TECHNOLOGY
CONVERGENCE 2035

Estimation of Technology Convergence

The art of war teaches us to rely not on the likelihood of the enemy's not coming, but on our own readiness to receive him; not on the chance of his not attacking, but rather on the fact that we have made our position unassailable.

Sun Tzu

Estimation of Technology Convergence by 2035

By

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United States Army War College
Class of 2020

About This Document

The Mad Scientist Fellows prepared this document as a group Strategic Research Project as partial requirement to complete the Master of Strategic Studies degree from the United States Army War College (USAWC). The research, analysis, and production of this product occurred over 24 weeks from October 2019 through March 2020 as part of the in-residence Army War College Senior Service College program. The team consists of one US Air Force Colonel select (O-6) one US Navy Commander (O-5), two US Air Force Lieutenant Colonels (O-5), and one State Department Foreign Service Officer: Louis Duncan, Patrick Lancaster, Lance Vann, Nicholas E. Delcour, Stephen Frahm, respectively.

Requirement

How, when, and where are artificial intelligence, biotechnology, quantum technology, nanotechnology, neurotechnology, autonomous technology, robotics, and information technology likely to converge in ways relevant to the United States Army over the next 15 years?

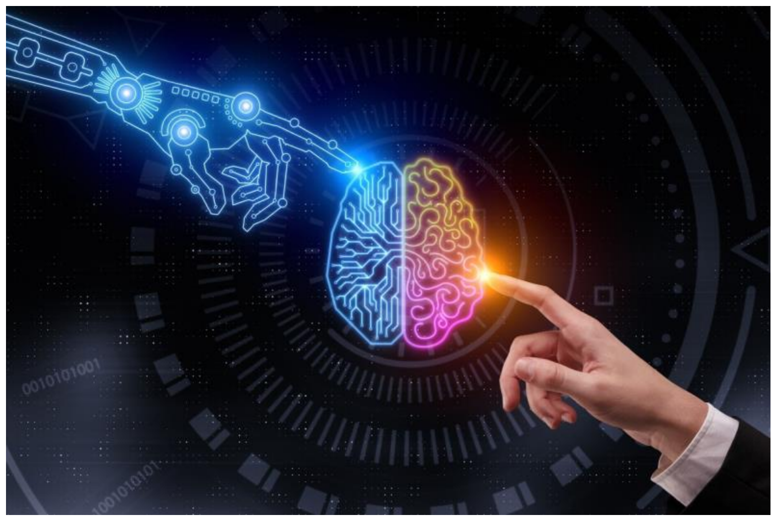


Image rendering by the Center for Disease Control to illustrate the use of a Microsoft bot to help screen COVID-19, otherwise known as the Coronavirus. The virus shutdown much of the US and the globe in Spring 2020.

This product was produced in multiple mediums, including digitally (primary), PDF-printed, and soft-bound book. Multiple methodologies were used to determine key findings and convergences, including Eigenvector network analysis and the Millhone analysis technique. The results of this study were provided to Mr. Thomas F. Greco, leader of the self-styled “Mad Scientists”, and executive agent to United States Army Training and Doctrine Command.

Analytic Confidence

The analytic confidence of convergences within Key Findings is categorized as high. Analytic confidence of each report is also indicated. The questions asked were complex and the timeline was relatively short due to competing academic requirements of the USAWC core curriculum. Source reliability and corroboration were moderate to high. The analysts (non-subject matter experts) worked both individually and collaboratively to answer the questions. They utilized a combination of structured analytic techniques including nominal group technique and network analysis among others. The team evaluated their analytic confidence utilizing Peterson's Analytic Confidence Factors coupled with the Friedman Corollaries.

Words of Estimated Probability

Analysts leveraged the Kesselman List of Estimative Words as their Words of Estimative Probability (WEP) for determining the likelihood of a capability's future threat in 10 – 20 years.

Source Reliability

Source reliability is noted at the end of each citation as low (L), moderate (M), or high (H). The citation is hyperlinked to the source. Source reliability is determined using Standard Primary Source Credibility Scale and the Trust Scale and Website Evaluation Worksheet.

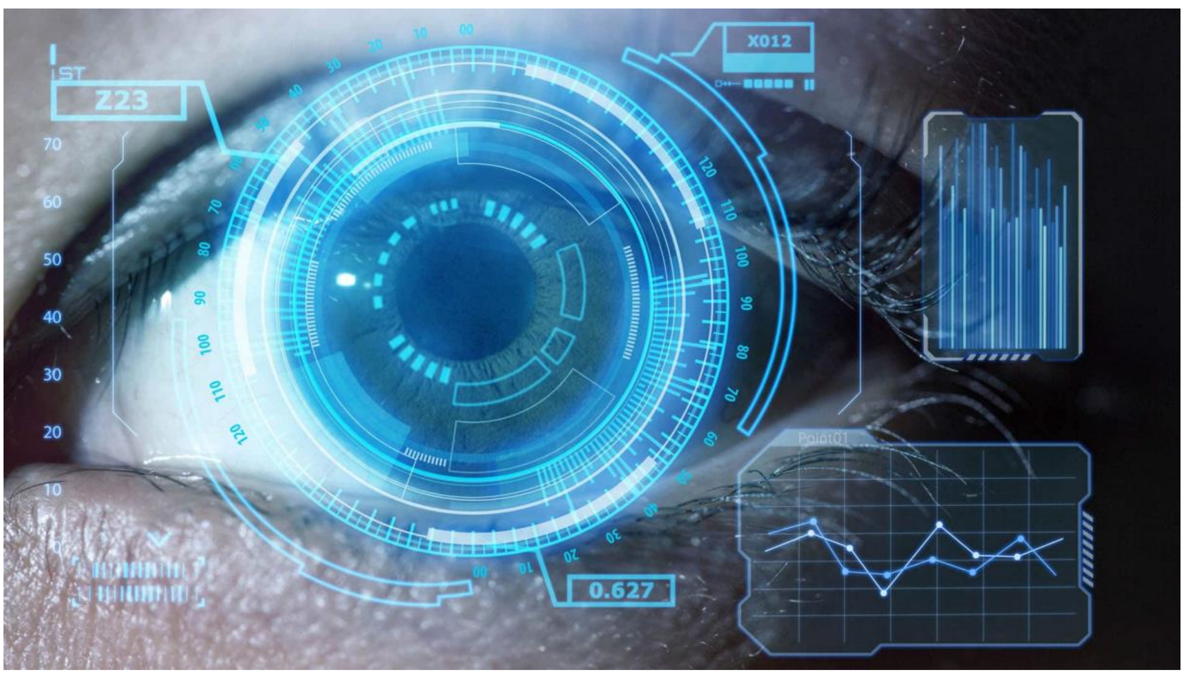


Image rendering of UNDARK's deep learning idea associated with Artificial intelligence.
Source: undark.org

Motivation, vision, and treasure can create amazing results associated with disruptive technology.

From "Risk Takers" [H]

"We had someone literally throw a yellow pages book at us and tell us, 'you think you'll ever replace this,' and we thought this guy was crazy because not only were we going to replace this, but that's not only where it ended—we keep going from there."
Kimbal Musk
(Older brother of Elon Musk)

"Elon had this ability to, to look at the world—this is a real problem that's going to happen in 20 years."
Kimbal Musk

"There really wasn't a chance that we weren't going to do anything. It was what are we going to do next?"
Kimbal Musk

"This is Elon saying he wants to go and enable human civilization to leave the planet Earth. It's about as big a vision as you can possibly imagine, and that's going to require funds, and he has enough funds to do it, so he's going to do it."
Kimbal Musk

"It's very unlikely that the Tesla investment is ever repaid to the taxpayers. Electric vehicles are really not possible in ways that would be effective for most consumers."
Eric Noble
President, the Car Lab

"It really feels good to have repaid the US taxpayer. That's really what's important here, and we didn't just repay the principle; we actually repaid it with interest and a bonus payment, so ultimately the US taxpayer actually made a profit of over $20 million dollars." (This loan was paid nine years ahead of schedule.)
Elon Musk
Entrepreneur

"I could afford probably a chain of islands, but that, again, was just not of interest to me."
Elon Musk Musk

From "Risk Takers" [H]

Key Findings

> A single technology is sometimes used to solve a single problem, but this can entail certain risks for governments. Instead, as technologies become more connected, their convergence becomes crucial.
>
> **Deloitte Insights**

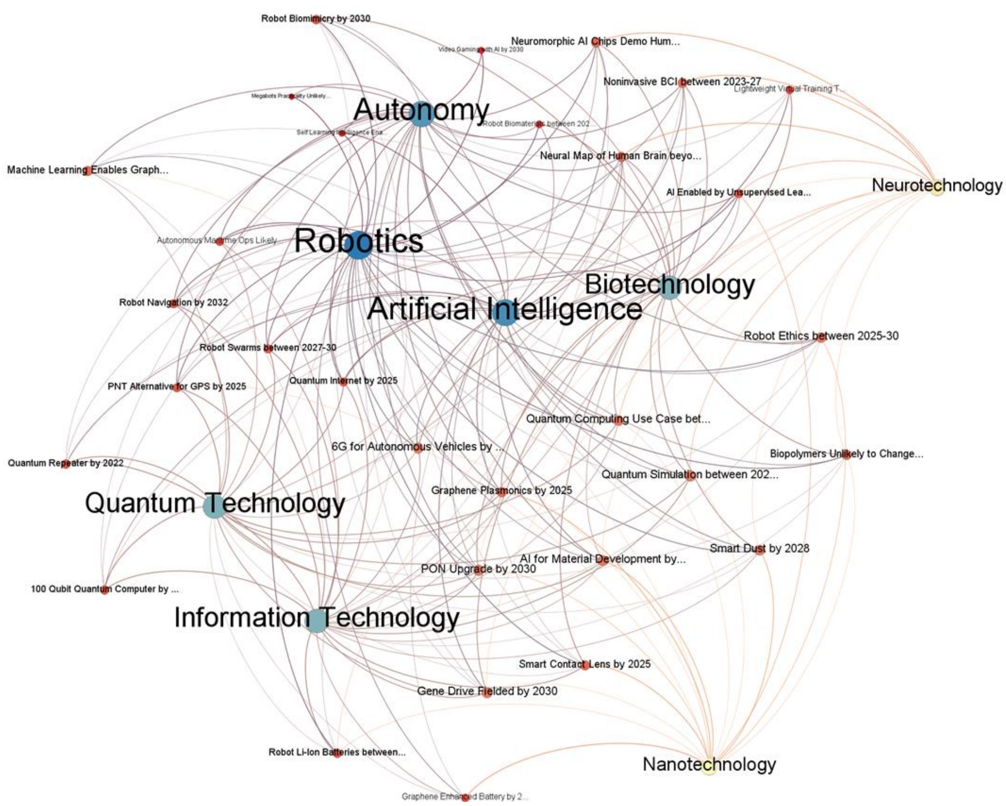
Introduction

How, when, and where are artificial intelligence (AI), biotechnology, quantum technology, nanotechnology, neurotechnology, autonomous technology, robotics, and information technology likely to converge in ways relevant to the United States Army over the next 15 years?

Based on 31 innovations likely to occur across all eight of the named disciplines, there are at least six distinct, substantial technology convergences also likely to occur that are relevant to the United States Army over the next 15 years.

It did not escape the team's notice that the unrestricted convergence of 31 innovations has the potential to produce 1.7069174e+46 possible outcomes. That said, based on analyses using nominal group technique, time series analysis, network analysis, and intuition, the team narrowed down the results to those six convergences in which they have the most confidence and meet the three goals of being significant, militarily relevant, and occurring on or before 2035.

A compelling metanalytic finding based in large part on viewing the disciplines and their associated innovations in a network rather than in isolation, is that robotics, AI, and



Eigenvector Analysis of Innovation Influence on Technological Disciplines autonomous systems will likely benefit the most from innovations in theirs and other disciplines, followed closely by biotechnology, information technology, and quantum technology. The two remaining disciplines, neurotechnology and nanotechnology, did not appear to benefit substantially from the identified innovations in the other disciplines; however, they were mass enablers of the advancements in the other fields.

Of the six identified convergences, those dealing with the architectures of specific disciplines and information technology proved vital, followed by AI, virtual applications, and physical devices or processes. The key findings are as follows:

Quantum Internet and Passive Optic Networks (PON)

Researchers from Sussex University have found a way to offer super fast and hyper-secure quantum internet all by exploring the technology of Quantum Computing Entanglement.
Source: cybersecurity-insiders.com

It is highly likely innovations in information technology architecture, AI, quantum technology, autonomous technology, and nanotechnology will enable decentralized AI management of information processing and networking by 2035. Robust PONs will provide future data availability and quantum internet will provide network security, as well as data confidentiality and data integrity. Over the same timeframe, the processing power of Internet of Things (IoT) devices will enable distributed and edge processing to be decentralized and remotely managed by AI. Driving this convergence are a number of research programs and recent accomplishments. Specifically:

China conducted quantum entanglement from space at a distance of 1200-km, as reported by Lee Billings on June 15, 2017 in the Scientific American.

- The Quantum Information Sciences (QIS) research center in Long Island, New York, consisting of a partnership between Brookhaven National Laboratory (BNL), Stony Brook University (SBU), and Mael Flament, CTO of Qunnect Inc., reported they can consistently perform quantum entanglement over a 60-mile fiber optic network. They are also testing a commercial quantum repeater and quantum memory mid-2020, which they anticipate will be available on the market in 2022.

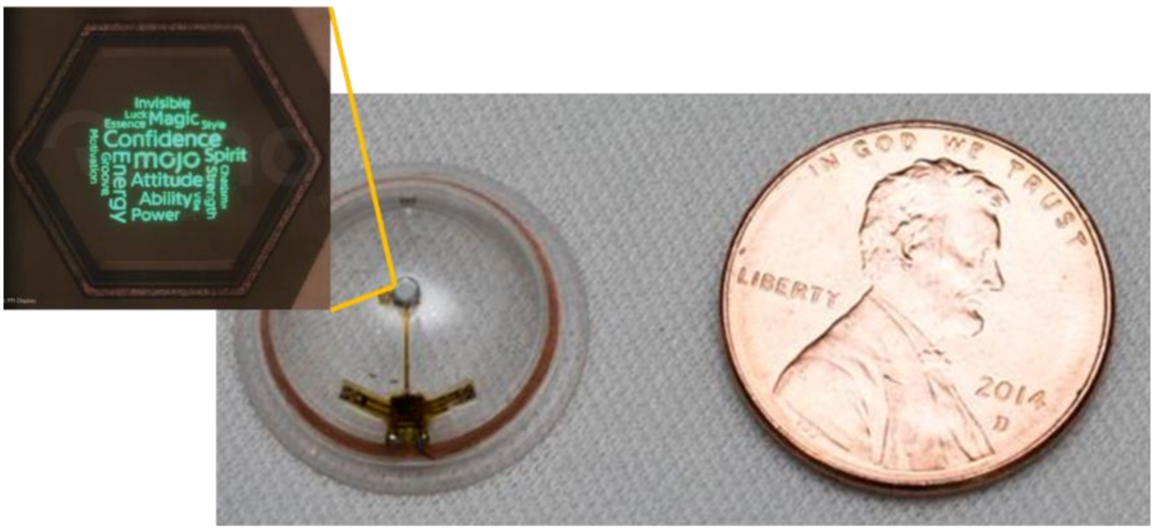
- US PON is being upgraded from 2.5G PON to 10G PON and the next upgrade will be to 25G PON and possibly 50G PON as reported in Broadband Technology Report March 20, 2019. In contrast, China Telecom Americas reported China already has 100G links and is transitioning to their Optical Network 2.0 which will deliver 200G and 400G.

Possible use case:

Quantum Internet delivers secure and protected data, delivering on Confidentiality, Integrity, and Availability (CIA). A robust PON architecture provides the overmatch, network agility, and network maneuver to conduct both offensive and defensive cyber operations and win in the Cyber Warfare Domain between 2030 and 2035.

Human Machine Interfaces

It is highly likely that innovations in nanotechnology, neurotechnology, biotechnology, information technology, quantum technology, and AI will allow for the mass production of human-to-computer interfaces that will reduce or even eliminate the use of mobile device visual/touch interfaces over the next 15 years. Over the same timeframe, noninvasive devices such as Augmented Reality (AR) goggles and contact lenses, will give way to invasive implants such as bionic corneal replacements and more advanced noninvasive Brain Computer Interface (BCI) options. A variety of recent research



Mojo Vision's prototype smart contact lens with high resolution micro display.
Source: CNET.com

initiatives and new products support this finding. Specifically:

- CNET Senior Editor Scott Stein personally tested working prototypes of smart contact lenses that enable night vision and micro screen display capabilities early in 2020 as illustrated above.

- French Engineering School IMT Atlantique developed a method to incorporate transparent, flexible graphene-based power sources into contact lenses that can power LEDs for several hours according to a recent press release.

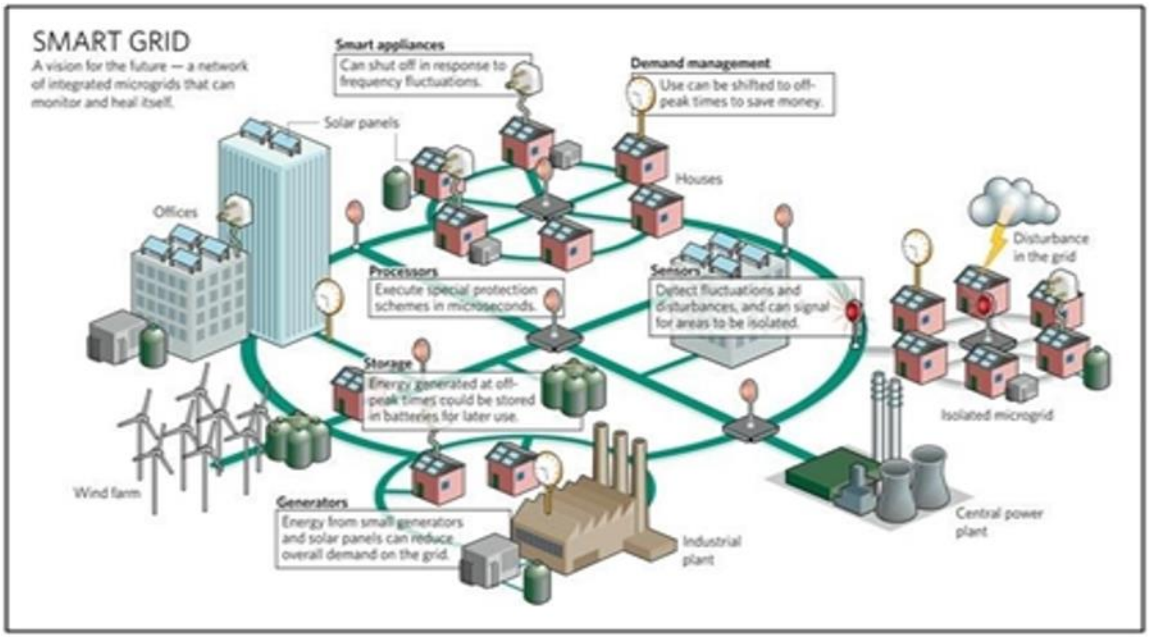
- Researchers from the Shenzhen and Nanyang Technological University propose that 6G with 1 terabit/second speeds and .1 millisecond latency will enable collaborative AI that communicates, thinks, and reports changes faster than a human can react.

Possible use case:

This convergence will permit advances like a physically integrated Heads-Up Display (HUD) for automatic identification and marking of friends, foes and unknowns in a soldier's field of vision while squad and platoon leaders will be able to push AR markers allowing for the concentration of fires or waypoints for movement.

Smart Cities

Large cities in technologically sophisticated countries are likely to integrate operations through the convergence of decentralized artificial intelligence, edge computing, autonomous systems, and 5G, by 2025. As telecommunications continue to advance, 6G will merge with these technologies, likely by 2035. While technical innovation is a primary driver for this convergence, other business and social factors significantly



Smart Grid Technology outlining interactions between city infrastructure
Source: engineering.electrical-equipment

influence this convergence as well. Specifically:

- C40 Cities represent a pact made between the “top 40 cities in the world” to create a path to reducing the global temperature by 1.5 degrees Celsius by 2030. C40 states the creation of smart cities will help them meet their goal. The list of smart cities throughout the world continues to grow exponentially making it likely the C40 will become the C100 before 2030.

- IBM’s Tririga artificial intelligence platform leverages the IoT to harvest complex federated building data to provide companies with strategies for optimizing building design, layout, usability, energy management, and maintenance. IBM states their AI saves 20-30% in building energy costs through automation.

- Siemens technology provides a similar IoT platform and is attempting to capture multiple city service markets. Siemens has demonstrated the ease of plugging in federated sensors from around a city into their platform within 10 minutes but state their application requires low latency information to improve timeliness and accuracy of services. In 2017, Hong Kong adopted Siemens IoT platform to create a “Smart City Hub” as a way to connect services with its citizens. Hong Kong officials report saving over 20% in public transportation costs since they started using Smart City Hub to manage its services.

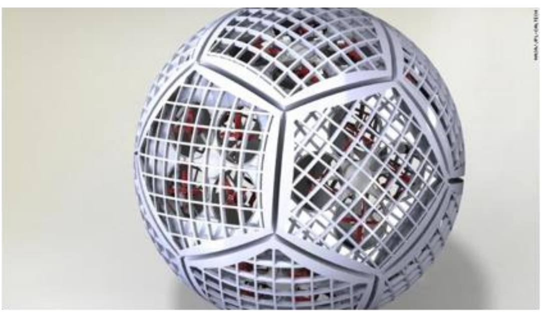
- NVIDIA’s EGX artificial intelligence chip, which is being used for edge computing, optimizes data management by enabling machine learning to occur closest to the sensor or suite of sensors. They’ve also integrated edge computing with its city services artificial intelligence platform, Metropolis, as well as Ericsson’s 5G hardware. Ericsson reports they have made 42 memorandums of agreement throughout the world to integrate this technology by 2025.

Possible use case:
The flexibility inherent in a decentralized, self-learning intelligence across a complex domain such as smart city could be leveraged to establish the sensor-to-shooter architecture for multi-domain operations and self-learning, decentralized intelligence used to operate a smart city could be engineered and deployed to learn our adversary’s region/city with potential non-kinetic effect.

Advanced Robotic Employment into Austere Locations

The convergence of system capacity (AI, IT, and computing), combined with electromechanical advancements (robotics), and autonomy will lead to robotic colonies employed for exploration, system management, and resource retrieval (e.g., mining, fossil fuel drilling, aquafer discovery). As resource competition and technology competition increases, austere and hostile locations become rich environments for advanced robotics employments. By 2035, these robotic colonies are likely to be employed off-planet, on and under the open ocean, in desert and hostile environments, and even underground. Specifically:

- Ecoppa's E4 robotic system was cleaning solar panels in open terrain, without water, in 2014, as seen in their YouTube capability demonstration.



According to CNN Business, the top images top are early renderings of shapeshifting robotics, designed to alter shape to adapt to expedition and task requirements. The bottom image is an actual prototype in NASA's robotics yard of it's Jet Propulsion Laboratory. Obtained from "This shapeshifting robot could explore other planets"

- In 2017 UC3M, a multinational partnership, was developing BADGER, an intelligent underground robot for urban environments, according to EurekAlert!, an Advancement of Science website. Solar panels are being built and maintained on the surface of lakes and reservoirs. K-water, a Korean Water Resources Corporation has demonstrated that a floating 100kW and 500kW, employed in South Korea, is 11% more efficient than overland capacity.

- The Yara Berkshire, the first autonomous shipping vehicle, currently under construction, is projected to run a precise inland water route in 2022.

- Royal IHC Mining, a Dutch company, is developing commercialized mining of the ocean floor, while NTNU, a Norwegian University research effort, introduced an environmentally sound methodology for the same efforts.

- NASA continues to explore space exploration in orbit, or in open trans-navigation, and Mars research and study.

Possible use case:
Colonies of autonomous robots work rapidly in multiple domains to perhaps decontaminate an area after a chemical attack, repair damaged equipment while under fire, or provide C2 nodes between soldiers and airborne or terrestrial operations centers.

Stealthy Robotic Systems

This swarm of search and rescue drones can explore new, potentially dangerous spaces without a human controller or even GPS.
Source: [discovermagazine.com]

The convergence of artificial intelligence, 5G (or higher) information technology and fabrication innovation (3D printers) with advances in battery and navigation approaches, bio-inspired robot designs, nanotech soft materials and multi-robot cooperative systems are likely to give rise to small and stealthy robotic systems that operate below detection thresholds by 2030. Expensive, and highly capable military platforms will likely be replaced by many, cheap, and good enough systems that create "battlefield mass". However, international action to limit the combat role of military robots make an international convention against deploying lethal autonomous weapon systems highly likely. Driving this convergence are a number of both technical and political considerations. Specifically:

- Battery technology evolution will be a key driver of robot capabilities according to Dr. Henrik I. Christensen, Qualcomm Chancellor's Chair of Robot Systems and a Professor of Computer Science at Dept. of Computer Science and Engineering UC San Diego. Competition between battery variations like graphene and lithium-ion will drive down the costs of both, providing a variety of power solutions for untethered robots by 2025.

- Soft robots made from the convergence of nano-and bio-technology tissue engineering are likely to result in bio-hybrid systems with unique sensing, dynamic response, and mobility according to biomedical engineer Giada Gerboni, PhD, Postdoctoral Fellow at Stanford University.

- "Multi-robot cooperative systems that mimic animal group behavior is viable and a cornerstone of unmanned aerial vehicles. Many applications could be done using a large swarm of simpler, cheaper robots rather than a single $1 million robot," said Souma Chowdhury, assistant professor of mechanical and aerospace engineering at University of Buffalo.

- Pragmatic diplomacy from major states eager to lock in their relative advantages while using collective power to lock out competitors, will likely result in an international agreement albeit with weakly enforceable provisions against combat robots.

Possible use case:

Large numbers of "Swarm-Bots" with high levels of flexibility, fabricated in real-time and on the spot (3D printing), will perform search and rescue missions. They will work autonomously and easily adapt to changing environments with unforeseen hazards e.g. natural disasters like hurricanes or earthquakes, collapsed buildings, and combat. AI will give them the ability to work autonomously without any infrastructure or centralized control system.

Autonomous Field Deployable Additive Manufacturing

Innovations within the next ten years in nanotechnology, bio-materials, AI enhanced materials prototyping, edge artificial intelligence chip computing, and sixth generation telecommunications are likely to result in field deployable autonomous systems capable of identifying, harvesting, and manufacturing rare earth materials for weapon system parts in austere locations by 2030. A number of products currently in development or production along with several large -scale research initiatives support this convergence. Specifically:

- Start-up company, Cintrine Informatics, uses an artificial intelligence platform to predict what materials would best be used in the design, as well as material availability within the supply chain. Panasonic was an early adopter of Cintrine's platform and has acknowledged significant improvements in the speed of material discovery by 25%.

- Australian start-up company, Earth AI, demonstrated the ability to locate rare earth materials using predictive modeling machine learning built from layers of commercially available historical terrain information and satellite imagery. To make this a reality, Earth AI is developing a suite of AI-enabled autonomous systems, such as swarming drones that communicate site prospects to mobile autonomous drilling rigs to extract the minerals.

DJI quadcopter for Earth Imaging, DJI image.
Source breakingdefense.com

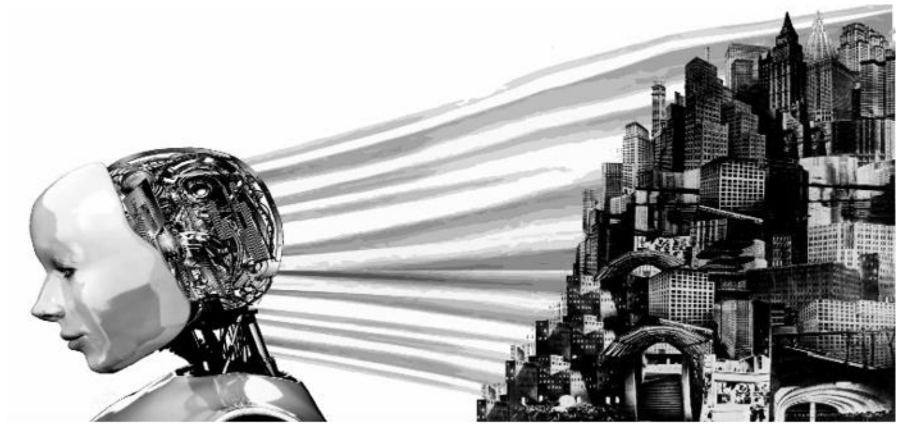
- Canadian artificial intelligence mining start-up, Goldspot, has partnered with over 100 major mining companies to evolve their practices with machine learning.

Goldspot anticipates exponential partnership growth within the next 3-5 years because of their ability to drive down cost and schedule risk for traditional mining companies.
- In August 2018, respected tech-forecasting firm Gartner estimated widespread usage of smart dust more than 10 years out, but on the path to commercialization. Smart dust would provide environmental data that makes this analysis possible.

Possible use case:

Long- and short-range autonomous drones prospect, extract, and manufacture materials for production for weapon system parts in austere locations by 2030.

Additional Finding



Artificial Intelligence Architecture pictorial representation. Source: futurearchitectureplatform.org

In order to unlock the potential of autonomy, robotics, biotechnology, and neurotechnology for the Department of Defense, likely requires a greater understanding of how information technology and artificial intelligence create the digital architecture. Renowned technologists and artificial intelligence experts have explicitly commented on this requirement.

- According to Michael Kanaan, Massachusetts Information Technology Artificial Intelligence Accelerator, Air Force Director of Operations, digital interoperability between weapon systems for multi-domain operations is limited. Verification of interoperability is late in the weapon system development and results in design trades to ensure product schedules are maintained. This includes computational hardware and logic considerations.

- According to Mr. Hunter Price, former Air Force Digital Services Director, real-time sensor-to-shooter operations across multiple domains requires an understanding of distribution of bandwidth, location of computational power, and latency impact on performance to weapon systems.

- 5G and 6G telecommunications offer significant opportunities in bandwidth to operate autonomous and robotic systems; however, latency and cost considerations must be considered if communicating to cloud infrastructure. Depending on the amount of autonomy given to the system, bandwidth can be optimized by pushing decision-making closer to the edge.

- According to Dr. Thomas Longstaff, Carnegie Mellon University Chief Technologist, indicated decentralized and swarm intelligence coupled with edge computing offers significant weapon system design flexibility.

- Dr. Thomas Longstaff also stated digital twins are required to improve the confidence and trust in the “artificial intelligence black box.”

- Quantum sensing offers substantial position, navigation, and timing advantages for real-time communications, especially when provided at the edge.

- Mr. Michael Kanaan also stated the Department of Defense (DoD) and traditional defense industrial does not have the technical expertise required to create the digital architecture. They should consider evaluating their current military and civilian workforce for pre-cursor computer language skills that could be quickly advanced to create this digital architecture. He suggested the individual services treat computer language like foreign language, providing an initial Defense Language Aptitude Battery (DLAB) to screen candidates with selectees to attend an 18-week artificial intelligence and machine learning kick-starter.

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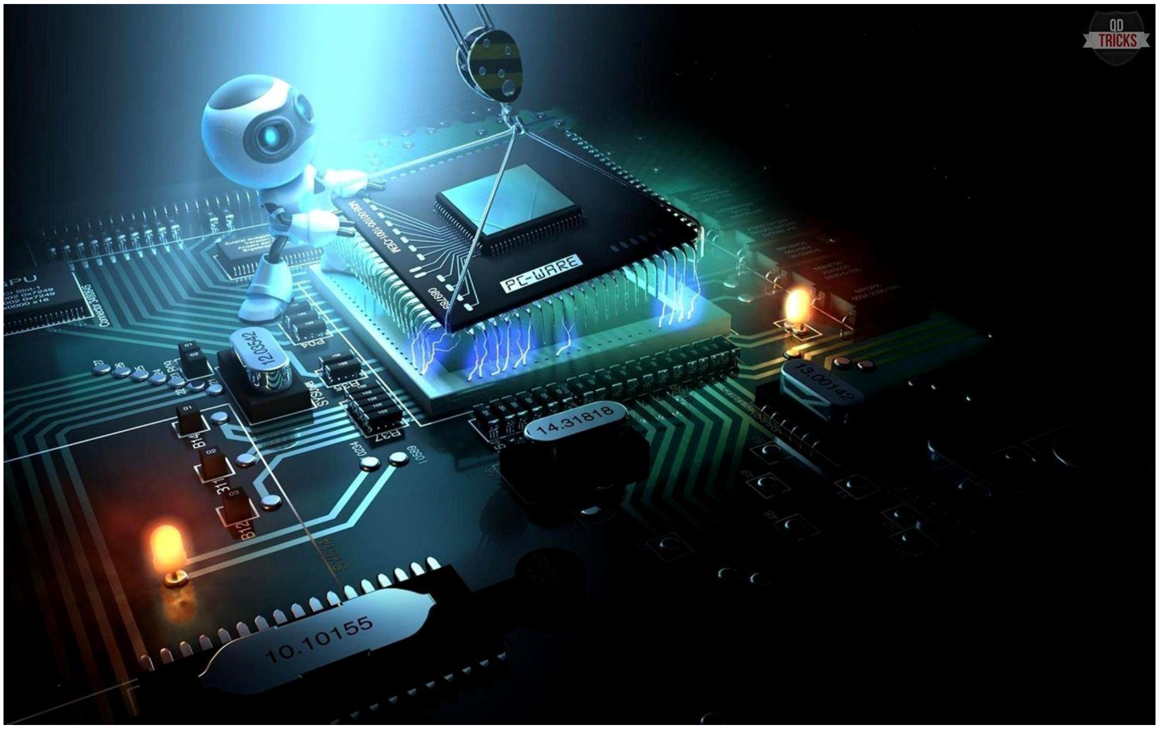
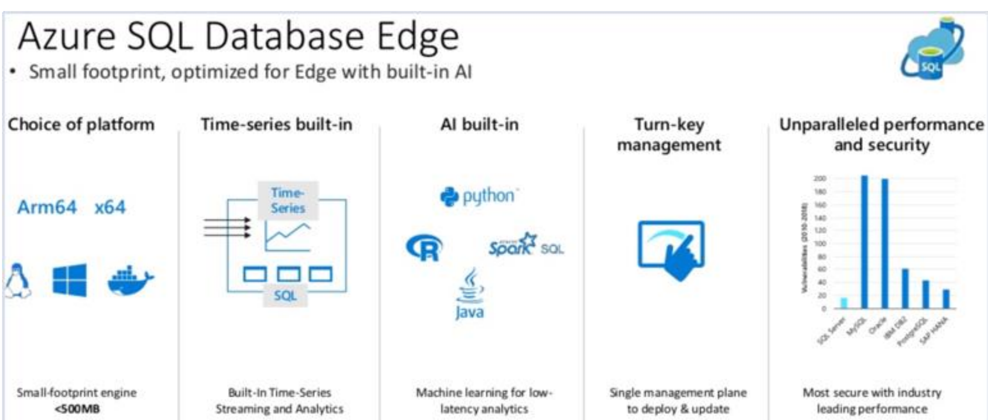


> The technology keeps moving forward, which makes it easier for the artists to tell their stories and paint the pictures they want.
>
> **George Lucas**

Quantum Internet and PON network-based convergence

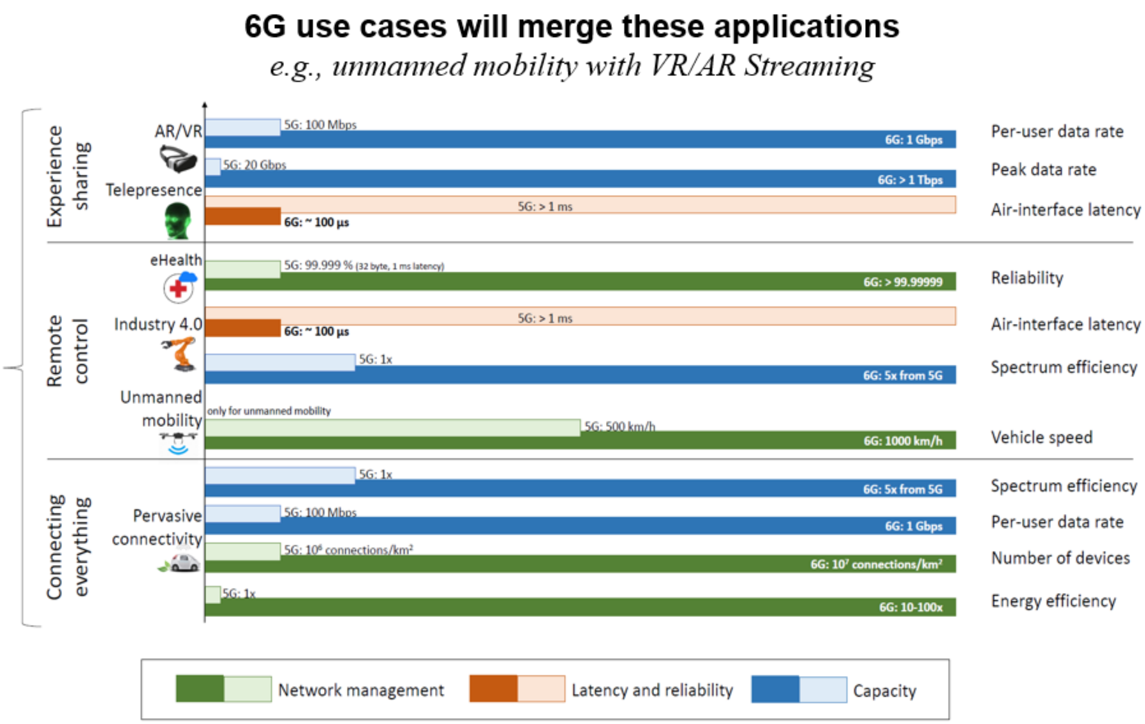
It is highly likely innovations in information technology architecture, AI, quantum technology, autonomous technology, and nanotechnology will enable decentralized AI management of information processing and networking by 2035. Robust PONs will provide future data availability and Quantum Internet will provide network security as well as data confidentiality and data integrity. Over the same timeframe the processing power of the Internet of Things (IoT) devices will enable distributed and edge processing to be decentralized and remotely managed by AI:

- Robust PONs capable of handling in excess of 25 Gbps will provide the connectivity required to support 6G data rates of 1 TBps per device with latency of .1 millisecond between 2030 and 2035.
- Long distance quantum internet will provide Confidentiality, Integrity, and Availability (CIA) of the IoT which will be managed by AI to optimize networking and information processing. Quantum computing will provide the computing power beyond what classical computers can provide to empower AI to optimize network management and reduce analysis and decision cycles by 2030.
- The number of Internet of Things (IoT) devices will increase from 22B devices in 2020, 41.6B requiring 79.4 zettabytes (ZB) of data in 2025, and over 50B devices in 2030. These devices will require less power and will provide increased processing capability with greatly increased demands for data. The number of IoT devices is predicted to be between 50-125B processors by 2030 which will make the IoT one of the most powerful meshed networks in the world. [HHH]
- Decentralized processing will be accomplished using remote AI and edge computing to leverage the connectivity and processing power of billions of IoT devices which



Azure IoT edge enabling the intelligent edge.
Source: https://www.slideshare.net/dpcons/azure-iot-edge-and-ai-enabling-the-intelligent-edge

will form a globally meshed network. Collaborative AI will then be able to leverage Autonomous devises capable of learning and working together to optimize the network. The IoT will be an AI sensor, processor, memory, and collaborative learning machine. H



Representation of multiple KPIs of 6G use cases, together with the improvements with respect to 5G networks.
Source: arxiv.org

Use cases:

- Azure SQL Database Edge is 2019 technology using AI to manage information processing networks which is a precursor to the more capable system needed in 2030-2035. H

- Between 2030 to 2035 the Quantum Internet will transverse the PON to support 6G devices operating on the edge of the network. The quantum internet will also include optical links. 6G devices will deliver 3D information to support High Speed Autonomous Vehicles with AI providing Information Processing and Network Management of the meshed network to optimize the interaction of devices using distributed processing. AI will remotely manage the billions of IoT devices across this secure network making this possible. H

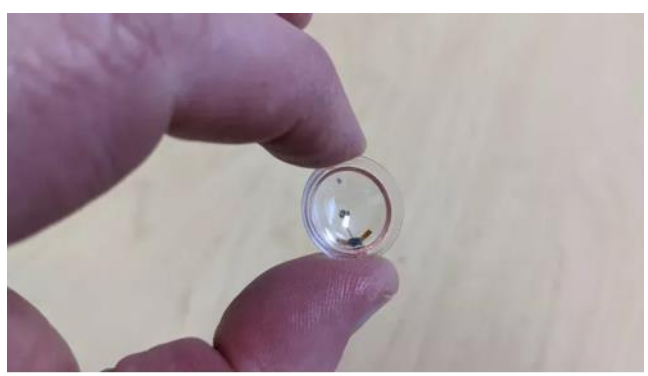
Human Machine Interface Time and Networked-Based Convergence

It is highly likely that innovations in nanotechnology, neurotechnology, biotechnology, information technology, quantum technology, and AI will reduce or even eliminate the use of mobile device visual/touch interfaces over the next 15 years. Over the same timeframe, noninvasive devices such as Augmented Reality (AR) goggles and contact lenses, will give way to invasive implants such as bionic corneal replacements and more advanced noninvasive options such as BCIs.

- AI for material development, PNT alternatives to GPS, graphene plasmonics, and devices such as smart contact lenses enable manufacturing prototypes of new mobile computing, navigation, communication, nano-sensor, and human-to-machine interface devices by 2025.
- Leveraging machine learning to create new biomaterials, unsupervised learning to enhance AI, PON upgrades, and acceptance of graphene battery technology is likely to drive the increased use of capacitors over traditional mobile energy sources along with wide-scale marketing of home and office use human-to-machine nanoscale interface devices by 2030.
- As information technology continues to improve, the world will likely move from 5G to 6G communications by 2035 allowing for secure and field deployable quantum computing, AI augmented human decision making, and near real-time human-to-machine connectivity for semi-autonomous operations.

Use cases:

- By 2025, industry shifts market share from smart phone/watch/tablet development to nano-scale mobile devices capable of providing smaller, faster, better human-to-machine interfaces. By 2030, FDA approval of semi-invasive wearable devices hits mainstream marketing. By 2035, 6G network speeds allow for wide-scale field deployability of permanent or removable nano-scale interface devices and adoption by consumers and military forces alike.



Mojo Vision's working prototype of AR smart contact lenses.
Source: Tomsguide.com

- Mojo Vision recently produced prototypes of Augmented Reality contact lenses (Figure 1) that could conceivably be integrated into corneal replacements to make bionic vision a reality with blink activated interface controls. The future for these devices are host for an advanced array of sensors and antennas capable of broadcasting videos or gathering environmental data, enhancing the IoT. Single use AR contact lenses prototypes, night vision and micro displays, currently exist and have military relevance, but have yet to receive FDA approval. FDA approval is most likely to take between three and seven years before commercial and military adoption can proceed.

"Smart City" Convergence

Large cities in technologically sophisticated countries are likely to integrate operations through the convergence of decentralized artificial intelligence, edge computing, autonomous systems, and 5G, by 2025. As telecommunications continue to advance, 6G will merge with these technologies, likely by 2035.

- Decentralized artificial intelligence coupled with edge computing is the key to accelerate delivery of services to consumers across a complex domain. Technical capabilities and regulatory hurdles indicate that this capability is likely to set to come online no earlier than 2030.
- Neuromorphic chips, simulating parts of human-like reasoning and memory on a single chip, are already being distributed and should show human-like memory and logic functions by 2027.
- Artificial intelligence has been integrated into edge computing, enabling decentralized artificial intelligence closer to the sensor or suite of sensors.
- Self-learning intelligent systems are likely to enable autonomous city services by 2030.
- Even though 6G will likely experience challenges in technical integration within metropolitan cities, as well as delays in obtaining regulatory approval to use artificial

Figure 1 NVIDIA's Metropolis Smart City platform leveraging edge computing and deep learning.
Sources: [NVIDIA.com] and
[University of Queensland Brain Institute].

intelligence to manage networks, it’s likely to provide the speed and low latency necessary for real time adjustments to city operations by 2035.

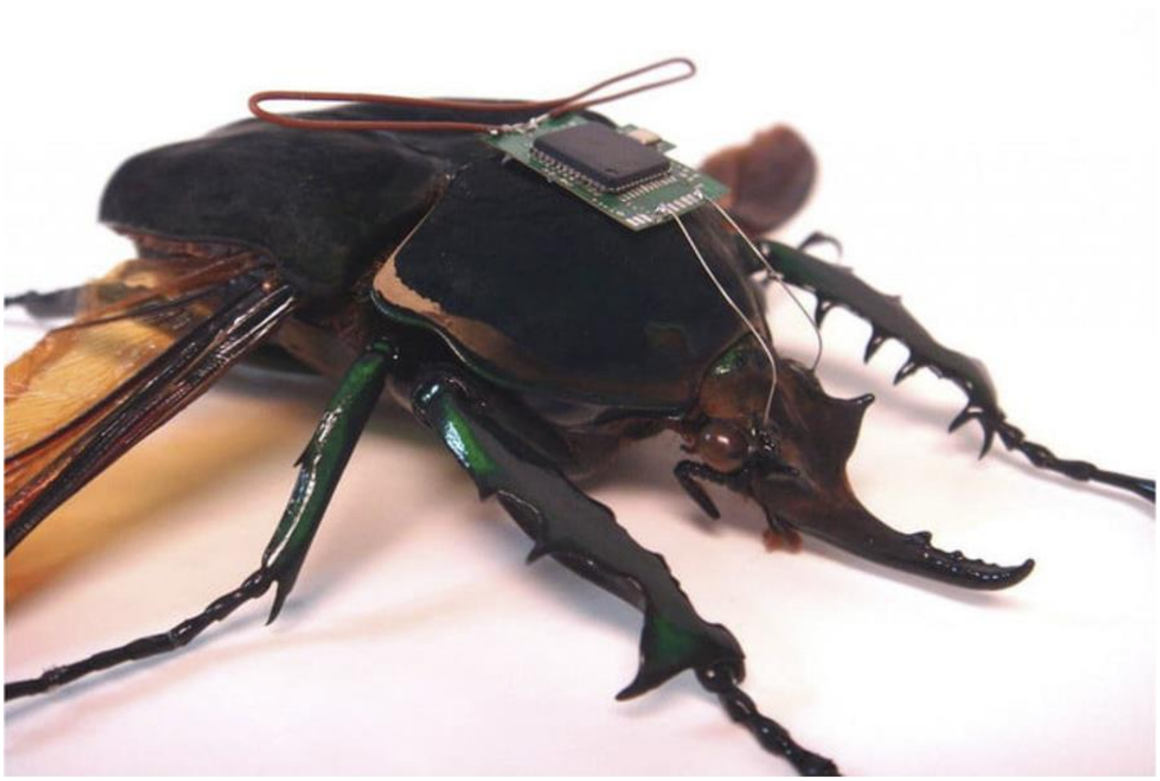
Use cases:

- The flexibility inherent in a decentralized, self-learning intelligence across a complex domain such as smart city could be leveraged to establish the sensor-to-shooter architecture for multi-domain operations.
- The self-learning, decentralized intelligence used to operate a smart city could be engineered and deployed to learn our adversary’s region/city with potential non-kinetic effects.

Autonomous Robotic Colony network-based convergence

By 2035, autonomous robotic colonies are likely to exist in austere, hostile, or otherwise uninhabitable societies. Development in biomimicry, autonomous swarm navigation, and scale development in undersurface and surface (water and land) autonomous vehicles, combined with quantum sensing, graphene battery development, and navigational micro-chip development make unmanned civilization possible. Purpose-driven technology enables possible oceanic, or even interplanetary resource collection and study. Finally, Royal IHC mining, SpaceX, NASA, K-water, and UC3M Robotics are currently investing in and studying those capabilities now.

With the emergence of multiple technologies within the next 15 years, unmanned, or robotic colonies become possible. These robotic civilizations *could* have numerous potential habitats and purposes. For example, distinct robotic colonies, again, could self-navigate, self-learn, self-sustain, and either transit under its own ability or maintain and utilize autonomous transport. Multiple milestones that make this possible come together

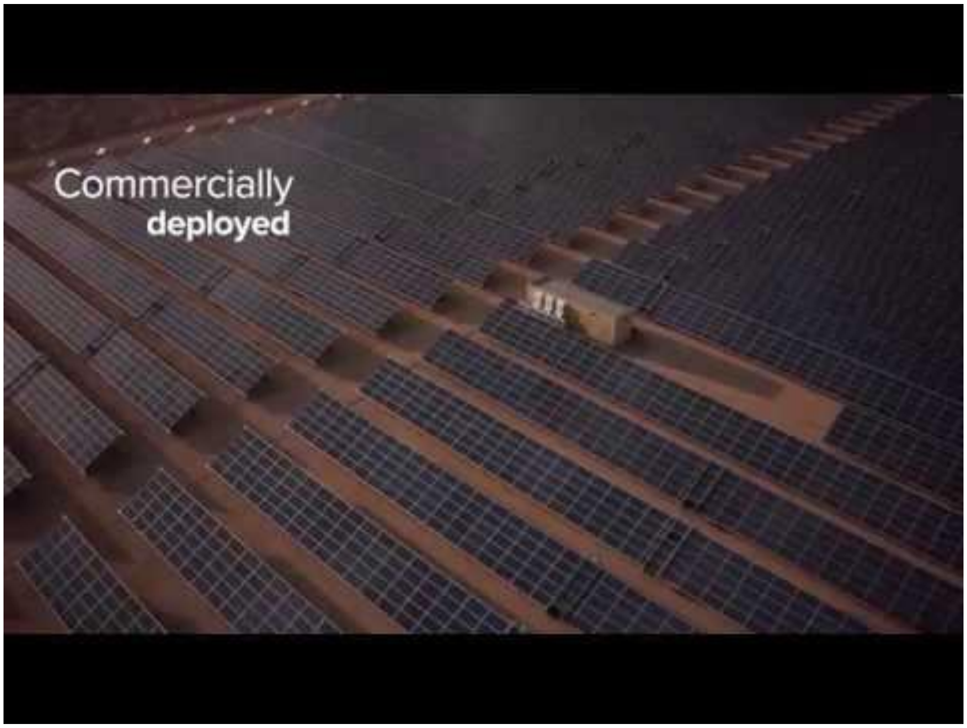


A cyborg beetle, part of DARPA's Micro Air Vehicles and Micro Electrical-Mechanical Systems research. DARPA has demonstrated ability to control insects in flight. Sources: digitaltrends.com and inverse.com within that timeframe. Moreover, the motivations and needs of humanity make this likely by 2035.

