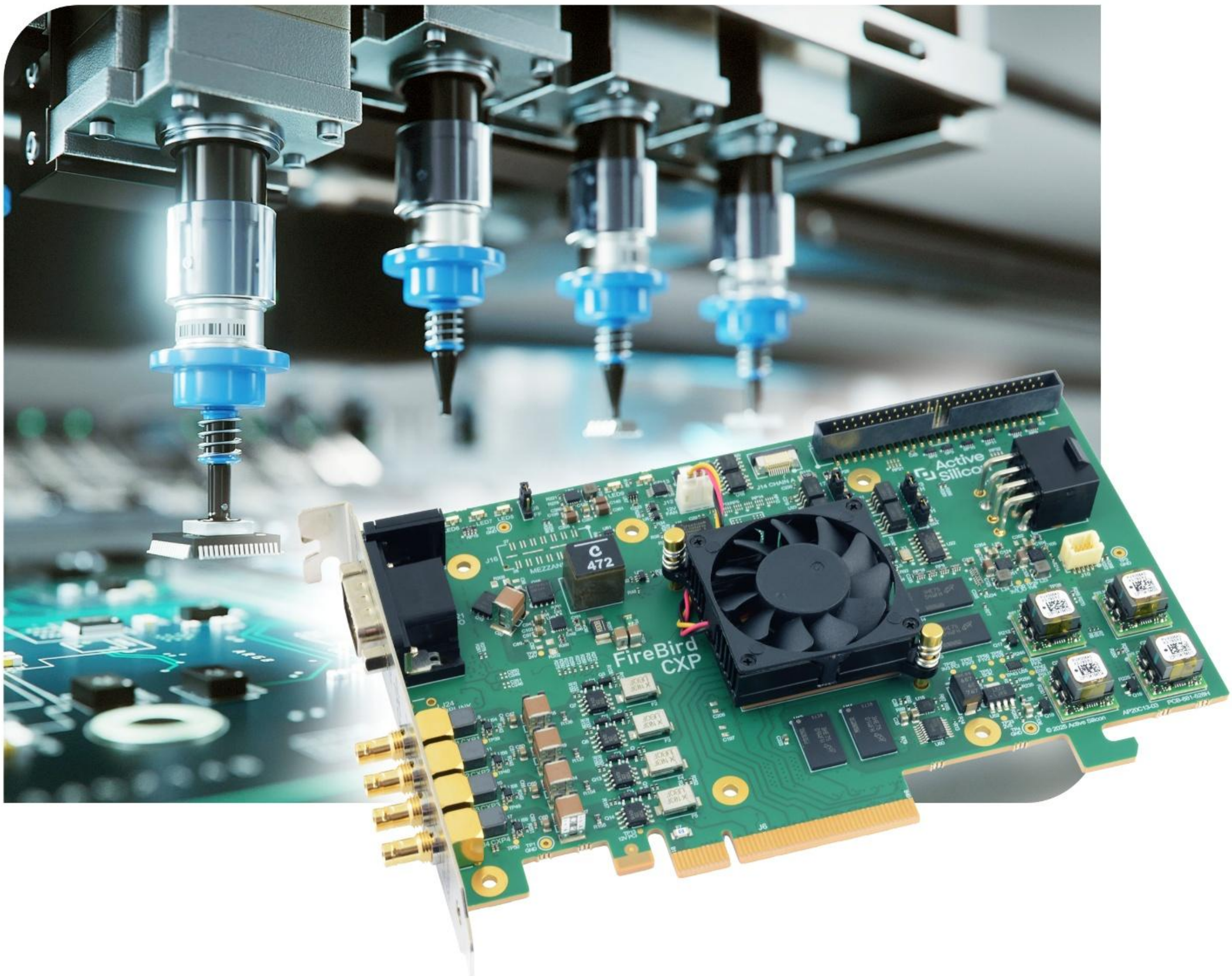
WHITE PAPER

UNDERSTANDING FRAME GRABBERS IN VISION SYSTEMS



Head Office:

Active Silicon Ltd
1 Waterside Court, Waterside Drive,
Langley, Berks, SL3 6EZ, UK.

