Accelerating Performance with the Artificial Intelligence of Things

Author:
Jane Howell
Global IoT Product Marketing Leader
SAS
Jane.Howell@sas.com

AI + IoT – A Superhuman Accelerator of Business Performance

Some technologies are inevitably bound together. Artificial intelligence (AI) and the Internet of Things (IoT) are a perfect example of two technologies that complement one another and should be tightly connected.

In the fast-growing world of IoT, which connects and shares data across a vast network of devices or "things," organizations win with analytics. For its ability to make rapid decisions and uncover deep insights as it "learns" from massive volumes of IoT data, AI is an essential discipline within analytics for any organization that wants to expand the value of IoT.

This paper explores how AI and IoT analytics (that is, the artificial intelligence of things, or AIoT) work together to create new value for organizations across a broad spectrum of industries – from manufacturers and retailers to energy, smart cities, health care and beyond.

The Impressive Growth of Connected Things

In 1982, a modified Coke machine at Carnegie Mellon University became the first connected smart appliance, able to report its inventory and whether newly stocked drinks were cold.[1] Fast forward a few decades, and we are living in a world where there are more connected things than humans. Business Insider Intelligence projects that there will be more than 55 billion IoT devices by 2025, up from about 9 billion in 2017.[2]

The rapidly expanding IoT extends connectivity and data exchange across a vast network of portable devices, home appliances, vehicles, manufacturing equipment and other things embedded with electronics, software, sensors, actuators and connectivity. From consumer wearable devices to industrial machines and heavy machineries, these connected things can signal their environment, be remotely monitored and controlled – and increasingly, make decisions and take actions on their own.

IoT is everywhere. It is a home automation system that detects changing conditions and adjusts the thermostat or lighting. It is production equipment that alerts maintenance technicians to an impending failure. Or an in-vehicle navigation system that detects your speech recognition to interpret commands. Commercial fleets

[1] Browning, Daniel. IOT Started with a Vending Machine. Machine Design. July 25, 2018 https://www.machinedesign.com/industrial-automation/iot-started-vending-machine

[2] Newman, Peter. IoT Report: How Internet of Things Technology Is Now Reaching Mainstream Companies and Consumers. Business Insider. July 27, 2018. https://www.businessinsider.com/internet-of-things-report

equipped with dozens of sensors to communicate their status. And much more.

This ecosystem of connected devices, people and environments generates a torrent of complex data. For instance, today's cars and trucks are like data centers on wheels, equipped with sensors that can monitor everything from tire pressure to engine performance, component health, radio volume, driver actions – even the presence of obstacles or rain on the windshield. A connected vehicle puts out around 25GB of data per hour.[3] Autonomous, self-driving vehicles may put out as much as 1GB of data per second.[4]

However, being connected and exchanging masses of data is only the start to the IoT story.

Transforming IoT Data into Business and Operational Outcomes

Organizations that can capture IoT data and transform it into insight using AI will see real business value:

- Greater efficiency and productivity, as AI makes complex decisions and automates manual tasks.
- Cost reductions as AI optimizes processes to reduce marginal transaction costs.
- Higher profitability – as much as a 38 percent lift by 2035, according to Forbes.[5]
- Faster innovation life cycles, as AI makes it easier for organizations to start, scale and grow their operations.
- Better products and faster customer service, such as bots powered by speech recognition.
- Faster time to market by reducing complexity and enabling continual experimentation.

Crossing the Chasm to Collective Learning

A smart, connected device is made up of four layers:

- Physical elements such as the mechanical and electrical parts.
- Smart elements such as sensors, processors, storage and software.
- Connectivity elements such as ports, antennas and protocols.

[3] Hunt, Gordon. How Much Data Does Your Car Collect? More Than You Think. Silicon Republic. https://www.siliconrepublic.com/enterprise/data-privacy-connected-cars-infographic

[4] Mearian, Lucas. Self-driving cars could create 1GB of data a second. Computerworld. July 23, 2013 https://www.computerworld.com/article/2484219/self-driving-cars-could-create-1gb-of-data-a-second.html

[5] Columbus, Louis. Artificial Intelligence Will Enable 38% Profit Gains by 2035. Forbes https://www.forbes.com/sites/louiscolumbus/2017/06/22/artificial-intelligence-will-enable-38-profit-gains-by-2035/

- Onboard analytics, in some cases, to train and run AI models at the edge.[6] [7]

The physical components are amplified by the smart elements. The smart elements are in turn amplified by connectivity, which enables monitoring, control and optimization. But by itself, connecting things does not promote learning. It paves the way, but that is just the foundation.

At the most basic level, the data generated from IoT devices is used to trigger simple alerts. For example, if a sensor detects an out-of-threshold condition, such as excessive heat or vibration, it triggers an alert and a technician checks it out. In a more sophisticated IoT system, you might have dozens of sensors monitoring many aspects of operation.

