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EIGHT KEY CONSIDERATIONS WHEN IMPLEMENTING

AI IN MANUFACTURING

PLANNING FOR SUCCESS IN YOUR JOURNEY TO IMPLEMENTING AI

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A FOUNDATION FOR AUTONOMOUS MANUFACTURING

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With the emergence of regulatory, socio-economic, and pandemic concerns, manufacturers are accelerating their artificial intelligence (AI) and data analytics efforts to meet the need for more autonomous manufacturing lines.

Autonomous manufacturing

Why the high hopes for autonomous manufacturing? The key drivers for autonomous production systems are to enable machines to improve their own performance and make insightful decisions that can be acted on by industrial systems, like manufacturing execution systems (MES), material requirements planning (MRP), and enterprise resource planning (ERP).

Role of AI

AI enables machine decision-making that can be used for quality control, preventive maintenance, throughput optimization, etc. Those companies willing to invest in AI will continue to lead the manufacturing industry.

AI and Industry 4.0

The concept behind Industry 4.0 is largely to attain higher levels of digitalization of industrial environments, enabling greater efficiency, agility, and productivity through real-time, data-driven control of industrial operations. AI is a powerful and essential vehicle for increasing Industry 4.0 productivity and efficiency, and for paving the way to autonomous manufacturing.

"Robots already play a central role in this new era of hyper-agility and autonomous production, and their importance to industrial processes will continue to grow. Our own research points to a positive shift in manufacturers' perceptions of intelligent factories and automation," said Christine Boles, Vice President, Internet of Things Group - General Manager, Industrial Solutions Division."[1]

1. Christine Boles, "A Faster, Simpler Path to AI-Enabled Robotics: The UP Squared RoboMaker Developer Kit, Powered by Intel and AWS, February 26, 2020, https://blogs.intel.com/iot/2020/02/26/faster-path-to-ai-enabled-robotics/#gs.bsllfp.

This document takes you through key considerations when implementing AI with an eye towards autonomous manufacturing. Some of the concepts discussed here are also covered in more detail in two similar Intel documents on edge computing and 5G in industrial environments.

INTEL MANUFACTURING SURVEY[2]

145 manufacturing participants across 133 companies

59% of manufacturing participants wanted "intelligent" solutions to take on manual or labor-intensive jobs.

62% wanted smart machines that can partner with humans to complete tasks.

10 Benefits of More Adaptive and Autonomous Manufacturing

1. ***Continuously optimize production line performance***
2. ***Automatically identify root causes of process issues***
3. ***Swiftly react to production quality variances***
4. ***Quickly respond to production flow changes***
5. ***Rapidly reconfigure and repurpose production lines***
6. ***Increase coordination between production equipment***
7. ***Eliminate error-prone human intervention***
8. ***Decrease the need for manual reprogramming***
9. ***Minimize downtime with equipment self-diagnostics***
10. ***Implement tighter control limits***

WHAT IS AUTONOMOUS MANUFACTURING

Manufacturers are implementing Industry 4.0 concepts to make their processes more intelligent and agile, enabling them to better respond to market uncertainties and customer demand for greater personalization and fulfillment flexibility.

This phase, called the intelligent or smart factory, will be followed by autonomous manufacturing – a phase with higher digital intensity that allows manufacturers to greatly reduce or eliminate human intervention at the operations level. Moreover, production processes will continuously improve through the ability of manufacturing equipment to make decisions and self-optimize.

Human intervention

Some participants in an Intel survey of manufacturers stated the future factory, even if run by robots, still needs humans on premises — just in case.

Higher digital intensity

Autonomous manufacturing is founded on the control of a holistic view of quality and production data from start to finish. Two essential digital requirements are:

A data-model-driven view of production

This view adapts to learnings from AI, machine learning (ML), and deep learning (DL) technologies.

Software-defined control systems

Control systems have the flexibility to carry out manufacturing process enhancements determined by AI, ML, and DL technologies.

GLOSSARY OF ACRONYMS

AI	Artificial intelligence
COTS	Commercial off-the-shelf
DL	Deep learning
ERP	Enterprise resource planning
FPGA	Field-programmable gate array
GPU	Graphics processing unit
IA	Intel® architecture
IoT	Internet of Things
IIoT	Industrial Internet of Things
IT	Information technology
MEC	Multi-access edge computing
MES	Manufacturing execution systems
ML	Machine learning
MRP	Material requirements planning
OT	Operational technology
ROI	Return on investment
SDM	Software-defined manufacturing

2. Drs. Irene Petrick et. al., Industry 4 .0 Demands the Co-Evolution of Workers and Manufacturing Operations, https://newsroom.intel.com/wp-content/uploads/sites/11/2018/04/abstract-intel-manufacturing-research.pdf

Software-Defined Manufacturing

Industry 4.0 is facilitating a move to software-defined manufacturing (SDM) systems that are much more flexible and agile than today's fixed-function, monolithic manufacturing systems. SDM decouples manufacturing software and hardware, so processes and tasks, like "predictive analysis," can be run on different general-purpose hardware platforms, such as edge computing devices or IoT gateways. SDM systems also enable autonomous manufacturing by providing manufacturers the flexibility to dispatch AI algorithms where and when they are needed.

