Collaborative Work with Large Amount of Graphical Content in a 3D Virtual World

Evaluation of Learning Tools in vAcademia

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***Abstract*—In this paper, we suggest a method for collaborative work with large amount of graphical content in 3D virtual worlds. We argue that applying this method will benefit educational and other professional use of this technology. The most common problems with applying 3D virtual worlds in everyday teaching and learning are steep learning curve and demand for computational and networking resources. The suggested method allows reducing the load on CPU, and therefore, designing convenient and sophisticated tools for collaborative work with graphics inside a 3D environment. We present the methods of generating images, the design, and implementation of tools we developed for vAcademia virtual world based on this method. We discuss the educational value of the possibilities to work with large amount of graphical content in a 3D virtual world, which were limited before. We provide performance evaluation of the suggested method based on a series of tests which we applied to the whole system and specific algorithms. In addition, we present the initial result of user evaluation.**

***Keywords*—3D virtual worlds; image processing; educational content; Virtual Whiteboard, vAcademia.**

I. Introduction

Three-dimensional Virtual Environments and Social Virtual Worlds (3D VWs) provide both opportunities and challenges for education, and many topics in this area need further research [1, 2]. Despite the repeated positive conclusions, 3D VWs have not become widely used, and researchers often report that their studies have experimental nature. The most common problems with applying 3D VWs in everyday teaching and learning are steep learning curve and demand for computational and network resources [3, 4]. While the computers and networks are constantly improving, the 3D VWs also require improvement to make them more convenient for educators and to deal with the steep learning curve.

The work presented in this paper is addresses one of the most serious challenges for applying 3D VWs for learning – enabling collaborative learning scenarios which require large amounts of 2D graphical content displayed. We present the design of a collaborative graphical workspace of vAcademia 3D VW [5, 6], which is implemented as a set of tools for collaborative work on 2D graphical content. We argue that such a workspace should be designed specially for learning and integrated into the 3D environment. We propose that integration of such a workspace is of high value, as they ease the collaborative process and reduce the necessity for using additional services. Implementing tools that are familiar to educators can facilitate the process of adapting the system.

The main challenge for the implementation of tools for 3D VWs is the fact that this technology is resource-demanding. We suggest a method for collaborative work with large amount of graphical content in 3D virtual worlds. The method is based on a mathematical and a programming model for texture generation [7], based on stream processors (SPs) [8]. The model allows us to pass the calculations of graphics on to the stream processors in order to reduce the load on CPU. The originality of the approach is in its ability to deal with large amounts of *meaningful* graphical content which is meant for educational or other serious purposes and not just artistic textures.

The method was used for implementing a set of tools for collaborative work on media content within vAcademia. These tools enable collaborative and convenient work with various types of dynamic and static graphical content inside the 3D VW. The tools and the underlying mechanism were tested, first, evaluating their performance in regular and exceptionally stressful conditions. In this paper, we will also describe examples of the practical application of the system developed and present the initial result of user evaluation.

II. Background and Related Work

A. Learning Tools in 3D Virtual Worlds

3D VWs provide a unique set of features that can be used for learning, such as low cost and high safety, 3D representation of learners and objects, interaction in simulated contexts with high immersion [9, 10]. Possibilities for synchronous communication and interaction allow using 3D VWs by various collaborative learning approaches [11]. Possibilities for simulating environments on demand and for active collaborative work on the content allow applying situated learning [12] and project-based learning [13] approaches. Constructivist approaches, such as problem-based learning, are also popular among the adopters of 3D VWs [14].

Social constructivism is often used in a 3D virtual environment, as the technology allows learners to co-construct their understanding [15, 16]. In addition, 3D VWs are used for educational simulations [17] and demonstrating complex concepts [18, 19].

One of the most serious challenges in adapting 3D VWs for learning is the lack of features that educators use in everyday teaching: "Most virtual worlds were not created for educational purposes. Second Life, nonetheless, is being adapted by educators […]. Many of the features educators take for granted in Learning Management Systems do not exist in Second Life" [2]. There is a belief among educators that the 3D VWs should be better used for simulating situations that are difficult or impossible to implement in reality, and not replicating the real-world educational structures [20]. However, the absence (or inaccessibility) of familiar and convenient learning tools in the 3D VWs is also contributing to the general attitude towards the technology.

B. *Large Amount of Graphics in 2D Platforms*

Nowadays, many examples can be found of large amounts of textual and graphical information that needs need to be on the user's display at a time. This is often required in synchronous collaborative activities, when users have to be aware of what the others are doing. Such activities are typical for collaborative learning approaches, for example, social constructivism [21]. However, in practice software limitations do not allow implementing them to the full extent on either 2D web-conferencing (webinar) platforms or in 3D VWs.

Modern web-conferencing platforms provide a shared workspace, means for content presentation, and various forms of interaction (see, e.g., [22, 23]). However, it should be noted that in most cases, a passive learning approach is used in 2D web-conferences when the information (e.g., a lecture or a presentation) is delivered. Web conferences are often interactive (e.g., questions, comments, and discussion) and collaborative (e.g., mind-mapping, posting notes on slides, and using a shared workspace) but, a single screen (with the content provided by the teacher) is used almost always. The example of using breakout rooms illustrates synchronous collaborative activities in web-conferencing platforms, "allowing small groups to undertake tasks and bring outputs back to a plenary full group discussion" [24]. In this case, each group of learners still works with a single shared workspace/screen, and the results are discussed one by one.

The implementation of such scenarios in 2D does not require large amounts of textual and graphical information on the user's display. The reason, however, is not in the lack of demand, but most likely in the technological limitations. When a collaborative scenario requires displaying multiple workspaces side by side, they can be located as tiles, but even with large monitors, this approach is rarely convenient. Alternatively, multiple workspaces can be set to different sizes (e.g., a teacher can enlarge them when required [25]).