All these scenarios add value to and from connected devices. But the real value of IoT comes at yet another level of sophistication. It happens when devices learn from their specific use or from each other and then automate actions. It happens when they can adapt, change behavior over time, make decisions, act and tune their responses based on what they learn.

For example, a model using IoT data to detect failures can push machine controls to the appropriate IoT powered actuators to reduce the possibility of failures on similar equipment. Self-driving vehicles can transmit their experiences to other cars in the network.

These capabilities are the basis for the personalization required of IoT applications:

As humans, we want to be treated individually and know that our habits, behavioral patterns and preferences are considered. For instance, think about a consumer wearable technology that monitors movements to detect signals of an impending injury in an athlete. No two humans move the same, so the application would only be meaningful with great personalization. For another example, retailers use IoT-enabled cameras for object detection along with machine learning to deliver tailored advertisements and offers to shoppers at the right moment.

As machines become more complex, they need personalization too. Two pieces of industrial equipment of the same make and models do not perform identically under different conditions and might not be used in the same way. Treating them alike misses IoT opportunities for greater operational efficiency, enhanced safety and better use of resources. For example, when producing semiconductor wafers, AIoT improves yield by determining the optimal path for wafer lots to travel during the manufacturing process. This eliminates scrap waste and optimizes product quality.

[6] IIC, Edge Computing Task Group https://www.iiconsortium.org/pdf/Introduction_to_Edge_Computing_in_IIoT_2018-06-18.pdf

[7] Aslett, Matt. 451 Research https://www.sas.com/content/dam/SAS/documents/marketing-whitepapers-ebooks/third-party-whitepapers/en/data-analytics-at-the-edge-110405.pdf

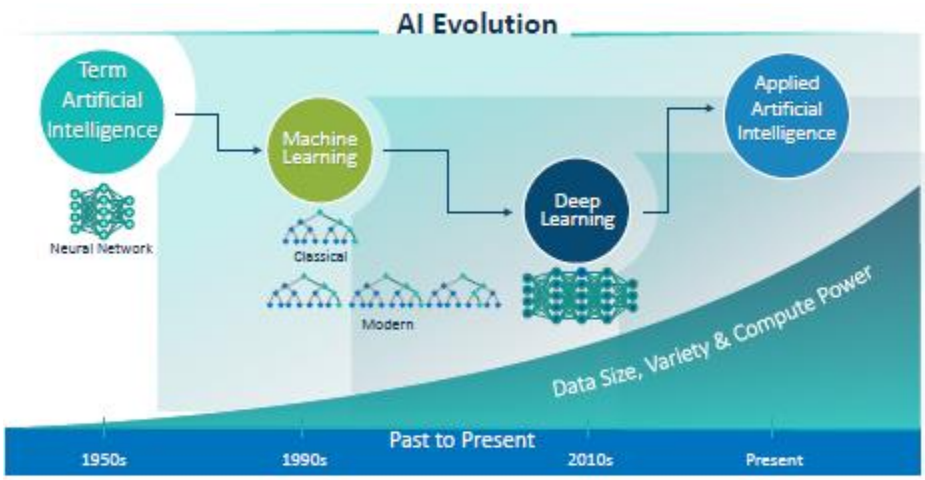

Figure 1: The Evolution of AI

The term artificial intelligence was coined in 1956, but AI has become more popular today thanks to increased data volumes, advanced algorithms and improvements in computing power and storage.

Early AI research in the 1950s explored topics like problem solving and symbolic methods. In the 1960s, the US Department of Defense took interest in this type of work and began training computers to mimic basic human reasoning. For example, the Defense Advanced Research Projects Agency (DARPA) completed street mapping projects in the 1970s. And DARPA produced intelligent personal assistants in 2003, long before Siri, Alexa or Cortana were household names.

This early work paved the way for the automation and formal reasoning that we see in computers today, including decision support systems and smart search systems that can be designed to complement and augment human abilities.

While Hollywood movies and science fiction novels depict AI as human-like robots that take over the world, the current evolution of AI technologies isn't that scary – or quite that smart. Instead, AI has evolved to provide many specific benefits in every industry.

The Potential of AI and the Intelligence of Things

AI-powered connected smart devices and environments learn from a greater network of data sources (including each other) and contribute to collective intelligence. There are numerous examples across industries that illustrate this potential:

- Utilities and manufacturers can detect underperforming assets and predict the need for maintenance or automated shutdown before costly or hazardous equipment failures occur.