Tel: +44 (0)1753 650600
Email info@activesilicon.com
Website: www.activesilicon.com

North America:

Active Silicon, Inc.
479 Jumpers Hole Road, Suite 301,
Severna Park, MD 21146, USA.

Tel: +1 410-696-7642
Email: sales.us@activesilicon.com
Website: www.activesilicon.com

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1. Introduction

Frame grabbers play a crucial role in machine vision by capturing and processing high-quality images for a wide range of applications. This white paper explores the intricacies of frame grabbers, their uses, and the technologies that make them indispensable in modern vision systems. Also known as acquisition cards or image capture cards, we will refer to them solely as frame grabbers for the purpose of this white paper.

The paper looks at the constituents of a frame grabber, and the operation of these components. It also covers optimizing a vision system for speed or specialized processing tasks.

We often refer to Active Silicon's CoaXPress, CoaXPress over Fiber, and Camera Link frame grabbers – our FireBird range. You can see more about the options available on our website.

2. What is a Frame Grabber?

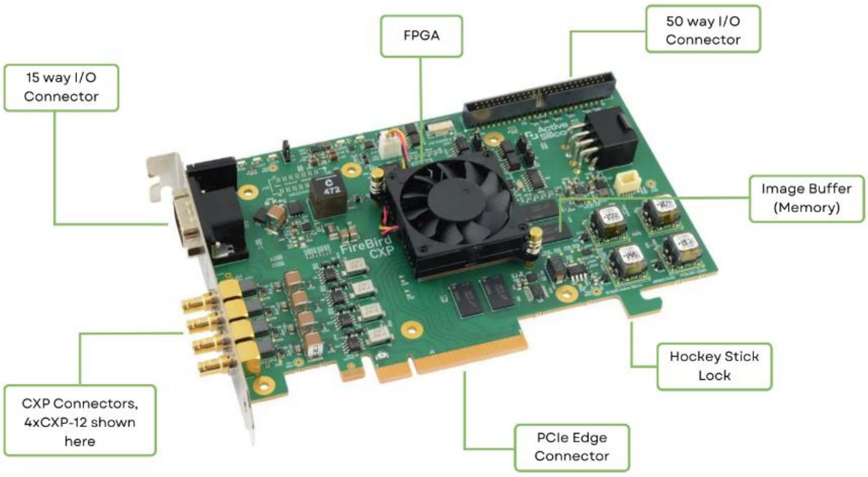
A frame grabber is a hardware component designed to capture images from cameras in real-time. It serves as a bridge between imaging devices (cameras/image sensors) and computer systems, facilitating the transfer and processing of still images or video data.

Frame grabbers usually come in a PCI Express form factor card for easy integration into a main PC chassis, leaving I/O connectors accessible on the end panel.

More robust embedded form factors are also available, for example PCIe/104 (stackable) and CompactPCI Serial (rackmount).

Frame grabbers are used in systems that require high-speed, high-resolution video acquisition without loading the CPU. These systems, such as used in industrial automation, medical imaging, and scientific research setups, need to capture large volumes of data in real time. Frame grabbers are preferred when resilience and reliability are critical because they provide dedicated, high-performance image acquisition with reduced risk of data loss or corruption.

Frame grabbers typically consist of three main components: the front-end interface, the data processing circuitry, and the PCIe bus interface. These components work in tandem to efficiently manage the flow of image data from the camera to the host computer. Different frame grabbers are used to handle various types of camera outputs, including analog, digital, and network-based signals. In this paper we are covering frame grabbers for digital imaging signals and focus on CoaXPress, CoaXPress over Fiber and Camera Link frame grabbers.



3. Benefits of Using Frame Grabbers in Vision Systems

Integrating frame grabbers into vision systems and using interface standards that were specifically developed for the machine vision market, like CoaXPress and Camera Link, offers numerous advantages:

High-speed image acquisition: Frame grabbers can capture images at rates of thousands of frames per second, enabling analysis of fast-moving objects or processes.

Efficient data transmission: Frame grabbers allow transmission of packed data (constant stream) over the connection from the camera, thereby maximizing frame rates while still delivering unpacked data (byte aligned) into the host PC for efficient processing. The data transmission is also at high speed with very low latency.

