3D Interfaces of Systems

František Hrozek[*]
Department of Computers and Informatics
Faculty of Electrical Engineering and Informatics
Technical University of Košice
Letná 9, 042 00 Košice, Slovakia
frantisek.hrozek@tuke.sk

Abstract

3D interfaces allow easy and intuitive human-computer communication. These 3D interfaces are most often used in the virtual reality (VR) and VR systems. This fact was the reason for creation of this dissertation thesis which focuses on the formal description of the process of VR system creation. Thesis is divided into five sections. The first section presents the current state of the VR, 3D interfaces and formalization of the creation of the VR system. The second section deals with the description of VR system creation using formal methods. For description of this creation was used modified waterfall model. Thesis focuses on the second step of this modified model - Analysis. Seven categories were identified for this analysis and each one category creates a logical group of possibilities that can be used for the VR system analysis. The third section focuses on questionnaires which were created for the needs of this thesis. Questions in the questionnaire were divided into two groups. The first group was focused on students' actual state of knowledge about 3D interfaces and VR technologies. The second group of questions was focused on students' suggestions to VR systems which were created using defined formal description. Suggestions were used to modify and improve these VR systems. The fourth section presents in detail VR systems that use 3D interfaces and were created using defined formal description and modified using suggestions from questionnaires. The last part summarizes the dissertation thesis results and its contribution to the science and the practice.

Categories and Subject Descriptors

I.3.1 [**Computer Graphics**]: Hardware Architecture; I.3.2 [**Computer Graphics**]: Graphic Systems; I.3.6 [**Computer Graphics**]: Methodology and Techniques; I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism—*Virtual reality*; I.3.8 [**Computer Graphics**]: Applications

Keywords

3D interfaces, virtual reality, virtual-reality systems, formalization

1. Introduction

Since the creation of the first computer systems it was necessary to solve communication between humans and computers (human-computer interaction, HCI). These first systems were controlled by a signaling system that offered a limited form of communication between human and computer system. However, development of new technologies also allowed development of new types of interfaces. These new interfaces brought a wide spectrum of new possibilities for the human-computer interaction. The development of interfaces and technologies also allowed computer systems to adapt to human, and not vice versa (human-centered computing, HCC). Currently, interfaces are divided into three types:

1. character interfaces (command line, terminal),
2. graphics interfaces (Graphic User Interface, GUI),
3. bio-adapted interfaces, natural interfaces and interfaces based on virtual reality technologies.

3D interfaces belong into the third type and allow easy and interactive human-computer communication (e.g. motion control of gaming consoles, touch control of mobile phones, tablets and notebooks, voice control and others). 3D scanners, data gloves, position trackers, 3D displays, augmented reality, touch screens/displays, 3D printers and others belongs to the 3D interfaces. Laboratory of intelligent interfaces of communication and information systems (Slovak acronym LIRKIS) was created at our department (Department of Computers and Informatics, Faculty of Electrical Engineering and Informatics, Technical university of Košice, DCI FEEI TU of Košice) to study 3D interfaces and their problematic.

These 3D interfaces are most often used in the virtual reality (VR) and VR systems. This fact was the reason for creation of this dissertation thesis which focuses on the formal description of the process of VR system creation. Another goal of this dissertation thesis was to point out

---

[*] Recommended by thesis supervisor: Assoc. Prof. Branislav Sobota. Defended at Faculty of Electrical Engineering and Informatics, Technical University of Košice on August 31, 2012.

Hrozek, F.: 3D Interfaces of Systems. Information Sciences and Technologies Bulletin of the ACM Slovakia, Vol. 5, No. 2 (2013) 17-24

the complexity of the 3D models creation process, which are integral part of these systems. To address the goals it was necessary to study the problematic of VR systems, 3D interfaces and the current state of the VR systems formalization.

Based on the studied problematic and the practical experiences (earned from creation of the previous VR systems) was created formal description of the process of the VR system creation. Several VR systems were created using these description. For creation of these systems was used hardware and 3D interfaces located at the DCI and LIRKIS laboratory.

2. Overview of the Current State of Problematic

2.1 Virtual-Reality System

VR system represents an interactive computer system that is able to create an illusion of physical presence in places in the real world or in imaginary worlds.

VR systems can be divided according to used hardware and software resources into four types [8]: *Input VR*, *Basic VR*, *Intermediate VR* and *Immersive VR*.