- Digital twins are a virtual representation of a physical asset or device, frequently located in a remote location.[5] IoT devices have several sensors installed on them, as well as sensors for the environment around them. AIoT brings this sensor data together to create a true real-time digital twin. The digital twin shows the device's operating condition, no matter where it's physically located to create a true real-time digital twin. Deep learning can be added to a digital twin for more understanding. Image and video analytics are used to capture operating conditions that are missed by regular sensors. And, recurrent neural networks (RNN) add temporal data analysis and pattern detection in real-time data streams that are prevalent in digital twins. With these deep learning capabilities, digital twins provide a new level of insight for your remote devices. Research is emerging on industrial IoT applications that will help augment existing applications of digital twins. With IoT, data is collected from sensors on a device, on neighboring devices, the environment around a device, and whatever interacts with the device. The speed is real time, and connectivity allows us to span distances instantly in many cases. Advances in streaming analytics now enable us to process this real-time data using machine learning and artificial intelligence.
- Drones can comprehend unknown surroundings on the fly – even in dark, obstructed environments beyond the reach of internet or GPS – to investigate hazardous areas such as offshore operations and mines. Enhanced with analytics, drones can help transform essential but expensive, inefficient processes – such as vegetation management and power line surveillance – so that savings can be allocated to other strategic initiatives like grid modernization.
- Robotic platforms travel the aisles of a warehouse, picking parts or goods off the shelf and delivering them to the right place, avoiding collisions along the way. Collaborative robots ("cobots") work alongside humans to do heavy lifting, stage materials for assembly or complete repetitive tasks and motions.
- Shipping containers and tractor-trailers can monitor conditions such as temperature, humidity, exposure to light, weight distribution, and CO2 and oxygen levels to maintain the integrity of loads and speed delivery and check-out.
- Remote monitoring devices provide at-home diagnostics, alert caregivers when intervention is needed and remind patients to take their medications.
- Cities can deploy connected sensors into the physical infrastructure to constantly monitor for energy efficiency, air pollution, water use,

traffic conditions and other quality-of-life factors.

- In semiconductor manufacturing of wafers and dies, many tests cannot be run until the packaging phase. With computer vision, it is practical to take images of the wafer earlier in the production process and inspect it for issues. The inspection can be used to find defects and determine the number and location. This will allow an earlier determination of final yield from the wafer. With previous labeled images of diagnosed defects, it is also possible to classify the defect types using computer vision. This will help augment a larger root cause analysis for process improvement.

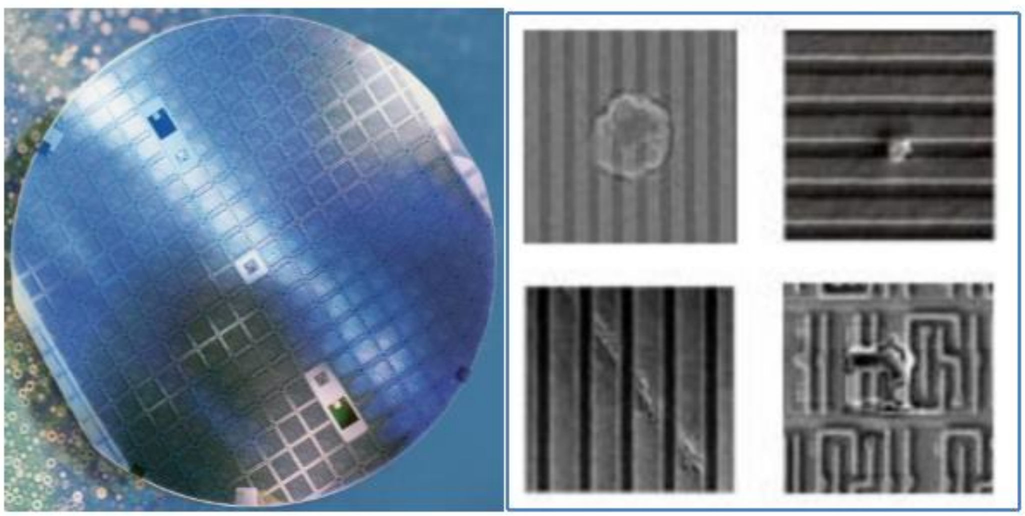

Figure 2: Silicon Wafer and Wafer Defects

Defect detection in discrete parts – With visual inspection of discrete parts, you can more easily catch several production defects. These are various issues in production quality. For example, in aerospace and automotive parts production, you can determine incomplete finishes or casting issues.

