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GPU-Optimized Image Processing and Generation Based on Deep Learning and Computer Vision

Yiyu Lin[1*], Ang Li[2], Huixiang Li[3], Yadong Shi[4], Xiaoan Zhan[5]

[1]Computer Science and Engineering, Santa Clara University, CA,USA

[2]Business Analytics, University College Dublin, Dublin,Ireland

[3]Information Studies, Trine University, AZ, USA

[4]Computer Science, Fudan University, Shanghai,China

[5]Electrical Engineering, New York University, NY, USA

*Corresponding author E-mail:lihuixiang95@gmail.com

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ABSTRACT

In recent years, deep learning has become a core technology in many fields such as computer vision. The parallel processing capability of GPU, greatly accelerates the training and inference of deep learning models, especially in the field of image processing and generation. This paper discusses the cooperation and differences between deep learning and traditional computer vision technology and focuses on the significant advantages of GPU in medical image processing applications such as image reconstruction, filter enhancement, image registration, matching, and fusion. This convergence not only improves the efficiency and quality of image processing, but also promotes the accuracy and speed of medical diagnosis, and looks forward to the future application and development of deep learning and GPU optimization in various industries.

INTRODUCTION

In recent years, deep learning has established itself as a cornerstone technology across various fields, especially in computer vision. This technology, capable of performing tasks that once seemed out of reach for machines, has fascinated many and revolutionized numerous industries. Despite its widespread acclaim and adoption, deep learning remains akin to a black box; its internal workings are not fully understood by the majority of users, including many trained scientists within the field. [1-2]The enigmatic nature of deep neural networks means that while they can achieve remarkable results, the reasons behind their successes or failures often remain unclear.However, this opaqueness does not diminish the value of the lessons learned from both triumphs and setbacks in deep learning applications. These experiences have underscored the critical importance of handling data correctly and have driven home the necessity of rigorous experimentation and validation. In this article, we aim to demystify some aspects of deep learning by exploring its immense potential and its intricate relationship with classical computer vision techniques.

We will delve into the synergies and distinctions between deep learning and traditional computer vision approaches, shedding light on how deep learning models have come to outperform many classical methods. A significant part of this exploration will focus on the role of Graphics Processing Units[3-4] (GPUs) in enhancing the capabilities of deep learning for computer vision tasks. GPUs have been pivotal in accelerating the training and inference of deep learning models, making it feasible to process and generate images with unprecedented efficiency and quality.By examining these topics, we aim to provide a comprehensive overview of how deep learning, empowered by GPU optimization, is transforming image processing and generation. This will include a discussion of the underlying technologies, practical applications, and future directions in the field. Through this journey, we hope to provide insights that will help demystify the 'black box' of deep learning and highlight the transformative potential of GPU-accelerated computer vision.

RELATED WORK

2.1 Computer Vision

Computer Vision, also known as Machine Vision, is a discipline that lets machines learn how to "see" and is an important application field of deep learning technology[5], which is widely used in security, industrial quality inspection, and automatic driving scenarios. Specifically, it is to let the machine identify the object in the picture or video taken by the camera, detect the location of the object, and track the target object, to understand and describe the scene and story in the picture or video, to simulate the human brain visual system. Therefore, computer vision is also commonly referred to as machine vision, and the goal is to build artificial systems that can "sense" information from images or videos.

The development of computer vision begins with biological vision[6]. For the origin of biological vision, the academic community has not yet formed a conclusion. Some researchers believe that the earliest biological vision formed in jellyfish about 700 million years ago, and some researchers believe that biological vision emerged in the Cambrian period about 500 million years ago. The reason for the Cambrian explosion has long been a mystery, but what is certain is that during the Cambrian period, animals developed visual abilities, which allowed predators to find prey more easily, and prey to detect the location of predators earlier. [7-8]Visual abilities intensified the game between hunters and prey and gave rise to more intense rules of survival and evolution. The formation of the visual system has strongly promoted the evolution of the food chain and accelerated the process of biological evolution, which is an important milestone in the history of biological development.

2.2 Computer vision application scenarios

After decades of development, computer vision technology has been applied in many fields such as traffic (license plate recognition, road violation capture)[9], security (face gate, community monitoring), finance (face payment, automatic ticket recognition of counters), medical (medical image diagnosis), industrial production (automatic detection of product defects), etc. Influence or are changing People's Daily life and industrial production mode. In the future, with the continuous evolution of technology[10], more products and applications will emerge, creating greater convenience and broader opportunities for our lives.