VR systems can be also divided based on dynamics of observer and environment. This categorization divides VR systems into these four classes [8]:

1. SESO class (static environment - static observer),
2. DESO class (dynamic environment - static observer),
3. SEDO class (static environment - dynamic observer),
4. DEDO class (dynamic environment - dynamic observer).

Subsystems of VR systems are divided according to senses which they affect [9]: *Visualization subsystem*, *Acoustic subsystem*, *Kinematic and statokinetic subsystem*, *Touch subsystem* and *Other senses* (e.g. sense of smell, taste, sensibility to pheromones).

For creation of the VR system can be used several software tools which can be divided into these three groups: *visualization engines of VR systems*, *applications for 3D models creation* and *scripting languages*.

2.2 3D Interfaces and their Technologies

This chapter provides a brief overview of 3D interfaces and their technologies [10][6]:

1. **3D Scanners:** A 3D scanner is a device that analyzes a real-world object or environment to collect data on its shape and possibly its appearance (i.e. color). 3D model acquisition process consists of two stages: *3D scanning* and *data processing*. Based on the used technology, 3D scanners can be divided into two categories: *contact* and *non-contact scanners*. Non-contact scanners can be further divided into two categories: *passive* and *active*.

2. **Data gloves:** A data glove is a device, which serves for capturing mechanical and gesture information from the hand. Various technologies are used for capturing this information from the hand. These technologies can be divided into two categories [3]: *determining the shape of the hand* and *position tracking*. The shape of the hand and fingers are determined by various types of bending sensors. The hand position and rotation is sensed in the 3D space using position tracking.

3. **Head mounted display:** A head mounted display (HMD) is a display device, worn on the head (or as part of a helmet), that has small display optic in front of one (monocular HMD) or each eye (binocular HMD). HMD are used in virtual reality and augmented reality applications. Another classification of HMDs is based on how the user sees real world. This classification divides HMDs into two categories: *immersive* and *see-through*. See-through HMDs have two subcategories: *video see-through* and *optical see-through*. HMD position and orientation is sensed in 3D space using position tracking.

4. **Interface for walking:** Interfaces for walking use various techniques that allow users to move in any direction. These interfaces can use for example movable tiles, a torus treadmill or surfaces with the shape of sphere. For motion in a virtual environment can be also used systems that use a bicycle, gestures sensing or linear treadmills, but these systems don't allow natural motion of the user.

5. **Position tracking:** Position tracking serves for sensing user's position and rotation in a 3D space. Position tracking devices are divided into these categories (depending on the technology used for position and rotation tracking) [4]: *mechanical*, *magnetic*, *ultrasonic*, *optical* and *inertial trackers*.

6. **3D displays:** 3D displays can be divided according to the used technology into *holographic displays*, *volumetric displays*, *light field displays* and *stereoscopic displays*. Stereoscopic displays are the most affordable 3D displays currently. This type of displays is further divided into *passive*, *active* and *autostereoscopic displays*.

7. **Augmented reality:** There are several definitions of augmented reality (AR). One of them was defined by Ronald Azuma [1]. This definition says that AR combines real and virtual, is interactive in real time and is registered in 3D. Based on how a user sees augmented reality there can be two types of systems: *optical see-through systems* and *video see-through systems*. According to the method how virtual objects are aligned with a real scene image there are two systems used: *marker systems* and *markerless (semi-markerless) systems*.

8. **Rapid prototyping:** Rapid prototyping is rapid manufacturing technology that creates 3D models of objects from thin layers. Creation of such as object consists from several steps. In the first step a computer model of object is created. In the second step the computer model is divided into thin layers. In the third step virtual layers are used for creation of physical layers from which the final physical model is created. There are several rapid prototyping technologies, e.g. stereolithography, selective laser sintering or 3D printing [2].

9. **Touch screens:** Touch screens allow easy, effective and interactive interaction with the displayed content. There are several ways how touch screens determine position of the finger on the screen. Current touch screens use *infrared light*, *change in resistivity* and *change in capacity* [5].

2.3 Formalization and VR Systems

The formalization of the entire process of the VR system creation is not the main research area of researchers and developers in these days. The researchers and developers rather focus on solving of local (partial) VR system problems, which are related to:

1. description of interaction techniques in virtual environments,
2. description of time dependencies in distributed virtual environments,
3. description of VR scene using scene graph,
4. description of VR objects,
5. communication between interfaces and VR system engine.

