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Computer vision for product quality

Delivering AI-embedded, industrial IoT analytics for the edge and the cloud

Executive summary

Modern manufacturers are looking for new ways to tackle age-old challenges as they continue to face escalating demands and complexity in today's rigorous markets. This white paper introduces how manufacturers can address product quality challenges with the latest advancements in computer vision by leveraging analytics-driven intelligence wherever it's needed — from the edge to the cloud — and provides industry example applications that demonstrate how computer vision can help manufacturers innovate, reduce costs, and stay competitive.

Manufacturers are facing increasing complexities as they embrace the journey of digital transformation, and Siemens and SAS have responded by partnering to deliver AI-embedded, industrial Internet of Things (IIoT) analytics for the edge and the cloud. Having the right technology, such as computer vision, and processes in place is essential for improving manufacturing quality in key areas, including asset performance and field quality.

Product quality: a core factor of success or failure

The challenge for manufacturers remains the same today as it was years ago: produce a product that meets market needs, is reliable, is delivered on time, and is profitable. While the challenge is consistent and familiar, the ever-changing landscape and shifting dynamics in today's global market have made the road to success more complex and treacherous. Thanks to recent advances in edge and cloud technologies for industrial Internet of Things (IIoT), quality problems can be addressed in a much more cost-effective and robust manner than in the past.

Quality has emerged as a unifying concept, aligning the product lifecycle through design, manufacturing, and the customer experience. More now than at any other time, quality will determine success or failure of the overall business model, requiring companies to re-think their approach. Today's manufacturers face countless issues surrounding product quality and production in general for example:

- Limited visibility and understanding of data from disparate systems and multiple operational processes
- Achieving overall manufacturing yields
- Scrap and rework; the cost of poor-quality goods

A lack of visibility across operational processes hampers a manufacturer's ability to react to changes in product quality and operational performance. Without this information, it's difficult to make fact-based business decisions, leaving manufacturers to rely on employee intuition and guesswork. This can be very expensive if the decisions made are based on incomplete or inaccurate information.

Downstream quality issues can also lead to significantly reduced customer satisfaction rates. This is especially true when problems appear after the organization manufactures and sells the product. If companies can't integrate both manufacturing and post-sales quality data, they don't know where problems are occurring or how to fix them.

The cost of poor quality

Manufacturers set and monitor specific targets associated with product quality because they understand that quality is a critical driver of profitability and overall success. Those who are responsible for specific targets are on the front line. And that front line is a complicated production environment with hundreds, if not thousands, of variables affecting end-product quality.

As quality excursions rise in the production environment, scrap rates can skyrocket, making it critical for quality engineers to be able to quickly identify and address the root cause. But with so many data points in different formats from many sources, it is easy to lose valuable time and production capacity. To achieve higher manufacturing quality at a lower cost, it is essential to be able to corral all production and process data so

Product quality challenges manufacturers face today

- **Disconnected view of enterprise quality**
  Disparate and isolated data sources limit a manufacturer's ability to see quality issues across the entire operation. Without such a holistic view of the data, companies are often unable to solve underlying quality problems or make improvements.
- **Failing to achieve yield and throughput goals**
  The inability to know when quality control problems arise harms yield and throughput goals. Without the ability to know when a failure will happen and how to prevent it, manufacturers must rely on human intervention, which drives down yield and throughput.
- **Excessive scrap and rework**
  Poor-quality goods that result in high rework and scrap costs can devastate a company's bottom line. Without a clear understanding of quality effects on manufacturing and service costs, organizations can be left with a broken business model, unexpected expenses, and reduced yields.

manufacturers can analyze quality issues and explore improvement areas, as well as predict end of line quality and know when targets will be missed. If companies can't maximize yield and throughput while reducing scrap, energy, and rework costs, they can't meet customer expectations or profitability metrics.

The cost of poor quality can be broken down into four categories:[1]

1. Under utilization of assets in the production process. Companies plan extra capacity in their assets to accommodate lost production due to scrap, rework, and unplanned downtime of those assets.
2. Scrap and rework itself. Both incur additional cost in the manufacturing process through use of extra raw materials and labor.
3. Warranty costs. Most industrial products carry a warranty, and warranty costs increase when low quality products enter the market.
4. Lost sales, which really speaks to a company's brand. Strong brands enable companies to maintain market share and price resulting in profitability. Quality issues experienced by customers can negatively affect the company's brand.