C. *Large Amount of Graphics in 3D Virtual Worlds*

3D VWs allow building learning environments that can accommodate multiple workspaces or virtual screens and convenient switching between different points of view (i.e. observing multiple screens or focusing on one). Therefore, when the passive learning approach is implemented in a 3D VW, the display does not need to be split into sections. Instead, natural 3D navigation or camera navigation and zoom are used. This allows using multiple virtual screens, for example, one with presentation slides, another with video or text notes. These affordances of the 3D space allow implementing active teaching methods too, providing each user with personal virtual screen or each group with multiple screens.

However, in practice, existing 3D VWs allow using very limited numbers of virtual workspaces for collaboration on graphical content. For example, an environment may accommodate 2–5 virtual screens within the visibility area. This allows conducting several types of educational activities, including lectures and presentations. However, conducting activities that require active collaborative work with media content remains problematic. Another common practice is creating many screens with static images. This allows creating virtual galleries which can be explored collaboratively and discussed by a group of learners, but without active involvement in creating or modifying the content displayed. In such a way, the possibilities for conducting educational activities are also limited.

Many 3D VWs offer the "virtual screen" functionality. However, the features of such screens often have inferior implementation because of performance limitations related to the use of CPU for processing images. For example, the 3D VW "Sametime 3D" built on OpenSimulator platform has a tool for working with sticky notes. However, the notes can only be placed on special square slots, their size is constant, and there is no possibility to use any other tools on the same screen (e.g., drawing). These limitations obstruct the effective use of the tool.

D. *Technological approaches to Processing Large Amounts of Graphics*

Processing large amounts of images in 3D VW is mostly required when working on serious tasks, such as collaborative work and learning. In other tasks, displaying images, video or flash is also often required; however, the amount of content is smaller. Usually, an image is calculated on a CPU on client side (e.g., in Second Life™ and Blue Mars™) or server side (e.g., in Open Wonderland™) and then loaded into the stream-processor memory as a texture.

Thus, we can conclude that the use of dynamic 2D images in existing 3D VWs is very limited. One of the most popular platforms that is widely adopted for educational purposes – Second Life even has a hard limit of five dynamic images that can be rendered for one user at a time. This fact can be technically explained by the use of CPU for generating images. This technical limitation does not allow educators to implement some of the learning scenarios to their full potential.

III. Interactive Virtual Whiteboard of vAcademia

Interactive virtual whiteboard (VWB) is the main tool (or a container of tools) for collaborative work on 2D graphical content in vAcademia. Multiple VWBs of different sizes can be set up in any location of vAcademia (Fig. 1). In addition, every participant can set up an extra VWB during a class and present some content on it. Multiple users can stream or share their content simultaneously by simple mechanisms such as drag-and-drop. A colored laser pointer can be used for focusing attention on a certain element of the board. Additional auxiliary mechanisms allow user to switch easily between the displayed data for better overview.

Fig. 1. Multiple VWBs and virtual laser pointers in use

vAcademia has a dedicated interface for placing objects in virtual locations (Fig 2, bottom right). VWBs of different sizes and designs are stored in the Object Gallery and available for every user [6]. User-created whiteboards are put on the ground, but can be moved and rotated (Fig. 2, left). VWBs that are part of Standard Locations cannot be relocated during a live session, however, they can be modified in advance and saved as templates to be used in specific settings (e.g., a large number of whiteboards or specific placement pattern) [6].

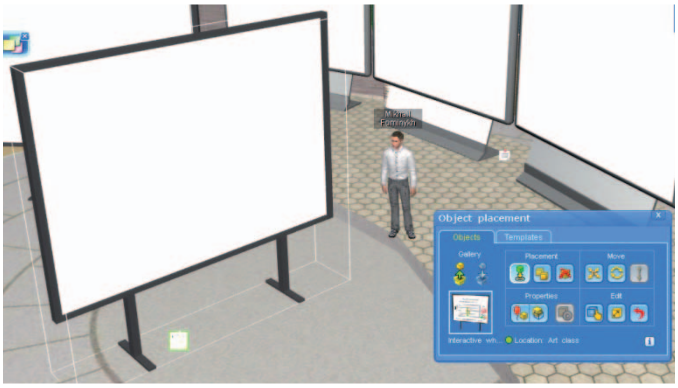

Fig. 2. Placing a VWB in a virtual classroom

VWB can be used for displaying and annotating slides, sharing the desktop, sharing the application that runs on the teacher's or student's computer, sharing the web camera, drawing figures, typing text, and inserting text or graphics from the clipboard. The VWB's tools can be accessed from the context menu (Fig 3). The image shows the full menu (Fig. 3), but it can be extended or reduced if a specific tool is used (e.g., Figs. 8 and 10) or if the VWB is occupied by another user. The first row of the menu contains only one button – a laser pointer that can be pointed to any place on any VWB or other objects. The second and third rows contain all the VWB's tools that are presented in Section IV. The forth row contains buttons that focus the user's view on a specific VWB, on all VWBs in the virtual location, or sets the view into free camera mode. The fifth row has a button to search through the previous contents on the specific VWB (Fig. 3).

Fig. 3. Accesssing VWB's tools

In addition to the context menu, the content on a VWB can be placed by drag-and-drop. Images and slide presentations can be uploaded to a Resource Collection in advance and dragged to a VWB during a live class (Fig. 4) [6]. Test and quiz results can be displayed on a VWB using drag-and-prop [6].