Microservices

Software processes and tasks can be realized as microservices designed to simultaneously run on a wide variety of platforms, and dispatched and terminated as needed. Typical microservice categories are:

- **Application services**
  Extract, process/transform, and send sensed data to an endpoint or process.
- **Device services**
  Control and interact with manufacturing devices, like sensors and actuators.
- **Core services**
  Provide intermediary communications and a data repository between manufacturing devices and IT systems.
- **Analytics services**
  Perform complex AI-based actuation based on sensor data.

Microservices framework

An example of a framework supporting microservices is EdgeX Foundry*, an open source project under the LF Edge* umbrella within The Linux Foundation* that provides a key ingredient and a forum for participants to collaborate. EdgeX Foundry's framework has reached more than five million container downloads. Figure 1 shows examples of microservices deployed on an edge computing device.[3]

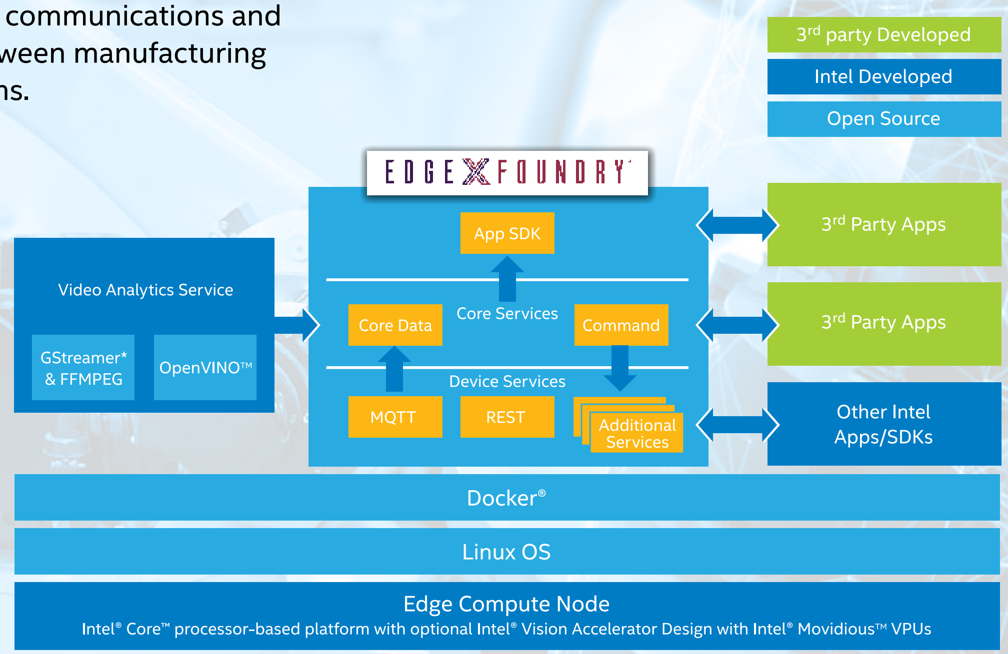


Figure 1. EdgeX Foundry Solution Example.[3]

3. Intel website, "The Open Retail Initiative," https://www.intel.com/content/www/us/en/retail/open-retail-initiative.html

Eight Key Considerations When Implementing AI in Manufacturing

The journey to implementing AI within a software-defined manufacturing framework can be complicated and require significant upfront planning, including making decisions in the following eight areas:

1. Establish Clear Goals

Manufacturers just starting an AI deployment program have many decisions to make. At the top of the list is establishing program goals, which could include improving product yield, defect detection, equipment availability, or all of the above.

Next is deciding which applications to tackle and in what order. Consider which AI microservices provide the best return on investment (ROI) and would benefit most from deployment flexibility.

Quick win

Deploying an AI solution doesn't have to be daunting. A recommendation is to begin with a pilot project, going after some low-hanging fruit for a quick proof-point on ROI.

Interorganizational cooperation

Consider the relationships between organizations such as information technology (IT), facilities, operations, and the project team. Is your IT and operational technology (OT) infrastructure converged, giving your operations equipment access to the core IT network and making it easier to link your systems together? It is always better to partner with both IT and OT organizations from the start.