3. Goals of the Dissertation Thesis

The dissertation thesis was focused on formalization of the entire process of VR system creation. Individual goals of the dissertation thesis:

1. Formalization and description of the process of VR system creation.
2. Formalization and description of the VR system runtime.
3. Creation of VR systems using defined formal description and using hardware and interfaces which are located at the DCI and at the LIRKIS laboratory.
4. Testing of created VR systems and their subsequent modification according to feedbacks obtained from tests.

4. Chosen Methods

These methods and ways of solution were used to achieve goals defined in previous section:

1. Detail analysis of VR systems and 3D interfaces using knowledge gained from the study of literature and from creation of previous VR systems.
2. Definition of a life cycle model for the process of VR system creation and the definition of its individual steps.
3. Identification of categories which creates logical groups of possibilities for the VR system analysis.
4. Detail description of these categories using flow graphs, data-flow graphs and timed colored Petri nets.
5. Creation of VR systems using defined formal description and available hardware and 3D interfaces.
6. Testing of created VR systems and their subsequent modification according to feedbacks obtained from surveys (using SWOT analysis).

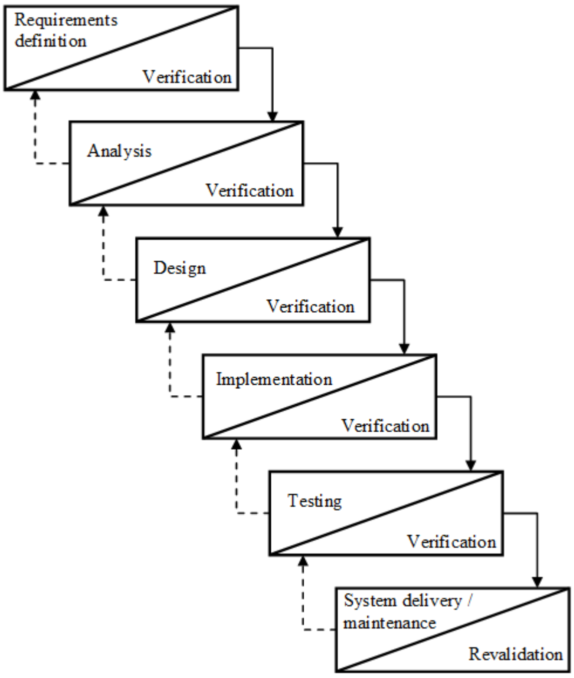

Figure 1: Modified Waterfall model for the VR system creation.

5. Obtained Results

5.1 Formalization of the process of the VR System Creation

VR system creation is a complicated process that consists of several steps which a creator of the VR system needs to know. Currently there is no uniform and comprehensive description of these steps what causes problems in the VR systems creation. To solve these problems a description was proposed. This description use Waterfall model [7] that was modified for the VR system creation needs. The dissertation thesis mainly focuses on the description of the second step of this modified model - Analysis.

5.1.1 VR System Life Cycle

A waterfall model was chosen for the description of the VR system life cycle. This model was subsequently modified to the needs of VR system, whereas hardware and software are much more closely tied in the VR system than in the software system. Modifications made in the Waterfall model:

1. steps *System requirements* and *Software requirements* was joined into one step - *Requirements definition*,
2. step *Program design* was changed to *Design*,
3. step *Coding* was changed to *Implementation*.

This modified Waterfall model has six steps (see Figure 1): *requirements definition*, *analysis*, *design*, *implementation*, *testing* and *system delivery and maintenance*.

Table 1: Relation between interfaces, parameters and subsystems of the VR systems (part of the table).

x	x	x	x	VR subsystems	other				
x	x	x	x		Touch subsystem				
x	x	x	x		Kinem. and statokin. subsystem				
		x	x		Acoustic subsystem				
x	x	x			Visualization subsystem				
Parameters		Input/Output				VR subsystems			
3D	2D	Input	Output		Interfaces	Visualization subsystem	Acoustic subsystem	Kinem. and statokin. subsystem	Touch subsystem
		x	x	Basic	keyboard (buttons)			x	
x	x	x	x		mouse			x	x
x	x	x	x		joystick			x	x
	x		x		touch screen			x	x
x	x	x			monitor	x			
	x		x		scanner (2D)	x			
	x	x			printer (2D)	x			
		x			speakers		x	x	
	x	x	x		paper	x			

