Unlocking the power of connected objects

with Edge-native AI

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Executive Summary

Industries across the globe have digital transformation strategies, with the aim to capitalize on the ability to connect and communicate with objects. These strategies depend on Artificial Intelligence (AI) in edge computing environments (Edge AI) to harvest, interpret and act upon critical operational information. Data coming from connected objects is rich in operational information, but notoriously challenging to analyze because of its volume, sparsity and multidimensionality. These challenges are exacerbated by the real-time nature of many of the high value digital services that industrial companies require.

Industries across the globe have digital transformation strategies, with the aim to capitalize on the ability to connect and communicate with objects. These strategies depend on Artificial Intelligence (AI) in edge computing environments (Edge AI) to harvest, interpret and act upon critical operational information.

This technology provides sophisticated personalized and context-aware intelligence for high value use-cases that include condition monitoring, security and anomaly detection, predictive maintenance

Data coming from connected objects is rich in operational information, but notoriously challenging to analyze because of its volume, sparsity and multidimensionality. These challenges are exacerbated by the real-time nature of many of the high value digital services that industrial companies require.

Moreover, as industry players implement embedded AI solutions to harvest object data and intelligence, integration across objects, machines and other operating technology (OT) and between OT and information technology (IT) is needed to maximize business value. This results in AI intelligence hierarchies that typically span multiple objects within machines, many machines and systems and depend greatly on machine data derived from embedded AI solutions. These hierarchies cannot achieve scalability with point solutions. Instead, standardized API interfaces are needed amongst objects, the OT and the IT layers in AI intelligence hierarchies. MicroAI's technology incorporates an extensive range of standardized APIs for this purpose.

The stakes are high for embedded system providers, equipment OEMs, software and systems integrators and industrial end-users. It is crucial that Edge AI solutions are designed from the outset with future-proofed AI environments at the Edge, which incorporate careful design considerations at the object level, machine level-level and across entire OT and IT hierarchies. This will enable players across entire industrial value chains to use Edge AI as a key market differentiator.

Introduction

The fourth industrial revolution is upon us, with cyber-physical convergence that is supported by a range of technologies including the Internet-ofThings (IoT), to enable a seemingly endless range of transformative digital services. With IoT and the right analytical tools, connected object data and intelligence can be harvested, analyzed and acted upon to yield tremendous operational benefits. These include personalized or mass customization and contextualization of data as well as enhanced security.

The benefits include, extended object and machine longevity, reduced down-time and optimized operations, using sophisticated capabilities that include, condition monitoring, predictive maintenance, enhanced automation and beyond. This is punctuated by new security threats and attack surfaces that must be addressed as objects become increasingly connected and digitally enabled.

Conventional operational management tools are inadequate for the digital services that are being developed. Even traditional AI operating in the cloud to provide a one size fits all doesn't enable the right level of personalization. Instead, sophisticated Artificial intelligence (AI) that does both inference and training is needed to contend with the unique challenges for connected objects, machines and systems that operate in edge computing environments. This is commonly referred to as Edge AI and is heralding innovative solutions, such as the MicroAI's AtomML™, which is discussed in this report.

MicroAI is responding to the need for connected objects and next generation applications' need for personalized or mass customization and contextualization of data as well as enhanced security. MicroAI's solutions use Edge-Native AI technology that overcomes the limitations of the first generation Edge AI tools via higher quality modeling and the ability to detect cyber instructions at the moment of intrusion

Massive Market Opportunities

Edge AI is becoming pervasive as industries pursue their digital transformation strategies. Edge AI calls for standardized solutions with sufficient efficiency, performance and reliability to support the growing range of usecases that need to be supported. The Global Edge AI hardware and software market is forecast to increase from USD 720 million in 2020 with a 25 percent cumulative annual growth rate (CAGR) to reach USD 2200 million in 2025. Over this time period, the percentage of revenues generated by Edge AI software is forecast to increase from 45 to 68 percent. The shift in revenue mix in favor of software solutions reflects the anticipated maturation of Edge AI across a growing range of use-cases and implementation scenarios.

Edge AI solutions will have a major impact on a number of verticals including:

Healthcare, from medical devices and surgical tools to vaccine supply chains

Industrial, including predictive maintenance and monitoring

Transportation, from autonomous vehicles to smart shipping for perishable goods

Agricultural, precision agriculture for monitoring and predicting yields

Retail, from inventory scanning to demand forecasting and self-service applications

Industrial use cases for Edge AI are diverse and include industrial automation (currently a USD 150B global market), machine condition monitoring (USD 2.9B market with 7-10% CAGR over next five years), industrial anomaly detection (USD 2B market with 15-20% CAGR over next five years), and predictive maintenance (USD 3B market with a 25% CAGR). Industrial anomaly detection is also valuable in providing additional security for devices and networks. The business value of Edge AI will increase tremendously in the coming years. As this occurs it is crucial that players across the entire value chain, including embedded system providers, equipment vendors, systems integrators, solution providers and end users, incorporate Edge AI into their digital strategies and technology architectures.