To achieve higher manufacturing quality at a lower cost, it is essential to be able to corral all production and process data so manufacturers can analyze quality issues and explore improvement areas, as well as predict end of line quality and know when targets will be missed.

Addressing quality challenges with computer vision

Computer vision is a field of artificial intelligence (AI)[2] that trains computers to interpret and understand the visual world. Using digital images from cameras and videos combined with deep learning[3] models, machines can accurately identify and classify objects — and then react to what they "see." From spotting defects in manufacturing to detecting early signs of plant disease in agriculture, more accurate diagnostics, quicker drug development, and better research, computer vision is being used in more areas than one might expect.

In high-speed manufacturing, being able to quickly detect good parts from faulty ones can reduce waste dramatically by allowing operators to take timely corrective action before the product hits the market. In complex manufacturing, computer vision can reduce warranty claims and improve customer satisfaction by identifying flaws that may have escaped attention before products were shipped. And when quality problems are reduced or eliminated, sustainability efforts are advanced — no additional natural resources are needed for rework and no scrap is sent to the landfill.

Benefits of improving manufacturing quality

Increase production yield
- Reduced scrap, waste, and rework
- Reduced warranty claims and aftersales defects
- Lower safety stocks
- Lower water and energy usage
- Less waste to landfills

Increase production line throughput and lower energy use
- Lower energy use and pollution to produce the same amount of end product

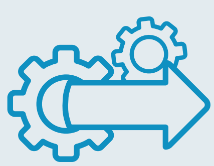
Increase end-product quality
- Enhanced customer satisfaction, margins, and brand value by enabling products with first-class quality, which are available on time and meet or exceed customer expectations
- Reduced number of warranty claims and/or product recalls

How computer vision works

Computer vision works in three basic steps:

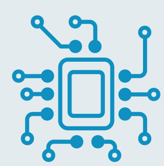
Acquire an image

Images, even large sets, can be acquired in real-time through video, photos or 3D technology for analysis.



Process the image

Deep learning models automate much of this process, but the models are often trained by first being fed thousands of labeled or pre-identified images.



Understand the image

The final step is the inferencing step, where an object is identified or classified with a certain probability.

Thanks in part to computer vision and AI, today's IIoT-enabled manufacturing systems can go a step further — they can also take a variety of automated actions based on detailed understanding of captured images.

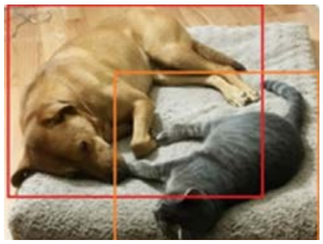
Examples of computer vision in action

Analyzing the images – deep learning

Image classification

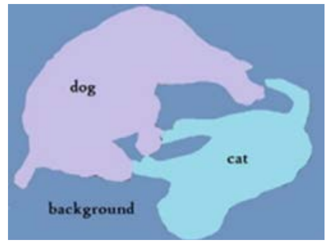
Most of the popular convulutional neural network models for image classification such as VGG, ResNet, and Darknet

Object detection



YOLO-v1, YOLO-v2, Faster R-CNN

Image segmentation



UNET for semantic segmentation Mask R-CNN for instance segmention

Keypoints detection

Image regression and multi-tasking learning for keypoints detection

Figure 1: Basic tasks of computer vision[4]

Computers are trained to achieve one or several of the following basic tasks:

- **Image classification** refers to the task of labeling an image as belonging to one of several predefined categories, based on the main content in the image. The image in Figure 1 could be classified into categories such as animal, dog, or cat — this is typically how image classification works.
- **Object detection** can achieve classification and localization of different objects in an image at the same time. Object detection finds the objects of interest and draws a bounding box around each object, so you know which object it is and where it is located.
- **Semantic segmentation** classifies each pixel of an image into one of the predefined categories, creating a mask image that shows the exact boundaries of each object. The third image in Figure 1 has three semantic categories: dog, cat, and background. In semantic segmentation, each pixel is assigned to one of these three categories, identifying the exact boundaries of the dog and the cat. In addition, instance segmentation differentiates pixels that belong to different instances of the same object type.
- **Key points detection** involves detecting multiple interest points in an image simultaneously, such as facial landmark detection. In Figure 1, the eyes, ears, and noses of the dog and cat are detected.