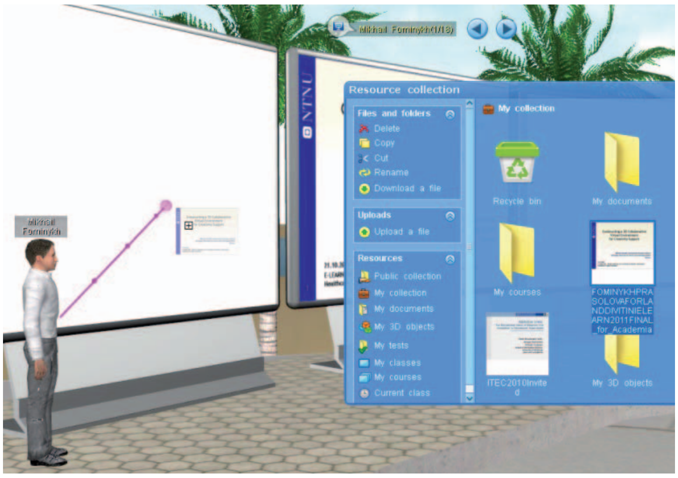

Fig. 4. Placing content on a VWB

IV. METHOD AND TOOLS

The VWB had the following major requirements that are based on a preliminary evaluation of the needs of common teaching practice. The VWB should be able to display images from two sources simultaneously and independently, and the system should support up to 50 VWBs within the visibility scope of the user.

The design of vAcademia VWB and the tools for collaborative work on graphical content is based on using a dynamic texture with two independent layers which are combined in one static texture when rendering. Generally, the lower level is used for permanent content, while the upper level – for temporary content that can be changed or erased. This allows having a temporary dynamic figure above several different lower-layer contents (such as slides). In other situations, the lower layer may contain a dynamic image, while the upper layer may remain unchanged (such as for commenting on a video when the comments must remain visible above all the frames).The tools available via the VWB of vAcademia can be classified into three groups by the method of generating the resultant image.

A. *Sharing Changing Blocks*

Requirements: The system should be able to support up to three simultaneously working image-sharing processes in any location, with up to 1024 to 1024 pixels resolution each, and with a frame rate at least 5 FPS. The frame rate is considered as a requirement for the performance of the system only. However, it also depends on the Internet connection speed, and therefore meeting the requirements does not guarantee the desired frame rate (in case of low connection speed).

Design: The Sharing Changing Blocks method of generating the resultant image is based on an algorithm for DWT for image compression with quality reduction, which is adapted for SPs. It identifies the changing rectangular parts of the image by using occlusion query [26]. The algorithm is based on the filter cascade scheme that allows implementing the forward DWT in one pass. The method uses the lower layer of the VWB and processes the dynamic image. Quality may be adjusted by DWT coefficients.

Implementation 1: Sharing an application window allows to share the content of any window. The window is translated even if minimized or overlaid. The control over the window can be given to any user in the location.

This feature can support various scenarios when a live demonstration of third-party software is required. For example, a hands-on tutorial on a specific application can be conducted with sharing its window. Another example is a synchronous distant-education session when learners are working with a specific software application (e.g., programming user environment), share windows with this software, and a teacher controls and facilitates the process (Fig. 5).

Fig. 5. Sharing application window (Scratch programming language)

Implementation 2: Sharing screen area allows sharing any square area on the desktop, which may contain any working applications.

This tool can be used in a distance-education session when the use of multiple software applications is required to be shared. For example, a teacher can share a part of the screen to demonstrate contents using different applications, e.g., a web browser or a video player (Fig. 6). In active learning scenarios, students can work in several applications and stream their screens into the virtual environment, demonstrating the flow of work, and the teacher can observe them in one space.

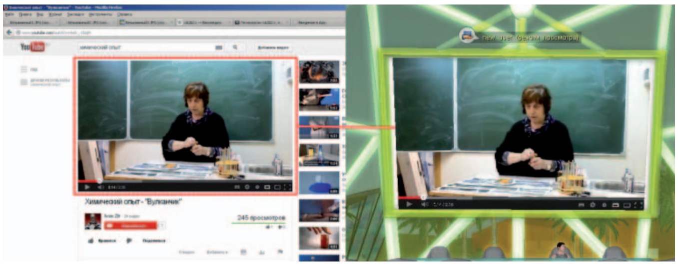

Fig. 6. Sharing screen area (video from the web is streamed into a VWB)

Implementation 3: Sharing a web-camera image allows sharing the web-camera image and adjusting its size.

This tool can be used for building trust in the beginning of a distance class or a course, e.g., for introducing the participants. Each of them can use a personal VWB to share the image from the web-camera. Another example is a scenario when hand gestures or facial expression need to be shared, e.g., in language learning (Fig. 1).

B. *Sharing Attributed Vector Figures*

Requirements: The system should support simultaneous drawing or typing on up to 25 VWBs with the average performance degradation less than 15% and peaking performance degradation less than 25%.

Design: The Sharing Attributed Vector Figures method of generating the resultant image is based on triangulation of vector primitives with attributes for one- or two-way rasterization. Displaying (both typed and inserted) text is implemented by using font textures, rasterizing each symbol on demand. The method uses the upper layer of the VWB and processes the dynamic image.

Implementation 1: Drawing figures and typing text allows to draw, erase, copy, and paste several types of geometric figures and text on the VWB. Drawing and typing actions from the time of cleaning the VWB can be undone. The undo depth is unlimited, which would be a performance prohibitive operation if using CPU only.

This tool can be used in multiple collaborative learning scenarios when drawing and typing is required, for example, taking notes during brainstorming session, creating mind maps, and sketching prototypes (Fig. 7, left).

Implementation 2: Inserting text tool allows inserting text from the clipboard to the VWB as long as it fits its size.

This feature can be used together with drawing figures and typing text (Fig. 7, right), allowing participants to work in third-party applications and share results on the VWBs.

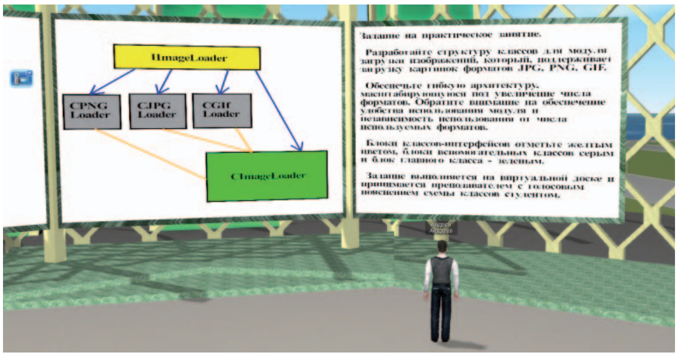

Fig. 7. Drawing and inserted text on a VWB

C. *Processing Static Images*

Requirements: The system should support simultaneously changing static images on five VWBs within the visibility area. The average performance degradation should be less than 10% and peaking performance degradation less than 15%.