The universal nature of some emerging technology applies to the broad spectrum of machine-enabled human societies and robotic colonies alike. Among these are the technological capabilities like lithium-ion or graphene battery development, machine learning, and PNT navigation without the aid of GPS. Moreover, more nuanced technology, like smart dust, swarm AI and autonomous navigation increase reliability and connectivity. Finally, the fiber back bone and wireless technology advancements, enabled by advancements in quantum technology ensure seamless operations in a robust society.

Here are some applications for robotic colonies that make them likely:

Land Surface



Video of Ecoppia's E4 robots maintaining and cleaning solar panels without water.
Source: ecoppia.com

Much of the Earth's land surface is uninhabitable. Humans can operate in or through these environments, while bringing and using their own life support systems. One of the easiest examples is a desert environment; that desert environment could be the Sahara Desert or the center of Antarctica. These parts of the planet may prove useful for various applications, such as solar or wind power development, as well as scientific research of planetary, weather, or any other field of study that uninhabitable, sparsely populated areas could provide. The Office of Polar Programs requested $535 million dollars for FY19, of which $420 million were for infrastructure support, including over $100 million on logistics.[H] Finally, over $6 million was requested for Polar Environment, Health, and Safety (PESH).[H] The requirements for manned involvement in the polar regions, among others, becomes clear.

With the advent of an autonomous shipping fleet likely by 2035, which will not require human life support systems or requirements, logistical flow in and out of the polar regions would decrease. With the human error estimated as high as 96%, and with crew expenses for transport shipping vehicle support accounting for 30% of the budget, eliminating these issues will bring down cost substantially.

The highly likely advancement in robotics to create biomimicry, create locomotion, and use both soft and hard material sciences can make robotic societies more than suitable for harsh environments on the surface. Furthermore, with the highly likely advent of robot navigation in disordered environments by 2035, the survivability increases substantially. The likelihood of the availability of swarm artificial intelligence availability and high likelihood of advanced PNT navigation and telecommunication availability by 2025 create onboard possibility for robotics. Finally, 6G availability (or localized 5G), Quantum internet and 100 Qubit prototype quantum computers, all by 2035 (2035, 2025, and 2030, respectively, for likely initial fielding) will ensure robotic connectivity, updates, and guidance (if needed or desired).[M]

Use Case

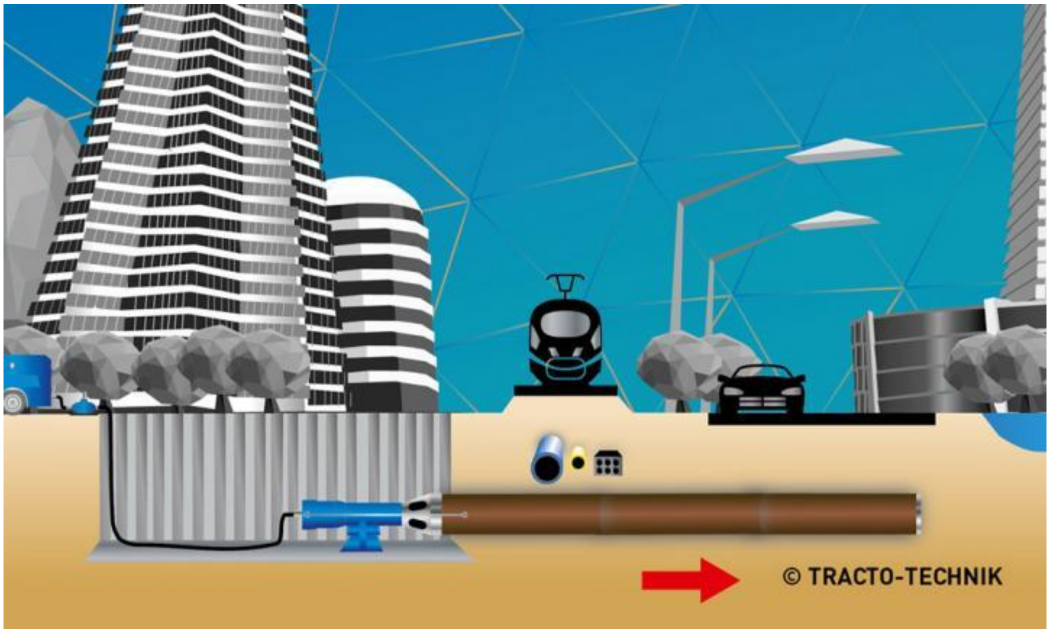
Robots of some shape and size, are likely to exist in a desert society to provide maintenance support, logistical support, data collection, and protection (environmental) in an effort to further science, energy production, while promoting green energy concepts, utilizing AI and autonomous technology across highly advanced systems.

Land Underground

As first world societies continue to advance, and developing societies lay the initial architecture and foundation of advanced societies, subsurface applications have critical implications. For example, China has 100 cities with over 1 million people, each. Safety is of paramount concern, while daily disruption can cost time and resources to any government or corporation and sew discontent among any inconvenienced by traffic, loss of connectivity, or other currently readily available technology. Subsurface technology, intricately linked in smart cities, or even fed by smart cities, likely by 2030, (i.e., originating in and disseminated by smart cities) to the urban or rural communities surrounding them.

Robotic colonies, coupled with AI (possibly creating virtual AI colonies) can use antbot and biomimicry technology, coupled with advanced navigation of the NOAC chip and AI swarm navigation technology, while relying on smart dust technology and riding on previously unrealized connectivity, and are likely to exist by 2035. Human society can benefit from this technology in ways never before considered. These robotic colonies *could* live in sewage system, gas piping system, and other underground, hostile environments incapable of supporting human life. UC3M Robotics is currently developing the Badger project, funded by Horizon 2020, is working on technology to 3-D

DARPA Subterranean (SubT) Challenge effecting development of the autonomy, perception, networking, and mobility challenges necessary for underground exploration and mining. Source: darpa.mil



Rendering of an intelligent underground robot for urban environments. Scientists from Germany, Greece, Italy, and the United Kingdom (UC3M Robotics participants) work on the BADGER (roBot for Autonomous unDerGround trenchless opERations, mapping, and navigation). Source: eurekalert.org

print, using specifically designed robots, within piping and around cable to reduce noise and disruption.[H] Furthermore, enabled by AI self-learning, vehicular autonomy, swarm robotics and navigation in disordered environments coupling with advanced PNT, all converging by 2030, these robotic societies could navigate subsurface on required existing infrastructure for every society. Finally, these robotic societies can repair damages, solve problems, discover sink holes before they become catastrophic, determine un-sound structural anomalies, and detecting water contaminants, while not disrupting the human society they support. Finally, this same technology has uses for discovery in mining, fuels, or freshwater aquafers. In fact, DARPA's 2019 challenge was for underground purposeful autonomous robotics.[H] This is likely by 2035.

Use case: In Tokyo, Los Angeles, and Beijing, with current population of 38 million, 18 million, and 23 million, respectively (one source estimated Beijing may have 50 million inhabitants by 2050), subsurface robots and AI, using biomimicry, composed of soft and hard materials, monitor and maintain critical infrastructure of these megalopolis societies.[HHH] Together, enabled by smart dust and incredible connectivity, light-weight materials and sophisticated battery technology, these robotics and AI ensure safe, fresh water, sound energy, electricity, and structure, while monitoring to protect against fires, contaminants or other seismic activity.

Water Surface

Like some land surfaces, the surface of open-water ocean is uninhabitable, and two-thirds of the planet are covered in water. The open space and austere location create unique, opportune environments. For example, the study of weather, or even solar energy collection/management. There also may be other advantages and opportunity never-before considered due to the inability to inhabit and govern those areas, and rightly so. Any ocean-based vessels are at the mercy of weather systems, including hurricanes and typhoons. Robots, though, which can engage in biomimicry of sea life, use solar energy and self-sustain without food, water, or temperature management issues, may open untapped resources to aid humanity. Currently, K-water, based in South Korea, has demonstrated open water solar energy.[H] While not alone in this endeavor, they have further demonstrated an greater than 11% effeciency in open water photovoltaic solar energy on 100kW and 500kW power management.[H] This potential increase in power efficiency and collection *could* couple with autonomous sea vehicles (currently under construction for large-scale shipping and development for small-scale applications), advanced PNT, and robotic technology in biomimicry and energy management to create autonomous open water robotic colonies, likely, by 2035.

As with land surface robotics, logistics, and autonomous vehicle technology, the same opportunities, risks, and cost-benefit analytics apply. However, robotics and autonomous vehicles can employ advanced technology. For example, robotics, AI, and autonomous

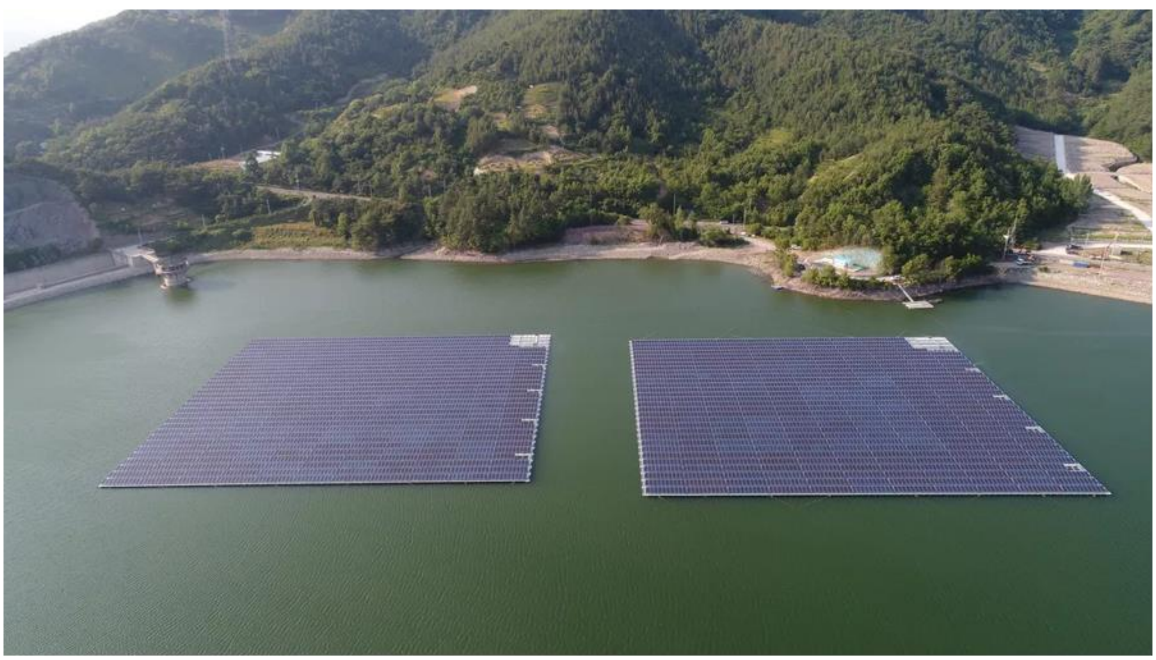


Photo of floating solar cells Geumjeon floating power plant in South Korea. Source: medium.com systems *could* fold up solar panels, dive underwater several hundred feet, below disruptive weather systems, and resurface after time. Connectivity and battery capacitance, coupled with AI, *could* ensure pre-emptive actions, appropriate test systems, and corrections of failed systems. It then *could* sustain sub-surface resilience, before re-surfacing and re-employing its systems.

Use Case

Sea-surface robotics, coupled with AI, and autonomous sea vehicles can utilize future technology of robotics (biomimicry and material science) to sustain, maintain, and completely manage sea-surface solar farms in the open ocean. The increased connectivity and computing will enable uninterrupted energy supply trains. This capability is likely, based on emerging technology to create never-before considered energy development.

Water Undersurface

Photo from the Norwegian University of Science and Technology website, touting "new solutions for evaluation, exploration, and extraction of sea-based minerals under societal responsibility for the environment and the international heritage of mankind.
Source: Norwegian University of Science and Technology

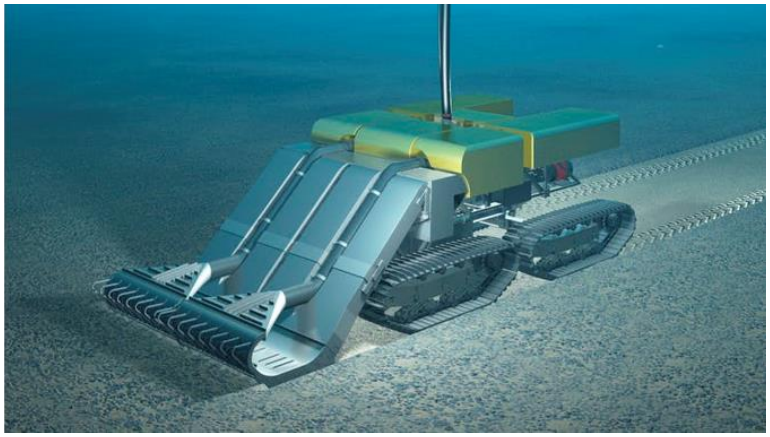
The undersurface of the sea holds considerable mysteries. Various motivations associated with science and curiosity, like seeing a giant squid, for example, create significant global interest. Governments, too, have interest undersea, but more at the sea bottom. Some of those interests include mining and mapping, as well as managing fiber optics and undersea warfare. Underwater is considered among the most difficult and hostile

Three-dimensional model of the Marianas Trench, the deepest part of the known ocean, where only three-crewed expeditions have reached.
Source: The Atlantic

environments to sustain life. It is similar to space exploration in that light. For human exploration of undersea environments, temperature and pressure management, as well as crew sustainment of clothing, oxygen, food, and fresh water make logistics and exploration untenable.

Robotics and autonomous undersea vehicles, however, have resilience for these environments. They can mine, record, explore, and report, using emerging communication capability, while benefitting from biomimicry and other navigation advancements. Through design perfections, robots and autonomous vehicles can easily sustain pressurization management, as one example. Royal IHC Mining is currently pursuing robotic extraction of polymetallic nodules, collections of rare earth metals (inluding platinum and tellurium) that form at 350C and under the pressures of the sea

Rendering of subsea crawler created by Royal IHC mining to harvest polymetallic nodules for the ocean floor. Source: theconversation.com

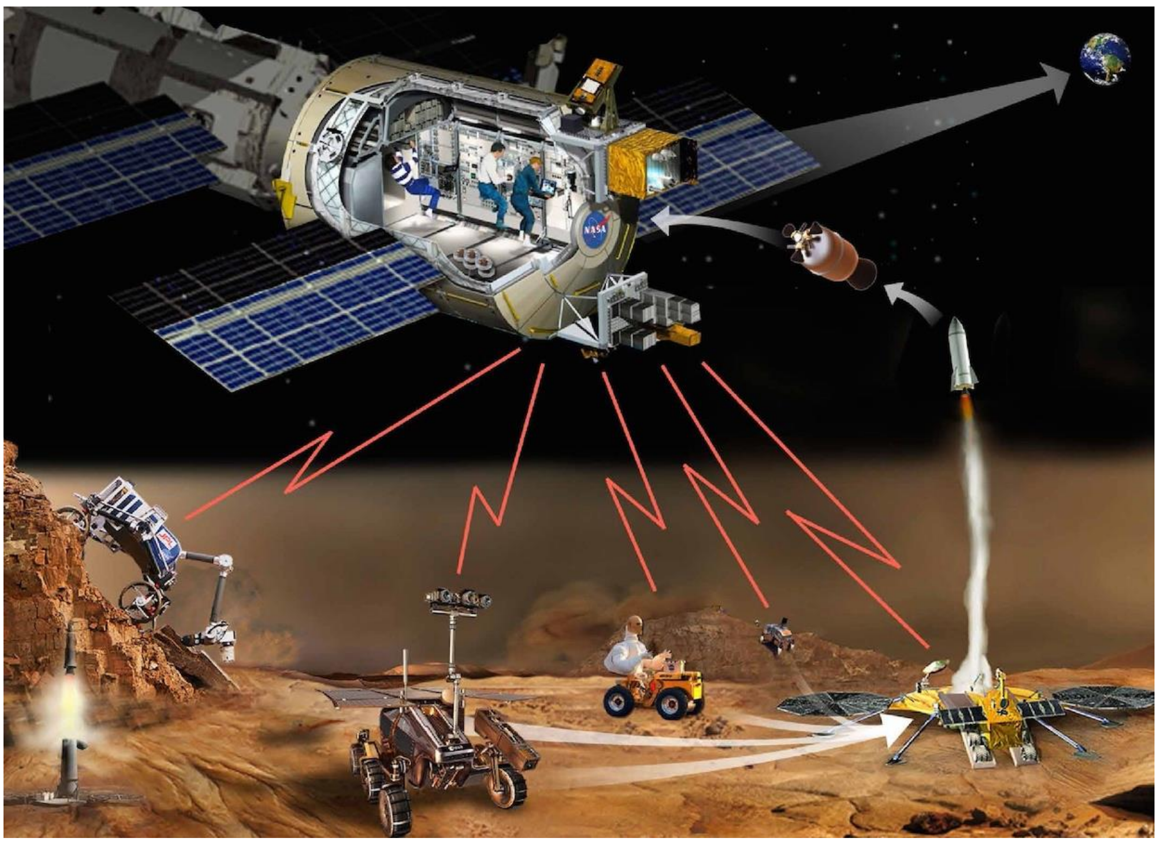


floor at depths of 4 thousand to 6 thousand meters.[M] These environments are so hostile, that only three manned crews have ventured into the Marianas Trench, the deepest part of the ocean, where humanity may yet capitalize on rich resources. Furthermore, a full undersea robotic colony can sustain itself and maintain a fleet of undersea vehicles and robotics, while using lots of tech and delivering on requirements. Emerging PNT, power systems, and swarm and autonomous robotics, employing biomimicry enabled by previously unknown connectivity, all likely by 2035, may enable humanity in previous unreachable ways on this planet.

Use case: autonomous undersea robotics can explore deep caverns, study wildlife, mine for rare earth minerals, and drill for fossil fuels. These vehicles are unhindered by surface weather, and they would not require tethers to the surface for manned vehicles. Upon task completion, they could deploy air balloons, and sound a beacon, automating a surface collective response. Furthermore, autonomous undersea vehicles can manage and lay fiber optic sea cables, which are currently responsible for 99% of all communications.[H]

Outer Space and Inter-Planetary Exploration

Like undersea environments, space exploration is dabbled in, at best. That is mostly due to the extraordinary logistical requirements to not only overcome the Earth's gravity, but also to carry enough life-sustaining equipment and resources to make the journey. This applies to travel and study to the moon, other surfaces, or into open space. However, if the physical, physiological, and logistical constraints can be overcome, the potential for space mining, biotechnological developments, cosmology, and communications development, never fully considered, become possible. Furthermore, humanity may do it just for the advancement in human endeavor, or Manifest Destiny for a new world in a new century.



Rendering of robotic automated systems conducting planetary research, mining, and other task requirements, then relaying data and resources to a space-based manned vehicle.
Source:spectrum.ieee.org

Recent capabilities in space exploration, like NASA emplacing the Mars rover with advanced autonomous robotic capabilities or Space X demonstrating impressive simultaneity in deploying 60 satellites at once or landing two shuttles on a barge at once, have not only demonstrated the possible, but also reinvigorated the potential.[HH] With the emergence of autonomy, advanced material sciences, advanced navigation, and unprecedented connectivity to unique robotic designs, space exploration becomes less a thing of science fiction, and a more likely event (all these technologies are likely to converge by 2035). The environmental limitations of space are less a roadblock and more a hurdle. Aside from study, resource and energy retrieval, as well as biomaterial development, may be the biggest benefactors (growing tissue in space without the burden of gravity, or using available resources to build in spaces).[HH] Robotic space colonies are likely by 2035

Use Case

deployed robotics with swarm technology, navigate to asteroids, or other surfaces, mine, and ship to building locations for space construction (as seen in Figure 9.), using advanced, AI and IT enabled, distributed command and control with onboard learning capabilities, thus creating unprecedented momentum toward a second space age from the backbone of a virtual age.

Other Environments

It is important to consider the possibilities of this convergence, not only for the possibilities listed here, but also for response to chemical, biological or nuclear events, as well as forest or urban fires, to name but a few. With these emerging technologies, robotic colonies *could* alter the safety requirements, and environmental controls, unlike ever before. Shape-shifting robotics, like those being explored by NASA currently, can disrupt technology in all physical domains.[H]

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were generally reliable and corroborative. The analyst had adequate time for research but worked alone and did not use a structured method, despite utilizing multiple technological convergences over multiple time horizons, and in multiple enviornments. Furthermore, due to the significat range of the possibilities for robotic colonies, this estimate *could* change as emerging technologies embrace unrealized potential and previously untenable environments.

Stealthy Robotic System network-based convergence

Innovations in longer-life, rapid charging batteries, navigation in a GPS-denied environment, bio-inspired robot designs, nanotech soft materials and multi-robot cooperative systems (Swarms) converging with artificial intelligence, 5G (or higher) communication and advanced fabrication like 3D printing are likely to encourage the development of small and/or stealthy robotic systems that operate below detection thresholds by 2030. As industrial-scale robotics manufacturing evolves, future warfare is likely to see a rebalance away from militaries built around the few, expensive, and highly capable platforms to many, cheap, and "good enough" systems that create "battlefield mass". However, commercial and international action to limit the combat role of military robots will likely result in an international convention against deploying lethal autonomous weapon systems (LAWS).

- Long-life, quick charging battery research is advancing in a variety of ways (i.e. enhanced li-ion and graphene) resulting from the high demand in commercial markets. Tesla filed a patent in 2019 for a new breed of lithium-ion batteries that could last for a million miles in their cars. Innolith, a Swiss startup, says its new high-density lithium-ion batteries is "four times the current state-of-the-art for lithium-ion... Roughly three times what is generally accepted as being the next improvement in lithium. And it's two times the energy density target [that] organizations like the US Department of Energy have set." Volkswagen pledged $48 billion to the leading battery manufacturers in Asia to max out current battery tech. A recent Bloomberg New Energy Finance study estimated lithium-ion battery production capacity will nearly quadruple by 2021. The graphene battery market will reach $115M by 2022, with a 38.4 percent combined annual growth rate each year thereafter

- The intrinsic properties of materials in soft robots created from the convergence of nano-and bio-technology allow for an "embodied intelligence" that can potentially reduce the mechanical and algorithmic complexity in ways not possible with rigid-bodied robots. Soft robotics can be combined with tissue engineering and synthetic biology to create bio-hybrid systems with unique sensing, dynamic response, and mobility. Bioinspired soft robots can expedite the evolution of co-robots that can safely interact with humans.

- Thomas Schmickl of the Artificial Life Laboratory at the University of Graz in Austria says the possibility to create swarms that mimic the way simple animals (like the insect world) behave in ingenious ways as a group can provide some insight into how to simulate intelligence. The US military has come to much the same conclusion with respect to combat missions. Swarm robotics has become not just viable but a cornerstone of coming drones – unmanned aerial vehicles, in military parlance. Souma Chowdhury, assistant professor of mechanical and aerospace engineering at Buffalo" said: “It’s becoming known that there are a lot of different applications which could be done by not using a single $1 million robot, but rather a large swarm of simpler, cheaper robots," he said. "These could be ground-based, air-based, or a combination of those two approaches."

- Moral concern about the use of robots by the military within the tech industry coupled with pragmatic diplomacy from major states eager to lock in their relative advantages while using collective power to lock out competitors, will likely result in an international agreement with weakly enforceable provisions against combat robots.

Use Cases

- Militaries are developing doctrine that moves away from emphasizing platforms with greater capabilities, (i.e. the F-35 fighter jet) to the concept of saturating an enemy with swarms of cheaper, more expendable robots.

- Ash Carter, Director of the Belfer Center for Science & International Affairs at Harvard Kennedy School and former defense secretary, talked about “swarming, autonomous vehicles” —the use of greater volumes of aircraft or ships in a conflict. The emphasis in American military technology in recent decades has been on developing weapons platforms that are deployed in fewer numbers but boast much

Russia is planning to use swarms of more than 100 drones. Each drone would pack an explosive charge, and the swarms would be unleashed on convoys and other targets. Source: Popular Mechanics greater capabilities, such as the F-35 fighter jet. However, backed by low-cost production techniques such as 3D printing, a different model that seeks to saturate an enemy with swarms of cheaper, more expendable robots is viable.

- Robert Work, former deputy secretary of defense, believes this will give the US an advantage over its more authoritarian rivals, who are likely to place more emphasis on completely automated solutions because they do not put so much trust in their people. “Tech-savvy people who have grown up in a democracy, in the iWorld, will kick the crap out of people who grow up in the iWorld in an authoritarian regime,” he said.

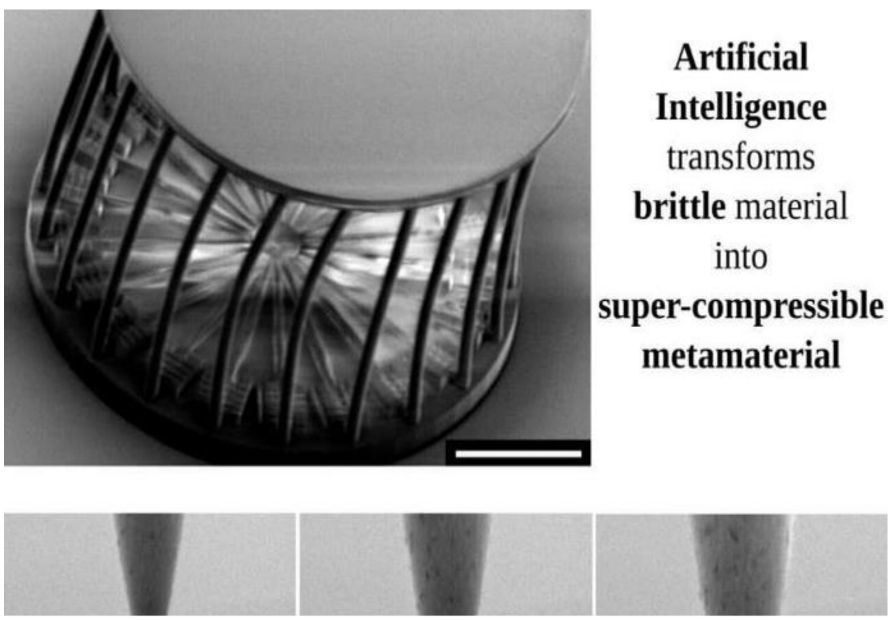
- Swarm robotics can be used to tackle dangerous tasks to reduce or eliminate the risk for humans. They are flexible and scalable which permits adding or removing robots as needed to give the right amount of resources according to the evolving requirements of the job. Swarm robotics are also useful when it’s necessary to accomplish tasks within very large or informal environments because of their ability to work autonomously without any infrastructure or centralized control system. Certain environments change rapidly over time—natural disasters like hurricanes or earthquakes. Buildings may collapse, altering the original layout of the environment and creating unforeseen hazards.

The Robotics Institute's multi-jointed Snakebot robot, which was deployed to search for survivors following the Mexico City earthquake last fall, was been named Ground Rescue Robot of the Year by the Center for Robot-Assisted Search and Rescue (CRASAR)
Source: cmu.edu

Autonomous Field Deployable Additive Manufacturing time and intuition-based convergence

Innovations within the next ten years in nanotechnology, bio-materials, AI enhanced materials prototyping, edge artificial intelligence chip computing, and sixth generation telecommunications are likely to result in field deployable autonomous systems capable of identifying, harvesting, and manufacturing rare earth materials for weapon system parts in austere locations by 2030.

- Competition between expensive but light and powerful graphene batteries and cheap but heavy Lithium Ion batteries, will likely drive down the costs of both, providing a much wider variety of power solutions for untethered robots by 2025.



Phys.Org discussion of new material produced through artificial intelligence. Source phys.org.

- At approximately the same time, advances in biomaterials appropriate for making weapon system parts and alternative materials rapidly prototyped using artificial intelligence will enable autonomous system manufacturing in austere deployed locations.

- Low cost commercially available smart dust sensors capable of providing ideal soil conditions needed for mineral extraction will be available by 2028.

- Swarms of drones enabled by swarm artificial intelligence through edge artificial intelligence computing will communicate through sixth generation telecommunications prospective sites for autonomous drilling systems to explore by 2030.

- International concern about the use of the military extracting minerals to support the army coupled with pragmatic diplomacy from major states eager to lock in their relative advantages while using collective power to lock out competitors, will likely result in an international agreement with weakly enforceable provisions against mineral extraction.

Use Case

- Long- and short-range autonomous drones prospect, extract, and manufacture materials for production for weapon system parts in austere locations by 2030.

Technological Innovations

> Just because something doesn't do what you planned it to do doesn't mean it's useless.
>
> **Thomas Edison**

Introduction

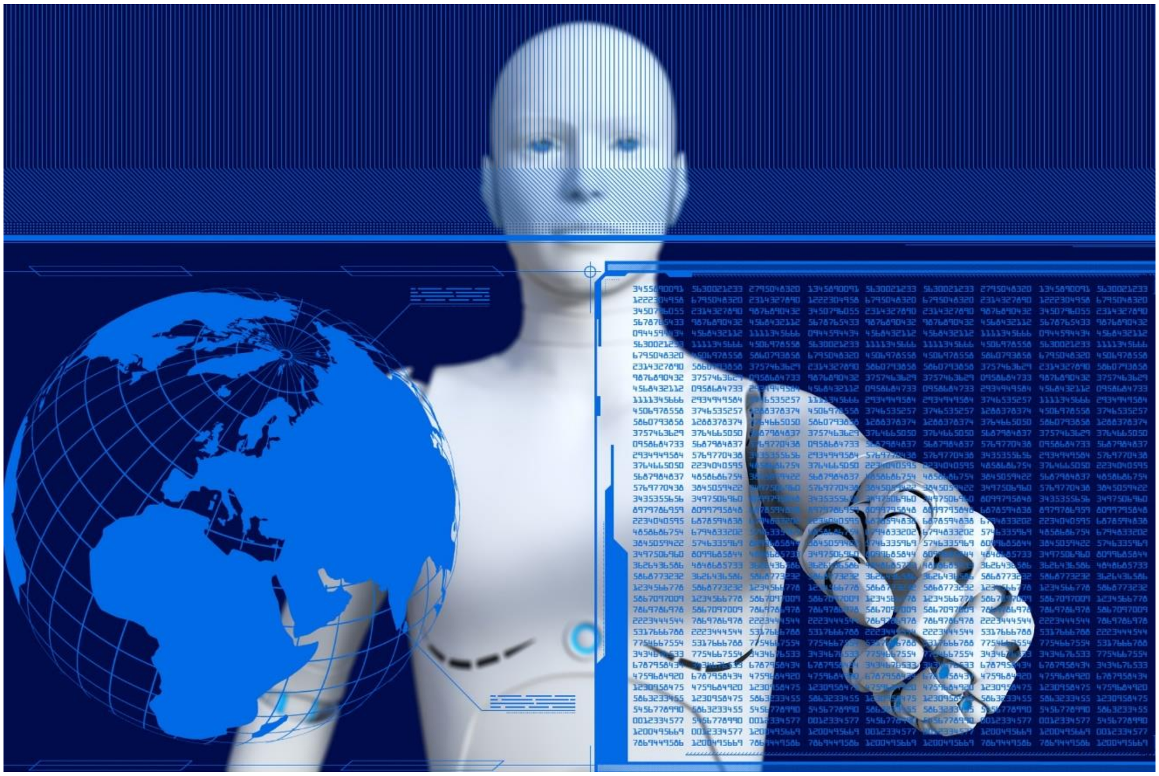
According to a recent report published in Deloitte Insights by Joe Mariani, Adam Routh and Allan V. Cook, leaders can easily fall into the trap of thinking about technology as single-shot solution to a single problem.[M] The most difficult problems in the future will require multiple technologies working together seamlessly. The more complex technology becomes, the more distinct technologies will rely on each other. As a result, strategic level leaders should pursue these technologies with an eye towards convergence. Leaders at the strategic level must learn how disparate technology designed to address individual goals can convergence to collectively build new opportunities.[M] Ignoring that convergence potentially risks duplicate programs, noninteroperable systems, and wasted time and money. The future is out there, but it can only be seen together.

Brian Patrick Green, director of technology ethics at the Markkula Center for Applied Ethics, asserts that new technological convergences allow access to paradigm shifting innovations to those who have never had the power to act, with very few barriers to access.[H] The emerging dilemma is that those who were once constrained by weakness, are now somehow expected to constrain themselves through judgment or ethics.[H] Similar issues have been faced throughout history concerning access to nuclear or chemical weapons, but this issue is much different in nature. More specifically, cheap yet effective technologies are proliferating at an exponential rate that threaten even the greatest of world powers.

For example, industry leaders Elon Musk and Mustafa Suleyman, along with a large contingent of United Nations members, have pushed to impose limits or bans on “killer robots”; drones that are enabled through AI with little to no human intervention.[H] Alvin Wilby, Vice President of research at Thales, warns that violent extremist organizations will soon join the ranks of those with access to lethal artificial intelligence.[H] The overarching problem is that as machines become fully autonomous, and they will, a moral dilemma emerges that takes humans out of the kill chain decision.[H] This would be a great advantage for rogue regimes and terrorist organizations, and a huge quandary for those working to prevent such actions.

Lethal autonomous terrorism is perhaps the most predictable facet to this issue; however, less than moral testing and development of such capabilities by China and Russia could pose even greater threats. According to Sally Cole, Senior Editor at Military Embedded Systems, this is an area of concern because, “China is determined to become the global leader in AI by 2030, and Russia is also focusing heavily on AI.”[H] It is concerning because the Defense Innovation Board is pushing ethics principles on American development of combat and noncombat AI systems; whereas, China and Russia are not constrained by similar globally accepted restrictions.[H] America's development and defense of AI systems will be reactionary to the developments of other nations as a result of our moral and ethical constraints on the mainstream use of these technologies.

Artificial Intelligence



> I think artificial intelligence will likely change the character of warfare, and I believe whoever masters it first will dominate on the battlefield for many, many, many years.
>
> **Mark Esper**

Introduction

Artificial Intelligence

The Massachusetts Institute of Technology (MIT) defines artificial intelligence "as the quest to build machines that can reason, learn, and act intelligently."[H] There has been much discussion on the progression of Artificial Intelligence (AI) in academia, commercial industry, and even the military. Many see AI through three lenses, which depending on your source of reference indicate some degree of overlap. These categories are narrow (or weak) intelligence, general intelligence, and superintelligence.[H]

Narrow intelligence can be defined by machines that continue to improve their performance for a defined set of tasks when exposed rich sources of data.[H] This machine intelligence is built upon an intricate set of neural networks capable of continued learning and rapid application of solutions. [H] Narrow intelligence is thought to be prevalent through many industries at this time, such as finance, medicine, transportation, agriculture, manufacturing, robotics, and everyday home applications. [H] These environments are information-rich and provide multiple scenarios for learning.[H] Also, learning can be both supervised and unsupervised. "Supervised learning is typically done in the context of classification, when we want to map input to output labels, or regression, when we want to map input to a continuous output."[H] In simple terms, supervised learning takes from observations or data structures to improve its understanding of the domain.[H] Unsupervised learning allows for the understanding of data "without using explicitly-provided labels."[H] Unsupervised learning is able to learn from unstructured data.[H] Under the guise of narrow intelligence, unsupervised learning is still occurring within specific domains.[M]

General intelligence, on the other hand, goes well beyond predicting and takes the form of human intelligence.[HH] This form of intelligence implies machines can understand complex concepts such as emotion, rational and irrational behaviors.[HH] A more important distinction from narrow intelligence, is the machine does not require supervised learning, rather it teaches itself. [HH]

Many researchers are still attempting to understand how to achieve general intelligence.[HH] Cognitive scientists, computer scientists, computer engineers, and a myriad of other disciplines have teamed up to understand how to emulate neo-cortex functions in a machine.[HH] In humans, the neo-cortex is responsible for executive function, higher-level cognition.[HH] To some degree, the composition of the neo-cortex, as well as how it interacts with the environment and the other parts of the brain is still a mystery.[HH] MIT highlighted this as the main challenge to creating a general intelligence platform.[HH]

Research Emphasis

Artificial intelligence has largely been used in society for decades but recent focus on robotics often lead people to think of machines that act like humans. However, many do not realize that artificial intelligence operates under the surface of the items we own. Discussion with leaders in the field of artificial intelligence have indicated that most see the physical item, such as a smartphone, that improves the quality of their lives but not the artificial intelligence. Similarly, military leaders see the value of end items, like a M1A1 Abrahams tank or a F-22 Raptor, but fundamentally don't appreciate a digital architecture that could link these systems together. Artificial intelligence experts interviewed during this study highlighted the importance of first creating a digital roadmap, which includes machine learning, before acquiring major weapon systems. This architecture allows for prototyping weapon system concepts and effectiveness against threats by using digital twins.

With respect to this report, artificial intelligence enables and converges with all areas requested by the decision-maker to investigate. In many instances, companies have created physical architecture software platforms for others to create application programming interfaces (APIs) to conduct their research, development, productization, and manufacturing. This allows for rapid innovation and potential disruption of your competitor.

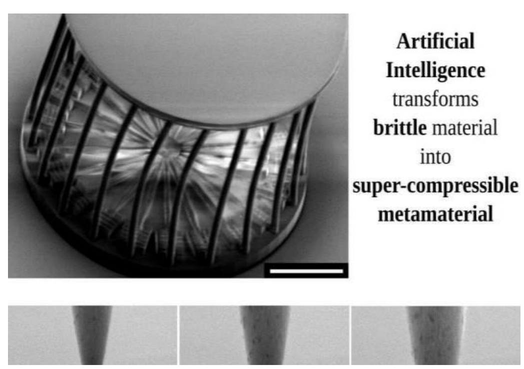
Artificial Intelligence Will Enable Advanced Material Development, Likely by 2025.

Executive Summary

Artificial intelligence (AI) will likely further accelerate material development by 2025. Despite the concern for lack of transparency in AI algorithms, the efficiency and cost savings will drive broad acceptance in material development. This is due to the need to accelerate delivery of new products to the market.

Discussion

AI is no stranger to material science. The use of AI in material science to develop products dates back to the early 1990s.[M] During this timeframe, machine-learning focused primarily on improving development and manufacturing techniques.[M] Since that time, the two communities have continued to evolve their relationship and are now focused on pioneering new materials that are cheaper, lighter, stronger, and may have extremely versatile properties required for dynamic environments.[M] Additionally, companies are looking for rapid discoveries of new material combinations in order to maintain their competitive advantage in the world economy.[M] In 2018, the University of Vancouver demonstrated the agility gained by using AI to drive down the material discovery, testing, and production process from 9 months to 5 days.[M] Professor Berlinguette, lead materials researcher at the University of Vancouver, said the key to making rapid advancements is building AI into the entire process, rather than in certain areas.[M] Despite the lack of broad acceptance of this approach in industry, the disruption caused by start-ups will drive major corporations to adopt by 2025.[MMMMM]



Phys Org discussion of new material produced through artificial intelligence: Source: phys.org.

As a part of the materials development process, material availability is one of the first considerations in determining the product's timeline for getting to the market. Manufacturers typically look for materials already in the supply chain. Machine learning has optimized the management of the end-to-end materials supply chain by predicting the best supplier sources, as well as alternative materials and designs with corresponding suppliers.[M] Start-up company, Cintrine Informatics, uses a sequential learning AI platform to predict what materials would best be used in the design, as well as material availability within the supply chain.[M] Cintrine's machine learning model is initially trained by the developer but continues to learn without human intervention, while improving its accuracy through transfer learning.[M] Panasonic was an early adopter of Cintrine's platform and has acknowledged significant improvements in the speed of material discovery by 25%.[M] Panasonic's success led them to publicly applaud Cintrine's sequential learning methodology for material selection for product development.[M] Similarly, AGC Glass Europe, a global premier materials developer, recently partnered with Cintrine to introduce agility into high performance glass development process.[M] Marc Van Den Neste, AGC Chief Technology Officer, stated "the future of materials development is speed" and "artificial intelligence is expected to dramatically change how the scientists design experiments or value data, leading to breakthrough results."[M]

In cases where materials are not readily accessible, locating resources further upstream, such as prospecting and extracting them from the earth may be required. This serves as a high risk activity for traditional mining companies due to the cost and time to discover new extraction sites.[M] The typical cost is $150 million to discover a new site and takes approximately 5-10 years.[M] Despite rare earth materials becoming harder to find, mining companies are beginning to use AI to accelerate identification of new prospects and extraction of these minerals.[M]

Australian start-up company, Earth AI, demonstrated the ability to locate rare earth materials using predictive modeling machine learning built from layers of commercially available historical terrain information and satellite imagery. They located 17 new sites over two years, spending approximately $136,000 dollars in exploration, compared to major regional mining corporations spending $663 million to find 22 new sites.[M] Earth AI stated innovation must be driven into the entire mining process.[M] To make this a reality, Earth AI is developing a suite of AI-enabled autonomous systems, such as swarming drones that communicate site prospects to mobile autonomous drilling rigs to extract the minerals.[M] Earth AI has already demonstrated this concept and is seeking additional venture capital funding to make their company fully operational.[M] Venture capitalists indicate Earth AI will likely receive financial backing from innovative product development companies looking for agility and cost efficiency.[M] Currently, Earth AI has secured partnerships with five major Australian product companies that advertise themselves as leaders in areas such as electric vehicle technology.[M]

A recent report produced by Deloitte on AI in mining indicated companies such as Earth AI have a significant advantage over these larger traditional mining companies that are slow to adopt these techniques.[M] They go on to say this is partly due to an aging infrastructure that is managed by a culture that is resistant to modernize because of the lack of trust in artificial intelligence.[M] Despite the hesitation by these major mining conglomerations to change, Canadian AI mining start-up, Goldspot, has partnered with over 100 major mining companies to evolve their practices with machine learning.[M] Goldspot anticipates exponential partnership growth within the next 3-5 years because of their ability to drive down cost and schedule risk for traditional mining companies.[M]

In the world of advanced material development, the entire material ecosystem must be understood. The use of AI to link product design with material properties, availability, suitable substitutes (which can create more robust designs), as well as raw material sources are the key to agility. Industry appears to be acknowledging the benefits of partnerships with AI start-ups making AI commonplace in advanced material development likely by 2025.

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Louis Duncan

Fully Autonomous Air Transportation Enabled By Swarm Artificial Intelligence In Metropolitan Cities Likely By 2025

Executive Summary

Aviation experts have set their target of employing fully autonomous air transportation powered by swarm artificial intelligence in metropolitan cities, likely by 2025. Despite the stringent regulations required for controlling unmanned aircraft in commercial airspace, industry will use artificial swarm intelligence to demonstrate safety.

Discussion

Lilium autonomous transportation aircraft start-up test flight.
Source Lilium.com

Autonomous air transportation offers many advantages in metropolitan cities. University of Michigan researchers, Ford Motor Company, and NASA state that, with the correct design, air transportation can help curb climate change by reducing the number of carbon emitting cars on the road.[M] Scientific American reported electric vertical take-off and landing (VTOL) flying vehicles stand to reduce greenhouse emissions by 52%.[M] Furthermore, autonomous air taxis stand to improve overall productivity of workers in metropolitan areas. As Jeff Holden, former Uber Chief Product Officer and advocate for aerial ridesharing states, "In the US, we have the honor of being home to 10 of the world's 25 most congested cities, costing us approximately $300 billion in lost income and productivity."[M]

Major aircraft manufactures Boeing and Airbus are currently in a race to be the first to commercialize fully autonomous air transportation.[M] They have taken an interim step in this process by prototyping autonomous air vehicles that are planned to operate in and around metropolitan cities, such as Dallas, Texas and Los Angeles, California.[M] Uber has partnered with Boeing in hopes to be the air taxi of choice in these cities by 2023.[M] The popularity of the autonomous air services has become a favorite with tech start-ups, with major investors such as Toyota and Daimler backing them financially.[M] China and Austria tech start-up Ehang, demonstrated their two person autonomous flying taxi concept in 2016[M] and is now taking their company public. Ehang received national approval to operate a taxi service in Guangzhou, China; however, without additional funding, risks bankruptcy.[MM] Despite limited authorizations to operate in national airspace, aviation companies will use artificial intelligence to demonstrate safe autonomous delivery operations in controlled environments as a pathway to approvals.

On April 23, 2019, Wing, an Alphabet Incorporated Google company, obtained the first Federal Aviation Agency (FAA) approval to use autonomous drones for delivering packages in certain locations, most of which do not involve delivery in metropolitan areas.[M] On Mar 2, 2020, Wing, along with 50,000 other “interested parties” requested unmanned air vehicles be integrated into the national airspace with commercial air traffic.[M] Wing uses the artificial swarm intelligence approach by placing multiple assets into the air at the same time and feeding these aircraft flight data from Google cloud over commercial communication networks.[M] These aircraft, in turn, provide information back to Google cloud with information they have learned about the flight conditions.[M] This enables the autonomous algorithm to continually be updated and shared with the rest of the aircraft.[M] Despite FAA’s unwillingness to expedite approvals of this technology, Wing and other autonomous aircraft companies will seek endorsement in Europe.[M] This is due to the European Aviation Union Safety Agency establishing a goal of allowing artificial intelligence enabled autonomous vehicles to fly in European airspace by 2025.[M] The European Union states they have a significant shortage of air traffic management personnel with an anticipated 53% increase in European flights looming by 2040; they plan to institute artificial intelligence throughout aviation to improve overall efficiency.[M]

German autonomous flying car start-up company, Lilium, plans to satisfy regulators by demonstrating a systematic commercial airworthiness approach; first starting with manned flight then gradually transitioning to autonomous.[M] Lilium has partnered with Tesla to garner their technical expertise in demonstrating autonomous system product safety.[MM] Lilium’s air vehicle will act as a sensor, collecting data as it flies, and will likely provide performance feedback over a communication link to a server that will update the autonomous flying algorithm.[MM]

Similar to Tesla, Lilium indicated they will partner with NVIDIA to use their neuromorphic computing chips to enable the air vehicle to update its own autonomous model based on the changing environment. [M] Also, this would ensure the air vehicle could fly without being tethered to a data cloud for decision-making, which would be important in the event the communication link was disrupted.[MMM] As a part of the artificial swarm intelligence model, the air vehicle would share its learning with the other vehicles to improve their autonomous algorithms.[MM] It is unclear how these aircraft will communicate with one another; however, given their operations will likely occur at low altitudes in and around cities, they could leverage high-speed wireless technologies. Lilium anticipates their fully autonomous air taxi will be in metropolitan cities by 2025.[M]

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Louis Duncan

Self-Learning Intelligence Will Enable Autonomous City Services likely by 2030

Executive Summary

As cities become more technologically advanced, opportunities for automating essential services become possible. Self-learning artificial intelligence will orchestrate the automation of city services, likely by 2030. Despite most cities lacking integrated digital infrastructure across services, leveraging the internet of things will enable artificial intelligence to fasten them together. Due to radical changes in climate change, metropolitan cities will use smart technologies to optimize energy management.

Discussion

The "Internet of Things" ("IoT") is often thought of as the ability to connect machines together and interact with a person via the internet.[M] Many modern machines, like cars, smartwatches, smartphones, and traffic systems can communicate over networks other than the internet, such as commercial cellular towers.[MM] Furthermore, Cisco reports by

NVIDIA's Metropolis Smart City platform leveraging edge computing and deep learning. Source: NVIDIA.com and University of Queensland Brain Institute.

the end of 2020, approximately 50 billion devices will be connected over the internet.[M] The data sources coming from these devices follow similar communication protocols but provide different pieces of information.[M] These pools of data are a target rich environment for machine learning systems, as they thrive on large amounts of complex information.[M] Despite the dissimilarities in information, artificial intelligence has evolved to learn from unstructured data.

IBM's Watson artificial intelligence platform, as well as many other platforms, has demonstrated the ability to sort through pools of data to identify patterns relevant to specific domains.[MM] As an example, IBM's Tririga artificial intelligence platform leverages the IoT to harvest complex federated building data to provide companies with strategies for optimizing building design, layout, usability, energy management, and maintenance.[M] IBM states their artificial intelligence saves 20-30% in building energy costs through automation.[M]

IBM indicates the future of city management requires a good understanding of unstructured data.[M] They go on to say 80% of the data available today is unstructured and requires an application layer that enables the information to be quickly parsed into meaningful details.[M] Computer scientists often refer to this application layer as a "data refinery."[M] Despite the costly processing and storage overhead with creating and maintaining data refineries, edge computing is beginning to push machine learning closer to the source of the sensor.[M]

NVIDIA, Intel, and other computing chip companies have now developed chips that have processing speeds and storage capacity equivalent to certain aspects of the human brain.[MM] NVIDIA's edge computing chip, which also supports Tesla's self-driving cars, is being deployed around cities to support traffic management, public safety, manufacturing, logistics, access control, and public transit.[M] NVIDIA's edge computing chip has self-learning artificial intelligence resident on the device and sends specific domain data to the cloud and other edge computing devices to improve the machine learning algorithms.[M] NVIDIA's approach to making city automation more robust requires the machine to teach itself through artificial swarm intelligence approach.[M] Due to the interest of curbing climate change, metropolitan cities around the world have agreed to drive down carbon emissions by creating smart cities using technologies from companies like NVIDIA and IBM.[M]

C40 cities represent a pact made between the "top 40 cities in the world" to create a path to reducing the global temperature by 1.5 degrees Celsius by 2030.[M] C40 states the creation of smart cities will help them meet their goal.[M] As a example, Tokyo partnered with Panasonic to prototype the application of smart cities in the towns outside of the city and noted a "40% reduction of CO2 emissions."[M] Other cities following a similar path include Copenhagen, Glasgow, London, and New York City.[M] The range of automated services enabled by self-learning artificial intelligence are endless and include building management, traffic management, public safety, autonomous transit, intrusion detection, and local authority notification.[M] The list of smart cities throughout the world continues to grow exponentially making it likely the C40 will become the C100 before 2030.[MMMM]

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Louis Duncan

Human Brain Models to Enable Unsupervised Artificial Intelligence Likely by 2030

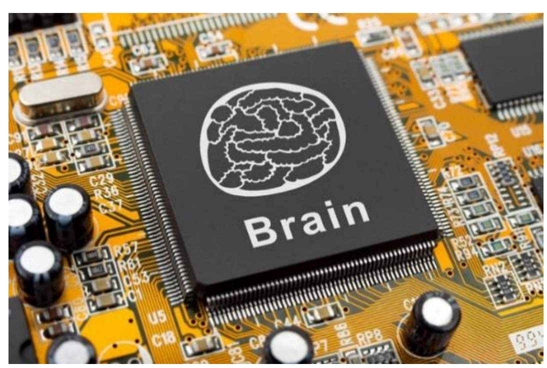
Executive Summary

Industry collaboration with neuroscientists, physicists, as well as many others, make unsupervised learning in artificial intelligence likely by 2030. Despite the lack of understanding of how the human brain works and the lack of computing power that matches the human brain, industry will rapidly iterate brain-inspired computing chips designs and architectures, making machines with human intelligence a reality.