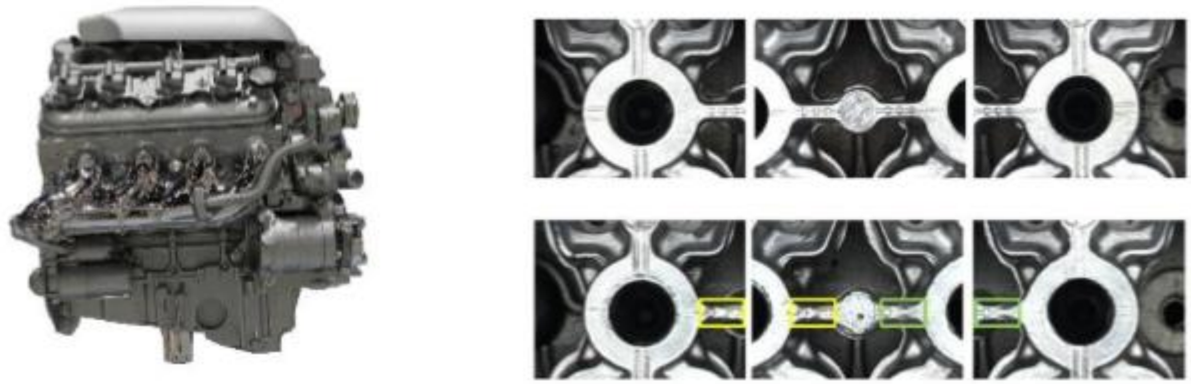

Figure 3: Automotive Engine and Casting Defects

Infrared patterns for heat buildup in power substations – Using specialized cameras, you can capture images for different spectrums. Infrared cameras can capture a more complete picture of temperature deviations and patterns than what would be possible with individual temperature sensors. This allows for new applications such as monitoring power substations for components getting ready to fail.

If we can train an algorithm to suggest the next best move in the complex game of Go (we can), we can train an algorithm to adjust the chillers in a data center or the blade angle of a wind turbine, or to dispense the right amount of medicine at the right time.

This adaptive, predictive and “learning” capability is particularly important in the Industrial Internet of Things (IIoT) because there is so much at stake where system failures and downtime can result in life-threatening or high-risk situations.

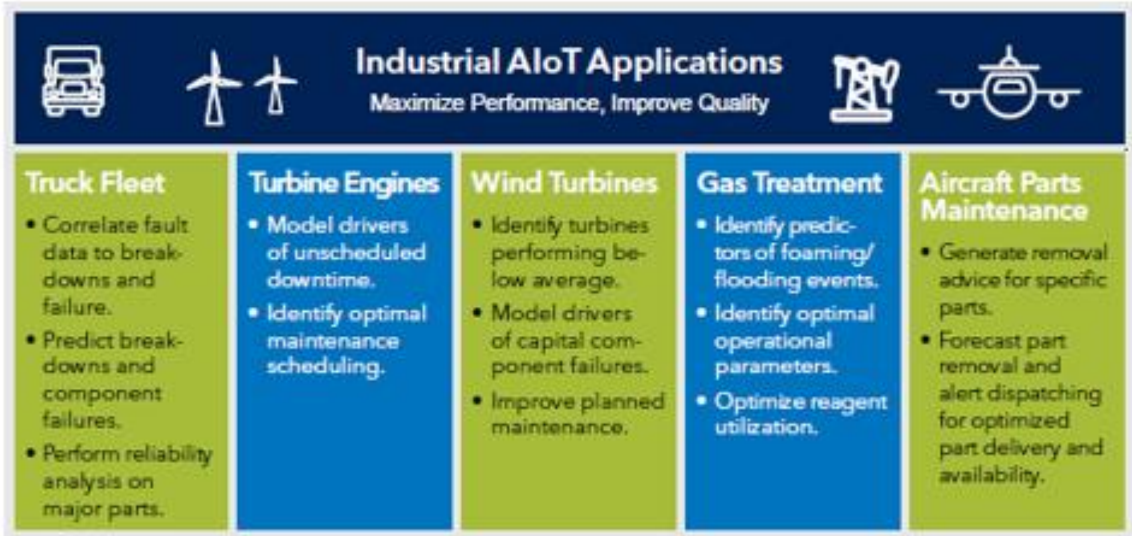

Figure 4: Industrial AI-driven IoT Applications

Bringing Advanced Analytics to the Edge

Where analysis of IoT data takes place depends on issues of bandwidth and latency:

- For applications that can tolerate some delay or are not bandwidth-intensive, such as collecting summary data of a device's operation, the IoT device sends data to the cloud or data center, which analyzes it in light of historical performance and other trends. Insights gained from the analysis can then be used to make decisions on subsequent operation of the device, including modifying the control program on the device itself.
- For cases where mobile or remote assets churn out lots of data that must be analyzed quickly – such as self-driving vehicles or drones – or where bandwidth is constrained, data processing is moved as close to the data source as possible – to the edge.

With AI-powered capabilities, IoT data can be transformed, analyzed, visualized and embedded across the entire ecosystem – edge devices, gateways and data centers, in the fog or in the cloud.

