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SUPERCOMPUTER AS A PLATFORM FOR INNOVATION DEVELOPMENT

Introduction. *The largest in Ukraine supercomputer complex SKIT with total peak performance of reaching 43 trillion operations per second operates at the Glushkov Institute of Cybernetics of NAS of Ukraine. The supercomputer effectively solves the tasks of the widest possible spectrum, from the study of the Earth's interior to linguistic studios, from genetics to modeling the evolution of black holes.*

The complex has found one of its applications in solving photogrammetric problems within the framework of R&D project of the NAS of Ukraine in partnership with Pixelated Realities NGO that deals with the promotion of digital methods for restoration, reconstruction, and research of objects of cultural heritage and with planning and revitalization of urban space.

Purpose. *The purpose of the project is to create a specialized hardware and software complex based on the SKIT supercomputer to solve the resource-intensive photogrammetric problem.*

Materials and methods. *The software and hardware complex is based on original architecture of the SKIT supercomputer and photogrammetric method of building 3D scenes, which is reproducing the 3D objects by photographs. The task of photogrammetry involves the processing of several ten thousand photographs to create 3D scanned images of monuments, historic buildings, archaeological excavations, and urban objects using RealityCapture software.*

Research results. *The project innovative result is the creation of the first in Ukraine specialized software and hardware system that uses high-performance computations to solve the problems of 3D reconstruction by photographs. Also, the Institute of Cybernetics, together with its partners, has developed Cloud Studio specialized hardware and software system.*

Conclusions. *The creation of specialized supercomputer segment and examples of its use have demonstrated the effectiveness of such solutions in 3D modeling and animation, as well as the presence of a significant interest and a large market of supercomputer technologies. The Cloud Studio continues a successful experience of creating specialized computing systems designed to solve important applied R&D problems.*

Keywords: photogrammetry, 3D modeling, and supercomputer.

The Glushkov Institute of Cybernetics of the NAS of Ukraine has created and put into operation the largest supercomputer SCIT in Ukraine. Its total peak performance reaches 43 trillion operations per second. The supercomputer effectively solves the widest spectrum of problems, from the Earth's interior study to linguistic research, from genetics problems to simulation of the black hole evolution. Among the SCIT users there are more than 30 academic institutes, several universities, public institutions, and corporations. The supercomputer center provides researchers with tools to implement their know-how in real competitive products — innovations or practical R&D results.

In addition to routine R&D projects related to the creation of new computing architectures or

the study of algorithms for planning the queue of computational tasks, the Institute of Cybernetics is implementing projects that have a long-term scientific value and innovative products that are interesting not only to the scholarly research community, but also to Ukrainian industry and business.

One of the SCIT applications was solving the photogrammetric problems within the framework of collaboration between the Glushkov Institute of Cybernetics of the NAS of Ukraine and *Pixelated Realities* NGO initiated in the spring of 2016. The latter is engaged in the promotion of digital methods for the restoration, reconstruction, research of cultural heritage objects and for planning and revitalization (improvement) of urban space. The photogrammetric tasks comprise processing several ten thousand photos, which takes a couple of months with the use a regular workstation. **The project innovative component** is the creation of the first in Ukraine specialized software and hardware solution based on supercomputer to solve the resource-intensive photogrammetric tasks using *RealityCapture* software [1]. During the year, the partners have managed to implement many projects to scan monuments, historic buildings, archaeological excavations, and urban sites, and even have taken part in the creation of a documentary film about the Chernobyl Nuclear Power Plant in virtual reality.

The key **scientific result** that has made it possible to create a specialized software and hardware is the SCIT architecture: diskless compute nodes enable to easily reconfigure and to structure the computing field changing the operating system and workflow thereby adapting it to a specific task.

The architecture of image processing and 3D scene cluster is fundamentally different from that of conventional clusters. Unlike the classical R&D tasks processed in the batch job mode, when the researcher puts the task on the queue, determines the amount of resources, and waits for the completion of the process, the 3D modeling and animation tasks are processed in the streaming mode. The data are continuously replenished from the cloud storage, processed in interactive mode, with the generated frames or models sent back to the repository. Usually, such tasks require the active use of graphic accelerators and large RAM.

