What Should a Virtual/Augmented Reality Course be?

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Abstract

Never before has Virtual and Augmented Reality hardware been so affordable allowing so many new applications of these technologies; however, developing these applications implies specific skills that are not usually acquired in core courses in Computer Science/Engineering. In this context, specific courses introducing the basics on these technologies seem to be most relevant. With this panel we intend to foster a discussion concerning what should an introductory course on Virtual/Augmented Reality be as of 2017. A review of the courses described in literature is presented as well as guidelines issued by professional/scientific associations concerning a basic Virtual Reality course identifying a set of relevant aspects to be considered when organizing such a course.

Categories and Subject Descriptors (according to ACM CCS): K.3.2 [Computers and Education]: Computer and Information Science Education—Computer science education, Curriculum I.3.7Computer Graphics Three-Dimensional Graphics and RealismVirtual and Augmented Reality

1. Introduction

"Virtual and augmented realities are now embodied in a multitude of applications, practices, and industries. It has never been more apparent that immersive realities are a fixture of our day-to-day lives ...." [Que16]. This requires qualified developers; however, acquiring the necessary skills to become experienced in this field is a hard undertaking if not guided, and thus introductory courses, either in traditional or in more modern formats, are of vital importance. In 2008 G. Burdea, author of one of the first textbooks intended to support a Virtual Reality (VR) course [BC03] [Bur04], made an informal world-wide survey (http://vrtechnology.org/resources/public/survey.html) finding more than one hundred courses; still, he concluded that the majority of the Universities offered no such courses. We found other courses not included in this list, as well as courses addressing also Augmented Reality (AR). We also found courses in non-traditional formats, as a MOOCs and professional/technical courses, but we will focus on traditional University courses offered to Computer Science/ Engineering students. The rest of this proposal is organized as follows: an overview of different Virtual/Augmented Reality (VAR) courses described in literature is given, recommendations on a Virtual Reality basic curriculum issued by scientific/professional societies are summarized, and important issues to be considered when planning and organizing a course are identified. Finally conclusions are drawn.

2. VAR Courses described in literature

There have been Virtual Reality courses for years; however, only very few seem to have been reported in literature. We were able to found some papers describing several Virtual Reality/Augmented Reality (VAR) courses (mainly Virtual Reality) with different approaches and offering advice on how to organize such courses. We notice that these courses are mainly offered to Computer Science/ Engineering students, but also to other engineering students (e.g. Electrical or Industrial Engineering) at undergraduate and postgraduate level. Some of them imply previous knowledge in Computer Graphics and are offered as extensions to such courses, most have practical assignments using specific hardware, and the more recent courses have an emphasis on using the low-cost hardware currently available. Table 1 summarizes the information about the courses we were able to gather mainly based on the papers.

The course presented by Stansfield [Sta05] is an elective course lectured to Computer Science students having some Computer Graphics background. The course provides an introduction to Virtual Reality and an opportunity to incorporate capstone elements that allow undergraduate students to apply many computing skills previously acquired. It includes lectures and an on-going, semester-long team project based on an open software platform developed at Sandia National Laboratories (SNL) and on a software platform developed in-house. Students develop a complete VR system having access to specific Virtual Reality hardware, as head-mounted displays and trackers.

Zara [Zar06] presents another course for students having already a background in Computer Graphics. It is mainly based on

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VRML and students'projects evolve from simple 3D scenes to complex, interactive virtual environments. A strong negative correlation between the perceived difficulty of the course and the students'Computer Graphics background was observed, suggesting that a Virtual Reality course may be viewed as a natural extension to Computer Graphics education.

Cliburn [Cli06] incorporates Virtual Reality concepts in an introductory Computer Graphics course. Students develop simple VR applications as a final project based on an in-house toolkit for multi-monitor graphics programming. According to the author, these projects were "immersive, interactive, and certainly imaginative, satisfying Burdea and Coiffet's three I's of Virtual Reality "and "contained a virtual world, immersion, sensory feedback, and interactivity, fulfilling Sherman and Craig's definition as well ".

Cliburn et al. [Cli08] present resources to support low-cost virtual reality and describe the Virtual Reality laboratory at the author's university. The paper discusses stereo projection systems, tracking, and haptics, focusing on low-cost implementations which are accessible to most institutions. This laboratory provides a teaching environment for undergraduate students to learn about VR topics such as navigation, immersion, and stereo imaging. According to the author, it provides "an excellent learning environment that encourages students to build exciting virtual worlds and to take part in undergraduate research projects".

