Bosch Software Innovations; GE Digital; LTI; OpenText; Prodea Systems; relayr; Software AG; WSO2

Recommended Reading: "Magic Quadrant for Industrial IoT Platforms"

"Market Guide for IoT Platforms"

"Use the IoT Platform Reference Model to Plan Your IoT Business Solutions"

"Predicts 2018: Expanding Internet of Things Scale Will Drive Project Failures and ROI Focus"

"Implementing and Executing Your Internet of Things Strategy: A Gartner Trend Insight Report"

"Architect IoT Using the Gartner Reference Model"

Virtual Assistants

Analysis By: Van L. Baker

Definition: Virtual assistants (VAs) help users or enterprises with a set of tasks previously only made possible by humans. VAs use AI and machine learning (such as natural-language processing, prediction models, recommendations and personalization) to assist people or automate tasks. VAs listen to and observe behaviors, build and maintain data models, and predict and recommend actions. VAs can be deployed in several use cases, including virtual personal assistants, virtual customer assistants and virtual employee assistants.

Position and Adoption Speed Justification: The VA space is increasingly dominated by conversational interfaces such as Apple's Siri, Google Assistant, Microsoft's Cortana, IPsoft's Amelia, Nuance's Nina, Amazon Alexa, and IBM's Watson Assistant. Increasingly, behavior and event triggers will enhance VAs. Devices such as Amazon's Echo and Google Home, together with the broad deployment in cellular phones, have put VAs in a position of importance in the consumer's mind. We also continue to see more business-oriented VAs being created, with tools such as Dailogflow Enterprise Edition, Alexa for Business and Watson Assistant. Adoption grows as users get more comfortable with them, technologies improve and the variety of implementations multiplies:

- Unobtrusive, VA-like features — such as Gmail's Smart Compose with recommended sentence completion, and the discovery features in Microsoft's Graph that find unknown resources — are embedded in existing products.
- Use-case-specific VAs have also emerged — such as personal financial advisors, health and wellness coaches, and calendaring agents.
- Chatbots that are subsets of VAs are increasingly used to answer customer questions about products and services.
- VAs can act on behalf of consumers, employees and businesses, but the use cases are all based on the same, constantly improving, language-centric artificial intelligence (AI) technologies.

User Advice:

- App development leaders should develop a VA strategy that includes voice and text enablement, because VAs will deliver significant benefits to the enterprise's workforce and its customers
- Anticipate that VAs will proliferate as people and businesses move to conversational user interfaces. Individuals may use several different VAs, while businesses migrate from one deployment to multiple VAs that are composed of groups of specialist chatbots, with narrowly scoped intents, working together with a master chatbot to coordinate the classification of requests.
- Businesses that haven't begun the process of deploying VAs to interact with customers and employees should start now, because customers and employees are increasingly expecting conversational interfaces to be available to address help desk and customer service desk issues.
- Adopt the VAs that are emerging in cloud office suites first, followed by SaaS offerings such as those from SAP, ServiceNow and Salesforce, and consumer application environments such as Facebook.
- Look for opportunities to leverage VAs to make users more productive with their business apps and mobile platforms in targeted, well-defined use cases.
- Incorporate analytics to measure the impact of VAs on behavior and performance. Closely monitor the use of VAs, especially in virtual customer assistant (VCA) use cases, and implement an architecture where handoff to human agents is automated to ensure customer satisfaction.
- Utilize VAs in different use cases: including customer support and engagement, and employee support and enablement, as well as employees' use of personal virtual assistants for services such as HR.

Business Impact:

- VAs have the potential to transform the nature of user behavior, and customer and employee service, as well as the way work is done and how workplace activities are structured.
- There are many providers of VAs and the quality varies dramatically, so expect rapid changes to the provider landscape.
- VAs can be built using tools and hosted AI services licensed from providers or created using professional services. Performance of the VA is dependent on the quality of the dataset used to add domain-specific information, and the quality of the hosted-language-oriented AI services.
- Security and the collection of personal information are still concerns, but users are growing more comfortable in their interactions with VAs. VAs that are embedded will be the first to gain traction; but as enterprises deploy the technology, so VAs will be broadly used by employees and customers.
- As they mature, VAs may act for the user, forming a relationship with the user over time. VAs shift the responsibility for understanding the process from the user to the system, by corresponding with the user.

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: 1-Page; Amazon; Apple; Google; IBM; IPsoft; Microsoft; Nuance; Oracle; [24]7.ai

Recommended Reading: "Market Guide for Virtual Customer Assistants"

"When Will AI Virtual Support Agents Replace Your IT Service Desk?"

