УДК 004.3

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Organization of a cluster System Based on the GPU for high-performance image-processing

A graphical cluster architecture based on the simultaneous solution of different classes of problems with the virtualization of hardware resources was proposed. Hardware and software components to build a cluster system are choice. On the basis of the proposed architecture the problem high-resolution image fusion is solved.

Keywords: cluster, graphics processor, virtualization, hypervisor, image fusion, discrete wavelet transform, CUDA, MPI.

Introduction

In today's world, the increase in processing information leads to the need to increase the performance of computing devices for solving problems in different branches. Examples of such tasks are: modeling of complex dynamic processes, processing and storing large amounts of data. For example, modeling the spread of pollutants in the atmosphere, this is associated with the solving of large systems of differential equations [1], analysis and processing of satellite images, which are characterized by high-resolution [2], analysis and processing of huge amounts of data accumulated by the weather and climate over a long period of time [3].

Architecture is an important factor affecting the performance of a computer system with respect to a particular task or class of problems.

Long been an increase in speed of information processing is achieved through parallelism. Therefore, development of methods for organizing parallel computing systems for high performance data is an actual scientific task.

The goal of this work is to build a universal graphics cluster system for solving problems of high-performance data processing and solving concrete of the problem at its base satellite imagery fusion.

The task of this work is to develop architectures, the choice of hardware and software components, as well as the practical implementation of parallel versions of algorithms for image fusion based on the proposed architecture.

The use of GPU as a basis for building cluster systems

Parallel computer systems can be classified according to the level at which the hardware supports parallelism [4]:

- multi-core systems;
- symmetric multiprocessor system;
- distributed computer systems;

Distributed computer is a computer system with distributed memory, in which computing devices combined into one system over the network. This type of parallel computer systems shows a high ability to scale. The main subclasses of distributed computer systems are as follows:

- cluster systems;
- massively parallel computers;
- the grid system;
- specialized parallel computers;
- FPGA-system;
- GPGPU-system.

GPGPU architecture causes of particular interest at this time. GPGPU (General Purpose GPU) - referred to as a system allows calculation of general purpose cards.

General-purpose computation on graphics cards are the trend of modern research in the field of computer engineering. They can leverage the power of modern graphics cards to solve problems that are not limited to computer graphics.

Graphics processors are, in fact, co-processors considerably optimized for the task of computer graphics - in particular for solving linear algebra problems.

Currently, there are several technologies (for example, CUDA and OpenCL) [5], allowing the use of a sufficiently large power of modern graphics cards without inquiry into the low-level programming.

One of the biggest advantages of these systems is the high prevalence (every modern personal computer equipped with a video card that supports general-purpose computing), and low cost per unit of computing power compared to (for example) cluster systems.

Cluster systems and graphics processors are promising combination of features for construction of modern high-performance computing systems for data processing. GPUs provide parallel processing by

SIMD-principle with using a large number of threads of instructions (100, 1,000 or more) [5].

At the same time, GPU-based systems have a relatively small amount of memory.

In turn, the cluster consisting of multiple nodes, allows for independent processing of data using virtually unlimited storage capacity, but with time delays when transferring data from one cluster node to another.

Combining the cluster architecture, and graphic processors in each node in the cluster to take advantage of each architecture (Fig. 1).

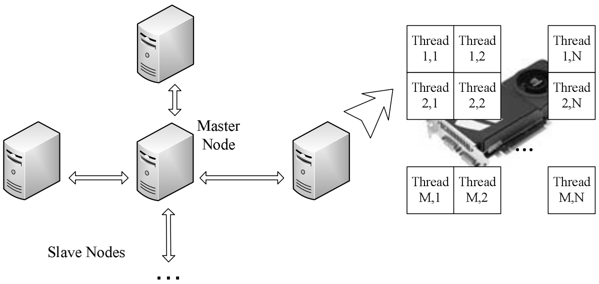


Figure 1 - The general principle of the cluster system based on GPU

The use of graphics cluster systems mentioned in the literature [6-7] as an effective tool for solving problems of climate modeling, image processing, etc.