Discussion

The term "unsupervised learning" means a machine can learn by decoding unlabeled, unstructured data and decide which content is applicable to the task.[M] Artificial intelligence applications currently rely on "supervised learning" which requires the machine to learn through structured data that has been labeled. [M] Supervised learning is often reported as being time intensive because of the requirement for humans to label the data and place into bins for computers to learn.[M] As a result, supervised learning is considered more accurate in its performance.[M] Despite unsupervised learning being inaccurate, researchers have recently experienced breakthroughs in computing architectures that have led to improved performance.

Major technology companies IBM, Intel, and NVIDIA have partnered with renowned artificial intelligence academic institutions such as Carnegie Mellon, MIT, and others to create advanced unsupervised machine learning computing architectures capable of enhancing the speed and accuracy of artificial intelligence similar to smaller mammalian brain function, like mice.[MMMM] This is due to combination of newly created machine learning approaches and improved computing power. These areas combined are beginning to revolutionize unsupervised learning architectures. For instance, researchers have introduced concepts such as adversarial neural networks which pit one artificial intelligence model against another to improve their accuracy.[M] This approach reinforces the machine's ability to advance its knowledge on tasks quickly. Industry has coupled this learning model with wafer-sized computing chips that have the equivalent of one billion human neurons and are approaching supercomputing speeds.[M] NVIDIA reports their machines can learn a



Viewzone discussion on microchips ability to miimic human brain functions. Source viewzone.com.

new complex task, like playing the Chinese game "Go" within a shift in their plant.[M] Despite these computer chips lacking another 85 billion neurons to match the entire adult human brain, IBM is reportedly on-track for achieving 10 billion neurons by 2030, enough capacity to support neocortex functions.[M]

Ray Kurzweil, futurist and renowned artificial intelligence expert, states computer chips will express human intelligence by 2029.[M] NVIDIA and Intel are attempting to make this a reality by collaborating with neuroscience organizations, such as the Human Brain Project (HBP) to gather as much information about human brain architectures, as well as gain feedback from these communities about the accuracy of the human learning represented on their computer chips.[M] HBP mapped the cerebellum and basal ganglia, areas of the brain responsible for motor function, within a two year time-frame.[MM] Additionally, Intel was able to apply this information to demonstrate 450 human olfactory receptors on their neuromorphic computing chip.[M] They have moved on to the hippocampus, the epicenter for long-term memory and how the brain interprets the world.[M] Computer scientists have created a hippocampal algorithm but indicate additional human brain model testing is required.[M] The interaction between the hippocampus and the rest of the neocortex will be the key to unlocking the brain's human intelligence architecture.[M] Once the neocortex is mapped and integrated with the computer architecture, machines will have the capacity for human reasoning.[M] With the continued support of major technology companies; the hippocampus model will likely be available for integration by 2022, with the remaining lobes (frontal, temporal, parietal, and occipital) being mapped and integrated in two year spans, concluding in 2030.

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Louis Duncan

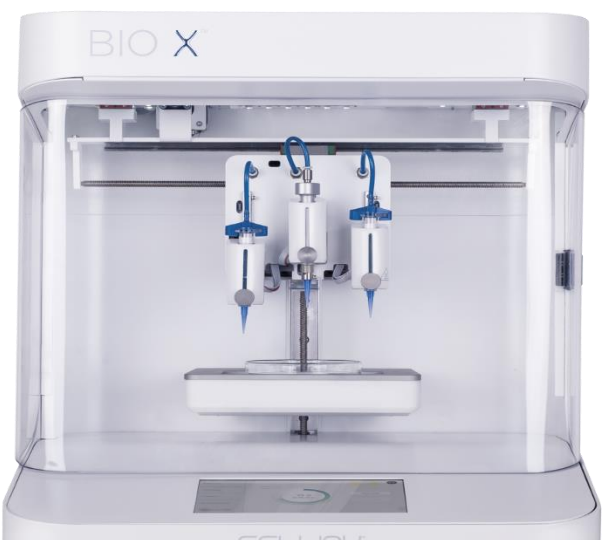
Machine Learning Will Enable Innovative Graphene Combinations by 2025, FDA Approval of Graphene as a Biomaterial Likely by 2030.

Executive Summary

The medical community has long desired the ability to resolve chronic disease, illness, and injuries as quickly as possible. The advances in machine learning converging with mineral science, biology, and medicine offer this possibility by introducing graphene as biomaterial, likely to receive FDA approval by 2030. Despite the lack of agility in the FDA approval process, machine learning will accelerate the acceptance by rapidly modeling the effects of biomaterials introduced into the body.

Discussion

The collaboration between materials development and machine learning dates back to the early 1990s.[M] Today, artificial intelligence is used to identify new material compounds offering breakthroughs in applications in energy, aviation, computing, and medicine to name a few.[MM] A common theme across these areas is the utilization of machine learning to determine the wide range of graphene use cases. For example, graphene is an extremely durable and adaptable compound, to the extent it could be used to bolster the resiliency of human cells.[M] Furthermore, the University of Missouri demonstrated the utility of machine learning and graphene combinations, generating over a billion useful sequences in two days.[M]



Cellink bioprinter: used for printing biomaterial cellular structures. Source Cellink.com.

Artificial intelligence has been integrated into medicine since the early 2000's.[M] Advances in understanding on how to apply machine learning to accelerate clinical care continues to evolve. The world of medicine is a data rich environment which provides the ideal conditions for machines that are able to quickly sort through volumes of complex data, whether constructed or deconstructed, to derive solutions.[M] IBM's Watson artificial intelligence platform has been integrated into the Memorial Sloan Kettering Cancer Center to accelerate cancer diagnosis and treatment.[M] In some cases, Watson more accurately and quickly diagnosed cancer than the medical doctor.[M] In addition, Watson was able to learn from peer-reviewed medical literature and provide immunotherapy options to treat the cancer.[M] Despite the destructive efforts of cancer, as well as other diseases, artificial intelligence is being used for regenerative medicine to someday counter these effects.

The National Institute of Health (NIH) reported machine learning was used to identify and model stem cell biomaterial combinations, which included graphene, to regenerate damaged cardiac tissue.[M] Researchers reported it took 5-7 days to determine the appropriate stem cell-biomaterial combination and three dimensionally print.[M] Furthermore, they stated the machine learning models quickly improved its accuracy for modeling the preconditions requiring medical intervention, from 50% at the beginning to 72% by the end of the trials.[M] Despite tissue engineering primarily being used in laboratories, the market push to solve major medical issues will lead to clinical integration by 2030.

According to the European tissue engineering community, tissue engineering is expected to generate $60.9 billion from Fiscal Year (FY) 17 through FY20 and as is currently on track to match these numbers.[M] The United States forecast indicate tissue engineering will grow from $13.4 billion in FY18 to $34.7 billion by 2024.[M] FDA's approval to use biomaterials for skin grafts has exponentially increased the number of biotech companies entering into this market.[M] Cellink, a Sweden tissue engineering start-up company that combines three dimensional printing with biomaterials, is aggressively expanding research into clinical settings.[M] Due to Cellink connecting researchers with clinicians through the democratization of biomaterial models and subsequent printing methodologies, they are able to improve their machine learning algorithms for different biomaterial combinations and precision of printing.[M]

Dr. Joseph Sector, head of University of Alabama's organ transplant program, stated this technology solves societies' problem of "determining who lives and dies" because the rationing of organs.[M] The Federal Drug Administration (FDA) has recently acknowledged the importance of advancing approvals for tissue engineering and printing for clinical and public use.[M] As a result of the interest for augmenting damaged organs, Cellink has elevated graphene infused human cell printing to the top of the FDA approval list.[M] Cellink, among many other companies across the globe, are racing to obtain biomedical graphene patents as they see strong evidence that graphene is an extremely versatile material the human body accepts.[M] The FDA stated the updates to their regulatory framework coupled with models that demonstrate human safety, graphene approvals will be accelerated.[M] Scott Gottlieb, FDA Commissioner, highlighted the innovative steps his organization has taken since to rapidly bring technology to the

consumer, such as incorporating artificial intelligence into clinical trials to bring 72 breakthrough technologies to the market in 2018.[M]
Given the body of research demonstrating the biocompatibility of graphene, as well as the market demand to resolve chronic human diseases and injuries, the FDA's approval of graphene as a biomaterial is likely to occur by 2030.

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

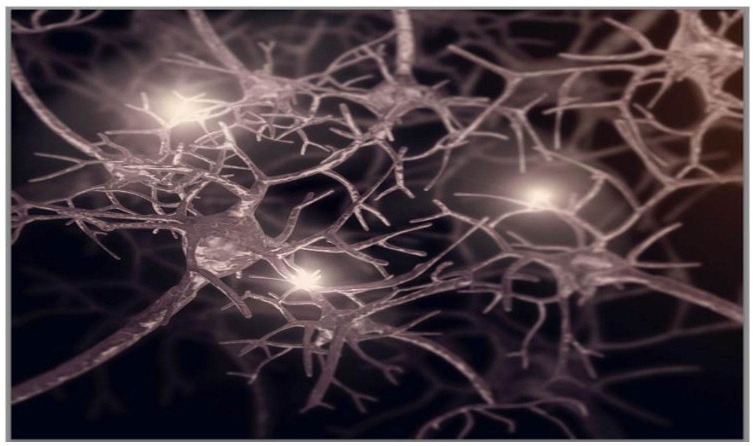
Author: Louis Duncan

Neuromorphic Artificial Intelligence Computer Chips Likely to Demonstrate Episodic Human Memory by 2027

Executive Summary

Neuromorphic Artificial Intelligence (AI) computer chips are likely to demonstrate episodic human memory by 2027. For machines to more closely perform complex human tasks, researchers and major tech companies are aggressively pursuing the development of computing hardware and software that emulates human intelligence. Despite the lack of robust human brain models, industry will invest heavily in mapping human memory, as this serves as the foundation for human cognition and has the potential for unlocking unsupervised machine-learning.

Discussion



Queensland Brain Institute demonstrating neuronal networks firing together when exposed to a stimulus. Source: qbi.uq.edu

Neuromorphic artificial intelligence (AI) computer chips, or AI chips, may be described as silicon-based wafers that emulate the human brain architecture, relying on intricate synaptic neural networks that evoke responses when exposed to certain stimuli.[M] AI chips are able to do this because computational memory and processing are resident on the same silicon wafer, compared to traditional computing which separates the two.[M] Furthermore, the latency of the synaptic signal transmission is significantly reduced because processing and storage are intertwined, which is similar to human brain neuron network.[M] Mike Davies, Director of Intel's Neuromorphic Lab, highlighted that this architecture enables neuromorphic chips to process complex cognitive games faster than some supercomputers.[M] Intel's Loihi neuromorphic chip has been reported to make decisions on complex games like sudoku within 4 milliseconds, "100 to 1,000" times faster than the supercomputer used for the Human Brain Project.[M] Also, neuromorphic chips, like Loihi, appear to be faster than the human brain for some tasks. The Massachusetts Institute of Technology (MIT) reports the human brain processes images within 13 milliseconds.[M]

Researchers at the University of Milan suggest neuromorphic chips may have the ability to process information faster than humans but lack the ability to learn dynamic, complex tasks.[M] Current neuromorphic chips learn through presentation of static information, rather than observing its environment and inferring actions from what is remembered.[M] Neuropsychologists refer to this as episodic memory in the human brain, and requires interactions between the hippocampus and temporal lobes.[MM] Despite neuromorphic chips lacking episodic memory, technology giants NVIDIA, Intel, and IBM are partnered with neuroscientists to map the hippocampus, making this model available for integration into neuromorphic chips likely by 2022.M

The tech industry and neuroscientists have already demonstrated the ability to map the basal ganglia and cerebellum, key components for motor control, within two years.[MM] The first hippocampus model was created in 2018 but researchers state additional iterations are required to understand the interactions with the neocortex (temporal, frontal, parietal, and occipital lobes) and have crowdsourced the model development through an international conglomeration of neuroscientists.[MM] Once scientists finish mapping the hippocampus, unlocking the neocortex will likely follow the similar two year timeline as the basal ganglia and cerebellum, making the model of the temporal lobe likely by 2027. This is due to computer scientists already demonstrating hippocampal algorithms that show rudimentary forms of episodic memory.M

In addition to neuromorphic chip developers being keenly interested in brain mapping, Crunchbase reports 367 neuro-tech start-up companies were created in 2019 and are finding ways to map neural activities to create an "ecosystem" of neuro products ranging from brain-computer interfaces to neuropsychological pharmaceuticals.[M] Most of these companies are targeting patients with some form of neurodisorders. Society for Brain Mapping and Therapeutics (SBMT) partnered with NASA to create the first Brain Technology and Innovation Park in Pacific Palisades, CA to map the path of neurodiseases such as mental disorders, which they reported will cost the world $16 trillion by 2030.[M] Similarly, the G-20 Summit recognized the financial strain neurodisorders was having on the world economy and created a "World Brain Mapping and Therapeutic Initiative."[M] This effort would focus on mapping the Alzheimer's disease process, which is often found within the hippocampus.[MM]

Regardless of the lack of robust human brain models, intersecting interests between tech giants, neuroscientists, and government organizations will accelerate the world's understanding of the brain's architecture. In the case of neuromorphic chip developers, they will be the benefactors of this momentum and will result in artificial intelligence with human memory likely by 2027.

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Louis Duncan

Initial Smart Cities Likely by 2025, Fully Realized by 2035.

Executive Summary

Cities will be digitally integrated with city operations through the convergence of decentralized artificial intelligence, edge computing, autonomous systems, and 5G, likely by 2025. As telecommunications continue to advance, 6G will merge with these technologies likely by 2035. Despite current federated city operations, major technology companies will evolve city infrastructure to make this occur. This is due to metropolitan cities wanting to harness technology to remain globally competitive.

NVIDIA's Jarvis Multimodal Artificial Intelligence Demonstration.
Source: blogs.nvidia.com

Discussion

Command and control of current metropolitan infrastructure requires significant human intervention to conduct daily operations.[M] As a result, citizens are becoming frustrated with the lack of the government progress in making their lives easier through the seamless integration between tech and public services.[M] Furthermore, researchers report 70% of the world's population will be living in major cities by 2050, placing a greater strain on infrastructure.[M] It is expected the daily data creation will be approximately 21 zetabytes daily, which will require a well thought through architecture strategy that includes machine learning logic, processing, and storage.[M] Despite the challenges in data management in the future, machine learning logic and data storage will be moved closer to the edge to prevent disruption of services.[M] Due to the economic opportunities smart cities offer, major tech firms and governments will be motivated to make this occur. Researchers indicate smart cities stand to generate an additional $463.9 billion from 2020 to 2027 for city markets.[M] Again, they indicate cities that understand how to create the digital infrastructure will be the most successful.[M]

Singularity.net states decentralized artificial intelligence is the key to accelerate delivery of services to consumers across a complex domain.[M][M] Decentralized intelligence pushes machine-learning to the edge of the device, resulting in low latency of autonomous actions.[M] Fundamentally this solves the delay self-driving cars experience when communicating large volumes over a network to the cloud.[M] NVIDIA reports similar processing delays are often experienced when companies attempt to update their artificial intelligence in data centers through complex Internet of Things (IoT) environments.[M] To prevent latency, Walmart's artificial intelligence IoT lab in New York City has made significant investments in bandwidth to process 1.6 terabytes per second.[M] Despite IoT's intensive bandwidth requirements, advances in IoT software platforms and edge artificial intelligence computing chips coupled with 6G will create a meshed network of city services.

Venture Beat reports NVIDIA's IoT platform service "Metropolis" has been deployed to 50 cities around the world.[M] This is due to the growing number of sensors distributed around these cities.[M] For instance, it is expected that there will be one billion traffic cameras on city streets by the end of 2020.[M] Siemens technology provides a similar IoT platform and is attempting to capture multiple city service markets.[M] Siemens has demonstrated the ease of plugging in federated sensors from around a city into their platform within 10 minutes but state their application requires low latency information to improve timeliness and accuracy of services.[M] In 2017, Hong Kong adopted Siemens IoT platform to create a "Smart City Hub" as a way to connect services with its citizens.[M] Hong Kong officials report saving over 20% in public transportation costs since they started using Smart City Hub to manage its services.[M] Vietnam is also attempting to follow a similar path as Hong Kong but anticipates the lack of digital infrastructure will be a significant barrier.[M]

NVIDIA's Aerial Radio Access Network. learning. Click on link to view article.
Source: Forbes.com
and University of Queensland Brain Institute.

NVIDIA's EGX artificial intelligence chip, which is being used for edge computing, optimizes data management by enabling machine learning to occur closest to the sensor or suite of sensors.[M] At 240 teraflops, EGX provides supercomputer speeds and storage capacity at the edge.[M] As a result, the edge computing system becomes more efficient in communication with IoT platforms.[M] This concept is now being used in Las Vegas and San Francisco to track pedestrian and traffic to determine optimal economic zones for cities.[M] Similarly, these cities among others, are keenly interested in the use of edge computing with IoT's for smart city grid power management.[M] Smart energy grids are expected to harvest energy from green energy sources and efficiently distribute to metropolitan cities around the world.[M] Smart energy grids are expected to generate $6.5 billion in profits by 2027.[M] Currently, the United States is reportedly leading the way with this technology, with over ten major cities using advanced machine-learning tools and another 181 projects in the works across the country.[MM]

NVIDIA has partnered with 5G provider Ericsson, to enable city services through IoT.[M] Jensen Huang, NVIDIA CEO, stated this is natural relationship between both companies, as "NVIDIA pushes the data to the edge, where 5G is waiting."[M] NVIDIA has integrated its edge computing with its city services artificial intelligence platform, Metropolis, as well as Ericsson's 5G hardware.[MM] In 2017, this concept was first deployed to Hong Kong and Taiwan to support the transportation industry.[M] Furthermore, NVIDIA has integrated edge computing with legacy telecommunication architecture by bolting on these artificial intelligence chips to their radio access networks.[M] Ericsson reports they have made 42 memorandum of agreements throughout the world to integrate this technology by 2025.[MMMM] Although the digital infrastructure will benefit from a significant increase in data bandwidth, autonomous transportation may not be adequately supported due to the significant information processing requirements.[M] Researchers state depending on how autonomous vehicles are architected to communicate with either edge computing or the cloud data center and how many vehicles are communicating over the network at the same time, significant latency may be experienced.[MM] Despite potential 5G bandwidth limitations, 6G will enable low latency data communications required for autonomous transportation.[M]

6G frameworks are anticipated to follow a similar development path as 5G and are likely to be available by 2035.[M] However, it will provide a significantly higher data rate, approximately 1 Tbps, which is more conducive to a IoT network operations.[M] Researchers state that even though this network will be fast, it could quickly become saturated by high bandwidth sensor requirements.[MM] Furthermore, they go on to say it will be imperative for network engineers and application developers to work closely on optimizing data flow for their "vertical", such as autonomous transportation to prevent latency.[MM] One researcher made the comment, "Robots don't understand what delay means, whereas humans do."[M] The 6G research community has made it abundantly clear that because of the complexity of managing a high speed network of this magnitude, unsupervised "no shot" learning will be required.[M] Despite regulators not necessarily accepting this "black box" approach to managing society's communication infrastructure, the concept of "digital twin" is being recommended to demonstrate the reliability and safety of the artificial intelligence algorithms.[MM]

The convergence of decentralized artificial intelligence, edge computing, and advancements in telecommunications will create digital cities. Cities will need to understand how to architect the digital infrastructure to mitigate the effects of latency that could impact the reliability of the services to the provide to their citizens, as well as compromise safety.

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Nicholas E. Delcour and Louis Duncan

Lightweight Real-time Training Systems Enabled by Unsupervised Artificial Intelligence Likely by 2025

Executive Summary

The gaming industry is driving radical improvements in gaming hardware to improve the user experience. As a result, lightweight, high-fidelity training systems will be based off unsupervised artificial intelligence gaming technology, likely by 2025. Despite the lack of flexibility in the creation of training vignettes, computing tech giants will enable mobile computing for training that easily adapts to changing environmental conditions. Due to commercial industry's interest in using virtual training to reduce cost and improve performance, adoption of this technology will be widely accepted as common practice within the next five years.

Discussion

Magic Leap claims "The Helio browser brings the web to life in three dimensions."
Source: magicleap.com

Many commercial companies are beginning to combine virtual reality goggles with realistic training scenarios to accelerate the training of their employees. The medical community has begun to evaluate the implications of this approach. UCLA school of medicine documented a 230% performance improvement in surgeons trained on a new, complex surgical technique, learning the procedure 20% faster than their peers.[M] These training systems leverage artificial intelligence capable of adjusting the complexity of the training environment based on the user's performance. Updates to these artificial training models come at the expense of time and money, requiring significant amounts of manual labor to manipulate the architecture. Technology giants, Intel and NVIDIA, recognized the need to revolutionize this industry by unveiling computer chips, known as neuromorphic artificial intelligence chips, that enable artificial intelligence to rapidly teach itself with less human intervention.[M] This technology applied to a training scenario would result in a machine that would think and act more like a teacher and would quickly tailor scenarios to a user's learning. Despite training systems relying on humans to generate individual training scenarios, the gaming industry will pave the way for realistic training scenarios capable of adjusting to the changing environment. This is due to the convergence of mobile, high-powered computing devices and unsupervised artificial intelligence gaming engines.

Real-time training systems offer many advantages in rapidly educating new workforces to handle complex tasks. Corporate America spends approximately $130 billion annually on digital training tools.[M] Jensen Huang, NVIDIA Chief Executive Officer, states the future of training is joined at the intersection of artificial intelligence and virtual reality.[M] NVIDIA recently released an artificial intelligence enabled hologram for the gaming industry to accelerate game-play learning.[M] This is not surprising as NVIDIA, much like their competitor Intel, is using artificial intelligence to improve user experience. Intel goes as far as to use virtual reality and artificial intelligence programs to train electrical safety within its engineering community.[M] Intel reported electrical safety is a major area of concern, as OSHA reports "1/10 electrical incidents" often result in death. Prior to the introduction of this training, Intel had 24 nonfatal electrical incidents.[M]

Gaming artificial intelligence continues to evolve, as computers learn and adapt to changing conditions.[M] Recent gaming engines have demonstrated the ability to self-learn and teach itself new strategies to win against expert gaming strategists.[MM] Renowned artificial intelligence university, Udacity, is instructing computer scientists to use these advanced gaming engines to teach autonomous systems, such as cars and drones.[M] Tesla is leveraging this concept to accelerate machine learning in its autonomous car program.[MM]

Similar machine learning architecture is now being adopted by mobile operating system platforms, to provide real-time learning when coupled with virtual reality (VR).[M] Mobile VR training systems are likely to be widely used in industries where safety practices must be reinforced to prevent injury.[M] The New York Police Department is currently testing mobile VR simulators as a part of realistic training environments experienced on the job.[M] Additionally, Think Mobile states militaries are on the path to integrate VR simulations by 2025.[M] Booz Allen Hamilton indicated military mobile VR platforms must incorporate deep learning to ensure operational environments keep pace with changing battlefield conditions.[M]

UX Design reported that in the next five years, the convergence of augmented reality, virtual reality, and artificial intelligence will give way to a mixed reality, blending both the digital and physical worlds.[M] As a result, mobile training platforms will be capable of quickly tailoring to new workspaces.[M] This is due to emergence of mobile application user experience designers leveraging the advancements of machine learning architectures inherent on mobile devices.[M] Magic Leap, a mixed reality start-up in Plantation, Florida, spent the last five years developing this concept, making it commercially available for $2,295.[M] Since their roll-out in 2018, Magic Leap appears to have made tremendous progress in acquiring well-known industry customers, such as Lucas Films, the Smithsonian, HBO, as well as many others.[M] This is due to the open software development kit (SDK) architecture made available for companies to create their own applications for their respective domains.[M]

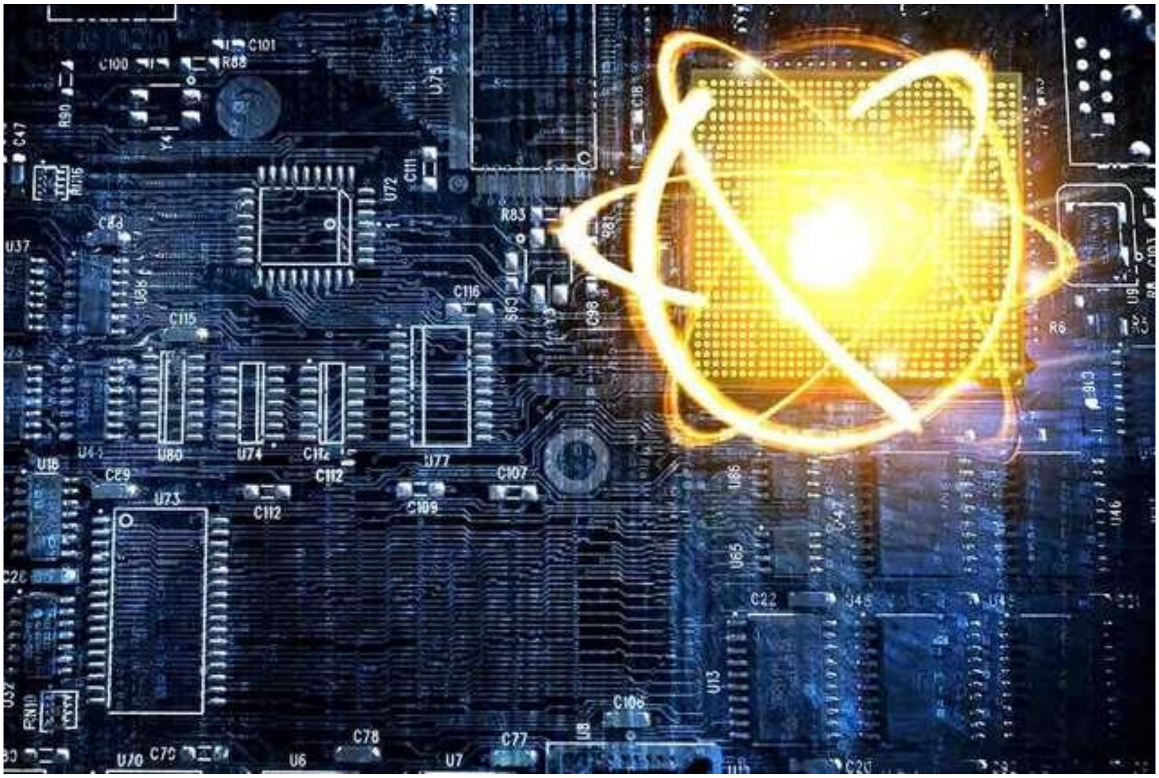
As advancements in gaming systems continue, high fidelity mobile operating training systems will also improve. This will give rise to the growth of user experience designer applications capable of rapidly adapting to new environments by leveraging unsupervised artificial intelligence for those respective domains, likely by 2025.

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Louis Duncan

Quantum Technology



> Trying to understand the way nature works involves a most terrible test of human reasoning ability. It involves subtle trickery, beautiful tightropes of logic on which one has to walk in order not to make a mistake in predicting what will happen. The quantum mechanical and the relativity ideas are examples of this.
>
> **Richard P. Feynman**

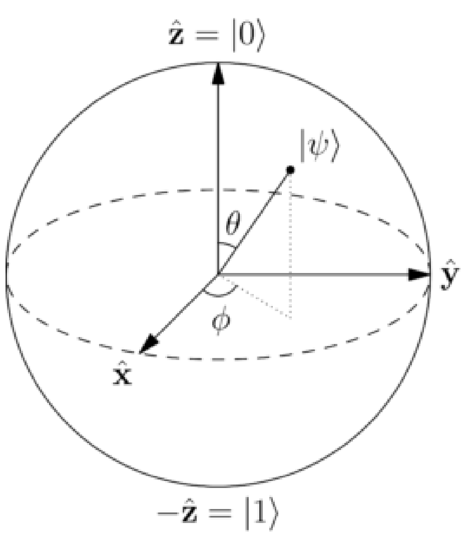
Introduction

"Quantum Technology is a class of technology that works by using the principles of quantum mechanics (the physics of sub-atomic particles), including quantum entanglement and quantum superposition.[M] A smart phone is a type of quantum technology – its semiconductors use quantum physics to work. Quantum technology became part of life 50 years ago through nuclear power. The latest feats of engineering are harnessing more of the potential of quantum mechanics and is starting to control entanglement and quantum superposition." [H]

Quantum Entanglement

"According to Paul Martin, quantum technology expert at PA Consulting Group, when two atoms are connected, or entangled, despite being separated and the properties of one is changed, the other changes instantly. In theory, this would be the case even if the entire universe separates the entangled atoms. Quantum mechanics postulates that simply observing an atom changes its properties. This offers the potential to enhance the security of communication through quantum protected cipher keys. For example: an intercept by an eavesdropper of a transmission with one clockwise and one counterclockwise spinning entangled atoms causes a change in the 'spin' of the atom, affecting the overall quantum state of the system and resulting in the detection of the eavesdropping attempt."[H]

Quantum Superposition



Bloch Sphere, a geometric representation of quantum superposition. Each qubit state is a point on the surface of the sphere.[M]

According to Professor Alan Woodward from the University of Surrey, an expert in computer security, "superposition is a system that has two different states that can define it and it's possible for it to exist in both. For example, in physical terms, an electron has two possible quantum states: spin up and spin down. When an electron is in superposition, it is both up and down at once – it is a complex combination of both. Only when it is measured does it drop out of superposition and adopt one position or the other. If you build algorithms in the right way, it's possible to effectively harness the power of that superposition."[M] It's the crux of the Schrodinger's Cat thought experiment - a cat, a flask of poison and a radioactive source are in a sealed box. If a Geiger counter detects radioactivity, it shatters the flask, releasing the poison and killing the cat. Since the radioactivity detection is a statistical process, the cat can be both alive and dead while the box is sealed, with the outcome only confirmed when you open the box and observe the cat to be in one state or the other. The practical application of this mind-bending version of reality is most obvious in quantum computers. While digital computers store data as bits (the ones and zeros of binary), quantum computers use qubits that exist as a one, zero or both at the same time. This superposition state creates a practically infinite range of possibilities, allowing for incredibly fast simultaneous and parallel calculations."[H]

Research Emphasis

Developments in Information Technology (IT) and Nanotechnology are the primary influence on Quantum Technology. More importantly, the four fundamental quantum sciences (Quantum Communications, Quantum Computing, Quantum Simulation, and Quantum Sensing) have shown strong convergence with the other technologies we researched. Quantum Communication provides data Confidentiality, Integrity, and Availability (CIA), which is essential to Cyber Security.[H] Quantum Information Sciences (QIS) research is routinely publishing successful reports on quantum communications and quantum internet experimentation, testing, and demonstrations. (See trip report in Appendix) Quantum Computing provides the processing power to solve complex problems classical supercomputers are unable to resolve. In 2020 QIS produced a 5000-qubit Annealing machine, a 61-Qubit Analog machine, and a 53-qubit Universal machine.[H] [H] [H] Quantum Simulation is valuable to increase the knowledge of QIS by allowing researchers, scientists, and students to model large quantum systems and to test algorithms. Also, the workforce is learning how to program quantum computers and write software while they test and experiment with these powerful simulators. Further, hybrid simulators like D-Wave Leap 2 is being offered in 2020 to provide businesses with real-world solutions for optimization, run up to 10,000 variable problems.[M] Quantum Sensing and the development of chip-sized atomic clocks provide an alternative Position, Navigation, and Timing (PNT) source as an alternative to the Global Position Satellite (GPS) system.[M] Efforts are underway to make GPS more resilient and robust, but the ability to place PNT sources, atomic clocks, onboard DoD systems for military and Critical Infrastructure and Key Resources (CIKR) for US Government is key to victory in a contested environment and can provide overmatch.[H]

Scalable Room-Temperature Quantum Repeater Highly Likely by 2022

Executive Summary

Brookhaven National Laboratory, Stony Brook University, and Qunnect Inc. are highly likely to produce a single photon quantum repeater prototype by 2022. The quantum repeater components are being tested in the lab on a standard 8-foot x 4-foot lab optics table. Qunnect Inc., has reduced the size of some of the components to fit in standard server chassis, and the components can operate at room temperature without environmental controls. The summer of 2020 will be the first time some of the core components of a quantum repeater of this design will be field deployed and tested in an operational environment at room temperature.

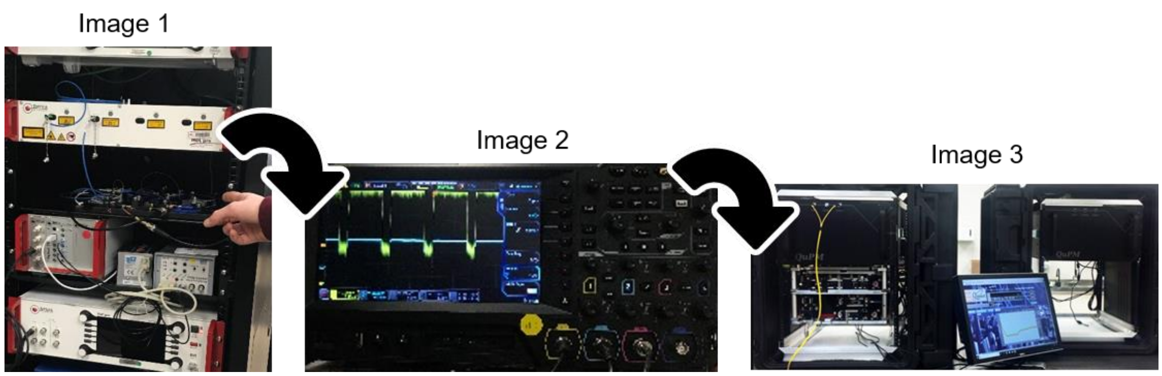


Image 1 *on the left is a Quantum Bank where lasers pulse through the small polarization encoding components being pointed at in the rack; the part entangles photons to create a qubit. The individual qubits, illustrated by* ***Image 2****, are transmitted from Brookhaven National Laboratory over a 60-mile fiber optic cable to Stony Brook University.* ***Image 3*** *is the quantum memory device at Stony Brook, which stores the qubits and will eventually connect to another 40-mile quantum internet connection extending the network to 100 miles. (Images provided with permission of Dr. Eden Figeruoa and Mael Flament)*

Discussion

(Unless otherwise cited, the underlying facts in this report have been verified by Dr. Noel Goddard and Mael Flament. Read the complete trip report from the March 6, 2020 site visit to Brookhaven National Laboratory, Stony Brook University Laboratory, and Qunnect Inc.)

As server sized quantum repeater components test successfully summer of 2020, they are highly likely to reach the commercial market in early 2022. At approximately $80,000 for a portable quantum memory device, the components of a quantum repeater are relatively inexpensive when compared to building a lab and the equivalent lab optics table and devices required to replicate the device functions. The quantum memories can be used as stand-alone devices, intended to synchronize and regulate data flow between nodes in a network, similar to existing buffers in telecom networks. At present, the memories store and release single photons with high fidelity and storage times compatible with real-world networking (unique to Qunnect's products). Future developments include the use of addressable arrays to store more than one photon at a time, increasing efficiency and capacity of data transfer over quantum networks. In parallel, the QIS research centers continue to work, solve, and independently develop components to build the quantum internet of the future. The creation of portable devices that can operate at room temperature while utilizing existing fiber networks will allow for the rapid expansion of the quantum internet once the key components are in place. [H] This testing contributes directly toward the goal of connecting the 17 US national laboratories via a quantum internet by 2025.

Despite the quantum memories successfully testing at laboratory scale, some components still need to be realized to perform the medium distance (50 mile) fiber-bed demonstration which will result in ~80% of the components necessary to complete the quantum repeater product. Due to Brookhaven, Stony Brook, and Qunnect operating with a lean team and budget the QIS research center is not moving as fast is it could. However, all sites are expanding, and development will accelerate with the arrival of USDOE funds.

The realization of the Quantum repeater product has both basic R&D and engineering challenges. If realized, the quantum repeater will enable a second generation of quantum communication protocols utilizing entanglement swapping. This is the key to truly quantum-secure networking.

The QIS research collaboration is reaching out to the US Professional Military Education (PME) institutions seeking Computer Science and Engineering students needing thesis work in quantum information sciences and photonics engineering. If successful, this could help eliminate personnel resource restraint and even potentially lead to additional funding from the Department of Defense (DoD). The DoD approach appears to be a good fit. The Department of the Navy (ONR) has funded several projects at SBU. Regardless of the resource challenges the technology has been proven in the lab, and confidence is high, the technology will successfully transfer to the smaller rack-mounted cases.

Analytic Confidence

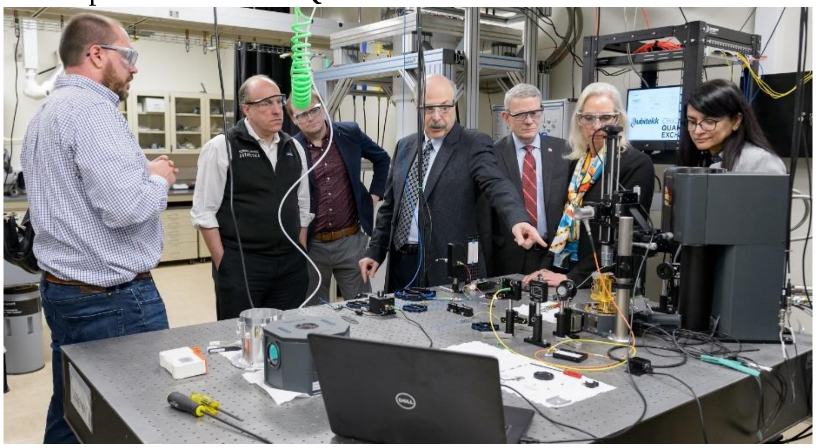
The analytic confidence for this estimate is *high*. Sources were mostly reliable and tended to corroborate one another. There was adequate time, but the analyst worked independently using a semi-structured method.

Author: Patrick Lancaster

United States Likely to Connect Multiple National Labs Using Quantum Internet by 2025

Executive Summary

The Quantum Information Science Research Centers are likely to achieve a quantum internet by 2025 due to receipt of funds and grants and the ability to leverage partnerships with US National Laboratories, universities, and industry to accelerate quantum internet development. The US Quantum Initiative Act directed the creation of a 10-year plan to accelerate the development of quantum information science and technology and authorized $1.2B over the next five years. The US Department of Energy (DOE) committed up to $625M on January 10, 2020, to establish two to five QIS Research Centers.



Department of Energy Under Secretary for Science Paul Dabbar and Argonne and UChicago scientists and leaders discuss quantum entanglement along Argonne's quantum loop, a 52-mile fiber-optic testbed for quantum communication in the Chicago suburb.
Source: Argonne National Laboratory

Discussion

The DOE effort to connect all 17 National Laboratories over a secure quantum internet will create the first US-wide quantum internet. The initial quantum internet development effort is a distributed effort led by QIS Research Centers at Argonne National Laboratory, Brookhaven National Laboratory, and Pacific Northwest Laboratory. H The US triad approach of partnering National Laboratories, universities, and industry is delivering tangible results as each location as they individually focus on solving various challenges. A US Quantum Internet is a crucial step toward developing a way forward for protecting US Intellectual Property (IP) and Critical Infrastructure and Key Resources (CIKR). Figure 1 is leadership discussing Argonne's quantum loop, which is a testbed for transmitting quantum-entangled photons across a 52-mile real-world environment. H

Brookhaven National Laboratory has a functional 60-mile connection to Stony Brook University Laboratory, where they are working on developing a quantum repeater that can extend the distance of a quantum internet an infinite range through connecting multiple network links using quantum memory. H Quantum internet repeater testing will begin in a few months using small commercial-sized equipment which operates at room temperature. H Brookhaven, Stony Brook, and Quunect are developing LIQuIDNET which will transmit quantum information over a 100-miles by connecting Stony Brook Campus, Brookhaven Campus, Manhattan Landing (MANLAN), and New York State Education and Research Network (NYSERNet).H

In a parallel effort, Brookhaven is working to establish an optical line of sight quantum channel between Brookhaven and Stony Brook over a 25-mile open-air connection. H Further, Brookhaven has developed a portable quantum-entanglement photon source and successfully installed the system in server racks at the Scientific Data and Computing Center (SDCC), which is the networking hub. The creation of the portable source allows for rapid quantum network expansion over existing fiber networks. H The Pacific Northwest Laboratory is proving their partnership with Microsoft will be invaluable to the US Quantum Initiative Act goals. QIS Research Center work goes far beyond quantum core competencies to the development and production of QIS materials. H

The path for Quantum Internet development is often described in six stages: 1-trusted repeater, 2-prepare and measure, 3-entanglement distribution networks, 4-quantum memory networks, 5-few qubit fault tolerances, and 6-quantum computing. H However, the QIS Research Center comprised of BNL, SBU and Qunnect speak in terms of the three phases of Quantum Internet development where Phase 1 is personnel, materials, technology, standards, methods, and specifications. Phase 1.0 is driving Phase 2.0, which is the design and development of quantum internet devices and components which perform the functions of traditional internet devices but for a quantum internet. Phase 3.0 is configuring the Phase 2.0 devices and components into systems and quantum internet networks. The development of the three quantum internet phases is coinciding at each of the QIS research centers, and testing and experimentation is fueling diverse approaches to solving QIS technical challenges.

As the QIS research centers build more Phase 2.0 devices and components and provide Phase 3.0 proof of concept and use cases, the quantum internet effort will gain additional funding and support. With private and public financing for QIS already exceeding $13B, it is apparent government and industry are highly motivated to establish a quantum internet. Intelligence sharing, Intellectual Property, and CIKR are a few use cases examples where quantum internet would provide the tamper-proof network security required to both detect and prevent network intrusion. Quantum entanglement hacking is currently not possible by even the most powerful quantum computers. The first nation with quantum internet will enjoy security and reduced risk over those who do not have secure networks. Especially if QIS delivers radically improved quantum computing as a technology is shared and processing power capable of breaking RSA encryption. H

Despite over $13B in global QIS funding, many challenges and hurdles remain, and the 2016 roadmap lacks details is outdated. [H] The US QIS research centers need to collaborate and publish an updated roadmap that meets the requirement of the US Quantum Initiative Act to produce a 10-year plan. Despite quantum internet testing and experimentation is being performed using single photons QIS labs are experimenting with using grids of photons of 100 and 1000 photons to increase the efficiency of quantum internets. Not all QIS reports are accurate as China reported successful 1200 km photon entanglement transmission but failed to say they only successfully transmitted 1 in 6 million photons. [H] However, current milestone achievements, the combined US triad partnership approach, the US government support, and DOE commitment to success will lead to the connection of all 17 National Labs over a quantum internet by 2025.

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were mostly reliable and tended to corroborate one another. There was adequate time, but the analyst worked independently using a semi-structured method.

Author: Patrick Lancaster

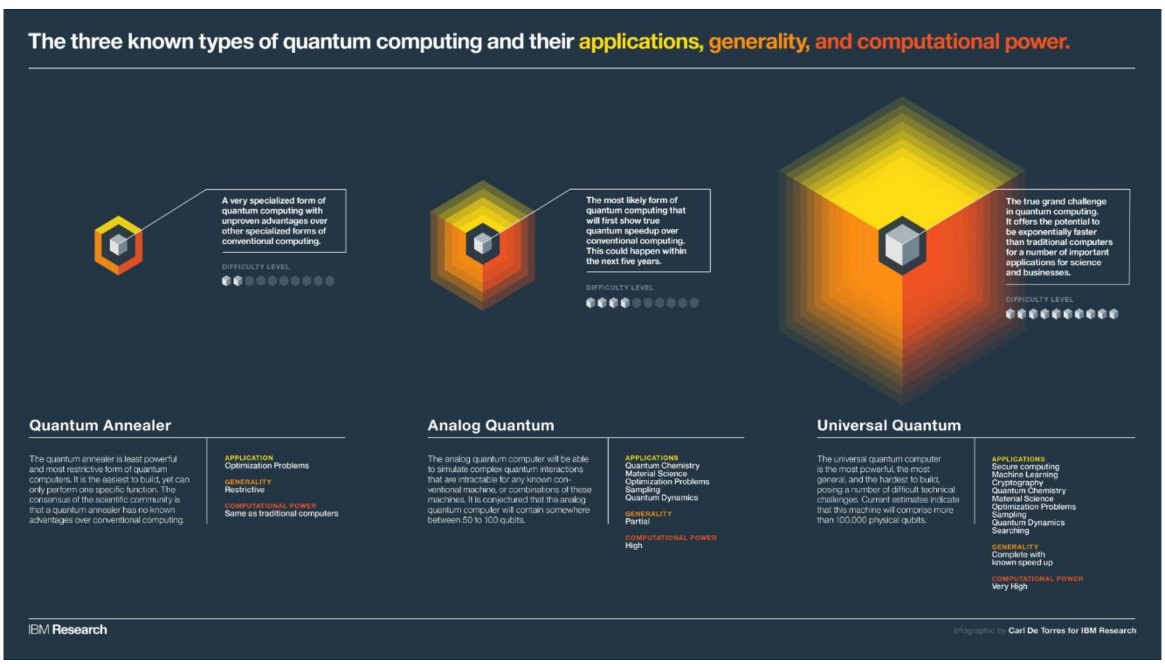
Universal Quantum Likely to Enable Artificial Intelligence by 2030

Executive Summary

Universal Quantum computers will likely exceed the capability of classical computers, which will enable Artificial Intelligence (AI) as well as voice recognition, machine translation, and advanced computer vision. The quantum computer industry is developing rapidly, and experts agree that beginning in 2030, quantum computers will start to outpace classical computers. These universal quantum computers will pave the way for researchers to apply quantum algorithms to Artificial Intelligence (AI) techniques to create a new discipline called Quantum Machine Learning (QML). AI and Machine Learning (ML) are two key research areas for quantum computing based on the ability of quantum computing to represent several states simultaneously, which pairs well with techniques used in AI. Also, quantum algorithms enable machines to answer specific questions much faster by increasing the number of calculation variables a machine can manage. Beginning in 2030, universal quantum computers will surpass classical computers and unlock the potential of powerful AI and ML technologies.

Discussion

Quantum annealer, simulation or analog quantum, and general-purpose or universal quantum are the three types of quantum computing. The first type of quantum annealing



Comparison of three types of quantum computing and their applications, generality, and computational power. Source: [medium.com]()

is designed only to perform one specific function and lends itself toward optimization and flows and is the least powerful of the quantum computer types. [H] However, quantum annealing is proving to be important as D-Wave recently sold a 5,000-qubit machine “Advantage” to Los Alamos National Laboratory. Advantage is built for commercial applications and designed to solve business optimization problems. [H] The second type is a simulation or analog quantum circuits that are moving the science forward, but there are limitations to quantum simulators. For example, the practical full state limit for a quantum simulator is 48-qubits, but experts believe methods can increase the capacity to 100-cubits. Scientists are finding creative ways to overcome the limitation, and Argonne National Laboratory, a Quantum Information Science (QIS) Research Center, recently achieved a 61-qubit simulation of Grover’s quantum search algorithm on a massive conventional supercomputer with .4 percent error. Argonne was able to overcome the practical full state limit of 48-qubits through data compression techniques. [H] The third type is universal quantum computers, and Google is a leader in this space and successfully demonstrated “Sycamore,” a 53-qubit universal quantum computer. [H] These are the most powerful type of quantum computers and are the type with the capability and capacity to train AI between 2030 and 2035. Most press on quantum is written about universal quantum and the race for quantum supremecy, which is where IBM, Google, and Rigetti Computing are leading.

Universal quantum holds the most significant potential for the future of computing, and the current goal is to reach 128-cubits. Quantum computers need to exceed the capability of current quantum simulators. IBM Research, in collaboration with MIT-IBM Watson AI Lab, describes the potential to enable ML on quantum computers soon. As quantum computers become more powerful and their quantum volume increases, they will be able to perform feature mapping, a key component of ML, on highly complex data structures at a scale far beyond the capability of the most powerful classical computers. [H] As universal quantum reaches and 128-qubits with improvements in stability and noise reduction, AI will be able to benefit from the quantum advantage for ML. Researchers are not yet ready to simulate the quantum advantage using conventional computers. [H]

Despite quantum annealing already producing a 5,000-qubit machine expert agree, the technology can only produce the computational power to match conventional computers. Due to simulators or analog quantum computers having a theoretical maximum capacity of 100-qubits, they also do not have the computational power developers are seeking to unlock from quantum computing. Universal quantum computing is the most powerful of the three types of quantum computing but also holds the most serious technical barriers like stable hardware, software development, and distribution platforms that need to materialize before achieving its potential. The downward trend in quantum computing investment is also a challenge as there were 11 deals at $240M in 2017, 16 deals at

$119M in 2018, and 7 deals at $82M in 2019. [H] However, the 2017-2019 investments will be realized over the next few years as the industry experiments, tests, and builds. Although there has been a reduction in investment toward research and development in quantum computing, the US Quantum Initiative Act has also authorized $1.2B toward the acceleration of the Quantum Information Sciences. [H] Therefore, the industry will continue to develop rapidly and experts agree by 2030, we could see universal quantum computers outpace classical computers. [H]

Analytic Confidence

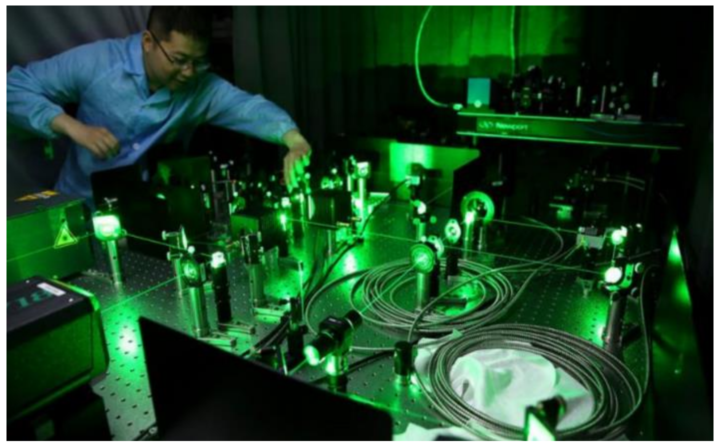
The analytic confidence for this estimate is *moderate*. Sources were mostly reliable and corroborated one another regarding the 6G roadmap. There was adequate time, but the analyst worked independently using a semi-structured method.