"Use Master Chatbots to Improve Conversational Experiences"

"Four Channels for Conversational Technologies"

"Top 10 Strategic Technology Trends for 2018: Conversational Platforms"

Silicon Anode Batteries

Analysis By: Masatsune Yamaji

Definition: Silicon anode batteries are an extension of widely used lithium ion (Li-Ion) batteries. Early generation Li-Ion batteries used lithium as the anode material. This was replaced with carbon/graphite, following a number of widely reported overheating and explosion incidents. Next-generation Li-Ion batteries are likely to use silicon anodes that utilize silicon nanotubes, or a comparable coating process. This will result in significantly higher energy storage and longer battery life.

Position and Adoption Speed Justification: Claims from companies and research teams range from three to 10 times greater energy storage than current Li-Ion batteries (with three times greater being more realistic in the short term). Significant volume and weight savings, and a longer operating lifetime, are additional benefits of the technology. Charging times will be similar to those of existing Li-Ion batteries. The technology will find widespread use in mobile devices, PCs, IoT endpoints, electric vehicles (EVs) and home energy storage/solar installations. Environmental benefits are achieved from reduced material usage, lower transportation costs in the supply chain and increased energy efficiency during usage. Use of silicon nanowires also supports an increased number of charge/discharge cycles, leading to longer battery life. Related technology development involves the use of carbon nanotubes in the cathode. The combination of both silicon nanowires in the anode and carbon nanotubes in the cathode promises significant benefits, but this is yet to be quantified. Graphene is another material that could improve the performance of these batteries. Research at Lawrence Berkeley National Laboratory has shown potential gains in energy density using lithium sulfur graphene chemistry.

A number of suppliers are rushing to develop and evaluate this technology. Large, established companies are also working to develop silicon anode technology, including Panasonic (which is a supplier of cells to Tesla), LG Chem and 3M.

Initial implementations will probably offer only modest performance improvements, compared with the full capability of the technology. Potential inhibitors to adoption include higher cost, marginal performance advantages over existing technologies, customer risk aversion to change technologies, and the challenge of adapting manufacturing to incorporate a silicon anode.

User Advice: This is a near-term, yet emerging, battery technology requiring interested parties to actively seek engagement with Silicon Anode Battery vendors for early adoption:

- Vendors should evaluate the technology aggressively, and begin to make appropriate system design changes in anticipation of the new batteries.
- Users of equipment in isolated areas, with limited power availability, should evaluate offerings in preparation for early adoption.
- Makers of EVs should evaluate these batteries. While charging time is not affected, the energy stored is significantly higher, resulting in longer journey times between charges.

Business Impact: Cost is a critical factor in all potential applications of this technology. If competitive cost targets can be met, then the longer working times might facilitate more-powerful mobile devices and applications:

- Because of their smaller physical size and weight, silicon anode Li-Ion batteries offer the potential for use in mobile devices, IoT endpoints and other equipment, causing smaller carbon footprints.
- EVs and related systems should receive a boost from this battery technology, but it will take five to 10 years.
- Improved energy density for large-scale energy storage systems could speed adoption of renewable energy technologies such as solar and wind.
- End-of-life issues are unaffected for this change of anode technology. No additional impact (on recycling or toxicity) is expected at this time.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: 3M; Amprius; LG Chem; Nexeon; Panasonic; PNNL

Recommended Reading: "Cool Vendors in Power and Energy Electronics"

Blockchain

Analysis By: David Furlonger; Rajesh Kandaswamy; Fabio Chesini

Definition: A blockchain is an expanding list of cryptographically signed, irrevocable transactional records shared by all participants in a network. Each record contains a time stamp and reference links to previous transactions. With this information, anyone with access rights can trace back a transactional event, at any point in its history, belonging to any participant. A blockchain is one architectural design of the broader concept of distributed ledgers.

Position and Adoption Speed Justification: Blockchain has become the de facto term that commentators use to describe all things relating to its original Bitcoin protocol construct as well as multiple other aspects of ledger and token technologies and subjects. This is unfortunate as it creates significant misunderstandings concerning the various value propositions and capabilities of both the original model as well as how the first concepts have evolved over the last 10 years.

In reality, core developers have evolved the original block and chain ledger architecture into a wide variety of different information management and transaction execution models using multiple varieties of consensus algorithms, data and network governance models, token creation and distribution, and use cases.