Design 1: The Processing Static Images method of generating the resultant image is based on resizing the source image, applying Filters, asynchronous unpacking, and uploading it. The method uses the lower layer of the VWB and processes the static image.

Implementation 1: Slideshow allows opening a PDF or PPT presentation on a VWB and navigating the slides forward and back.

This tool allows replicating classroom settings that are commonly used for presentations and lectures (Fig. 8). As opposed to the physical classroom, a teacher can use two or more screens for slides, and learners can upload their slides to personal VWBs. The main advantages of vAcademia's VWB over similar tools in other 3D VWs are that a large number of screens with slides can be deployed in a single virtual location and that the tool is integrated into the system.

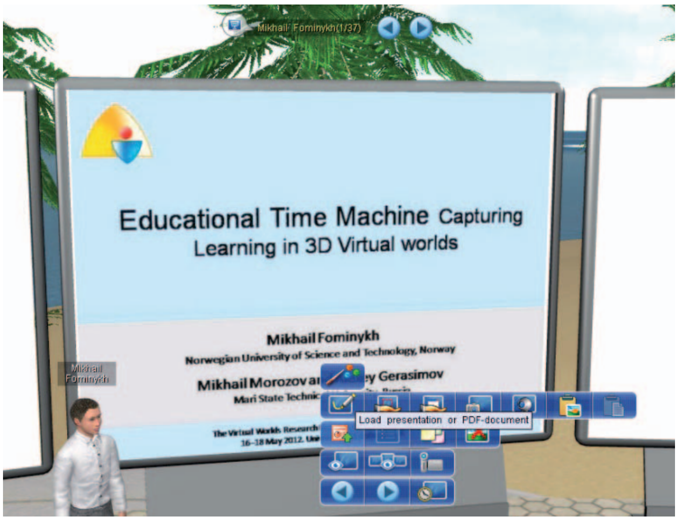

Fig. 8. Slide-presentation controls

Implementation 2: Area print screen allows displaying any square area on the desktop. Image quality can be adjusted.

This tool can be used in collaborative learning activities when a part of the desktop needs to be presented to all the participants. For example, this can be the result of an individual assignment which needs to be discussed. Another common situation can be the need to present a quick snapshot that fixes a status of a working application, enabling to compare with the next status later.

Implementation 3: Image insert allows inserting from the clipboard, from Resource Collection, and from applications (drag-and-drop). Image quality can be adjusted.

This tool provides flexibility that is necessary for selecting educational material on demand and on the fly. Such flexibility is important for a teacher, as the materials prepared in advance (e.g., a presentation, demos, or web resources) are often not sufficient. Teachers often need to augment the core educational material with specific examples to stress a certain point or answer an unexpected question. Image insert tool allows bringing additional images to the virtual class very quickly.

Design 2: Processing static images from 2D scene is based on a FS of a high number of alpha-blending Filters with different source images, blending settings, and hardware scissors. A 2D image or a rasterized image of a letter is taken as an input parameter.

Implementation 4: Backchannel allows displaying text-chat messages on a VWB. An additional tab appears in the text chat of all users in a location when a backchannel tool in used on a VWB. Messages in this tab immediately appear on a VWB (Fig. 9).

Backchannel is a powerful mechanism for improving the contact between the speaker and the audience that is becoming increasingly popular and taking multiple technological implementations [27]. In the traditional classroom settings, backchannel is often used as a simple feedback tool, but also a means of interaction in active and collaborative learning scenarios (e.g., [28]). In a virtual classroom, the backchannel tool performs the same function, as in a physical one. However, such a simple interaction mechanism can be considered more valuable in a virtual environment, as the non-verbal interaction and awareness mechanisms are very limited in such environments.

Fig. 9. Backchannel tool in use

Implementation 5: Sticky notes tool allows placing text or graphical notes on a VWB. It is a full-scale tool for collaborative work. Every user can place sticky notes on VWBs, move them on the surface of the VWB or between the boards, modify the contents of the notes, and change their color and size. The teacher (creator of a scheduled class) can modify both his/her own sticky notes and those of the class attendees. All actions with notes can be seen by all users in real time (Fig. 10).

The surface of the VWB with sticky-notes is a 2D-image (texture) which is applied when rendering the 3D scene. Since the sticky notes is a collaborative tool, it is reasonable to assume that the content of the VWB needs to be updated frequently (e.g., when one of the users makes changes to a sticky note, it should be updated immediately and for every user). This entails the need for high-speed texture generation that is implemented using the method we suggest.

Sticky notes can be used in a wide range of educational activities, including brainstorming, project-work discussions, and SCRUM sessions [29].

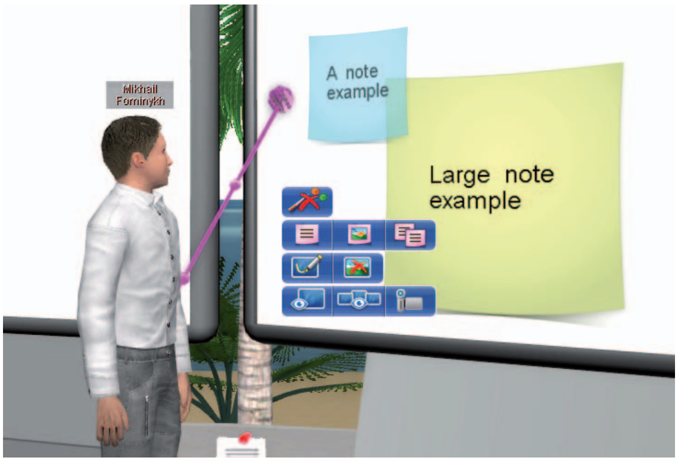

Fig. 10. Examples of sticky notes and tool's context menu

V. Evaluation

A. *Performance Evaluation*

In this section, we present the results of testing the tools for collaborative work on 2D graphical content and the underlying mechanisms. We provide technical details that might be difficult to interpret for an educator. However, we discuss the meaning of the evaluation results from the user point of view in the Discussion.