Author: Patrick Lancaster

China's Alibaba Quantum Laboratory (AQL) Likely to Achieve 100 Qubit Prototype by 2030

Executive Summary

Alibaba Quantum Laboratory (AQL) released an ambitious 15-year roadmap to develop quantum computer prototypes capable up to 100 qubits by 2030.[M] Further, by 2025, China expects to exceed the Google 53 qubit quantum computer and build the fastest quantum computers in the world. China announced a $10B National Quantum Information Science Research Facility located in Hefei, and China will open in 2020, which will accelerate QIS development. Further, an AQL cloud service subsidiary Aliyun ("Alibaba Cloud"), announced on February 23, 2018, they and the Chinese Academy of Sciences jointly launched an 11-qubit quantum computing service, which is available to the public on the Quantum Computing Cloud Platform.[M]



(Image by WIRED)
Source: nextbigfuture.com

Figure 1 China's AQL subsidiary Aliyun "Alibaba Cloud" launched an 11-Qubit quantum computing service.

Discussion

China's quantum focus has been on developing Quantum communications, quantum internet, and quantum key distribution (QKD). However, China's is entering the quantum computing race and is prepared to leverage the new National Laboratory for Quantum Information Science (NLQIS) to catch and even proclaims to be able to surpass US efforts.[M] Google developed a 72-Qubit system in 2017 which proved too difficult to control so Google had to go back to the drawing board. However, on October 23, 2019, Google announced a 53 Qubit Quantum computer "Sycamore" completed a calculation in 3 min 20 seconds, which the world's fastest conventional network would take 10,000 years to perform. IBM challenged Google's claim and completed the task with "Summit" in 2.5 days after IBM altered the traditional computer to manage the calculation better. [M] Google and IBM have both reached the 50 qubit benchmark while China is still working at about half that qubit capability. Therefore, China has some catching up to do with regards to quantum computing, while China enjoys a significant lead in quantum communications and quantum key distribution (QKD).

Despite China publishing a 15-year roadmap to achieving quantum computing supremacy INTEL Chief Technology Officer (CTO) Mike Mayberry told WIRED he sees broad commercialization of the technology a 10-year project while IBM says quantum computing can be mainstream in five years.[M] The industry is running into fault tolerance as the limiting factor in performance as they continue to increase Qubits and Quantum computing processing capability. However, China's proclamation that they achieve QIS breakthroughs in 2030, and the global leader by 2035 is farfetched. Multiple countries recently invested over $1B to accelerate the development of QIS technologies, and China is lagging and only now shifting quantum efforts toward quantum computing.[M]

Analytic Confidence

Analytic confidence in this estimate is *high.* Sources were mostly reliable and corroborated one another. There was adequate time to gather information, but the analyst worked independently and used a semi-structured method.

Author: Patrick Lancaster

Quantum Simulation Likely to Accelerate Quantum Computing Between 2025 and 2030

Executive Summary

Direct access by businesses, students, researchers, and scientists to quantum simulation provides a free platform for experimentation and testing. As diverse groups use open-source quantum simulation to test new and different algorithms, they will increase knowledge and learning in the areas of quantum programming, computing, and physics. Therefore, the quantum simulation will likely accelerate quantum computing between 2025 and 2030.

Physicists have simulated the creation of elementary particle pairs out of the vacuum by using a quantum computer.
Source: IQOQI/Harald Ritsch

Discussion

The history of classical computing reveals as hardware becomes available that simulates and accelerates the development of new algorithms. One example is heuristics, which worked much better than theorists could initially explain and were discovered experimentally. We can expect the same with making quantum simulators open source for public experimentation and testing. [H] Deep learning is an example where researchers lack a theoretical explanation of why deep learning works as well as it does. Quantum simulation presents an opportunity to validate the performance of new algorithms where we do not yet understand why they work. [H]

D-Wave Systems Inc. signed an agreement with NEC Corporation to form D-Wave's Leap Quantum Cloud Service. [M] Leap uses NEC's cloud technology and D-wave's older 2000-qubit annealer machine to provide customers with quantum annealing simulation services. [H] In the year since launching Leap, the number of customer applications build using the D-Wave systems has grown from 80 to more than 200 across diverse applications from protein folding, financial modeling, machine learning, materials science, and logistics. [H] NEC anticipates it will offer the next-generation D-Wave 5000-qubit machine "Advantage" mid-2020. [H] Traditionally, quantum annealing machines were unable to speed up solution times compared to the best classical computers running the best algorithms for the same problems. Leap will be using a hybrid approach, and which combines annealing and classical techniques. When they find the core of the problem, then they send that off to the quantum processor, and using this approach they believe they can solve large problems with the 5000-qubit annealing machine. [H] Another simulator is the IBM Qiskit, which is a free Quantum kit for programming in Python where the customer can log in and program on Quantum computers. In March 2019, Qiskit had 100,000 users that had run 5.5 million experiments. [H] IBM also provides the Quantum Experience where customers can create an account and have access to free tutorials and YouTube videos, which teach them how to get started programming and building quantum circuits. [H] Multiple simulators will benefit those experimenting, and quantum will benefit from the multiple algorithms they are testing. Also, the process of coding and using the algorithms will better educate the workforce on how quantum computing works and will help accelerate the development of the technology. [H]

Despite the excitement surrounding quantum computing and Quantum Information Sciences (QIS), the technology is full of formidable challenges. The quantum computing challenges include but are not limited to stability, noise, temperature, and understanding of the algorithms. Making quantum simulators and quantum computer simulation open source will increase development and accelerate quantum computing. [H] Also, the workforce, which is using these simulators to research and, in some cases, solve real-world challenges, is becoming familiar with the power of quantum computing. This familiarity will help bring the technology into the workplace and provide business leaders and decision-makers with tacit knowledge of QIS. The open-source approach of delivering new quantum hardware platforms where developers can write software and experiment with new algorithms creates a symbiotic relationship where both hardware and software development occurs. [H] Therefore, as the industry is offered products like "Leap" and "Qiskit the investment in the open-source quantum simulation will lead to software and algorithm innovation and learning, which will promote quantum computing. Therefore, it is likely the increased use in the quantum simulation is likely to accelerate quantum computing between 2025 and 2030.

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were mostly reliable and corroborated one another. There was adequate time, but the analyst worked independently using a semi-structured method.

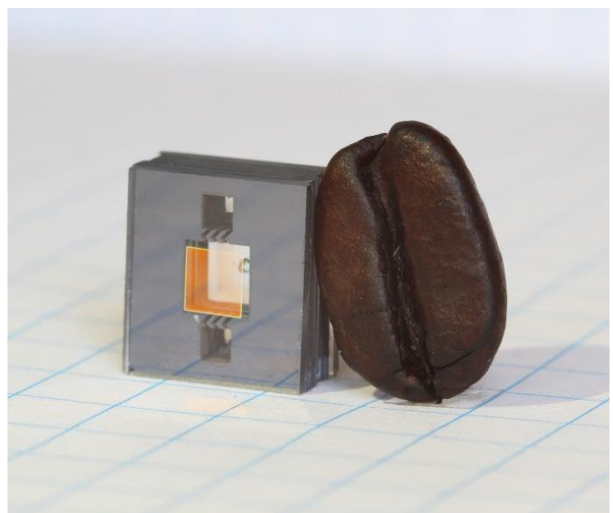
Author: Patrick Lancaster

Highly Likely a PNT Alternative to GPS Available for Navigation and Telecommunications Systems by 2025

Executive Summary

The Time and Frequency Division at the National Institute of Standards and Technology (NIST), through collaboration with the Defense Advanced Research Projects Agency (DARPA) has developed the Chip-Scale Atomic Clock (CSAC). The latest "NIST on a Chip" (NOAC) efforts have produced Chip-Scale Optical Clocks (CSOC) capable of 1.7 x 10^{-13} at 4,000 seconds stability, which is about 100x better than chip-scale microwave clocks. The CSOC performance is accurate enough to make it a potential replacement for traditional oscillators used in navigation and telecommunications systems.

Discussion



The Heart of NIST's next-generation miniature atomic clock-ticking at high "optical" frequencies – is the vapor cell on the chip, shown next to a coffee bean for scale. The glass cell (square window in the chip) contains rubidium atoms, and vibrations provide the clock "ticks." The entire clock consists of three microfabricated chips plus supporting electronics and optics. Source: Hummns/NIST.gov

Chip sized atomic clocks could hold the key for alternative timing data in a GPS-denied environment and DARPA is making highly accurate prototypes. [H] The goal of NOAC is to manufacture and distribute these new technologies to the public sector to increase technology transfer and improve lab-to-market opportunities to strengthen US economic competitiveness through advanced manufacturing. [H] Further, the precision of new Global Positioning Satellites (GPS) has improved and the internal atomic clocks which provide the timing work at a factor 100x higher than the original nuclear clocks. [H] The atomic clocks used in new Global Positioning Satellites are 100 times more accurate than the atomic clocks in the first GPS satellite. The CSAC and CSOC technology NOAC is developing produces a highly stable and precise timing source that can meet this requirement. [H] For small portable devices which require PNT the chip sized atomic clock provides benefits through reduced power, weight, reliability, and size. Using onboard PNT eliminates the requirement for a GPS receiver. The chip sized atomic clocks require very little power to operate. The onboard CSAC and CSOC atomic chips do not requiring an external GPS signal so the device using internal PNT is much harder to jam or spoof with false GPS signals. [H] Beyond the economic impacts of losing GPS the SCAC and SCOC PNT solutions also have application to include: Internet of Things, Networks, Communications, Robotics, Medical, Autonomous Vehicles, and the DoD. [H]

The US Army is wants to be less dependent on GPS. Army Futures Command recently formed an Assured PNT Functional Team to focus on providing alternate trusted PNT when GPS is denied or degraded. [H] The US economy also depends on GPS. The estimated financial impact of a 30-day GPS outage is $16B-$35B with an additional $15B if the outage occurs during a critical planting season for US farmers. Not including farming, the economic loss would average $1B per day. [H] NOAC efforts to produce a readily available and trustworthy commercial GPS alternative by 2025, which can provide an alternate PNT source in the event GPS is lost, is critical. [H]

DARPA's Atomic Clock with Enhanced Stability (ACES) Program is developing its next-generation battery-powered Chip-Scale Atomic Clock (SCAC) with 1000 times improved performance. One team headed by NASA's Jet Propulsion Laboratory (JPL) has demonstrated a SCAC which meets the ACES Program target metrics with 100x improvement over previous designs. DARPA states the NIST NOAC SCOC in Figure 1 above is the size of three small chips and uses far less power than the NASA JPL SCAC and provides 50x improvement over the SCAC. [H]

Despite the successful quantum sensing tests, both NIST and DARPA are still working on perfecting the SCAC and SCOC miniature atomic clock precision timing prototypes. The GPS satellite constellation remains the gold standard for PNT. NIST on a Chip (NOAC) and DARPA ACES are just two possible GPS alternatives. Multiple agencies are working to find alternative GPS solutions and the Space Development Agency even proposed fielding an alternate satellite constellation. [M] The US Quantum Initiative Act authorized $1.2B toward Quantum Information Sciences (QIS) research but that investment includes all quantum research. With only a small portion of the $1.2B going toward quantum sensing the US has not made a serious investment to solve this challenge. However, it is highly likely that the US will increase the quantum sensing research investment if GPS is disrupted and the US economy starts losing $1B per day. [M]

Analytic Confidence

Analytic confidence in this estimate is *high.* Sources were mostly reliable and corroborated one another. There was adequate time to gather information, but the analyst worked independently and used a semi-structured method.

Author: Patrick Lancaster

Nanotechnology

> Nanotechnology is the idea that we can create devices and machines all the way down to the nanometer scale, which is a billionth of a meter, about half the width of a human DNA molecule.
>
> **Paul McEuen**

Introduction

Nanotechnology is the study and application of extremely small things (one to 100 nanometers) and can be used across other science fields, such as chemistry, biology, physics, materials science, and engineering.[H] One nanometer is a billionth of a meter, or 10^{-9} of a meter.[H] Hence, nanoscience and nanotechnology involve the ability to see and to control individual atoms and molecules.[H]

Research Emphasis

Nanotechnology is a particularly compelling realm of science since it provides both minimally and non-invasive means of augmenting other disciplines, and even the human body, with emerging technologies. Commercial and military leaders alike recognize the potential in this field and have invested billions of dollars in capital to advance many of the innovations highlighted in this chapter. It is highly likely that emerging trends in this discipline will improve industrial safety, reduce pollution, improve materials development, and shorten warfare as we know it. With specific relevance to this research, nanotechnology is changing how humans compile information, process mass amounts of data, power nano-devices, and even making it so the blind can see.

As noted in the key findings, nanotechnology is a mass enabler advances in the other seven disciplines researched throughout this project. In many instances it provides a means of powering, calibrating, strengthening, and shrinking devices and components we rely on every day. More importantly, nanotechnology provides the glue at the atomic level for the convergence of an almost infinite number of technological advances that shape the future development of science, technology, and human affairs.

Graphene Enhanced Battery Commercial Growth Throughout 2020s, Highly Likely to Replace Lithium Ion by 2030

Executive Summary

A growing demand for graphene batteries and improved large-scale production methods make it highly likely that graphene will replace lithium ion batteries by 2030. Despite subpar performance against lithium ion batteries and the inflated cost of processed graphene, the material's strength, elasticity, rapid charge rate, negligible degradation, and ability to quickly deliver power are rapidly driving up market demand for the emerging nanotechnology.

Discussion

Graphene is simply a single layer of graphite, akin to a honeycomb, arranged in a one atom thick, crystalline structure.[H] It was first discovered in 2004 at the University of Manchester, and rapidly gained popularity in the battery industry due to its high rate of conductivity and ability to store an electrical charge without significant degradation.[M] For example, the physical structure of graphene offers decreased resistance, and allows electricity to pass through it near the speed of light.[H] This far surpasses that of silver, copper, or other commonly used conductive materials. Furthermore, graphene can be used as a capacitor to physically store energy as a charge rather than through chemical reaction methods utilized in modern day batteries.[H] As a result, supercapacitors charge in a matter of minutes rather than the hours it takes for conventional batteries.[M]

The graphene battery market will reach $115M by 2022, with a 38.4 percent combined annual growth rate each year thereafter.[M] The electric automobile industry is a compelling use case playing a key role in this forecast, with transportation fuel cells dominating the market by 2030.[M] As justification, the price of lithium ion batteries cannot decrease much in the future due to the relatively high cost of lithium as a rare earth material.[M] However, the cost of graphene will drop as much as 80% with the onset of commercial production.[H] Additionally, graphene batteries are moldable, printable, lighter, and charge much faster than lithium ion batteries.[M] The body and frame of the car could house the battery and it could charge through simple contact with an electrode at each stoplight.[M]

These qualities alone seemingly make graphene a suitable substitute for lithium ion batteries, but several barriers currently prevent wide-scale commercial adoption. First, graphene supercapacitors have not replaced batteries in cars or electronic devices because they require a much larger space to hold the same amount of energy as a lithium ion battery.[H] Modern day lithium ion batteries hold an average of 200 Wh/kg (Watt Hours/Kilogram) whereas graphene supercapacitors average only 28 Wh/kg.[M] The best

Seeker explores the evolution of graphene batteries.
Source: seeker.com

supercapacitor to date reached the 131 Wh/kg mark, but that is far from surpassing lithium ion and is not commercially viable.[M] Second, in 2013 graphene was the most expensive material in the world at $1,000 per micrometer-sized flake[H]; however, the cost dropped to $50/kg in 2020.[H] Despite the sharp drop in price, it is still drastically more expensive than lithium at $8.75/kg and must compete with a robust, proven market base.[H]

Over the next decade, the battery industry seems poised to adopt a hybrid variant of lithium-graphene batteries as a trade off until the market matures. In 2014 Angstom Materials introduced battery anodes containing graphene that reduced the effects of charge/discharge cycles.[H] By 2016 Huawei introduced a graphene-enhanced lithium ion battery improving heat dissipation and charge capacity of their cell phone batteries.[H] Just one year later, Samsung unveiled a graphene ball lithium ion battery with a forty-five percent better charge capacity and five times faster charge rate.[H] All of these advancements show steady increases in commercialization, and forecasts predict increased investment and growth over the next decade (See Figure 1).

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the decade-long timeline associated with this estimate, this report is sensitive to changes based on new information.

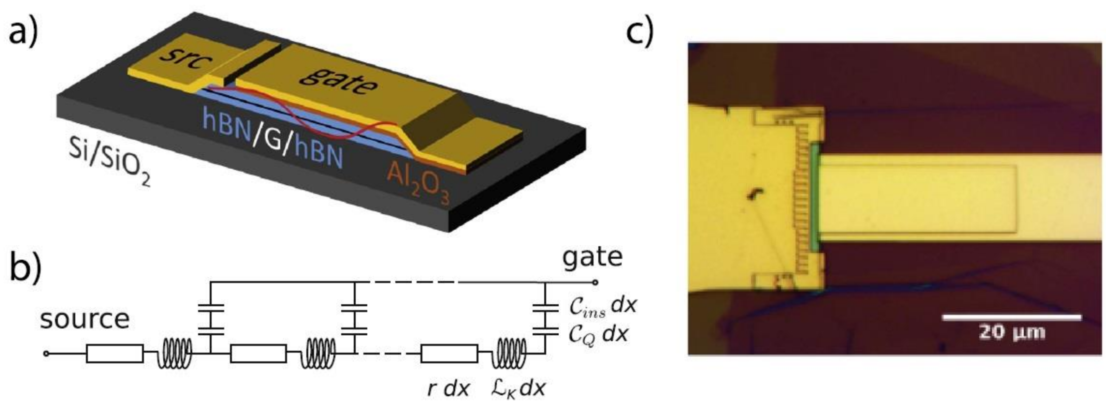
Author: Lance Vann

Graphene Plasmonics Highly Likely to Solve Quantum Computer Scalability and Thermal Limitations by 2025

Executive Summary

Graphene's electrical conductivity and thermal stability, coupled with the creation of a two-qubit logic gate, makes it highly likely that the cryogenic and vacuum limitations of quantum computing will be solved by 2025. Despite the relative newness of this technology and the high cost of graphene-based nanotech, commercial demands for faster processing speeds at nano scales, with stability surpassing industry standards for fault-tolerance, signals that graphene plasmonics offers a path to scalable photonic quantum computing by 2025.

Discussion



Sketch of a graphene plasma resonance capacitor (PRC) made of encapsulated graphene (blue/black) equipped with and edge contact and a top gate (golden). A thin layer of Al2O3 (brown) is used to isolate graphene from the top gate. (b) Distributed line model of the graphene resonator. (c) Optical image of a typical T-shape encapsulated PRC sample obtained by etching a broad BN-graphene-BN stack.
Source: [physicsworld.com]

Traditional computing encodes data in a binary fashion of zeroes and ones, whereas quantum computing uses qubits that can be in two states at the same time, allowing photons to interact with one another.[H] The only feasible way to read the state of each photon was through thousands of single-photon detectors housed in a $12 million dollar computer.[H] Xian-Min Jin, research team leader from China's Shanghai Jiao Tong University, asserts "It is economically unfeasible and technically challenging to address thousands of modes simultaneously with single-photon detectors…this problem represents a decisive bottleneck to realizing a large-scale photonic quantum computer."[H]

Traditional quantum computing also requires cryogenic and vacuum technology creating limitations for scalability and widespread application.[H]

Researchers at the University of Vienna recently found ways to overcome these problems through the use of graphene-based, two-qubit quantum logic gates (See Figure 1).[H] Two-qubit logic gates allow the interaction of single plasmons, similar to photons but in a plasma, traveling on carbon nanoribbons made of graphene.[H] Given graphene's stability, the plasmons are securely bound to their nanoribbons, but can achieve multiple interactions with other plasmons through the newly designed logic gates.[H] This process overcomes the need for single-photon detectors as outlined above by Jin, and allows for multiple gates on each ribbon which is necessary for quantum computing.[H] Given that graphene conducts heat ten times better than copper and conducts electricity 250 times better than silicon, graphene-based logic circuits improve the speed of microprocessors by a thousand times, require a hundredth of the power required by silicon-based computers, and are much smaller than logic circuits that use silicon transistors.[H] Therefore, this technological advancement breaks the three to four gigahertz processing speed upper limits, all on a nanoscale processor that operates at room temperature.[H] These qualities alone seemingly make graphene logic gates they key to scalable quantum computing, but several barriers currently prevent wide-scale commercial adoption. First, this process has only been proven twice in history by the independent research teams at the University of Vienna and Shanghai Jiao Tong University. Furthermore, the science behind this is mostly proven through calculations rather than actually constructing and replicating working devices.[H] Second, in 2013 graphene was the most expensive material in the world at $1,000 per micrometer-sized flake[H]; however, the cost dropped to $50/kg in 2020.[H] Electronic grade silicon currently trades at approximately $2/kg[H], so the key way for graphene to become affordable is widescale commercialization of production methods and adoption by leading consumer industries.

For now the computing industry is poised to adopt a hybrid variant of silicon plasmonics, including photonics, while graphene-based systems slowly assume market share.[M] The photonics market is expected to reach $929 million dollars by 2023, with a 7.84 percent combined annual growth rate (CAGR) each year thereafter.[M] IBM, Intel, and Kothura are the most prominent industrial adopters of this technology.[M] As for graphene, the market is expected to reach $552 million dollars by 2025 with a CAGR of 38 percent over the forecast period.[M]

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were generally reliable and tended to corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Lance Vann

FDA Approval for Smart Contact Lenses Highly Likely by 2025

Executive Summary

A growing demand for electronically enhanced vision, advances in nanotechnology and increased commercial investment make it highly likely that smart contact lenses will be approved for commercial use by 2025. Despite the lack of FDA clinical trial approval, corporate investments, patents, and the demand for aesthetic integration of human-machine interfaces will drive adoption of this technology.

Discussion

The term "smart contact lens" encompasses a broad genre of ophthalmological products. Contacts that treat Myopia or ones that auto-darken due to light stimulation are the most advanced commercially marketed products to date.[H] According to the American Academy of Opthamology, some of the most advanced products in the queue for FDA approval include contacts that deliver medication, telescopic lenses, and Augmented Reality (AR) contacts.[H] Despite the secrecy of the research and development process, AR contact lenses are showing signs of a technological convergence due to the application of multiple emerging nanotechnologies.[M]

The company Mojo Vision created a prototype AR contact lens that integrates nano batteries, CPUs, displays, radio transmitters, wireless/ Bluetooth receivers, night vision, cameras, and vision correction on contact lenses.[H] At the most recent Consumer Electronics Show in Las Vegas, Mojo Vision was not part of the event, but seized the opportunity to display their AR advances to a select few journalists. Scott Stein, a reporter for CNET, got to personally experience night vision and a micro screen display, who reported that the experience was much like a shrunken down, advanced version of Google Glass.[H] Aside from the demonstrated operability of the new technology, the

CNET tech review of Mojo Vision's AR contact lenses. To view video, click on picture or go to: Source CNET.com largest barrier thus far is figuring out how to power the device.[H] Until recently, AR lens prototypes were powered using a device that was worn around the wrist, but recent advances in flexible micro batteries and graphene based flexible electronics are bridging that gap.[H] Other methods under development include solar power and piezoelectric sensors that harvest power from eye movements, but they are not as feasible as graphene battery technology.[H]

Despite the existence of working AR contact lens prototypes, FDA approval may provide barriers to market entry. Medical approval for new devices averages three to seven years due to the varying length of clinical trials.[H] Additionally, any biocompatibility or safety issues that come up during this process can increase the approval timeline.[H] A promising sign is that the FDA recently granted Mojo Vision's AR contacts a "breakthrough device" designation which is likely to fast track the clinical trial process absent emergent safety issues.[H]

Regardless of market barriers, the argument for commercialization of smart contact lenses is strong. Mojo Vision hold patents related to AR contact lenses dating back over ten years and raised more than $100 million dollars in investments from tech giants such as Motorola, LG, and HP.[H] Furthermore, the company is made up of IT veterans from Apple, Google, and Microsoft, along with ophthalmology industry experts from Johnson & Johnson, Philips Healthcare, and Zeiss.[H] Lastly, Mojo Vision crafted a partnership with the Vista Center for the Blind and Visually Impaired delivering services to more than 3,000 children and adults with blindness or impaired vision each year.[H] Through this mutually beneficial arrangement, Mojo Vision has a readily available test bed of patients who can provide clinical trial feedback on the safety, operability, and even aesthetics of this emerging technology.[H]

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were reliable and tend to corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the five-year timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Lance Vann

Smart Dust Likely to Achieve Mainstream Commercial Usage by 2028

Executive Summary

A growing demand for smaller medical sensors, industrial/agricultural monitoring, Internet of Things (IoT) sensing, and advances in nanotechnology make it likely that smart dust, tiny computers designed to function together as a sensor network, will achieve mainstream commercial usage by 2028. Manufacturing costs, privacy concerns, and FDA approval for medical use cases are barriers to market entry, but growing capital investment from General Electric, IBM, and Cisco Systems, and previous FDA approval of similar internal human monitoring devices, signal the likelihood of mass commercialization within the next eight years.

Discussion

Penn State's College of Earth and Mineral Sciences defines smart dust as, "tiny computers that are designed to function together as a wireless sensor network."[H] In 2018 the common size of these devices were as small as a grain of rice, but have since been reduced to 6.5 mm^3, the size of a grain of sand.[H] Potential use cases include the monitoring of crops, mechanical equipment, supply chain inventories, industrial structures, and medical monitoring/stimulation (See Figure 1).[H] For example, smart dust sensors could be distributed on crop fields to monitor water requirements or pest control.[H] Additionally, similar devices could be added to fluids and lubricants to monitor machinery stresses, or even embedded in industrial structures to sense stress fractures or material degradation.[H] Simply put, smart dust's data gathering and reporting abilities will have profound effects on the IoT.[M] According to Forbes' Enterprise Tech contributor, Bernard Marr, smart dust holds the capacity to multiply IoT technologies up to a billion times over what it was in 2018.[M]

Despite the existence of working smart dust prototypes, manufacturing costs, privacy concerns, and FDA approval of medical applications provide barriers to market entry. First, most smart dust applications require the sensors to be cheap and disposable in nature. There are no cost estimates specifically for smart dust, but similar disposable microelectromechanical systems (MEMS) contain $.002 cents of silicon per device. However, the price of silicon would need to drop to $.0004 cents per device before they meet affordability constraints.[M] Second, once smart dust is distributed, it is essentially impossible to recover. In turn, corporations would have access to a multitude of sensors capable of gathering audio and/or visual data without the consent of those being

Dr. Kristofer Pister, professor of electrical engineering and computer sciences from the University of California Berkley, outlines the future of smart dust..
Source: Omnibus Forum

monitored.[H] Third, medical approval for new devices averages three to seven years due to the varying length of clinical trials.[H] Additionally, any biocompatibility or safety issues that come up during this process can increase the approval timeline.[H] There is no data on clinical trials yet, but if the FDA granted smart dust a "breakthrough device" designation, it could fast track approval to the shorter end of this timeline.[H]

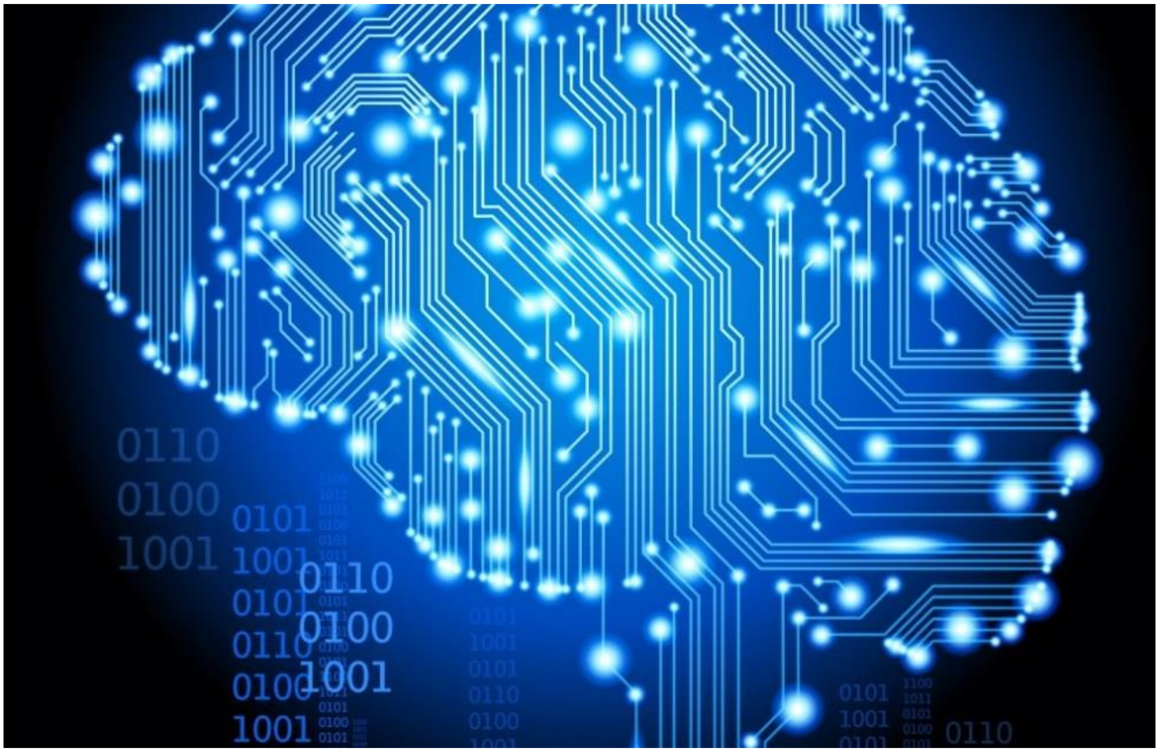
Regardless of market barriers, the case for mainstream commercial usage of smart dust is compelling. In August 2018, respected tech-forecasting firm Gartner estimated widespread usage of smart dust more than 10 years out, but on the path to commercialization.[H] Additionally, the inability to reduce the size of the power supply greatly inhibited the size of each smart dust particle for many years. However, through advances in solar, heat, and graphene-based power sources, scientists are now shrinking devices faster and smaller than ever thought possible.[H] Furthermore, in 2005 Paladin Capital Group, an investment firm with more than $1B dollars backing and worldwide access, acquired Crossbow Wireless Sensor Networks.[H] This a positive indicator of market acceptance given that Crossbow is a top end-to-end solutions supplier for wireless sensor networks and one of the largest manufacturers of Smart Dust sensors in the world.[H]

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were generally reliable and tended to corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the eight-year timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Lance Vann

Neurotechnology



> Moore's Law-based technology is so much easier than neuroscience. The brain works in such a different way from the way a computer does.
>
> **Paul Allen**

Introduction

According to Dr. Oliver Muller, Professor of Computational Neuroscience at the University of Freiburg, "Neurotechnology is defined as the assembly of methods and instruments that enable a direct connection of technical components with nervous systems. These technical components are electrodes, computers, or intelligent prostheses."[H] Neural signals are used to better understand how the brain communicates through a synaptic network, and are translated into electrical inputs for Brain Computer Interfaces (BCIs). BCIs range from invasive to fully non-invasive in nature and direct brain stimulation, prosthetics control, and brain mapping.

Research Emphasis

Neurotechnology is not a new science, but recent advances in this discipline are paving the way for the convergence of many additional technologies. Whether the brain is fully or partially mapped, a greater understanding of neural pathways and synaptic connections brings greater understanding of how the brain initiates and controls bodily functions. Additionally, as electrical impulses are correlated with specific movements or actions, researchers discover better ways for technology to integrate and enhance the lives of humans. As such, top tech medical research institutions invest billions of dollars into this field and integrate closely with the FDA in realizing the potential of emerging advances in this field.

As noted earlier, neurotechnology does not directly benefit from the innovations presented in this research. However, the future of this science is compelling to the Department of Defense and the commercial market alike since it likely holds the solution to physical brain injury, neural disease, and even future computing methods built around neural and synaptic architectures. As with nanotechnology, neurotechnology binds the convergence of an almost infinite number of technological advances that shape the future of medical, commercial, and military affairs.

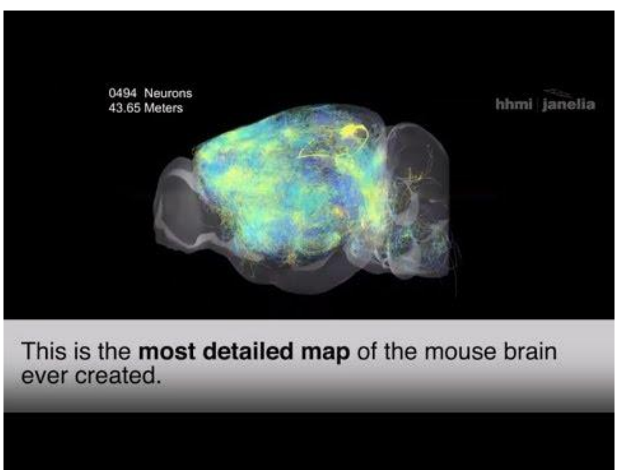
Neural Map of the Human Brain Highly Unlikely by 2035

Executive Summary

Though scientists have successfully mapped the brain of a nematode and portions of the brains in fruit flies and mice, the neuroscience community is highly unlikely to map the human brain in its entirety by 2035. The first step in making this a reality is data collection; however, a single neural map of the brain would be the largest dataset ever recorded. For example, one millionth of the brain's neural pathways contains more data than all the contents of the Library of Congress. Despite advances in microscopy and supercomputing, algorithms used to interpret neural segmentation are limited at best, making an accurate map of the brain is highly unlikely within the next fifteen years.

Discussion

In 1986, biologist Sydney Brenner created a draft neural map of a nematode's brain, which subsequently took more than 20 additional years to finalize as the first-ever connectome (neural map).[H] Over two decades, Brenner and his team mapped a network of 302 neurons and 7,000 synaptic connections in this simple 1mm-long organism.[H] The next significant breakthrough in the field did not occur until 2019 when the Howard Hughes Medical Institute produced a 1,000 neuron portion of a mouse brain, with an end goal of mapping the full 70 million-neuron organ.[H] (Fig 1) The process used by the team took as little as a day to map a single neuron, but a few years ago it took up to two weeks.[H] Earlier this year, the same organization announced that they had successfully mapped 25,000 neurons and 20 million connections in the core of a fruit fly brain, as part of a partnership with Google.[H] This landmark accomplishment took more than 12 years to complete and came with a $40 million dollar price tag.[H]



Howard Hughes Medical Institute researchers demonstrate neural pathways in a mouse brain.
Source: [Youtube (Howard Hughes Medical Institute)]

To put these three accomplishments in perspective, brain mapping progress jumped from 302 neurons and 7,000 connections over 20 years, to 25,000 neurons and 20 million connections over a span of 12 years. Given the most recent technological breakthroughs in this field and the case studies provided above, it would still take 48 million years to completely map the human brain using similar methodologies. Furthermore, the algorithms used to interpret neural segmentation miss bits of neurons or erroneously merge two into one.[H] As a result, humans are still required to check all mapped segments to ensure validity, greatly extending the timelines toward a legitimate brain map.[H] Eyewire is a crowdsourcing effort that enlists the help of over 290,000 volunteers to assist with these efforts, but their work still falls far short the fifteen-year period of this estimate.[H]

Mapping the brain will only be a starting point for true application. According to Dr. John Mazziotta and Dr. Arthur Toga of the UCLA School of Medicine, "brain imaging will provide the bridge among the phenotypes, the genotypes, and the behaviors of the human species."[H] Furthermore, Dr. Bobby Kasthuri believes that reading neural activity and linking these actions to specific functions of the human body could eventually lead to a cure for neurological disorders such as autism and schizophrenia.[M] With regards to military application, neural maps could likewise be used for precisely targeted non-invasive neural stimulation, which is showing promise for accelerated motor skills acquisition among pilot trainees.[H]

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were generally reliable and tended to corroborate one another. There was adequate time, but the analyst worked alone and did not use a structured method. Furthermore, given the lengthy time frame of the estimate, this report is sensitive to change due to new information.

Author: Lance Vann

FDA Approval for Non-Invasive Brain Computer Interface Prosthetic Device Likely Between 2023-2027

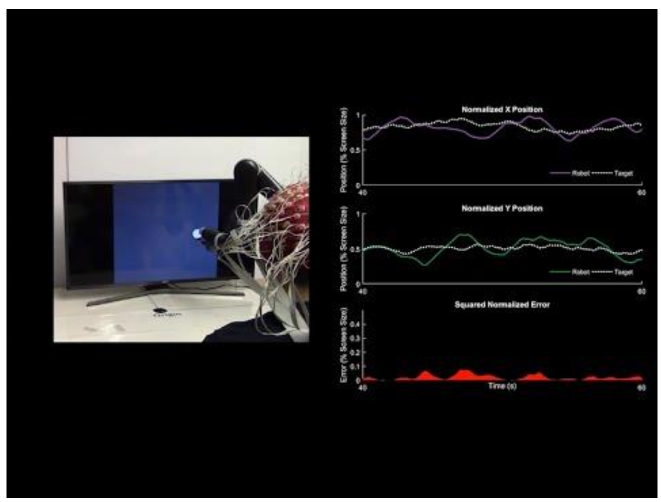
Executive Summary

Demonstration of the first ever non-invasive prosthetic Brain Computer Interface (BCI), and the desire to wirelessly read neural stimulations, make it likely that manufacturers will receive FDA approval for medical devices between 2023 and 2027. Despite poor signal quality and a lack of device portability, advances in electroencephalogram technology, its supporting software, and the demand for mobile platforms will overcome these barriers. Medical, commercial, and military applications will enter the consumer market upon FDA approval which will take up to seven years dependent on clinical trials.

Discussion

Surgically implanted BCIs allow physically impaired humans to control robotic prosthetic devices using electrodes imbedded in the brain.[H] Despite the benefits, these implants pose substantially higher risk to patients due to brain fragility and the extremely precise surgery to imbed and secure electrode leads.[H] For example, wire strands must be rigid enough to puncture the brain and provide stability, but also minimize damage, shock, and inflammation to the surrounding tissue.[H] Due to hazards associated with invasive BCI procedures, researchers at Carnegie Mellon University developed non-invasive technologies and successfully demonstrated the device in 2019.[H]

Carnegie Mellon researchers demonstrate first ever non-invasive BCI controlled robotic arm. Click on picture or go to: https://youtu.be/UkZquERzoOo to view video. Source: Engineering.cmu.edu (Carnegie Mellon University College of Engineering)



Non-invasive neurotechnology is not a new science, but several barriers exist preventing widespread use in the field of prosthetics. Electroencephalograms and transcranial direct current stimulation are examples of existing technologies, but they do not offer the precision or portability required for prosthetic use or patient mobility.[H] Furthermore, non-invasive BCIs receive "dirtier" readings than implanted electrodes due to signal scattering as inputs pass through bone and tissue.[M] In August 2018, respected tech-forecasting firm Gartner estimated heightened expectations for BCI devices in five to ten years, but they did not delineate between invasive and non-invasive applications.[M]

Undeterred by these shortcomings, medical, commercial, and military interest in this field are driving continued research and investment. All invasive and non-invasive BCIs have been experimental up to this point; however, the FDA released draft guidance in 2019 outlining the medical approval process for both.[H] FDA approval is the linchpin in the success of widespread use and acceptance of this technology. Medical approval for new devices averages three to seven years, but physical and technical limitations with non-invasive methods will increase the timeline.[H]

Nonetheless, Transparency Market Research predicts 14.9% annual investment growth until 2024, with the global market reaching $1.2 billion dollars by then.[M] Likewise, DARPA brought military applications into the fold by investing over $2 billion dollars in its AI Next campaign.[H] As part of this program, DARPA awarded research funding to six commercial and academic organizations as part of the Next-Generation Nonsurgical Neurotechnology (N^3) program in 2018.[H] The impetus for this project is rooted in applications such as active cyber-defense of networks and multi-tasking requirements inherent in controlling drone swarms.[H] Thus far, effective military application of BCI technologies has been limited to invasive techniques and applied to handicapped volunteers with clinical need.[H] The N^3 program is aimed at bridging that gap and applying this science to healthy, able-bodied individuals.[H] The use cases are likely to grow exponentially through not only medical applications, but also through non-invasive BCI education, marketing, and entertainment platforms.[M]

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were generally reliable and corroborate one another. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, given the long timeline associated with this estimate, this report is sensitive to changes based on new information.

Author: Lance Vann

Biotechnology

> The rewards for biotechnology are tremendous - to solve disease, eliminate poverty, age gracefully. It sounds so much cooler than Facebook.

George M. Church

Introduction

According to the online Oxford Dictionary, biotechnology is the exploitation of biological processes for industrial and other purposes, especially the genetic manipulation of microorganisms for the production of antibiotics, hormones, etc.[M] The best definition is "technology based on biology," as quoted by BIO, who purports their mission and vision to be: "To advance biotechnology innovation by promoting sound public policy and fostering collaboration, both locally and globally."[HH] Finally, BIO also sees the value in biotechnology to "harnesses cellular and biomolecular processes to develop technologies and products that help improve our lives and the health of our planet. We have used the biological processes of microorganisms for more than 6,000 years to make useful food products, such as bread and cheese, and to preserve dairy products."[H] Finally, according to the Khan Academy, biotechnology includes any biological aspect manipulated for the benefit for anything else, including beer brewing, genetically superior fruits, and larger beef cattle, for example.[H] Under this definition, and from other sources, this broad subject matter, and these broad definitions, include prosthesis.[H]

A cyborg beetle, part of DARPA's Micro Air Vehicles and Micro Electrical-Mechanical Systems research. DARPA has demonstrated ability to control insects in flight.
Source: [spetctrum.ieee.org]

BIO drives the point, that humans have been cultivating breeding pets and wildlife, and altering their biological environment for their benefit for millenia. It is easy to forget that every breed of dog is the same species of canine, all manipulated by humans. However, biotechnology has taken leaps. It is now commonplace, if still exciting to consider the advent of renewable biomasses, biofuels and the biofuel refinement process, just to name a few. Medicinally, biotechnology has led to advanced development in allergen, and anti-allergen technology, vaccinations, and non-traditional medicines.

Focusing on the effort to move the science fiction to the reality, DARPA has fielded cyborg insects, who's flight path the scientists can control.[H] China, despite self-identifying as a nation who values ethics and regulation, has genetically modified and fielded twin "designer babies," resistant to HIV, and placing human DNA into primates, which may make the primate smarter than its genetically unaltered peers.[HH] This is problematic because of current conventions against human DNA transferrance and manipulation, as well as China's stance, but also global implications for the future.[H] Nevertheless discover and science drive on.

Research Emphasis

The scope and framework of biotechnology is so vast and large, that it was hard to remain scoped. Medical research seemed persistent, but noncommittal at best. While doing specific research for immunomodulation, anti-alergen, drug development, the research becomes very compartmented, where techniques, practices, and medicines will exist (or already do in many cases), but timelines and practices require no commitment (best released when most needed financially or otherwise) and medical standards are of "best practice", rather than field-wide requirements driven. Research included allergens, anti-allergens, non-traditional medicine, and vaccination. No effective research was deterministic by 2035 in this arena.

A genetically altered feline, whose DNA is splice with jellyfish DNA, making it glow in the dark..
Source: [livescience.com]

Radically shifting, based on research, toward genetical manipulation bore fruit. CRISPR and the gene drive were of particular interest. Since gene drive has the ability to annihilate pestilent species (which could include humans), the results were surprising, based on the need. The African Union badly wants the gene drive technology in an effort to preserve life and stop the spread of malaria.[H] Meanwhile, the creator worried about implications, and developed the daisy drive to limit the far reaching possible effects of genocide.[H] Furthermore, cross-genetics, designer babies, and designer pets have more applications. As Labradors and Shepherds are the primary working dogs, breeding hip, joint, and cancers out of the breeds has many merits. With experimental genetics, like splicing jellyfish into household pets, which may have future implications, the novelty is notable, but the obvious application is minimal.[H]

Finally, biomass and biofuels seemed unworthy of significant research. Initially, the research in biotechnology began there, but biofuels and biofuel refinement are likely to continue and not advance much beyond that capability in the next 15 years. The cost of the fuels process is significant, and the population increases will drive more resources to food and fresh water for people and food for animals, vice fuels.[H] Within the next 15 years, the environment will not likely shift significantly.

Tom Cruise in an advertisement poster for "Edge of Tomorrow" wearing a "Fighting Exoskeleton", enhancing the wearer while engaging in combat operations using active AI to heighten mental acuity.
Alfred Molina as Spider-Man villain Dr. Octavius in Spider-Man 2, wearing an AI, enabled, prosthetic.
While Both are impressive imaginative ideas for biotechnology, neither are likely by 2035

Finally, any prosthesis and exoskeletons are especially relevant. These are relevant for wounded warriors, laborers, amputees, or permanently injured or disabled personnel. However, these technologies more closely align in robotics, neurotechnology, nanotechnology, and some autonomy and AI. While biomaterials and the biological connection drive them as biotechnology, there is nothing largely biological about them. From discussions with the other Mad Scientists Fellows, neurosynapses and muscle twitch responses fit more conveniently in other technologies, being affixed to biological organisms post development. However, this technology is in continuous development, mostly to replicate normal human (and pet) motion and behavior. It is highly likely this will continue in a similar manner. Unfortunately, it is unlikely that humans will adopt super-human capabilities, even for those who ever known “normality (e.g., people born without limbs, or with limbs amputated at young ages). The prospects, not at all likely by 2035, could, further down the road, look like appendages similar to Spider-Man’s antagonist, Dr. Octavius. Despite this unlikely nature, it is not unlikely that other nations or bad actors may experiment beyond standard ethical realms in human manipulation.

Biopolymers Will Likely Remain Niche and Novel Well Beyond 2035

Executive Summary

Biopolymers, while possessing incredible potential, if application hype remains, will likely not realize widespread commercial utilization by 2035. In fact, there seems to be little-to-no commitment by industry to switch from petrochemical-designed to bio-designed polymers due to cost, and developmental constraints.

Discussion

At first blush, biopolymers seem to be the technological savior of the environment and all emerging technologies. Academia and environmentalists tout multiple benefits and ease of manufacturing in applications from nanoscience and nanoparticle development to bioplastic toys and novelties to drug delivery advancements.[H] However, even in the most environmentally conscience governments and companies, the reality falls short. While the technology exists, the most likely commercial availability will not drive innovation or large-scale development by 2035.

Biopolymers can be and are generated by numerous methods, including genetic manipulation for multitudinous applications, most critically in tissue engineering, drug delivery, and biodegradable plastic production.[H] In fact, Denimer Scientific has developed a Canola-based plastic called polyhydroxyalkanoate (PHA), and touts it as "a breakthrough in the production of plastics—and the health of our environment."[MH] Furthermore, combinatory with other emerging technologies, like nanoscience, may create great efficiency and environmental benefit.

A nanoparticle that is less than two nanometers in size may require excesses of ten-fold and three-fold of reducing agents and capping ligands, respectively.[H] Those materials, like hydrazine, N-dimethyl formaldehyde, and sodium borohydride, are considered highly environmentally toxic, rife with biological and environmental risks.[H] Biopolymer capping and reducing, performed with chitosan, soluble starches and cellulose, among others, are easily bioregenerative and biodegradable, even if the same quantities are used.[H] Moreover, some agents are self-correcting to be re-used.[H]

Representation of "the" grand challenge of biopolymer advancement. With costs significantly higher than petrochemical polymers, the main advantage to biopolymers is biodegradability. But that is largely unrealized.
Source zerowasteeurope.eu

Despite the daily applications of biopolymers in the medical community: coagulants and adhesives are the most pervasive with tissue engineering in its infancy, with no real sense of urgency in biopolymer development or advancement.HH Furthermore, the seeming boon of biopolymers in nanoscience appears to not be worth the investment, because currently, biopolymer applications, here and in plastics, to replace poly-plastics (petrochemical bases), do not appear worth the cost. With all indications that cost will increase between 20% to 100% over already existing petrochemical plastics.[MM] Finally, even in applications like trash bags would still require non-biodegradable components, not easily separated from those that are biodegradable, negating a lot of environmental potential wins.[M] At best, one online article (one of few or any referencing a timeline or date), says that biopolymers could set a zero emission, biodegradable plastics infrastructure by 2050, well beyond 2035.[M]

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were generally reliable and numerous, with academic sources corroborating each other, and other sources more hopeful and visionary than substantive. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, due to the niche potentials and largely unfielded nature of this technology and its accessibility, this estimate is likely to change due to unexpected consequences, like forced government regulation.

Author: Nicholas E. Delcour

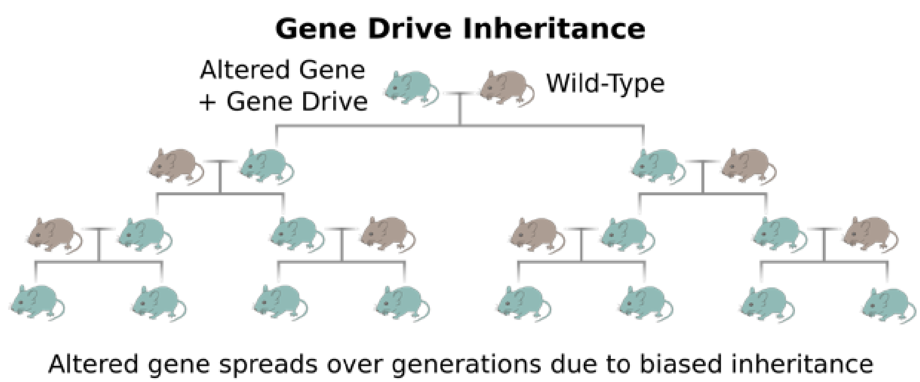
Gene Drive Likely Fielded for Pestilent Species Control by 2025 With Successes Realized By 2030

Executive Summary

Gene drive, genetic biotechnology that targets specific DNA and carries to offspring, is capable of being fielded currently; however, regulation, ethics, and fear keep the drive at bay. Due to global, environmental uncertainties, deriving from unbounded unintended consequences, all rational actors are actively studying gene drive technology, while not fielding it, yet, despite a significant appetite for control. Despite severe risky consequences, benevolent actions will highly likely result in successful fielding by 2030.