2. Develop Industrial Protocol Convergence Strategy

A fundamental reality of Industry 4.0 is it must be tackled from the bottom up, starting with getting OT infrastructure connected and data normalized. This can be a complex endeavor given the operational domain may encompass many different protocols and communications networks.

Standards body

IIoT technology was created to help solve manufacturing device connectivity and data convergence issues, reinforced by powerful open standards. One of a wide range of open standards bodies focused on industrial manufacturing is the Open Process Automation Forum (OPAF), which launched in November 2016.

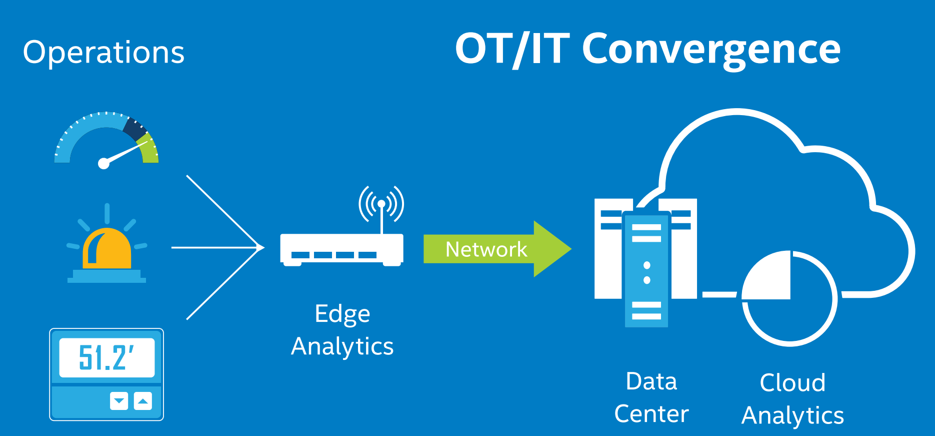
The forum has a diverse membership, consisting of end users, control system manufacturers, control system integrators and suppliers, and academics, as well as other standards organizations. A key objective is to establish a process control architecture that is standards-based, open, secure, and portable.

Machine protocol standards

OPAF is part of The Open Group* and has developed a standards-based, open, secure, and interoperable process control architecture developed through the collaboration of global leaders in process industries, systems integrators, suppliers, integrated DCS vendors, academia, and other standards organizations.

3. Make Databases Ready for AI

Imaging and other AI-based applications tend to generate huge amounts of data that create large implications for databases. It is important to structure databases to store different data types, like images from dynamics pick and place machines



and time-series data for stepper motors. At some point, this data is ingested, stored, and fused, and it may be necessary to perform these applications in near real time.

Database location tradeoffs

Where AI algorithms run, at the edge or in the cloud, has a large impact on databases and application performance. When AI is run in the cloud, vast amounts of data must be sent over manufacturers' networks and stored. This approach can also lead to unacceptable latency, high network bandwidth usage, interruptions due to intermittent network connections, and data security vulnerability.

Another option is to run the AI inference engine on edge computing devices that filter and process data, including making predictions. Since predictions are made at the edge, much less data needs to be sent to the cloud for storage. A small subset of the overall data is sent to the cloud for future AI model training and tuning.

AI links to enterprise databases

A major motivation behind Industry 4.0 is to bridge a company's information systems (e.g., operations, inventory, purchasing, etc.) to provide a centralized view of data across the organization. This requires a convergence of OT and IT infrastructure.

6 Benefits from Applying Open Standards

1. ***Economies of scale enabled by standards and open-source software projects***
2. ***A pool of shared industry knowledge and best practices***
3. ***Access to more solutions vendors***
4. ***Less effort and risk to integrate new technology generations***
5. ***Faster vendor innovation due to market incentives***
6. ***Lower TCO from consolidating existing systems***

4. Understand Software Stack Tradeoffs

AI software development can be rather complex, and deciding how to acquire, deploy, and deliver AI capabilities will have enormous implications on schedules and future scalability.

Make or buy AI software

Is it better to develop AI application software in-house or purchase it from a solution supplier?

MAKE		TRADEOFFS		BUY
Allocate in-house resources with AI expertise	HIGHER –	Development effort	+ LOWER	Integrate third-party software and resolve data incompatibilities
Specify software features based on in-house dev capabilities	HIGHER +	Feature flexibility	– LOWER	Use the standard software package or pay for new features
Control the path to future solution modifications	+ LOWER	Vendor lock in	HIGHER +	Consent to possible limitations working with other suppliers
Plan for software development time and risk	LONGER –	Schedule	+ SHORTER	Deploy faster since software development is done
Situation and solution dependent	TOSSUP	Cost (In-house dev. versus license cost)	TOSSUP	Situation and solution dependent
Maintain an internal support team	HIGHER +	Ongoing support effort	+ LOWER	Get support through the supplier

Proprietary or open source AI software

Is it better to buy AI applications using vendor-owned proprietary software or open source software?