Offloading image processing tasks: By handling preprocessing functions onboard or moving the data directly to a GPU, frame grabbers reduce the computational load on the host CPU, enhancing overall system performance. This ensures that the system operates efficiently, maintaining high data rates and enabling real-time analysis without delays or performance degradation caused by CPU resource constraints. See 5.8 for more information on GPU processing.

Real-time synchronization: Many frame grabbers support multi-camera setups, ensuring precise timing and synchronization between multiple imaging devices. This capability is also important in line scan applications (a line scan camera captures images one line at a time like the scanner on a photocopier), where consistent timing between the stationary camera and moving object is essential for accurate image reconstruction. See 6.1 for more about triggering.

Advanced preprocessing: Onboard functions such as debayering, color correction, and image enhancement improve image quality before data reaches the host computer. See 5.5 for more details.

4. Basic Operation

Frame grabbers serve as the bridge between the image capture device and the host processing system.

Modern frame grabbers acquire image data through digital input sources. Once the frame grabber receives the image data from the camera, it carefully manages the transfer to ensure image integrity. If the incoming signal is analog, the frame grabber uses an onboard analog-to-digital converter (ADC) to transform it into a digital format suitable for further processing. The digitized or original digital data is then subjected to initial conditioning and synchronization, ensuring that each frame is accurately captured and timed. The processed frames are buffered in the frame grabber’s large onboard memory, allowing for smooth handling of high-speed or high-resolution image streams without overwhelming the host system. This buffering stage is crucial for bridging differences in data rates and for facilitating stable, efficient transfer. Finally, these image frames are transmitted from the frame grabber to the host computer – typically through a high-speed PCIe interface using direct memory access (DMA) techniques – where they become available for further processing tasks, analysis, or long-term storage.

Some frame grabbers also perform basic preprocessing tasks such as noise reduction or image adjustments (delivering a Region of Interest), and may support advanced features like synchronization, triggering (see 6.1) and on-board image compression.

CoaXPress frame grabbers support data integrity through error-checking and validation protocols to ensure that the image data is accurately captured. During operation, a frame grabber receives raw image data from a camera via the high-speed CXP interface. It then buffers the incoming data, applies error detection mechanisms, and validates the data for completeness and correctness.

5. Components and Architecture

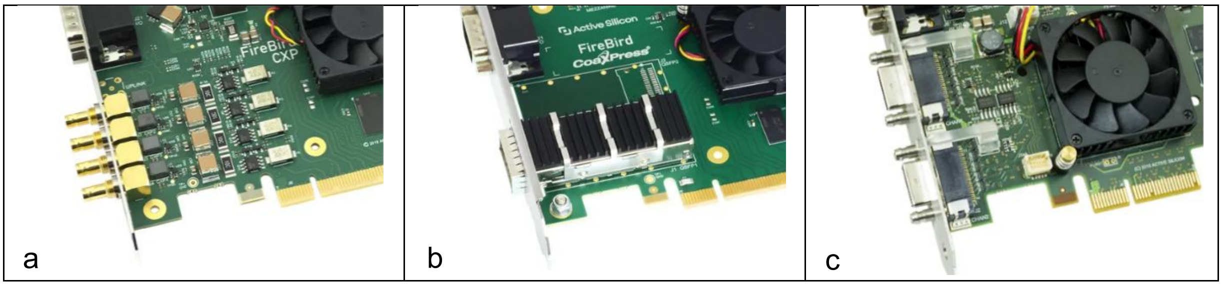
Understanding the architecture of a frame grabber reveals how various components work together to deliver high-quality, real-time image data.

5.1. Input Interfaces

Frame grabbers support a range of physical connections to the cameras. Common machine vision data transmission standards include CoaXPress, CoaXPress over Fiber and Camera Link, offering different bandwidth and performance characteristics.

Some connection types for frame grabbers are pictured below:

a) CoaXPress board with four HD-BNC (micro BNC) connectors.
b) CoaXPress over Fiber board with one or more QSFP+ connectors.
c) Camera Link board with two SDR (mini) connectors.



You can read more about Machine Vision Standards on our [Machine Vision Standards resource webpage.]

5.2. Processing Unit

Modern frame grabbers employ FPGAs for real-time data processing, see 5.9 for more about FPGAs).