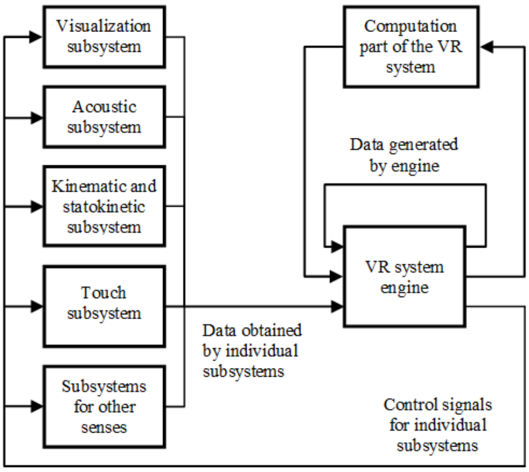

Figure 2: Data flow between engine, subsystems and computing part of the VR system.

5.1.2 Analysis

VR system analysis is not a trivial problem, because there are a lot of possibilities how this analysis can be done. Therefore, seven categories were designed. These categories unite mentioned possibilities into logical groups. Tables, flow graphs, data-flow graphs and simulation networks (using timed color Petri nets), which formally describe individual possibilities of the VR system analysis, were created based on these categories.

Analysis Based on Hardware

VR system hardware can be divided into two parts (computing hardware and interfaces). Because of this, analysis based on hardware is divided into two parts:

1. **Computing hardware of the VR system:** this hardware can be made from *one* or *more computing units*. During the analysis based on hardware, it is also important to take into consideration the network infrastructure which interconnects individual computing units. It is also necessary to consider the possibility of using computing on graphics cards (GPGPU) which can significantly improve calculation performance.
2. **Interfaces of the VR system:** Currently, there are a lot of interfaces which can be used in the VR system creation. These interfaces differ from each other for example by their price or complexity. Therefore were designed five subcategories which can be used for analysis of the currently most widely used VR system interfaces.
   (a) *First subcategory* - distribution of interfaces based on their type (input/output).
   (b) *Second subcategory* - distribution of interfaces based on their complexity (basic, intermediate, immersive).
   (c) *Third subcategory* - distribution of interfaces based on the subsystems of VR systems in which they are used.
   (d) *Fourth subcategory* - distribution of interfaces based on their parameters.
   (e) *Fifth subcategory* - distribution of interfaces based on possibility of their combination.

Two tables were created based on these subcategories:

1. Table that describes relation between interfaces, parameters and subsystems of the VR systems. Part of this table is shown in the table above (Table 1).
2. Table that describes combination possibilities of individual VR system interfaces.

Analysis based on software

In this analysis it is necessary to focus on parameters (options) offered by VR system software. These parameters can be divided according to *subsystems of VR systems* and *software types* in which are implemented. A table was created based on this distribution. This table describes relation between parameters, subsystems of the VR systems and software types. Part of this table is shown in the next table (Table 2).

Analysis based on the data flow between individual parts of the VR system

This analysis can be divided into two parts:

Table 2: Relation between parameters, VR subsystems and software types (part of the table).

		x	VR subsystems	other				
		x		Touch subsystem				
		x		Kinematic and statokinetic subsystem				
		x		Acoustic subsystem				
x	x	x		Visualization subsystem				
					VR subsystems			
Modeling software	Scanning software	VR system engine		Parameters	Visualization subsystem	Acoustic subsystem	Kinematic and statokinetic subsystem	Touch subsystem
x		x		collisions solving	x	x	x	x
x	x	x		calculation of the position	x	x	x	x
x		x		calculation of the rotation	x	x	x	x
x		x		calculation of the scale	x	x	x	x
x	x	x		point-clouds triangulation	x			
x		x		real physics	x	x	x	x
x		x		scripting language	x	x	x	x
x		x		calculation on several CPUs	x	x	x	x
x		x		calculation on GPU	x	x	x	x

1. **Data flow between engine, subsystems and computing part of the VR system** (Figure 2) - in this data flow were identified tree sub data flows:
   (a) data flow between subsystems and engine of the VR system,
   (b) data flow between engine and computing part of the VR system,
   (c) data flow inside the VR system engine.
2. **Data flow between interfaces (devices) and engine of the VR system** (Figure 3) - in this data flow were identified three parts which enter to the communication process between interfaces and engine of the VR system:
   (a) **Inputs:** here belongs any input and input-output (input part) interfaces together with input data,
   (b) **Outputs:** here belongs any output and input-output (output part) interfaces together with output data,
   (c) **VR system engine**.