Proprietary Software		TRADEOFFS		Open Source Software
Use the software as it comes from the supplier	TOSSUP	Development effort	TOSSUP	Potentially modify the application, if needed
Deploy the standard software package or pay for new features	– LOWER	Feature flexibility	HIGHER +	Add new features (in-house development or third party), if needed
Accept limitations working with other suppliers	HIGHER –	Vendor lock in	+ LOWER	Control the path to future solution modifications
Situation and solution dependent	TOSSUP	Schedule	TOSSUP	Situation and solution dependent
The cost for modifications may be more	TOSSUP	Cost	TOSSUP	The cost for modifications may be less
Situation and solution dependent	TOSSUP	Ongoing support effort	TOSSUP	Situation and solution dependent

Monolithic or modular, microservices-based infrastructure

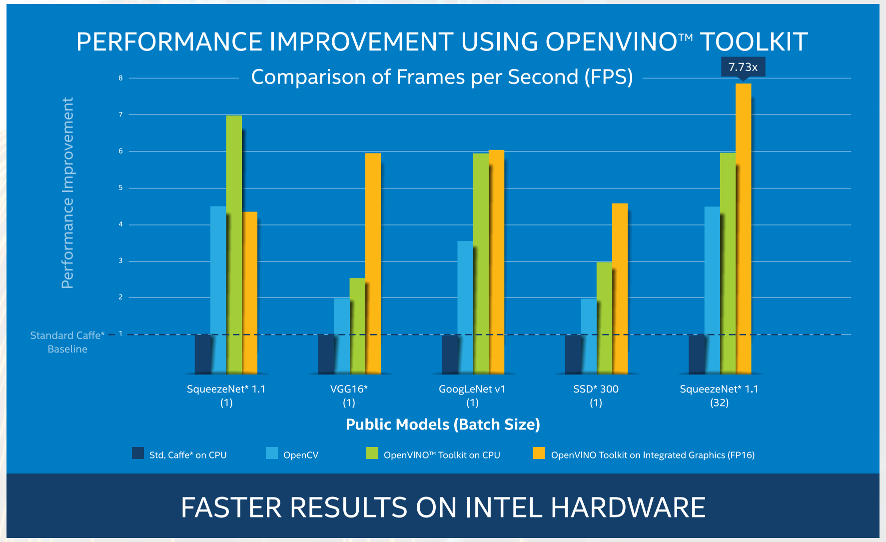
Is it better to have a single, monolithic system running one AI code base or decentralized computing platforms hosting modular AI microservices?

Monolithic		TRADEOFFS		Modular Microservices
Save time by deploying a system that is likely turnkey from one supplier	+ LOWER	Development effort	HIGHER –	Integrate middleware to orchestrate software modules running on various computing platforms
Work through platform compatibility constraints to deploy new features	– LOWER	Feature flexibility	HIGHER +	Create software for a specific job independent of the computing platform
Implement hardware/software solutions offered by primarily one vendor	HIGHER –	Vendor lock in	+ LOWER	Choose which hardware and software to implement
Get started quickly with out-of-the-box solution	SHORTER +	Schedule	– LONGER	Deploy middleware to manage microservices
Pay extra to scale solution and for overprovisioning penalty	HIGHER –	Cost	+ LOWER	Pay less for general-purpose hardware (and over-provisioning) than proprietary hardware
Maintain a large and complex application	TOSSUP	Ongoing support effort	TOSSUP	Manage middleware and distributed hardware

Intel® Deep Learning Deployment Toolkit

An example of open source AI software is Intel's Deep Learning Deployment Toolkit, available via the OpenVINO toolkit. It takes a trained model and tailors it to run optimally for different hardware units like CPUs, GPUs, and FPGAs.

For acceleration on CPUs, the toolkit uses the MKL-DNN plugin — the domain of Intel® Math Kernel Library (Intel® MKL), which includes functions necessary to accelerate the most popular image recognition topologies. The toolkits can also utilize the hardware resources of Intel Processor Graphics to provide a significant performance improvement, as shown by the 7.7 times frames per second speedup compared to a baseline shown below.[4]



4. Intel webpage, "Accelerate Deep Learning Inference with Integrated Intel® Processor Graphics Rev 2.0," https://software.intel.com/content/www/us/en/develop/articles/accelerate-deep-learning-inference-with-integrated-intel-processor-graphics-rev-2-0.html

5. Map Out Hardware Deployment Model

Although IT departments and operations teams have different requirements and priorities, the IIoT can be used to better converge their systems and satisfy broader corporate goals. As more and more data is generated by an ever-increasing number of sensors and production devices, many manufacturers are finding their data centers and cloud infrastructure are getting overwhelmed.