Over the past decade enterprise executives have come to realize the inadequacies of implementing the original concept in terms of scalability, programmability, etc. Significant hype remains about the value of blockchain and distributed ledgers. It is not yet clear whether the general public will readily accept nonintermediated information management and transaction execution models and decentralized governance. It is also less than clear whether enterprises and vendors will relinquish control. During the next five to 10 years, convergence in architectural deployment styles is as likely as platform offerings converge. Distributed ledgers will gain similar functional characteristics (e.g., Zero-knowledge proofs, tokens, privacy controls, APIs, secure wallets, etc.). Market differentiation in ledger varieties will lie in the inherent capabilities to solve particular business problems. In the medium term, unless and until more standards, interoperability, viable and secure economic models, flexible quality user interfaces and enterprise scale capabilities are developed and adoptable in a mission-critical context, widespread acceptance of blockchain (beyond its current format) and distributed ledgers will remain problematic.

User Advice: Blockchain introduces challenges to enterprise and government operating models by introducing decentralized data/transaction management and governance. This negates the need for expensive intermediation. The use of a cryptographic token as a form of value also destabilizes the operation of financial systems raising questions about pricing, risk management, competitive positioning, funding, etc. Open source and the distributed nature of programming and applications threaten the centralized control that traditional technology vendors have had over the market. These issues have led to the evolution of multiple other forms of ledger constructs under the broader term of distributed ledger, which blockchains now fall under. These newer distributed ledger varieties often do not use tokens, nor do they offer the same kind of decentralized operating models that the original construct promised. As distributed ledgers have gained more momentum, they are superseding the initial blockchain concept via the use of executable programs allowing customized applications to be developed on top of the ledger protocol.

Use clear language and definitions for internal discussions about the nature of the technology, the ledger being developed and the business intention. Ensure that nontechnical executives understand the differences in business outcomes (for example, from both an operational risk and an ecosystem perspective) that each variety of ledger enables. Closely monitor distributed ledger developments and platforms, including related initiatives in areas such as consensus mechanism development, data management (e.g., sharding, channels, sidechains, etc.), authentication, governance models and decentralized applications (dapps).

If resources permit, consider distributed ledgers for proof of concept (POC) experimentation, but make sure your team has both the technical and business skills to understand the problem to be solved. Identify integration points with existing infrastructures (e.g., digital wallets, core systems of record, etc.) to determine future investment plans. Evaluate the total cost of ownership, especially against existing database systems and be very cautious about vendor lock in and merely replatforming the enterprise.

Business Impact: Blockchains continue to have high visibility, not least due to the wildly speculative volatility in the underlying tokens and the unclear nature of the participants. Block and chain architectures will likely not be suitable for many enterprise activities, especially taking into account the aspects of decentralization, risk, governance, etc. Presupposing the technical and business challenges of the broader concept of distributed ledgers can be overcome enterprises are most likely to gravitate instead toward experimentation with more multiuse architectural varieties. However, startups may continue to seek disruptive opportunities using the original block and chain concept and enterprise executives should undertake scenario planning accordingly.

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Bitcoin; Dash; Ethereum; Litecoin; Zcash

Recommended Reading: "The Future of Money Is the Programmable Economy, Not Just Bitcoin"

"Maverick* Research: In a Post-Bitcoin World, Metacoin Platforms Enable the Programmable Economy"

"Hype Cycle for the Future of Money, 2014"

"The Bitcoin Blockchain: The Magic and the Myths"

Sliding Into the Trough

Connected Home

Analysis By: Fernando Elizalde

Definition: A connected home is networked to enable the interconnection and interoperability of multiple devices, services and apps, ranging from communications and entertainment to healthcare, security and home automation. Solutions are delivered over many interlinked and integrated devices, sensors, tools and platforms that learn from patterns and behaviors in the home.

Contextual, real-time smart experiences at the local or cloud level enable individuals and other connected services in the household to control and monitor the home remotely or within.

Position and Adoption Speed Justification: The connected home is a concept that overarches several technologies, devices, applications, services and industries. As such, it is defined in this innovation profile to provide a framework for the Hype Cycle of the same name.

The concept has evolved to include, without being exhaustive:

- Media entertainment
- Home security
- Monitoring and automation
- Energy management products and services
- Health and fitness

The connected home is evolving from being designed to follow simple rule-based programming into the rendering of increasingly intelligent systems. Truly intelligent solutions that learn from the consumer behavior and habits within — and even outside — the home to deliver contextualized and personal experiences are starting to appear. Despite much of the advancements in orchestrating and integrating discrete connected home solutions through smart home hubs and cloud integration, this is achieved only in tightly closed implementations.

