USC Viterbi School of Engineering

CSCI 538 Augmented, Virtual & Mixed Reality
Units: 4-1
Term—Day—Time:
Fall & Spring - Thursdays 10:00am to 1:20pm,
Lab 1:20-2:20pm

Location: Online
(Previously : SCI-108 - School of Cinematic Arts)
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Hours of Service:
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Course Description

This course covers the technical and experiential design foundation required for the implementation of immersive environments in current and future virtual, augmented, and mixed reality platforms.

The curriculum covers a wide range of literature and practice starting from the original Computer Science and HCI concepts following the evolution of all supporting technologies including visual displays for VR, AR and MR, motion tracking, interactive 3D graphics, multimodal sensory integration, immersive audio, user interfaces, IoT, games and experience design.

Learning Objectives

The objective of the course is to establish and cultivate a broad and comprehensive understanding of this rapidly evolving and commercially viable field of Computer Science and prepare the student for participating in the production of highly integrative immersive applications, immersive social platforms, cross disciplinary academic research projects and leading developments in Medical, Industrial and Manufacturing R&D.

During the duration of the course students are expected to work in collaborative group projects and develop working prototypes, demo experiences, immersive platforms, unique controllers and new innovative technologies that can be used in the development and production of immersive environments in the fields of entertainment, education, training, medical and industrial innovation.

Topics include:

- Historical Overview, Current Trends and Future applications of Immersive Technologies
- Best practices in VR,AR and MR including design, prototyping and an ethical code of conduct
- Overview of human physiology, psychology of immersion, and usability factors
- A critical framework for evaluating current and emerging immersive reality technologies and applications
- Design and Technological foundations for Immersive Experiences
- Input devices – controllers, motion trackers and motion capture technologies
- Output devices – Head Mounted VR Displays, Augmented and Mixed reality glasses
- 3D interactive and procedural graphics in game engines
- Immersive surround sound
- Haptic and vibrotactile devices
- Systems architecture and integrative immersive media platforms
- Rapid prototyping and physical computing
- VR programming

Prerequisite(s): an introduction to computer graphics or permission of instructor.
Co-Requisite (s):
Concurrent Enrollment:
Recommended Preparation: It is assumed that the student is a strong programmer.

Mission statement – Fall 2020

As you all know COVID-19 brought disruption across many aspects of our lives including education. The University as well as the instructors of this class are committed to offering high-quality education to our students and have been working around the clock to provide structures for them to learn and excel, following an online or hybrid learning environment.

This class specializes in Immersive Technologies, often called XR or the Immersive Continuum to emphasize the strong relationships between Virtual, Augmented and Mixed Reality. These technologies consist of some unique computational hardware and software platforms that are extremely powerful. Developing for XR requires a totally different mindset for designing content that is often antithetical to any other 2D or pseudo-3D computational environments and interactions designed for traditional computers and user interfaces

The user experience, design, systems architecture, development platforms and tools required for the development of these applications, require a transition to User-Centered design, and Whole Body Interaction as well as holistic models that are based on learning and understanding the significance of sensorial, cognitive and psychological components of immersion and presence in synthetic environments as well as architecture, ergonomics, user interfaces and of course some new technical skills and expertise.

XR technologies should be approached as new mediums under a completely new computational paradigm that is currently being deployed across all industry verticals with an emphasis on Medical, Manufacturing, Automotive, BIM and Architecture, Engineering, Education, Journalism, and Entertainment to name but a few.

Since the beginning of this class three years ago we have worked with and provided education and real-life professional skills to almost 400 students while facilitating growth in a tech sector that becomes exponentially more important at the industry. Demand for highly skilled XR developers has skyrocketed last year (2019) with the website Hired.com reporting increasing demand over hiring AR/VR engineers by 1400% (https://hired.com/state-of-software-engineers).

This class is very ambitious and along with lecture series it offers the opportunity for students to form bigger teams and work on larger scale practical projects that we often develop in collaboration with other labs and centers across USC as well as other international research institutions, and small or big tech and XR companies. These joint collaborations are used to frame a problem, introduce new hardware or software to students to work with and they typically lead to multiple valuable outcomes for students as they have the unique opportunity to learn new applied skills and walk out with a practical demo project they can include in their portfolio and demonstrate their skills in practice. In addition, students are welcomed to develop their own games and immersive experience.