Miyata et al. [MUH10] introduce an educational framework for creating Virtual Reality applications through group work, and highlight its advantages. The authors use group work-based projects focused on Virtual Reality (VR) applications to teach graduate students a method of knowledge creation for solving complex problems. Although this is not a typical Virtual Reality course as it is aimed at more general goals, the authors present a set of projects developed by the students and results of the course evaluation, which suggest that a group work-based solution is suitable to teach students to create Virtual Reality applications as well as a training framework for undergraduate students.

Hafner et al. [HHO13] teach a practical course on Virtual Reality focused on simulating an interdisciplinary industrial project offered to graduate and undergraduate students in various engineering study programs (namely, mechanics, and electrical engineering, computer science, physics and engineering management). The course includes lectures, demos, and practical classes based on 3DVIA Virtools and an in-house developed software. Students have access to state-of-the-art hardware and software as well as the possibility to work with low-cost equipment.

In a previous paper [—], we present an elective course on Virtual and Augmented Reality offered to Computer Engineering and Electrical Engineering students at MSc level. This course includes lectures, demos, practical assignments, and a final project based on a set of low-cost hardware. The practical assignments used to be based on VTK and OpenCV; however, in the last edition we have introduced Unity and the Vuforia plugin, as it allows developing much more interesting and complete applications involving the same or less effort. This seems to have been a positive evolution of the course (yet to be confirmed at the end of the semester).

Rodriguez [Rod16] describes a course, offered to Computer Science students at MSc level, on Vision and Augmented/Virtual Reality aimed at preparing graduates for professional activities related to games, interaction, simulation, and computer vision in a variety of industries. The course has a focus on immersive displays and gesture recognition. It combines lectures and practical sessions and includes a final course project based on a set of low-cost devices. This course is based on a laboratory following the BYOD (Bring Your Own Device) approach.

Takala et al. [TMPT16] describe in much detail three iterations of an annually organized capstone course on Virtual Reality offered to students of different backgrounds; however having a Computer Graphics background is strongly recommended. They collected data regarding developed VR applications, development experience, and course feedback from students over several years using it to improve the course between editions. The authors claim that the gradual improvements on the course and on the software developed in-house paid off, as the most recent course editions produced the best student feedback and the highest quality VR applications, and conclude that "a VR course can be affordable for educators and uncomplicated for students".

3. Curricula defined by professional/scientific organizations

As Virtual and Augmented have currently a broad application, offering courses for different audiences is important for making these technologies accessible to a wider range of students. However, while students from other fields (as Mechanical and Industrial Engineering) may be interested and able to take such courses, we will focus on the recommendations issued by professional societies in Computer Science and Engineering. The first set of guidelines we were able to find was issued by the European Association for Virtual Reality and Augmented Reality in 2008 (http://kb.eurovr-association.org/index.php/Training_and_Education_in_VR/VE).
This Association defined a basic curriculum corresponding to a minimum number of 32 course hours and addressing the following topics:

- Introduction to Virtual Reality (VR)
- Principles: Computer Graphics in VR
- Principles: Perception and Human Factors (Designing and developing 3D UI: strategies and evaluation)
- Principles: Interaction in VR (Selection and manipulation, Travel, Navigation, Way finding, System control, Symbolic input)
- Hardware: Output (Visual, Auditory, Haptic, Vestibular, and Olfactory Channels)
- Hardware: Input (Tracking Systems, Input Devices)
- VR contents (Standards and Designing)
- Software: Platforms (Introduction, VR runtime systems, Real Time Physics Engines, Distributed Virtual Environments, Collaborative Virtual Environments, Game Engines)
- Mixed Reality (Mixed Reality Continuum - AR to VR, Mixed Reality Technologies)
- Applications of VR
- Future of VR
- Exercises/Demonstrations

According to these recommendations, a general course should cover all these topics and may develop particular topics accord-

Table 1: *Courses described in literature (∗- strongly recommended; na - information not available)*

Author/ Year	VR	AR	CG requir..	Level	In-house S/W	Other Libs	Specific VR H/W	Low-cost VR H/W
[Sta05]	✓	-	✓	BSc	✓	S/W by SNL	✓	-
[Zar06]	✓	-	✓	MSc	-	VRML	-	-
[Cli06]	✓	-	-	MSc	-	na	-	-
[Cli08]	✓	-	✓	BSc	✓	-	✓	✓
[MUH10)	✓	-	na	MSc	na	na	✓	na
[HHO13]	✓	-	-	B/MSc	✓	3DVIA Virtools	✓	✓
[SDM15]	✓	✓	-	MSc	-	VTK, OpenCV, Unity	✓	✓
[Rod16]	✓	✓	✓	MSc	-	OpenCV, Unity	✓	✓
[TMP*16]	✓	-	✓*	MSc*	✓	Processing, Unity	✓	✓

ing to specific needs. However, specific courses may be tailored for particular technical areas. These courses may address selected VR techniques and technologies (e.g. haptic devices, aural input/output), or specific platforms and tools. More comprehensive courses may also address specific application areas or industries (as VR in Medicine, 3D/VR Computer Games, VR in Automotive Industry).