AIoT in Action

IoT Data with AI Reduces Downtime Helps Truckers Keep on Trucking

Millions of trucks transport fuel, produce, electronics and other essentials across highways every day. But unplanned downtime can exact a tremendous toll on any fleet operator and their customers who depend on timely deliveries. Volvo Trucks and Mack Trucks, subsidiaries of the Swedish Manufacturer AB Volvo, have met this challenge through remote diagnostic and preventative maintenance services based on IoT technologies with advanced analytics including artificial intelligence.[8] With these solutions, Volvo Trucks and Mack Trucks can help their customers maximize a vehicle's time on the road and minimize the costs of service disruptions by servicing connected vehicles more efficiently, accurately and proactively.

Volvo Trucks' Remote Diagnostics monitors data from each truck for fault codes triggered when something is amiss with a major system. Thousands of sensors on each truck collect streaming IoT data in real time to provide context around where the event happened and what conditions were present during the fault. Similarly, Mack Trucks' GuardDog Connect helps customers evaluate the severity of issues and manage repairs by remotely collecting data from the vehicle in the form of fault codes and other parameter data, then ranking them based on severity. If a fault requires immediate action, an agent contacts the customer to explain the situation and recommended action. If it's less time-sensitive or does not involve a potential injury, the repair is planned for when it makes the most sense for the operation.

The results of pairing sensor data and IoT technologies with advanced analytics including AI have been impressive. For Volvo Trucks, diagnostic time was reduced by 70 percent and repair time by 25 percent.[8] Mack Trucks points to benefits for all stakeholders – dealers experience a more efficient process, and greater uptime keeps customers happy.

Smart Copiers and Printers Report When They Need Service or Supplies

Konica Minolta Japan is the distributor and service provider arm of Konica Minolta Inc., which primarily manufactures office equipment such as copiers and digital print systems.

Historically, the company kept each customer supplied with three spare toner cartridges per unit. But sometimes customers didn't want the toner taking up their office space, or they would discard the toner without using it because its expiration date had passed.

After adopting AI with connected sensors on the copiers and printers, Konica Minolta Japan was able to track consumption of toner and send replacement toner cartridges when needed. Combining data from the devices with external data and applying machine learning, the company generates forecasts that enable just-in-time delivery for better customer satisfaction.

Konica Minolta Japan also uses data from remote sensors to establish proactive maintenance. The company now forecasts the life of parts based on the status of use and sends service personnel to the customer before a problem develops.

[8] Bjorlin, Courtney. IoT World Today https://www.iotworldtoday.com/2018/11/09/volvo-trucks-iot-enabled-fleet-uses-sas-to-boost-uptime/

Soccer Player Selection Goes High-Tech with AI

Football. Soccer. Whatever you call it, the world's most popular sport is being transformed by a Dutch sports analytics company bringing AI to the game. SciSports uses streaming data and applies machine learning, deep learning and AI to capture and analyze this data for a variety of uses, from player recruitment to virtual reality for fans.

Traditional football data companies only generate data on players who have the ball, leaving everything else undocumented. This leads to an incomplete picture of player quality. Seeing an opportunity to capture the immense amount of data happening away from the ball, SciSports developed a camera system called BallJames.[9]

BallJames is a real-time tracking technology that automatically generates three-dimensional digital images and data from video. Fourteen cameras placed around the stadium record every movement on the field. BallJames then generates data such as the precision, direction and speed of the passing, sprinting strength and jumping strength. The result is a much more comprehensive view of players.

Machine learning algorithms calculate the quality, talent and value of more than 200,000 players in more than 1,500 matches a week in 210 leagues. This analysis helps clubs find talent, look for players that fit a certain profile and analyze their opponents.

To accurately compile 3D images, BallJames must distinguish between players, referees and the ball. Using event stream processing enables real-time image recognition and analysis using deep learning models.

When Is a Smart Device an AI Device?

Many smart devices are not AI-enabled devices. For instance, a device that can be controlled from an app or learn user preferences is smart, but that's not AI.

For a smart, connected thing to be a thing in the AI-driven IoT, it needs to be able to make a decision or perform a task without human intervention. For example:

- A residential heating system that learns temperature preference is not an AIoT system unless it does something – it adjusts the temperature on your behalf.
- An autonomous vehicle is an AI system – it drives for you. When it is connected to other cars or the internet, it is a "thing" in the artificially intelligent IoT – the AIoT.

SUCCESS WITH AIOT: 4 ESSENTIAL STEPS

Looking beyond the physical infrastructure of the intelligent IoT – the sensors, cameras, network infrastructure and computers – there are 4 essential steps that underpin a successful deployment:

[9] McCaskill, Steve. Forbes https://www.forbes.com/sites/stevemccaskill/2019/01/28/this-analytics-firm-wants-to-make-soccer-transfers-more-like-video-games/#5fc543e7777a

- Think real-time analytics. Use event stream processing to analyze diverse data in motion and identify what's most relevant.
- Deploy intelligence where the application needs it, whether in the cloud, at the network edge or at the device itself.
- Combine AI technologies. AI capabilities such as object identification or processing natural language by themselves are valuable; used in synergy, they are indomitable.
- Unify the complete analytics life cycle, from streaming the data, filtering it, scoring the data using the model and storing relevant results to continuously improve the system.