Shortcomings of traditional data centers

An important consideration is where to process data coming from operations. AI-based algorithms are typically hosted in the data center or cloud due to their high computing and storage requirements, but this approach can have significant drawbacks with respect to:

- Sluggish response: Transmission delay to/from the cloud
- High network usage: Massive data transmitted over the network
- Network security risk: Possible data tampering during transmission
- Reliability gaps: Intermittent network stoppages
- Storage system stress: Vast sensor data volumes to be stored.

The right location to process data

On-location AI processing is emerging as a better alternative for real-time, and mission- and safety-critical manufacturing applications. If possible, most data should be processed locally on a computing device at the edge, and only necessary data should be backhauled to remote computing systems.

Hardware deployment

When developing IIoT architecture, consider the economic and performance benefits from spreading AI microservices across the network, as shown in Figure 3.

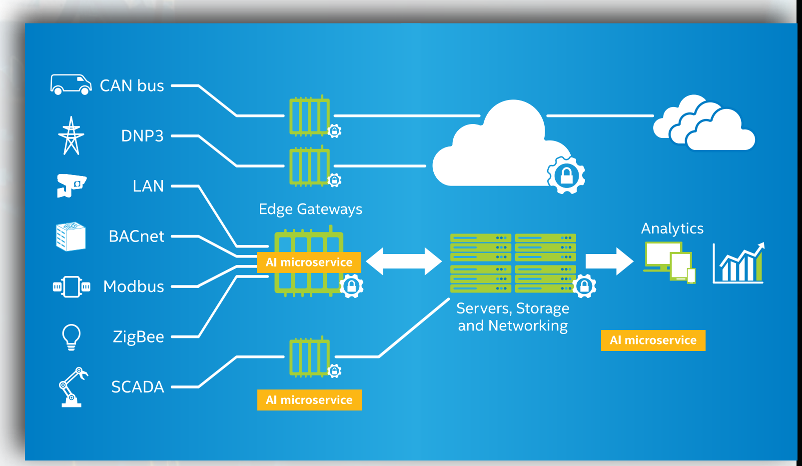


Figure 3. IIoT Archiecture enable AI microservices across the network[5]

5. Intel and Dell, "Build a Bridge Between IT and the IoT," April 2017, https://cdrdv2.intel.com/v1/dl/getContent/612476

6. Take a close look at data security

Industry 4.0 and IIoT technologies enable more smart manufacturing devices to get connected and transmit data across networks, but in turn, can also increase a manufacturer's cyberattack surface.

All data is not equal

Since all data is not equal, categorize it to determine which is most confidential and critical to the company and customers. The more valuable the data, the greater the effort should be to protect it.

Keep data local

Data can be better protected when stored on-premises rather than in a third-party cloud or hosted private cloud. Still, the servers and storage devices in local data centers require their own hardware security, like secure boot technology and data-level security.

Encrypt data at rest and in motion

Data encryption is not 'free,' but it is a very cost-effective way to safeguard data moving across networks. What about data at rest in a storage device or a computing platform? Encrypted data can impact computing performance because it must be decrypted before use, but with today's security accelerators, the impact should be negligible.

Data stored on a processor or in a memory system can be susceptible to compromise by sophisticated hackers. However, Intel® Software Guard Extensions (Intel® SGX) on select Intel® processors helps prevent attackers or malware from gaining access and control of the computing platform, applications, and data. This technology (Figure 4) also helps protect critical applications, even when an attacker has physical control of the platform.

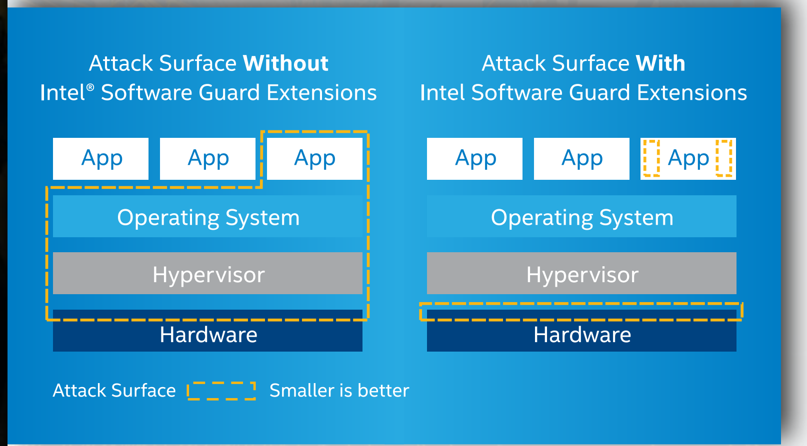


Figure 4. Intel® Software Guard Extensions (Intel® SGX) Reduces the Attack Surface

