A study on Multiple-Instance GPU, Evolution, Architecture and Applications

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***Abstract*—Multiple Instance GPU (MIG) is a promising technology for improving the efficiency and scalability of GPU-based systems. MIG allows multiple users or workloads to share a single physical GPU while maintaining performance and resource isolation. This study covers the evolution of GPUs, the architecture of MIG, and various applications of MIG, including virtualization, deep learning inference, and high-performance computing. The study also discusses the architectural considerations of MIG for scalable GPU virtualization and the challenges in implementing MIG in real-world systems. The references provided offer further insights into the technical details of MIG and its potential for improving the performance and cost-effectiveness of GPU-based systems.**

Keywords—Graphics Processing Unit (GPU), Multiple Instance GPU (MIG), GPU virtualization, deep learning inference, high-performance computing.

I. Introduction

Graphics Processing Units (GPUs) were initially developed to render complex images for gaming and visualization purposes. However, their processing power and parallel computing capabilities have since made them an essential tool for a wide range of computational applications. In recent years, the use of GPUs has grown rapidly in the field of High-Performance Computing (HPC). Multiple-Instance GPU (MIG) is a recent feature introduced by NVIDIA that enables a single physical GPU to be partitioned into multiple instances, each with its own resources and performance characteristics. MIG was first introduced in the NVIDIA A100 GPU and is now also available in the latest NVIDIA A30 and A40 GPUs. In traditional GPU architectures, each user requires a dedicated GPU to run their graphics-intensive applications. This leads to a significant increase in hardware costs, power consumption, and space requirements. MI-GPU aims to address these issues by allowing multiple users to share a single GPU.

II. Background

Graphics Processing Units (GPUs) have evolved from their initial use in computer graphics to become an essential component in high-performance computing. GPUs are specialized hardware accelerators that can perform parallel computations on large data sets. With the increasing demand for high-performance computing, GPUs have become popular in a wide range of applications, from scientific simulations to machine learning.

A. Types of GPUs

There are two main types of GPUs: integrated and discrete. Integrated GPUs are built into the CPU and are used for low-intensity graphics processing, such as browsing the web or watching videos. Discrete GPUs, on the other hand, are separate cards that are installed in the computer and are used for high-performance computing.

B. Currently Available GPUs

The two major GPU manufacturers are NVIDIA and AMD. Nvidia's current lineup includes the GeForce RTX 30 series, while AMD's current lineup includes the Radeon RX 6000 series.

NVIDIA's GeForce RTX 30 series is built on the Ampere architecture, which features second-generation RT cores and third-generation Tensor cores. The RT cores are used for real-time ray tracing, while the Tensor cores are used for AI and machine learning. The GeForce RTX 30 series is currently the most powerful GPU lineup available, with the flagship RTX 3090 offering 24 GB of GDDR6X memory and 10496 CUDA cores.

AMD's Radeon RX 6000 series is built on the RDNA 2 architecture, which features ray tracing and variable rate shading. The Radeon RX 6000 series is also capable of machine learning, with support for AMD's Infinity Cache technology. The flagship Radeon RX 6900 XT offers 16 GB of GDDR6 memory and 5120 Stream Processors.

C. Applications of GPUs

GPUs are used in a wide range of applications, including scientific simulations, video rendering, and machine learning. In scientific simulations, GPUs can accelerate the computation of complex models, such as weather forecasting and molecular

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dynamics. In video rendering, GPUs can speed up the process of rendering high-quality graphics and animations. In machine learning, GPUs are used for training and inference in neural networks.

III. Evolution of Multiple Instance GPUs

The concept of multiple instance GPUs has been around for several years, but it has gained traction in recent times with the growing demand for GPU-based computing in various fields such as machine learning, scientific simulations, and data analytics. One of the earliest instances of multiple instance GPU architecture was NVIDIA's Virtual Compute Server (vCS), which was introduced in 2012. vCS allowed multiple virtual instances of a GPU to be created and shared by different users. Since then, various other multiple instance GPU solutions have been developed by different companies, including AMD's MxGPU and Intel's GPU sharing technology.