Use cases that extend beyond consumer solutions and bring the consumer experience to extensions of the home, such as hospitality industry and the connected car, are starting to be defined.

Adoption of connected home solutions continues growing, albeit at a slow place, differing by regions and countries within regions. Yet the drive created by the introduction of virtual private assistant speakers (VPA-speakers) of the like of Amazon Echo and Google Home continues and is expected to increase as such products are introduced in more countries. Gartner's 2018 Artificial Intelligence Consumer Perceptions Survey, conducted in the U.S. and U.K., suggests strong interest among respondents to let AI fully or partially manage the utilities such as heating and lighting (72% of respondents) and home security (69%) in the home. However, market fragmentation and dynamism in the market somewhat hinder faster consumer adoption. Consumers may be wary of spending on solutions that may soon become obsolete or whose value is not well-communicated by the vendors. Also, privacy issues and the security of shared personal data is an increasing concern among consumers.

User Advice: The market is consolidating fast around open ecosystems through cloud integration and open API adoption, where voice recognition solutions is dominating the user interface. The differentiating factor in the next 12 months will be the faster adoption of machine learning techniques to deliver learning solutions and faster integration into open ecosystems. With such horizon, vendors must:

- Go beyond the programmable home and add intelligence by using analytics engines and machine learning techniques to create and shape a "learning" home that will deliver the intelligent home.
- Develop partnership strategies to build your existing expertise in devices, services and customer relationships. Provide a unified user experience and compelling integrated connected-home solutions across products, brands and platforms.
- Partner with software providers for a unified platform. Base your solutions on standardized protocols to speed up market adoption.
- Open up APIs and make products work with market-leading connected home ecosystems.
- If you are a single solution vendor, don't lose focus on your own brand recognition while partnering with home ecosystems.
- Offer ease of use and reasonable hardware costs, differentiating the quality of experience on the services you have on offer by providing efficient support.
- Deliver high levels of trust and data transparency to consumers.

Business Impact: Connected-home solutions affect a wide spectrum of manufacturers (of white goods, entertainment electronics and home automation, security, and fitness and health products), as well as providers of network infrastructure and services, ranging from energy utilities and surveillance to healthcare, assisted living, insurance, communications and digital entertainment.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: ADT; Amazon; Apple; Belkin International; Deutsche Telekom; Google; HomeControl; Insteon; Samsung; Vivint

Recommended Reading: "Market Insight: The Move From the Connected Home to the Intelligent Home"

"Market Insight: How Sensors Drive New Interactions in the Future Connected Home"

"Market Trends: Removing Buyers' Friction in the Connected Home With Smarter, Self-Healing Devices"

"Market Insight: Five Lessons From Successful Vendors in the Connected Home"

"Market Insight: Selling Connected Home Solutions to Multifamily Housing Developers"

"Market Insight: Address 3 Critical Security Issues to Differentiate Yourself in the Connected Home Market"

Autonomous Driving Level 4

Analysis By: Jonathan Davenport

Definition: Self-driving vehicles that can operate without human intervention in most situations are classified as Level 4 using the SAE International's rating system.

The vehicles will not be capable of driving in all locations or conditions, such as driving during snow or heavy rain, or in areas that have not been electronically mapped, but must always be able to maintain a safe operation even if the driver does not take over.

Position and Adoption Speed Justification: There is a lot of interest (and investment) in autonomous driving solutions, as the automotive industry pursues the end goal of developing fully autonomous vehicles. However, the challenges of creating autonomous vehicles should not be underestimated. High-profile accidents, such as the Uber vehicle that was involved in a fatal collision in Arizona, show the need for improved validation of the technology. This coupled with the need for regulatory approval, highlight the challenges that the industry still faces to bring a mainstream solution to market.

Despite this, automotive manufacturers aim to commercialize the technology for consumer use early in the next decade. This leaves several years of hype between today and when a product is available for use by consumers.

User Advice: The economics of Level 4 automation will make private ownership cost prohibitive, certainly to begin with. As a result, Level 4 autonomous vehicles need to be designed for mobility as a service (MaaS) fleets.