Analytics with computer vision systems helps:

- Inspect MORE
- Inspect FASTER
- Inspect ACCURATELY

Computer vision from the edge to the cloud

Edge

With the massive amount of streaming data being generated and processed every day, edge computing has become an exciting facet of the IoT. Edge computing helps fill gaps that cannot be tackled with cloud computing alone, particularly when dealing with computer vision.

Edge computing is recognized as an element in distributed computing where data is processed at or near where it is generated by things and people - at the edge. Edge devices are pieces of hardware which allow for local processing of data from the systems they are connected to, but which can be managed centrally from the cloud.

Effective use of edge processing means that instead of transmitting data, including videos and images, to the cloud for computer vision detection, the data is processed by hardware located near the same physical locations where the images or video are captured. This means that, unlike cloud-based computing where the relatively large data sizes for image and video files make real-time processing prohibitive, moving models to edge devices allows a stream of images from camera or other input buffers to be continuously processed locally. This enables immediate detection, classification and segmentation of objects (known as scoring), and allows AI to be deployed to use cases, which necessitate immediate reaction to changing data such as interactive production optimization.

Siemens MindSphere® IoT as a service solution enables the distribution and management of machine-learning models to edge devices, where integration with SAS® Event Stream Processing allows for extremely low-latency reaction to events. This allows for a variety of time-sensitive use cases, while still enabling management of the platform from the cloud.

Edge computing is advantageous in three aspects:[5]

- **Speed:**
  The strongest driving force for edge computing is its speed. Without edge computing, an autonomous car would need to scan the road using local cameras, send the images to a cloud data center for analysis, and then receive the computed data from the cloud for display. Completing that entire process would take a considerable amount of time, whereas edge computing can reduce latency by fulfilling all the steps on the car's computer. The processing algorithm runs locally and saves the device-to-cloud round trip, thus making it possible to build more responsive applications that avoid data transfer and achieve real-time reactions.
- **Security and privacy:**
  Moving large volumes of data over a network is fraught with risk – even with the best possible security in place. Edge computing can improve security and privacy by limiting the amount of data being transferred over the network. Leveraging intelligent filtering techniques can help filter out redundant data, which can significantly reduce volumes. Isolating large amounts of data in a localized environment avoids the transfer over networks, reducing the overall footprint of potential vulnerability.
- **Cost-effectiveness:**
  With massive amounts of data generated and processed each day, it is not practical to constantly build or upgrade data centers for data storage and transfer. In fact, it is nearly impossible to store all of today's continuously generated data; especially high-dimensional data such as images and videos. Furthermore, most of the data are completely irrelevant and only a small portion is worth storing. The strategic use of capable edge devices makes things much easier. After data stream in and are analyzed, any data that do not trigger an alarm can be discarded and the end user is also free to apply further business rules related to data retention if so desired.

What is streaming analytics at the edge?[6]

Streaming analytics extracts insight from data before it's stored in a static operational data store, data warehouse, or data lake. Whereas traditional analytics processing imposes unnatural breaks in information flows and latency, streaming analytics operates against the organic stream of data flowing from digital systems.

The ability to analyze data while it's in motion (i.e. streaming) enables organizations to respond to events as they logically unfold in real time. As a result, streaming analytics is being applied to a wide variety of use cases in which situational context and responsiveness are paramount. When streaming analytics is applied to data from devices or systems outside the traditional enterprise network, it's referred to as edge analytics.

The move to the edge is the emerging frontier in digital transformation. That said, streaming analytics can be applied to information flowing out of everything from traditional enterprise applications to social media and other digitally native services. As a result, streaming analytics applications exist on the edge, in the cloud, and everywhere in between.