The problems of constructing a universal cluster system based on GPU

At the organization of the universal cluster system based on the graphics processor raises the following issues:

- ensure the independent functioning of each cluster node in the solving of different tasks simultaneously;
- provide a flexible configuration of independent cluster architecture for the simultaneous solution of various problems;
- provide dynamic allocation and migration of system resources between cluster nodes.

The above problems arise due to the fact that in constructing the cluster system presents a restriction on the number of available physical nodes. We denote this number Q .

Each task or a class of problems requires organization of the cluster (the set of available memory resources, CPU, GPU, etc., a set of operating systems and other software components). We denote the set of required resources as a vector:

$$r_i = \langle hdd_i, ram_i, cpu_i, gpu_i \rangle \quad (1)$$

where

hdd_i - the need for data storage resource;

ram_i - the need to share memory;

cpu_i - the need for CPU resources;

gpu_i - the need to share the GPU;

The organization of the cluster is complicated by the fact that these resources are needed in various combinations at a same time (a cluster should be able to solve different problems independently of each other).

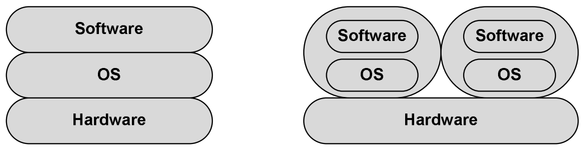
In fact, we want to map the vectors of resources for each task in the real physical resources of the cluster system:

$$\sum_{i=1}^{N} r_i = Q\langle hdd_i, ram_i, cpu_i, gpu_i \rangle, \quad (2)$$

where

N - The number of independent tasks to be solved on a cluster.

To ensure the condition (2) can offer two ways to organize each cluster (Fig. 2).



a) b)

Figure 2 - Organization of a cluster node

In Fig. 2a shows the host organization, in which the physical resources of the site are directly provided by the operating system and application software. This is the easiest way, but in this case the condition (2) becomes independent tasks could be hard, because within a single operating system is almost impossible to organize a stand-alone access to the different tasks in the same physical resources. At the same software applications and tasks may require different types of operating systems, which is also impossible for this organization.

In Fig. 2b shows an alternative organization of a cluster node. Each node represents a group of containers, each of which has access to the same physical resources, but in each container isolate environment is organized to carry out its operating system and its software suite. This solution is called virtualization, and containers - virtual machines.

There are many ready-made solutions for virtualization [8]:

- VMWare;
- Virtual Box;
- Parallels;
- Xen;
- KVM.

We must take into account that the virtual machine - a layer between the hardware and the guest operating system. Therefore, when constructing high-performance cluster impractical to use virtualization platform, which is presented in the form of a software product that runs under the host operating system.

Based on the above criteria has been drawn up a comparative table of the known virtualization platforms that provide a "pure" virtualization, i.e., running in the hypervisor on the hardware platform without the need for a separate operating system (see Table. 1).

Table 1 - Comparison of virtualization platforms

Virtual machine	Host-CPU	Host-OS	Supported OS	License
VMWare ESX	Intel x86, AMD64	No	Linux, Windows etc.	Proprietary
Virtual Box	Intel x86, AMD64	Linux, Windows etc.	Linux, Windows etc.	GPL
Parallels	Intel x86, Intel VT-x	Linux, Windows etc.	Linux, Windows etc..	Proprietary
Xen	Intel x86, AMD64	Linux	Linux, Windows etc.	GPL
KVM	Intel AMD	Linux	Linux, Windows etc.	GPL2
Hyper V	Intel x86-64, AMD64	No	Linux, Windows etc.	Proprietary

Analysis of the table. 1 shows that the "pure" virtualization provides a small number of virtual machines (Hyper 5 and VMWare ESX). Given the fact that VMWare ESX provides a wide range of supported operating systems and that the observable node in the cluster hardware configuration allows the use of this virtualizer for free licenses, product VMWare ESXi 5.0 has been selected as a platform for virtualization.