Think real-time analytics

Analyze high-velocity big data while it's still in motion – before it is stored – so you can take immediate action on what's relevant and ignore what isn't. Seize opportunities and spot red flags hidden in torrents of fast-moving data flowing through the business.

Event stream processing plays a vital role in handling IoT data, and will be even more vital with advances like 5G, to:

- Detect events of interest and trigger appropriate action. Event stream processing pinpoints complex patterns in real time, such as an action on a person's mobile device or unusual activity detected during a banking transaction. Event stream processing offers quick detection of threats or opportunities.
- Monitor aggregated information. Event stream processing continuously monitors sensor data from equipment and devices, looking for trends, correlations or anomalies that could indicate a problem. Smart devices can take remedial action, such as notifying an operator, moving loads or shutting down a motor.
- Cleanse and validate sensor data. When sensor data is delayed, incomplete or inconsistent, several factors could be at play. Is dirty data caused by an impending sensor failure or a network disruption error? A variety of techniques embedded into data streams can detect patterns and troubleshoot data issues.
- Predict and optimize operations in real time. Advanced algorithms can continuously score streaming data to make decisions in the moment. For example, information on a train's arrival could be analyzed in context to delay a train's departure from another station, so commuters won't miss their connections.

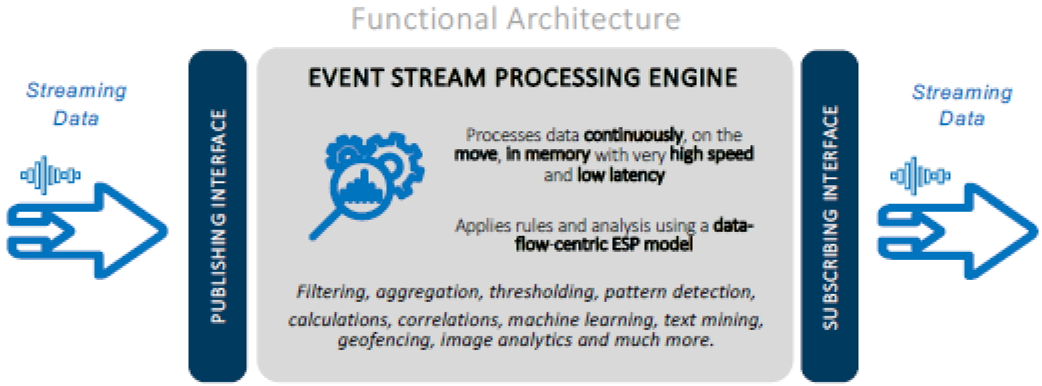

Figure 5: Event Stream Processing Analyzes Data in Motion

Deploy Intelligence Where the Application Needs It

The use cases described earlier entail data that is constantly changing and in motion (such as a driver's geolocation or temperature inside a data center) as well as other discrete data (such as customer profiles and historical purchase data). This reality calls for analytics to be applied in very different ways for different purposes. For example:

- High-performance analytics does the heavy lifting on data at rest, in the cloud or otherwise in storage.
- Streaming analytics analyzes large amounts of diverse data in motion, where only a few items are likely to be of interest, the data has only fleeting value, or when speed is critical, such as sending alerts about an impending collision or component failure.
- Edge computing enables a system to act on the data immediately, at the source, without pausing to ingest, transport or store it – a must for many uses in the sensor driven world of IoT devices and services.

It's a multi-phase analytical approach. The key principle to remember is not all data points are relevant and not all need to be sent to permanent storage. Sometimes the question calls for complex analytics, and sometimes speed is more important. Sometimes the data must be analyzed at the edge, and sometimes it needs to go back to a data center. The analytics infrastructure must be flexible and scalable to support all those needs today and into the future.

Combine AI Technologies

To realize the highest returns with AIoT, look beyond deploying a single AI technology. Take a platform approach where multiple AI capabilities work together, such as machine learning and deep learning, for natural language processing and computer vision.

For example, a research clinic of a large hospital combines several forms of AI to provide diagnostic guidance to its physicians. The clinic uses deep learning and computer vision on radiographs, CT scans and MRIs to identify nodules and other areas of concern on the human brain and liver. This detection process uses deep learning techniques such as convolutional neural networks (CNN) to analyze visual imagery.

The clinic then uses a completely different AI technology – natural language processing – to build a patient profile based on family medical history, medications, prior illnesses and diet; it can even account for IoT data, such as pacemaker data. Combining natural language data with computer vision, the tool enables valuable medical staff to be much more efficient.