Discussion

First order gene drive is naturally occurring in nature, creating the most resilient of species. In science, since 2014, variations of synthetic gene drive have been in development by multiple laboratories and nations.[M] While the terminology of "gene drive" refers to the genetic manipulation that propagates a species from offspring to offspring across generations, multiple variations and targeting exist. However, the specific technology is not as important as the implications of the technology. For example, in sophisticated species with long life spans, gene drive would take centuries to take hold, but specific insect species, deemed pests, could be eliminated within one year.[H] This could include food sources, and naturally occurring flora and fauna.[M]



Visual representation of gene drive permanence and modification. Source: [MIT MEDIA LAB](#) .

Despite risks, significant portions of the global population see the benevolent quality of the technology worth that risk.[MH] The African Union pushes for the gene drive to eliminate pestilent mosquito populations responsible for over 200 million cases of malaria, 400 thousand of which result in death, per year.[HH] Additionally, two attemps at moratoriums have taken place within the UN to address regulations and limits on the gene drive, and neither bore fruit.[MM] Moreover, other nations see potential in the gene drive to eradicate invasive species in an effort to preserve naturally occurring species. New Zealand specifically researched eliminating black rats, while North America looks to eliminate other insect pests.[M]

To meet both requirements, scientists developed the daisy drive to create a short-term genetically manipulated gene drive (the specific DNA coding will only last a few generations of offspring). [H] While seemingly safer and more benevolent, the same risks exist: could the drive propagate beyond its specifications, could the drive unexpectedly jump between species, and could other interaction between species create unknown consequences/side effects?[H] The daisy drive is expected to be possible and successful by 2024, with fielding successes realized by 2030, depending on totality of the initiative (continuous introduction of altered species and other pesticides will accelerate and effect better successes).[H]

The inherent risk is the ease and availability of gene drive technology. Rogue nations and actors can field and realize effects from the gene drive within one year's time. Furthermore, the action is likely unattributable. Gene drive is inexpensive and has benevolent benefits on continental scales. Nations like China that provide benevolence to African nations in order to obtain their own interests can reap benefits in droves. Furthermore, China operates outside the acceptable norms of ethical genetic behavior.[M] Most recently, China used gene drive technology on embryos to generate twins with genetic resistance to HIV, as well as "unacceptable" species manipulation, implanting human brain tissue in primates, that have superior memory to their unaltered species. [M]

Within the next 10 years, gene drive is likely to be fielded, despite regulatory restrictions. It can be fielded by ethical nations for benevolent reasons, or by rogue nations indifferent to consequences. However, the likelihood increases as artificial intelligence and high processing computation enables more precise targeting and sophisticated modelling.[H]

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were generally reliable, numerous, and corroborative. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, due to the highly experimental nature of this technology and its accessibility, this estimate is likely to change as it leverages other emerging technologies.

Author: Nicholas E. Delcour

Information Technology

> Developments in information technology and globalised media mean that the most powerful military in the history of the world can lose a war, not on the battlefield of dust and blood, but on the battlefield of world opinion.
>
> **Timothy Garton Ash**

Introduction

Information Technology (IT), by definition, is the use of any computer, storage, networking, and other physical devices, infrastructure, and processes to create, process, store, secure, and exchange all forms of electronic data. Typically, IT is used in the context of enterprise operations as opposed to personal or entertainment technologies. The commercial use of IT encompasses both computer technology and telephony. [H]

Within the Department of Defense, Command, Control, Communications, Computers, Combat Systems and Intelligence (C5I) and Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) are two acronyms often used to describe IT systems. It is essential to understand the terms C5I and C4ISR include all aspects of end-to-end connectivity from the data the devices sending the information (transmitter) is sending across the network to the device receiving the data (receiver) which has to create useable information from the data.

"The Cyber, Command, Control, Communications, and Computers Assessments Division (C5AD) is the interoperability assessment and integration arm within the Joint Staff, J6. C5AD conducts assessments of existing and emerging Cyber and C4 capabilities in a persistent environment to achieve interoperable and integrated solutions that satisfy joint, interagency and mission partner operational requirements." [H]

Research Emphasis

Developments in artificial intelligence (AI), Quantum Technology, and Nanotechnology all influence IT. IT and AI form a very symbiotic relationship as AI can make IT more efficient and can run fully automated. However, for AI to be effective, the IT architecture must be upgraded. [H] The Quantum Information Sciences (QIS) contain several areas where technology advancements converge with or benefit IT. Quantum Sensing research and development is producing chip-sized atomic clocks that are potential precise timing sources and alternatives to Global Positional Satellites. [H] Quantum Internet research and development is providing viable solutions for the first quantum internet, which would be a secure internet with built-in intrusion detection. [H] Quantum Computing and Quantum Simulations are not only testing and experimenting with algorithms but are selling services to solve business optimization problems as with D-Wave Leap and Leap 2. [H] Nanotechnology influences IT through the miniaturization of processor circuits and packing more processing power into computers and by making computer memory faster and able to store more information. [H]

The two areas, which were the focus of the Information Technology research were Passive Optic Networks (PON) and 6G. PON will have a profound impact on network performance and the ability of the network to handle data demands of the future. The relevant 6G Key Performance Indicators (KPI) are: 1Tbps per customer/device data rates, the latency of ~.1ms, and millimeter precision will provide the capability and capacity for Ultra-High-Speed Autonomous Vehicle technology. [H] These and other KPIs enable fielding of technology, which 4G and 5G cannot support. Further, to capitalize on the full potential of AI in 2030, you need both an upgraded PON, 6G, and the architecture of the infrastructure to be interoperable and accessible. However, our research points out the US is upgrading from 2.5G PON to 10G PON by 2025 with no plan to improve after 2025. [H] With 20B Internet of Things (IoT) devices in 2020 and that projected to increase to 50B-125B devices by 2030, the PON must be expanded to at least 50G PON by 2030. [H] [H] Demand for data will increase with the expansion of 5G 2020-2030, and data demand will rise with 6G in 2030 at 1Tbps. [H] Therefore, recommend the US to expand the PON to 50G-100G PON in 2025 in preparation for the launch of 6G and plans to compete with China at 200G/400G PON or attempt to overmatch. [H] It is crucial to consider the plan is for quantum internet to ride over the fiber optic PON infrastructure.

6G Likely to Enable Ultra-High-Speed Autonomous Vehicles by 2035

Executive Summary

Sixth Generation (6G) wireless technology is likely to enable high-speed autonomous vehicles by 2035 by providing the bandwidth and low latency required for safe operation. 6G wireless Key Performance Indicators (KPI) include wireless data rates of up to 1 terabit per second coupled with .1 millisecond latency while simultaneously providing exponential gains in accuracy, spectrum management, and power consumption. The convergence of 6G KPIs will enable collaborative Artificial Intelligence (AI), which will place high-speed autonomous in a connected meshed network where they communicate, think, instantaneously report changes, faster than a human can react. The 6G roadmap forecasts viable commercial 6G products by 2030 but based on the challenges associated with Fifth Generation (5G) implementation, this is likely overly ambitious. Additionally, the 3rd Generation Partnership Project (3GPP) and several of the United Nations Sustainable Development Goals (UN SDGs) are shaping policies to prepare government and industry for the commercialization of 6G.

KPI	5G	6G
Traffic Capacity	10 Mbps/m^2	$\sim$ 1-10 Gbps/m^3
Data rate DL	20 Gbps	1 Tbps
Data rate UL	10 Gbps	1 Tbps
Uniform user experience	50 Mbps 2D everywhere	10 Gbps 3D everywhere
Latency (radio interface)	1 msec	0.1 msec
Jitter	NS	1 μsec
Reliability (frame error rate)	10^{-5}	10^{-9}
Energy/bit	NS	1 pJ/bit
Localization precision	10 cm on 2D	1 cm on 3D

Comparison of 5G and 6G KPI's; NS = Not Specified. Source: arxiv.org (Cornell University College of Computer Science)

Discussion

Although 5G can support autonomous vehicle technology, the bandwidth, latency, and buffering limit the performance of 5G for unsupervised commercial applications. Further, the 5G KPI limitations become critical when you increase the speed of autonomous vehicles, which makes 5G unable to support ultra-high-speed autonomous vehicles. In contrast, the 6G KPIs are capable of safely supporting autonomous vehicles traveling at speeds of 1000 km/h, which enables not only automobiles but also aircraft. [H]

6G will likely change how the world views the internet, wireless networks, and proximity. In addition to the improved KPIs, 6G will create synergy across the Internet of Things (IoT), allowing network engineers to push computing power to the edge of the network, and devices will think and act using collaborative AI in a symbiotic relationship. [H] The 6G environment will be a paradigm shift as consumers experience AI learning and adapting in real-time. The 6G KPIs and the distributed computational power of the Internet of Things (IoT) will create a network that emulates a distributed neural network. [H]

6G will require a robust topology and meshed infrastructure for path and data diversity from the terrestrial segment to the space segment. [H] This redundancy will require a considerable investment and expansion of the Low Earth Orbit (LEO) satellite constellation as well as the terrestrial Passive Optic Network (PON) telecommunications backbone. [H] To comprehend 6G latency, you can test your reaction time using the hyperlink at the end of this sentence, and the average human reaction time falls between 200-250ms; note your computer may add a 10-50ms delay. [H]

Despite the 5G connected car testing success, the 5G network is years away from being supporting commercial autonomous vehicles. [H] The 5G network is a hybrid of 4G LTE and 5G technology, as 4G LTE provides network coverage gaps and 5G network management functions. Therefore, 5G does not have the capacity or capability to support commercial autonomous vehicles safely. However, companies have developed private 5G networks that are capable of supporting autonomous vehicles within restricted areas. Still, the 5G networks are unable to support driving autonomous cars on public roads and highways. [H] Even with the technical challenges with fielding 6G, multiple sources: IEEE Communications Magazine [H] Hong Kong University of Science and Technology, Tsinghua University, Shanghai Tech University, Hong Kong Polytechnic University, and The Chinese University of Hong Kong [H] agree on the KPIs, and a commercial 6G device will be available by 2030. The implementation for 6G will be similar to 5G, which started at 3.7M antennas in 2017 and will grow to 9M by 2021. [H] While the 6G roadmap is accurate for an arrival of a commercial product in 2030, and it will take several years for the 6G terrestrial, vertical, and space segments to be fully populated. [H] However, due to the number of nations, companies, universities, working on 6G, it is likely all remaining challenges will be resolved, and the 2030 initial delivery roadmap is accurate.[H]

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were mostly reliable and corroborated one another, especially regarding the 6G roadmap. There was adequate time, but the analyst worked independently using a semi-structured method.

Author: Patrick Lancaster

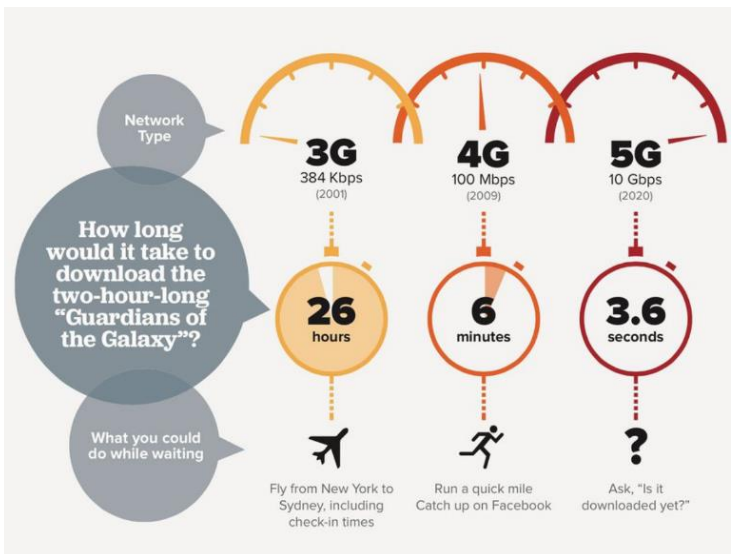
US Next Generation Ethernet Passive Optic Networks Likely Inadequate to Support 6G Between 2030 and 2035

Executive Summary

The fiber Passive Optic Network (PON) is the telecommunications backbone that provides network connectivity between crucial network nodes. Therefore, the US must engineer the PON with enough capacity to handle future growth as telecom providers field new technology. As wireless devices upgrade from 4G - 100 Mbps to 6G - 1Tbps, there is not only exponential growth in data requirements but also in the Internet of Things (IoT) and the number of devices connected, so more devices connect and compete for bandwidth. Just as with warfare, where the novice talks tactics, the expert talks logistics. The discussion about engineering a robust PONs for the future growth to give the US a strategic advantage is where the expert shows they understand the center of gravity is the PON and logistics over the network. The expert understands the newest whizzbang technology is worthless when connected to a network crippled with bottlenecks and latency. However, the US is lagging and just now transitioning from 2.5 Gb/s PON to a 10 Gb/s PON to meet IEEE standards. The 10 Gb/s PON is inadequate to support 5G, and the US plans for Next Generation Ethernet Passive Optic Networks (NG EPON) are likely inadequate to support 6G between 2030 and 2035.

Discussion

Providers of Cable Television, Wireless Internet, Remote Services, Internet of Things (IoT) devices all selling Passive Optic Network (PON) bandwidth space along with their products. Cable television companies use the Data Over Cable Interface Specification (DOCSIS) 3.1 modem, which provides 80% of US households with 1 Gb/s service, which transit over the



Comparison of 5G increased bandwidth requirements over 4G, and the unmentioned impact this data flow from trillions of devices will have on the 10G PON infrastructure. With 6G projected to provide 1Tbps download speeds, the PON will quickly become a bottleneck unless upgraded significantly. Retrieved from https://twitter.com/JimHarris/status/1080534178448453632/photo/1 [H]

PON. Cell phone providers sell 4G LTE and 5G data plans which terminate at a cell phone tower and then transit gigabytes of data over the PON. There is a multitude of internet-based businesses that provide services over the internet and profit from passing gigabytes of data over the PON. Lastly, each device connected to the Internet of Things (IoT) communicates over the internet, and the data transits across the PON. The PON is being upgraded from 2.5 Gb/s to 10 Gb/s to meet IEEE standards. However, as IEEE attempts to engineer enough capacity for future requirements, the industry demand for data and bandwidth is outpacing the architecture. The Cable industry announced the DOCSIS 4.0 cable modems are certified for 5 Gb/s capacity and will deliver on the 10 Gb/s promise over hybrid fiber-coaxial networks in 2021. The data demands of 5G wireless, 10 Gb/s cable modems, and the Internet of Things (IoT) will quickly saturate the capacity of the new 10G PON. Therefore, the IEEE is working on standards for the 25G-PON by 2025.

Standard	Nomenclature	Bandwidth	Wavelengths	Primary Focus
25G/50G-EPON (IEEE 802.3ca)	High Speed EPON	2 x 25G Down 2 x 10G Up 2 x 25G Up	High O-band Down Low O-Band Up	Business services/MDU 5G Transport
50G-PON (G.hsp.50G)	High Speed GPON	50G Down 10G/25G/50G Up	High O-band Down Low O-Band Up	Business Services/MDU 5G Transport
100G/200G-PON (G.hsp.TWDM)	High Speed GPON	2 to 4* x 50G Down 2 to 4* x 10G/25G/50G Up	High O-band Down* Low O-Band Up*	Business Services/MDU 5G Transport
IEEE 802.3cs (Super-PON)	Long Reach (50km) – Large Split (1024)	16 x 10G Down 16 x 2.5G/10G Up	L-Band Down C-Band Up (like NG-PON2)	Suited for Greenfield Residential/5G Transport
ITU G.9807.3 (Super-PON)	Long Reach (50km) – Large Split (1024)	16 x 10G Down 16 x 2.5G/10G Up	L-Band Down C-Band Up (like NG-PON2)	Suited for Greenfield Residential/5G Transport
WDM-PON*	Point to Point WDM	16* x 10G/25G PtP Down/Up Symmetrical	?	5G Fronthaul (eCPRI)

* Proposed

Notes:
- IEEE 25G-EPON promoted by North American MSOs
- ITU 50G-PON backed by Chinese operators and vendors
- Super-PON promoted by Google

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Future PON – standard, nomenclature, bandwidth, wavelengths and focus and who is backing the technology
Source: calix.com

The IEEE 802.3 Working Group has formed a study group to develop objectives for the Next Generation of Ethernet Passive Optical Networking (NG-EPON). The Study Group is looking at four key technology areas: number of wavelengths, the bit rate per wavelength, transceiver tunability, and channel bonding. While the study group is looking at alternative solutions to advance from 10 Gb/s to 25 Gb/s and then creative modulation techniques to increase data rates over the 25 Gb/s paths, which could potentially yield data rates of 50 Gb/s and even 100 Gb/s. [H] At a minimum, the US needs to immediately start planning to upgrade to a 25G PON, which would be the conservative incremental approach, and two requirements would need to be met. The first is cost efficiency, and 25G PON meets this requirement as there are no high-cost optical technologies required, such as tunable lasers. Second, there must be a requirement for the technology, and the exponential demand for data from 5G, Cable, IoT, and residential market presents a strong opportunity for a high-density PON. [H] 5G market size is expected to reach $15,951.7M by 2026 with a Compound Annual Growth Rate (CAGR) of 81.9% through 2026. [H]

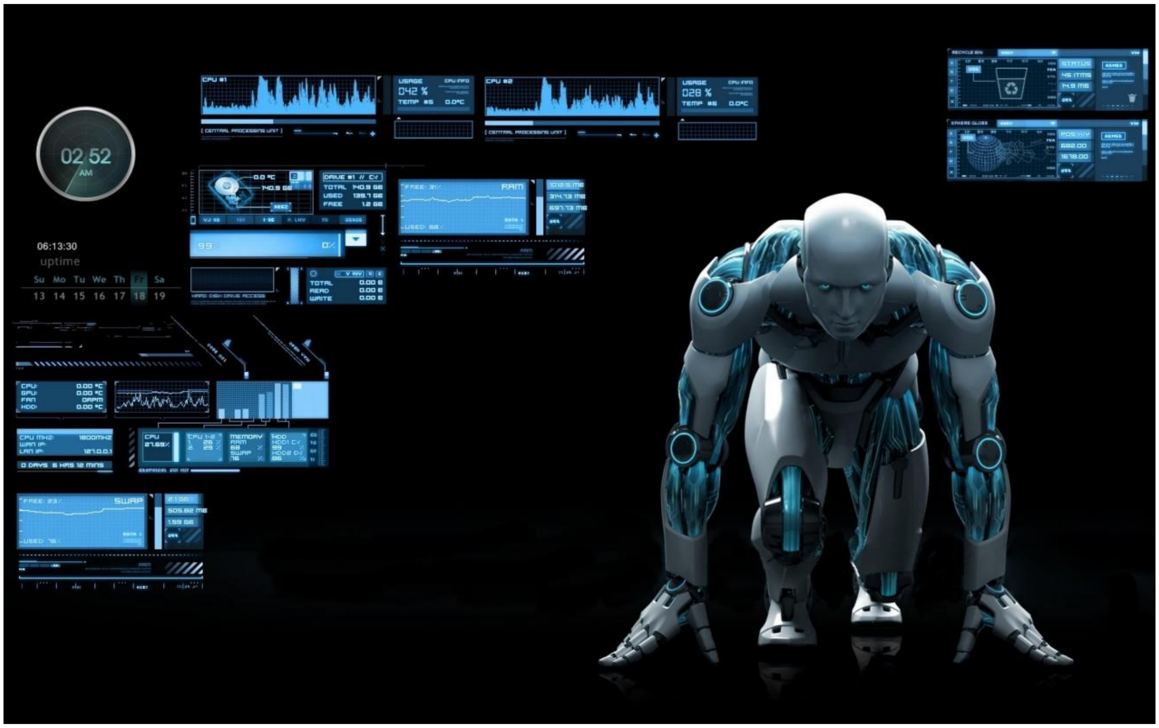
Despite the clear path for 5G growth and expansion and roadmap to delivery of the first 6G device in 2030, there is no sense of urgency to upgrade the PON to a 50G or 100G PON. Due to 6G devices reaching the market in 2030, the PON will be a choke point. The Next Generation Ethernet Passive Optic Network (NG EPON) will likely be inadequate to support 6G between 2030 and 2035 due to the exponential increase in devices and the 100x increase in data per device. [H]

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were mostly reliable and corroborated one another. There was adequate time, but the analyst worked independently using a semi-structured method.

Author: Patrick Lancaster

Robotics



> Rather than wringing our hands about robots taking over the world, smart organizations will embrace strategic automation use cases. Strategic decisions will be based on how the technology will free up time to do the types of tasks that humans are uniquely positioned to perform.
>
> **Clara Shih**

Introduction

Robots and the field of robotics refers to the development of machines capable of carrying out tasks without a human operator based upon a set of instructions that's provided by a computer.[H] Pre-programmed machines perform jobs that are repetitive, dangerous, dirty, or expensive for human labor.[H]

Robotics is influenced by developments in artificial intelligence (AI), information technology (IT), nanotechnology, biomimicry and advanced material design and fabrication. While it's true that robots can utilize AI,[H] the presence of AI isn't a prerequisite to building a robot. Robots designed to carry out highly specialized, repetitive tasks on production lines or in warehouse environments are a good example. However, converging AI and robotics into the overall design of the machine is increasingly where research is focused.[H] When AI is integrated with robotics there is an increased level of autonomy. The robot can analyze and evaluate the best course of action given the data provided from the outside world, either communicated remotely or collected by the machine using sensors.[H]

Research Emphasis

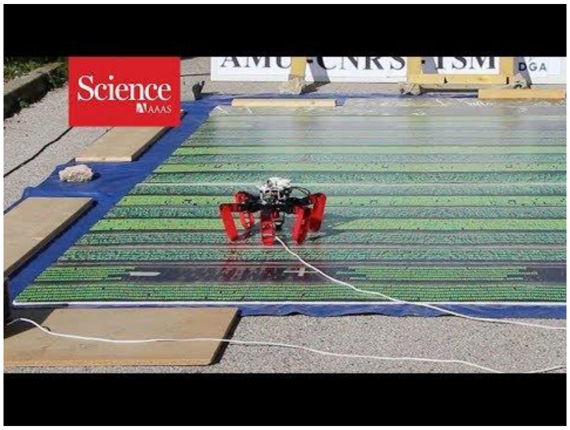
Advanced developments in the field of robotics are often animal-inspired (e.g. Boston Dynamics Spot.)[H] Bio-inspired robotic system design learns from nature to make a mechanism that is simpler and more effective.[H] Biomimicry (bugs, flying insects, octopus, snakes, etc.) offers attractive locomotion systems for robots. Bio-inspired research in the field of artificial swarm intelligence studies insects like ants and termites for coordination of multiple robots as a system of large numbers of mostly simple physical robots.[M] Collective behavior emerges from the interactions between the robots with the environment.[M] The field of Soft Robotics uses advanced material design to create robots than can jump, squirm, and grip. And, unlike hard robots, they can handle tomatoes without bruising the fruit, resurface unscathed after being run over by a car, and journey through radiation, disaster zones, and outer-space with few scars.[H]

Robotics are highly likely to be a force multiplier for the military. Emerging autonomous robotic systems are increasingly used to augment, individuals and platforms. The augmentation of human systems with robotics, particularly swarming, will permit longer duration missions, enable greater lethality, improve the ability to protect capital platforms from attack, and increase individual human and unit performance. However, moral concern about the use of robots by the military within the tech industry coupled with pragmatic diplomacy from major states eager to lock in their relative advantages while using collective power to lock out competitors, will likely result in an international agreement with weakly enforceable provisions against combat robots.

Between 2032 and 2037, Robot Navigation Highly Likely to Successfully Operate in Disordered and Hostile Environments

Executive Summary

It is highly likely that between 2032 and 2037, navigation systems will become robust enough to give mobile robots the capacity to traverse highly disordered and hostile environments. This type of navigation is essential for sought after commercial applications like self-driving cars and trucks, robot last mile delivery services and is proving successful in extreme environments like space, offshore oil and gas platforms and search and rescue operations. These systems offer the promise for success in more difficult applications like military combat.



This ant-inspired robot can navigate better than civilian GPS
Source: sciencemag.org

However, since harsh environments are by their nature unpredictable or unknown, available research methods that apply the use of standard simulations with known assumptions in laboratory environments alone will be insufficient to prove system reliability. Significant research effort is still required to bring these technologies to an appropriate readiness level for military application.

Discussion

In the past two decades commercial, retail, healthcare and industrial robots have become ubiquitous. One of the grand challenges to overcome to advance their utility is creating systems that can adapt, learn, and recover from navigation failures and make and recognize new circumstances.[M] The potential commercial success promised by self-driving trucks and cars and last mile delivery “bots” are pushing more robust solutions forward.[M] As a result, robot navigation solutions are garnering hundreds of billions of dollars in private research funding[M] and potential DOD and NASA use cases are also drawing significant public monies.[H] Nevertheless, navigation systems for these robots remains a significant challenge even in the most predictable of environments.[M] It becomes especially challenging when the robot must operate in harsh and unpredictable environments like those posed by military situations.[H]

For example, consider the challenge of space exploration. Outer space environments are largely unknown. Communications between operators and deployed systems face significant delays due to the long distances that separate them. GPS infrastructure does not exist to provide necessary positioning information. Extra-terrestrial body surfaces are difficult to navigate due to the unstructured, sandy and rocky terrain, and micro-gravity results in further locomotion challenges. Nonetheless, robot systems like the Mars Curiosity Rover have shown that it is possible to operate successfully in that harsh environment.[H]

While outer space is one clear example of a harsh environment, there are many other activities on Earth that equally involve interactions with harsh environments. In recent years, to better address key health, safety and environment concerns, the oil and gas industry has shifted towards the deployment of robotic systems for inspection activities on interior surfaces that may be filled with oil, or exterior submerged structures in off-shore platforms that are difficult to access and subject to harsh sea conditions.[M]

Search and rescue applications share some common challenges with space exploration, as these environments are commonly unstructured, unknown and are varying in topological landscapes. Robots are often needed to search for survivors in areas inaccessible to human rescue teams, assess safety conditions prior to human entry, and map unfamiliar environments. As such, technologies developed for this purpose must be sufficiently flexible and robust to perform a variety of tasks in differing environments. (See SnakeBots)

To resolve one of these problems, engineers at the Massachusetts Institute of Technology (MIT) are testing a navigation method that doesn't require mapping an area in advance. Instead, their approach enables a robot to use clues in its environment to plan out a route to its destination.[M] AntBot, the brand-new robot designed by CNRS and Aix-Marseille University (AMU) researchers at ISM, uses a similar approach. It copies the desert ants' exceptional navigation capacities.[M] According to Julien Dupeyroux from Aix Marseille Univ, CNRS, ISM, Marseille, France “AntBot is equipped with an optical compass used to determine its heading by means of polarized light, and by an optical movement sensor directed to the sun to measure the distance covered. Armed with this information, AntBot has been shown to be able, like the desert ants, to explore its environment and to return on its own to its base, with precision of up to 1 cm after having covered a total distance of 14 meters.”[M] Dupeyroux said Antbot suffers from several limits: signal failure when around tall buildings; a relatively small area of accuracy for smaller devices like smartphones, and not being particularly good on cloudy, rainy, or snowy days.[M] He also said that AntBot’s small motors easily overheated and have a limited power supply: “We are currently working on new actuation to make our robot able to perform 100-meter-long trajectories in real-world conditions.”[M]

Analytic Confidence

Analytic confidence in the estimate is moderate. There was adequate time and the task was not particularly complex. The reliability of the sources available on this topic were average with several high-quality sources available for the estimate. The available sources did tend to corroborate each other.

Author: Stephen Frahm

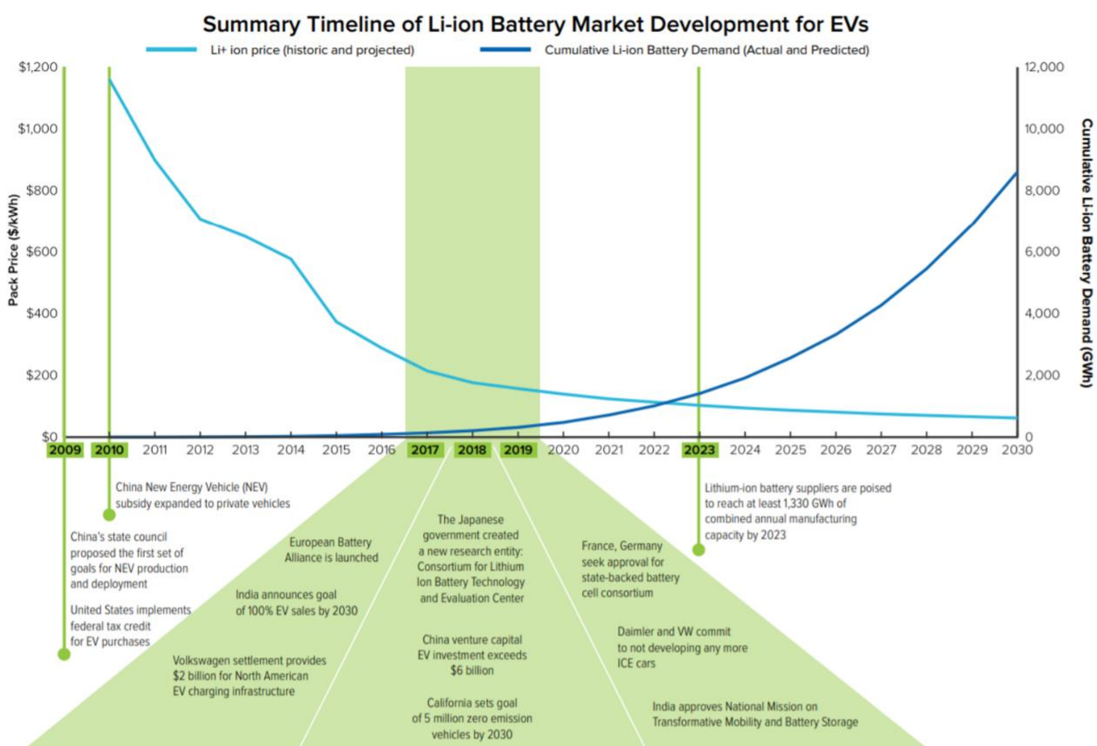
Longer Life, Quick to Charge Lithium-Ion Batteries for Military Robots Highly Likely in Five to 10 Years

Executive Summary

Battery power is a limiting factor for military use robots. The sea change towards electric vehicles makes it highly likely in the next five to 10 years that longer life, quick to charge lithium-ion battery (LIB) technology will give mobile robots enough strength, longevity and stealth for military uses. Despite limits to what lithium-ion batteries can do, how long they can do it and ongoing issues with safety, the near future of battery technology relies on continued improvements to already existing lithium-ion technology.

Discussion

LIBs are ubiquitous: in smartphones and other gadgets; electric vehicles, and robots.[M] But for mobile robotics, LIBs are still a bottleneck.[M] Mobile robots, like electric cars, typically run using finite energy resources, supplied by finite batteries. Mobile robots need electrical components to control and power their machinery with enough power to perform tasks without having to constantly recharge. [M] Military robots, especially in combat, also demand a power source that can preserve stealth[M] and doesn't spontaneously combust when it gets too hot.[M] Adding gasoline powered generators to



Source: Rocky Mountain Institute (rmi.org) supplement and recharge the batteries does not address these problems. Simply adding batteries increases the weight of the robot and its demand for power offsetting the gain.

Countries around the world are increasingly acknowledging the shift that's needed from a fossil fuel-driven economy to one that is sustainable, green and attempts to mitigate climate change. Big technology and car companies are aware of the limitations of LIB technology and are increasingly concerned that hard-to-procure materials, like cobalt and nickel LIBs rely on will become increasingly unavailable.[M] Among battery experts, "the consensus is that someday something better will have to come along."[M]

Tesla filed a patent in 2019 for a new breed of lithium-ion batteries that could last for a million miles in their cars.[M] Innolith, a Swiss startup, says its new high-density lithium-ion batteries is "four times the current state-of-the-art for lithium-ion... Roughly three times what is generally accepted as being the next improvement in lithium. And it's two times the energy density target [that] organizations like the US Department of Energy have set."[M]

German automakers are also heavily reliant on Asian battery manufacturers (like Samsung, LG Chem, or China's state-run CATL) who can turn out lithium-ion batteries at the volumes required for fleet-sized orders.[M] Volkswagen pledged $48 billion to the leading battery manufacturers in Asia to max out current battery tech.[M] A recent Bloomberg New Energy Finance study estimated lithium-ion battery production capacity will nearly quadruple by 2021.[M].

Army scientists and their partners at the University of Maryland and Johns Hopkins Applied Physics Laboratory developed a high-energy aqueous lithium-ion battery that won't catch fire no matter how damaged it becomes. These new batteries continue to operate in conditions where traditional batteries fail.[M] Aqueous lithium-ion batteries may influence the development of future electronic devices because the batteries can be made in different shapes and sizes, allowing for a more flexible and efficient design.[M] Cresce said the Army hopes to integrate the aqueous lithium-ion batteries into hybrid and electric military vehicles with the added possibility of expanding the technology into the commercial vehicle industry.[M]

"With just one year accelerated funding, we were able to take our bench technology and turn it into a prototype," Cresce said. "We're going to manufacture prototypes with the hopes that we can get this into the field between 2026 and 2028 on a device that the soldier can wear and use in the field. I really hope we can stick that timeline, because it would fit in very much with the modernization of the U.S. Army as we move forward."[M]

Analytic Confidence

Analytic confidence in the estimate is moderate. There was adequate time but the task was complex. The reliability of the sources available on this topic was moderate with several high-quality sources available for the estimate. The available sources did tend to corroborate each other.

Author: Stephen Frahm

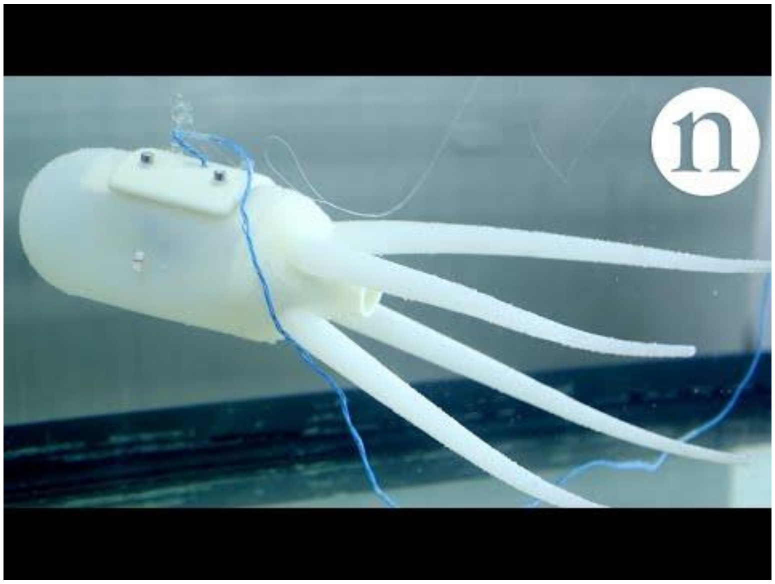
Capable Soft Robots Highly Likely in 5 to 10 Years

Executive Summary

It is highly likely, within 5 to 10 years, soft robotic technologies will be used in real world applications for manufacturing, health care, warehousing, personal services and the defense industry. A growing demand from commercial markets is fueling Increases in research and development of soft robotics in smart materials and mathematical modeling of compliant systems. Soft robots are safer in human-robot cooperation, can adapt to new and harsh environments and can be repaired and replaced cheaply and quickly. However, most demonstrations using new materials and fabrication strategies have been “one-offs” and must still overcome basic hurdles to achieve wide-scale adoption. Better fabrication technologies including 3D printing are inspiring confidence.

Discussion

The idea of human-robot cooperation, in which robots support human workers by undertaking exhausting or dangerous subtasks of their work is becoming reality. Gears, motors, and electromechanical actuators—the conventional ‘hard’ technologies of robotics—are fundamental to many of the robotic platforms in use today. However, they are best suited to known environments like a factory floor.



1Video from Nature Research: Robots aren’t usually soft and squidgy. But inspired by the octopus, engineers are creating robots that can twist their way around problems that rigid robots can’t handle.

Laboratories around the world have begun to explore ways to use new materials in robotics technology like artificial muscles and other compliant materials made possible by emerging advanced manufacturing and assembly strategies.[M] These promise a new generation of robots that are power- efficient, multifunctional, compliant, and autonomous in ways that mimic biological organisms. They will also be safer for human-robot shared proximity.[M] According to Harvard professor Daniel J. Preston, soft robots be able to leave the factory and venture into harsh environments like high radiative fields, outer-space, and inside Magnetic Resonance Imaging (MRI) machines. In the wake of a hurricane or flooding, a hardy soft robot could manage hazardous terrain and noxious air. "If it gets run over by a car, it just keeps going, which is something we don't have with hard robots,"[M]

Soft technologies allow robots to have more substantial interaction with their environment providing safer and more robust interfaces than are currently available with conventional robotics. Soft robotics that mimic biology results in robots with more lifelike body movements and flexibility allowing the them to go places and do things their hardbody counterparts can’t. By replacing classical robotic components made from metal, rigid plastics and electric motors with fluids, shape memory alloys, electro-active polymers or stimuli-responsive materials it is possible to add in “design and control strategies focused on the ability to have safe physical human-robot interactions”.[M] This kind of capability is in high demand. The report “Global Soft Robotics Market - Segmented by Type, End-user, and Region - Growth, Trends, and Forecast (2018-2023)” indicates that the Soft robotics market is projected to reach a market value of $3.3 billion by 2023 at a growth rate of 40.5% over the forecast period (2018-2023).[M] According to Jonathan Rossiter and Helmut Hauser at Bristol Robotics Laboratory “soft robotics is set to have a major impact on all aspects of our society and industries, ranging from manufacturing and consumer devices to medical applications and wearable technology.”[H] Giada Gerboni, a postdoctoral fellow at Stanford University in Collaborative Haptics and Robotics in Medicine says it’s a mistake to view soft robotics as conflicting with traditional hard robots: “I would not say that soft robots are better, but it is only a class of robots — or a way to do robotics — that we cannot avoid considering anymore,” she said. “Soft robots have already demonstrated to have great potential in navigation tasks because they can articulate their body easily, and their navigation is not compromised by abruptly contacts with unknown objects”[M]

While soft materials are possible, manufacturing techniques remain a challenge. According to Nikolaus Correll, University of Colorado Boulder: "Right now, we're able to make these things in the lab on a much larger scale, but we can't scale them down. The same is true for nano- and microscale manufacturing, which can't be scaled up to things like a building façade."[M] An additional problem is that soft, flexible materials with complex surfaces and movements are difficult to equip and cover with sensors made with traditional manufacturing techniques.[M] "Embedded printing of sensors is a powerful process that could enable and enhance seamless integration of sensors into soft robots, but there does not yet exist a suitable, commercially available, easy to use platform that allows users to simultaneously print soft actuators and sensors,"[M]

Researchers at the Army's Institute for Soldier Nanotechnologies (ISN), located at MIT, developed a 3-D printing platform that enables both the modeling and design of complex “magnetically actuated devices.”[H] According to the researchers: “Their findings could lead to new biomedical applications, magnetic ink optimized to strengthen soft robotic functionality, and new on-demand flexible material systems for integration into Soldier systems.”[H] Researchers who specialize in 3D printing have long sought to make an entire robot in one print--a machine that would be able to walk itself away from the printer when it's done. This would make it easier to print more robots faster. It would also make it possible to 3D print robots without human supervision, for example on the moon or Mars.[M]

Analytic Confidence

Analytic confidence in the estimate is moderate. There was adequate time but the task was complex. The reliability of the sources available on this topic were average with several high-quality sources available for the estimate. The available sources did tend to corroborate each other.

Author: Stephen Frahm

Bio-Inspired Robots Widely Available by 2027

Executive Summary

It is likely that bio-inspired robots like wheeled and nonwheeled snake robots (snakebots) that emulate and match the capabilities of their biological counterparts will be widely available by 2027 to take on jobs that are dirty, dangerous or dull. Research on snakebots is advancing rapidly and this type of robot has already proved its merit. Snakebots can undulate their way into tight spaces and sticky situations, where the environment may be unhospitable and unpredictable for people, and even canines. A snakebot developed by Carnege Mellon University successfully assisted in the search for survivors in the 2017 Mexico City earthquake. Despite the promise of snakebots, there are still limitations with current locomotion and navigation technology that researchers must resolve. Existing environment mapping and sensing technologies are also inadequate for this purpose.

Discussion

The way to make robots co-operate is to learn from the animal kingdom, says Dr Edmund R. Hunt, a postdoctoral fellow at the University of Bristol, UK. - and working together will allow them to tackle otherwise impossible tasks.[M] Biomimicry is copying nature while bio-inspired design is learning from nature and making a mechanism that is simpler and more effective than the system observed in nature. Serpentine robot biomimicry is a compelling example. Biological snakes' elongated spines allow them to hunt underground in confined tunnels, above ground in grassy fields and easily climb up in the tree tops. Robots that emulate the capabilities of their biological counterparts make it possible to create useful tools capable of carrying sensors, taking samples, and making physical changes in a wide variety of environments.[M]

The Robotics Institute's multi-jointed Snakebot robot, which was deployed to search for survivors following the Mexico City earthquake last fall, was been named Ground Rescue Robot of the Year by the Center for Robot-Assisted Search and Rescue (CRASAR)
Source: cmu.edu

Snake robots are especially effective for appraising conditions that are unstable and dangerous and in terrain that is difficult to traverse. Carnegie Mellon University researchers deployed a snake-like robot to assist in the search for trapped survivors in Mexico City following the 7.1-magnitude earthquake that shook the city on September 19, 2017. The snakebot provided rescue workers with a video feed from two different passes through the rubble. "The snake robots developed by the Biorobotics Lab are amazing and unique in their capabilities," said Andrew Moore, dean of the CMU School of Computer Science. "What happened in Mexico City over the past few days, I believe, is just the beginning of what will someday be a heroic story for robots."[M]

The Sarcos Coporation developed the Guardian S-robot for military operations. This snake-like robot gives soldiers the ability to check out subterranean, confined space or unstructured environments. It can transmit visual, audio and data intelligence and can carry up to a 10-pound payload, including sensors for chemical, biological, radiological and nuclear detection.[M] "According to SINTEF, the independent Norwegian research organization, snakebots excel in situations 'where the robot is required to, traverse narrow passages and move over wide gaps and perform complex and light-to-medium-load manipulation operations."[H] For example, in addition to the two snakebots described above, NASA is also developing snakebots for space exploration.[H] The Australian Centre For Robotic Vision is developing surgical snakebots,[H] while Israeli forces developed a snakebot for the battlefield in 2009.[H]

Despite the promise of robots using serpentine locomotion, there are still challenges in perfecting how to move (locomotion) and where to move (navigation).[M] A camera on the front of the robot can help an operator see the immediate area around the robot, but this has limitations in low-light conditions and highly cramped environments. In disaster scenarios, sensors for perceiving sound and smell may be more useful in detecting signs of life, but those are not yet perfected. In addition, snakebots are unable to create an effective map of the environment to provide the inspector with good remote situational awareness.

Analytic Confidence

Analytic confidence in the estimate is moderate. There was adequate time and the task was not particularly complex. The reliability of the sources available on this topic were average with several high-quality sources available for the estimate. The available sources did tend to corroborate each other.

Author: Stephen Frahm

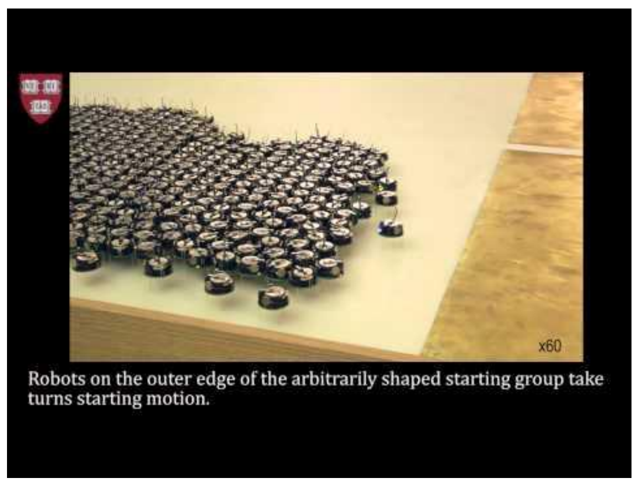
Highly Likely Within 7-10 Years Robot Swarms More Than Sum of Parts

Executive Summary

It is highly likely that within 7-10 years, small, cost-effective, and mostly autonomous multi-robot cooperative systems (Swarms) will come together in a way that the whole will equal more than the sum of the parts. Swarm robotics carries the potential of solving complex tasks using simple devices. Swarm robotics prove particularly useful when it's necessary to accomplish tasks within very large or informal environments like military combat because of their ability to work autonomously without the need for access to means of communication infrastructure or centralized control system. US, UK, and China (among others) have signaled that they plan to deploy human operated swarm systems, in the face of challenges to maintaining full human control over them. Despite their potential, if Swarm-bots are more autonomous than human controlled, they may constitute Lethal Autonomous Weapon Systems (LAWS) and would not comply with the 1981 Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons which may be Deemed to be Excessively Injurious or to have Indiscriminate Effects (CCW Convention).

Discussion

Swarm robotics represents an innovative technological solution to overcoming a grand challenge for robots.[M] A swarm is a group of systems that operate as a collective. It is not a specific type of system, but a specific type of configuration, namely "a large group of locally interacting individuals with common goals"[M] like a school of fish or flock of birds; the individuals interact and work as a group to achieve a collective goal.



From Harvard University Programmable self-assembly in a thousand-robot swarm. Source: science.sciencemag.org

In swarms operators steer subsets of the swarm, the rest respond as a group through internal communication and coordination.[M] Through coordination and task distribution, swarms can accomplish complex missions, giving them three major benefits: (a) scalability—it is easy to change the size of the swarm depending on the mission; (b) adaptability—they can be used for different types of missions; and (c) robustness—if a single node fails, other nodes can take over.[M]

Decentralized swarms are considered especially promising because they rely less on constant communication with the operator. Battlefields often lack good communications infrastructure and communications links cannot always be maintained during battle.[M] As decentralized swarms have no single point of failure, they are also more robust against electromagnetic weapons that can disable, alter or take over weapon systems. Article 36, a UK-based not-for-profit organization working to promote public scrutiny over the development and use of weapons, in their paper to the U.N. Convention on Certain Conventional Weapons that conceivable examples of missions for swarms include: “overpowering enemy air defenses, overwhelming enemy fighter aircraft in dogfights, engulfing warships, reconnaissance over large areas or urban areas, forming nets of underwater mines, and functioning as anti-access/area denial systems (known as A2/AD systems).”[M]

Swarms of simple robots that assemble into different configurations to tackle various tasks can be a cheaper, more flexible alternative to large, task-specific robots.[M] While the costs of complex weapon R&D have risen exponentially, units within swarms have low per-unit costs. That allows not just major militaries but actors with small budgets to field high numbers, adding new mass calculations to the battlefield.[M] The appeal of swarm engineering lies in the transformative capabilities that emerge when large groups of simple agents are given free reign. The more exciting prospect is that over the next decade we will start to see large swarms of robots cooperating.[M]

In February, 2019, the UK defense secretary said "swarm squadrons" will be deployed by the British armed forces in the coming years.[H] “Swarms of small attack drones that confuse and overwhelm anti-aircraft defenses could soon become an important part of the modern military arsenal,” he said, “something that would mark a major evolution in robot-enabled warfare.”[H] The US Department of Defense demonstrated one of the largest micro-drone swarms in October 2016.[H] The swarm showed advanced swarm intelligence, such as decision-making, self-healing, and adaptive formation flying. Perdix drones, as they are called, work as a collective organism, sharing a distributed brain that enables them to adapt to each other and make decisions to benefit the entire swarm. Without a leader, the swarm adapts gracefully to drones leaving or entering the team.[H] Ideally, the Pentagon hopes to use these small, cost-effective, and autonomous drones to accomplish the same things they used large, expensive drones to do. They would equip humans with information to make better decisions faster. China is also pursuing this technology. In December 2018, at the Global Fortune Forum in Guangzhou, Ehang UAVs set a world record for the largest drone swarm ever deployed.[M]

Russia is planning to use swarms of more than 100 drones. Each drone would pack an explosive charge and the swarms would be unleashed on convoys and other targets. Source: popularmechanics.com/military

Improvements in autonomous capabilities and increased global military interest in swarms have sparked discussions about their impact and the appropriate response by the international community.[M] The prime forum for these discussions is the series of debates on lethal autonomous weapon systems (LAWS) that take place under the auspices of the 1981 Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons which may be Deemed to be Excessively Injurious or to have Indiscriminate Effects (CCW Convention). LAWS are difficult to define, but they can generally be viewed as weapon systems that can select and engage targets without human intervention.[M]

The challenges of human control over swarms in particular—while relevant to the discussions on the CCW Convention—also go beyond LAWS. According to Maaike Verbruggen (Netherlands) from the Institute for European Studies at the Vrije Universiteit Brussel, "the dispersed nature of a swarm means that control over it functions differently from controls over most existing autonomous systems, and the international community needs to consider how to translate existing concepts and frameworks onto such distributed and networked military systems."[M]

Analytic Confidence

Analytic confidence in the estimate is moderate. There was adequate time, but the task was complex. The reliability of the sources available on this topic was moderate with several high-quality sources available for the estimate. The available sources corroborated each other.