To save interim results of calculations in the compute nodes, a specialized system based on high-speed SSD drives with a speed of 600 MB/s and an aggregate speed of 18 GB/s was created.

THE SCIT ARCHITECTURE

The cluster-type supercomputer (Fig. 1) is a set of compute nodes, with multiple processors sharing a common operating system and memory (SMP architecture), which are united by several local area networks of different purposes and performance. Among the compute nodes, there are separate nodes for centralized control of the computing process. The supercomputer includes servers specializing in managing common file resources and external user access to the cluster. The cluster complex has one or more specialized compute nodes with additional hardware and software, which are integrated in small complexes with control nodes.

The cluster complex consists of several cluster-type supercomputers connected by a common file system and control networks. The clusters in the complex have common control structures.

The specialized software and hardware complex for solving the reconstruction tasks is designed on the SCIT-4 cluster based on the HP ProLiant Gen8 BladeSystems platform, which has the following characteristics:

- The cluster consists of 12 nodes based on Intel Xeon E5-2600 CPUs with a frequency of 2.6 GHz, 192 compute cores, 36 NVidia Tesla M2075 accelerators, and 768 GB RAM;
- It is integrated with the data repository of cluster complex with a capacity of 150TB;
- 56 Gbps Infiniband FDR data transmission network between nodes.

Each node has a real performance of 1 TFlops, 16 cores (32 cores in HyperThreading mode), 64 GB RAM, and 3 NVidia Tesla M2075 accelerators.

PHOTOGRAMMETRIC TASKS

Photogrammetric tasks are among the problems to be solved. The photogrammetry method involves the creation of point clouds of real world objects from photographs filmed at different angles. The point clouds form the basis of a 3D model and a photorealistic texture. The photogrammetric method is an affordable and fairly accurate way of 3D scanning. The input images are obtained using conventional cameras and unmanned aerial vehicles. Further processing of images requires a huge computing capacity, since calculating even a small number of photos with the use of ordinary personal computer can last weeks or months. In addition, it is rather difficult to store a large number of high-quality photos for scanning and to calculate models based on these materials requires a powerful and stable computing technique. The SCIT supercomputer [2—5] is able to cope with the outlined scope of tasks.

Photogrammetry finds application in many fields: geodesy, cartography, military affairs, archeology, architecture, and others [6—8]. It is difficult to imagine a progress in any industry without surveying, testing, studying samples, experimenting, analyzing data, etc. Having a virtual image of object makes unnecessary to go to the real object location for looking at it carefully. In particular, this method can be used to register objects of cultural and historical heritage by creating 3D models. Historical events, natural phenomena, human negligence, etc. can lead to irreversible changes in the objects of importance to humanity. Therefore, it is important to record in the original form all things that have not been lost.