First, we compared the performance of the algorithms using SPs and CPU. Second, we explored the general efficiency of the system, i.e. performance degradation when using many tools simultaneously, measuring the average and peak values. In both cases, we present the average results acquired by running the system on 20 different hardware configurations with Intel CPU and NVidia / ATI graphics adapters from the same price range. On each hardware configuration 10 runs were conducted for each image size. Third, we conducted a user evaluation among a group of students.

1) *Performance of the Algorithms on SPs and CPU*

We compared the performance of the algorithms by SPs and CPU to confirm the rationale behind using SPs (instead of CPU) for image processing in vAcademia. Although such comparison data do not provide insight into the overall improvement in the software performance, they can be used for evaluating the power of SPs.

The results presented above demonstrate that the advantage of SPs over CPUs is about 70 times for the forward Discrete Wavelet Transformation algorithm, about 28 times for the inverse, and 42 times for rasterization of attributed vector primitives. We transformed this algorithm to be performed on SPs, and it exemplifies the superiority of the method. The maximum benefit is achieved for large images, as in this case the time of image processing is more significant in comparison with the time of preparation for transformation. The rate of the inverse Discrete Wavelet Transformation algorithm is lower, as the large number of passes is required and correspondingly the greater total preparation time of for transformation.

Overall, the improvement acquired by using SPs differs from the ratio of the peaking performance of SPs to the peaking performance of CPU not more than twofold, which can be considered satisfactory.

2) *General Efficiency of the System*

The data acquired from comparing the performance of the algorithms on SPs and CPU do not fully demonstrate how the performance of the whole system (software product) changes. The reasons include specifics of SPs and CPU working in parallel and that the computational power is used not only for executing an algorithm. Therefore, we tested the general efficiency of the system when the suggested approaches were implemented and applied. In this part of the evaluation, we tested if these approaches satisfy the requirements presented in Section IV.

We collected the data for the practical evaluation of the system by selective replaying 3D recordings of classes. The number of simultaneously working tools was regulated by excluding the required number of VWBs from a re-played 3D recording (that originally contains the maximum number of VWBs). Both layers of the VWB were utilized. We used presentation slideshows and single images on the lower level, and drawing vector figures on the upper layer. However, the VWBs were not actively used.

We present the results by demonstrating the ratio of the average and peaking performance degradation to the number of simultaneously working VWBs (Fig. 11). The testing process is also presented (Fig. 12). The analysis of data reveals that 50 simultaneously working VWBs reduce the performance of the client software not more than by 7%, which is a satisfactory result (Fig. 11).

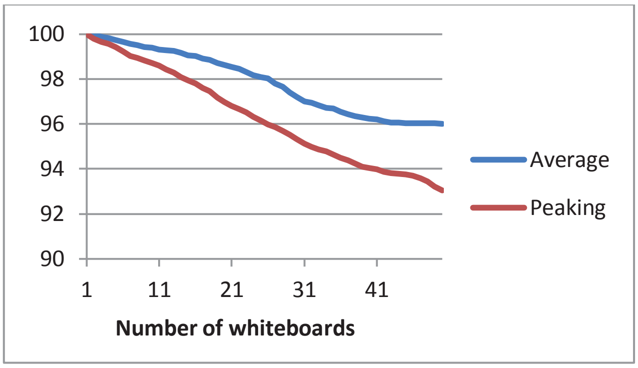

Fig. 11. Average and peaking performance degradation as a function of the number of VWBs

Fig. 12. The process of testing performance degradation as a function of the number of VWBs

In the next case, we used the same settings, but up to 25 VWBs that were actively used – constantly changing images on the upper layer. We present the average and peaking performance degradation as a function of the number of actively used VWBs (Fig. 13). The analysis of data reveals that the peaking performance degradation reaches 22% when the number of actively used VWBs is 25. The average performance degradation reaches 13% (Fig. 13).

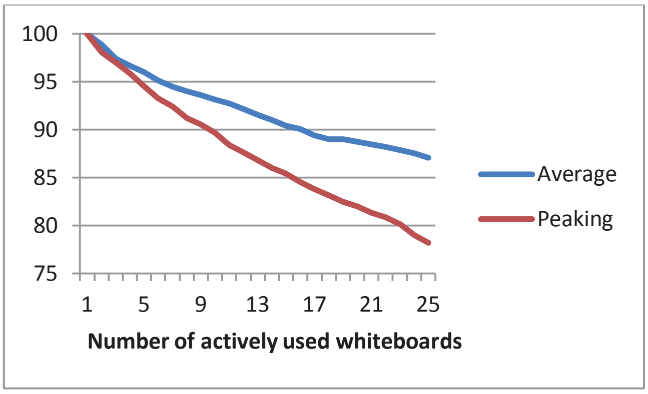

Fig. 13. Average and peaking performance degradation as a function of the number of actively used VWBs

In the following case, we tested how simultaneously changing images (processing static images method) reduces the system's performance. This task is chosen as one of the most intensive, and it was essential to provide a smooth functioning of this method. We present the average and peaking performance degradation as a function of the number of simultaneous changes of images on VWBs (Fig. 14). The analysis of the data demonstrates that five simultaneous changes reduce the performance of the system by 14% in the worst case and by 8% on average.

Fig. 14. Performance degradation as a function of the number of simultaneous changes of images

The results acquired during testing indicate that all the technical requirements for the tools for collaborative work on 2D graphical content were satisfied. The implementation of image processing algorithms on SPs improves the performance using only CPU computational power tenfold and more.