Computer vision tasks depend on image features (image information), and the quality of image features largely determines the performance of the vision system. Traditional methods usually use SIFT, HOG, and other algorithms to extract image features, and then use [11]SVM and other machine learning algorithms to further process these features to solve visual tasks. Pedestrian detection is to determine whether there are pedestrians in the image or video sequence and give accurate positioning. The earliest method is [12]HOG feature extraction +SVM classifier and the detection process is as follows:

1. Use the sliding window to traverse the entire image to obtain the candidate region

2. Extract HOG features of candidate regions

3. Use SVM classifier to classify the feature map (to determine whether it is human)

Using the sliding window will appear duplicate areas, using [13]NMS(non-maximum) to filter the duplicate areas

The results of classification are strongly dependent on manual feature extraction methods, which can only be completed by experienced researchers.

Against this background, the feature extraction method based on neural networks comes into being. Yann LeCun applied convolutional neural networks to the field of image recognition for the first time in 1998. Its main logic is to use convolutional neural networks to extract image features, predict the categories of images, and constantly adjust network parameters through training data. Finally, a set of network LeNet[14] which can automatically extract and classify image features is formed. This method was very successful in handwritten digit recognition tasks, but it did not develop well in the following time. [15]On the one hand, the main reason is that the data set is not perfect, can only handle simple tasks, and it is easy to overfit large-size data. On the other hand, is the hardware bottleneck, when the network model is complex, the calculation speed will be particularly slow.

2.3 Deep learning and GPU image recognition

The GPU has shown a significant acceleration in image recognition. For example, a study conducted by Salad.com compared the performance of 22 Gpus on AI image tagging, highlighting how even older Gpus can play a critical role in tasks like image tagging. GPUs are widely used to speed up the training and reasoning processes of convolutional neural networks (CNNS)[16], which are at the heart of modern image recognition technology. CNN can extract features from images and classify them, but this process requires a lot of computational resources. The high parallel processing capability of GPUs allows these networks to process more images in less time, resulting in faster learning and more accurate recognition.

In practical application, this acceleration effect is very significant. For example, in medical image analysis, GPU-accelerated deep learning algorithms can quickly identify abnormalities in[17] X-ray or [18]MRI images, helping doctors make diagnoses faster.

2.4 GPU image processing applications

1. Autonomous driving: Gpuscan quickly process large amounts of data from vehicle sensors, including video streams, radar, and lidar signals, to identify road conditions, pedestrians, and other vehicles in realtime. The efficient computing power of GPUs is indispensable for real-time decision-making and the safe operation of vehicles. As autonomous driving technology continues to advance[19], the role of GPUs will become more important, especially in handling more complex traffic scenarios and enhancing the accuracy of decision-making systems.

2. Personalized Medicine: In the medical field, [20]Gpusis driving the development of personalized medicine. Using deep learning to analyze large amounts of patient data, Gpus can help doctors and researchers identify disease patterns and provide more precise treatments. For example, in cancer research, GPU-accelerated algorithms can analyze tumor samples to help researchers understand the genetic characteristics of cancer and develop personalized treatment plans for patients.

Nevertheless, developments in GPU technology are accelerating research and innovation across a wide range of industries. In finance, retail, entertainment, and more, [21]GPU-accelerated deep learning algorithms are being used for data analysis, market forecasting, and customer service optimization. These applications not only improve operational efficiency but also provide deeper insights to help businesses stay ahead in a highly competitive market.

METHODOLOGY

Medical images produced by medical imaging devices have multiple dimensions, including 2D, 3D, and 4D images, as well as 2D video images (endoscopic or microscope videos). With the improvement of image dimension and algorithm complexity, the computational amount of medical image processing is also increasing greatly. For most medical image processing algorithms, image pixels can be independently processed as threads, which has the characteristics of data-parallel computation, which is the basis of GPU parallel acceleration. GPU has the characteristics of high parallelism, multi-thread, multi-stream processor, and high memory bandwidth, which can realize the high-performance accelerated calculation of the whole process of medical image processing.