Author: Stephen Frahm

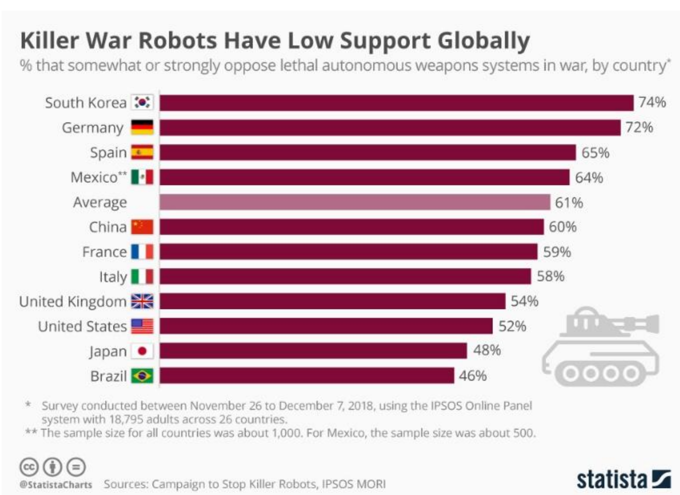
States Within the Rules Based International Order Ban Lethal Autonomous Robots in 5-10 Years

Executive Summary

It is likely that most states operating within the rules based international order will, within 5-10 years, determine that lethal autonomous robots are unacceptable under the rules of war because of generally accepted ethical concerns. Since 2014, more than 90 countries have met eight times at the Convention on Conventional Weapons (CCW) to discuss concerns raised by “killer robots”. Human Rights Watch and a coalition of 118 nongovernmental organizations in 59 countries are working to encourage a preemptive ban on fully autonomous weapons and require meaningful human control over the use of force. The group urges states to adopt a new treaty to this end. Despite this effort, a small number of military powers – most notably Russia and the United States – have blocked progress toward that objective. China is included in the group of 29 countries that have explicitly called for a ban on killer robots but limited their objection to use only. Non-state violent extremist organizations (VEO) who may use fully autonomous weapon systems to dramatically increase their capacity to create incidents of mass destruction are unlikely to adhere to an agreement negotiated between states.

Discussion

Human society is in an age right now when it is human beings, not algorithms, who must decide whether technology will make our lives better or worse.[M] Thomas Jefferson said in 1816, “Laws and institutions must go hand in hand with the progress of the human mind. As that becomes more developed, more enlightened, as new discoveries are made, new truths disclosed, and manners and opinions change with the change of circumstances, institutions must advance also, and keep pace with the times.”[H] This is ageless wisdom applicable to current social and political discourse on lethal autonomous robots.



Killer War Robots Have Low Support Globally. Source: statista.com

Since the Cold War, states and increasingly non-state actors, have chased technological innovation and its integration into ever more complex weapons. War machines assume an unprecedented importance. Hables Gray, Professor of Cultural Studies of Science and Technology at Godard College, stated: “War is a discourse system, but each type of war has different rules of discourse. In postmodern war, the central role of human bodies is eclipsed rhetorically by the growing importance of machines.”[M] This is leading to a mistaken belief in what some describe as ‘risk-free’ war when technology allows combatants to engage targets at long range with high accuracy removing all risk to those firing the weapons.[M] Technology is viewed almost as a neat answer to complex questions posed by the human and physical terrain of war.

During the April 2018 George W. Bush Presidential Forum on Leadership, Amazon founder Jeff Bezos said: "I think autonomous weapons are extremely scary” and suggested that there would need to be international treaties governing the use of autonomous weapons. These treaties, he believes, would regulate the use of such weapons and prevent hacking and misuse of technology.[M] On September 26, 2019, foreign ministers from France, Germany, and dozens of other countries endorsed a declaration at the United Nations against lethal autonomous weapons systems.[H] “This declaration is yet another step down the path leading to the inevitable treaty that’s needed to prevent a grim future of killing by machine,” said Mary Wareham, arms advocacy director at Human Rights Watch and coordinator of the Campaign to Stop Killer Robots. “If these political leaders are really serious about tackling the killer robots threat, then they should open negotiations on a treaty to ban them and require meaningful human control over weapons systems and the use of force.”[M]

The eight meetings on Lethal Autonomous Weapons Systems (LAWS)by the Convention on Conventional Weapons (CCW) since 2014 have found widespread agreement among virtually all the 80 participating states on the need to retain some form of human control over the use of force. Thirty countries now vigorously promote a ban treaty as essential to stigmatize the removal of human control from weapons systems.[M] UN Secretary-General António Guterres is also concerned that “killer robots could take the place of soldiers.” Deeming the prospect of machines with the power and discretion to take human life “morally repugnant and politically despicable,” Guterres has called for a new treaty to be negotiated, and offered UN support towards that goal, as detailed in his Agenda for Disarmament.[H] In 2020, you should be watching for… growing international rejection of “killer robots”—weapons that would kill without meaningful human control—and increasing calls for a new treaty to preemptively ban them.

Since 2014, the United States has participated in the international discussions of lethal autonomous weapon systems (LAWS) under the auspices of the CCW[H] However current U.S. policy does not prohibit the development or employment of LAWS. The United States does not currently have LAWS in its inventory, but senior military and defense leaders have stated that the United States may be compelled to develop LAWS in the future if potential U.S. adversaries choose to do so.[H]

In September 2017, Vladimir Putin told Russian students about science that: “Artificial intelligence is the future, not only for Russia, but for all humankind. It comes with colossal opportunities, but also threats that are difficult to predict. Whoever becomes the leader in this sphere will become the ruler of the world,”[M] Russia’s delegation to the CCW Group of Government Experts has opposed any international regulation of LAWS and continually emphasizes the national security and dual-use benefits that LAWS may provide.[M] Russia also argues that there is no proper legal precedent for a preemptive international ban on an entire class of weapons and declares that any international regulation of LAWS is likely to be politicized.[M]

At the 2018 CCW GGE meeting, the Chinese delegation stated that China supported a ban on the use— but not development—of LAWS acknowledging the dual-use benefits of the enabling technologies behind LAWS.[M] China has invested heavily in developing autonomous weapons, which Chinese military leaders increasingly refer to intelligent or “intelligentized” military technology as their confident expectation for the future basis of warfare. [M] Some believe that China is maintaining “strategic ambiguity” about the international legality of LAWS to pursue its military goals.[M]

Terrorist groups are increasingly using 21st-century technologies, including drones and elementary artificial intelligence.[M] Instead of trying to replicate the Predator, the Islamic State (IS) and other militant groups cleverly adapted smaller drones to their purposes. In the 2017 battle for Mosul, for example, IS dispatched small and agile consumer drones armed with grenades to agitate the Iraqi forces trying to retake the city.[M] AI could allow terrorist groups to acquire or develop lethal autonomous weapons, which would dramatically increase their capacity to create incidents of mass destruction.[M] UC Berkeley computer scientist Stuart Russell, stated that the biggest winners from an AI arms race would be “small rogue states and non-state actors such as terrorists” who can access these weapons through the black market.[M]

Analytic Confidence

Analytic confidence in the estimate is high. There was adequate time, but the task was complex. The reliability of the sources available on this topic were moderate with several high-quality sources available for the estimate. The available sources did tend to corroborate each other.

Author: Stephen Frahm

Autonomous Technology

> Americans fear losing control if they're forced to ride in autonomous vehicles. These same Americans fly in airplanes every day that largely are flown by computers, and impressively efficient ones at that.
>
> **Adam Lashinsky**

Introduction

Autonomous technology, usually thought of as vehicles or robots, is broader and bigger than and has been around for years, in manufacturing plants, automotive industries, software design, and now independent vehicles and robotics. 21st Century Technology and the advent of expansive internet operations and wireless operations is undergoing a resurgence as 3G gives way to 4G, followed by 5G, to be replaced by 6G. The concepts of Internet of Things (IoT), Autonomous Things (AuT) and Internet of Autonomous Things (IoAT), have also surfaced.[H] The best definition, and the simplest found throughout the research was by Northwestern University: "…any kind of technology that can function without being told what to do by a person…"[H]

Productions lines use autonomy and have for decades; autonomous vehicles operate on their own, at various levels for various reasons with various technology; robotics and prosthetics use autonomy, enabling man-machine interface and machine advancement in human capability. By 2035, the virtual spectrum will use autonomy for distributed learning and machine learning on unsupervised AI running on autonomous software and autonomous decision making. The advent of the virtual age will employ autonomy in a significant way.

A rendering of fully automated AI associated in vehicle operation.
Source: medium.com

A photograph of real-world automated manufacturing for BMW in their Leipzig, Germany plant.
Source: kingstar.com

Autonomy has three true categories: full autonomy, manual operations, and everything in between. Multiple sources and platforms describe everything in the middle differently. According to Human Factors Issues in Combat Identification, the list has seven levels from most autonomous to least:

Automation Control Tradeoff

1. Autonomous Operations
2. Management by Exception
3. Management by Consent
4. Management by Delegation
5. Shared Control
6. Assisted Manual Control
7. Direct Manual Control

Source: *Factor Issues in Combat Identification*

Additionally, familiar to most are the levels of autonomy associated with autonomous vehicles:

Level 5. Fully Autonomous
Level 4. Vehicle Operates Nearly 100% autonomously (driver rarely monitors)
Level 3. Driver Does Not Monitor 100% (driver must monitor in particular situations)
Level 2. Autonomous Acceleration, Slowing, and Steering (monitored by driver)
Level 1. Basic Autonomy (e.g., cruise control and anti-locking braking system)
Level 0. No Autonomy

Source: roboticsbusinessreview.com

A rendering of automation, associated with driving, found in a discussion by Sanjay Ravi, General Manager, Automotive Industry, Microsoft Industry. This image was used in his reflection of the Consumer Electronic Show 2019, which had substantial focus on AI.
Source: cloudblogs.Microsoft.com

Regardless of how the levels of autonomy are measured, the hardware side of autonomy is tangible, mostly comfortable, and obvious. Manufacturing, public transportation, vehicles (includes space, air, land and sea surface, and sea and land sub-surface), robotics, and even weaponry. Additionally, however, autonomy includes software with and without AI, both supervised and unsupervised. The latter, less understood may prove most critical in the future.

Research Emphasis

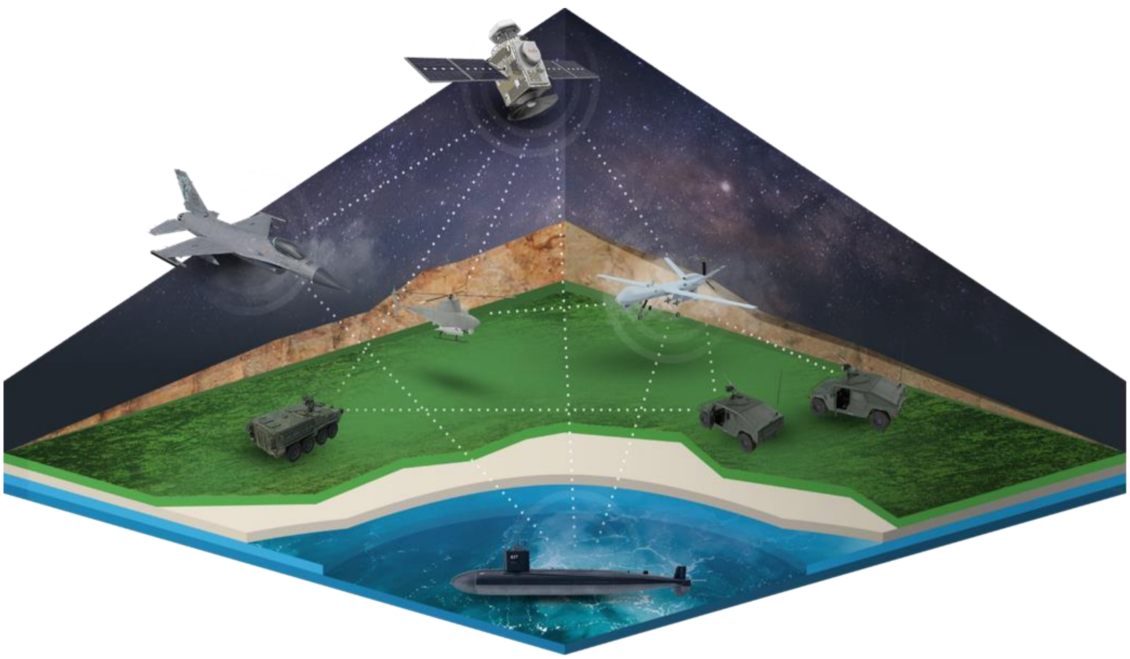
Due to overlap of technologies, combined with understanding (or lack of) in software management, mut of the research focused on software and AI automation. Robotics, specifically bipedal, quadrapedal, etc., can replace legs with wheels, and then discuss automated vehicles. Furthermore, wheels could become propellers, and then take to the air or the sea. However, automated software to enable distributed learning, distributed systems control, and advanced strategy, were most impressive. Early research showed farm equipment, deep sea, open water, or austere hostile terrain as the most likely applications for autonomous vehicles. The reason being regulation and risk to populace.

Pictures of the U.S. Air Force's XQ-58A Valkyrie, the robotic wingman for combat aircraft, first tested in 2019. It was designed with open-architecture, modular software, and hardware to enable 21st century warfare in a way never considered. Source: popularmechanics.com/military

Other applications, generally small, which pose little risk to human life, or in software. Space, undersea, and desert land were of particular interest. Advanced AI, designed and focused on sophisticated AI architecture, Quantum computing capacity, and advanced IT systems were particular intersting. Advanced planning directorates, driven by IT experts, with multiple concepts of operations and courses of action alter future calculi to corporate, government, and military systems. An example of such capability would be a fully automoted, software-driven, AI-enabled planning directorate within a US Combatant Command. The notion led to multiple discussions with the AI, IT, and

Quantum researchers to explore all possibilities. They were noteworthy, to say the least. Robotics, on most levels, was disappointing.

Robotics involved too much hype and too much constraint. Robotics, by 2035, will be tethered to human endeavors, while software will lead to never before considered strategy, strategems, and solutions. Thus, research was explored universally, but mostly delved into the virtual realm.



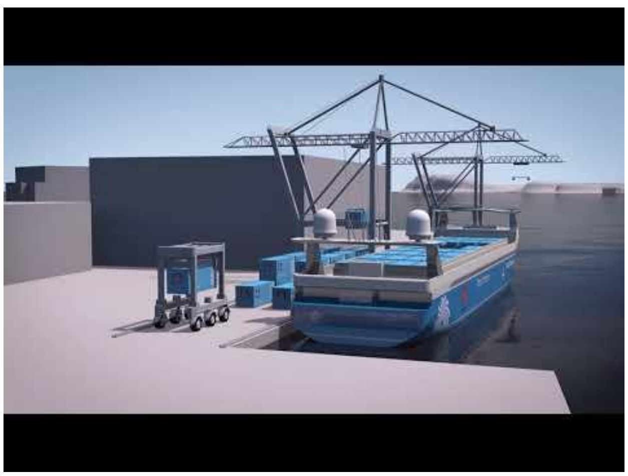
A visual representation of combat autonomy, enabling Mission Command, Distributed Command and Control and Mesh Networking, as seen on the Scientific Systems for Collaborative Mission Autonomy.
Source: ssci.com

Autonomous Ships Under Construction With Fully Autonomous Fleet Likely by 2035

Executive Summary

By 2035, an autonomous shipping fleet is likely to be seaborne and functional. As the population grows, and all nations and economies continue to become more globalized, the need for maritime shipping will only increase. In 2020, the first autonomous maritime shipping vessel will trans-navigate its first route. Additionally, many companies and agencies are looking into autonomous sea vehicles for various applications. Finally, cost reductions will lead to likely autonomous sea fleets by 2035.

Discussion



The world's first autonomous and electric container vessel is one step closer to launch, as YARA signs a deal with VARD worth appr NOK 250 million to build the vessel. VARD will deliver Yara Birkeland for launch in early 2020, and the vessel will gradually move from manned operation to fully autonomous operation by 2022
Source: Yara.com

Maritime shipping is an economic heavyweight that will only increase as the population surges from its current 7.8 billion to approximately 9.8 billion people by 2050.[H] It is valued at $951 billion, despite a decade-long economic dwindle, but it is responsible for the movement of $12 trillion in trade goods.[HH] What's more, in this enormous industry, human error is estimated at between 75% and 96% of all maritime accidents, while the crew expenses alone account for 30% of the budget.[HH] Finally, one study predicted $7 million in savings over a 25-year life of a single autonomous maritime shipping vessel.[H]

Despite safety and regulatory concern and inhibition with autonomous vehicles, autonomous shipping continues forward.[M] This year, 2020, the Yara Birkeland, will voyage with a manned crew, expecting to go fully autonomously by 2022.[H] The route is considered on an inland water way, travelling within the ports of Brevik and Larvik, reducing truck hauls by 40 thousand trips per year, with an expectation to increase road safety.[H] Furthermore, the precedent for brown water travel, within sovereign territory, eliminates Safety and Regulations for European Unmanned Maritime Systems, International Convention on Safety of Life at Sea, and other international governing bodies, leaving national laws free to choose.[M] However, with China expected to be the lead world economy by 2025, possessing"A over 100 cities with over 1M people each, and Singapore, within China's sphere of regional hegemony at the Strait of Malacca (first island chain), international convention will likely support well-governed sea-travel (South China Sea).[H] Regardless of the international outcome of regulation, coastal nations with challenging inland terrain, like Japan, Chile, China, do not have to comply with international convention.

Challenges are abound for autonomous sea vehicles. Cyberthreats alone account for $1 billion dollars in revenue in existing seafaring shipping.[H] However, when comparing this to the scale of industry and cost of human crew requirements—not only their fees, but the ship design to support life—these challenges are likely to be overcome by the advantages.

Ultimately, with Europe and Asia both heavily invested in maritime shipping, and its associated technological opportunities for cost savings and environmental impact (zero emission, biofuel, and sea protection being most significant), the advent of autonomy is emergent.[H] Moreover, with new environmental requirements levied on the maritime shipping indsustry by the International Maritime Organization (IMO), driving sulfur cap from 3.5% to .5% in fuel oil for ships (driving up expense requirements unilaterally), cost savings, where attainable, will matter, especially as profitability of maritime shipping wanes (expected at 3.4% from 2019-2024, plateauing out after a continuous decline for most of the 2010s).[H] Finally, with Ocean Infinity's autonomous defense surface fleet, Armada vessels, and Rolls-Royce's (who, incidentally sold the autonomous maritime division to Kongsberg Maritime for the Yara Berkshire) desire for an autonomous shipping fleet by 2030, momentum and modest investment would support autonomous sea fleets.[HM] However, it is unlikely that international regulation, nor other emergent technology needed, like artificial intelligence and cyber defenses will be immediately available; testing and married

1Mikael Makinen, president of Rolls-Royce Marine, declared that, "Autonomous shipping is the future of the maritime industry. As disruptive as the smart phone, the smart ship will revolutionize the landscape of ship design and operations"
Source: emerj.com

development and the 2-year delay of the Yara Birkeshire make the fielding of an autonomous sea fleet likely by 2035.[HHH]

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were highly reliable, numerous, and corroborative. The analyst had adequate time for research but worked alone and did not use a structured method. However, given the cost and time requirement for sealiner construction, as well as military, private industry, and social independent development and relevance, this estimate is not likely to change significantly.

Author: Nicholas E. Delcour

Autonomous Artificial Intelligence Is Highly Likely To Be Commercially Available By 2027 And Globally Available By 2030

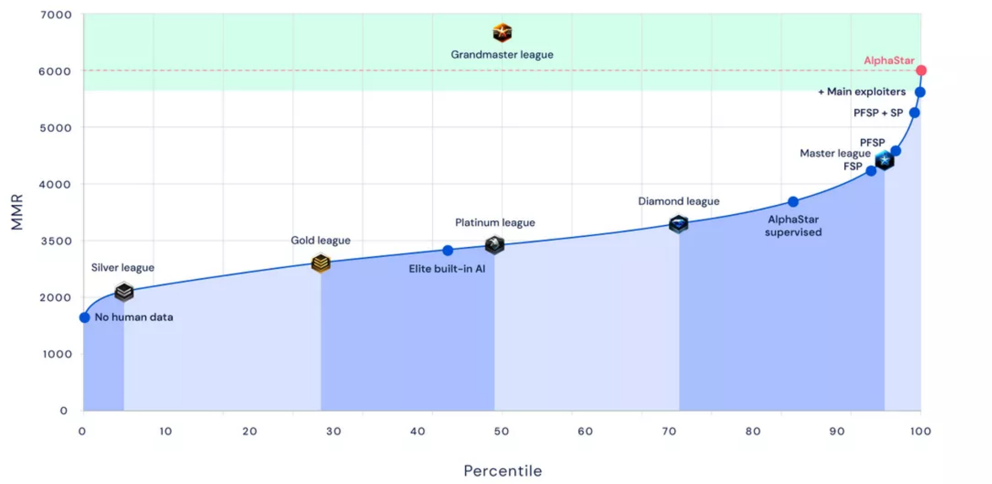
Executive Summary

Autonomous software, coupled with state-of-the-art artificial intelligence (AI) is highly likely to drastically alter future strategic calculus, empowering all markets, by 2027. DeepMind, the AI division of Google, and Blizzard, the online videogame corporation, have recently advanced AI, creating a virtual player that outperforms nearly all humans in strategy development. Coupled with the desire of the medical community to anticipate, diagnose, and correct health problems and the military community's scientific methodology for strategy development, this commercial industry and the global need will see expansive commercial application by 2030.

Discussion

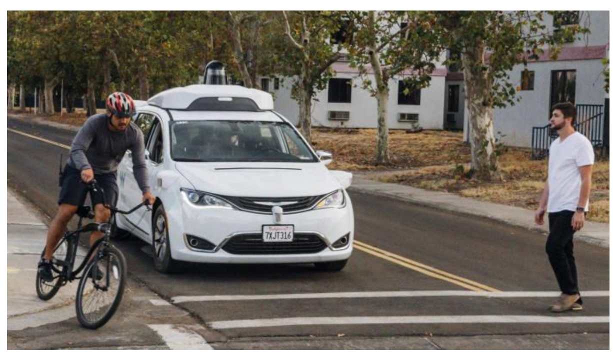
Recently, DeepMind and Blizzard teamed together to create an AI character, named AlphaStar, in the Massive Multi-Online (MMO) game StarCraft II , enabling AI learning and development.[H] Advanced development within the autonomous software, has let the AI learn unsupervised, while imposing certain limitations to limit the cyber capabilities from seizing unfair advantages over humans.[H] For example, the computer was not allowed to button click faster than humans, and so it could not self-replicate for 22 clicks.[H] Additionally, AlphaStar was not able to "see" more of the game or environment than humans.[H] This is interesting in itself since the AI developed unique and independent strategy; the limitation was required to keep the technology from expanding its strategy to do those things.[H] Both human strategists and the AI had 10^{26} options per individual move, at equal pacing.[H] The result was an advanced strategy AI, capable of creating and executing a successful strategy better than 99.8% of all humans.[H] According to, *The Verge*, AI of like AlphaStar is meant to branch beyond video gaming, but AlphaStar demonstrates that, "with enough time, effort, and resources—sophisticated AI software can best humans at any competitive cognitive challenge."[H]

Screen capture of Starcraft II
Source: Lifewire.com



AlphaStar, DeepMind's AI gameplayer, is capable of defeating 99.8% of the world's greatest grandmaster players in StarCraft II, touted as the greatest strategy game ever built. Of note, AlphaStar is unsupervised, where supervised AlphaStar is much less capable, as seen on this figure.
Source: theverge.com

DeepMind, based in London, and Waymo, based in California, both owned by Alphabet, Inc. (under the Google umbrella) have been using AI to enable automotive autonomy for taxi services in CA.[HH] Together, using Population Based Training (PBT), they have been advancing AI decision calculus for autonomous driving, and, in the process, have advanced AI learning, reducing false positives by 24% and reducing training, time, and resources by 50%.[H] Waymo describes this comparative training model as "Darwinian" in nature.[H] It is akin to being fitted for eyeglasses where an individual narrows the field by simply answering which is more or less clear. Moreover, advanced those techniques, they additionally employ "Island Population Training" for forced software and learning evolution within isolated "societies", while



Waymo's self-driving taxi, enabled by DeepMind's AI software, shown here to demonstrate understanding and safety in societal interoperation.
Source: Financial Times

simultaneously killing the weaker comparative result, or unsuccessful software-created evolution or strategies.[H] Furthermore, DeepMind even induced 15-minute-interval training, separate from normal operations, to eliminate the development of learned pattern recognition instead of advanced strategy refinements within its autonomous functionality.[H]

Separately, in 2017, International Business Machines (IBM) published a five-year plan to "remake healthcare".[H] IBM's vision includes hyperimaging, verbal analysis, advanced capability in diagnoses, and molecular analysis, all enabled by AI and hardware (software enabled).[H] Additionally, Partners Healthcare, in that same year, launched an initiative for a 10-year project to boost AI use.[H] Based in Boston, Partners Healthcare plans to use GE Healthcare-created AI and autonomy across multiple Massachusetts hospitals and corporations to advance medical care significantly.[H] Finally, the military scientific method of Jomini, employed in some capacity by nearly every military force across the globe, focuses on science and methodology in the military. The best advantage, if produced by AI and autonomous software in practical application, is almost certain to benefit from advanced strategic calculus associated from machine learning.[H]

Despite, ethical, moral, and regulatory concerns and, not insignificantly, DeepMind's commitment to not allow AI-enabled autonomous weapons, autonomous strategy is ambiguous at best.[H], Once the technology is freely available across all commercial markets, empowered under benevolent systems, like healthcare or the foreseen safety of self-driving cars, the technology will be available to all markets, including those less benevolent. Relevantly, the global nature of militaries, healthcare, and MMOs will ensure the global distribution to all actors. It is highly likely this technology will be commercially available by 2027 and employed en masse by 2030 (even at significant cost).

Additionally, despite concerns over complex adaptive system environments, vice fixed environments, like a chess board or video game (well-constrained and defined), these barriers are not likely to inhibit the reach of this technology.[H] The simplistic nature of chess (in environmental constraints), led AlphaStar to master the game within eight hours.[H] Additionally, according to *the Verge*, when discussing the complexity difference of StarCraft II and chess in the comparison, the 10^{26} options per button choice in StarCraft II drives substantial strategic analysis by AlphaStar.[H] Currently, the longest chess game ever, between Ivan Nikolic and Golan Arsovic, lasted over 20 hours for the 269 moves.[H] AlphaStar mastered the game in less than half the time of that one game, and demonstrated 23 magnitudes greater decision calculus per choice, vice that entire game. The barrier of unconstrained environments is not likely to constrain the unsupervised AI learning within DeepMind. Finally, even in unconstrained environments, like parking a car, for example, may be logically constrained. Parking a car, suggested as an example by Artificial Intelligence—A Modern Approach, contextualizes some aspects of environments well.[H] Truly, the scale of parking space can be reduced by logic (e.g., parking in the center of an interstate would not pass a logic-based solution, and therefore rejected by AI; additionally, the dimensions of the car relative to space available is more accurately estimated by machine observation than a casual driver unable to correctly parallel park—the AI will know if the car will fit before making the attempt).

Analytic Confidence

The analytic confidence for this estimate is *very high*. Sources were highly reliable, numerous, and corroborative. The analysts had adequate time for research and worked together with synergistic effect. A structured method was not used, however. This estimate is not likely to change significantly, unless it were to accelerate from system inputs of classified military capabilities or other secretive corporate development (currently protected as intellectual property), veiled by reduced promotion and visibility until field-ready.

Author: Louis Duncan and Nicholas E. Delcour

Large Robots Highly Unlikely to Available By 2035

Executive Summary

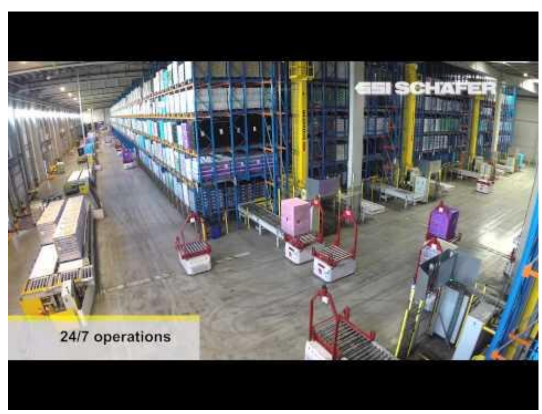
Large Robots, distinct from large autonomous vehicles, are overhyped and are highly unlikely be developed and employed by 2035. Megabots, a company dedicated to the realization of large robots, equipped with random weaponry and capabilities, were built for sports advancements. Though they may seem a first step toward logistical support, warfare support, or security, they fall short. The expense and limitations make similar robots highly unlikely for any practical application, and, therefore, highly unlikely to be available by 2035.

Discussion

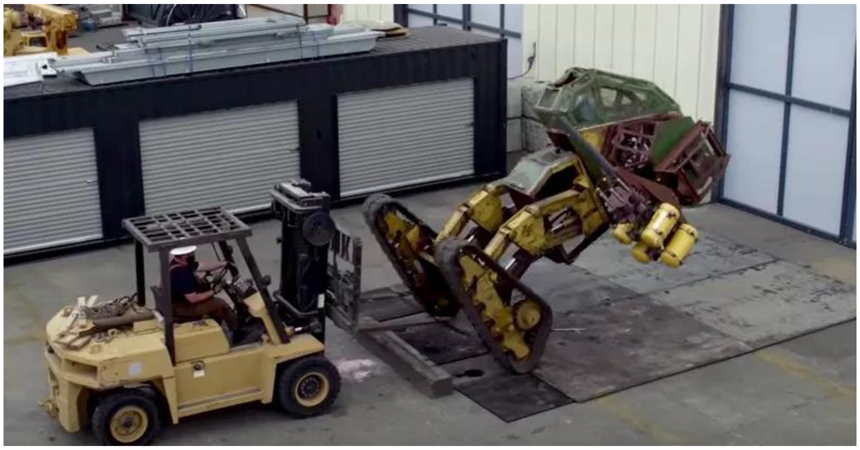
Large robots (defined here as anything over one ton), equipped with various weaponry, like heavy fists, air cannons, or "missile launchers" were created as a visionary sport vehicle in 2015.[H] As of today, they are bankrupt, owing to outlandish costs associated with the logistics and funding.[H] One of Megabots large robots costs approximately \$2.5 million.[H] Also, it costs several thousand more dollars to ship and move one of these robots.[H]

Megabot robot fully constructed with tracked wheelbase.
Source: *https://youtu.be/DXtMgGCh2aI%20*

The practicality of giant robots is, rightly so, questionable. As with most emerging technology, there are two questions that investors or builders must solve: what motivations drive technology, and what problems does the technology solve? For Megabots, the motivation was to create a new sport, similar to battle bots.[HH] The problem is that cost, scale, power, and application are easily financed and obtained for battle bots. That is not the case for giant robots. Also, giant robots do not solve any problems. They are novel. In fact, looking into commercial logistics or into war machines for motivations or problem solving, one quickly sees that



2XL, a Belgium-based company fields a warehouse fueled by Automated Guided Vehicles (AGV)
Source: *logwia.com*



"MegaBots" tests the durability of its giant robot with a crash test. The top-heavy robot easily tips over. (Video screenshot by Bonnie Burton/CNET)
Source:cnet.com

robots are not built any larger than they must be. Looking at Figure 2, the automated vehicles match the scale of the largest packaging available.[HH] Interestingly enough, the large robots from Megabots, weighing several tons each, have little applicability, even in war, but on any surface where weight distribution is an issue: they sink.[H] They also appear to be top heavy.[H]

While corporations, and others, can learn much from Megabots, like track or wheeled robotics are more easily constructed and more reliable, the true value is not there for robotic vehicles. What's more, one robot requires two pilots, instead of reducing manpower associated with each vehicle. Lastly, the robot fight, enabling the sport of pilots fighting mech against mech, was considered "boring" by well-respected online sources that follow technology.[H] Of note, the reason for such a "boring" sporting event was to avoid injuring the pilot; the very concept may prove it unworthy of hazardous duty.[H] If super slow, unrealized fighting potential, moving potential, or just poor design create too much risk to make the sport worthwhile, then practical application for similar systems (weight, size, scale) may not have future realization. Regardless,

Rendering of "The Atlantic's" vision of killer robots, meant to enable war and eliminate humanity throughout the endeavor.
Source: theatlantic.com

despite the hype that "robots that can kill" will make their way to the battle field, or that robots (cybernetic or otherwise) will look like us (e.g., Terminator, A.I., or old fictional literature), the practical application does not exist for motivations or for problem solving.[L] It is highly unlikely that large robots will be available by 2035.

Analytic Confidence

The analytic confidence for this estimate is *high*. Sources were generally reliable and corroborative. The analyst had adequate time for research but worked alone and did not use a structured method. Furthermore, due to the failure of Megabots as a sport, rather than a technological innovation, this estimate *could* change as emerging technologies create industry for unrealized potential.

Author: Nicholas E. Delcour

ANNEXES

Annex A
Terms of Reference:

Requirement:

How, when, and where are artificial intelligence, biotechnology, quantum technology, nanotechnology, neurotechnology, autonomous technology, robotics, and information technology[1] likely to converge in ways relevant to the United States Army over the next 15 years[2]?

- What is the likely nature of the convergence (how will it look)?
  - Is this convergence likely to produce competitive advantages in some fashion?
  - If so, for how long are those advantages likely to persist?

Methodology:

In general, the team intends to model the technologies and conduct background research on advances in the eight interest areas (with noted emphasis on artificial intelligence, bio, and quantum technology). Information will be gathered through a variety of means, to include but are not limited to, interviews with academia, medical professionals, industry leaders, political scientists, military strategists, and federal government experts. Finally, the team intends to estimate logical outcomes based on trends within the eight interest areas while anticipating alterations based on expected global changes.

The team expects to execute this project in the following four steps (Note: This is a notional timeline only. The team expects divergences from this and intends to remain flexible to take advantage of any opportunities):

- Step 1: Data collection from multiple open source outlets (October-December 2019)

[1] The Mad Scientist Fellows understand TRADOC's priorities are Artificial Intelligence, Quantum Computing, and Biotechnology; however, we will consider the other areas as time permits and as they influence the acceleration of convergence of the priorities. Also, the team will use Wikipedia as a basis for definition for these areas.

[2] The Mad Scientist Fellows understand TRADOC's priority is 2028-2035; however, our intent is to outline a technology convergence roadmap starting in 2019 and continuing through 2035. Ideally, this could help decision-makers better align departmental investments in the near-term planning, programming, and budgetary cycles.

    - Evaluate academic, commercial, military, medical and any other applications of technology
    - Explore viability of the tech base (origin of financial support—venture capital, government, etc.)
    - Evaluate products, concept pathway(s) to markets
    - Evaluate peer adversaries' current and future soft power approaches

- Step 2: Synthesize (January-February 2020)
    - Evaluate opportunities for dual use technologies
    - Determine conceptual framework for technology inclusion (prototyping, beta-testing, clinical trials, etc.)
    - Evaluate the subcultures that use the technology and how they intersect with the United States government and military?

- Step 3: Postulate future operational concepts (March 2020)
    - Compare and contrast synthesis with commercial and government futurists concepts
        - Evaluate the accuracy of previous predictions (if possible, establish confidence bands)
    - Create technology convergence roadmap and corresponding brief

- Step 4: Outbrief (MAR-APR 2020)

Challenges:

- The timeline is aggressive, especially when considered with other Army War College requirements
- Acquiring unbudgeted funding may be required for additional travel to engage with subject matter experts; the team will leverage commercially available tools to the max extent possible to mitigate this challenge
- Use of open source information may put in to question the pedigree and reliability of sources; the team will attempt to corroborate information with other sources if time permits
- This technology is so new, there may be limited information available in open sources
- Some research may not yet be published, but based on the nature of this study, a publication the day after completion may render it obsolete

- Technological ideas within this study are unconstrained, but all members belong to government entities, so parochial mindsets and biases could inadvertently narrow the study
- The team has limited expertise in developing statistical models and confidence bands; the team will leverage open source statistical modeling tools to the greatest extent possible but may still need assistance in learning

Resources:

- The team will utilize United States Army War College databases
- The team will interview and collaborate with subject matter experts
- The team will utilize all available open source media
- The team is composed of a unique, diverse, intergovernmental, five-member team:
    - US Air Force Program Manager, with a background in Air Force Materiel Command spanning S&T, product development/deployment/sustainment of stealth airframes, and support to USSOCOM.
    - US Naval Information Warfare/Chief Information Officer, with a background in cybersecurity, project management, and acquisitions.
    - US Air Force Logistics Readiness & Aircraft Maintenance Officer with a background in Supply Chain Management, DoD budgetary processes, and contingency deployment operations.
    - US Air Force Mobility Command Pilot, with a background in nuclear, space, cyberspace, and information operations and applied sciences and mathematics
    - US Department of State Foreign Service Officer with service in Asia, Africa, Europe, and throughout the Western Hemisphere.
- The team will leverage personnel and professional relationships with military and other government scientists and engineers

Administration:

- The technology convergence roadmap will be peer-reviewed Spring 2020
- The draft out-brief will be ready for presentation upon completion of peer-review, with final out-brief April 2020.
- Junior Mad Scientist researchers:
    - Team Point of Contact:
        - Louis Duncan
    - Alternate Team Point of Contact:
        - Pat Lancaster
    - Team Members:

- Stephen Frahm
- Nick Delcour
- Lance Vann

Annex B
Assessing Analytic Confidence

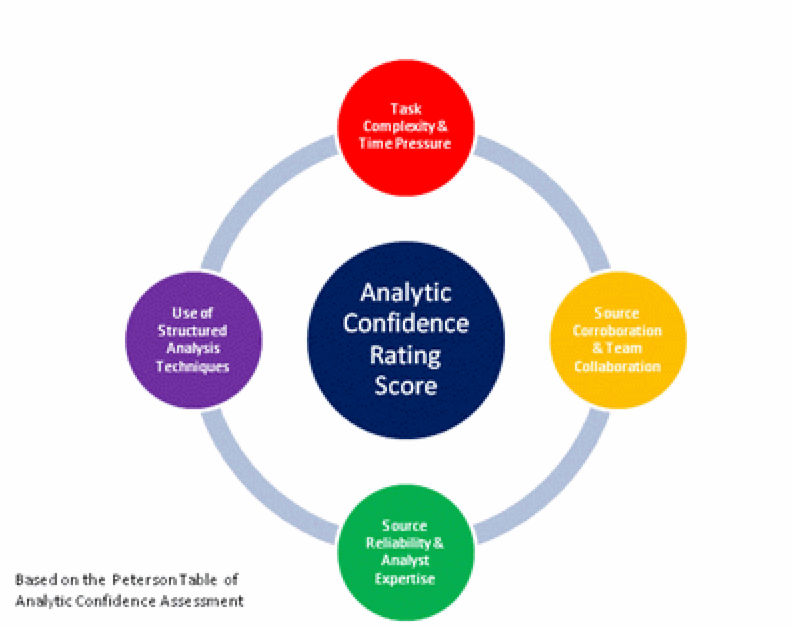
The analysts that wrote this report are non-subject matter experts. They worked both individually and collaboratively to answer the questions. They utilized a combination of structured analytic techniques including nominal group technique and network analysis among others. The team evaluated their analytic confidence utilizing Peterson's Analytic Confidence Factors coupled with the Friedman Corollaries.

Peterson Factors

- How reliable are the sources?
- How well do the independent sources corroborate each other?
- What is my/my team's level of expertise?
- How effective was my analytic collaboration?
- Did I use any structured techniques in my analysis?
- How difficult did I perceive the task to be?
- Did I have enough time to complete the task?

Friedman Corollaries

- Is my estimate within the range of reasonable opinion surrounding the question?
- How likely is it that new information will change my estimate?



Peterson's Analytic Confidence Worksheet

	Points Possible	Points
Use of Structured Method(s) In Analysis	(1-10)	
For example: ACH, IPB, Social Networking, Bayes, Simulation, etc…		
10 indicating highest possible score when considering factors below		
Consider		
Number of		
Applicability of methods to the analysis		
Level of robustness of method		
Degree to which methods' results coincide		
Overall Source Reliability	(1-10)	
A rating of 10 indicates the highest reliability		
Source Corroboration/Agreement: *Level of conflict amongst sources*	(1-5)	
5: No confliction amongst sources		
4: Very little conflict amongst sources		
3: Moderate conflict amongst sources		
2: Significant conflict amongst sources		
1: Sources conflict on nearly all points		
Level of Expertise on Subject/Topic & Experience	(1-5)	
5: Deep intimate knowledge and understanding & 3+ years experience with topic		
4: Wide knowledge & 1-3 years experience with topic		
3: Moderate knowledge & 6-12 months experience with topic		
2: Minimal knowledge & 0-5 months experience with topic		
1: No knowledge & no experience with the topic		
Amount of Collaboration:	(1-5)	
5: Part of aggregated individual analyses		
4: Work on a team		
3: Worked with a partner		
2: Casual discussion		
1: Completely individual work		
Task Complexity	(1-5)	
5: Minimally complex & challenging		
4: Somewhat complex & challenging		
3: Moderately complex & challenging		
2: Quite complex & challenging		
1: Very complex & high challenging		
Time Pressure: *Time given to make analysis*	(1-5)	
5: No deadline		
4: Easy to meet deadline		
3: Moderate deadline		
2: Demanding deadline		
1: Grossly inadequate deadline		
	Score:	
	Total Possible:	**45**
	Score/Total Poss:	
		X10
	Analytic Confidence Adjusted Score:	

Annex C
Standard Primary Source Credibility Scale

Source reliability is noted at the end of each citation as low L, moderate M, or high H. The citation is hyperlinked to the source, unless the source is a paid subscription; in that instance a footnote is provided at the end of each writing illustrating the source for credibility. Source reliability is determined using the Trust Scale and Website Evaluation Worksheet found in Annex

Importance	Factor	Description	Satisfies Criteria (Yes /No)
HIGH	Has a good track record	Source has consistently provided true and correct information in the past	
	Information can be corroborated with other sources	Information provided by the source corroborates with information from other primary and/or secondary sources	
	Information provided is plausible	High probability of the information being true based on the analyst's experience of the topic/subject being investigated	
	Information is consistent and logically sound	Information provided is consistent when queried from different angles and is logically sound	
	Perceived expertise on the subject	Source is perceived to be an expert on the subject / topic being investigated and/or is in a role where subject knowledge is likely to be high	
	Proximity to the information	Source is close to the information – a direct participant or a witness to the event being investigated	
	Perceived trustworthiness	Source is perceived to be truthful and having integrity	
MEDIUM	No perceived bias or vested interest in the subject / topic being investigated or on the outcome of the research	Source has no perceived bias or vested interest in the subject / topic being investigated or on the outcome of the research	
	Provides complete, specific and detailed information	Information provided is specific, detailed and not generic	
LOW	Is articulate, coherent and has a positive body language	Source is articulate, coherent, has a positive body language and does not display nervousness or body language that can be construed to be evocative of deceptive behavior	
	Recommended by another trusted / credible third party	Source is recommended by others the analyst trusts but the analyst herself does not have any direct experience working with the source	
	Sociable	Source comes across as outgoing and friendly. Easy to get along with and talk to	
	Perceived goodwill to the receiver	Perceived intent or desire to help the receiver or the analyst	

Annex D
Trust Scale and Web Site Evaluation Worksheet

Trust Scale and Web Site Evaluation Worksheet
(Updated OCT 2013)

Piece of Evidence #:												Score:	Trust Scale:
Criteria	**Tips**	**Value**	Y or N	Y or N	Y or N	Y or N	Y or N	Y or N	Y or N	Y or N	Y or N	0	15-20 High
Content can be corroborated?	Check some of the site's facts	2											11-15 Moderate
Recommended by subject matter expert?	Doctor, biologist, country expert	2											6-10 Low
Author is reputable?	Google for opinions, ask others	2											5-0 Not Credible
You perceive site as accurate?	Check with other sources; check affiliations	1.5											
Information was reviewed by an editor or peers?	Science journals, newspapers	1.5											
Author is associated with a reputable org?	Google for opinions, ask others.	1.5											
Publisher is reputable?	Google for opinions, ask others.	1.5											
Authors and sources identified?	Trustworthy sources want to be known	1											
You perceive site as current?	Last update?	1											
Several other Web sites link to this one?	Sites only link to other sites they trust	1											
Recommended by a generalist?	Librarian, researcher	1											
Recommended by an independent subject guide?	A travel journal may suggest sites	1											
Domain includes a trademark name?	Trademark owners protect their marks	1											
Site's bias in clear?	Bias is OK if not hidden	1											
Site has professional look?	It should look like someone cares	1											
Total		**20**											

19 Dec 2001: The criteria and weighted values are based on a survey input from 66 analysts. For details see: http://daxnorman.googlepages.com/analysis. Edited for simplicity by Kristan J. Wheaton, OCT 2013
3 Feb 2012: Excel Spreadsheet which adds auto-sum was produced by Bill Welch, Deputy Director, Center for Intelligence Research Analysis and Training, Mercyhurst College.
26 Jan 2013: Trust Scale and Web Site Evaluation Worksheet is in the PUBLIC DOMAIN.

Annex E
Kesselman List of Estimative Words

Certainty 100%

Almost Certain	86-89%
Highly Likely	71-85%
Likely	56-70%
Chances a Little Better [or Less]	46-55%
Unlikely	31-45%
Highly Unlikely	16-30%
Remote	1-15%

Likelihood

Impossibility 0%

Annex F
Acronyms

ACES Program– Atomic Clock with Enhanced Stability Program (DARPA)
AGV – Automated Guided Vehicles
AI - Artificial Intelligence
Aliyun – Alibaba Cloud service subsidiary
AMU – Aix-Marseille University
AQL – Alibaba Quantum Laboratory
AR – Augmented Reality
A2/AD – Anti-Access/Area Denial
BCI – Brain Computer Interfaces
BIO - Biology
BNL – Brookhaven National Laboratory
CA - California
CAGR – Combined Annual Growth Rate
CCW – Convention on Conventional Weapons
CIA – Confidentiality, Integrity, Availability
CIKR – Critical Infrastructure and Key Resources
CMU – Carnegie Mellon University
CRISPR – Cluster Regularly Interspaced Short Palindromic Repeats
CSAC – Chip-Scale Atomic Clock
CSOC – Chip-Scale Optical Clock
CTO – Chief Technology Officer
C100 – Top 100 Cities in the world
C4ISR – Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
C40 – Top 40 Cities in the world
C5AD – Cyber, Command, Control, Communications, and Computers Assessment Division
C5I – Command, Control, Communications, Computers, Combat Systems and Intelligence
DARPA – Defense Advanced Research Projects Agency
DOCSIS – Data Over Cable Interface Specifications
DNA – Deoxyribonucleic Acid
DOE – Department of Energy
FAA – Federal Aviation Agency
FDA – Federal Drug Administration
Gbps – Gigabytes per second
GGE – Group of Government Experts
GPS – Global Position Satellite
HBO – Home Box Office

HIV – Human Immunodeficiency Virus
HBP – Human Brain Project
IBM – International Business Machines
IEEE – Institute of Electrical and Electronics Engineers
IMO – International Maritime Organization
IoT – Internet of Things
ISIS – Islamic State in Syria
ISN – Army's Institute for Soldier Nanotechnologies. Located at MIT
IT – Information Technology
Km/h – Kilometers per hour
KPI – Key Performance Indicators
LAWS – Lethal Autonomous Weapon System
LEO – Low Earth Orbit
LIB – Lithium-ion Battery
LIQuIDNET – Liquid Net
LTE – Long-Term Evolution
MANLAN – Manhattan Landing
Mbps – Megabytes per second
MEMS – Microelectromechanical Systems
MIT - Massachusetts Institute of Technology
ML – Machine Learning
MMO – Massive Multi-Online
MRI – Magnetic Resonance Imaging
NASA -
NG EPON – Next Generation Ethernet Passive Optic Network
NIH – National Institute of Health
NIST – National Institute of Standards and Technology
NLQIS – National Lab for Quantum Information Science
NOAC – NIST on a Chip
NYPD – New York Police Department
NYSERNet – New York State Education and Research Network
N^3 – Next-Generation Nonsurgical Neurotechnology
ONR – Office of Naval Reseach
PBT – Population Based Training
PHA - Polyhydrozyalkanoate
PME – Professional Military Education
PNT – Position, Navigation, and Timing
PON – Passive Optic Networks
PRC – Plasma Resonance Capacitor
QIS – Quantum Information Sciences

QKD – Quantum Key Distribution
QML – Quantum Machine Learning
R&D – Research and Development
SDK – Software Development Kit
SBMT – Society for Brain Mapping and Theraputics
SDCC – Scientific Data and Computing Center at Brookhaven National Laboratory
SBU – Stony Brook University
Tbps – Terabytes per second
UAV – Unmanned Autonomous Vehicles
UCLA – University of California Los Angeles
UK – United Kingdom
UN – United Nations
UNSDG – United Nations Sustainable Development Guide
US – United States
USDOE – United States Department of Energy
VEO – Violent Extremist Organization
VR – Virtual Reality
VTOL – Vertical Take-off and Landing
Wh/kg – Watt Hours/Kilogram
3D – Three Dimensional
4G – 4^{th} Generation
5G – 5^{th} Generation
6G – 6^{th} Generation

Annex G
Definitions

Artificial Intelligence (AI)—In the field of computer science, this is referred to as "machine intelligence."

Artificial Swarm Intelligence—A form of artificial intelligence that relies on the aggregation of learning through multiple agents.

Autonomous Technology—Any kind of technology, including software, physical, virtual, and any combination thereof, that can function without human interference.

Autonomous Things (AuT)—Emerging terminology for autonomous entities, like vehicles or robotics, that will operate within any physical environment, including around humans, without human interference.

Biofuel—Any fuel derived directly from living matter.

Biomass—The total organic material, by area or volume, usable for food, energy, or other productive value, defined by its reusable or recyclable nature.

Biomimicry—the design and production of materials, structures, and systems that are modeled on biological entities and processes.

Biopolymer—A polymeric substance (compound or mixture of compounds, in repeating structural units, at the molecular level) that occurs naturally, or by manipulation, in living organisms, such as proteins, cellulose, and DNA.

Brain Computer Interface (BCI)—A computer-based system that acquires brain signals, analyzes them, and translates them into commands that are relayed to an output device to carry out a desired action. BCIs can be invasive or noninvasive in nature.