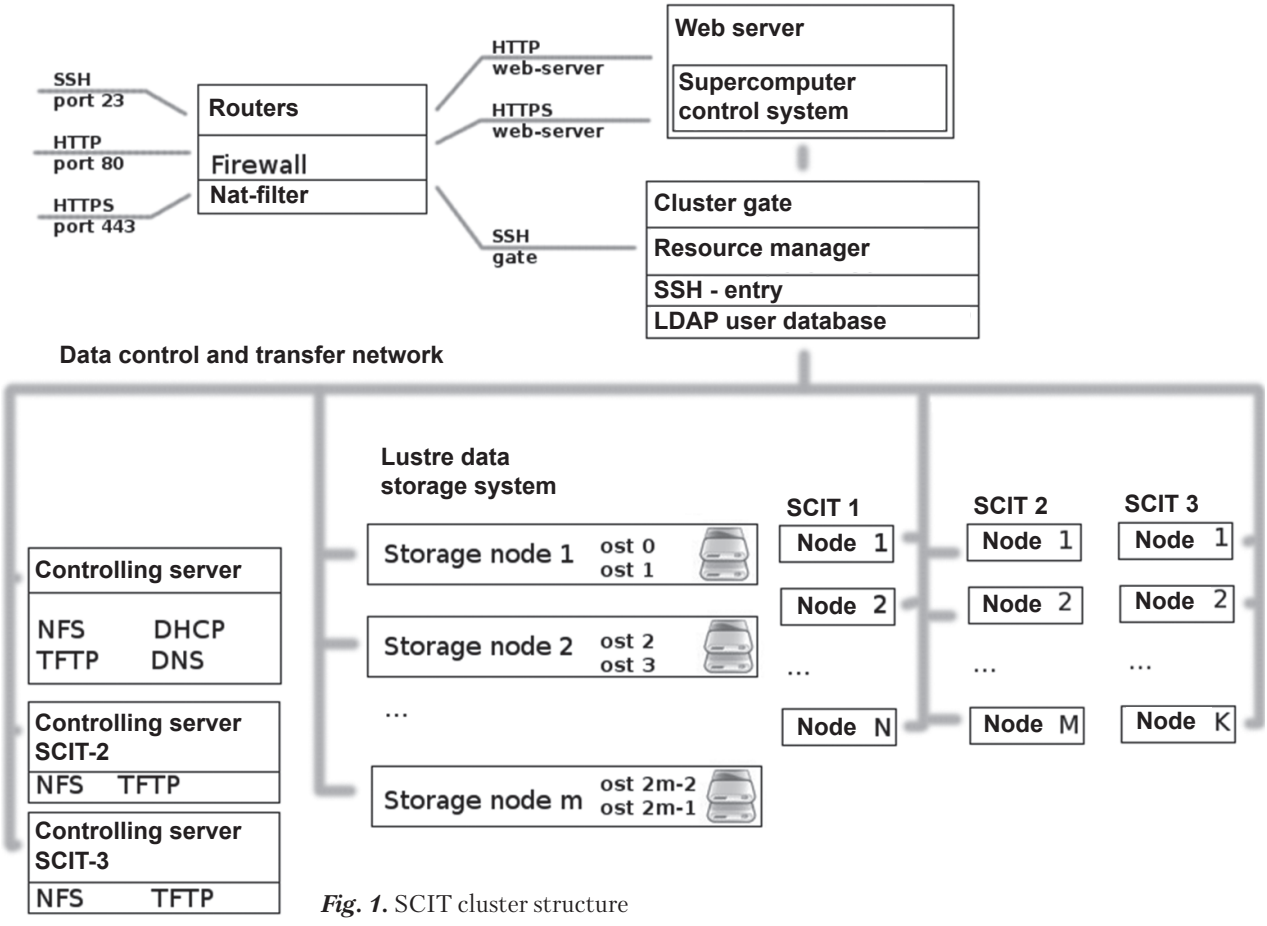

Fig. 1. SCIT cluster structure

The task of cinematography is similar: it is to create a 3D animated film. Each object in the virtual space is processed in the same way as for photogrammetry, the only difference is that drawings are used as source material instead of photographs. Usually, animation is used for work with children. In the view of intensive information traffic, the animated films are likely the most effective to familiarize children with advanced technologies [9—11].

Selected projects implemented using the SCIT cluster infrastructure

The examples below have been created with the use of *RealityCapture* software [1].

1. Monument to Duke (Armand de Richelieu), Odesa (Fig. 2)

Project description: 890 photographs; time of initial collation of camera positions is 8 hours; point cloud calculation takes 36 hours. A model of 800 million polygons has been obtained.

Historical information. **Armand-Emmanuel Sophie Septimanie de Vignerot du Plessis, 5th Duke of Richelieu and Fronsac** was born on September 14 (25), 1766, in Bordeaux, Municipality of Bordeaux, Occitan, France and died on May 17, 1822, in Paris, France. Since 1803, the Governor of Odesa. In the years of his administration, Odessa greatly increased in size and importance, eventually becoming a European metropolis of that time. The grateful Odesites erected a bronze monument to him. It was found on June 30, 1827. The sculptor was Ivan Martos [12].