Here is a brief overview of the evolution of Multiple Instance GPUs:

a. Virtual Compute Server (vCS) by NVIDIA: The concept of Multiple Instance GPUs was introduced by NVIDIA with the launch of the Virtual Compute Server (vCS) in 2012. vCS allowed multiple virtual instances of a GPU to be created and shared by different users.

b. AMD MxGPU: In 2016, AMD introduced MxGPU, a hardware-based virtualization solution that allows multiple virtual instances of a GPU to be created and assigned to different users or applications. MxGPU supports up to 32 virtual machines per physical GPU and allows for efficient sharing of GPU resources.

c. Intel GPU sharing technology: In 2019, Intel launched GPU sharing technology, which enables multiple users to access a single GPU simultaneously. This technology supports up to 4 virtual machines per physical GPU and can be used in cloud computing environments to provide efficient sharing of GPU resources.

d. NVIDIA A100 multi-instance GPU: In 2020, NVIDIA launched the A100 multi-instance GPU, which allows up to 7 virtual instances of a GPU to be created and assigned to different users or applications. The A100 supports hardware isolation and provides high performance and low latency for each virtual instance.

IV. Architecture of Multiple Instance GPUs

Multiple Instance GPUs are typically implemented using a combination of hardware and software. The hardware provides the physical resources, such as processing cores, memory, and I/O interfaces, while the software provides the virtualization layer that allows multiple users to share those resources.

The virtualization layer is responsible for managing the allocation of resources between the different virtual instances of the GPU. This includes managing memory allocation and access, scheduling processing tasks, and ensuring data isolation between the different instances.

The new Multi-Instance GPU (MIG) feature[1] with NVIDIA Ampere architecture is shown in Fig. 1. GPUs are securely partitioned into up to seven separate GPU Instances

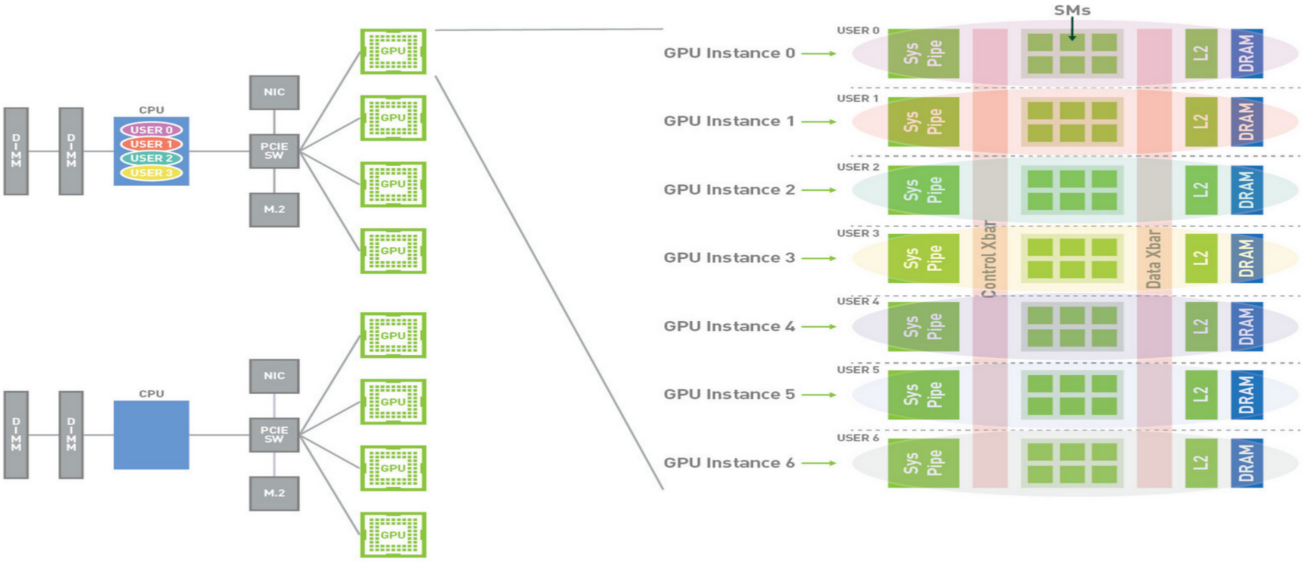

Fig. 1: MIG in NVIDIA Ampere GPU[1].

for *Compute Unified Device Architecture* (CUDA) applications, providing multiple users with separate GPU resources for optimal GPU utilization. This feature is particularly beneficial for workloads that do not fully saturate the GPU's compute capacity and therefore users may want to run different workloads in parallel to maximize utilization.