3.1 Image Reconstruction

Image reconstruction refers to the measurement of human body data by a sensor or energy source, and the three-dimensional structure or function information of the human body is obtained by the reconstruction algorithm. Image reconstruction is a time-consuming process in medical image processing. To ease the computational pressure, researchers used to use relatively simple imaging models for direct analysis. For example, in CT reconstruction, [22]FBP (Filtered back projection) is a more common algorithm in analytical methods. In FBP, the projection data is processed by FFT filtering, and the [23]3D image is reconstructed along the projection direction by the multiplication of the system weight matrix and projection data. The CT projection reconstruction model is shown in Figure 3. The signal received by the detector is the X-ray projection data of the X-ray tube source passing through the human body. To obtain a complete CT tomography image, X-rays need to be continuously rotated at least 180° along the center of the human body.

Table 1. Comparison of Imaging Technology

Imaging Technology	MRI	PET/SPECT	Ultrasound
Imaging Principle	Hydrogen nucleus magnetic resonance	Gamma-ray transmission attenuation	Ultrasound reflection
Reconstruction Algorithm	FBP, FFT, 3DRP, Iterative Algorithms (ART, SIRT, MLEM, etc.), GRAPPA, ISENSE, CS-MRI, etc.	Iterative Algorithms (MLEM, OSSPS, etc.)	3D Interpolation
Spatial Resolution (mm)	0.5	0.5	3
Suitable for Body Parts	Soft and hard tissues	Soft and hard tissues	Soft tissue
Radiation Exposure	None	Yes	Thermal effect

Although the analytic algorithm is simple and the reconstruction speed is fast, the imaging quality is poor because the real imaging process is not introduced, such as the noise is not considered, and the measurement data with high signal-to-noise ratio is required, which is often limited by radiation dose or system constraints. In recent years, the iterative method has been widely used in the process of image reconstruction, which can significantly reduce radiation dose, reduce noise, and improve image quality[23-24]. Table 1 summarizes the reconstruction principles and related technical characteristics of several commonly used medical imaging techniques.

The basic principle of the iterative reconstruction algorithm is to estimate the initial 3D image, perform forward imaging simulation on it, compare it with the actual measurement data, correct the 3D image estimation according to the error results, and repeat the process until convergence. In this process, a lot of data calculation is required. In the past, image reconstruction was often used[25]ASIC (Application Specific Integrated Circuit) and FPGA (Field Programmable Gate Array). Field Programmable Gate array (FPGA), DSP (Digital Signal Processing chip), and other chips to accelerate. Compared to these chips, Gpus can provide better programming flexibility and a more reasonable development cost-performance ratio. Currently, there is a large amount of open-source software that uses GPU-accelerated image reconstruction and commercial software from medical device manufacturers. The acceleration performance of GPU can be significantly improved by parallelizing reconstruction tasks, optimizing memory merge, and reducing thread divergence and competition. Table 2 shows the GPU acceleration ratio of each module of the CS iterative method of MRI reconstruction. With the addition of GPU, the total acceleration ratio can reach 53.9 times

3.2 Filter enhancement

Affected by many factors such as imaging equipment and acquisition conditions, the original medical image is susceptible to noise pollution and image quality degradation or distortion. The filtering and enhancement of medical images can suppress noise, reduce distortion, and enhance image information, to facilitate subsequent image processing and analysis. [26-28]Traditional image filtering enhancement techniques are divided into the spatial domain and frequency domain, both of which can be used to eliminate image noise and enhance image features at the same time. Median filtering, Gaussian filtering, diffusion filtering, and bilateral filtering are commonly used for processing. These filtering algorithms are equivalent to decomposed convolution operations in the image domain or product operations in Fourier frequency domain space, so they are extremely suitable for GPU parallel acceleration computation. Table 3 shows the comparison of the acceleration effect of non-local mean denoising for 3D images (512x512x128) with different parameters, and the average GPU acceleration ratio can reach more than 30 times.