A simplified 3D model of the monument is available at https://skfb.ly/Wxy6.

2. Passage Hotel, Odesa (Fig. 3)

Project description: 5200 photographs; time of initial collation of camera positions is 23 hours; point cloud calculation takes 196 hours. A model of 2 billion polygons has been obtained.

Historical information. *Passage* Hotel is a hotel complex and shopping gallery, a monument of history and architecture of the late 19th—early 20th centuries, in Odesa, at 34 Preobrazhenska St., (corner of Deribasivska and Preobrazhenska Streets, Primorsky District).

Fig. 2. Monument to Duke (Armand de Richelieu), Odesa

The *Passage* Hotel was built on a historic site. The first buildings belonged to two officers who received a plot for buildup at the end of the 18th century and sold it for the construction of a rental house in 1822 to businessman Kramarev. The house was built in the 1840s. Anna Sinitsina sold it to Moses Mendelevich, a merchant of the first guild. Mendelevich demolished the revenue house and began to build Passage (the Mendelevich Passage). The design authors were architects Lev Vlodek (leader of the group) and Tova Fischer and sculptor Samuel Milman. The sculptural group has not been preserved in its original form because of the fire of October 31, 1901. Some parts of the group and the tower over the main entrance at the corner of Preobrazhenska and Deribasivska Streets were eradicated and have not been restored. The main figures of the group, Mercury and Fortune, are many times repeated in the decorative elements. At the time of its commissioning, *Passage* was furnished according to the most advanced standards as it had electric lighting generated by autonomous power plant, steam heating, telephones, and elevator. There were 162 comfortable rooms in the hotel [13].

The name of the building, Passage, originates from French and means «a gallery with shops on both sides thereof». It was a new type of shopping mall. The first floors of the building were originally equipped as shopping places [13].

Fig. 3. Passage Hotel, Odesa

Before the Bolshevik coup, due to the location in the city center, the Passage hosted prime, the most reputable shops: Kochricht jewelry shop, perfume and haberdashery shop by Auderskyi Jr., Katsman underwear boutique, Izefer shop of gramophones and musical instruments, G. Beckel gastronomy shop, Halperin haberdashery boutique, Kuznetsov Association porcelain ware store, *New Time* bookstore by Suvorin, Eyshysky postal cards shop, and *Passage* Courtyard Photo Studio by Ya. Belotserkovsky. During the Romanian occupation of Odesa (1941—1944), *Passage* worked as usual, with shops operating under brand names in Ukrainian [13].

3. Primorskyi Boulevard, Odesa (Fig. 4)

Project description: 6000 photographs; time of initial collation of camera positions is 44 hours; point cloud calculation takes 220 hours. A model of 1.4 billion polygons has been obtained.

Historical information. Prymorskyi (Seaside) Boulevard (New Boulevard in 1827—1831, Seaside Promenade in 1831—1857, City Boulevard in 1857—1877, Feldman Boulevard in 1919—1941, Nicolas' Boulevard in 1877—1919, 1941—1944) is a street in the historical downtown of Odesa. It runs from the City Duma (Council) to the Vorontsov Palace. The one side is built up, while the other is a green embankment towards the port. In the surroundings, there are Pushkinska Street, Tchaikovsky and Vorontsovski Lanes, Catherine's and Dumska Square. From the Boulevard to the pot ne can get going down the Potemkin stairs or by funicular [14].

While reconstructing the boulevard in 2008, having removed the asphalt pavement, the remains of a culture closely related to the ancient Greek one dated back the 6^{th}—5^{th} centuries BC and fragments of Yeni Dunya fortress were discovered. The archeological excavations were stopped since they could not be continued unless the whole boulevard pavement was dismantled, with the site where the artifacts were found covered with a glass dome and operating as mini-museum [14].