B. *User Evaluation*

We present a small-scale user evaluation of the tools for collaborative work on 2D graphical content in vAcademia and their pedagogical value. We conducted a collaborative working session with students from Computer and Information Science department, giving them a task which would require the system to process large amounts of graphical content. The data were collected from the system logs, a questionnaire offered to the students after the session, and an interview with the teacher.

A group of 23 second-year computer science students participated in the evaluation. All of them had experience playing computer 3D video games. In addition, few students used vAcademia within other courses previously. Therefore, no tutorials on vAcademia were given prior the session, but also no questions about the platform were asked.

We conducted the evaluation within Advanced Software Development course. The students were given a task to design a class diagram based on provided templates. In particular, they had to design a tool for collecting memory statistics. Practically, the group gathered in one location in vAcademia, and the teacher provided a slide presentation with images that contained the templates for the diagram. Each student uploaded the presentation to a personal VWB, selected a template, and drew a diagram on top of it (Fig. 15). Technically, the provided the presentation uploaded into the lower layers of the VWBs, and the students were drawing in the upper layers using the Sharing Attributed Vector Figures method. The session concluded with voluntary presentations of the resultant diagrams, their analysis, and a discussion.

Fig. 15. Userevaluation session

After the working session, we offered a questionnaire with eight Likert scale questions requesting students to reflect on their experience of using the VWB. The students selected ‘strongly agree’ (SA), ‘agree’ (A), and ‘neutral’ (N) options for all questions (Table I). Options ‘disagree’ and ‘strongly disagree’ were not selected.

TABLE I. QUESTIONNAIRE RESULTS

Question	SA	A	N
It was clear what functions the VWB has and how to access them.	16	7	
It was comfortable "to look" at VWBs (to change the view angle).	15	8	
VWBs displayed the contents crispily and precisely enough to understand them.	14	9	
VWBs displayed the contents quickly enough, and delays did not influence the process of working on the task (one student did not respond).	14	8	
Increasing the # of VWBs in the virtual auditorium during the class did not lead to visible delays.	13	10	
VWB is a convenient (handy) enough tool for working on similar tasks.	13	8	2
Working with vAcademia tools is more comfortable than with traditional tools, for similar tasks.	15	8	
It was clear how to work in vAcademia.	19	4	

VI. DISCUSSION

A. *Multiple Virtual Whiteboards*

Interaction is one of the most important components of the learning process. vAcademia’s VWB is a tool that facilitates interaction and increases it effectiveness.

When a teacher acts as a lector, a one-way interaction is traditionally used. Several multifunctional screens (VWBs) provide a teacher with freedom and flexibility in presenting information and transferring knowledge. Such freedom and flexibility are possible by means of a selection of types of educational materials (visual and audible) and a tool for sharing these materials with learners. It can be compared to the variety of instruments in a symphony orchestra that opens the possibility for creating musical masterpieces or to the variety of colors that allow painters to convey their vision of the world on canvas more accurately.

In collaborative learning activities, a whiteboard plays the role of the workspace. A single whiteboard can be used as a shared workspace in both physical and virtual classroom. With multiple VWBs, a teacher can set up the group and even individual workspaces.

This possibility allows recreating several traditional-classroom (or computer-classroom) learning activities in a 3D space. Using multiple whiteboards can be the foundation for successful teaching in a traditional classroom. One of the authors of this paper remembers how he studied physics at school. The classroom was different from the others. Apart from the equipment for conducting experiments and the teacher’s (at that time) blackboard, the full length of one of the walls was covered with additional blackboards. At every physics class, 5–6 students could work on practical tasks simultaneously and discuss the solutions afterwards with the teacher and the whole class. This approach provided high achievements and contributed to creating a friendly social atmosphere. However, such classroom facility is exceptionally rare, and most of the classroom activities are designed for a single-person workspace (one whiteboard).

In a 3D VW, the availability of multiple VWBs allows conducting practical classes (as in the example above) where students share their progress, workbooks, or reports on individual VWBs. Another example is an open (individual or collaborative) writing activity where a group of students can work on several pieces of text being aware and learning from each other.

The availability of multiple workspaces (such as whiteboards) is critical for many learning approaches, for example for the flip teaching (or flipped classroom). In the real-world settings, flip teaching implies studying new material at home and practicing (or doing the traditional homework) in class [30]. In distance education terms, the new material (e.g., video lectures or textbooks) is studied asynchronously, while the practical assignments are done in the synchronous mode. Applying this approach in the virtual-world settings, the students will always need individual or group workspaces. In cases such as solving mathematical problems or working with a software application, an individual workspace is required. In cases such as discussion or brainstorming, group workspaces can facilitate the collaborative process.

The scenarios exemplified above can be implemented in a physical classroom, however, most of the real-life learning activities are designed for one room and for one whiteboard.

The features of the 3D virtual environment allow creating any learning environment at a lower cost. At the same time, it is challenging (if not impossible) to implement the exemplified scenarios with multiple workspaces in a 3D VW without the features of the VWB. In such a manner, multifunctional group and individual virtual screens implemented as the VWB extend the variety of learning scenarios which can be applied in 3D VWs, and therefore, increase the educational potential of this technology.

Specific features of the 3D VWs allow learning scenarios that are impossible or problematic in the real-world settings. VWB allows implementing some of such scenarios too. One room – one whiteboard is a traditional classroom scheme. It did not change much with the new advanced technologies. In some advanced classrooms, you can see two whiteboards (e.g., one for slides and another for a backchannel) or an interactive whiteboard (e.g., in addition to a basic whiteboard). The reason for using a very small number of whiteboards (or workspaces) is not only technological and even architectural (placing 20 whiteboards in a classroom is a challenge), but also pedagogical or instructional. The technology of 3D VWs and the VWB of vAcademia resolve the first part of the problem, but designing learning scenarios that would benefit from a large number of whiteboards is a matter of discussion.