Thus, the hardware configuration of a cluster node as follows:

- CPU: Intel Core 2 Quad Q8400;
- RAM: 4 GiB;
- HDD: 4TiB;

Main characteristics of the hypervisor are installed on each node:

- not more than 200 MB is the hypervisor itself;
- provides the following guest operating systems running: Windows, Red Hat, Solaris, Debian, Mac OS X, Ubuntu, etc.;
- Direct Driver technology to access the input-output devices;
- organization of resources in the form of dynamic pools.

The architecture of a cluster system based on GPU

As a result of using virtualization technology, the graphic structure of the cluster will be as follows: Fig. 3

In Fig. 3 shows the M cluster nodes (in the real system $M = 8$). Each node has a set of shared resources (CPU, memory, GPU, etc.).

On the hardware of each node is deployed hypervisor VMWare ESXi. In the cluster there are virtual machines with guest operating systems of Windows and Linux families.

A virtual network interface that enables connection to a virtual host cluster network introduced in each virtual machine to form a common computing infrastructure in the composition of

Cluster network is based on an Ethernet network with a transfer rate 1Gbit / s.

As a result, based on a single physical cluster at any time you can get any number of virtual clusters, as the union of the virtual nodes in a single computing system.

Flexible configuration of the cluster structure provided by the control system. VMWare vSphere Client used as a control system. Control terminal is introduced in cluster to run this software. In Fig. 5.4 shows the interface of the controlling terminal when connecting to the host (physical node) in the browse mode host (Fig. 4).

In order to communicate with the outside world cluster system has access to the Internet via two independent channels.

The solving of image fusion task on a cluster of GPUs

As mentioned previously, the proposed architecture of the graphics cluster system is intended for solving high-performance data processing, in particular, images with high resolution.

Currently, almost the constructed system is used to solve two independent problems: the analysis of climate data [3] and the processing of satellite images with equal division of resources (50%).

As an example, consider the implementation of the results obtained on the graphic cluster for the problem of satellite imagery fusion, which is described in [9].