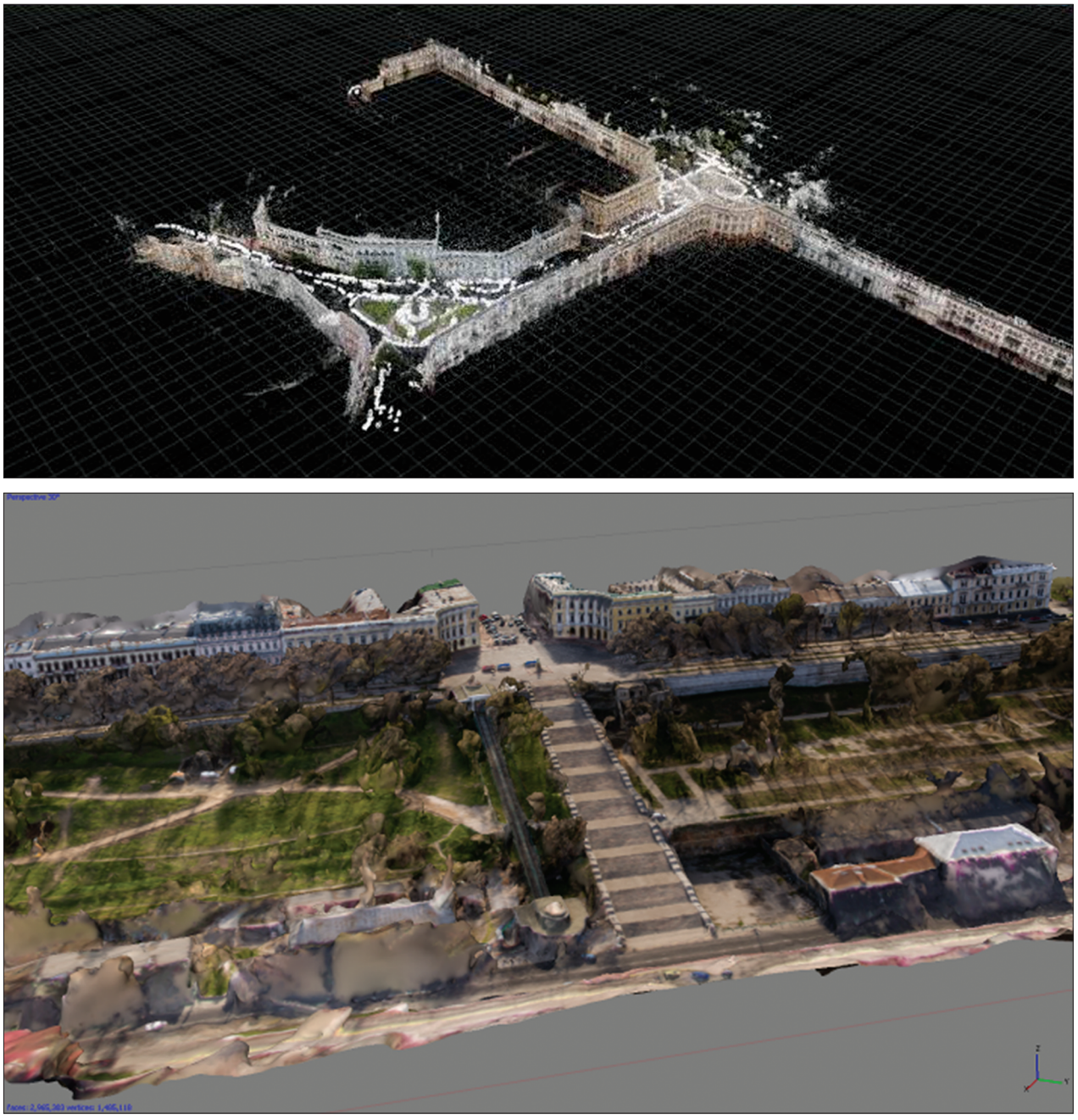

Fig. 4. Prymorskyi Boulevard, Odesa

4. Chornobyl 360 (Fig. 5)

Project description: 8700 photographs; time of initial collation of camera positions is 22 hours; point cloud calculation takes 58 hours. A model of 1.2 billion polygons has been obtained.