5.3. Memory and Buffering

Onboard memory buffers temporarily store image data during capture, ensuring that high-speed data flows do not overwhelm the system. Techniques such as double-buffering help maintain continuous data acquisition, minimizing the risk of dropped frames even in high-throughput applications.

5.4. Output Interfaces

After processing, the image data is transferred to the host system via interfaces like PCI Express (PCIe). The choice of output interface affects latency and overall system performance – crucial factors in applications that demand real-time processing and analysis.

When selecting a computer for a frame grabber, consider the type and number of PCIe slots available, as this determines compatibility and performance. Most modern frame grabbers use PCIe x4, x8, or x16 slots, with higher lane counts (x8 or x16) required for high-bandwidth applications, such as high-resolution or high-frame-rate cameras. Ensuring that the motherboard has the correct slot size and sufficient electrical bandwidth is crucial; some slots may be physically x16 but only support x4 electrically, limiting data throughput.

Thought should also be given to useful features such as “hockey stick” card locks and PCIe card retaining systems for rugged and high-vibration environments.

5.5. Image Preprocessing

Techniques such as noise reduction through digital filtering help improve image clarity. Some systems may also incorporate color correction and calibration routines to ensure that the reproduced images closely match the original scene.

On-board debayering, which converts raw Bayer-pattern image data from color cameras into full-color RGB images in real time is sometimes offered. Extensive software libraries allow further processing functions.

Features such as Region of Interest (ROI) deliver a portion (or portions of an image), and simple manipulations such as mirroring or flipping the image can be done within the grabber.

5.6. Data Formatting

The raw data captured is reformatted into standard image formats such as RGB or grayscale for compatibility with various downstream applications. Additionally, some frame grabbers offer on-the-fly compression options, balancing the need for high resolution with the constraints of storage and transmission bandwidth.

5.7. Error Handling

Frame grabbers include robust error handling features such as data packet validation, status monitoring, and, in the case of CoaXPress over Fiber, forward error correction to ensure image integrity and system reliability.

5.8. DMA Engine and GPU Processing

The DMA engine is a critical component of frame grabbers that enables efficient data transfer between the device and the host computer's main system memory. DMA stands for Direct Memory Access and allows for the movement of data without direct CPU intervention, significantly reducing the processing overhead and improving system performance.

Using the DMA with NVIDIA and AMD’s specific GPUS and GPU Direct for Video and Direct GMA application programming interfaces (APIs) gives ultra-low latency peer-to-peer data transfers from frame grabber directly to the GPU card memory. This provides a seamless path for deeper image analysis and further image processing making the augmentation of your system with Deep Learning or Artificial Intelligence (AI) simple.

5.9. Field Programmable Gate Arrays (FPGAs)

FPGAs are reconfigurable hardware components for parallel processing and can be programmed to perform complex image processing tasks with remarkable efficiency.

Advantages of using FPGAs in vision systems include parallel processing capabilities for handling multiple image streams simultaneously, the ability to implement complex algorithms directly in hardware, and flexibility to adapt to changing imaging requirements through reprogramming. When compared to CPU-based processing, FPGAs offer significant advantages in speed and efficiency for many image processing tasks.

Active Silicon frame grabbers are designed with an FPGA at their heart to allow processing functions that can't be delivered using a processor or standard component. Releasing updates when needed enables our hardware to remain current. Disruption to existing operations is minimized, ensuring that customers' software remains unchanged.

5.10. Customization and Optimization

Frame grabbers can be tailored to meet the specific demands of diverse applications. Many frame grabbers allow users to adjust settings such as exposure time, gain, and other imaging parameters in real time. This flexibility is often supported by comprehensive software controls and intuitive user interfaces provided by the device's accompanying software or drivers. Many frame grabbers and devices today support the GenICam software standard to allow users to interact with them using a standardized API. Read more about GenICam here.

ActiveCapture, the GenICam based front-end software for Active Silicon's FireBird frame grabbers, allows access and control of cameras and frame grabbers. It provides a simple and easy method to configure the hardware system, allowing control of various image acquisition features such as triggering and image resolution.

The software development kit for FireBird, ActiveSDK, contains comprehensive example applications and optimized libraries for a variety of programming languages (see 6.4).

Third-party software applications deliver additional functionality tailored to specific applications. Examples include LabVIEW, which provides unique productivity accelerators for test system development, and MATLAB, a programming and numeric computing platform for analyzing data, developing algorithms, and creating models.