industrial automation

USD $150 billion

global market estimate

machine condition monitoring

USD $2.9 billion

global market estimate

7-10% forecasted cagr

industrial anomaly detection

USD $2 billion

global market estimate

15-20% forecasted cagr

predictive maintenance

USD $3 billion

global market estimate

25% forecasted cagr

Edge AI Hierarchy

The evolution of AI to the edge has followed an initial path with on premises computing, followed by cloud-based AI, and finally, to the edge. With the proliferation of smart devices however, it is no longer practical to design systems that run AI computation in the cloud alone due to costs, latency, inefficiencies and security issues. With the advent of the first generation of Edge AI we begin to see the first step of hyperconvergence where workflows can run independently on either the edge or in the cloud. Standardized APIs used on MicroAI solution set facilitate connecting machine data across both OT and OT-IT systems. As the volume of data and need for real-time analytics and decision-making grows, the hybrid cloud-edge configuration is moving the balance increasingly toward the edge. As devices and manufacturing become smarter, the intelligence in the system also needs to be designed for the edge. This does not mean the cloud disappears, but rather we only use the cloud when necessary, with the majority of computing happening at the edge. Most first generation edge AI devices were designed primarily for cloud-first in contrast to MicroAI's Edge-Native technology that provides numerous benefits over earlier edge AI offerings. We will soon see how Edge-Native AI is the next step in innovation of smart devices and apps.

> **MicroAI's Edge-native AI technology that provides numerous benefits over earlier edge AI offerings.**

Some examples will illustrate the relationship between the edge and the cloud in an Edge-Native context. A Tesla generates a tremendous volume of data daily. The majority of the data generated does not need to be sent to the cloud and it is quite expensive to do so. Edge AI can handle the majority of the computing in the vehicle and only send data to the cloud when an anomaly or an issue requiring repair, for example, appears. At this point the edge AI device can send an alert to the cloud and the driver is notified of the need for servicing. Similar situations arise in healthcare. Physicians and nurses are constantly receiving alarms from devices on patients and many of these alerts are false positives not requiring attention. Alarm fatigue is a serious problem that can harm patient outcomes. With Edge-Native AI in a medical device there is an improvement in personalization and contextualization of the data that can lower the rate of false positives. Only critical care issues of importance to clinicians and patients will be sent to the cloud to trigger the appropriate medical care that is needed. When physicians and nurses have the need to monitor populations of patients this capability is critical to both health outcomes and financial success of the healthcare provider.

When we push AI to the edge it facilitates automation of manufacturing processes. In industrial manufacturing we find large numbers of smart sensors, objects, devices and robots. Many of these will interact in assemblages that generate vast amounts of data. Embedding MicroAI's AtomML into industrial applications in these contexts creates opportunities for generating vast amounts of data at the micro-level that provides a better macro view of industrial manufacturing processes in real-time.

Mastering the Connected Objects Data Challenge

Conventional data management tools address specific operational tasks, such as for machine and plant control, alarm resolution and workflow management. However, these are a far-cry from the transformative digital services that are emerging and must contend with:

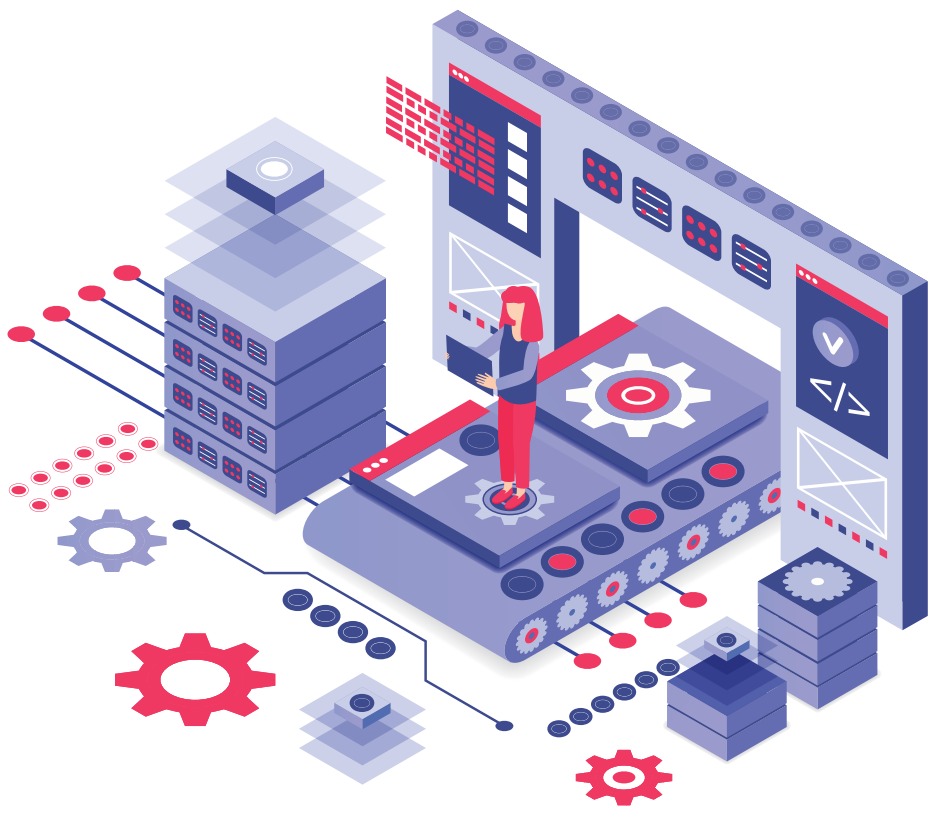
The requirement for context and personalization : For many devices and systems an anomaly can be context dependent and based on other data from different sensors and devices over time. Without proper personalization or customization and contextualization, some AI systems will provide false alarms or inaccurate insights. In areas such as healthcare it is vital to understand the context of the patient if vital signs deviate from the norm. Apps with edge AI are also enabling users to personalize features within the app with more granularity.