Many see the widespread adoption of MaaS to be driven by the emergence of Level 4 vehicles, coupled with other macroenvironmental trends such as:

- Growing urbanization
- Increased use of public transportation, taxis and bikes by young people
- The growth in "as a service" solutions

Level 4 vehicles will not be able to handle all road conditions and situations. As a result, these fleets will likely operate in geofenced areas where the operator is confident that the vehicles are capable of handling every situation they will encounter. In situations where the vehicle is unable to continue driving, it will need to initiate a "safety protocol." The safety protocol will require the AI system to be capable of assessing the least dangerous maneuver and bringing the vehicle to a halt at the side of the road. In such situations, vehicles may be remotely piloted, utilizing teleoperation systems.

To see mass adoption of Level 4 vehicles, work is also needed to help the general public trust autonomous vehicles and to ensure the right legal framework is put in place to support a smooth transition of these vehicles onto the world's roads.

Level 4 vehicles would not require steering wheels, accelerator and brake pedals, or mirrors, but may have them to overcome issues around regulation and to help drive the car in exceptional environmental conditions.

To deliver autonomous driving functionality, Gartner assumes Level 4 autonomous driving ECUs must have:

- More than 80 TFLOPS of processing capability
- More than 10GB of DRAM
- More than 300GB of nonvolatile storage
- Faster than 1 Gbps data link interface

Business Impact: Level 4 automation could lead to dramatic changes in how people move around and what activities they are able to engage in while in the vehicle. The introduction of Level 4 MaaS vehicles will start people's migration from owning their vehicle (automotive customers) to instead becoming consumers of transportation provided by third-party fleets. This will impact retention and significantly change the profile of automotive OEMs' customer base, especially in urban and suburban areas. Vehicle OEMs will increasingly sell to mobility providers or they may become providers themselves, owning the fleet of cars they build.

This risks vehicles becoming a commodity. To address this risk, the automotive industry needs to prepare for this change and consider how customer relationships and brand loyalty should be nurtured.

People travelling in the vehicles will be able to shop online, work on a laptop, watch video content and engage with other passengers in a way that has never before been possible. This will transform time that was previously "wasted" such as on commutes into work, making people far more productive.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Alibaba Group; Aptiv; Baidu; Ford Motor; General Motors; Intel; Mercedes-Benz; NVIDIA; Volvo Cars; Waymo

Recommended Reading: "Market Insight: Cracking the Semiautonomous Machine-Human Handover Problem"

"Market Insight: Autonomous Driving Creates Opportunities for AI-Enabled Personal Technologies"

"Use Scenarios to Plan for Autonomous Vehicle Adoption"

"Market Insight: Prepare for Surging Semiconductor Business Opportunities Driven by Autonomous Vehicles"

"Automotive and Smart Mobility CIOs Must Play a Crucial Role in the Autonomous Driving Technology Stack"

Mixed Reality

Analysis By: Brian Blau; Tuong Huy Nguyen

Definition: Mixed reality (MR) is the merging of real and virtual worlds, where physical and graphical objects appear to interact and integrate naturally. MR, in concept, is a single technology. However, MR includes an underlying group of technologies encompassing the spectrum of immersive displays and interactive systems that spans from the digitization of real environments, to augmented reality (AR) and virtual reality (VR).

Position and Adoption Speed Justification: MR is an overarching technology that includes all immersive displays (mainly, head-mounted displays [HMDs]) and combines functionality that spans from the displaying of fully immersive virtual worlds, to ones that are augmented with matching graphics and overlays. Its position on the Hype Cycle curve is roughly similar to AR and VR technologies, but earlier in its maturity due to its more sophisticated capability and wide-ranging use cases. In some respects, MR devices will be the ultimate VR/AR systems, but the most sophisticated ones are still years away from being produced. However, its advanced capability means it is not as mature as its component technologies and likely won't be adopted at mass-market levels for five years due to limits of the technology and the lack of popular apps.

User Advice: MR will become a widely used human-machine interface technology in the coming years. Just as keyboard and mouse gave way to touch, future user experience technologies will integrate much deeper with how humans naturally interact with the real world. In similar situations in which AR or VR could be used, MR technologies will likely take a front seat as the preferred technology because it better integrates real-world objects and their virtual counterparts. For example, a person could see a chair, landmark or product, and using MR devices, would see contextual information visually integrated or overlaid with that person's view of that real-world object. Interaction is a key feature and benefit, and MR experiences should be designed into immersive and interactive features.

Businesses can use MR technology to enable new types of customer experiences and ones that are more personal for the user. As the technology matures, enterprises should monitor its ease of use and capability advancement to best determine when to start investigating how to integrate and use the technology. Use pilot projects to test assumptions. Furthermore, use the pilot projects as an educational exercise to best understand how to use HMDs and integrative graphics as part of a business process or product offering, or when providing apps and services to technology buyers.