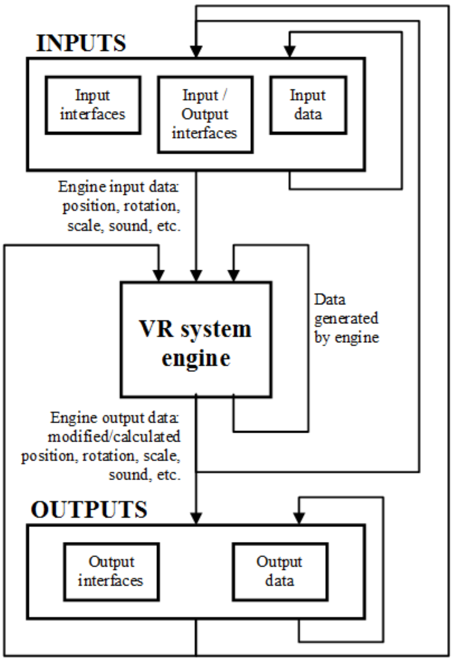

Figure 3: Data flow between interfaces (devices) and engine of the VR system.

Analysis based on creation of 3D models / world for the VR system

There are three ways how to create a 3D model:

1. **3D scanning** - 3D scanning process consists from two steps, as was mentioned before:
   (a) *3D scanning* - scanning of an object according to parameters defined in the preparation phase,
   (b) *data processing* - this step consists of three parts which could be combined together: *point-cloud triangulation*, *aligning and merging of scans* and *mesh simplifying* (optional step).
2. **3D modeling** - 3D modeling applications can be used in this method. 3D modeling process consists from these steps: *3D model creation*, *texturing* and *creation of animation for created 3D model.*
3. **their combination**.

Analysis based on VR objects

The whole VR system can be defined as strictly object system. This means that everything that exists in the VR system is an object (maps, buildings, sensors etc.). Even the VR system itself can be defined as object which contains other objects [9]. In terms of such definition it is possible to exploit the features of inheritance, encapsulation and polymorphism. Hierarchy of objects in terms of the VR system is shown in Figure 4.

As can be seen from the picture, the VR objects contains two blocks: *behaviour* and *representation*. The behaviour block describes the logic of the object. The representation block contains frames which are distributed according to the subsystems of the VR systems. Local information of one frame (e.g. sound of the object in acoustic frame) are used only by this frame and therefore are invisible for other frames. Global information are needed for all frames and therefore are shared (e.g. position of the object).

Analysis based on the optimization of the VR system performance
Optimization of the VR system performance can be divided to four parts. Therefore was this analysis divided to four levels:

1. **Optimization on the level of the computing hardware** - Solution to this optimization is replacement of whole computing unit (units) or replacement / modification of its (their) individual parts.
2. **Optimization on the level of the VR system engine** - This optimization can be done by increasing calculation efficiency or reducing requirements for the VR system engine.
3. **Optimization on the level of the input data** - This optimization is based on the reduction of the input data for applications running in the VR system.
4. **Optimization on the level of the output data** - This optimization is based on the reduction of the data flow for VR system outputs (input/output interfaces, output interfaces, output data).

Analysis based on the parallelization
Data creation for the VR system and data processing in the VR system requires large demands on computing power and time. Solution to this problem is the use of parallelization. This parallelization can be performed on the level of *data processing* and *3D model creation.*

1. **Data processing** - this parallelization can be further divided:
   (a) *according to the number of computational nodes* - one node vs. multi-node systems,
   (b) *according to the level of parallelism in the VR system* - parallelism on the level of VR worlds, VR subsystems, VR objects, VR frames and algorithms.
2. **3D model creation** - parallelization on this level can be divided into three groups:
   (a) parallelization in the creation of a single object (scanning and modeling),
   (b) parallelization in the creation of several objects using 3D scanning,
   (c) parallelization in the creation of several objects using 3D modeling.

5.2 Questionnaires

Two questionnaires were created for the needs of this dissertation thesis. 64 students of the Virtual reality systems (SVR) course participated in the testing using these questionnaires. The first questionnaire (given to students at the start of the semester) had three questions and was focused on the current knowledge of students about VR technologies. The second questionnaire (given to students at the end of the semester) had also three questions. Its purpose was to determine what students think about VR systems and equipment with which they work during the semester and how to modify them. Questionnaire also focused on the students' satisfaction with the quality of the SVR course.