The simplest example is a gallery. Students receive an assignment (e.g., drawing a landscape, sketching a scheme, solving a mathematical problem, writing a text, or just uploading an image done in any other software application) and get an individual or a group whiteboard. The result would be a gallery of works. Each student or group can present their work to the whole class, answer questions, explore, and discuss all the other works. The results can be easily compared and analyzed. Students can vote for the best project.

Another example is an excursion. A regular slide presentation can be played not on a single screen as usually, but instead – each slide on a separate screen (first slide on the first whiteboard, second – on the second, etc.). In such settings, the phrase “Let’s go to the next slide” would have a literal meaning – the teacher and the students would have to walk along a line of slides. If necessary, the class can (again literally) go back. Such movements can make a class live, provide awareness of how the students are following the presentation, and help grasping the idea of the presentation as a whole. A similar approach is applied in Prezi (software for making dynamic presentations). This scenario can be modified to include different modes of active presentations (e.g., standing on a large platform and moving along the line of slides, or placing slides in certain meaningful places (not linearly) in a location, or going on a small virtual tour in a thematic environment and meet information screens).

The 3D recording feature of vAcademia makes it possible to implement another example – a chain. A teacher can conduct and record a lecture (or a small fragment) in a virtual classroom with one VWB. Later, the teacher can enter the 3D recording, place the second VWB and the second lecture inside the first recording. In such a manner, the whole course can be recorded. For a visiting user, the resultant recording will look like a continued story, but when attending the last part of it, all the previous parts are available and visible in the same location. Such an integrated recording will contain the history of a course. It may include both lectures and discussion, and can be visited by individual learners or by groups at any time.

B. *Discussion of the evaluation results*

Further in this section, we are discussing the evaluation results presented in the previous section.

1) *Performance Evaluation*

The stream processors texture generation model for 3D VWs that we developed and implemented as a set of tools presented in this paper can be seen as a technical solution that helps to overcome the most common problems with applying 3D VWs in everyday teaching and learning – steep learning curve and demand for computational and network resources.

The results of the comparison of performance of several algorithms on CPU and SPs confirm that the use of SPs (instead of CPU) for image processing of large amount of meaningful content in a 3D VWs is very much justified. Although, the numbers we acquired in this part of evaluation only influence overall software performance (do not completely define), the benefit of applying SPs is still significant.

The possibility to place a large number of VWBs with graphical contents in a single location allows a correspondingly large number of users to work simultaneously. We conducted the first part of the performance evaluation using 50 VWBs with contents in the visibility area. The number of 50 VWBs is based on the assumption that 2-3 classes (with 15-20 avatars) may be held in the visibility area, and each of the participants uses a VWB. Alternatively, a class with up to 50 participants can be held. However, we consider such numbers as extremes, as regular virtual classes typically do not exceed 20 participants, based on our observations. In vAcademia, classes can be conducted in instances of locations, which allows processing and visualizing each class separately.

When evaluating the active use of VWB by users, we conducted the performance evaluation with 25 VWBs. In this case, we assumed that the speed of the real-time updating of the graphical content on VWBs is critical only for the current class (not for the others in the visibility area). In such a manner, 25 users can work with VWBs within a single location that contains other 25 VWBs with static content without experiencing significant delays. In such a scenario, it is important to consider that the network connection of the users should be fast enough and stable. This might be challenging if all of them access the virtual session from a single physical classroom, increasing the network load.

Finally, we tested the process of simultaneously changing images. In this part of the evaluation, we conducted tests with five VWBs. The number of five VWBs is based on the preliminary tests where we observed that changes rarely occur simultaneously, as each user is working with own pace. In other words, the changes are more or less equally distributed in time, especially when the number of users working with VWBs is high. However, peaks may occur too. Five simultaneous changes was the highest value. The results of this part of the evaluation demonstrate that even on such rare occasions, the performance degradation is acceptable and will not affect the users significantly.

2) *User evaluation*

The results of the user evaluation demonstrate that the VWB successfully performs its functions: the features can be easily accessed, the content is displayed clearly, and no visible delays occur when 23 VWB are actively used in one location.

It has pedagogical value, as most of the students consider that it was convenient to use it and the vAcademia’s working environment is more comfortable than traditional tools. At the same time, the user evaluation we conducted is rather simple and has several limitations. We had only one group of rather specific participants, who performed only one task. A more extended evaluation is required, e.g., involving less experienced students and comparing tools in other 3D VWs.

VII. Conclusion

In this paper, we described an original method for collaborative work with large amount of graphical content in 3D virtual worlds. The method allows reducing the load on CPU, therefore, designing convenient and sophisticated tools for collaborative work with graphics inside a 3D environment. We demonstrate our design of a set of such tools, their implementation in vAcademia. The performance evaluation shows that the algorithms we applied are superior to the commonly used ones, which allows working with greater amounts of graphical content. The suggested method can benefit any 3D space where processing large numbers of 2D graphics is required. The first user evaluation we conducted with some of the tools demonstrated their stable work and confirmed their educational value.

As we noted in the discussion, the new learning and training activities are possible applying the method suggested in the paper. Our future work will include developing and evaluating scenarios for such activities. Another direction for the future work is conducting full-scale user evaluation testing all the features of the VWB in different learning scenarios.

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References

[1] M. Burkle and Kinshuk, "Learning in Virtual Worlds: The Challenges and Opportunities," in *8th International Conference on CyberWorlds (CW)*, Bradford, UK, 2009, pp. 320–327.

[2] S. Kluge and E. Riley, "Teaching in Virtual Worlds: Opportunities and Challenges," *The Journal of Issues in Informing Science and Information Technology,* vol. 5(1), 2008, pp. 127–135.

[3] J. Helmer, "Second Life and Virtual Worlds," Learning Light Limited, Sheffield, UK, 2007.

[4] S. Kumar, J. Chhugani, C. Kim, D. Kim, A. Nguyen, P. Dubey, C. Bienia, and Y. Kim, "Second Life and the New Generation of Virtual Worlds," *Computer,* vol. 41(9), 2008, pp. 46–53.