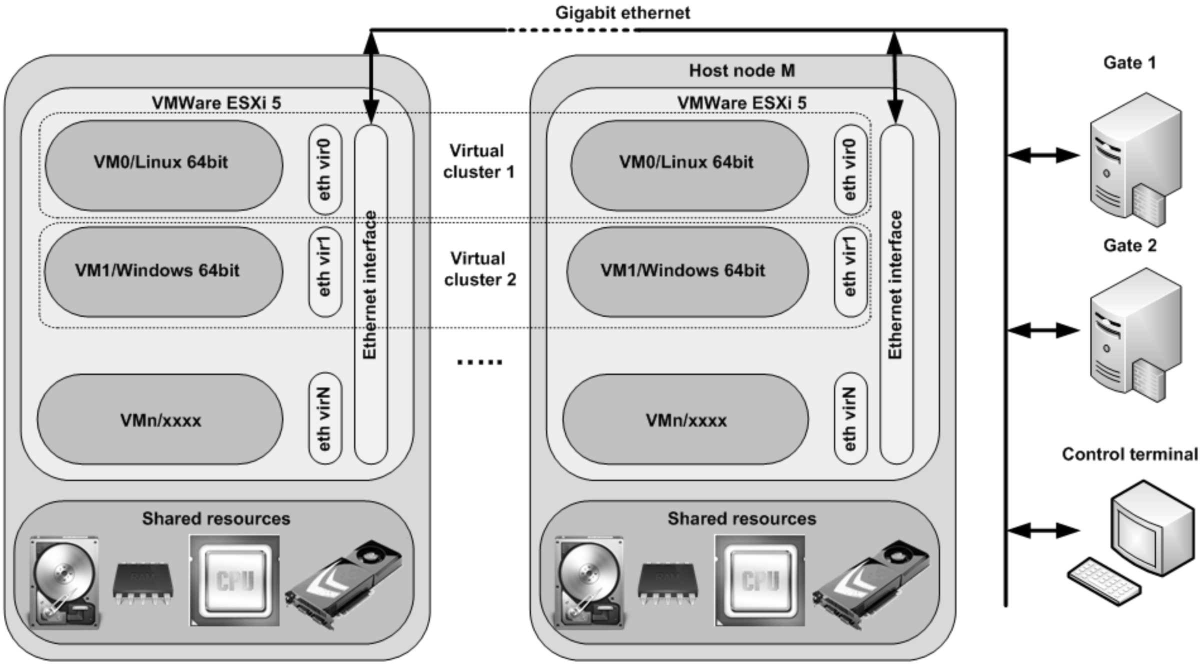


Figure 3 - Architecture of the graphics cluster system

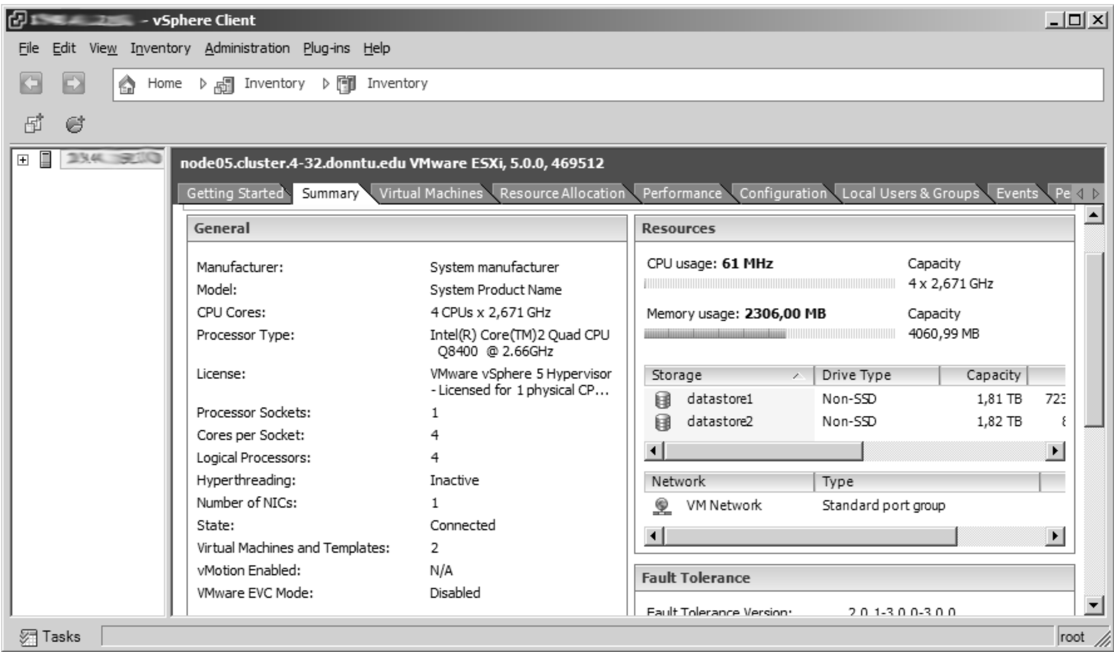


Figure 4 - Connection to the host in the mode of access to information about the host

Example of image fusion of multispectral images and panchromatic image with different resolutions are shows on Fig. 5.

A weighted average method [10] and the method based on color space conversion (IHS) [11] were chosen for comparing the effectiveness of parallel implementations. In addition, for all the implemented methods metrics have also been obtained for a cluster of processors (no GPU).

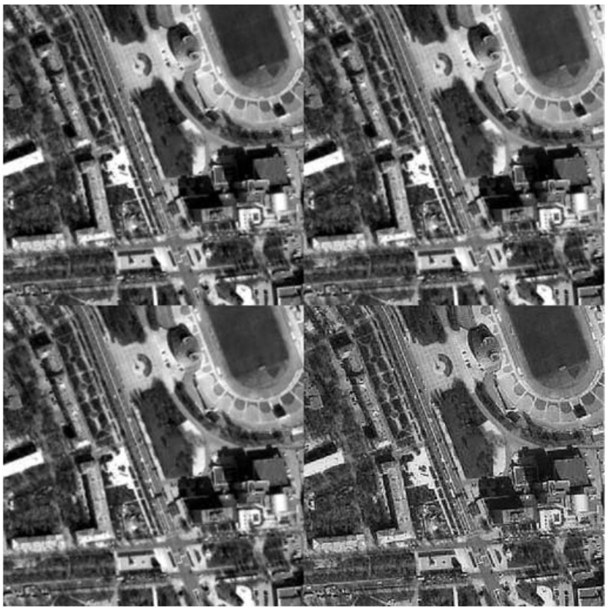


Figure 5 - Result of image fusion (from left to right and from top to bottom - WA, IHS, HDWT, DDWT)

For the experiments on real data we used data provided by the project USGS Global Visualization Viewer [13] from the U.S. Geological Survey. In the experiments we used images from Landsat 7 satellite. Satellite imagery is a photograph of areas of Donetsk region (Ukraine). When implementing the methods were used CUDA and MPI.