5.2.1 Questionnaires (start of the semester)

Questions in the questionnaire:

1. Do you know how following 3D interfaces work?
2. With which 3D interfaces have you met?
3. Where have you met 3D interfaces from the question n. 2? (possible answers: home, school, shop, friend and other)

3D interfaces in the questionnaire: 3D scanners, data gloves, head mounted displays, walk simulation interfaces, position tracking, 3D displays, 3D cameras, augmented reality, 3D printers and touch screens.

Evaluation of the results obtained from the questionnaires:

1. **Question n. 1:** Most known 3D interfaces are 3D displays (95.3%) and 3D cameras (89%). Least known 3D interfaces are walk simulation interfaces (3.1%).
2. **Question n. 2:** Most students have met with 3D displays (96.9%), touch screens (96.9%) and position tracking (73.4%). Approximately 36% of students have met 3D cameras. 20% of students met augmented reality. Other interfaces have less then 10%.
3. **Question n. 3:** Most students have met with 3D interfaces at shop (32%). Worst percentage had school (only 13%).

5.2.2 Questionnaires (end of the semester)

Questions in the questionnaire:

1. Rate VR systems and devices with which you have met in LIRKIS laboratory. (4 - best, 0 - worst)
2. How would you modify / improve VR systems and devices in LIRKIS laboratory?
3. What would you add, change or remove from SVR course?

VR systems and devices in the LIRKIS laboratory: stereoscopic VR system (INFITEC), stereoscopic displaying system (anaglyph), passive stereoscopic 3D display, system for autostereoscopic 3D visualization, augmented reality system (head mounted display), system for 3D scanning and system for 3D printing.

Evaluation of the results obtained from the questionnaires:

1. **Question n. 1:** Best average rate gain system for autostereoscopic 3D visualization (3.68). Worst average rate gain stereoscopic displaying system using anaglyph technology (1.58).

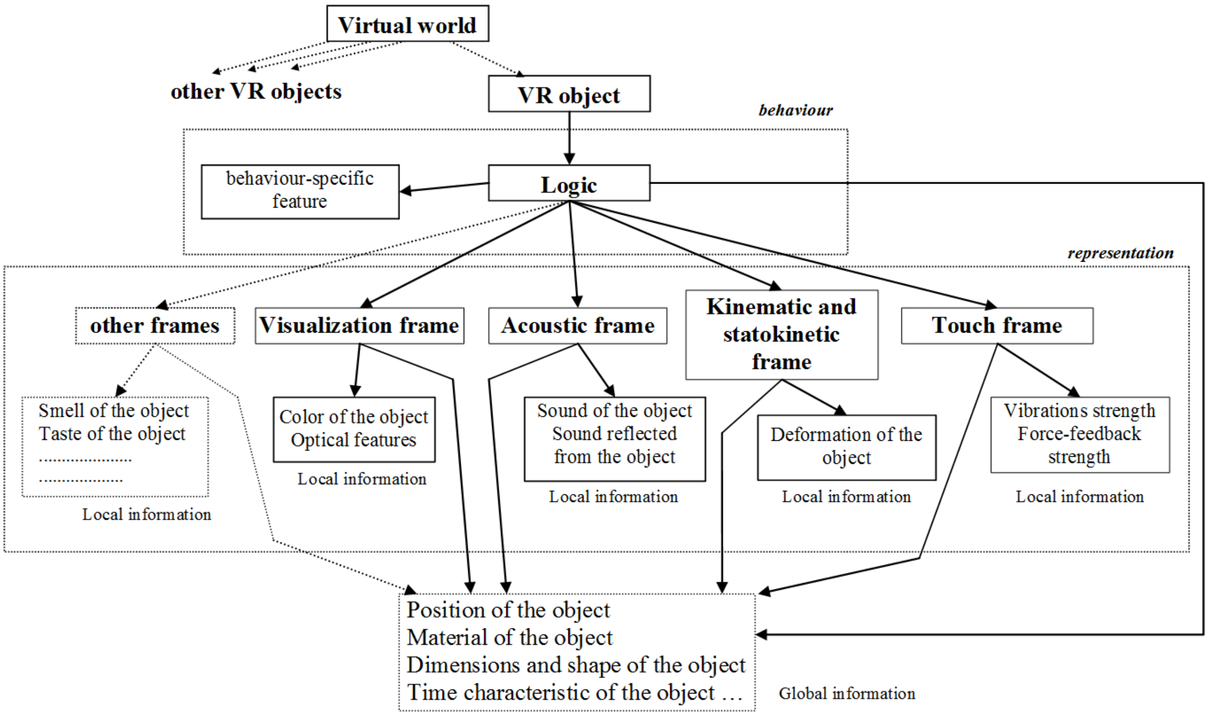

Figure 4: Frames of the VR objects according to the definition.