[5] M. Morozov, A. Gerasimov, and M. Fominykh, "vAcademia – Educational Virtual World with 3D Recording," in *12th International Conference on Cyberworlds (CW)*, Darmstadt, Germany, 2012, pp. 199–206.

[6] M. Morozov, A. Gerasimov, M. Fominykh, and A. Smorkalov, "Asynchronous Immersive Classes in a 3D Virtual World: Extended Description of vAcademia," in *Transactions on Computational Science XVIII*. vol. 7848, M. Gavrilova, C. J. K. Tan, and A. Kuijper, Eds.: Springer Berlin Heidelberg, 2013, pp. 81–100.

[7] A. Smorkalov, M. Fominykh, and M. Morozov, "Stream Processors Texture Generation Model for 3D Virtual Worlds: Learning Tools in vAcademia," in *International Symposium on Multimedia (ISM)*, Anaheim, CA, USA, 2013, in press.

[8] Joao Afonso, Luis Pedro, Pedro Almeida, Fernando Ramos, and A. Santos, "Exploring Second Life for online role-playing training," in *Research conference in the Second Life® world*, 2009.

[9] C. Dede, "Immersive Interfaces for Engagement and Learning," *Science,* vol. 323(5910), 2009, pp. 66–69.

[10] R. Mckerlich, M. Riis, T. Anderson, and B. Eastman, "Student Perceptions of Teaching Presence, Social Presence, and Cognitive Presence in a Virtual World," *Journal of Online Learning and Teaching,* vol. 7(3), 2011, pp. 324–336.

[11] M. J. W. Lee, "How Can 3d Virtual Worlds Be Used To Support Collaborative Learning? An Analysis Of Cases From The Literature," *Society,* vol. 5(1), 2009, pp. 149–158.

[12] E. R. Hayes, "Situated Learning in Virtual Worlds: The Learning Ecology of Second Life," in *American Educational Research Association Conference*, 2006, pp. 154–159.

[13] L. Jarmon, T. Traphagan, and M. Mayrath, "Understanding project-based learning in Second Life with a pedagogy, training, and assessment trio," *Educational Media International,* vol. 45(3), 2008, pp. 157–176.

[14] S. Bignell and V. Parson, "A guide to using problem-based learning in Second Life," University of Derby, Derby, UK, 2010.

[15] T. Coffman and M. B. Klinger, "Utilizing Virtual Worlds in Education: The Implications for Practice," *International Journal of Human and Social Sciences,* vol. 2(1), 2007, pp. 29–33.

[16] J. Molka-Danielsen, "The new learning and teaching environment," in *Learning and Teaching in the Virtual World of Second Life*, J. Molka-Danielsen and M. Deutschmann, Eds. Trondheim, Norway: Tapir Academic Press, 2009, pp. 13–25.

[17] L. Falconer and M. Frutos-Perez, "Online Simulation of Real Life Experiences; the Educational Potential," in *21st World Conference on Educational Multimedia, Hypermedia & Telecommunications (Ed-Media)*, Honolulu, Hawaii, 2009, pp. 3564–3569.

[18] G. A. Dekker, J. Moreland, and J. van der Veen, "Developing the Planck Mission Simulation as a Multi-Platform Immersive Application," in *3rd World Conference on Innovative Virtual Reality (WINVR)*, Milan, Italy, 2011, pp. 1–9.

[19] C. Youngblut, "Educational Uses of Virtual Reality Technology," Institute for Defense Analyses, Alexandria, VA, USA, D-2128, 1998.

[20] P. Twining, "Exploring the Educational Potential of Virtual Worlds – Some Reflections from the SPP," *British Journal of Educational Technology,* vol. 40(3), 2009, pp. 496–514.

[21] L. S. Vygotsky, *Mind in society: the development of higher psychological processes*. Cambridge, MA, USA: Harvard University Press, 1978.

[22] A. Mavridis, T. Tsiatsos, and S. Tegos, "Exploiting Web Conferencing to Support Collaborative Learning," in *15th Panhellenic Conference on Informatics (PCI)*, Kastoria, Greece, 2011, pp. 78–82.

[23] K. Kear, F. Chetwynd, J. Williams, and H. Donelan, "Web conferencing for synchronous online tutorials: Perspectives of tutors using a new medium," *Computers & Education,* vol. 58(3), 4// 2012, pp. 953–963.

[24] S. Cornelius and C. Gordon, "Facilitating learning with web conferencing recommendations based on learners' experiences," *Education and Information Technologies,* vol. 18(2), 2013/06/01 2013, pp. 275–285.

[25] D. Gronn, G. Romeo, S. McNamara, and Y. H. Teo, "Web conferencing of pre-service teachers' practicum in remote schools," *Journal of Technology and Teacher Education,* vol. 21(2), 2013, pp. 247–271.

[26] M. Wimmer and J. Bittner, "Hardware Occlusion Queries Made Useful," in *GPU Gems 2: Programming Techniques for High-Performance Graphics and General-Purpose Computation*, M. Pharr, Ed. Boston, Ma, USA: Addison-Wesley Professional, 2005, pp. 91–108.

[27] C. Atkinson, *The Backchannel: How Audiences are Using Twitter and Social Media and Changing Presentations Forever*. Berkeley, CA: New Riders, 2010.

[28] P. Vu and P. J. Fadde, "When to Talk, When to Chat: Student Interactions in Live Virtual Classrooms," *Journal of Interactive Online Learning,* vol. 12(2), 2013, pp. 41–52.

[29] D. Gray, S. Brown, and J. Macanufo, *Gamestorming: A Playbook for Innovators, Rulebreakers, and Changemakers*. Sebastopol, CA: O'Reilly Media, 2010.

[30] B. Tucker, "The Flipped Classroom: Online Instruction at Home Frees Class Time for Learning," *Education Next,* vol. 12(1), 2012, pp. 82–83.