Carbon Nanotubes—Cylindrical molecules that consist of rolled-up sheets of single-layer carbon atoms (graphene).

Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)—A specific family of DNA sequences; the term has come to be used as the general tool or term for editing genomes. Cas9, or CRISPR associated protein 9, is the most usual method of targeting genome manipulation; however, it too has, and continues to, advance to other gene modifications and processes.

Complex Adaptive System—A system where the whole is more complex than the parts, and where solid understanding of individual parts does not equate to understanding of the system in which they reside.

Connectome—A comprehensive map of neural connections in the brain. More broadly, a connectome would include the mapping of all neural connections within an organism's nervous system.

Decentralized Artificial Intelligence—Artificial intelligence distributed to semi-autonomous and autonomous systems. This form of artificial intelligence typically leverages the internet of things to share information and provide updates.

Digital Twin—A virtual representation of physical object which typically covers its lifecycle. Digital twins have also been used to model artificial intelligence agents to determine their behavior.

Drug Delivery—The wholistic methodological process by which pharmaceuticals are directly pushed to organs, tissues, or even genomes, using nanoscience and modulation technology.

Edge Computing—High-speed data and storage capability closer to the point of service. This is often used in conjunction with the internet of things, decentralized artificial intelligence, swarm artificial intelligence. Edge computing is being used to reduce latency in refresh rates to semi-autonomous and autonomous systems.

Electroencephalogram—A test that detects electrical activity in your brain using small, metal discs (electrodes) attached to your scalp.

Gene Drive—A tool of genetic engineering to propagate particular genes to the offspring of any species, such as immunities, sterility, or gene design.

Graphene Plasmonics—Graphene plasmonics enables the manufacture of novel optical devices working in different frequency ranges (from terahertz to the visible) with extremely high speed, low driving voltage, low power consumption and compact sizes.

Immunomodulation—Modification of the immune response or the functioning of the immune system.

Internet of Autonomous Things (IoAT)—Emerging terminology, meant in various levels of synonymity with the Internet of Things and Autonomous Things, meant to show the intersection of these emerging technologies.

Internet of Things—The connection of devices through the internet. This concept is being used in manufacturing and major metropolitan cities to fasten sensors together to provide updates about ongoing operations.

Island Population Training—An Artificial Intelligence (AI) development technique, whereby independent, localized population-based training is meant to evolve in isolation to focus development within tighter parameters, accelerating learning. The resultant AI is then comparatively developed against other AI competitors to apply additional evolved learning approaches to population-based training, resulting in a more advanced development.

Lethal Autonomous Weapon Systems (LAWS)—a special class of weapon systems that use sensor suites and computer algorithms to independently identify a target and employ an onboard weapon system to engage and destroy the target without manual human control of the system.

Logic Gate—A basic quantum circuit operating on a small number of qubits. They are the building blocks of quantum circuits, like classical logic gates are for conventional digital circuits.

Machine Learning—Computational algorithms that can deconstruct data into meaningful models. Machine learning enables artificial intelligence to continue to learn.

Microelectromechanical System (**MEMS**)**—**A process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit batch processing techniques and can range in size from a few micrometers to millimeters.

Mixed Reality—Is the merger of virtual reality and the physical environment.

Neuromorphic Computing Chips—High-speed computing devices that contain both memory and processing on the chip. Neuromorphic chips emulate similar neuronal patterns as the human brain and offer machines an opportunity to emulate human intelligence.

Next-Generation Nonsurgical Neurotechnology (N^3) Program—A program to develop high-performance, bi-directional brain-machine interfaces for able-bodied service members. Individual devices can be combined to provide the ability to interface to multiple points in the brain at once.

No Shot Learning—Machine learning that does not require a model to learn.

One Shot Learning—Machine learning that requires a model to learn.

Photonics—A branch of technology concerned with the properties and transmission of photons, for example in fiber optics.

Piezoelectric Sensor—A device that uses the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge.

Platform software services—Software that provides a platform for developers to build, run, and deploy their applications.

Population-Based Training (PBT)—An Artificial Intelligence development technique utilizing advanced neural networks, incorporating various and a significantly large number of parameters, and then perpetuating the best results multiple times over; this is a form of Darwinian, reinforced training to evolve for the most successful capabilities.

Quantum Communications—a field of applied quantum physics closely related to quantum information processing and quantum teleportation. Its most interesting application is protecting information channels against eavesdropping by means of quantum cryptography.

Quantum Computing—the use of quantum-mechanical phenomena such as superposition and entanglement to perform computation. A quantum computer implemented theoretically or physically, is used to perform such computation.

Quantum Sensing— use of a quantum object to measure a physical quantity (classical or quantum). The quantum object is characterized by quantized energy levels. Specific examples include electronic, magnetic, or vibrational states of superconducting or spin qubits, neutral atoms, or trapped ions. It is also defined as the use of quantum coherence (i.e., wave-like spatial or temporal superposition states) to measure a physical quantity and the use of quantum entanglement to improve the sensitivity or precision of a measurement, beyond what is possible classically a quantum sensor is a quantum device that responds to a stimulus. Usually this refers to a sensor which has quantized energy levels, uses quantum coherence to measure physical quantity, or uses entanglement to improve measurements beyond what can be done with classical sensors.

Quantum Simulation—simulating a quantum system by quantum mechanical means. Quantum simulation can model larger quantum systems compared to classical or even supercomputers. Quantum simulators permit the study of quantum systems that are difficult to study in the laboratory and impossible to model with a supercomputer. In this instance, simulators are special purpose devices designed to provide insight about specific physics problems.

Robot—a machine capable of carrying out tasks without a human operator based upon a set of instructions provided by a computer.

Soft Robotics—the specific subfield of robotics dealing with constructing robots from highly compliant materials, like those found in living organisms. Soft robotics draws heavily from the way in which living organisms move and adapt to their surroundings.

Supercapacitor—High-capacity capacitors with lower voltage limits than other types of capacitors, and functionally, they lie somewhere in between electrolytic capacitors and rechargeable batteries. They charge much faster than batteries, store much more energy than electrolytic capacitors, and have a lifespan somewhere between the two (more than rechargeable batteries and less than electrolytic capacitors).

Supervised Learning—Machine learning that requires training data to continue to learn.

Swarm Robotics—an approach to the coordination of multiple robots as a system which consist of large numbers of mostly simple physical robots. A desired collective behavior emerges from the interactions between the robots and interactions of robots with the environment.

Tissue Engineering—The use of cells, engineering materials, and biochemistry to improve or replace biological material and functions.

Transcranial Direct Current Stimulation—A non-invasive, painless brain stimulation treatment that uses direct electrical currents to stimulate specific parts of the brain.

Unsupervised learning—Machines that learn with minimal supervision and limited amounts of labeled data.

Virtual reality—A simulated environment that may or may not represent the actual physical environment.

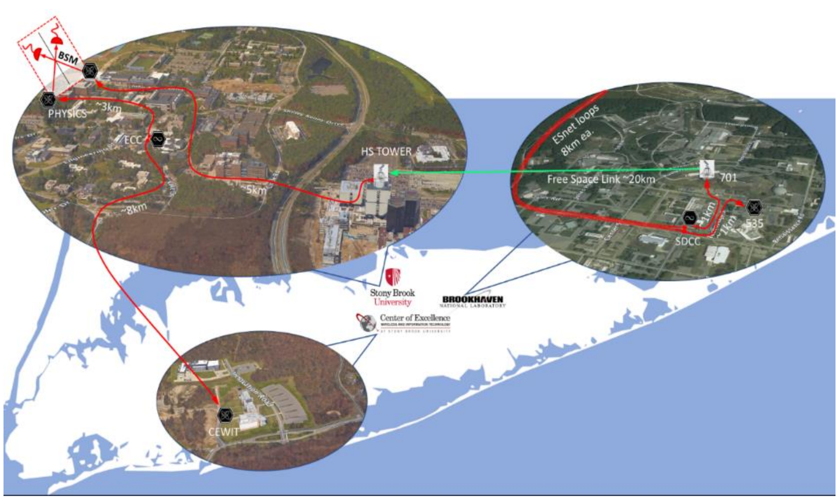
Annex H
March 5, 2020 Site Visit to Brookhaven National Laboratory, Stony Brook University, and Qunnect Inc. - Trip Report

Executive Summary

The closest Quantum Information Science (QIS) Research Center to the US Army War College in Carlisle, PA is in Long Island, New York and comprised of a partnership between Brookhaven National Laboratory (BNL), Stony Brook University (SBU), and Qunnect Inc. BNL is located ~25 miles (40km) east from SBU, and Qunnect sits in a research park SW of the SBU campus. Together their partnership is one of the top US Quantum Information Science (QIS) Research Centers. The Department of Energy (DOE) announced in January 2020 they were funding up to $625M to acellerate QIS development at two to five QIS research center locations over the next five years. BNL, SBU, and Qunnect are competing for USDOE funding. The USDOE has been very supportive of the BNL, SBU, and Qunnect efforts. Dr. Figueora recently received over $2M in funding for the BNL laboratory and Qunnect is in final negotiations for a phase-II Small Business Innovaton Research award.

Points of Contact [H]

Dr. Mehdi Namazi, Chief Executive Officer, Qunnect Inc.
Dr. Eden Figueroa, Chief Science Officer, Qunnect Inc. (Joint Appt at BNL & SBU)
Dr. Noel Goddard, Chief Operating Officer, Qunnect Inc.
Mael Flament, Chief Technology Officer, Qunnect Inc.
Dr. Paul Stankus, Quantum Astrometry, BNL Physicist [H]



Map of three sites

Brookhav

The tour started at BNL where Dr. Noel Goddard and Mael Flament escorted me through tight security to the BNL Quantum Lab which is still being assembled. Dr. Eden Figueroa joined the group at BNL along with Dr. Paul Stankus and both provided a detailed tour of main laboratory containing the 3 optics tables and a separate room where they are developing a free-space link adaptive optics project. While only 1 of the optics tables is populated with lenses and devices for experiments and tests, the laboratory anticipates full build out in the coming months with the arrival of the USDOE funding. BNL currently contains a number of custom-built lasers and equipment for creating telecom frequency Qubits (dubbed the Quantum Bank) pictured below, image 1 on the left of Figure 1. BNL is where the QIS research center generates qubits and transmits them over fiber optic cable to SBU. Figure 1 below illustrates the process and components required for a quantum repeater and the comments below the images explain the process in greater detail.

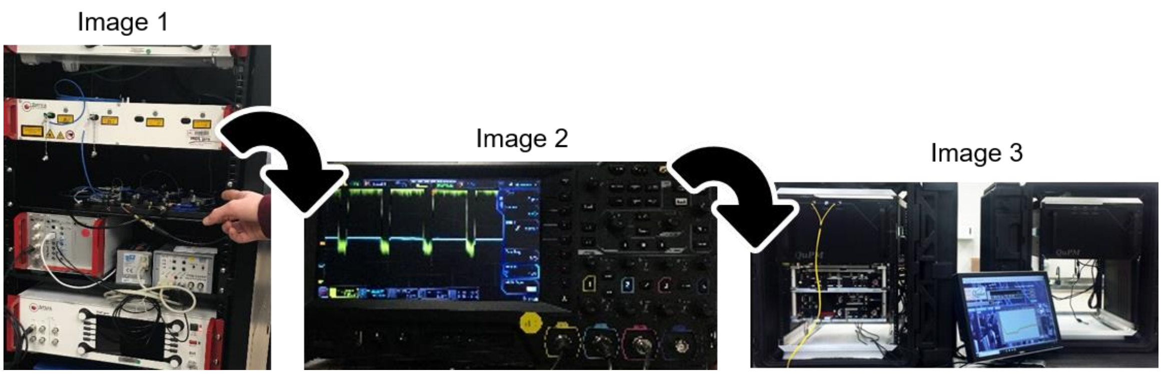
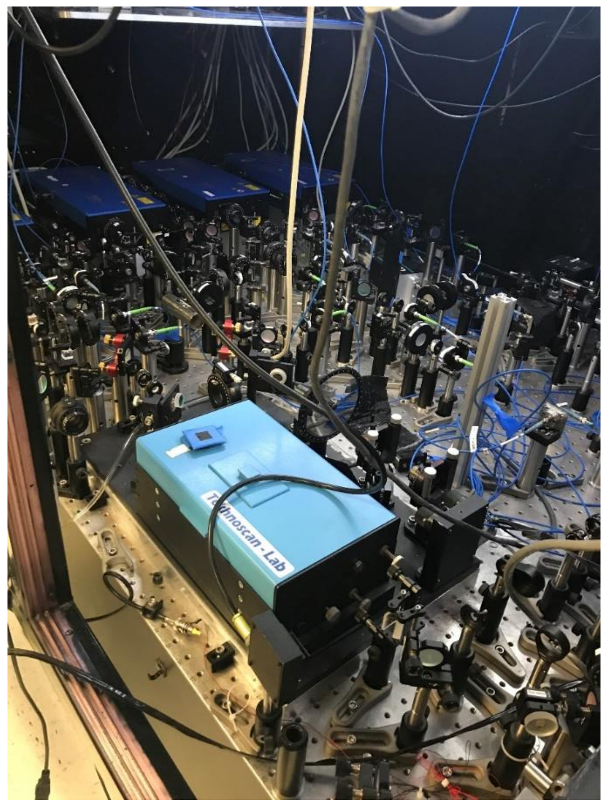


Image 1 on the left is a "Quantum Bank" where lasers pulse the small component being pointed at in the rack; this creates qubit streams. The individual qubits, illustrated by Image 2, are transmitted from Brookhaven National Laboratory over a 60-mile fiber optic cable to Stony Brook University. Image 3 are two portable quantum memory buffer devices at Stony Brook, which store/buffer the qubits and will eventually connect to another 40-mile quantum internet connection extending the network to 100 miles.
The adaptive optics experiment involves two telescopes where a single-photon will be transmitted over open air from BNL to SBU ~25 miles away (note the difference in distances to the fiber transmission are due to the circuitous route of buried fiber cables). Testing is still being conducted in the lab at short distances using high speed cameras and will eventually be done outside the lab with incremental distance increases.
"This link will enable several critical quantum experiments between Brookhaven and SBU and proof-of-concept demonstrations as the technology for longer-distance quantum communications over fiber is being developed." [H]

Stony Brook University (SBU)

SBU is the most mature lab of the three sites and it is important to understand the relationship and history between the Qunnect CEO & CTO which were both students of the CSO, Dr. Eden Figueroa, while attending SBU. The shared history explains why the partnership environment is collaborative, supportive, positive and very constructive. The goal is server sized quantum repeater components; with preliminary tests during summer of 2020 and reaching early commercial market in 22.

One of three light tables at SBU which is fully populated with equipment for testing and experiments. Note the new light tables at BNL are just now starting to be populated with lenses and devices so test and experiments can be setup. (Picture by Patrick Lancaster)



Qunnect Inc.

Qunnect Inc. lab and workspace is located on the SBU campus in the Center of Excellence for Wireless Internet Technology (CEWIT) building. Dr. Eden Figueroa and Mael Flament provided a detailed explanation of how they perform quantum entanglement and then store the state using quantum memory and using both components can create a quantum repeater. Mael Flament provided the following explanation of their approach to quantum memory: "*We use a photon-pair emitter and store them in different regions in the memory's atomic vapor cell. By doing this we intend to create grids of addressable photons that can be released on-demand (i.e. a step towards "entanglement banks"). To actually store them in different regions we displace the light beams with a device called an Acoustic Optical Deflector (AOD)."* Qunnect will test some of the server sized components required to make a quantum repeater over the summer of 2020. If successful, this could be the first demonstration of quantum internet links through existing and long-distance telecom infrastructure in the US. It will cover an initial fiber distance of 50 miles with plans to extend it over 100+ miles as the quantum repeater component suite matures into a product.

Quantum Memory

Qunnect displayed two of the cases which will house quantum memory and they are about the size of a standard desktop PC and operated at room temperature without environmental controls.

Qunnects original quantum memory storage device, both pictures are the same device, image on the left shows the equipment drawer slid down in the maintenance access position. The new device design for quantum memory is about one third the size and made to be sold commercially. (Picuture by Mael Flament)

Topics and notes from a meeting with Dr. Noel Goddard, COO, Qunnect Inc.

1) <u>Quantum Internet Roadmap</u>
Quantum analogues of all classical telecom devices are still in development (routers, switches, buffers, repeaters, etc)
1.0 Devices, 2.0 Devices being used together to create systems, 3.0 Systems being used for commercial applications

2) <u>Entanglement Swapping Communication</u>
Current QKD protocols do not use entanglement swapping. They are limited to short distances (<100km) and are venerable to attack. Attempts to extend the distance have been limited to relaying at trusted nodes (the venerable points).
Entanglement swapping will enable measurement device independent QKD (MDI-QKD) protocols which are “NOT” vulnerable to the attacks
Entanglement swapping has been demonstrated in foreign and US in a laboratories. China has demonstrated entanglement using satellites.
The key to extending entanglement swapping over long distances is quantum repeaters (in which a critical component is the quantum memory)
BNL/SBU/Qunnect is aiming to demonstrate entanglement swapping on real telecom fiber beds this summer. The group has access to fiber beds extending to NYC which, if successful, will be the first long distance network on US soil. The AFRL in Rome, NY wants to be the next extension on this network. Other DOE labs are possible sites as well.

3) <u>QC Standards have yet to be set</u>
Numerous physical systems (atomic media) can be used to construct quantum memories. The vast majority require significant deep cooling infrastructure. Qunnect is commercializing a technology that operates at ambient temperatures, facilitating real world deployment.
Other DOE labs are working on alternate technologies (most require deep cooling). There are pros/cons with each that lend themselves towards certain applications.

In our designs, the wavelength for quantum communications is defined by the atomic medium for memory storage. Depending on the standard, a wavelength will likely be chosen/protected. For Qunnect/BNL/SBU, this is 1367nm to be compatible with Rubidium based memories and the existing telecom fiber beds.
Communication protocols over entanglement swapping QC networks cannot be developed/invented until the networks are built. This is a complicated process of synchronization, switching, routing.

The Futures Team provided this list of questions and the following responses were graciously provided by Mael Flament, CTO Qunnect Inc.:

1) What type of material science is being researched to support miniaturization of quantum computing?
Can't really answer this one. However, from the Quantum Communications front there is a lot of ongoing work to create effective quantum photon sources that leverages material science. A good example is quantum dots.

2) Related to #1, how do they see power requirements increasing or decreasing as systems get smaller?
Won't address from the computing side; but from a communications side this is an interesting question. I may be biased on this answer.

Typically on-chip/nano-photonics quantum science solutions requires vacuum and cryogenics. From a scalability point of view it’s not very viable. However, the more you shrink it the smaller these systems become and at some point the vacuum/cryo requirements are easy to accommodate for. From the other approach (i.e. Qunnect's) room-temperature light-matter systems have a certain limit to their size miniaturization - however they don't require ancillary hardware to operate. I foresee both will reach size limitations within 5y and I think there won't be a big difference in the end between these sizes when all their operating equipment is considered.

Light-matter systems, like those Qunnect builds (e.g. quantum memory buffer) are size limited by the matter interface (atomic gas cell). In 5 years we anticipate it can shrink from a suitcase to a shoebox, and finally a large matchbox - but not smaller. The power requirements of the optical systems however is almost null (passive optical elements), as the main power requirements are the lasers - which are required in most Q-Comm scenarios anyways.

3) What is their logic for setting up the architecture? What trades do they make between hardware and software in establishing up the architecture?
Again ignoring the computational side of this and from a communications point of view, common monitoring software standards and communication protocols will be essential to the wide adoption of these technologies. The former will widely depend on the technology choices that powers these networks (e.g. type of photon entanglement sources), whereas the later should/will be hardware-agnostic. The field is currently inventing all the quantum analogues of common telecom devices. The end architectures will be defined by the ability to interface those devices to utilize a feasible communications protocol. Unlike classical

systems, the timing of photon arrival at different quantum devices is critical, so the software overlay to control the architecture will be significant.

4) What are the use cases they see for quantum computing in the future and why? What markets will be disrupted?
From a communications perspective I think we will see every growing hybrid approach. For the immediate-10yrs future, quantum entanglement systems will mostly be used where they have a clear advantage: high-security requirements or large data transfer (once large-scale entanglement networks are deployed). However, if costs of quantum hardware were to eventually match that of classical network components then there is no reason to not have it replace classical networks slowly altogether.

5) What do your roadmaps for commercialization of Quantum Computing, Quantum Communications, Quantum Internet, Quantum Sensing, Quantum Key Distribution, look like?
QKD: ongoing already (it's been around for a while); roll-outs will continue for the next 5y - after that it all depends on the status of entanglement based networks.

Entanglement based networks:
* Components: 1-5 years away
* Systems for R&D purposes only (sub-assemblies of basic components and testbed networks): 2-6 years
* Large-scale systems: 5-10 years
* Widespread adoption of tech: 10 years.

7) What are your major despite clauses for each of the Quantum Information Sciences (QIS) Technologies achieving their roadmap timelines.
For QComm its the availability the high-fidelity quantum memories. Hence why Qunnect is foccusing all its efforts on that first.

8) Do you see any convergence happening between quantum and other emerging technologies which will create innovation or new possibilities. For example, I see a likely convergence between 6G and Quantum Communications around 2035.
Way before hopefully. If next-gen telecommunications don’t integrate quantum tech or quantum-safe methods, then they/we have failed and we will rapidly see the repercussions as QComputers start to flourish.

Author: Patrick Lancaster

Annex I
Likely Quantum Technology Roadmap 2020-2035

Executive Summary

Quantum Information Science (QIS) research and development is likely to follow this quantum technology roadmap between 2020-2035. While global public funding has decreased since 2018 there has been an increase in global government spending. The reduction in the number of 2018 quantum patent applications to 558 from 619 in 2017 is an indication that things started to slow in 2018. While the initial patent and grant numbers have increased by 15% for 2019 the specific breakdown is not available by technology sector. The strong government support when combined with the steady public support will enable quantum development to continue on this quantum technology roadmap between 2020-2035.

Discussion

The following quantum technology roadmap was created using research and multiple roadmaps with staggered timelines based on the original date of publication and the existing predicted windows for technology deployment.
Despite the recent reduction in public funding for quantum and 2018 slowdown in patent applications quantum research and development will continue to follow the following roadmap. Government funding is increasing on a global scale and the US Quantum Initiative Act Authorized which was signed in 2018 authorized spending $1.2B to accelerate the development of Quantum Information Sciences (QIS). The global government spending includes China's $10B Quantum research center which is scheduled to open in 2020. [H] Quantum maybe one of the few sectors where the government takes back the technology lead from the private sector. Although the US Government is using a partnership approach and Government is teaming with both Industry and Universities to form QIS research centers across the US.

Quantum Communication

Key Milestones (2020-2021) *HHHM*

- Development and certification of quantum random number generator and quantum key distribution devices and systems.
- Addressing high-speed, high-technology readiness level, and low deployment costs.
- Novel protocols and application for network operations.
- Development of systems and protocols for quantum repeaters, quantum memories and long-distance communications.
- Efficient on-demand sources of entangled photon pairs or larger entanglement photonic micro-clusters; investigation of new photon source concepts to close the gap between system-level requirements on photon efficiency and experimental capability.
- Optical communications systems operating near the quantum limit for example using chip-based multi-mode optima receivers to approach channel capacity limits.
- Single photon detectors with >0.99 detection efficiency.
- Quantum cryptography with secure bit transmission rates of 10^8 per second.
- Efficient quantum interfaces between long-lived stationary memories (atomic and solid-state) and photons.
- Prototype quantum repeaters and linking of two or more small-scale quantum computers via high fidelity quantum communications channels.
- Efficient quantum frequency conversion between telecom photons and atom-like memories as well as superconducting microwave cavities.

Key Milestones (2022-2026) *HHHM*

- Cost effective and scalable devices and systems for intercity and intracity networks that demonstrate end-user-inspired applications.
- Scalable solutions for quantum networks that connect devices and systems, e.g. quantum sensors or processors. Addressing high-speed, high-technology readiness level, and low deployment costs.
- The demonstration of long-distance quantum communications channels consisting of multiple quantum repeaters, surpassing repeaterless quantum cryptography bounds.
- Advanced photonic components and protocols for quantum key distribution at rates hundreds of Mbit/sec over metro-scale (~50km) distances in network topologies that are upgradable with quantum repeaters.
- Development of on-demand single and entangled photon pair sources with sufficient purity, efficiency, and indistinguishability to produce large photonic cluster states.
- The development of photon-loss-protected photonic states for forward error correction,
    - allowing new forms of long-range quantum state transfer, cryptography, and mid-scale

    - photonic quantum information processors.
- Quantum repeater links beating repeaterless quantum cryptography rate-loss bounds
- The demonstration of long-distance quantum communication channels consisting of multiple quantum repeaters, beating repeaterless quantum cryptography bounds.
- High bit rate quantum cryptography over 1000s of kilometers. Construction of prototype
    - quantum internet consisting of multiple medium scale quantum computers connected via high fidelity quantum communication channels.

Key Milestones (2027-2035) [HHHM]

- Development of autonomous metro-area long distance >1000 km and entanglement-based networks, a 'quantum internet.'
- Protocols that exploit the novel properties that quantum communications offer.
    - Global quantum Internet.
- Networks capable of distributing entanglement at high rates over continental length scales, including efficient coherent interfaces to various types of quantum computers
    - (atoms, solid-state, microwave...).
- Quantum networks for efficient links between many quantum memories, highspeed
    - quantum teleportation, cryptography, and modular quantum computing.
- Small quantum networks are connected into global "quantum internet" whose functions, beyond secure communication and parallel computing, will include many other applications, including quantum digital signatures, quantum voting and secret sharing, anonymous transmission of classical information, and a host of sensing and metrology applications.

Quantum Computing

Key Milestones (2020-2021) HHHM

- Fault tolerant routes for making quantum processors with eventually more than 50 qubits.
- The construction of small-scale quantum computers with 50-100 qubits capable of performing 10^4 coherent quantum logic operations.
- High Fidelity logical qubits that function better than their physical constituents.
- Fault-tolerant quantum logic operations on 1-2 logical qubits.
- Quantum Random Access Memory qRAM prototypes.
- Application of 'mid-scale' quantum computers to quantum simulation, quantum machine learning, and demonstration of quantum supremacy.
- Quantum Characterization, Verification, and Validation (qCVV) of mid-scale quantum circuits with error correction.

Key Milestones (2022-2026) HHHM

- Quantum processors fitted with quantum error correction or robust qubits that outperform physical qubits.
- The construction of general-purpose quantum computers with 100-1000 qubits, combined with the ability to perform 10^5 quantum logical operations on multiple qubits with individual gated fidelities of 0.9999.
- Fault tolerant quantum logic operations on 10-100 logical qubits.
- Development of special purpose deep quantum learning circuits.
- Large-scale qRAM & quantum Machine Learning (ML) on medium scale quantum computers.
- Mid-scale, error corrected quantum computers.
- Application of special purpose quantum information processors in elementary particle physics and quantum gravity.

Key Milestones (2027-2035) HHHM

- Quantum algorithms that demonstrate quantum speed-up and outperform classical computers.
- Large-scale general-purpose quantum computers operating in fully fault tolerant fashion and capable of factoring large numbers, to solve hard linear algebra problems, to perform quantum simulation, and to perform Machine Learning (ML). Such quantum computers will be able to perform a side variety of computations that could not be performed classically.
- Large-scale special purpose quantum simulators, annealers, integrated quantum optical circuits networked with general purpose quantum computers.
- Strong experimental and theory connections between Quantum Information Sciences (QIS) and other fields such as high energy physics, quantum gravity, chemistry, and computational biology.

Quantum Simulation

Key Milestones (2020-2021) *HHHM*

- Experimental devices with certified quantum advantage on the scale of more than 50 (processors) or 500 (lattices) individual coupled quantum systems.
- Special-purpose quantum information processors such as quantum simulators and quantum annealers with hundreds or thousands of qubits & applications to quantum chemistry or the demonstration of fundamental quantum effects such as entanglement over hundreds to thousands of qubits.
- The development of highly coherent special purpose quantum information processors such as quantum simulators, quantum annealers, and integrated quantum optical circuits with hundreds or thousands of qubits.

Key Milestones (2022-2026) *HHHM*

- Quantum advantage in solving important problems in science (e.g. quantum magnetism).
- Quantum optimization (e.g. via quantum annealing).
- Special purpose quantum computers such as quantum simulators and quantum annealers with hundreds or thousands of qubits & applications to quantum chemistry or the demonstration of fundamental quantum effects such as entanglement over hundreds to thousands of qubits.

Key Milestones (2027-2035) *HHHM*

- Prototype quantum simulators that solve problems beyond supercomputer capability, including in quantum chemistry, in the design of new materials, and in optimizing problems such as occurring within the context of artificial intelligence.
- Quantum simulators established as universal tool for the characterization of fundamental quantum effects and the design of novel quantum technologies and materials.
- Large-scale special purpose quantum simulators and annealers; and quantum transducers to photonic communications channels.

Quantum Sensing and Meteorology

Key Milestones (2020-2021) *HHHM*

- Quantum sensors, imaging systems and quantum standards that employ single qubit coherence and outperform classical counterparts (resolution, stability) in a laboratory environment.
- Development of quantum sensing and metrology systems that use entanglement and squeezing to surpass the performance of semi-classical devices which are limited by the standard quantum limit.
- Best-of-class sensors based on NV-diamond (magnetometers), atom/ion traps (entangled quantum clocks), *squeezed light* (interferometers), engineered multi-photon quantum states spectrometers), atom interferometers (gyroscopes, gravitometers).
- Diamond quantum sensors for precision detection of spins, molecules, and biological processes.

Key Milestones (2022-2026) *HHHM*

- Integrated quantum sensors, imaging systems and metrology standards at the prototype level, with first commercial products brought to the market.
- Laboratory demonstrations of entanglement enhanced technologies in sensing.
- Demonstration of long-distance networked quantum metrology: quantum GPS and global quantum clocks.
- Mapping the atomic structure of individual small biomolecules under native conditions
- using quantum magnetometers.
- Noninvasive, real-time mapping of individual neurons using quantum magnetometers.
- The development of quantum sensor networks.

Key Milestones (2027-2035) *HHHM*

- Transition from prototypes to commercially available devices.
- Space based Quantum GPS and global quantum clocks to provide universal sub-millimeter position accuracy.
- Quantum sensing as an established tool for brain and neuroscience, including real-time recording and imaging of action potentials.
- Quantum sensing using solid-state spins established for mapping biomolecules under native conditions; applications in life sciences, chemistry, batteries...
- Detection of gravitational waves and dark matter with a space-based network of quantum sensors (e.g., clocks, atom interferometers).

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were mostly reliable and corroborated one another. There was adequate time, but the analyst worked independently using a semi-structured method.

Author: Patrick Lancaster

****Source roadmaps were published 2016 - 2019 and timeline is adjusted.***

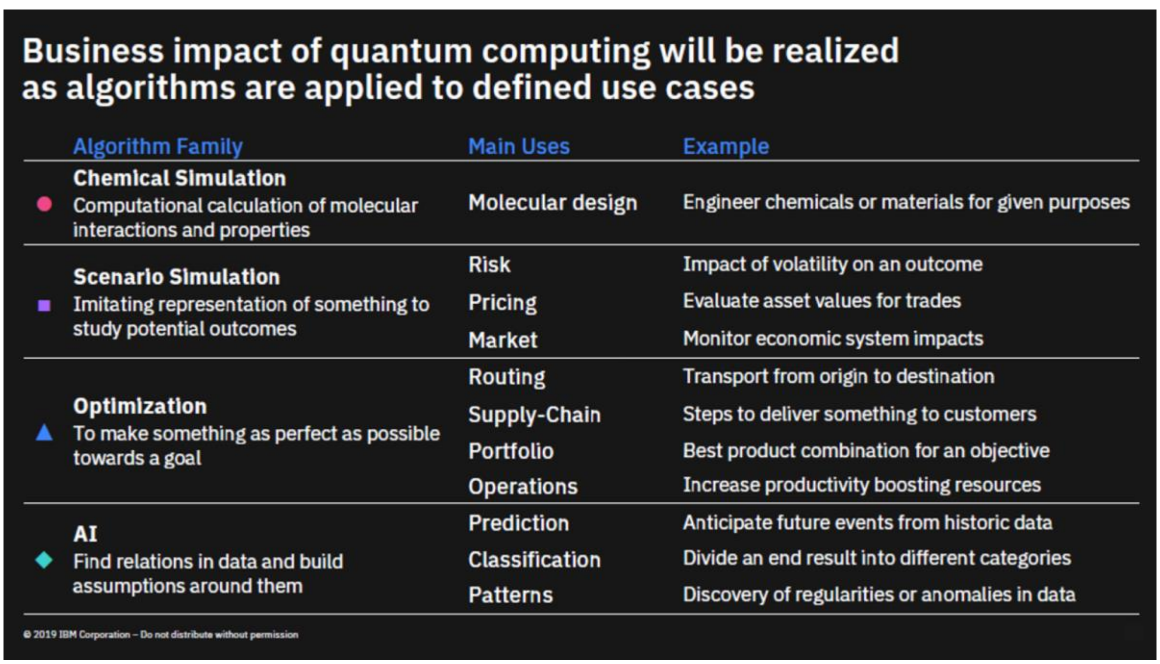
Annex J
Quantum Computing Use Cases Likely to Follow the IBM 2020-2035 Roadmap

Executive Summary

Use cases are valuable mechanism in comprehending both the convergence and practical application of new technology. IBM released a quantum computing use case roadmap with relative timeframes for these use cases to emerge. The approach is divided into use cases sorted into algorithm families and then provided main uses and examples.

Discussion

Quantum Computing Report shared IBM's quantum computing use cases roadmap which uses three horizons to describe when they expect industries and algorithm families to emerge: [H] Horizon 1 represents those use cases expected to become possible using a NISQ level machine within the next few years, Horizon 2 includes use cases that will require larger machines that have a greater number of higher quality qubits but are still not error corrected, and Horizon 3 includes use cases that are not expected to become possible until more powerful, fault tolerant quantum computers are available in 15 or more years. (Note that these classifications are always subject to change depending upon unexpected breakthroughs or challenges that occur during the development process.) [H]



Business impact of quantum computing will be realized as algorithms are applied to defined use cases

Algorithm Family	Main Uses	Example
Chemical Simulation Computational calculation of molecular interactions and properties	Molecular design	Engineer chemicals or materials for given purposes
Scenario Simulation Imitating representation of something to study potential outcomes	Risk	Impact of volatility on an outcome
	Pricing	Evaluate asset values for trades
	Market	Monitor economic system impacts
Optimization To make something as perfect as possible towards a goal	Routing	Transport from origin to destination
	Supply-Chain	Steps to deliver something to customers
	Portfolio	Best product combination for an objective
	Operations	Increase productivity boosting resources
AI Find relations in data and build assumptions around them	Prediction	Anticipate future events from historic data
	Classification	Divide an end result into different categories
	Patterns	Discovery of regularities or anomalies in data

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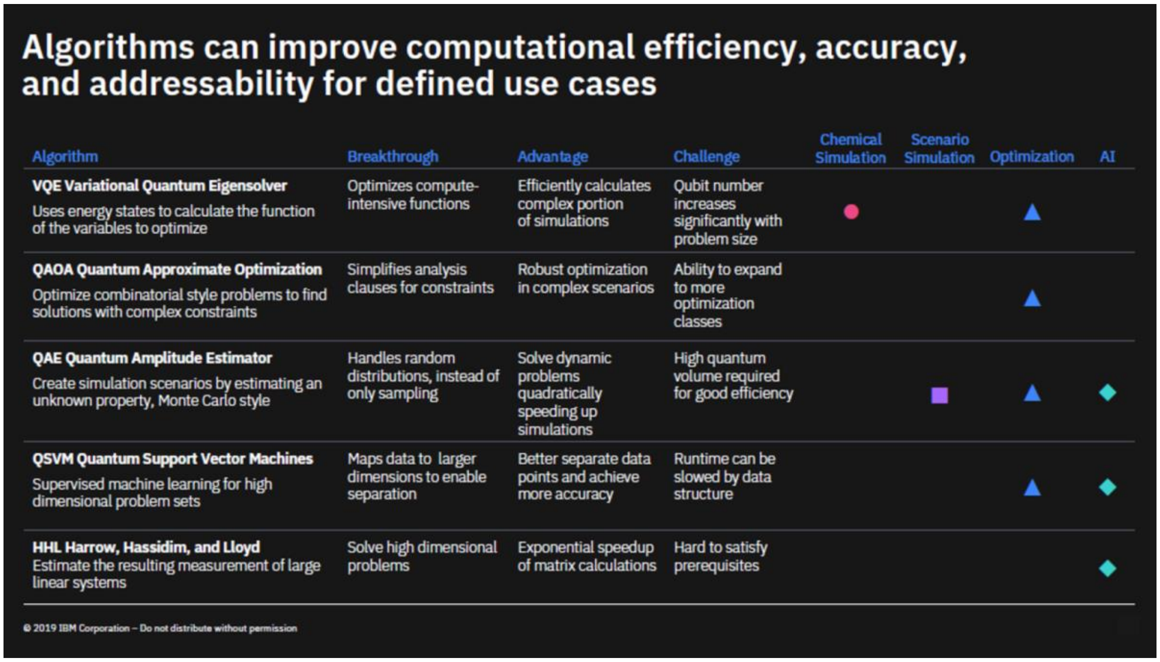
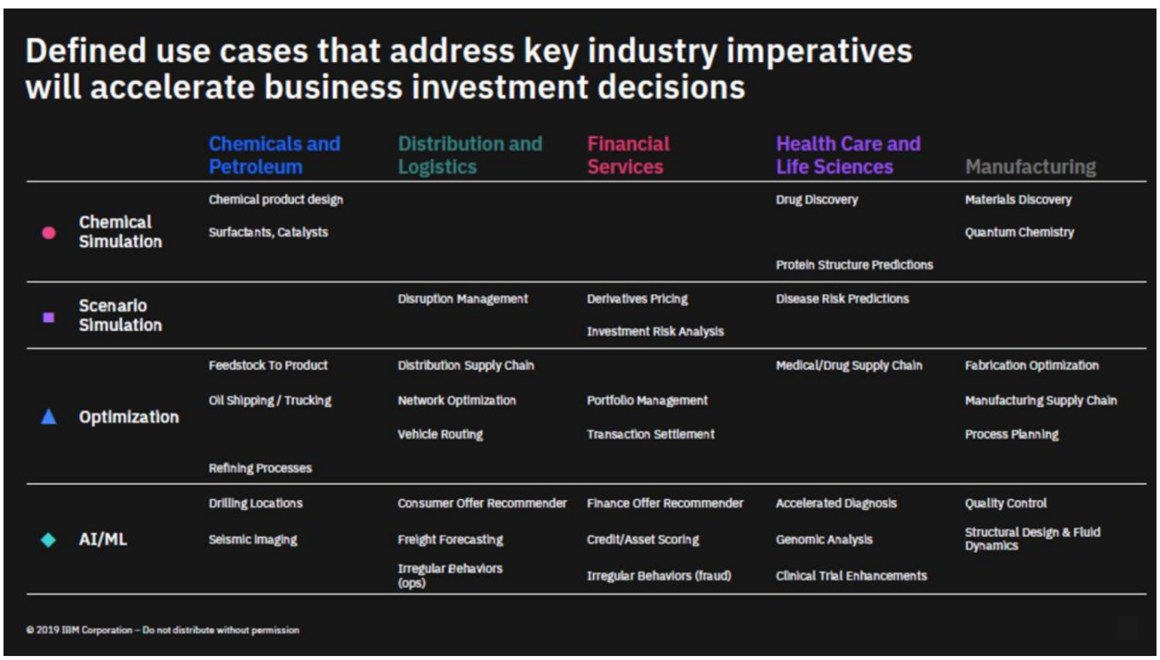
Business impact of quantum
Source: quantumcomputingreport.com



Algorithms can improve computational efficiency, accuracy, and addressability for defined use cases

Algorithm	Breakthrough	Advantage	Challenge	Chemical Simulation	Scenario Simulation	Optimization	AI
VQE Variational Quantum Eigensolver Uses energy states to calculate the function of the variables to optimize	Optimizes compute-intensive functions	Efficiently calculates complex portion of simulations	Qubit number increases significantly with problem size	●		▲	
QAOA Quantum Approximate Optimization Optimize combinatorial style problems to find solutions with complex constraints	Simplifies analysis clauses for constraints	Robust optimization in complex scenarios	Ability to expand to more optimization classes			▲	
QAE Quantum Amplitude Estimator Create simulation scenarios by estimating an unknown property, Monte Carlo style	Handles random distributions, instead of only sampling	Solve dynamic problems quadratically speeding up simulations	High quantum volume required for good efficiency		■	▲	◆
QSVM Quantum Support Vector Machines Supervised machine learning for high dimensional problem sets	Maps data to larger dimensions to enable separation	Better separate data points and achieve more accuracy	Runtime can be slowed by data structure			▲	◆
HHL Harrow, Hassidim, and Lloyd Estimate the resulting measurement of large linear systems	Solve high dimensional problems	Exponential speedup of matrix calculations	Hard to satisfy prerequisites				◆

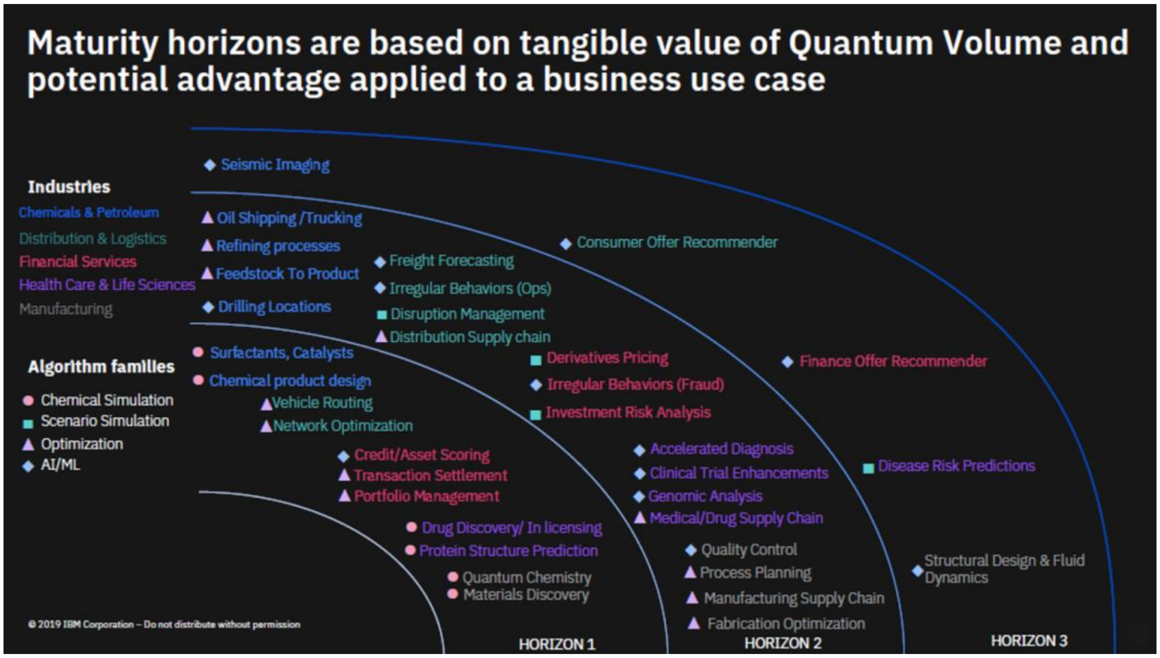
Algorithms for defined use cases.
Source: quantumcomputingreport.com



Defined use cases that address key industry imperatives will accelerate business investment decisions

	Chemicals and Petroleum	Distribution and Logistics	Financial Services	Health Care and Life Sciences	Manufacturing
● Chemical Simulation	Chemical product design Surfactants, Catalysts			Drug Discovery Protein Structure Predictions	Materials Discovery Quantum Chemistry
■ Scenario Simulation		Disruption Management	Derivatives Pricing Investment Risk Analysis	Disease Risk Predictions	
▲ Optimization	Feedstock To Product Oil Shipping / Trucking Refining Processes	Distribution Supply Chain Network Optimization Vehicle Routing	Portfolio Management Transaction Settlement	Medical/Drug Supply Chain	Fabrication Optimization Manufacturing Supply Chain Process Planning
◆ AI/ML	Drilling Locations Seismic Imaging	Consumer Offer Recommender Freight Forecasting Irregular Behaviors (ops)	Finance Offer Recommender Credit/Asset Scoring Irregular Behaviors (fraud)	Accelerated Diagnosis Genomic Analysis Clinical Trial Enhancements	Quality Control Structural Design & Fluid Dynamics

Use Cases That Address Key Industry Imperatives
Source: quantumcomputingreport.com



Maturity Horizons

Source: quantumcomputingreport.com

D-Wave and NEC have launched a quantum hybrid computer service named “Leap” and they are promoting “Leap 2” which be released in 2020. Leap 2 will offer customers with access to their 5000-qubit annealing machine “Advantage” and a hybrid approach to solving complex problems. [H] Googles 53-qubit universal quantum computer ‘Sycamore” set a record in October 2019 by solving a complex problem in minutes which experts estimated would take the best supercomputer 10,000 years to solve. [H] Despite the recent progress with quantum computing challenges with noise, stability, and temperature still exist. However, government funding has increased on a global scale and with an investment well over $12B it is clear the world sees the value and potential of quantum computing. [H] As breakthroughs and discoveries occur and use cases demonstrate the application of the technology the private sector will become more involved and invest heavily as the risk is reduce.

Analytic Confidence

The analytic confidence for this estimate is *moderate*. Sources were mostly reliable and corroborated one another. There was adequate time, but the analyst worked independently using a semi-structured method.

Author: Patrick Lancaster

Annex K
Quantum Computing Patents

Source: https://patentscope.wipo.int/search/en/search.jsf

Data was pulled on 17/10/19. A total of 5,512 patent applications were analysed when inputting DE:("Quantum computing")

Applicant	Number of patent applications
Microsoft Corporation	425
Elwha LLC	332
D WAVE SYSTEMS INC	307
INTERNATIONAL BUSINESS MACHINES CORP	296
Intel Corporation	242
Northrop Grumman Systems Corporation	143
GOOGLE INC	125
Marvell Technology Group	118
HEWLETT PACKARD CO	87
Kabushiki Kaisha Toshiba	52
NVIDIA CORP	49
President & Fellows of Harvard College	48
RIGETTI & CO INC	46
Massachusetts Institute of Technology	45
The Boeing Company	45
ELEMENT SIX (UK) LIMITED	33
SOURCE PHOTONICS (CHENGDU) CO, LTD	32
QUCOR PTY LIMITED	28
The Regents of the University of California	25
ELLIS FRAMPTON E	24
SAMSUNG ELECTRONICS CO LTD	23
Bank of America Corporation	22
PsiQuantum Corp	22
Royce A Levien	22

Application year	Number of patent applications
1998	12
1999	22
2000	27
2001	74
2002	109
2003	157
2004	212
2005	255
2006	247
2007	202
2008	254
2009	186
2010	169
2011	167
2012	287
2013	353
2014	350
2015	432
2016	581
2017	619
2018	558

Annex L
Ookla 5G World Map

The interactive Ookla 5G Map tracks 5G rollouts in cities across the globe. Updated weekly from verified public sources and Ookla data. [@Ookla5GMap]

GLOBAL 5G STATISTICS	
5G Deployments	7292
5G Operators	113

DEPLOYMENT TYPES	
☑ Commercial Availability	7077
☑ Limited Availability	17
☐ Pre-Release	197

Annex M
Background Paper on the Computer Language Initiative

Background

The Department of Defense (DoD) has a long history of recognizing the critical significance and value of enlisted and officer personnel who have secondary, non-English language proficiencies. Historically and continually, we actively seek to attract and retain personnel who, 1.) have evident aptitudes to learn foreign languages and, 2.) have existing foreign language fluencies.

The Defense Language Aptitude Battery (DLAB) is offered to measure an individual's linguistic aptitude. Recruits and existing personnel who score passing grades qualify for foreign language training and educational opportunities. Similarly, the Defense Language Proficiency Test (DLPT) is offered to measure an individual's existing fluency level in one or more identified and needed foreign languages. Those who score passing grades qualify for certain duty assignments where a specific language other than English is deemed valuable or mission critical. They also receive Foreign Language Proficiency Pay (FLPP) commensurate with their specific secondary language and with their level of fluency (as measured by recurrent annual testing, Service specific).

Justification

As our military continues to integrate the emerging technologies of the digital and information age, we must recognize the simple reality that information, of all categories and types, is increasingly created, obtained, exchanged and analyzed via computer use and computer technologies. Consequently, the languages of computers themselves—computer languages—are as critically significant to the needs of the DoD as any other non-native languages. Languages like Python, Java, and C++ each have their own unique vocabularies and sets of grammatical and construct rules just like any other.

Currently, however, none of the testing or incentivized pay programs outlined above measure or reward individuals who have proficiency or fluency in any computer language at scale. We need to correct that holdover from an earlier analog age, and we need to do so quickly. It is mission critical, across the entirety of the DoD.

Way Forward

By taking the step of formally recognizing computer languages as future and functional equivalents of all other human language, the DoD will signal to the world that we not only understand the changing realities of the information age, but that we are also at the forefront of cultural and operational modernization. It will signal to prospective recruits and existing personnel that our Department will always value our human element and that we will always provide dynamic and contemporary career opportunities. It will signal to the country's private sector that the DoD is no longer steeped in industrial-age constraints and can be counted upon as a contributing innovative partner. Most importantly, it will help us cultivate and better manage our greatest asset, our personnel.

Summary

Computer technologies of the 21st century will continue to advance and alter our methods of organizational and cultural operation. As a basic matter, we should identify and incentivize those amongst us who can fluently speak the operative languages of our changing times. The benefit to this initiative is that it is innovation in the organizational construct – we just require a paradigm shift to manage and treat computer languages commensurate to human languages.

Annex N
Academic Reasoning for the Computer Language Initiative

Framing

"The limits of my language mean the limits of my world." *Ludwig Wittgenstein—circa, 1940*

History of Language

Development of written languages, alphabet-based in particular, gave humans the ability to efficiently share information on a much grander scale than was ever before possible. This innovation not only allowed for humans to share across generations, but also across cultures, and thus accelerated the collective learning capacities of our societies at exponential speed.