5G Private Networks

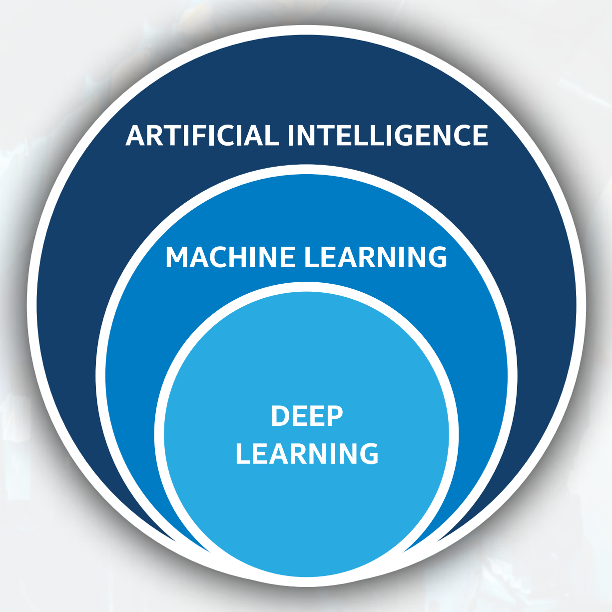
For a data security boost on the production floor, consider deploying 5G wireless private networks that provide highly secure and deterministic connectivity. Exclusive network access offers greater data protection and privacy than public wireless networks.

7. Explore Different Analytics Models[7]

There are many ways to achieve AI. For example, by stringing together a long series of if/then statements and other rules, a programmer can create a so-called “expert system” that achieves the human-level feat of diagnosing a disease from symptoms. In machine learning (ML), a machine automatically learns rules by analyzing a collection of known examples. Machine learning is the most common way to achieve AI today, and deep learning (DL) is a special type of machine learning.[6] The relationship between AI, ML, and DL is shown below.

Machine learning

Machine learning is a class of statistical methods that uses parameters from known, existing data and then predicts outcomes on similar, novel data.



Deep learning

With deep learning, the algorithm does not need to be told about the important features. Instead, it is able to discover features from data on its own using a “neural network.” When teaching a robot how to perform a task using DL, developers provide the DL algorithm with training data consisting of images or models of the task being accomplished. Neural networks can learn how to perform the tasks by analyzing databases that may have millions of examples.

Currently, DL is mainly used to analyze image and video data, but the technology also can support other types of data.

Why deep learning now

Several developments are enabling a deep learning revolution.

Bigger datasets:
The scale of available data has increased dramatically, providing enough input.

Advanced hardware:
Training a typical deep learning model requires a huge amount of computing power.

Smarter algorithms:
Cloud service providers have realized the value of AI and are investing heavilyin fundamental research in the field.

6. Mark Robins, “The Difference Between Artificial Intelligence, Machine Learning and Deep Learning,” May 27, 2020, https://www.intel.com/content/www/us/en/artificial-intelligence/posts/difference-between-ai-machine-learning-deep-learning.html

8. Act on the Analytics

The pace of innovation is quickening across all industries, including manufacturing and the intelligent factories of Industry 4.0. Unlocking the value of data via machine learning is propelling us into this next phase, and innovations in industrial IoT devices are helping manufacturers continually enhance operational efficiency.[7]

Here are some real-world examples of data analytics in action:

AI Helps Optimize Crop Yields

At NatureFresh Farms, greenhouse tomatoes grow in a bed of pulped coconut husks. It is a nutrient-free environment that allows the growers to completely control what goes into the plant. Sensors monitor the fruit’s progress toward perfect ripeness, adjusting light to accelerate or slow the pace of maturation. This kind of farming requires considerable processing power, and NatureFresh Farms uses Intel® Xeon® processors to power its AI algorithms.[8]

AI Engine Accelerated Inferencing

Intel, ADLINK, and Touch Cloud are working together to bring inference acceleration to a wide range of industrial and commercial technologies. In this integrated AI solution, ADLINK provides the optimized hardware platform and connectivity; Touch Cloud, the software application and analytics; and Intel, the IoT gateway processor, Intel® FPGA, and Intel® Movidius™ Myriad™ X vision processing unit (VPU), as well as the OpenVINO™ toolkit for smart vision application development. The AI-based solution is compatible with legacy infrastructure, while achieving the benefits of the IoT.[9]