The Computing Curricula series of reports prepared by the IEEE Computer Society and the Association for Computing Machinery have issued recommendations to support the design of Computer Science and Computer Engineering undergraduate degree programs. These reports present knowledge areas, corresponding core and elective knowledge units as well as course examples. Whereas Virtual Reality or Mixed, Augmented and Virtual Reality are not mentioned in the Overview Report of Computing Curricula 2005 (http://www.acm.org/education/curric_vols/CC2005-March06Final.pdf), the latest report include in the Human-Computer Interaction knowledge area an elective course for the undergraduate Computer Science programs (https://www.acm.org/education/CS2013-final-report.pdf, page 95) including the following topics:

- Output (Sound, Stereoscopic display, Force feedback simulation, haptic devices)
- User input (Viewer and object tracking, Pose and gesture recognition, Accelerometers, Fiducial markers, User interface issues)
- Physical modelling and rendering (Physical simulation: collision detection & response, animation, Visibility computation, Time-critical rendering, multiple levels of details (LOD)
- System architectures (Game engines, Mobile augmented reality, Flight simulators, CAVEs, Medical imaging)
- Networking (p2p, client-server, dead reckoning, encryption, synchronization, Distributed collaboration).

Three example courses in this document mention Virtual Reality: two courses on Computer Graphics, and another, on Human Computer Interaction, which devotes 2/16h lectures to Mixed, Augmented and Virtual Reality. On the other hand, the report on Computer Engineering (https://www.computer.org/cms/Computer.org/professional-education/curricula/ComputerEngineering Curricula2016.pdf) refers to augmented reality and virtual worlds in the core Knowledge Area of Emerging Technologies (page 83).

4. Main Issues to consider when organizing a course

After reviewing the related literature and the webpages of some of the existing courses we identified a number of issues that should be considered carefully when designing and organizing a course: target audience, level of the course (undergraduate, post-graduate), requirements for enrolling the course, topics addressed, class format, hardware and software, practical assignments, group organization, bibliography, staff requirements, main difficulties and constraints. While the expected target audience are Computer Science/Engineering students, the current importance of these technologies justifies offering it to other study programs as Electrical and Industrial Engineering, which is now more possible as the high-level libraries available have lowered the entry level. We found courses offered at BSc and MSc level; however, the later have the potential of providing a broader and more in depth view of the field and better prepare students. Concerning requirements, some courses are offered in a sequence and require (or strongly recommend) a previous Computer Graphics course; and others do not require any previous Computer Graphics knowledge. However, pre-requisites may help students cope with the amount of knowledge required to develop a VR application [TMPT16]. A central decision in planning a course is the set of topics to be addressed; in this respect, we have recommendations for a basic curriculum by scientific/professional associations that can be adapted to specific contexts. Class format, practical assignments, hardware and software, are also essential. We believe a present-day VR/AR course should have a "hands-on"approach, which has been made easier by the recent surge of low-cost VR hardware and dissemination of smartphones. The software platform must be carefully chosen: open source, well documented software having an active community is preferable [HHO13] . An important limitation to the practical assignments is the inability to completely test the developed applications with an ordinary computer; nevertheless, the currently available more affordable hardware lessens this difficulty [TMPT16]. While several books exist for years that can be used to support teaching the fundamentals of Virtual Reality, the rapid evolution of the field demands frequent updating. Regarding Augmented Reality, there has been a greater scarcity of specific books. Recently two books have been published that may be most helpful ([SH16] [Jer16]). The main difficulties and constraints for an institution to offer a Virtual Reality/Augmented Reality course, might be that lectures, practical assignments, software, and specific hardware must be updated frequently as the field evolves very rapidly. This is very time-consuming and may be more or less expensive, depending on the type of equipment and number of students of the course. When courses are offered to students with different backgrounds, particular care is needed in organizing students'projects and support from faculty along the development process. However, possibly the main constraint is having faculty with adequate background, research capability in the field, and the enthusiasm to constantly improve and update the course.

5. Conclusion

Virtual Reality and Augmented Reality evolve rapidly and hardware is becoming increasingly affordable meaning growing opportunities to be used. This implies an increasing need for specific education in the field. We presented a brief overview the courses reported in literature, recommendations concerning courses for under-graduates in Computer Science/Engineering, and identified relevant issues to be considered when planning such a course. As a result of this panel we do hope to help educators currently offering a VR/AR course improve it, and help institutions considering to offer it better understand possible alternatives and requirements.

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