2. **Questions n. 2 and n. 3:** Suggestions obtained from students were used for the improvement of created VR systems and SVR course.

5.3 Proposed VR systems

Several VR systems were created using defined formal description and suggestions gained from questionnaires. For creation of these systems was used hardware and 3D interfaces located at the DCI and in the LIRKIS laboratory.

Created VR systems (from simple to more complex):

1. System for 3D model creation based on real object,
2. System for stereoscopic 3D visualization (circular polarization),
3. System for autostereoscopic 3D visualization,
4. System for stereoscopic 3D visualization (INFITEC),
5. System for 3D printing,
6. System for augmented reality,
7. System for visualization of urban areas,
8. Drawing system,
9. System for preservation of cultural heritage.

6. Benefits of the dissertation thesis

Dissertation thesis was focused on the creation and runtime of VR systems that use 3D interfaces. According to the defined goals were achieved following results and benefits:

1. **Formalization and description of the VR system creation:**
    (a) For the formal description was in this work used waterfall model, which was subsequently modified according to the needs of VR system creation. The work itself was focused on the second step of this modified model - Analysis. For this step was defined seven categories which bring innovative view on the analysis step and create logic groups for individual analysis possibilities. These categories allow detail analysis of VR system whereby allow exact specification of key parameters for this system.

    (b) Detail description of individual categories allows creation of the VR system for people who have only basic knowledge about this problematic.

    (c) Two tables were created for analysis based on hardware. First table brings innovative view on the classification of interfaces used in VR systems. Second table brings innovative view on the possible combinations of VR system interfaces.

2. **Formalization and description of the VR system runtime:** Description of the data flow between the individual parts of the VR system during its runtime was used for formal description of the VR system runtime (this description is part of the analysis based on the data flow).

3. **Detail description of the entire process of 3D model creation using 3D scanners and 3D modeling applications:** This description brought comprehensive view on the process of the 3D model creation using both approaches. Graph, which was created for this description, allows identification of the best method for 3D model creation which leads to reduction of errors.

4. **Creation of VR systems using 3D interfaces:** Several VR systems were created using defined formal description. These systems were used not only for testing and presentation purposes but were also used for solving of problems which arisen from requirements of practice (preservation of the cultural heritage - 3D model creation of the State theatre of Košice and St. Michael chapel using 3D scanning).

5. **Creation of the questionnaires and modification of VR systems based on the gathered data:**
   (a) The primary purpose of these questionnaires was to obtain feedback from students about the created VR systems. Questionnaires shown that students were impressed by these VR systems.
   (b) The questionnaires also shown that students are interested in the issue of VR technologies and 3D interfaces.

In response to the previous results, dissertation thesis also brought other benefits:

1. Experiences earned about the 3D model creation (using 3D scanning and 3D modeling) have been implemented into the Virtual reality systems (SVR) course.
2. Created VR systems have allowed students to work with the latest 3D interfaces.
3. Several created bachelor thesis and semester projects were consulted by the doctoral student. This thesis and projects were focused on the 3D scanning, 3D printing, gesture recognition using data glove and augmented reality.
4. This thesis laid the foundations for the future study of 3D interfaces and VR systems at the DCI. Also laid the basis for a new grant tasks, future dissertation theses and cooperation with a practice.

Acknowledgements. This work is the result of the project implementation: Development of the Center of Information and Communication Technologies for Knowledge Systems (ITMS project code: 26220120030) supported by the Research & Development Operational Program funded by the ERDF and this work has been supported by KEGA grant project No. 050TUKE-4/2012: "Application of Virtual Reality Technologies in Teaching Formal Methods".

References

[1] R. Azuma. A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, 6(4):355–385, 1997.

[2] P. W. Carter. Advances in rapid prototyping and rapid manufacturing. In *Proceedings of Electrical Insulation Conference and Electrical Manufacturing & Coil Winding Conference*, pages 107–114, 2001.

[3] L. Dipietro, A. M. Sabatini, and P. Dario. A survey of glove-based systems and their applications. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, 38(4):461–482, july 2008.