Business Impact: During the next 10 years, MR and the user experiences that it enables will undergo a fundamental change above and beyond the capabilities of AR and VR. Today, MR capabilities focus on optimizing "hands-busy" work environments, and over time, MR will expand to include many types of experiences that can visually enhance everyday objects. New business models will emerge that change how customers buy products using MR or how they conduct operations by visually connecting the user's view of the real world with their data-driven virtual world counterparts. Potential use cases are training on use of equipment, entertainment experiences in which the user directly interacts with the content, maintenance of equipment using visually integrated instructions, or in-field service environments helping a remote technician with a complicated task. Once MR technology matures, its adoption will accelerate due to the transformative nature of its user experiences.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Sample Vendors: Acer; Facebook; Google; Lenovo; Magic Leap; Microsoft

Recommended Reading: "Market Insight: Mixed-Reality Immersive Solutions Are the Ultimate User Experience for Everyone"

"Competitive Landscape: Augmented Reality Tools for Enterprise, 2018"

"Top 10 Strategic Technology Trends for 2018: Immersive Experience"

"Forecast: Wearable Electronic Devices, Worldwide, 2017"

"Disruption Profile: Immersive AR and VR Technologies Transform Computing Experiences"

Smart Fabrics

Analysis By: Anshul Gupta

Definition: Smart fabric refers to a range of technologies that transform textiles used in clothing, accessories, upholstery and more into devices that can be deployed as sensors, switches, connectors, batteries or displays. The components and electronics may be embedded in the fabric or, in some cases, within the fibers themselves.

Position and Adoption Speed Justification: Smart fabric technology continues to improve with developments in sensor miniaturization and integrations with fabric. Technological advances allow new types of smart fabric every day. Flexible antenna and power sources are coming to market. These technologies can be embroidered onto cloth like an e-thread to enhance the signal strength of electronic devices or to power them. In addition, a robotic fabric is being developed, using cotton embedded with sensors made of flexible polymer, which moves and contracts. This would allow robots to have sensory skins or provide added strength to those who need it. Researchers are working on a prototype to magnetize conductive thread in smart fabric to store data that can be read by magnetometer. Using the magnetized fabric to authenticate at a magnetometer is a significantly cheaper alternative than RFID tags with a RFID reader.

Although smart fabric as a technology is developing rapidly, many of the current products are still in testing, the beta phase or first generation. Thus, the fabric appeals to technology enthusiasts, but is not ready for wider market adoption yet. A lack of standards, a complex manufacturing process, insufficient availability of miniaturized electronic components, low yield and high costs continue to be the main challenges preventing mass adoption of smart fabric. Other factors that impact smart fabric adoption include the high price of smart apparel, low longevity, achieving high-quality end products, cleaning without impacting electronic components, privacy concerns and exclusive marketing budgets to raise awareness.

Smart fabric exhibits characteristics such as lightness, breathability, waterproofing and heat resistance for use in a range of applications, including energy generation and storage, electronic controllers, sports monitoring, and heating wraps. Smart fabric with sweat-sensing capabilities can be used to derive information such as adrenaline, engagement levels and health parameters. Smart fabric with electromyography (recording electrical activity of the muscle) sensors could be used to measure muscle activity for professional athletes.

We expect use cases of smart fabric to extend beyond sports, professional athletes, healthcare and personal care to wider industries, including automobiles, manufacturing, military, emergency services and engineering. Advancements in battery technology, sensors and electronic components will allow easy integration with the fabric without causing discomfort to end users.

Smart fabric has quickly passed through the early Hype Cycle phases. However, the technology is yet to mature to a sufficient level to create a wide range of successful, follow-up/second-generation products, leading us to retain its same spot in the Hype Cycle as 2017.

User Advice:

- The rising adoption of health bands and sports watches opens up opportunities for smart garments made for fitness and sport activity tracking. Smart sensors embedded in fabric could be used to gain insights and optimize training for individual users.
- Smart fabrics could be used to automatically capture vital health parameters and transmit wirelessly to experts/doctors for analysis/action. This could have a transformative impact in healthcare, elderly care and remote care scenarios.
- Niche areas where smart fabric delivers a differentiated experience — such as professional training, gaming, healthcare and sports — will see faster adoption.