Cloud

The advent of the cloud was a major turning point for manufacturers as they look to keep up with the escalating complexity and demands of modern manufacturing, including the need to innovate, reduce costs, and remain competitive. The cloud continues to be relevant even as edge processing starts to become common. Without the ability to centralize data from connected devices, the AI models which are used in edge-processing architectures cannot be effectively trained. Additionally, the central management of those models, connected IoT devices and data they generate, is key to creating a standard digital platform across organizations.

MindSphere, a leading cloud-based suite of IIoT solutions and services, is uniquely positioned to provide these centralized capabilities. And, through open integration with edge devices from Siemens and other industrial hardware manufacturers, as well as a robust ecosystem of partners, MindSphere enables effective extension of analytic capabilities — including the use of computer vision to improve product quality — to the edge.

Edge to cloud deployment

Today's operators are immersed in high-performance environments with a rapidly expanding number of IoT devices and connection points, turning the IoT into the de facto state of things. The cloud enables operators to manage the massive volume of data that the IoT generates by securely storing and accessing it as it's needed. But to take full advantage of the data flowing from IoT devices in the manufacturing environment, operators must understand the value of intelligence at the edge. This is not to say that a cloud strategy will take a back seat to edge; actually, they're complementary strategies. Advances in computing, light-speed communications, and analytics make it possible to create analytics-driven intelligence wherever it is needed, from the fringes of the network to the cloud.

"The future of Industry 4.0 depends on edge computing."[7]

Think about the data lifecycle in a manufacturing environment. Data can travel from industrial assets to a data center. In this scenario, a machine generates data that usually requires format or protocol conversion to make it useful in decision making. Once formatted, the data is moved to either on premises or the cloud. When it goes to the cloud, it gets transported to one or several physical servers – a process that significantly impacts latency. Processing data at the edge allows workloads to be managed and analyzed where the data is generated — closer to network endpoints than a centralized data center or cloud.

What value does this produce for manufacturers? Many! But here's just one example: Is yield or overall equipment effectiveness (OEE) decreasing on the shop floor? With edge capabilities, manufacturers can see what's happening with a specific machine and make real-time decisions at the source that can improve manufacturing quality on the spot – significantly reducing the latency inherent in having to access that data from the cloud.

Manufacturers can quickly get more value from their IoT data with edge-to-cloud deployment. Consider these steps to prepare for deployment:

Analyze data close to where it originates. An in-memory, streaming analytics engine designed to be deployed at the edge, close to where data originates, can deliver advanced analytics for faster and more accurate decisions to help you understand events while they're in motion.

Understand what's relevant up front. Use new ways of analyzing event streams, such as a "stream, score, then store" process, instead of the traditional "stream, store, then score" approach.

Extend intelligence where it's needed. Move intelligence to the edge — to smart devices or processor-equipped sensors — and analyze streaming data with an array of advanced analytics, including AI and machine learning.

Example applications[8]

Addressing manufacturing quality challenges with computer vision

Food and beverage

Description
Although baking bread or pastries may seem like a simple task that many can perform well in the comfort of their own kitchen, manufacturing of baked goods at large scale presents several challenges. Appearance of the baked product is crucial in the eye of the customer, and many returns are driven by the way a product looks versus the way it tastes.

Challenges
- 100% inspection by workers is too costly
- Escaping defects cost exponentially more than non-escaping defects as additional investment is made in packaging, transportation, stocking, etc.

Results
- Quick training of computer vision models to recognize defective products (i.e. proper shape, symmetry, color, icing layout, etc.)
- End-of-line cameras with edge device and streaming analytics enable real-time processing at line speeds for 100% inspection in automated fashion

Automotive

Description
Automobile manufacturers leverage a wide array of technologies and subsystems to optimize functionality and cost. The hydraulic subsystems are critical as they are used for braking and power steering; two of the most important factors in control of a vehicle. Within these hydraulic systems, the high-pressure lines or hoses are critical in system functionality. Driven by the sheer diversity of vehicle designs, there a multitude of hydraulic hose variants being manufactured every day to feed busy automotive manufacturing lines.