Robotics Solution Integrates Machine Vision and AI

NexCOBOT, a NEXCOM company, offers a flexible, modular robotics solution powered by Intel® Vision Accelerator Design products. The solution brings together the insight of AI, the mobility of robotics, and the capabilities of machine vision, providing a new level of precision and optimization for manufacturing and industrial implementations.[10]

Deep Learning Brings Touch to Robots

Somatic focuses on adding sensorimotor neural systems and tactile feedback to robotic systems to expand their mapping of the environment beyond visual imagery to include contours, textures, shapes, hardness, and object recognition by touch. The company’s solution, called SenseNet, used Intel’s Reinforcement Learning Coach to help accelerate training and testing of many reinforcement learning algorithms. SenseNet’s API interface is practically the same as OpenAI’s, so integration with Reinforcement Learning Coach was very easy.[11]

7. Christine Boles, “A Faster, Simpler Path to AI-Enabled Robotics: The UP Squared RoboMaker Developer Kit, Powered by Intel and AWS, February 26, 2020, https://blogs.intel.com/iot/2020/02/26/faster-path-to-ai-enabled-robotics/#gs.bsllfp.

8. Intel website, “Intel-Powered AI Helps Optimize Crop Yields,” https://www.intel.com/content/www/us/en/big-data/article/agriculture-harvests-big-data.html.

9. Intel solution brief, “ADLINK and Touch Cloud Deliver AI Solutions Powered by Intel® Vision Products,” October 2018, https://software.intel.com/sites/default/files/managed/79/f7/Intel-Vision-Accelerator-Design-Products-Intel-ADLINK-Solution-Brief.pdf.

10. Intel solution brief, “NexCOBOT Leverages Intel® Vision Accelerator Design Products to Deliver Robotics with AI for Industry 4.0,” October 2018, https://software.intel.com/sites/default/files/Intel-Vision-Accelerator-Design-Products-Intel-Nexcom-Solution-Brief.pdf.

11. Intel website, “Deep Learning Brings Touch to Robots,” September 2018, https://software.intel.com/content/www/us/en/develop/articles/deep-learning-brings-touch-to-robots.html?spredfast-trk-id=sf199047477&utm_source=None&utm_medium=SoftwareInsider

INSIGHTS FROM AN INTEL MANUFACTURING TECHNOLOGIST

Steven Meyer,
Intel Sr. Principal Engineer
in Manufacturing IT

For 25 years, Meyer has been at the forefront of transforming Intel's semiconductor manufacturing from mostly manual processes towards the goal of complete automation.

Is Intel using AI in manufacturing?

Sure. We're performing predictive maintenance on expensive pumps that move chemicals to the production line, so we save money by servicing and replacing them when needed, and not on a fixed schedule. Some of our vision inspection systems now incorporate AI-based quality inspection, significantly reducing the amount of manual inspection required.

Has AI impacted your databases?

By automating our manufacturing, we've also unleashed a data explosion that greatly increases data analysis complexity. Our engineers used to review a very manageable amount of trend charts daily, but now the data curve has grown those charts to unmanageable numbers, so it's like looking for a needle in a haystack. Our new frontier is to have AI algorithms review the data for the engineers and just point out the handful that may be problematic.

Any key learnings from implementing AI?

Early on, we didn't spend enough time on benefits analysis, so sometimes we found ourselves working on the wrong thing. It's really important to do a proper net present value ROI upfront.

Any difficulties implementing AI?

For some pieces of equipment, our engineers want traceability on how an AI or ML algorithm came up with a decision. In other words, engineers want more of a heuristic decision with an explanation when a defect is detected; so a lack of visibility and understanding into an AI algorithm can sometimes be a problem.

How important are standards?

We standardize everything and are active members of a semiconductor standards organization, called SEMI, that has created more than 900 standards for semiconductor equipment. This helps make equipment somewhat plug-and-play, meaning we can use any vendor's equipment for a given process and 95% or more of our software stays the same. As a result, we get rapid time to ramp production because we can get it up and running at peak performance very quickly.

How do you minimize machine downtime?

Our equipment is sourced and installed globally, yet we're still able to keep our factories running and, when necessary, quickly fix equipment thanks to remote operations and remote troubleshooting. And Covid-19 makes us more remote. Our remote operations center technicians are now operating primarily out of their homes. In addition, our equipment vendors aren't able to travel, and they now access equipment through other remote technologies.

Open-Source Building Blocks

Open-source software, based on open standards, gives manufacturers the ability to deploy interchangeable solutions, many of which can run on commercial off-the-shelf (COTS) hardware. Here are a few Intel-sponsored, open-source software products for developing IA-based solutions.