Definition

Written language is any structured, rules-oriented system for constructing words and combinations of words into sentences to communicate information to an individual literate in that language. The information that can be communicated through writing is as limitless, or limited, as the language allows:

Semantics

The meaning of individual and combined words.

Syntax

The rules and constructs that govern the combining of those words into grammatical sentences—and through which words and phrases can acquire varying contextual and infinitely refined meanings.

Changing Paradigms

Traditionally, our human languages are used to exchange information directly from one human being to another. But when circumstances or efficiencies dictate, we routinely employ artificial interpreters as intermediaries.

It's also worth noting that, to an extent, this computer language initiative is nothing categorically new. Non-human devices have long been utilized. Aboriginal drums, American Indian smoke signals, 20th century telegraph machines, televisions, and cell phones are all examples of devices that were or are employed to accomplish efficient or mass means of disseminating information where distance, space, time, or practicality prevent direct communication.

Summary

The languages of computers themselves (constrained languages) are the means through which humans empower and instruct a computer to perform a task. Those purposes are clearly becoming more expansive, particularly in the sphere of artificial intelligence (AI) technologies and machine learning (ML) applications. While computer languages will never be a human's native language, none can argue that in today's computer driven age of information, these languages are becoming extraordinarily useful as, essentially, true secondary language skills.

It is worth recognizing that computer languages are, for all intents and purposes, legitimate languages unto themselves. In our 21st Century reality, computer languages now arguably facilitate and enable the spread and sharing of human information more efficaciously than any other existing languages, whether spoken, written, or both.

Annex O
Telephone Conversation between Lt Col Louis Duncan and Michael Kanaan, MIT on 19 Mar 20

This afternoon I met virtually with Michael Kanaan, the AF embed with the MIT artificial intelligence (AI) accelerator, to get his take on AI over the next 10-15 years...

Here is a summary of our discussion:

Mike helped kickstart the JAIC in the Pentagon and was the author of President Trump's AI strategy. He has worked across all the services to educate senior leaders on AI.

I asked Mike if he was king for day, what AI things would he go after for the next 10-15 years....

1) People--
Mike stated DOD "DOES NOT HAVE THE AI to know how to use it, bottom-line!"

He said the AF did a self-assessment last year of young airmen who had pre-AI software writing skills and had some level of understanding of software tools such as GitHub, Python, etc. and found 3100 enlisted airmen with this ability.

So, to get at the AF's issue of not having AI expertise, they are going to screen for people that have the aptitude, just like you do with a foreign language. He said Airmen with pre-AI skills have shown in studies to have similar brain activity as those that are fluent in multiple foreign languages).

He has convinced the AF to contract with AI firms to provide an 18 week class to these airmen, and will turn these airmen into AI technicians. They will own the digital roadmap for the AF (eventually). He said we must do this because our big defense contractors like Lockheed don't have the AI experience either and will not be able to carry the Department of Defense into the future without our help.

He said our weapon system KPPs should express what programming language the system should operate on. This is the only way DOD will be able to go fast in the FUTURE. Joint multi-domain operations require this level of understanding to create a flexible digital architecture.

2) He mentioned FY2020 NDAA language that he helped Congress draft that basically speaks to creating an organic Department of Defense digital/computer science workforce.

Specifically, “Section. 230 of the NDAA, Policy on the Talent Management of Digital Expertise and Software Professionals, purposefully includes the words incentivization, aptitude, and proficiency to treat these skills commensurately to language, measure them, and implement it as such.”

3) Third, he said DOD leadership is working through how to trust AI to operate any kind of weapon system. This is mainly because the leadership doesn't understand it (mainly because of the lack of skills in AI--see #1, compounded by contractors we hire that also don't understand it necessarily). He said the best place for all the services to start is on benign projects, such as implementing AI in the dental clinic, travel, and logistics. This would warm up DOD to AI concepts until the workforce is developed. He said the same AI tools you use for automating scheduling at the dental clinic and travel would be the same as those for operating advanced sensors on platform or driving an autonomous tank. Other options to warm up DOD to using AI for weapon systems would be to create digital twins and adversarial neural networks, to help people get comfortable with the results of what's in the “black box.”

4) Fourth, he said if you really wanted to do something meaningful near-term, is to use AI to wargame scenarios against our peer competition--using adversarial neural nets and reinforcement learning. This could easily be done with organic expertise and within the five-year timeframe using Earth AI and Google DeepMind gaming technology. He said we could crowdsource different solutions that would feed our adversarial neural networks. He said they started down this path with DeepMind before Google changed their mind about helping DOD.

Annex P
Telephone Conversation between Lt Col Louis Duncan and Dr. Thomas Longstaff, Carnegie Mellon on 12 Mar 20

Summary of the interview with Dr. Thomas Longstaff, Carnegie Mellon Software Engineering Institute, Chief Technology Officer, regarding the future of Artificial Intelligence.

1) Currently, the general population, military, and businesses are dabbling in supervised learning AI currently (not a game changer)--his words, "This is where the game is being played right now."; supervised learning is very time intensive due to data labeling but is fairly accurate.

2) Unsupervised learning is the future. It does not require a lot of human intervention because it does not require massive amounts of data labeling.

Methods:

- One shot learning--teach the machine a model and let it start learning on its own; currently happening within big tech companies; great at looking at complex patterns and solving problems; currently being used in material science to come up with different composites.

- No shot model--machine requires a general set of rules and it learns on its own; will see this widespread in about a decade; also great at looking at patterns and solving complex problems better than humans

- Reinforcement model--machine requires general set of rules, learns by being right and typically paired with adversarial neural networks; currently being used in big tech companies (can usually beat most humans playing cognitive/thinking games).

- People are beginning to merge no shot model and reinforcement model--to create machines/computers that continually teach itself new skills. He said in the very near future (10-15 years), you could deploy this into a city grid, and the computer could possibly understand everything.

Also, he said this combination of no shot and reinforcement learning would make future weapon systems with advanced sensors extremely intelligence and adaptive to their environment.

Other key points:

- The services are good at acquiring things, not understanding how to systems engineer something like the reinforcement learning + no shot model. His recommendation is the

Army should invest the systems engineering to develop the enterprise AI architecture to reap the greatest benefit. Otherwise, they will just focus on AI system by. He who owns the architecture wins (material science, security, intelligence, they all become interconnected).

- Neuromorphic chips will be needed to make this architecture work (and will be critical for weapon systems--but he emphasized we must know how to architect the integration between these systems to maximize machine learning at the enterprise level).

Annex Q
Competing Hypothesis

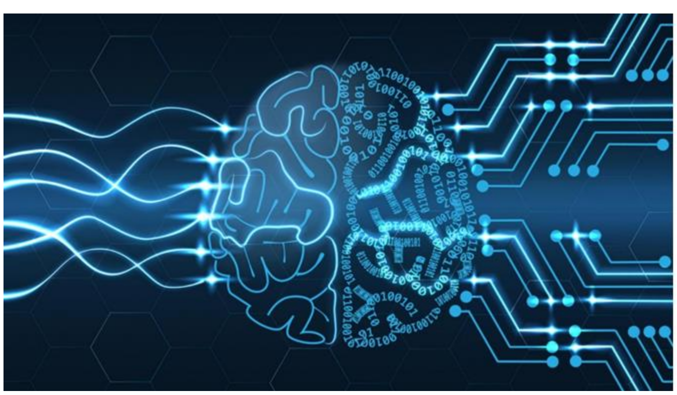
Executive Summary

While there is no issue with Mad Scientist Fellow conclusions, there are alternating and competing hypotheses on how these technologies will converge. Among those, and of primacy, are that of the eight technologies there is an order of importance, as enablers for other technologies; without these technologies, the others are unlikely and impossible. Secondarily, the physical nature of the possible is less important than the possibilities of within the virtual. The virtual aspect of the future leads the possible. However, the US Army War College requirement for graduation and course completion drove methodology, specifically, network analysis, or modified Millhone, for convergences, that competed with student research and analysis. There is NO ARGUMENT, though, that the convergences will drive the outcomes described here within, only that some are key enablers for others. Furthermore, once key enablers emerge, previously never-before-considered technological concepts become available. As cloud technology was never considered before the advent of computers, the additions of AI, 6G wireless capability, and 25, 50, and 100G PONs (US and China developments) change the nature of the possible.

Discussion

Of the Mad Scientist Fellows, those responsible for research in AI, IT, Quantum Technologies, and Autonomous Technologies agree that the convergences presented herein are likely, or highly likely (as presented), but that for those convergences to take place, some technologies are more important than others as key enablers. Fundamentally, these researchers find AI, IT, and Quantum as key enablers, and without the three, none of the rest come to fruition.

The rest is considered as fundamental to these three Mad Scientist Fellows, though beyond the scope of the US Army War College requirements, and beyond the scope of the



Rendering of the importance of the real, translated first in AI and then into the virtual or digital system, demonstrating the primacy of first thinking, then architecture, and only then, capability.

Source: digitalparamfreelancer.blogspot.com question, as requested by Mr. Greco, as leader of the Mad Scientists, and executive representive of US Army Training and Doctrine Command:

AI Architecture construction is of the utmost primacy. Without it, the rest of the convergences cannot exist. The need to construct the virtual cannot be overstated as the world moves out of the information age and into the virtual age. Whether on the cloud, or whether edge computing, or both, these two enable all things. The construction and design, readying the system for appropriate levels of AI and autonomy, matters the most, frankly. First and foremost, the purposeful vision and employment of AI will drive the rest of all infrastucture designment and implementation.

Conceptualization, showing the virtual strategy enabling the physical strategy, impacting global strategy. (source is highlighting a perpetual state of cyber warfare—if cyber capabilities are magnified, the outcome becomes invariably more problematic).
Source: securitybrief.co.nz

Quantum technology is equally important. However discoveries make it *slightly* less important. For example, quantum simulation accelerates computing speeds, despite not reaching quantum computing capability. That being stated, the raw capabilities of quantum computing, adding a magnitude of magnitudes for speed and capacitance, are absolute key enablers. These are fundamental to deep research and large-scale fielding of some convergences. Adding to these, quantum sensing, quantum encryption, and quantum communication, mitigates all competitors that do not have technical match. Furthermore, no technology exists for overmatch on these capabilities, which make GPS, among other technological capabilites unnecessary, or even obsolete. Finally, the speeds may drive irrelevance.

Finally IT is the backbone and even nervous system upon which an entire system can thrive. How vibrant, strong, and capable that backbone is, which will enable the Internet of Things, the Internet of Automated Things, and such capabilities. 3-D holography being enabled in homes, operations centers, command posts, and crises management headquarters is unprecedented. The levels of bandwidth and speeds that become available by 2035 are impressive and game-changing, to say the least. The importance of IT cannot be over stated. Without the capacity, capacitance and speed capabilities, robotics and some nano and neuro technologies are not possible. Finally, it is of critical importance to note that other, less responsible nations (with respect to biotechnology, specifically, among other capabilities) will have double the capacity that the United States, as leader of free-nation technological capability, will possess.

Beneficial technological achievements, only advanced by AI, IT, and Quantum capabilities, or further limited without them. 2018 US Government Accountability Office's National Security Long Range Emerging Threats Facing the United States as Identified by Federal Agencies.
Source: [gao.gov](gao.gov)

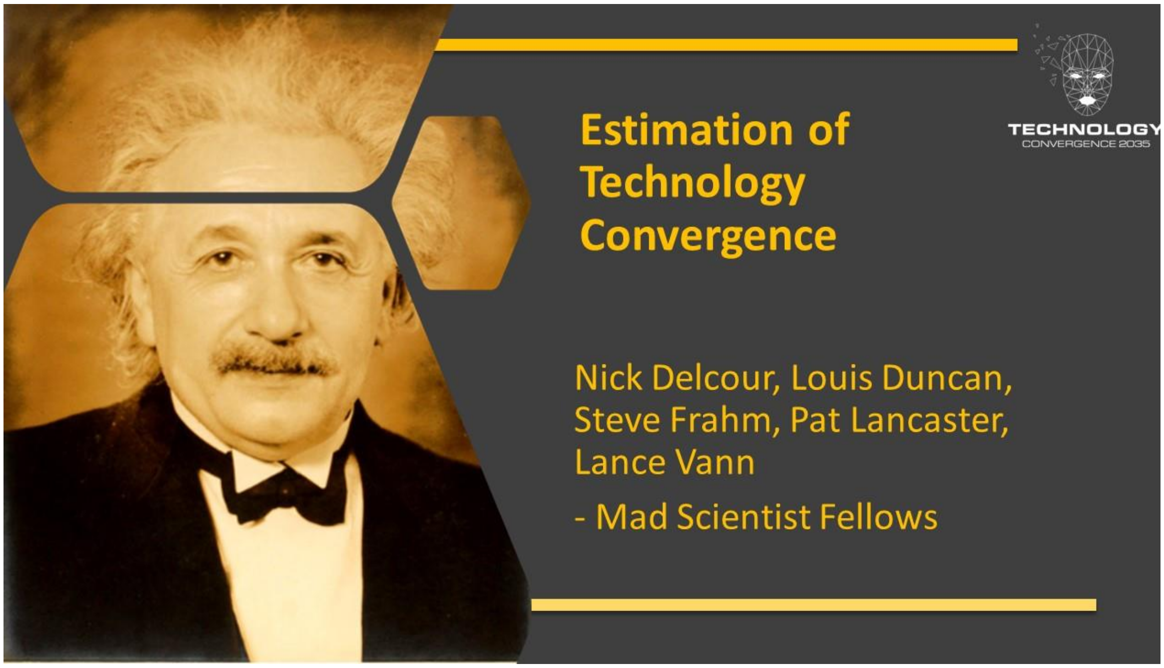
The clunky nature of robotics, including many moving parts (hydraulics, electrical actuation, etc.) can illustrate multiple vulnerabilities, not only to mal actors, but natural elements. While robotics are important in high level convergence, the physical restrictions associated to the technology are visually evident, vice the virtual capabilities of the AI, IT, and Quantum driven technological advancements and convergence. Clearly, the physical is driven by the virtual.
Source: [independent.co.uk]

These three technologies, listed in order of importance and need, will drive neurotechnology, nanotechnology, and robotics (autonomy is threaded throughout). For top level convergences, these three matter the most, vice convergences of all eight technologies. While many technologies can and will converge throught the next 15 years, and beyond, those will matter less, than when sophisticated AI, with baked-in architecture and distributed, unsupervised machine learning, on 25G, or even 50G (watch mal-actor nations), passive optics networks, driven by 6G capabiity. When these come to fruition, it is, intuitively only, likely that previously undreampt of capabilities will come to light, and then be fielded very quickly. These three equate to the genie in the bottle.

The virtual is the magnifier and/or disruptor, according to these three researchers, vice the convergence. The capability must be inherent within the virtual capability (AI strategy), as opposed to expensive, untested, unnecessary, and uncertain (ethics and regulations) battlefield robotics, which drive only the poorest tacticians temporarily, until overmatched.

Author: Louis Duncan, Pat Lancaster, and Nicholas E. Delcour

Annex R
Briefing Slides



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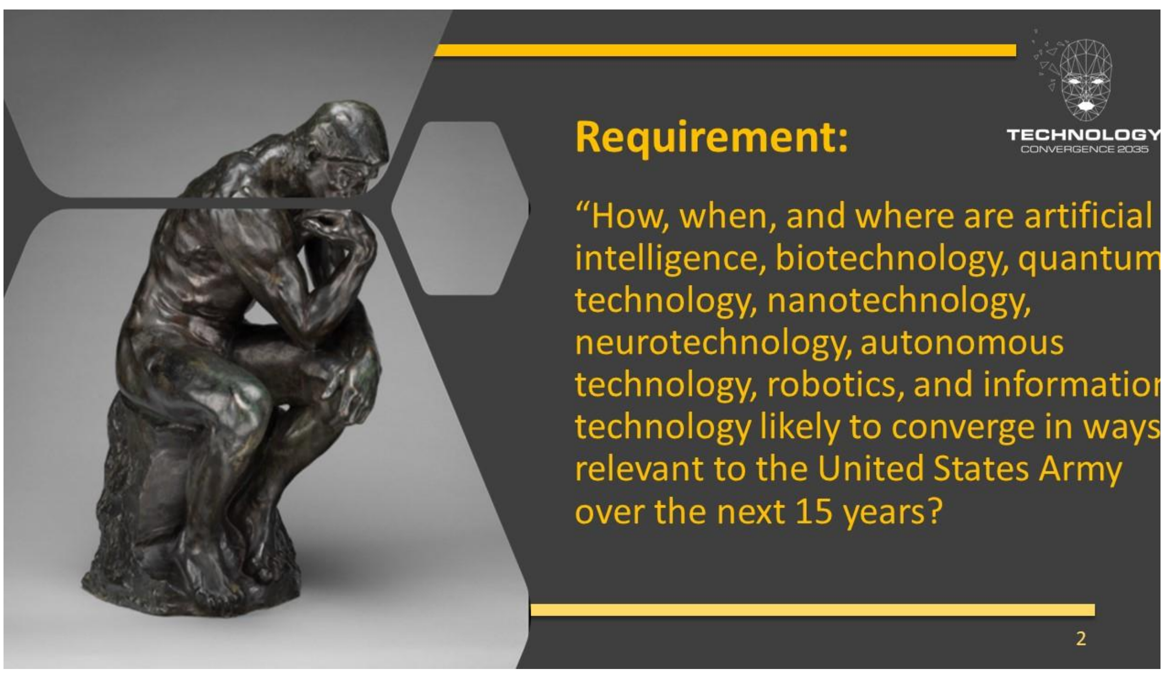

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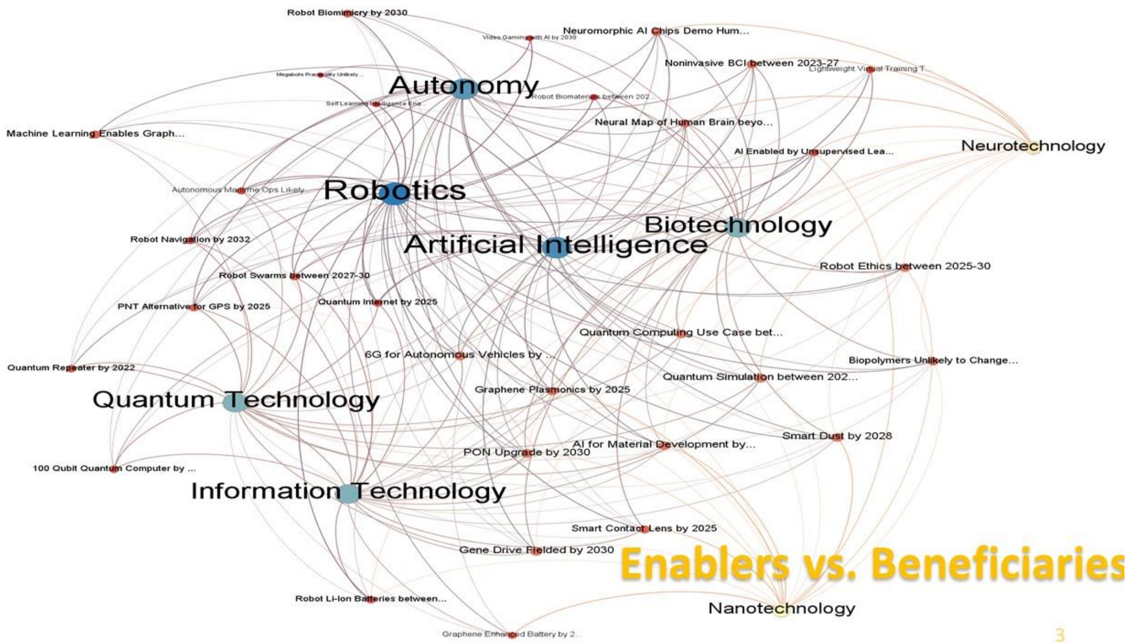

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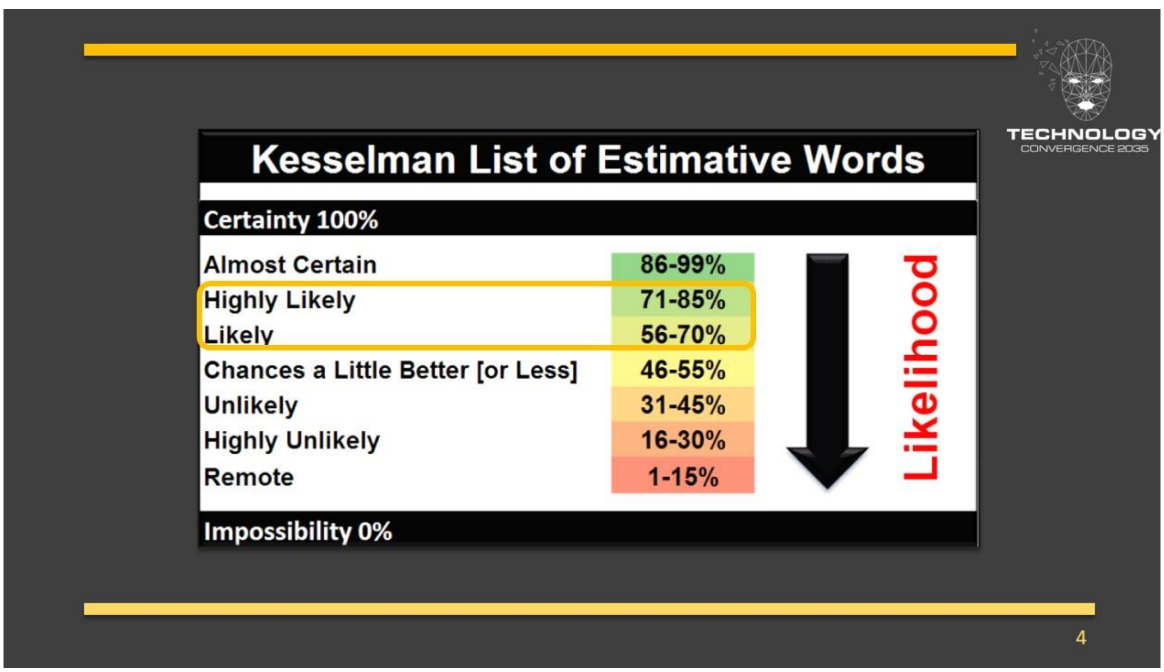

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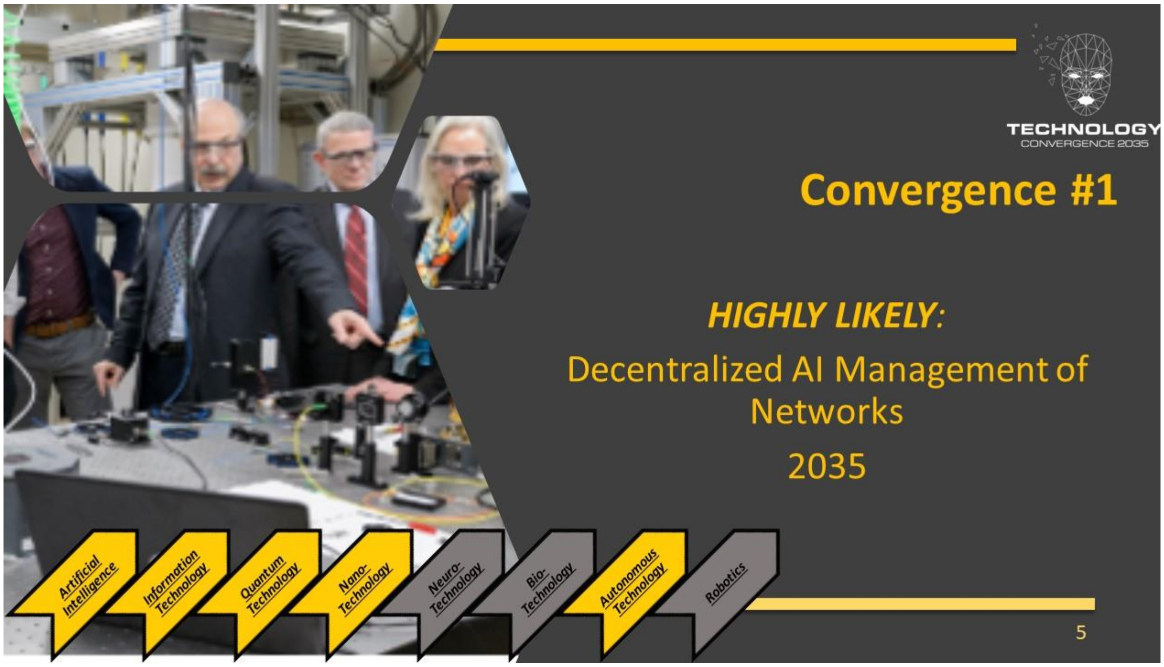

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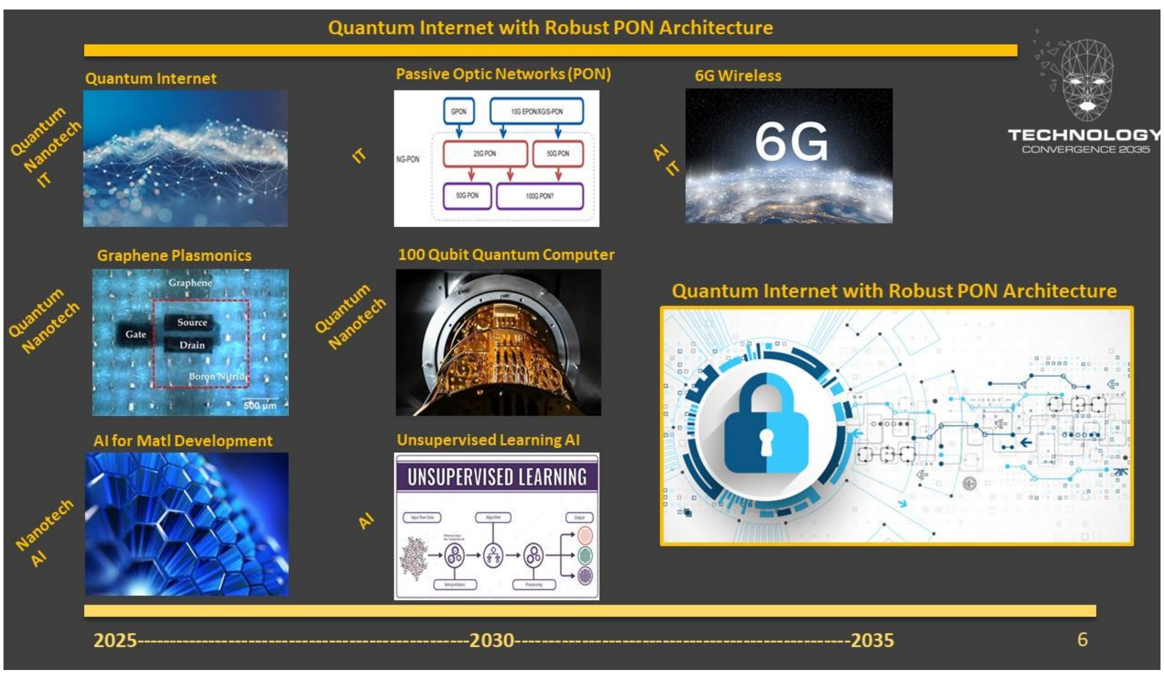

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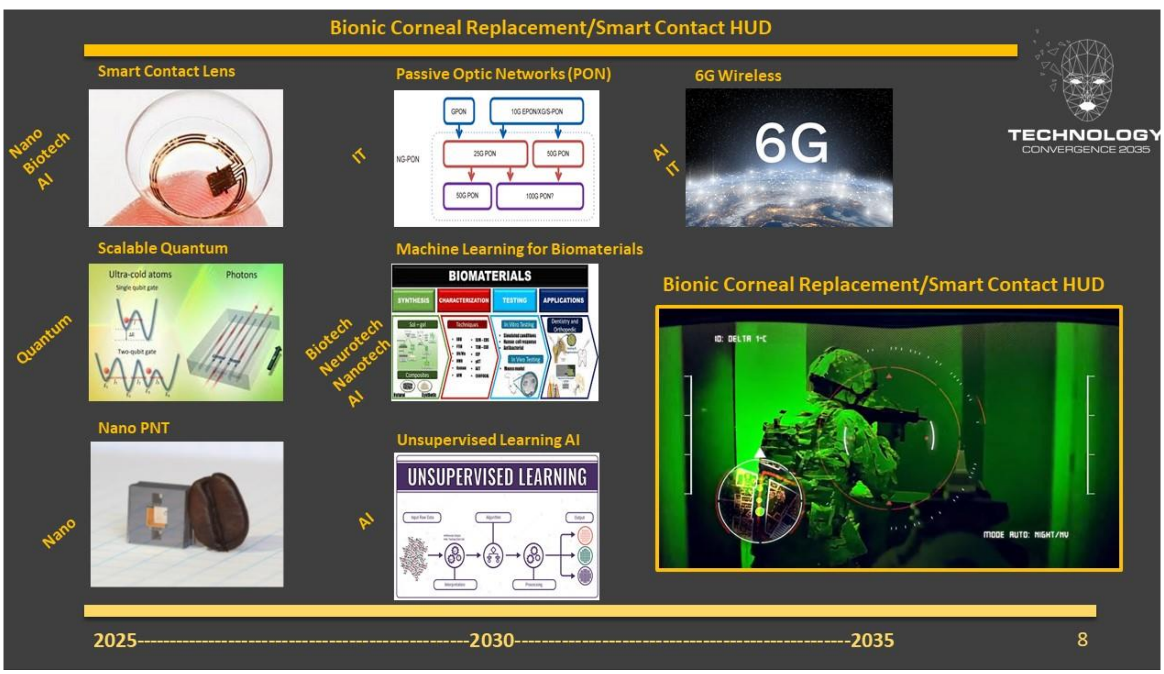

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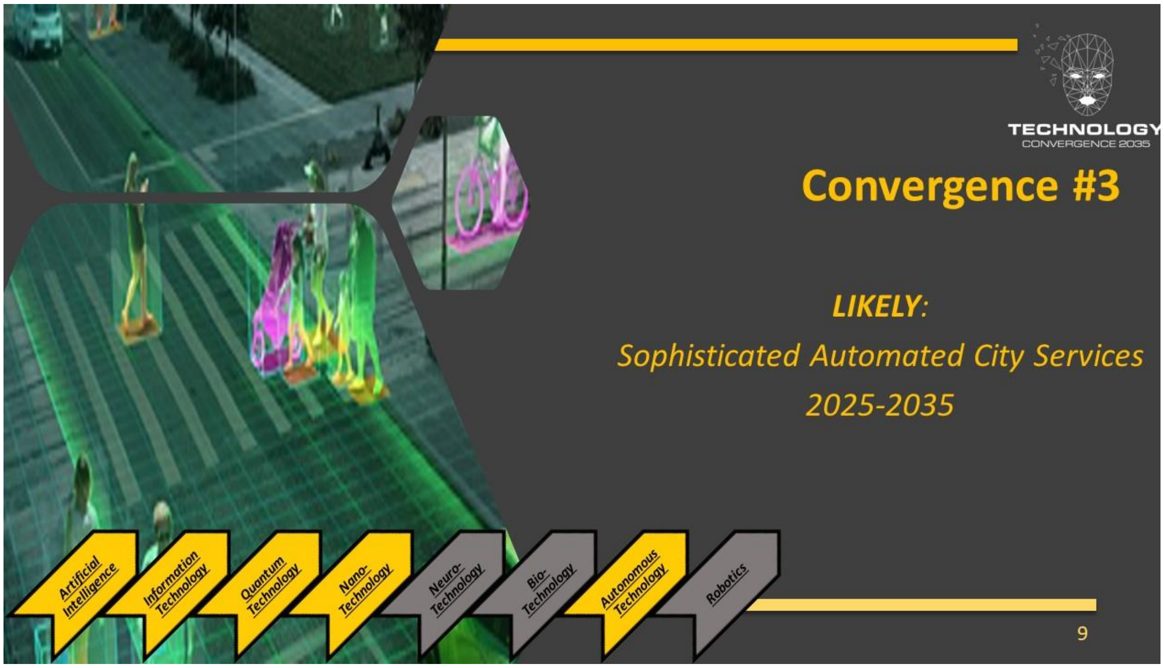

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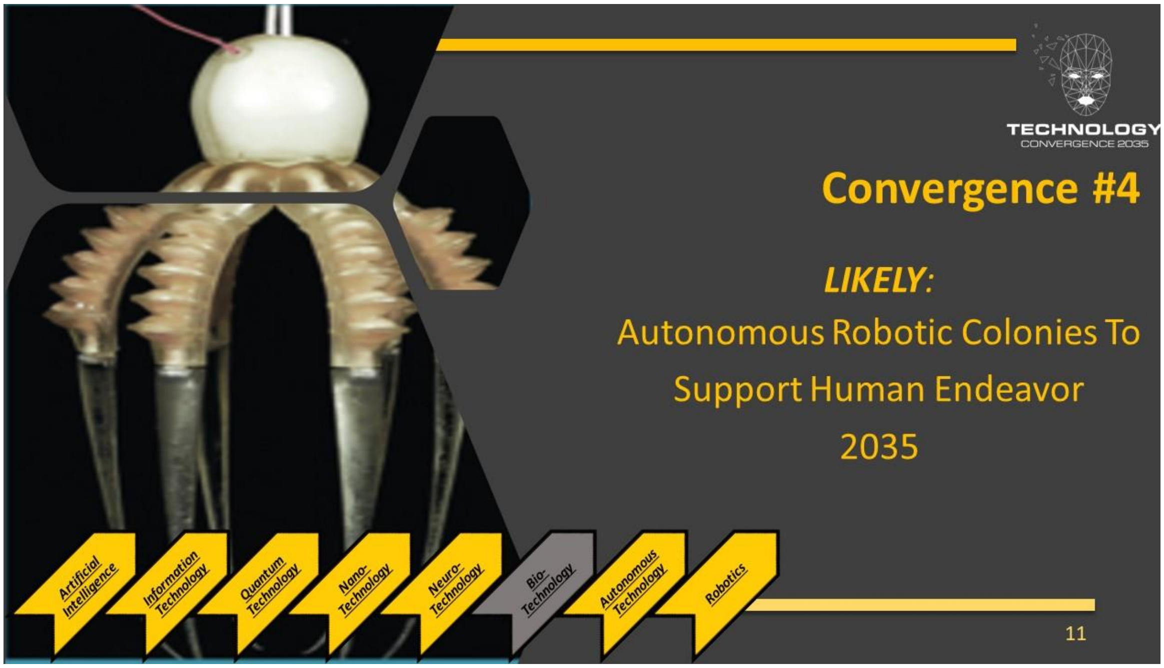

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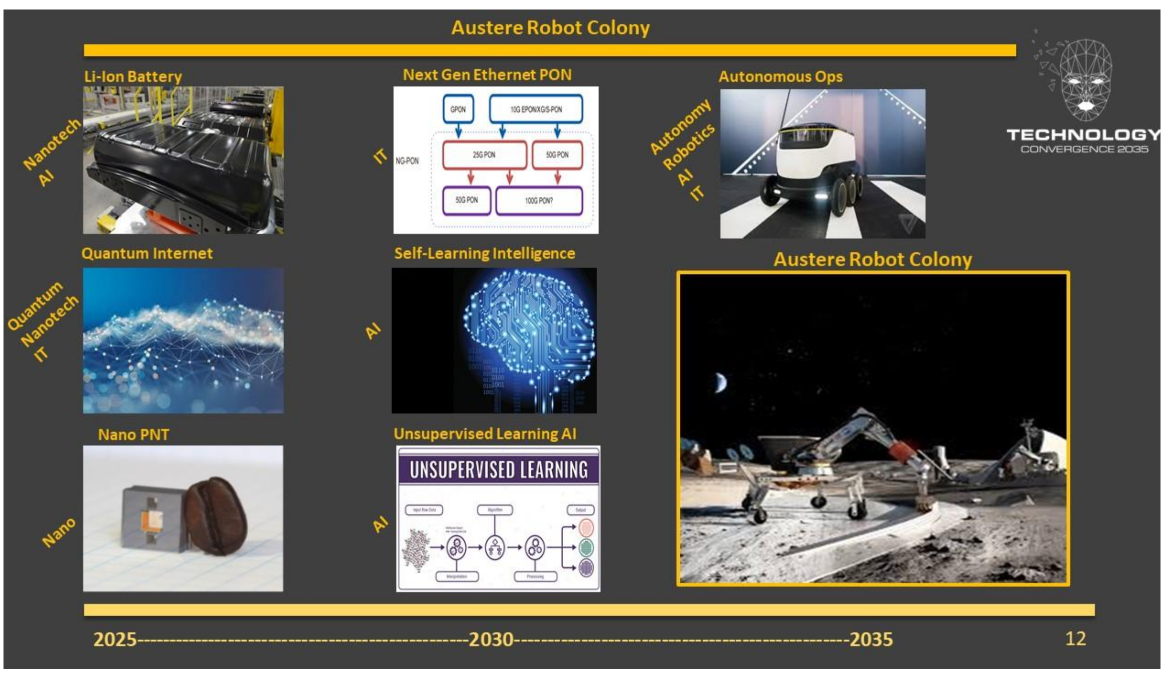

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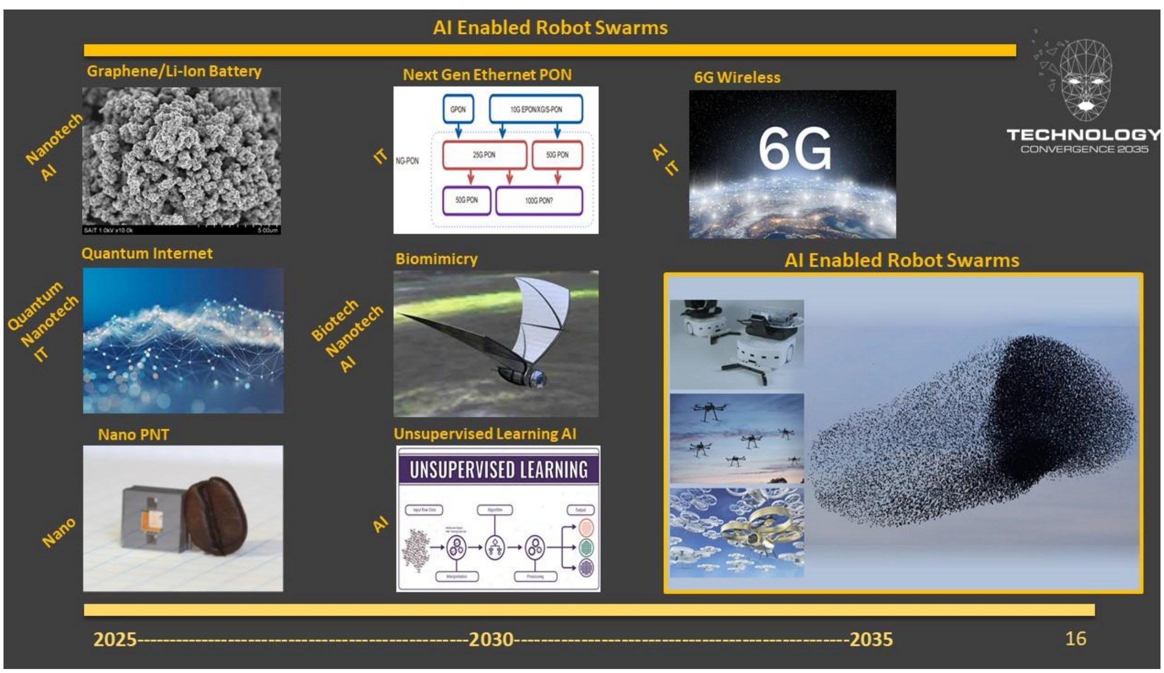

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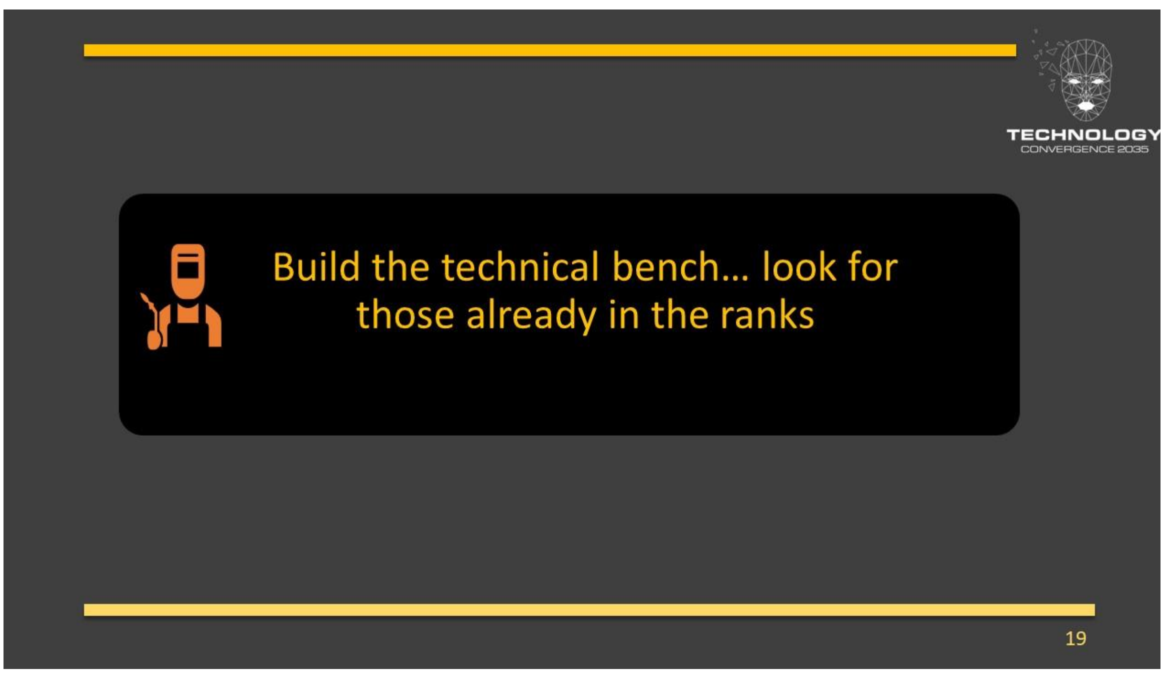

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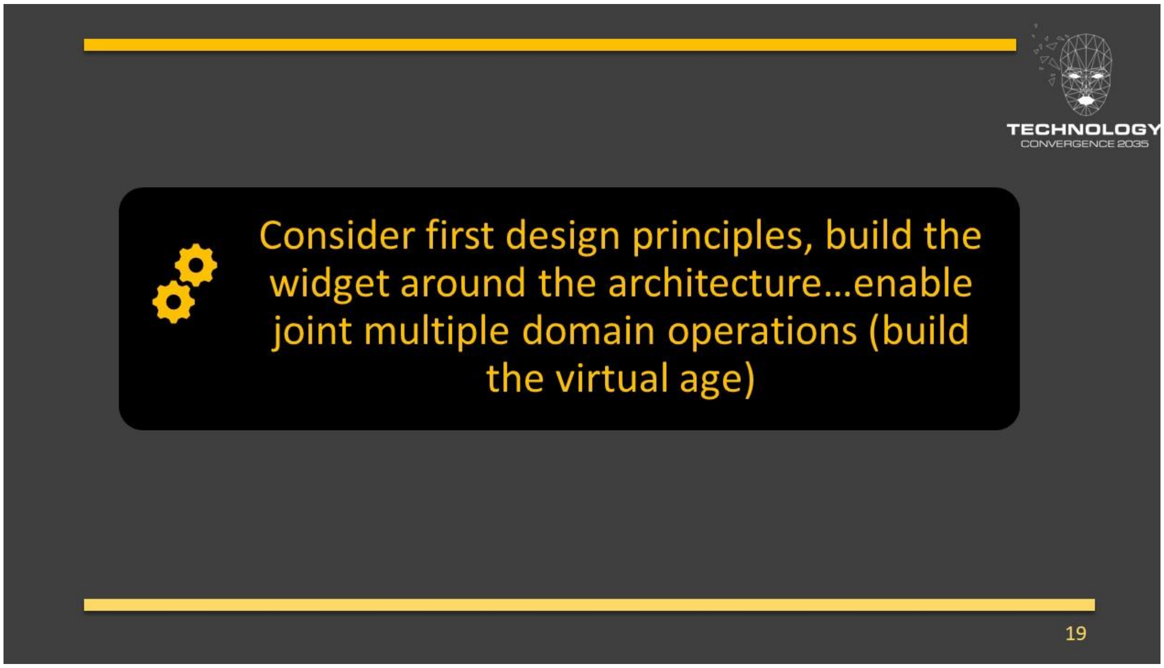

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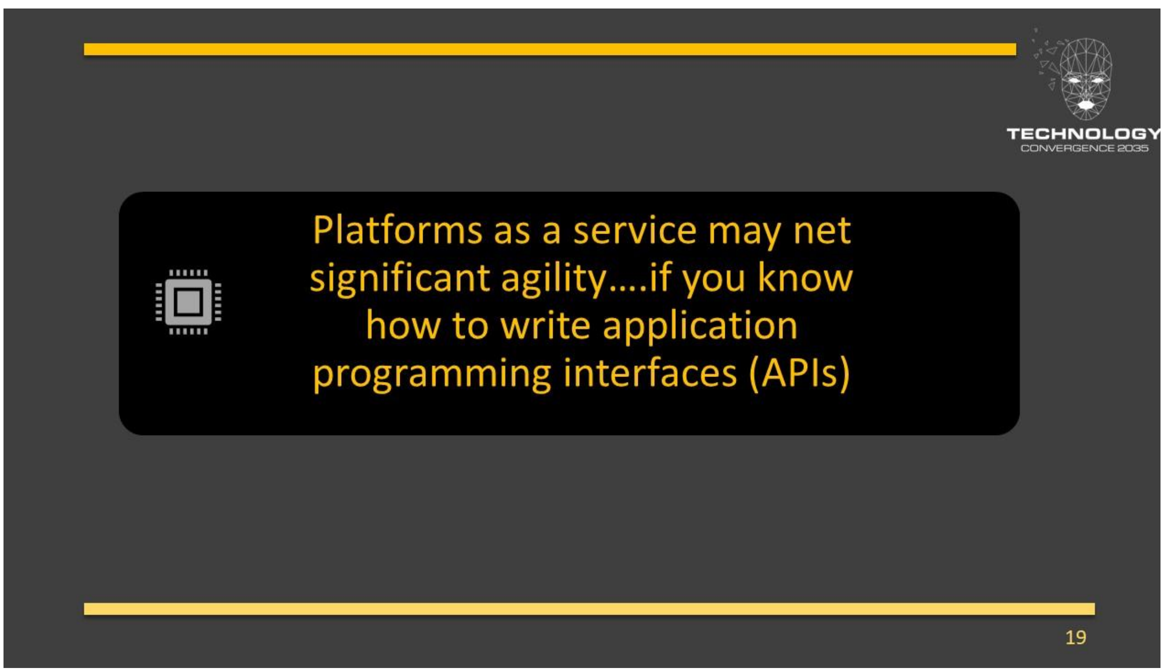

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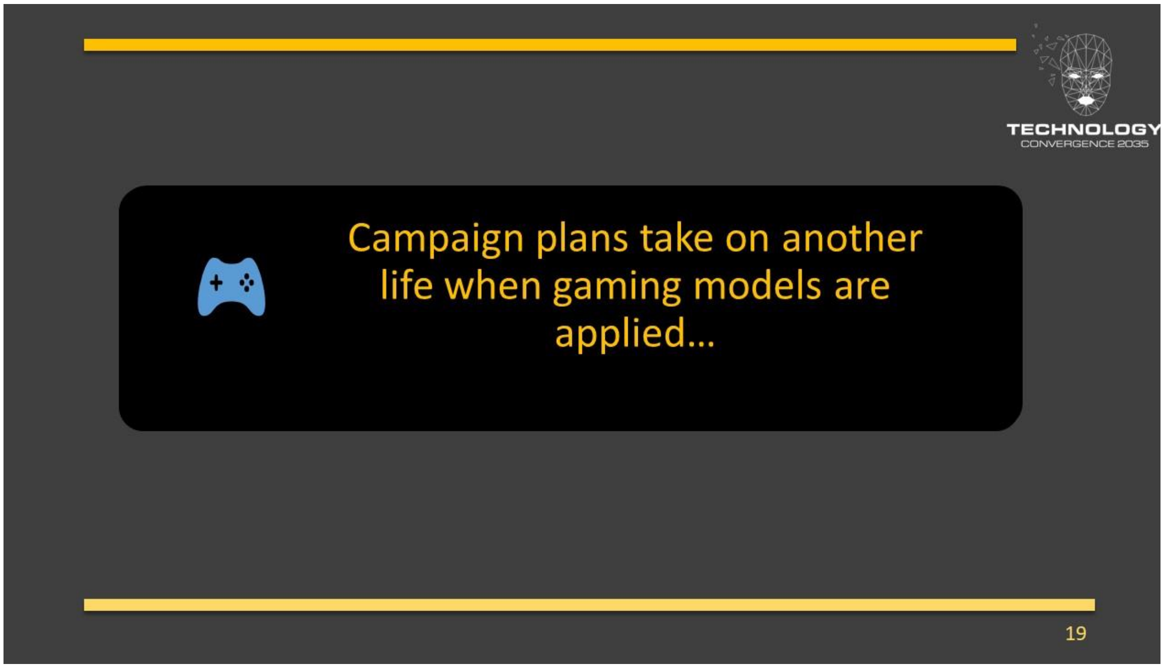

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As all these results were obtained, not by any heroic method, but by patient and detailed reasoning, I began to think it probable that philosophy had erred in adopting heroic remedies for intellectual difficulties, and that solutions were to be found merely by greater care and accuracy.

Bertrand Russell

It is astonishing how many men lack this power of 'holding on' until they reach the goal. They can make a sudden dash, but they lack grit. They are easily discouraged. They get on as long as everything goes smoothly, but when there is friction, they lose heart. They depend on stronger personalities for their spirit and strength. They lack independence or originality. They only dare to do what others do. They do not step boldly from the crowd and act fearlessly.

Dr. Theodore Cuyler

Because your own strength is unequal to the task, do not assume that it is beyond the powers of man; but if anything is within the powers and province of man, believe that it is within your own compass also.

Marcus Aurelius