Business Impact: Smart fabric technology providers should:

- Explore opportunities within fitness clothing, professional training, healthcare, automotive, military, fashion, emergency services, mining, engineering and manufacturing.
- Work with smart city solution providers with a focus on emergency services, healthcare and energy management.
- Partner with immersive solution providers to transform user interactive capabilities.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: adidas; Eeonyx; Peratech; Philips Research; StretchSense; Textronics; Under Armour

Recommended Reading: "Top 10 Wearable Technologies and Capabilities in 2017 and 2018"

Augmented Reality

Analysis By: Tuong Huy Nguyen; Brian Blau

Definition: Augmented reality (AR) is the real-time use of information in the form of text, graphics, audio and other virtual enhancements integrated with real-world objects and presented using a head-mounted-type display or projected graphics overlays. It is this "real world" element that differentiates AR from virtual reality. AR aims to enhance users' interaction with the environment, rather than separating them from it.

Position and Adoption Speed Justification: Current technology is best-suited for purpose-built, specialized solutions. As such, position and adoption speed will vary by vertical and industry. Current horizontal tasks seeing the most traction are task itemization, visual design and video guidance. This profile represents a homogeneous view of AR implementations across market segments.

Market interest remains fairly steady according to Google Trends, even as high-profile developments in the AR space continue to fuel interest and hype in this area. These developments include Apple's launch of ARKit, Google's launch of ARCore and Magic Leap's long-rumored HMD.

AR is currently struggling with mismatched expectations (vendors promising solutions beyond current capabilities) and poor implementations (for example, solutions delivered without immersive development knowledge or workflow integration, or not mapped to business value or need). B2C implementations are still struggling to show consumers value. Better and more transparent hardware, coupled with more compelling use cases, is needed before further progress can be made.

Based on Gartner inquiry and industry news, B2B AR continues to gain traction as more enterprises are discovering and seeing the value of using AR in their workflow. HMD sales reflect the burgeoning pilot deployments. Advancements in HMD hardware will provide more compelling hands-free use cases for AR, as well.

User Advice: Decide on the audience for your AR solution. Internal- and external-facing solutions are not transposable. Restrict initial trials to a specific task or goal. Set benchmarks against unaugmented solutions to understand risks and benefits. Set the business goals, requirements and measurements for your AR implementation before choosing a provider. Rich and robust offerings can bring value only if you have a clear intention for the deployment. For external-facing implementations, use AR as an extension of your brand and experience. For internal-facing implementations, use AR as a tool that will enhance employee job function. This could include, for example, delivering context-specific information at the point of need for mobile workers, reduction of head count in plant and maintenance operations, or enhancing business processes via AR-based training and instruction.

Business Impact: By leveraging device sensors, AR acts as a digital extension of users' senses, and it serves as an interface for humans to the physical world. It provides a digital filter to enhance the user's surroundings with relevant, interesting and/or actionable information.

AR bridges the digital and physical world. This has an impact on both internal- and external-facing solutions. For example, internally, AR can provide value by enhancing training, maintenance and collaboration efforts. Externally, it offers brands, retailers and marketers the ability to seamlessly combine physical campaigns with their digital assets.

As such, AR is broadly applicable across many markets, including gaming, industrial design, digital commerce, marketing, mining, engineering, construction, energy and utilities, automotive, logistics, manufacturing, healthcare, education, customer support, and field service.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: Blippar; Catchoom; DAQRI; Google; Microsoft; Ubimax; Upskill; Wikitude

Recommended Reading: "Competitive Landscape: Augmented Reality Tools for Enterprise, 2018"

"Market Guide for Augmented Reality"

"Market Insight: AR and VR Adoption Limited by Current Technology"

"Create More Compelling Immersive Experiences With Artificial Intelligence"

"Forecast: Wearable Electronic Devices, Worldwide, 2017"

"Competitive Landscape: HMDs for Augmented Reality and Virtual Reality"