Challenges
- Large number of hose variants
- Manual inspection is costly and inconsistent

Results
- Computer vision models trained to identify and classify different defect types (i.e. cuts, gouges, drag marks, etc.) with 99%+ accuracy
- Computer vision based automated end-of-line inspection drives nearly 100% coverage and improves classification consistency over a purely manual process

Medical Devices

Description
Pharmaceutical devices are complex and typically manufactured at large-scale quantities on high-throughput lines capable of 100M+ units per year. Many pharmaceutical companies are embracing digital transformation to realize improved profitability. One aspect of this transformation includes the use of cameras and streaming analytics technology to help automate defect detection on high-throughput lines.

Challenges
- Manual inspection is costly and doesn't detect some types of defects
- High cost of rejected product
- Line availability and throughput below expectation

Results
- 99% accuracy in defect identification and classification
- Line availability improved 5+%
- Line throughput improved 3+%

AI can improve manufacturing defect detection rates by up to

90%

Computer vision makes it possible to spot defects not easily visible to the eye.[9]

Featured example application

Surface Mount Technology (SMT) manufacturing process

Description

Surface mount technology (SMT) inspection machines, such as advanced optical inspection (AOI) and advanced X-ray inspection (AXI) machines, are often used for quality inspection of printed circuit boards (PCBs). AOI machines inspect visually available components such as missing or skewed components in PCBs, and AXI machines can look at defects that result from solder joints. In addition to providing images of component parts or solder joints, these machines also provide several measurements of the joints, such as diameter, thickness, eccentricity, and so on. These measurements can be used as additional inputs along with the computer vision models for defect classification. One application of computer vision technology is in the detection of head-in-pillow (HiP) defects from AXI machines. Head-in-pillow is an assembly defect in which the bumps from a ball grid array (BGA) don't coalesce with the solder paste on the PCB pad. Figure 2 compares a HiP joint with a good joint. This photo illustrates that for a HiP defect the solder has melted but has not properly joined to complete an electrical connection. A HiP defect can be caused by several factors such as surface oxidation, poor wetting of solder, or distortion of the integrated circuit package or circuit board by the soldering process heat.

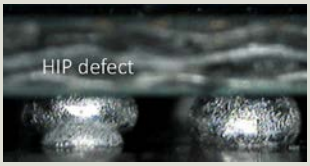


Figure 2: Head-in-pillow defect compared with a good solder joint

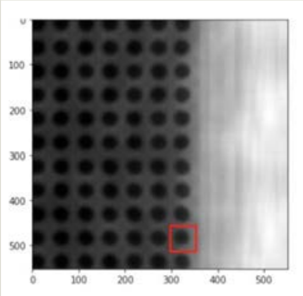


Figure 3: Defective joint shown in the enclosed red box

Figure 3 presents a sample image taken from an AXI machine that shows different joints. The joint enclosed in the red square in Figure 3 represents a HiP-defective joint.

Figure 4 shows the training sample, which consists of two defects and two non-defects. It is evident from Figure 4 that it is impossible to differentiate between the defects and non-defects with the human eye. Figure 5 shows emerging features after the application of image pre-processing techniques.

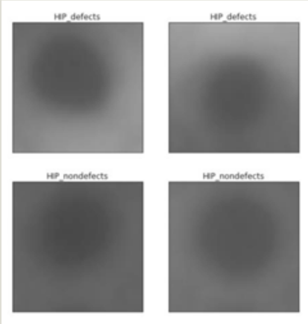


Figure 4 (below): Cropped training samples that consist of two defective and two non-defective joints

Challenges

- Raw images are not optimal for differentiation of defective versus non-defective joints
- Significant manual effort involved in evaluating joint measurement details
- Currently false positive numbers are quite high in the effort to detect defects

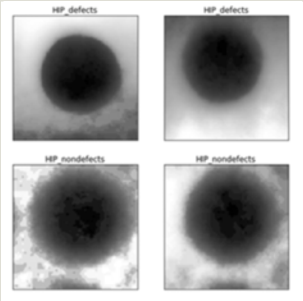


Figure 5 (above): Histogram equalization applied to raw data shows differences between defects and non-defects

Results

- Automated image pre-processing techniques (i.e., histogram equalization and image comparison) are applied to raw images to enhance features that differentiate between the good and bad joints. Computer vision models can achieve significantly high accuracies (> 90%) in the classification of defects and non-defects. There is also significant reduction in manual effort spent in making manual measurements of the joints.