The increasing number of objects The number of devices at the edge continues to grow dramatically. On the consumer edge more smartphones, tablets, wearables, voice assistants and speakers will use Edge AI in addition to the industrial devices. Decentralization to the edge coupled with the increase in numbers also creates security and privacy challenges for more cloud-based edge AI services in particular.

These needs generate data have the following characteristics that make edge AI an important component for intelligent systems:

- **Voluminous** , with individual machines often generating GBytes of data per day, depending on the number of data sources, their resolution and sampling rates.
- **Sparse** , since most systems have repetitive functions. It is the sporadic data that indicates trending conditions and anomalies that generally has the most value for digital services.
- **Multi-faceted** , where the interdependence between individual machine data streams typically has the most operational relevance.
- **Time sensitive** , where in many cases, machine data is most operationally impactful, when acted upon in real-time or near real-time.

To address these challenges innovations are needed at the edge to provide security, real-time monitoring and reduced costs that also enable new revenue models, improved margins and new services. Edge AI by itself will not be sufficient.



Transforming to a new App Paradigm : Edge-native AI

Traditional Cloud-based AI moves the computation component remotely in the cloud. The legacy of cloud-based AI means that many edge AI devices are also developed in the cloud and this results in a “one model fits all metaphor” that doesn’t address specifically the specificity of the device and its context. And this comes with costs for efficiency and overall performance.

Edge-native AI is developed specifically for each edge device and is a model-driven application.

The model runs where the data are collected, at the edge. This means the application will learn as it operates and each device and behavior will feed into model generation and learning. Driving learning directly into edge devices enables far more personalization and contextualization, reduces costs and accelerates product design and deployment. A smart device needs to be smart enough to provide situational awareness of the context and using this intelligence it knows when it is necessary to send an alert to the cloud or when real-time reaction at the edge will provide a better service. This is the true value of intelligence at the edge.

MicroAI

Since machine data is challenging to harvest with conventional techniques, it is often overlooked in industrial operations. However, this is set to change as digital services take hold and Edge AI solutions demonstrate the tremendous value locked up in machine data. Generic AI solutions will not suffice. Instead, specialized tools are needed to efficiently cope with the volume, sparsity and time sensitivity of multi-faceted machine data to deliver reliable and actionable operational outcomes. MicroAI's goal is to democratize edge AI for all connected devices by simplifying the design and deployment of predictive maintenance and security on the extreme edge while improving overall equipment effectiveness and security for industrial automation in edge environments.

For example, a digital service that manages the operational integrity of a robotic arm requires a solution to intelligently interpret machine data from multiple sensors and actuators. Normally a robotic arm will perform reliably and generate voluminous and sparse machine data. An AI solution must continuously monitor the robotic arm for normal operations, adapt to the normal changes in operational conditions, but react in near-real time when anomalous operations are identified. This is most effectively achieved using a Edge-native AI solution with a sufficiently small compute footprint, with inference and training to be embedded in the robotic arm. To achieve this, MicroAI has pioneered embedded AI capabilities with its AtomML technology.

The MicroAI platform has a modular architecture for versatile scalability

MicroAI Atom		MicroAI Network
High performance AI embedded directly in Microcontrollers (MCU), with 5 data channels, 64k RAM and 145k memory code	→ **seamless expandibility**	High performance AI in Microprocessor (MPU), environments to process high volumes of distributed time-series data, supporting dozens of machines, each with many outputs

MicroAI delivers AI driven output that includes alerts on anomalistic behavior/signs of failure, asset health scores, days to next maintenance and useful life remaining. This new edge-native approach efficiently supports the demands of individual machines with its embedded MicroAI solution and has seamless expandability with its MicroAI network deployment for anomaly detection and predictive maintenance across many machines.

MicroAI AtomML trains models at the edge within an edge server that federates assets within an industrial or manufacturing environment and harvests their micro data - sensors and/or tags from PLCs. AtomML translates the micro data into macro insights of the industrial manufacturing or processing, and automates actionable responses in real-time without cloud compute resources. The solution is focused on managing smart assets with dashboard visualizations and intelligent workflow automation.