6. Integration and Implementation

When deploying a frame grabber, successful integration and implementation are crucial for ensuring that the high-speed image capture and processing requirements of your system are met.

6.1. Triggering

Frame grabbers are designed to connect cameras and sensors seamlessly with host computers. This is enabled by standardized interfaces such as CoaXPress, CoaXPress over Fiber and Camera Link, ensuring compatibility with a wide range of imaging devices.

Integrating a frame grabber often involves syncing it with camera triggers or external timing signals. Synchronization ensures that the captured frames correspond accurately to the intended events or conditions.

Triggers can be driven by TTL, RS-422 or optically isolated inputs, so are perfect for complex industrial environments. With programmable delays, and complex multi-input triggering scenarios (common for line scan and multi-camera applications), they add the flexibility needed for advanced imaging systems.

Hardware triggers, often used in high-speed applications, provide minimal latency and ensure frame capture at exact moments, while software triggers offer flexibility for less time-sensitive processes. By utilizing trigger inputs and outputs, CoaXPress frame grabbers enable reliable synchronization in applications such as industrial inspection, scientific imaging, and motion analysis. For more detail on this, see our Technical Note Using an External Trigger Input with a FireBird CoaXPress Board.

6.2. Mechanical and Electrical Integration

Form Factor and Mounting: The physical design of the frame grabber must align with the host system's architecture. Some systems require custom mounting solutions or ruggedized enclosures, especially in industrial or outdoor environments.

Power and Cooling Requirements: High-performance frame grabbers may require specific power inputs – typically a PCI Express Graphics PEG connector – to provide power to cameras connected to it, and efficient cooling systems (such as high-CFM case fans, directed airflow over PCIe slots, or GPU-style heatsinks with onboard fans) to maintain optimal performance, particularly in elevated temperatures or continuous, high-throughput applications.

6.3. Software and Driver Support

Robust, well-supported drivers are essential for ensuring the frame grabber communicates effectively with the host operating system. These drivers handle the low-level interactions between the hardware and the system software.

Compatibility: Make sure the driver supports the intended OS (e.g., Windows, Linux) or any real-time operating systems (RTOS) if used in critical applications.

Firmware Updates: Regular firmware updates can address bugs, improve performance, and add features, so an update strategy should be in place.

6.4. APIs and Software Development Kits (SDKs)

Many frame grabber manufacturers provide APIs and SDKs that simplify the development of custom applications. These software tools allow developers to control the hardware settings, capture images, and process data in real time.

For example, an SDK may include libraries for adjusting exposure, gain, or image formats, and might support programming languages such as C++, C#, Python, or .NET.

Image Processing Integration: Software compatibility with image processing libraries (e.g., OpenCV) or proprietary analysis tools is essential for systems that require advanced analytics, such as defect detection or automated quality control.

6.5. User Interface and Configuration Tools

Graphical User Interfaces (GUIs): Many frame grabbers come with dedicated configuration software that allows users to adjust parameters, monitor performance, and visualize captured data in real time.

GUIs reduce the need for deep technical knowledge when configuring the system, making it accessible for operators. Built-in diagnostic tools can help troubleshoot issues, such as identifying synchronization problems or data bottlenecks.

7. Applications for Frame Grabbers

Frame grabbers are used in a wide range of applications. For example:

7.1. Industrial Automation

Frame grabbers are widely used in high-speed production lines for quality inspection, for example electronic circuit board assemblies, flat-panel displays, food inspection, pharmaceutical and metrology. Triggering functionality and high-speed image transfer are key factors in their suitability for these processes.

Line scan applications, such as flat screen inspection, detecting flaws in fabric, paper or EV battery manufacture, rely on frame grabbers to continuously grab an image for high-speed assessment.

7.2. Medical Imaging

Applications include research, diagnostics, and positioning techniques, such as radiation therapy positioning, benefit from the high-quality and high-speed imaging delivered by frame grabbers. Advances in diagnostic techniques requiring even more accurate image capture means that frame grabbers are becoming a more integral component in medical applications.

7.3. Scientific Research

Frame grabbers are also utilized in research and development setups that require high-resolution or high-speed imaging, such as microscopy, and astronomy.