Within the framework of *Chornobyl 360* documentary project, the Chornobyl NPP was scanned (together with the Arc). Based on the results of the ground-based and airborne surveys (with the help of an unmanned aircraft), the project team

Fig. 5. «Chornobyl 360»

received more than 20 thousand photographs to create a 3D model of the plant and its surroundings.

The scan was carried out right before the largest movable structure in Europe, the Arc, was placed above the old sarcophagus over the fourth power unit (the Shelter) for the next 100 years. The interim results of this work were presented on November 18, 2016, at the UN Headquarters in New York, at a special multimedia exhibition whose visitors had the opportunity to visit the Exclusion Zone through virtual reality glasses (http://ukraineun.org/press-center/191-8-lystopada-v-shtab-kvartyri-oon-vidkrytsya-multymediyna-vystavka-chornobyl360/).

5. Poshtova Square, Kyiv (Fig. 6)

Project description: 3800 photographs; time of initial collation of camera positions is 18 hours; point cloud calculation takes 42 hours. A model of 300 million polygons has been obtained.

In 2015, at the beginning of the reconstruction of the Poshtova Square in Kyiv, archaeologists uncovered unique artifacts from the times of Kyivan Rus — the remains of paved streets, buildings, and fortifications dated back to the 10^{th}—13^{th} centuries. According to the Director of the Archeology Center of Kyiv of Institute of Archeology of the NAS of Ukraine, Candidate of Historical Science Mykhailo Sagaidak, in 2015—2016, they discovered unique articles of the ducal age and the remains of riverside city quarter of medieval Kyiv [15]. From now on, it can be stated that on the territory of Poshtova Square there was the port with a lively trade.

As world practice shows, such discoveries usually become points of cultural attraction for tourist cities. The results of Poshtova Square excavations have given grounds to hope for the preservation of the ancient Kyiv street and its opening for visitors in the pristine condition. Under the

Fig. 6. Poshtova Square, Kyiv

guidance of the Archeology Center of Kyiv of the Institute of Archeology of the NAS of Ukraine, *Pixelated Realities* NGO recorded the archaeological excavations with medieval timber structures and created their 3D model in June 2016.

With researchers of Glushkov Institute of Cybernetics of the NAS of Ukraine engaged, a 3D model of the entire location has been created and a prototype virtual tour has been developed. The scaled-down model of excavations made on a 3D printer was presented during a press conference held on July 15, 2016, under support of the Ministry of Culture of Ukraine.

The digitization of archaeological finds enables to apply new approaches to a very urgent planning of conservation works and museumization of artifacts. Such 3D models can be printed out and sent to other researchers or used to view excavations of different ages within the same location. This is just one example of how the technologies make the modern museums different from the conventional ones and interesting for visitors. More information is available at https://www.youtube.com/watch?v=0j5dBaBDmMc.

6. Tustan Fortress, Urych Village (Sokoliv District, Lviv Oblast) (Fig. 7)

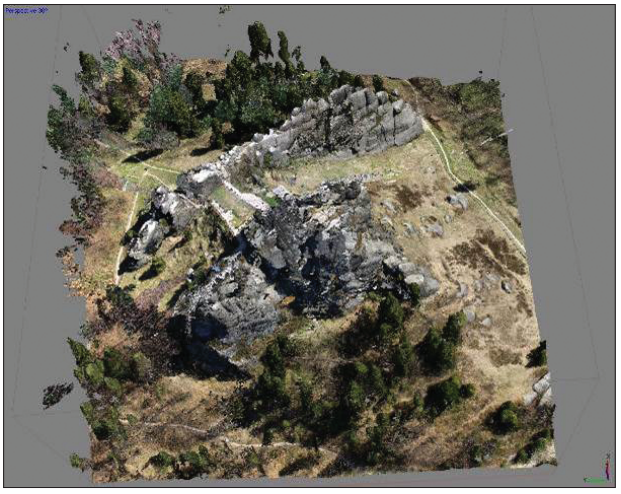

Fig. 7. Tustan Fortress, Urych Village (Sokoliv District, Lviv Oblast)

Project description: 9500 photographs; point cloud calculation takes 560 hours. A model of 800 thousand polygons has been obtained.