MicroAI's SpringBoard is a quick start deployment portal that makes it easy for companies to design, test, and deploy embedded AtomML on MCUs/MPUs and other IoT devices. It provides a single pane of glass for authentication, mobile SIM activation, credit card billing for connectivity, and easy onboarding of the AtomML SDK library.

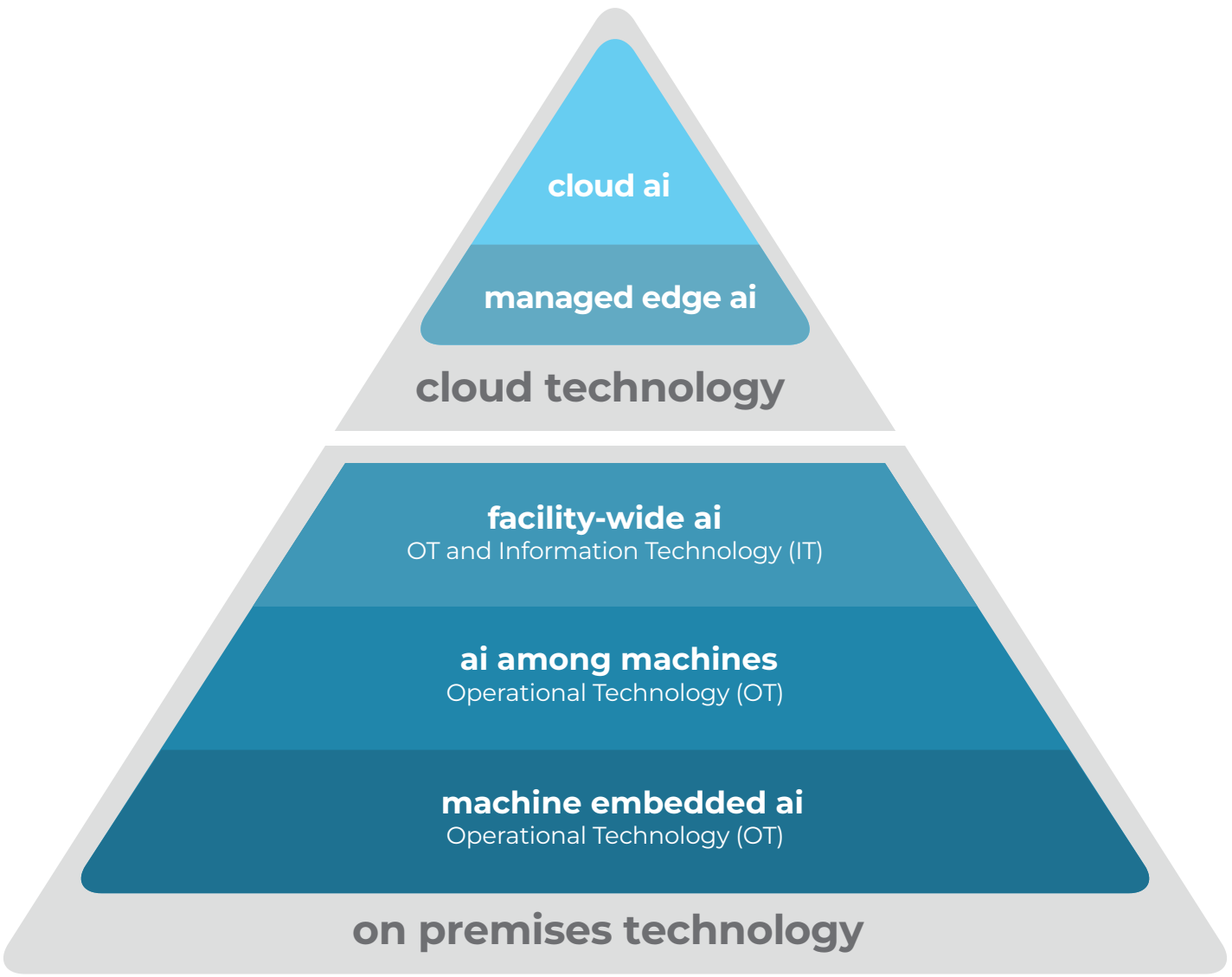
As digital services proliferate, Edge-native AI will become table-stakes for industrial machines and in many respects mirror the past success of IoT. As this occurs, it will become increasingly important for semiconductor and embedded solution providers and equipment manufacturers (OEM) to recognize the strategic importance for incorporating natively embedded AI in equipment designs from the outset. In addition, systems integrators, solution providers and industrial end users all have a vested interest in solutions that are optimized and future-proofed for Edge AI, with architectures that are easily integrated into broader digital transformation initiatives.

AI hierarchy for industrial digital services

The machine data and intelligence harvested from embedded AI has tremendous value beyond the individual machines that are being managed. The data and intelligence that is aggregated across multiple machines can be acted upon with additional AI capabilities to enhance digital services such as condition monitoring, anomaly detection and predictive maintenance. Real-time, constantly improving AI models for all devices or entire systems will offer the ability to reduce costs for connectivity and maintenance superior to cloud computing.