7.4. Broadcast

Frame grabbers facilitate synchronization of multiple cameras for live events, including sports events. Areas like goal-line technology rely on the synchronization of multiple high-speed cameras to validate in-play decisions. Image digitalization of older analog film can also be enhanced with high resolution cameras and frame grabbers.

7.5. New Opportunities

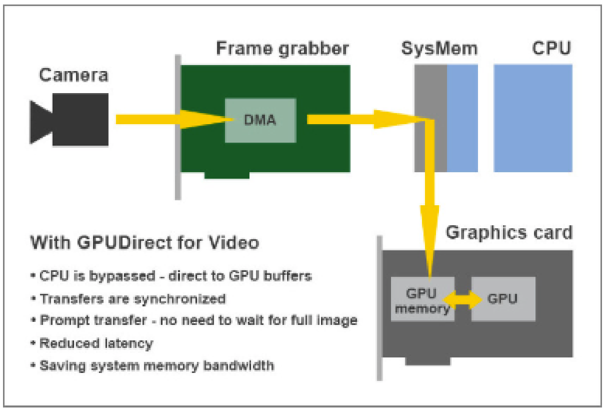
Machine learning (ML) and artificial intelligence are, of course, playing a pivotal role in the growing implementation of machine vision systems by enhancing their ability to analyze and interpret complex visual data. These technologies enable machines to learn from vast amounts of visual information, improving accuracy in tasks like defect detection, object recognition, and quality control.

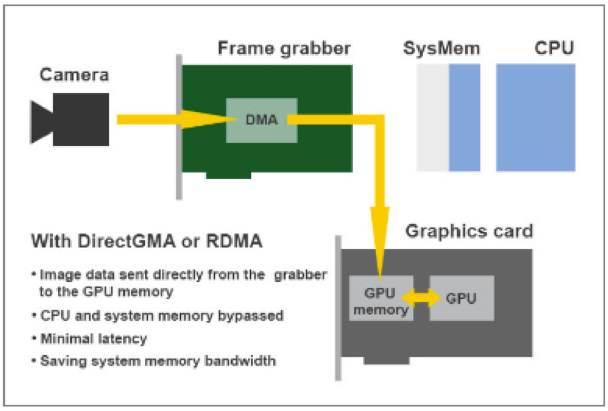
By enabling high-resolution, high-frame-rate image acquisition utilizing GPU processing, frame grabbers ensure that machine vision systems can provide the data needed for ML models to perform tasks like object detection, pattern recognition, and quality assurance with precision. As a result, industries such as manufacturing, healthcare, and logistics are benefiting from more efficient, precise, and automated vision systems, driving their widespread adoption.

8. FireBird Frame Grabbers from Active Silicon

Active Silicon has been designing and manufacturing imaging products for over 35 years and has a deep understanding of creating innovative high-speed acquisition cards.

All FireBird frame grabbers are fully GenICam compliant, providing reliable acquisition in real time and supporting systems with demanding triggering requirements. GPU processing is supported and FireBird frame grabber cards are compatible with both AMD‘s DirectGMA and NVIDIA’s GPUDirect for Video. You can read more about processing on a GPU on our resource page, GPU Solutions.





For a complete vision system, we offer the Oncilla range of machine vision computers – rugged industrial PCs with an integrated FireBird frame grabber, ready for immediate installation and operation.

9. Conclusion

Frame grabbers are vital components in modern vision systems, offering high-speed image acquisition, advanced processing capabilities, and seamless integration with a variety of camera interfaces.

As imaging technologies continue to advance, frame grabbers will play an increasingly important role in enabling new applications across industries, from industrial automation to medical imaging and beyond. The combination of powerful DMA engines, versatile FPGAs, and adherence to established machine vision standards ensures that frame grabbers will remain at the forefront of image acquisition and processing technology for years to come.

As we look to the future, we can expect further innovations in frame grabber technology, leading to even higher data transfer rates, more advanced onboard processing capabilities, and improved integration with emerging AI and machine learning technologies.

For expert advice, industry-leading products, and customized solutions for complex projects, get in touch with the team at Active Silicon and keep up with the developments as they happen.

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Head Office:

Active Silicon Ltd
1 Waterside Court, Waterside Drive,
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North America Office:

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