Historical information. Tustan is a destroyed rocky fortress of the times of Kyivan Rus located in Lviv Oblast. At present, only the rocks have remained from it. Based on archaeological survey, rocks scanning, and 3D-modeling, the Tustan National Historical and Cultural Reserve seeks to

Fig. 8. Cloud Pictures Studio

restore the original appearance of the fortress. In Urych, the visitors can see how the fortress appeared before, thanks to complementary reality program created by two young talented developers, third-year students of the Lviv Polytechnic National University. The app enables to imagine the scale of the building and demonstrates how the wooden fortress was constructed by ancient craftsmen amongst the steep rocks. The app is available at http://bit.ly/TustanApp.

7. Cloud Pictures Studio (Fig. 8)

Also, in 2016, the Glushkov Institute of Cybernetics of the NAS of Ukraine and its partners, *Panama Grand Prix* Ltd and *Pixelated Realities* NGO, created *Cloud Pictures Studio* special hardware and software complex to solve a wide range of 3D modeling tasks. The project aims to increase the capacity and to expand the scope of application of the SCIT supercomputer.

The developed *Cloud Pictures Studio* has significantly expanded the scope of SCIT application and caused a considerable interest among the creative community, in particular, among young architects, photographers, and 3D artists. The cloud studio was integrated into animation film studio, with project partner making calculations for the first in Ukraine full-length 3D animated cartoon *Mykyta the Rawhides Dresser* that was screened in October 2016, in Ukraine, and in early 2017, worldwide. The average duration of computation of a single frame was 4 hours. Totally, the cluster has computed 50 thousand frames, 60% of which are included in the final version.

As a result of the project implementation, *Cloud Pictures Studio* hardware and software complex has been launched to solve rendering tasks (visualization in computer graphics).

CONCLUSIONS

The experience of 2016 has demonstrated a significant interest, a sales market, a social impact, and urgent tasks for 3D modeling and animation.

The Institute of Cybernetics is creating special computer systems to solve important applied R&D problems.

In 2013—2014, a virtual hydrodynamic laboratory was established for modeling the dynamics of liquids and gases, calculating the dynamics of helicopter blades, turbines, flow around the body of dry cargo ship, etc. The implementation of *Cloud Pictures Studio* project is one more evidence of successful experience.

As part of the *Cloud Pictures Studio* initiative, photogrammetric surveys and computing resources have been provided for creating a 3D model of Yaroslav the Wise bust kept at the Sofia of Kyiv National Museum. The results have been used to create *Ukraine. Return of History-2* documentary film released on August 24, 2017.

It should be noted that the SCIT additional computing resources can be used not only in computer graphics, but also to meet the needs of a wide range of users of parallel and grid computations at the institutions of the NAS of Ukraine.

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СУПЕРКОМП'ЮТЕР ЯК ПЛАТФОРМА ДЛЯ ІННОВАЦІЙНОГО РОЗВИТКУ

Вступ. В Інституті кібернетики імені В.М. Глушкова НАН України функціонує найбільший в Україні суперкомп'ютерний комплекс СКІТ, загальна пікова продуктивність якого сягає 43 трлн операцій на секунду. Суперкомп'ютер ефективно вирішує завдання максимально широкого спектру — від дослідження надр Землі до лінгвістичних студій та від генетики до моделювання еволюції чорних дір.

Одне зі своїх застосувань комплекс знайшов в рамках науково-технічного проекту НАН України під час розв'язання задач фотограметрії при партнерстві з Громадською організацією «Pixelated Realities», що займається просуванням цифрових методів як для реставрації, реконструкції, дослідження об'єктів культурної спадщини, так і для планування й ревіталізації (пожвавлення) міського простору.