When machine data is aggregated across entire industrial facilities, it can support a range of business processes, with key capabilities, such as sophisticated benchmarking and predictive maintenance to enhance process workflows. For example, a manufacturing facility with multiple production lines might leverage facility-wide predictive maintenance capabilities to redistribute its operations amongst lines that are better performing and prioritize the early maintenance of poorer performing equipment.

An AI hierarchy is necessary for industries to fully capitalize on embedded AI and machine data for their digital services. Both machine embedded AI and AI amongst machines can be used for a wide range of operational technology (OT) functions, such as for automation, anomaly detection and predictive maintenance. Facility-wide AI, which derives data inputs from many machines and other operational systems, can support an enormous range of digital services that span both OT and information technology (IT) functions. In some cases there is value in extending Edge AI solutions to encompass multiple industrial facilities. These solutions might operate on premise, or in the managed edge or central cloud environments depending on the digital services being supported.



Getting the Edge AI design right with Edge-native AI

It is easy to lose sight of the subtle characteristics of the AI solutions needed for specific applications. This is particularly the case for Edge AI solutions, which must function and integrate across a diverse range of environments, from machine embedded systems with small compute footprints, to high performance on premise equipment, and in some cases, managed edge and cloud environments.

Unique demands for machine embedded Edge AI

In contrast to conventional AI solutions, which typically depend on large data sets and extensive computing power for training and inference, machine embedded AI solutions must operate effectively within relatively modest compute footprints. Solutions that are incorporated in machine designs from the outset generally deliver superior performance and enable embedded systems and OEM hardware providers to offer differentiated solutions. However, the AI solutions must also support retrofitted implementations, which we believe will continue to be used for the foreseeable future. Most installations cannot support extensive supervised AI model training. Instead, the solutions must incorporate largely unsupervised AI learning algorithms, and contend with the underlying challenges associated with machine data, including its volume, spasticity, multidimensionality and in many cases its real-time relevance.

Getting the AI hierarchy right with Edge-native AI

As industrial companies advance their digital services, they depend on operational intelligence and insights throughout their entire enterprise. This is punctuated by the need for integration amongst operational technologies (OT) and between OT and information technologies (IT).

Historically OT and IT ecosystems have tended to be siloed. As these silos are disrupted by emerging digital services, it is crucial that technical integration

As industrial companies advance their digital services, they depend on operational intelligence and insights throughout their entire enterprise.

challenges are minimized and that tangible business value can be attained with sufficient ease. This has direct implications for the Edge AI functionality needed throughout the entire hierarchy of a typical implementation. Embedded AI solutions must be consistent amongst machines and carefully architected to deliver business value from the machine data and intelligence that is harvested. AI point solutions will not suffice. Instead, standardized interfaces are needed to enable the OT and OT/IT integration that emerging digital services require. The key Edge AI requirements include the following:

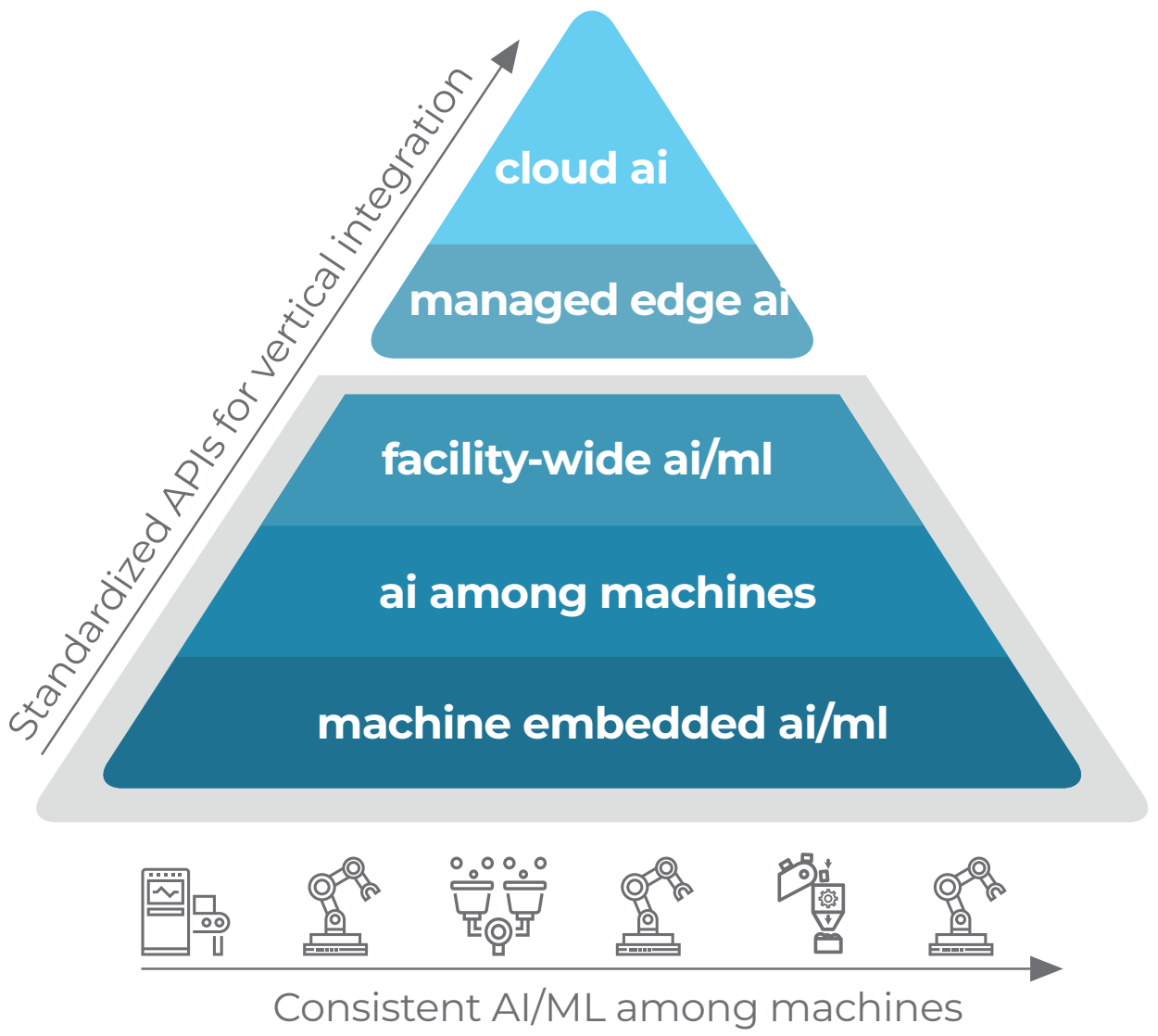
- Scalability and flexibility to support both current and future demands for machine operations and optimization.
- Standardized and extensible application interfaces (API) for managing the flow of data and intelligence, and;
- Solutions that anticipate hierarchical Edge AI architectures with OT/IT integration to support emerging digital services and transformation strategies.