Table 2. Execution Time/Speed-Up Comparison

Configuration	1 GPU Unit	CPU
	(16, 16, 1)	(128, 1, 1)
Execution Time (s)	71.4 / 39.4	70 / 40.2

Speed-Up	(IVB.D)	
(11, 3)	71.4 / 39.4	70 / 40.2
(21, 3)	514 / 38.5	504 / 39.2
(11, 5)	254132	244133.3
(21, 5)	18451319	17611334

3.3 Image registration

Medical image registration refers to two images with different meanings formed by some imaging means with different meanings for the same anatomical part of the same person, seeking a spatial transformation (or a series of), so that the corresponding points of the anatomical structure of the two medical images can be as consistent as possible in spatial position. [29]Consistency here means that the same anatomical point or at least all diagnostic points and points of surgical interest in the human body are matched. Medical image registration is the basis of image segmentation, image fusion, and other subsequent image processing.

The core of the medical image registration method includes three parts: spatial transformation, similarity measure, and optimization algorithm. Spatial transformation mainly involves matrix and interpolation operations in pixel space, and GPU has built-in acceleration Settings for matrix and interpolation operations. The similarity measure is to quantify the matching similarity degree between images by using the gray level or feature information of images and to realize the acceleration of [30]GPU by using parallel and merge algorithms. However, the optimization algorithm is mainly a sequential process, which makes it difficult to achieve related GPU acceleration. Table 4 shows a 3D elastic registration GPU acceleration situation. It can be seen that although the optimization algorithm cannot achieve parallel acceleration, the overall GPU acceleration ratio can still reach 4.69 times.

Table 3. Task Performance Comparison

Task	CPU	CPU-GPU
Iteration (s)	18.54	3.95
Matching Criterion (ms)	8.44	0.13
Optimization (ms)	1.03	1.41
Download p (ms)	N/A	0.025
Upload L (ms)	N/A	0.004

3.4 Image Matching

Image matching and image registration approximation, the purpose of which is to find an image that is similar to an image, but does not require spatial correction of the found image. According to the different information used in matching, matching algorithms can be divided into three categories: matching methods based on feature descriptors, matching methods based on spatial location information, and matching methods combining feature information and location information. According to the number of matches obtained, the matching algorithms can be divided into sparse matching algorithms, quasi-dense matching algorithms, and dense matching algorithms. Image matching is widely used for Content-Based Image Retrieval[31] (CBIR) in the field of medical images, which can quickly search clinical medical images with similar images from existing medical image databases. Doctors can refer to the diagnostic methods of pathologically similar cases to assist them in making a correct clinical diagnosis.

3.5 Image Fusion

As mentioned above, different types of medical imaging equipment provide patients with multi-level, multi-angle, and multi-node image data for clinical diagnosis and treatment, and there is redundant information and a lot of complementary information between data of different modes. [32]Multi-modal medical image fusion makes full use of the complementarity and redundancy of different modal images and fuses different modal medical images of the same lesion site to obtain fusion images with richer information and more accuracy than the original image. Generally, multi-modal medical image fusion first needs to register images of different modes, so that the pixel positions of the same anatomical part can correspond one by one under different images, and then fuse useful information in each mode according to the set strategy to generate images with better quality. As shown in Figure 7, according to different levels of image data processing, image fusion is mainly divided into pixel-level fusion, feature-level fusion, and decision-level fusion.

Integrating GPUs into medical image processing offers substantial advantages, significantly accelerating tasks such as image reconstruction, filtering, registration, matching, and fusion. [33-34]GPUs' high parallelism, multithreading, and high memory bandwidth enable efficient handling of data-intensive computations, reducing processing times and enhancing image quality. This integration results in faster, more accurate diagnostics and improved clinical outcomes, making GPUs a crucial component in the advancement of medical imaging technologies.

Conclusion

The parallel processing capability and efficient data processing characteristics of GPUs not only accelerate the training and deployment of deep learning models, but also expand the application scope of deep learning in various industries, and have become a key force in promoting the development of this field. From image recognition to natural language processing to complex reinforcement learning tasks, the influence of Gpus permeates every aspect of deep learning. Going forward, as technology continues to advance and innovate, the role of GPUs in deep learning and artificial intelligence will become even more important. The new generation of GPUs will bring higher performance and lower power consumption, further accelerating the research and application of deep learning, especially in areas requiring highly computation-intensive tasks.

In summary, the development of Gpus paints a promising blueprint for the future of deep learning, bringing opportunities for innovation and change to various industries. With the emergence of new technologies and the development of new application scenarios, Gpus will continue to play an irreplaceable role in the future era of artificial intelligence.

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