From these examples, it is clear that computer vision offers cross-industry advantages in manufacturing, resulting in fewer defects, greater productivity, cost reduction, and increased profitability.

For a more detailed overview of this example, refer to the SAS Global Forum Paper.[10]

Conclusion

As the landscape of today's global market continues to shift dramatically, addressing quality issues in manufacturing has become an imperative to success.

Manufacturers need to integrate data relevant to quality, productivity, and utilization. They must also monitor the health of processes and drive sustainable quality and yield improvements – all while containing costs. Having the right tools, such as computer vision, and processes in place is essential for improving manufacturing quality in key areas, including asset performance and field quality.

Manufacturers should approach the problem by working with a partner that can help them:

- Take advantage of the large volumes of data generated by IoT.
- Support multiple data domains (including material movement tracking, genealogy data, process data, and asset condition data), using a rich set of interactive root-cause analysis and quality improvement tools that can identify quality issues and operational performance degradations before they become serious problems.
- Gain process understanding across the entire manufacturing operation.
- Employ best practice workflows and case-management capabilities to document findings and problem-resolution measures, while promoting collaboration and knowledge sharing.
- Integrate computer vision systems with the production lines.

Resources / links

Learn more about the Siemens and SAS partnership

SAS resources
Computer vision
Production Quality Analytics
IoT Solutions
Bringing Computer Vision to the Edge: An Overview of Real-Time Image Analytics with SAS®
Streaming analytics: Life happens fast. Are your analytics keeping up?

Siemens resources
MindSphere - the leading industrial IoT as a service solution
Start for Free with MindSphere
AI for Industries

About MindSphere

MindSphere is a leading industrial IoT as a service solution. MindSphere powers IoT solutions from the edge to the cloud with advanced analytics and AI to connect and analyze data from connected products, plants and systems to optimize operations, create better products, and enable new business models. Integrated with the Mendix application platform, MindSphere enables Siemens, its global partner ecosystem and customers to quickly build and integrate personalized IoT applications.

About Siemens and SAS Partnership

Siemens and SAS are partnering to deliver AI-embedded IIoT analytics for the edge and the cloud. By using SAS streaming analytics technology, MindSphere customers benefit from the growing demands for IIoT analytics with AI and ML capabilities. The collaboration creates the most comprehensive, open-compatible AI framework for IIoT.

The partnership aims to help companies create new IIoT edge and cloud-enabled solutions by applying SAS streaming analytics and industrial device management through Siemens' MindSphere. Users gain access to industry-leading SAS advanced and predictive analytics in MindSphere, which can accelerate the adoption of ML and AI in IoT environments. Increased productivity and reduced operational risk through powerful predictive and prescriptive maintenance and optimized asset performance management are just some of the ways these new solutions can benefit customers working in a range of industries.

About Siemens digital industries software

Siemens Digital Industries Software is driving transformation to enable a digital enterprise where engineering, manufacturing and electronics design meet tomorrow. Xcelerator, the comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software, helps companies of all sizes create and leverage a comprehensive digital twin that provides organizations with new insights, opportunities and levels of automation to drive innovation. For more information on Siemens Digital Industries Software products and services, visit siemens.com/software or follow us on LinkedIn, Twitter, Facebook and Instagram. Siemens Digital Industries Software – Where today meets tomorrow.

About SAS

SAS is the leader in the advanced and predictive analytics category, with a market share more than twice that of the next closest competitor. Through innovative software and services, SAS empowers and inspires customers with the most trusted analytics. SAS embeds AI capabilities in its software to deliver more intelligent, automated solutions that help boost productivity and unlock new possibilities. From machine learning, deep learning, computer vision, and natural language processing (NLP) to forecasting and optimization, SAS' AI and IoT technologies support diverse environments and scale to meet changing business needs. SAS is used at more than 84,000 sites in 145 countries worldwide, including 92 of the top 100 companies on the Fortune 500® list. Our vision is to transform a world of data into a world of intelligence.[11]

Siemens Digital Industries Software

Headquarters
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe
Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific
Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3333

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[3] Deep Learning What it is and why it matters

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