Edge native AI offers improvements over traditional edge AI on a number of fronts:

- Having been designed from the outset for the edge vs the cloud, edge-native AI can reduce the time and need for data scientists to bring applications online or to market. MicroAI's fast-track integration tool, "Springboard", enables rapid onboarding

- The ability to detect zero-day intrusions with cyber attacks or anomalistic behavior on a connected device offers a dramatic improvement in risk mitigation for cyber security

The strategic importance of Edge-native AI provides opportunities for embedded system providers, equipment OEMs, systems integrators and end-users to differentiate based on the AI functionality that they enable. However, to achieve sustained differentiation, it is crucial that these players incorporate Edge AI capabilities in their solution designs from the outset, rather than retroactively. The players that get the solution right will be well positioned to capitalize on the burgeoning digital services that will fundamentally transform industries over the coming decade.



Selected Industrial Edge-native AI Use Cases

The variety of industrial Edge AI use cases will increase dramatically in the coming years as digital services mature. This will require greater intelligence, insights and operational agility from the underlying systems involved. In addition, with OT/IT integration, Edge AI will take on a variety of roles depending where in the hierarchy the AI resides, whether embedded in the machine, at a machine aggregation layer, facility wide, or across multiple facilities. Several selected use cases are summarized below to illustrate practical AI use cases.

Use Case: Robotic Arm Condition Monitoring

Industrial robots have been used for decades in manufacturing, particularly for highly deterministic applications such as spot-welding. In recent years, advances in key technologies including AI have enabled more sophisticated and dynamic industrial robotic use cases, such as bin picking, and collaborative and autonomous mobile robots.

Even simple industrial robots, such as robotic arms are challenging to intelligently manage and monitor because of the variety of machine data that must be analyzed in real-time. In the case of a robotic arm, the machine data spans a large number of sensor and actuator measurements from the robotic arm itself, and external sources that indicate other operational and environmental conditions (e.g. line speed, ambient temperature and humidity). Since individual machine data inputs are interdependent and can vary under normal operating conditions, it is not enough to monitor each input in isolation. For example, a robotic arm operating in a noisy environment is likely to have a different vibration condition monitoring profile to an equivalent robotic arm in a less noisy environment. In addition, since the machine data is voluminous and sparse and requires real-time performance, it is ideally suited for an embedded AI solution.