Tables 2 and 3 use the following notation:

- WA - weighted averaging method;
- IHS - a method based on color space conversion;
- HDWT - the method of discrete Haar wavelet transform;
- DDWT - the method of discrete wavelet transform of Daubechies.

As can be seen from Table 2, the implementation of IHS is the best time on a cluster with the GPU. This is because the GPU instruction set is more efficient to implement the IHS. In this implementation of the method HDWT is the best time on a cluster with the processor (see Table. 3). This is because the discrete wavelet transform is implemented efficiently using the arithmetic processor.

To evaluate the performance of the work we estimated the number of pixels processed per unit time, assuming that all operations, including, for memory, on average, are equal in difficulty.

In Fig. 6 shows a comparison of the increase in productivity for each method in the implementation of the graphics cluster with the proposed architecture. In analyzing Fig. 6, it can be concluded that the performance of parallel implementation on the GPU is in the range 2-18 times, depending on the method chosen.

Table 2 - Experimental results for a cluster of GPU

Width, px	Height, px	T_{WA}, s	T_{IHS}, s	T_{HDWT}, s	T_{DDWT}, s
16280	14960	0,73	3,01	3,61	3,70
8140	7480	0,90	0,85	0,98	1,02
4070	3736	0,32	0,30	0,34	0,35

Table 3 - Experimental results for a cluster of processors

Width, px	Height, px	T_{WA}, s	T_{IHS}, s	T_{HDWT}, s	T_{DDWT}, s
16280	14960	49,0	67,1	11,6	13,5
8140	7480	2,08	6,24	2,89	3,23
4070	3736	0,51	1,57	0,66	0,73

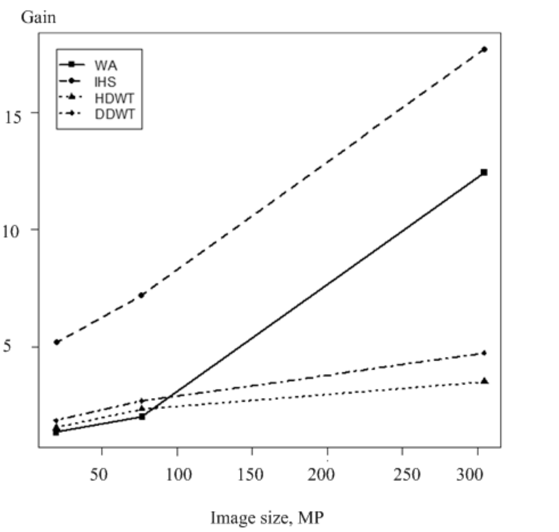


Figure 6 - Increase productivity for parallel implementations on the graphics clusterConclusion

Conclusion

Architecture and a set of software and hardware components for the graphic organization of the cluster with the ability to perform simultaneous of various classes of problems with providing a flexible resource allocation are proposed. The problem of satellite images fusion solved on the proposed architecture and obtained a practical acceleration of 2-18 times compared to the conventional cluster of processors.

The scientific novelty is the fusion of multispectral images in a cluster of GPUs.

The practical importance is the proposed architecture for a graphical cluster as a universal platform for independent high-performance problem solving. A further area of research due to the accumulation of data about resource used by cluster system for solving different classes of problems and generating recommendations and methods for optimal allocation of resources.