OpenVINO

OpenVINO™ toolkit, short for Open Visual Inference and Neural network Optimization toolkit, enables deep learning inference and easy heterogeneous execution across multiple Intel® platforms (CPU, Intel® Processor Graphics) that span cloud architectures to edge devices.[12]

Intel® Edge Controls for Industrial

This open-source software package accelerates the transformation of industrial control systems to software-defined solutions by delivering a software reference platform with compatible hardware that integrates real-time compute, standards-based connectivity, safety, virtualization, and IT-like management.

Intel® Edge Insights for Industrial

Taking advantage of microservices architecture, this modular, product-validated software enables extraction of edge data (e.g., time series, image/video, and audio) and allows it to be analyzed quickly and securely communicated across different protocols and operating systems.[13]

Open Network Edge Services Software (OpenNESS)

This multi-access edge computing (MEC) software toolkit enables edge platforms to on-board and manage applications and network functions with cloud-like agility across any type of network. It also provides the building blocks for various functionalities such as access termination, traffic steering, multi-tenancy for services, service registry, service authentication, telemetry, application frameworks, and device discovery and control.[14]

Intel® Deep Learning Deployment Toolkit

To utilize the hardware resources of Intel Processor Graphics easily and effectively, Intel provides the Deep Learning Deployment Toolkit, available via the toolkit. This toolkit takes a trained model and tailors it to run optimally for specific endpoint device characteristics and provides a unified API to integrate inference with application logic.[15]

Intel® AI Analytics Toolkit

The toolkit gives developers, researchers, and data scientists familiar Python* tools to accelerate each step in the pipeline: training deep neural networks, integrating trained models into applications for inference, and executing functions for data analytics and ML workloads.[16]

Intel® Data Analytics Acceleration Library

This library helps reduce the time it takes to develop high-performance data science applications. Enable applications to make better predictions faster and analyze larger data sets with available compute resources.[17]

12. OpenVINO* Toolkit, "Visualioze Your Data," https://01.org/openvinotoolkit.
13. Intel's Edge Insights for Industrial, https://www.intel.com/content/www/us/en/internet-of-things/industrial-iot/edge-insights-industrial.html.
14. Open Network Edge Services Software, https://www.openness.org/about#openness-overview.
15. "Accelerate Deep Learning Inference with Integrated Intel® Processor Graphics Rev 2.0," https://software.intel.com/content/www/us/en/develop/articles/accelerate-deep-learning-inference-with-integrated-intel-processor-graphics-rev-2-0.html.
16. Intel® AI Analytics Toolkit, https://software.intel.com/content/www/us/en/develop/tools/oneapi/ai-analytics-toolkit.html.
17. "Intel® Data Analytics Acceleration Library," https://software.intel.com/content/www/us/en/develop/tools/data-analytics-acceleration-library.html.

CONCLUSION

With the emergence of the IIoT and AI, a new kind of data-driven factory is emerging and paving the way for Industry 4.0. It is not just a 'smart factory,' marked by greater machine automation. It is an 'intelligent factory,' defined by hyper-agility.

Intel's flexible solutions, extensive ecosystem, and focus on convergence mak it possible for manufacturers to consolidate data and applications at the edge at a lower total cost of ownership (TCO), driving the deployment of intelligence from edge to cloud and helping realize the power and increased efficiency of Industry 4.0.

Companies choose Intel to help them accelerate the development of data-centric, interoperable Industrial IoT solutions so they can seize the massive innovation potential of Industry 4.0 and gain a competitive technological and competition advantage.

RESOURCES

Big data and IoT are enabling industrial process transformation. Intel and its ecosystem partners deliver industrial solutions optimized for scalable Intel® architecture, designed to reliably interoperate with the entire industrial environment.

Intel® Internet of Things Solutions Alliance
Members of the Intel® Internet of Things Solutions Alliance provide the hardware, software, firmware, tools, and systems integration that developers need to take a leading role in IoT.

Intel® Edge Insights for Industrial
Taking advantage of modern microservices architecture, this solution integrates data from sensor networks, operational sources, external providers, and industrial systems, and allows machines to communicate interchangeably across different protocols.

Intel® Smart Edge
This multi-access edge (MEC) platform is designed for industrial use cases for on-premise enterprise deployments that require low latency, private mobility, simplicity, and open architecture.

Intel® IoT Gateway Development Kits
Intel IoT Gateway development kits enable solution providers to quickly develop, prototype, and deploy intelligent gateways. Available for purchase from several vendors, the kits also maintain interoperability between new intelligent infrastructure and legacy systems, including sensors and data center servers.

For more information about Intel® solutions for industrial automation, visit **intel.com/industrial**.