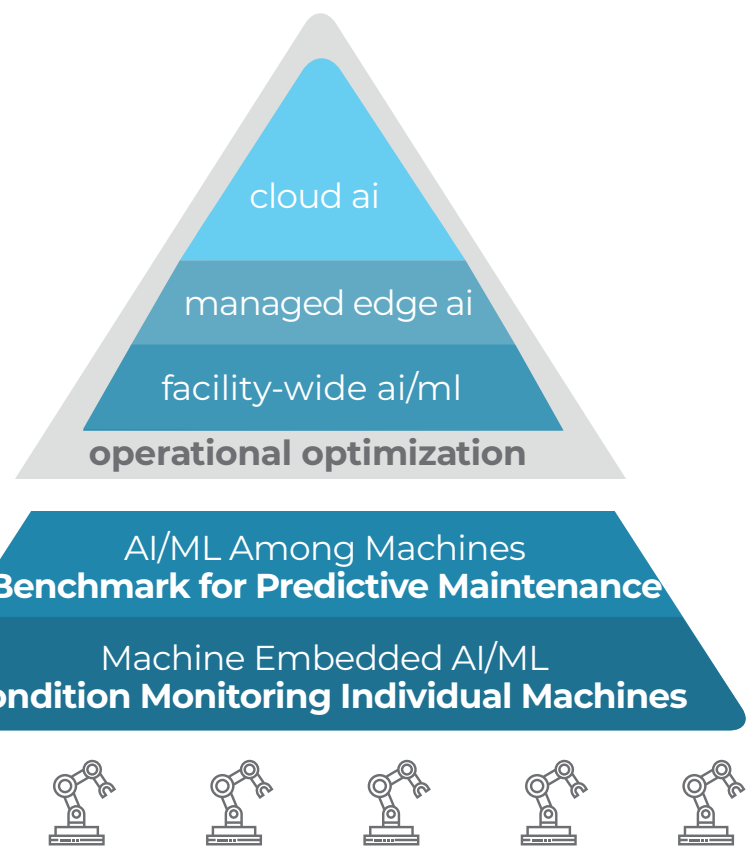
MicroAI has deployed its AtomML solution to successfully enable the intelligent condition monitoring and anomaly detection for robotic arms. This solution capitalizes on a:

Small compute footprint so that it can be embedded directly into the robotic arm.

A learning algorithm, which is largely unsupervised and can cope with dynamic operating conditions.

An efficient exception handling mechanism to cope with voluminous and sparse data to support real-time condition monitoring and anomaly detection demands.

Standardized application interfaces (API) so that the machine data and intelligence can be integrated amongst machines to support benchmarking and predictive maintenance capabilities, and integrated facility wide to support operational optimization initiatives.



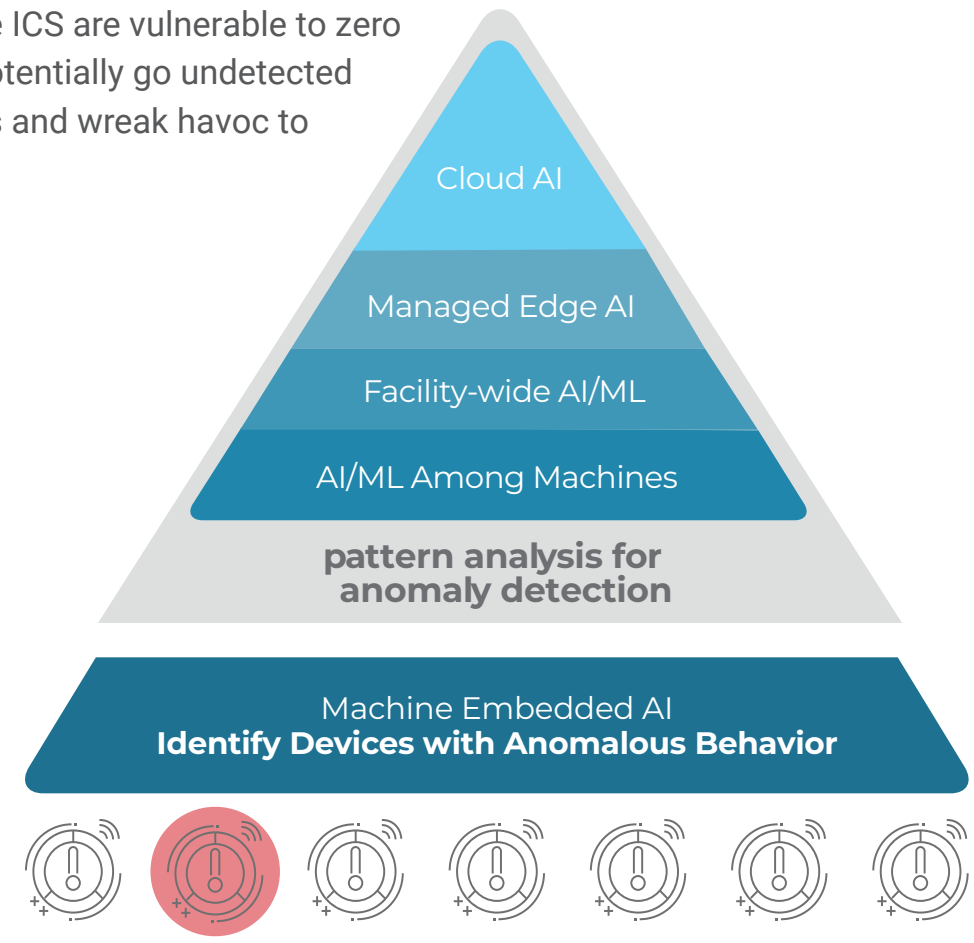
Use Case: Manufacturing Production Workflow Management

It is common for manufacturing facilities to have duplicate machines and parallel production lines to meet their output demands. Effective Edge AI hierarchies for condition monitoring and predictive maintenance, enable manufacturers to benchmark and estimate the relative condition of their production lines. With this intelligence, production workflows can be prioritized for high performing, and maintenance activities prioritized the poorly performing, production lines. Since operational workflow solutions typically incorporate IT functions, this use case is an example of OT/IT integration, where AI derived machine data and intelligence has the potential to create tremendous business value for a manufacturer, or other industrial company with duplicative infrastructure.