References

1. Air pollution modelling using a Graphics Processing Unit with CUDA. Computer Physics Communications / F. Molnár Jr., T. Szakálya, R. Mészárosa et al. – 2010. – V. 181. – P. 105-112.
2. A Framework for Multisensor Image Fusion using Graphics Hardware / S. Yoo, S. Jo, K. Choi et al. // Proc. of the 11-th International Conference on Information Fusion, June, 2008. – 2008. – P. 1-5.
3. Rodriges Zalipynis R.A. The Wikience: Community Data Science. Concept and Implementation / Rodriges Zalipynis R.A., Zapletin E.A., Averin G.V. // Proceedings of the 7th International Scientific-Technical Conference "Informatics and Computer Technologies" (ICT–2011), Donetsk, November 22–23, 2011. – Donetsk, 2011. – Vol. 1. – P. 113-117.
4. Tanenbaum E. Computer architecture / E. Tanenbaum. – 4th ed. – St. Univ, Peter, 2003. – P. 697.
5. Sanders J. CUDA by Example: An Introduction to General-Purpose GPU Programming / J. Sanders, E. Kandrot // Addison-Wesley, 2011.
6. Analysis methods for improving the performance of computers using graphics processors, software and hardware platform CUDA / S.D. Pogoriliy, Y.V. Boyko, M.I. Tribrat et al. // Mathematical machines and systems. – 2010. – No. 1. – P. 40-54.
7. Fan Z. GPU Cluster for High Performance Computing, ACM / Z. Fan, F. Qiu, A. Kaufman, S. Yoakum-Stover // IEEE Supercomputing Conference 2004, November 06-12, Pittsburgh, PA. – 2004. – P. 20-32.
8. Comparison of platform virtual machines: [Electronic resource]. – Access mode: http://en.wikipedia.org/wiki/Comparison_of_platform_virtual_machines
9. Babkov V. Fusion of multispectral images in the problem of satellite images processing / V. Babkov, K. Titarenko // Proc. of the conference Simulation and computer graphics, Donetsk, Ukraine, 2011. – Donetsk, 2011. – P. 25-29.
10. An Adaptive IHS Pan-sharpening Method / S. Rahmani, M. Strait, D. Merkurjev et al. // IEEE Letters on Geoscience and Remote Sensing. – 2010. – Vol. 7(11). – P. 1545-1550.
11. Pajares G. Wavelet-based image fusion tutorial / G. Pajares, J.M. de la Cruz // Pattern Recognition. – 2004. – Vol. 37. – No. 9. – P. 1855-1872.
12. USGS Global Visualization Viewer: [Electronic resource]. – Access mode: http://glovis.usgs.gov/.

Надійшла до редколегії 15.04.2012

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ОРГАНІЗАЦІЯ КЛАСТЕРНОЇ СИСТЕМИ НА БАЗІ GPU ДЛЯ РОЗВ'ЯЗАННЯ ЗАДАЧ ВИСОКОПРОДУКТИВНОЇ ОБРОБКИ ЗОБРАЖЕНЬ

Запропоновано архітектуру графічного кластеру, що орієнтований на одночасне розв'язання різних класів задач з віртуалізацією апаратних ресурсів. Обґрунтовано вибір програмних і апаратних компонентів для побудови кластерної системи. На основі запропонованої архітектури розв'язана задача високопродуктивного злиття зображень з високою розрізнювальною здатністю.

Ключові слова: кластер, графічний процесор, віртуалізація, гіпервізор, злиття зображень, дискретне вейвлет-перетворення, CUDA, MPI.

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ОРГАНИЗАЦИЯ КЛАСТЕРНОЙ СИСТЕМЫ НА БАЗЕ GPU ДЛЯ РЕШЕНИЯ ЗАДАЧ ВЫСОКОПРОИЗВОДИТЕЛЬНОЙ ОБРАБОТКИ ИЗОБРАЖЕНИЙ

Предложена архитектура графического кластера, ориентированного на одновременное решение разных классов задач с виртуализацией аппаратных ресурсов. Обоснован выбор программных и аппаратных компонентов для построения кластерной системы. На базе предложенной архитектуры решена задача высокопроизводительного слияния изображений с высоким разрешением.

Ключевые слова: кластер, графический процессор, виртуализация, гипервизор, слияние изображений, дискретное вейвлет-преобразование, CUDA, MPI.