[4] I. N. Durlach and S. A. Mavor. *Virtual Reality: Scientific and Technological Challenges*. NATIONAL ACADEMY PRESS, Washington, D.C., 1995.

[5] T. Hoye and J. Kozak. Touch screens: A pressing technology. In *Tenth Annual Freshman Conference*. University of Pittsburg, April 2010.

[6] F. Hrozek. Systems based on 3d interfaces. In *11th Scientific Conference of Young Researchers (SCYR 2011)*, pages 366–369, Košice, May 2011. FEEI TU.

[7] W. W. Royce. Managing the development of large sofware systems. In *Proc. of IEEE Western Conference (Wescon)*, pages 1–9, August 1970.

[8] B. Sobota. Riešenie niektorých problémov vizualizačného rámca systémov virtuálnej reality v paralelnom výpočtovom prostredí. Habilitation thesis, FEI TU Košice, 2008.

[9] B. Sobota, F. Hrozek, and Š. Korečko. Data structures and objects relations in virtual-reality system. In *Proceedings of the Eleventh International Conference on Informatics INFORMATICS'2011*, pages 159–163, Rožňava, Slovak Republic, November 2011. TU, Košice.

[10] B. Sobota, F. Hrozek, Š. Korečko, and C. Szabó. Virtual reality technologies as an interface of cognitive communication and information systems. In *2nd International Conference on Cognitive Infocommunications (CogInfoCom) 2011*, pages 1–5, September 2011.

Selected Papers by the Author

F. Hrozek, P. Ivančák. Depth Map Calculation for Autostereoscopic 3D Display. In *Journal of Computer Science and Control Systems (JCSCS)*, 5(1): 37–42, 2012.

F. Hrozek, B. Sobota. Simulation and Visualization of Water Flow. In *Acta Electrotechnica et Informatica*, 11(1): 25–32, 2011.

B. Sobota, J. Perháč, F. Hrozek. Využitie technológií GPGPU pri vizualizáciách, simuláciách a používateľských rozhraniach. In *AT&PJournal*, 17(11), 2010.

F. Hrozek. Data glove as input device for computer. In *Journal of Information, Control and Management Systems*, 8(4): 329–334, 2010.

F. Hrozek. Using Panoramic Pictures for 3D City Agglomerations Visualization. In *Electrical Engineering and Informatics, Proceedings of the FEEI of the Technical University of Košice*, pages 361–366, Košice, Slovak Republic, 2010. FEEI TU.

Cs. Szabó, F. Hrozek, B. Sobota. Preparing Panoramic Pictures for Visualization of City Agglomerations. In *Proc. of the 8th IEEE International Symposium on Intelligent Systems and Informatics (SISY 2010)*, pages 243–247, Subotica, Serbia, 2010.

F. Hrozek, B. Sobota, Cs. Szabó. Virtual Reality Technologies in Education. In *Proceedings of the Eleventh International Conference on Informatics INFORMATICS'2011*, pages 164–168, Rožňava, Slovak Republic, 2011. TU, Košice.

F. Hrozek, B. Sobota, Š. Korečko, Cs. Szabó. Preservation of Historical Buildings Using Virtual Reality Technologies. In *Science for education - Education for science I.*, pages 315–319, Nitra, Slovak Republic, 2011. CPU in Nitra.

F. Hrozek, B. Sobota, Š. Korečko, Cs. Szabó. Virtual Reality - Creation, Usage and Education. In *Proceedings of the 14th International Conference on Interactive Collaborative Learning (ICL 2011)*, pages 480–483, Piešťany, Slovak Republic, 2011.

F. Hrozek, B. Sobota, Š. Korečko, Cs. Szabó. Rendering a large set of graphical data in cluster environment. In *6th International Workshop on Grid Computing for Complex Problems*, pages 210–215, Bratislava, Slovak Republic, 2010. Institute of Informatic, Slovak Academy of Science.

F. Hrozek, B. Sobota, Cs. Szabó. 3D Visualization of Urban Areas. In *Proceedings of 8th International Conference on Emerging eLearning Technologies and Applications (ICETA 2010)*, pages 277–280, Stará Lesná, Slovak Republic, 2010. Elfa.

F. Hrozek, B. Sobota, R. Janošo. Visualization with 3D Interfaces. In *Proceedings of CSE 2010 International Scientific Conference on Computer Science and Engineering*, pages 328–335, Stará Ľubovňa, Slovak Republic, 2010. Elfa.