Much of the value of the AI-empowered IoT is the promise to act now. Make customers the right offer before they look away. Detect the suspicious transaction before it is approved. Help that self-driving car maneuver through the busy intersection without crashing into other moving vehicles. Do it now. Latency matters.

Clearly, many types of sensors and devices cannot wait for data or commands from the cloud. And for other uses, it just isn't necessary. For monitoring, diagnosing and acting on individual pieces of equipment, such as home automation systems, it makes sense to do the analysis as close to the device as possible. Sending locally sourced, locally consumed data to a faraway data center causes needless network traffic, delayed decisions and drain on battery powered devices.

With the exponential increase in IoT devices and their data volumes – along with demand for low latency – we have seen a trend to move analytics from traditional data centers toward devices on the edge – the "things" – or to other compute resources close to edge and cloud – to the fog.

A concept just a few years old, fog computing shifts data processing, real-time analytics, security and networking functions from a centralized cloud to network nodes and gateways closer to the IoT devices or services. Fog computing or "fogging" enables the data to be processed locally. Only the results, exceptions or alerts are sent to a centralized data center. Faster results, less bandwidth.

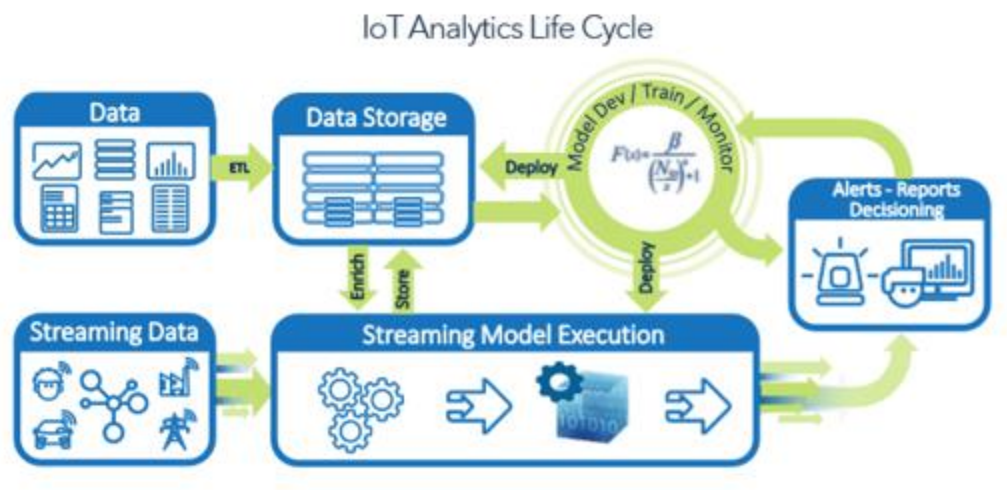

Figure 6: The IoT Analytics Life Cycle

Unify the Complete Analytics Life Cycle

To achieve value from the connected world, the AIoT system first needs access to diverse data to sense what is important as it is happening. Next, it must distill insights from the data in rich context. Finally, it must get rapid results, whether to alert an operator, make an offer or modify a device's operation.

Successful IoT implementations will link these supporting capabilities across the full analytics life cycle:

- Data analysis on the fly.
  This is the event stream processing piece of it described earlier. Event stream processing analyzes huge volumes of data at very high rates (in the range of millions per second) – with extremely low latency (in milliseconds) – to identify events of interest.
- *Real-time decision making/real-time interaction management*
  The streaming data about an event of interest – such as a car's constantly changing location, direction, destination, environment and more – goes into a recommendation engine that triggers the right decision or action.
- *Big data analytics*
  Getting intelligence from IoT devices starts with the ability to quickly ingest and process massive amounts of data – most likely in a distributed computing environment such as Hadoop. Being able to run more iterations and use all your data – not just a sample – improves model accuracy.
- *Data management*
  IoT data may be too little, too much and certainly in multiple formats that have to be integrated and reconciled. Solid data management can take IoT data from anywhere and make it clean, trusted and ready for analytics.

- *Analytical model management*
  Model management provides essential governance across the life cycle of analytical models, from registration to retirement. This ensures consistency in how models are managed – the means to track the evolution of models and ensure that performance does not degrade over time.[10]

If You Remember Only Three Things...

When you think IoT or think AI, the takeaway is clear:

1) If you're deploying IoT, deploy AI with it.
2) If you're deploying AI, think about the gains you can make by combining it with IoT.
3) Either one has value alone, but they offer their greatest power when combined. IoT provides the massive amount of data that AI needs for learning. AI transforms that data into meaningful, real-time insights on which IoT devices can act.