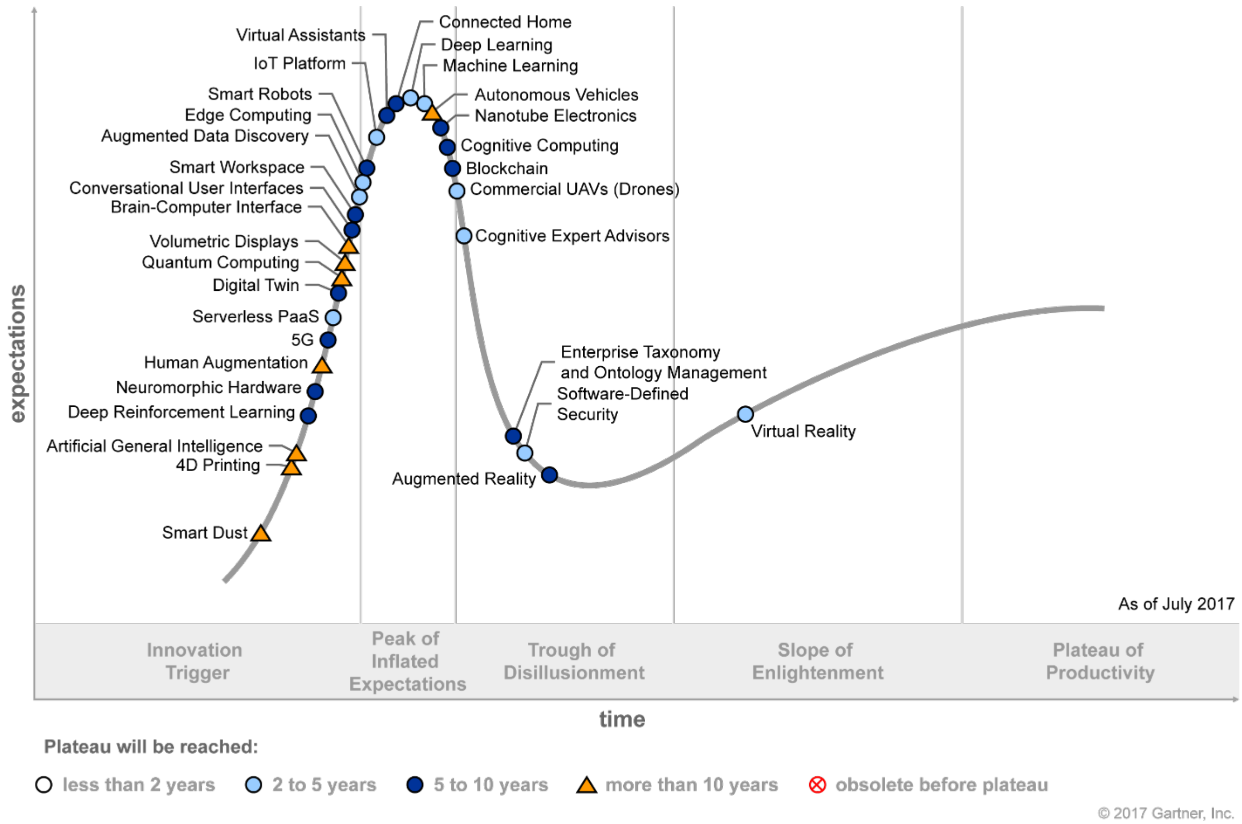
"Three Key Development Practices to Implement Effective Enterprise Augmented Reality Applications"

"Best Practices for Using Augmented Reality in Mobile Apps"

"Immersive Technologies Offer Infinite Possibilities"

Appendixes

Figure 3. Hype Cycle for Emerging Technologies, 2017



Source: Gartner (July 2017)

Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 1. Hype Cycle Phases

Phase	Definition
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant press and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the technology is pushed to its limits. The only enterprises making money are conference organizers and magazine publishers.
Trough of Disillusionment	Because the technology does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the technology's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the technology are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the technology to reach the Plateau of Productivity.

Source: Gartner (August 2018)

Table 2. Benefit Ratings

Benefit Rating	Definition
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (August 2018)

Table 3. Maturity Levels

Maturity Level	Status	Products/Vendors
Embryonic	▪ In labs	▪ None
Emerging	▪ Commercialization by vendors ▪ Pilots and deployments by industry leaders	▪ First generation ▪ High price ▪ Much customization
Adolescent	▪ Maturing technology capabilities and process understanding ▪ Uptake beyond early adopters	▪ Second generation ▪ Less customization
Early mainstream	▪ Proven technology ▪ Vendors, technology and adoption rapidly evolving	▪ Third generation ▪ More out-of-box methodologies
Mature mainstream	▪ Robust technology ▪ Not much evolution in vendors or technology	▪ Several dominant vendors
Legacy	▪ Not appropriate for new developments ▪ Cost of migration constrains replacement	▪ Maintenance revenue focus
Obsolete	▪ Rarely used	▪ Used/resale market only

Source: Gartner (August 2018)

Gartner Recommended Reading

Some documents may not be available as part of your current Gartner subscription.

"Understanding Gartner's Hype Cycles"

"Hype Cycle for Emerging Technologies, 2017"

"Toolkit: My Hype Cycle, 2016"

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