Мета. Створення спеціалізованого програмно-апаратного комплексу на базі суперкомп'ютера СКІТ для вирішення ресурсоємного завдання фотограмметрії.

Матеріали й методи дослідження. Програмно-апаратний комплекс створено на базі оригінальної архітектури суперкомп'ютера СКІТ та фотограмметричного методу побудови тривимірних сцен, який полягає у відтворенні 3D-об'єкту за фотографіями. Завдання фотограмметрії передбачає обробку десятків тисяч фотографій для створення тривимірних сканованих образів пам'ятників, історичних будівель, археологічних розкопів та урбаністичних об'єктів з використанням програмного забезпечення RealityCapture.

Результати дослідження. Інноваційним результатом проекту є створення першого в Україні спеціалізованого програмно-апаратного комплексу, який використовує високопродуктивні обчислення для вирішення завдань тривимірної реконструкції за фотографіями. Також в Інституті кібернетики разом з партнерами розроблено спеціалізований програмно-апаратний комплекс «Хмарна кіностудія».

Висновки. Створення спеціалізованого суперкомп'ютерного сегмента та приклади його використання продемонстрували ефективність таких рішень в напрямі тривимірного моделювання й мультиплікації, а також наяв-

ність значного інтересу та великого ринку суперкомп'ютерних технологій. «Хмарна кіностудія» продовжила успішний досвід створення спеціалізованих обчислювальних систем, призначених для розв'язання важливих прикладних науково-технічних завдань.

Ключові слова: фотограмметрія, тривимірне моделювання, суперкомп'ютер.

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СУПЕРКОМПЬЮТЕР КАК ПЛАТФОРМА ДЛЯ ИННОВАЦИОННОГО РАЗВИТИЯ

Введение. В Институте кибернетики имени В.М. Глушкова НАН Украины функционирует наибольший в Украине суперкомпьютерный комплекс СКИТ, общая пиковая продуктивность которого достигает 43 трлн операций в секунду. Суперкомпьютер эффективно решает задания максимально широкого спектра — от исследования недр Земли до лингвистических студий и от генетики до моделирования эволюции черных дыр.

Одно из своих применений комплекс нашел в рамках научно-технического проекта НАН Украины во время решения задачи фотограмметрии при партнерстве с Общественной Организацией «*Pixelated Realities*», которая занимается продвижением цифрових методов как для реставрации, реконструкции, исследования обьектов культурного наследия, так и для планирования и реализации (оживления) городского пространства.

Цель. Создание специального программно-аппаратного комплекса на базе суперкомпьютера СКИТ для решения ресурсоемкой задачи фотограмметрии.

Материалы и методы исследования. Программно-аппаратный комплекс создан на базе оригинальной архитектуры суперкомпьютера СКИТ и фотограмметрического метода создания трехмерных сцен, которое заключается в воссоздании 3D-обьекта по фотографиям. Задача фотограмметрии предусматривает обработку десятка тисяч фотографий для создания трехмерных сканированных образов памятников, исторических строений, археологических раскопок и урбанистических объектов с использованием программного обеспечения *RealityCapture*.

Результаты исследования. Инновационным результатом проекта есть создание первого в Украине специального программно-аппаратного комплекса, который использует высокопродуктивные вычисления для решения заданий трехмерной реконструкции по фотографиям. Также в Институте кибернетики вместе с партнерами разработано специальный программно-аппаратный комплекс «Облачная киностудия».

Выводы. Создание специального суперкомпьютерного сегмента и примеры его использования продемонстрировали эффективность таких решений в направлении трехмерного моделирования и мультипликации, а также наличие большого интереса и значительного рынка суперкомпьютерных технологий. «Облачная киностудия» продолжила успешный опыт создания специализированных вычислительных систем, предназначенных для решения важных прикладных научно-технических задач.

Ключевые слова: фотограмметрия, трехмерное моделирование, суперкомпьютер.