MicroAI's embedded Edge-native AI solution set incorporates standardized APIs to expose machine data and intelligence to higher level OT and IT systems, including operational workflow management systems.

Use Case: Industrial Control Systems (ICS)

ICS, across a variety industries – like manufacturing, oil and gas, defense, agriculture, mining, to name a few -- commonly operate in hostile environments and are vulnerable to large attack surfaces from which they can be compromised. Since bad actors are continually evolving their attack strategies and are attracted to large scale systems which can contain a variety of ICS, it is not sufficient to implement static security solutions that only address known vulnerabilities. Technology platforms like ICS are vulnerable to zero day attacks, which can potentially go undetected for extended time periods and wreak havoc to adjacent systems. This has led to vibrant innovation with AI techniques that are well suited to the MicroAI solution set. MicroAI's AtomML learns and continuously adapts to normal operational conditions and rapidly identifies anomalous behavior. This behavior can be continuously monitored in individual ICS using the embedded MicroAI and with pattern analyses amongst many systems using standardized APIs to enhance the anomaly detection and security protection capabilities.



Use Case: Medical Devices

Medical devices such as insulin pumps, continuous glucose monitors, and cardiac rhythm management devices must all respond to individual trajectories of disease and overall health, changes in the context of a patient and be capable of learning from an individual's health data profile. If a person is exercising versus sedentary or sleeping can have an impact on the biometrics that are monitored by devices. Feedback to patients should be in real-time and will increasingly also include data from other devices such as wearables, voice assistants or ambient monitors that provide more data on the context of the patient. This requires more complex models and a smaller computational footprint to be practical to health systems monitoring entire populations of patients. Edge-native AI applications will be essential for providing patients and providers with real-time monitoring of serious health conditions. Virtual care and the use of remote patient monitoring are accelerating due to the COVID-19 pandemic and creating tremendous demand for advanced AI-driven devices.

Another growing concern with medical devices is the threat of cyberattacks. The FDA has warned of the growing risks as devices become more complex. Fears of ransomware and other forms of cyberattacks against medical devices are increasing to where we can imagine a patient being held hostage of a device being turned off in exchange for ransom as a question of when, not if it will happen. Edge native solutions such as MicroAI enable both the real-time analytics and lighter computational

Conclusions and Recommendations

Machine data and intelligence provides tremendous operational value to industrial companies, particularly as they pursue digital transformation initiatives. Since machine data is typically voluminous and sparse, highly interdependent and time sensitive, valuable data insights cannot be harvested using traditional operational data management platforms. Instead,

> **The machine data and intelligence gleaned from embedded Edge AI systems provide operational insights that are of tremendous value**

embedded Edge AI solutions that can efficiently harvest, analyze and act upon machine data are needed. These embedded solutions require compact compute footprints and extensive self-learning capabilities to achieve the performance and scalability demands of typical industrial environments.

The machine data and intelligence gleaned from embedded Edge AI systems provide operational insights that are of tremendous value to a broad range of digital services, spanning multiple machines, other industrial systems and even entire facilities. This creates the need for Edge AI hierarchies, which allow for the aggregation and flow of data and intelligence amongst different OT and IT functions within industrial environments. This cannot be achieved with Edge AI point solutions. Instead, standardized APIs, such as those associated with the MicroAI solution set, are needed to expose machine data and intelligence amongst machines and other OT and between OT and IT systems.

MicroAI's Edge-Native AI solution promises to democratize edge AI by reducing the costs and complexity of implementation across numerous verticals. The combination of personalization, contextualization and scalability through lower costs offers the opportunity to create a new generation of apps with devices at the edge generating real-time insights and solutions.

To accelerate markets and businesses, Topio Networks offers detailed data insights and natural language analysis about the shape, structure and sizing of the thousands of use cases, verticals and technologies that are the building blocks of the fourth industrial revolution. Our data is constantly fed by the daily insights generated by our taxonomy driven, human curated AI Platform. The Topio Networks Market Intelligence Center provides free access to our industry research with detailed data about market sizing, innovations, funding and marketing activities for each specific use cases, industries and emerging technologies.

In addition, Topio Networks offers acceleration services to businesses by providing the content necessary to develop their go to market strategies, by tracking the company content and mapping it to the best practices of the industry and providing market access through events and lead generation.

To learn more about how Topio Networks applies AI and Natural Language Processing to create comprehensive research about thousands of use cases, **click here** .

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