AI and IoT already work together in our daily lives without us even noticing. Think Google Maps, Netflix, Siri and Alexa, for example. Organizations across industries are waking up to the potential. Gartner predicts that by 2022, more than 80 percent of enterprise IoT projects will include an AI component, up from only 10 percent today.[11]

"Without AI-powered analytics, IoT devices and the data they produce throughout the network would have limited value," says Maciej Kranz, Vice President of Corporate Strategic Innovation at Cisco.[12] "Similarly, AI systems would struggle to be relevant in business settings without the IoT-generated data pouring in. However, the powerful combination of AI and IoT can transform industries and help them make more intelligent decisions from the explosive growth of data every day. IoT is like the body and AI the brains, which together can create new value propositions, business models, revenue streams and services."

IoT Applications Already Benefit from the Power of AI

The technology is already proven for a huge variety of consumer, business and industrial applications. For example:

- Intelligent transport solutions are already speeding up traffic flows, reducing fuel consumption, prioritizing vehicle repair schedules and saving lives.

[10] Klenz, Brad. 2018. "How to Use Streaming Analytics to Create a Real-Time Digital Twin." Proceedings of the SAS Global Forum 2018 Conference. Cary, NC: SAS Institute Inc. https://www.sas.com/content/dam/SAS/support/en/sas-global-forum-proceedings/2019/3459-2019.pdf

[11] Gartner, Inc. Forecast: The Business Value of Artificial Intelligence, Worldwide, 2017-2025. By John-David Lovelock, Susan Tan, Jim Hare, Alys Woodward, Alan Priestley. March 12, 2018. https://www.gartner.com/document/3868267

[12] Kranz, Maciej. AI Business https://aibusiness.com/ai-and-iot-two-sides-of-the-same-coin/

- Smart electric grids have already proven more efficient in connecting renewable resources, improving system reliability and billing customers on more granular usage increments.
- Machine-monitoring sensors already diagnose and predict impending maintenance issues, trigger deliveries where and when needed, and prioritize maintenance schedules.
- Data-driven systems are being built into the infrastructure of "smart cities," making it easier for municipalities to run waste management, law enforcement and other programs more efficiently.

Whatever the industry, there are use cases in place to learn from and build on.

A report from the McKinsey Global Institute estimates that the IoT could have an annual economic impact of $3.9 trillion to $11.1 trillion by 2025 across many different settings, including factories, cities, retail environments and the human body.[13] With AI, the realization of this impact is getting closer everyday – and first movers take the prize.

Leaders should continue to innovate in areas such as:

- **Machine learning and deep learning to** find insights hidden in IoT data without explicitly being told where to look or what to conclude, resulting in better, faster discoveries and action.
- **Natural language processing (NLP) to** enable machines to intelligently interact with humans, such as via chatbots, and discover insights in large amounts of digitized spoken content.
- **Computer vision to** analyze and interpret what's in a picture or video through image processing, image recognition and object detection to provide insight not easily available with existing sensors. Cameras can sometimes be installed much more easily than other sensors. Cameras can also be retrofitted to existing assets passively, where adding sensors can more invasive. This is the technology behind the SciSports success.
- **Forecasting and optimization to** help AI systems predict future outcomes based on IoT data and deliver the best results under given resource constraints.
- **Recurrent neural networks (RNN) to** use sensor data to frequently capture measurement over time and look for issues that develop. RNNs can provide complex pattern recognition as well as specialized forecasting.

[13] Patel, Mark. Shangkuan, Jason. Thomas, Christopher. What's New with the Internet of Things? McKinsey & Company.

Reinforcement learning (RL) to understand how the controls of an asset (which the digital twin is mirroring) can be set to learn how to achieve optimal output. [14] [15] [16]

AI and IoT Don't Know the Meaning of Impossible

High-performance IoT devices and environments with thousands of connection points are proliferating across the network. It's the perfect storm. Declining hardware costs make it feasible to embed sensors and connectivity in just about anything. Advances in computing, light-speed communications and analytics make it possible to create AI-driven intelligence wherever it is needed, even at the fringes of the network.

Together, these technologies are ushering in a new era where the Internet of Things is just the state of things, and the term becomes superfluous, just as we no longer have to state: "World Wide Web" or "internet-connected."

➢ Return to IIC Journal of Innovation landing page for more articles and past editions

---

[14] Kahler, Susan. 2018. "Using Deep Learning to Forecast Solar Energy." https://blogs.sas.com/content/subconsciousmusings/2018/07/05/deep-learning-forecasts-solar-power/

[15] Hao, Karen. 2019. "The Rise of Reinforcement Learning" in "We Analyzed 16,625 Papers to Figure Out Where AI Is Headed Next." https://www.technologyreview.com/s/612768/we-analyzed-16625-papers-to-figure-out-where-ai-is-headed-next/

[16] 10 Burda, Yuri. 2018. "Reinforcement Learning with Prediction-Based Rewards." https://blog.openai.com/reinforcement-learning-with-prediction-based-rewards/