With MIG, each instance's processors have separate and isolated paths through the entire memory system - the on-chip crossbar ports, L2 cache banks, memory controllers, and DRAM address busses are all assigned uniquely to an individual instance. This ensures that an individual user's workload can run with predictable throughput and latency, with the same L2 cache allocation and DRAM bandwidth, even if other tasks are thrashing their own caches or saturating their DRAM interfaces. MIG can partition available GPU compute resources (including streaming multiprocessors or SMs, and GPU engines such as copy engines or decoders), to provide a defined quality of service (QoS) with fault isolation for different clients such as VMs, containers or processes. MIG enables multiple GPU Instances to run in parallel on a single, physical NVIDIA Ampere GPU.

MIGraphX is an open-source deep learning inference framework developed by the Advanced Micro Devices (AMD) corporation. It provides a unified and portable interface for deploying deep neural networks on various hardware platforms, including CPUs, GPUs, and FPGAs. MIGraphX supports several popular deep learning frameworks, including TensorFlow, PyTorch, and ONNX, and provides optimized implementations of common neural network layers and operators. It also includes a suite of tools for model optimization, quantization, and deployment.

One of the key features of MIGraphX is its ability to run inference on multiple devices simultaneously, enabling users to take advantage of heterogeneous compute resources and optimize the performance of their models. Additionally, MIGraphX supports distributed inference, which allows users to scale up their inference workloads across multiple machines. MIGraphX is designed to be easy to use and flexible, with a simple and intuitive API that allows users to quickly deploy their models on various hardware platforms. It is also optimized for performance, with efficient implementations of neural network operations and support for hardware acceleration.

V. Applications

Multiple Instance GPUs can be beneficial in various applications that require GPU-based computing. One such application is cloud computing, where multiple users may need to access the same GPU for their workloads. By utilizing multiple virtual instances of the GPU, cloud service providers can efficiently allocate GPU resources to different users, reducing costs and improving overall performance. Multiple Instance GPUs can also be useful in machine learning, where multiple models can be trained simultaneously on the same GPU, or in scientific simulations, where different simulations can be run in parallel on different virtual instances of the GPU.

Here are some examples of applications that can benefit from using Multiple Instance GPU (MIG) technology:

a. Cloud computing: MIG can be used in cloud computing environments to enable efficient and flexible GPU resource allocation to multiple users simultaneously.

b. Deep learning inference: MIG can be used to accelerate deep learning inference workloads by optimizing GPU utilization and enabling multi-tenancy.

c. Scientific computing: MIG can be used in scientific computing applications, such as molecular dynamics simulations, to accelerate GPU-accelerated algorithms.

d. Machine learning: MIG can be used to improve the performance and scalability of machine learning algorithms, such as support vector machines and decision trees.

e. Natural language processing: MIG can be used to accelerate natural language processing tasks, such as text classification and sentiment analysis.

f. Image and video processing: MIG can be used to accelerate image and video processing tasks, such as object detection and segmentation.

g. Financial modeling: MIG can be used to accelerate financial modeling tasks, such as Monte Carlo simulations and portfolio optimization.

h. Medical imaging: MIG can be used to accelerate medical imaging tasks, such as CT and MRI reconstruction.

i. Autonomous vehicles: MIG can be used to accelerate deep learning inference workloads in autonomous vehicles, such as object detection and tracking.

j. Robotics: MIG can be used to accelerate deep learning inference workloads in robotic applications, such as object recognition and navigation.

VI. Conclusion

Multiple Instance GPU (MIG) is a powerful architecture that enables efficient and flexible GPU resource allocation to multiple users simultaneously. With MIG, GPU resources can be partitioned into multiple instances, each with its own compute and memory resources, allowing multiple workloads to run concurrently on a single GPU without interference.

Recent works have shown that MIG can significantly improve the performance and scalability of GPU workloads in multi-tenant environments, making it a promising solution for cloud computing, virtualization, and other resource-sharing scenarios. However, there are still challenges to be addressed, such as optimizing MIG for specific workloads and improving the efficiency and scalability of MIG-enabled systems. Overall, MIG is an exciting development in GPU architecture that has the potential to revolutionize the way we use GPUs in a wide range of applications.

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