Up until now we have been producing and supervising an average of 12-15 projects a semester that include various original games, and prototypes for motion platforms such as Birdy (a unique VR flying simulator) and the Positron Chair, many room-scale, mobile VR and Mixed Reality games and applications using headsets such as the Oculus Rift, HTC Vive, Oculus Quest, Microsoft Hololens and Magic Leap. Some of the applications that student teams developed over the past years include a VR prototype for Parkinson's rehabilitation in collaboration with Keck School of medicine and the Creative Media and Behavioral Health Center, a series of Mixed Reality explorations in cybersecurity and privacy in collaboration with Symantec, a breathing VR rehabilitation tool for children with cystic fibrosis in collaboration with CHLA, a Mixed Reality experience for the prestigious USC science visualization project World in a Cell in collaboration with the World Building Media Lab and the USC Bridge Institute, a project on climate change in collaboration with the Annenberg School of Communication, the National History Museum in LA, Leica Geosystems and the USC Wrigley Institute (pending worldwide publication), a Mixed Reality ASL interpreter and educational

application for individuals with severe hearing loss and their caregivers in collaboration with Keck School of Medicine, a virtual experiment lab for studying perception and wind mechanics in collaboration with the prestigious center for neuroprosthetics at EPFL in Switzerland. Many of the student teams' immersive games projects were officially selected and presented at the prestigious USC Games Expo such as Rugo, Kingdom of Nature, Exam Artist, Fantasy Hex, Sole Survivor, Cooking with Glarb, Galaxiator, SmashVR and others that have been showcased by our industry collaborators such as Udaan developed for the Birdly VR flying simulator, that received a top in the class award by the organizers of the 2019 USC Games Expo and Space-Quest an immersive space adventure developed for the Positron Chair, the first-ever interactive game developed for this motion platform.

Course values:

Mentorship: All teams and students are closely mentored by the instructors who can offer theoretical and practical knowledge, project management insights, guidance, and resources to ensure the success of each project.

Participation: Participation, especially in online education, is key to harvest the most value from your program and this course. Broadcasting a lecture is not the ideal way of learning and there will be many ways to engage students in various forms of participatory learning.

Teamworking: This class offers the opportunity to students to form teams and build an XR project to add in their portfolio. Active learning is at the core of the philosophy of the class and the students are required to develop interpersonal and professional skills for team working. This semester, in particular, we will focus on emulating the workflow of virtual productions as currently emerging across the tech and entertainment industries in an attempt to offer students valuable insights and real-life working experience.

Learning and Reinforcement Structures:

- Lecture Series:

The duration of lectures is expected to be about 45 – 60 minutes. There will be breakout sessions of about 5-15 minutes each during which students can form smaller groups to discuss a topic, exchange views, connect with each other, and prepare questions for the Q&A session. The duration of the subsequent Q&A sessions will be up to 30 minutes. Additional guest lectures will be organized for specialized topics of interest. Our guest speakers are selected from both industry and academia. Depending on the needs of the students, we may have more than one lecture for each topic.

- Masterclasses:

Masterclasses are focused and specialized lectures or demonstrations that address specific needs and/or interests of the students, taught by experts from a broad network of academics and industry professionals. We encourage students to propose topics but also present their own additional material based on their core interests and expertise. Teaching is the best way to learn and build one's skills.

- Workshops:

Workshops are hands-on tutorials that cover specialized topics of interest and foster cross-disciplinary interactions. As above, students will be encouraged to propose and conduct additional workshops based on their backgrounds.

- External Resources:

Prior to lectures we will curate and provide high-quality external resources and proprietary material to supplement major areas of the curriculum. External resources may include articles, presentations, videos, book chapters and instructional material, media resources, open-source code, and collaborative XR projects.

- Mentorship Program:

Project teams will be mentored by the instructors and TA's on a weekly or biweekly basis and students are encouraged to connect with each other as we encourage cross mentorship and the exchange of knowledge between community members with different knowledge levels and expertise. This will include connections between beginners and experts in game development, technical art, research, and advanced specialized topics. We are also planning to introduce students and teams to other mentors, faculty at USC or other institutions as well as professionals that can further assist them with their projects.

- Open Q&A sessions:

Students submit questions to instructors curated by student moderators who directs the discussion to areas of interest. The Q&A sessions are intended to stimulate conversation, focus on specific topics of interest and to demystify assumptions, correct miscommunication, illustrate real-life examples of transdisciplinary ideation, and promote critical discussion.

Required Readings and Supplementary Materials

Primary:

- Kelly S. Hale (Editor), Kay M. Stanney (Editor). 2014. Handbook of Virtual Environments: Design, Implementation, and Applications, Second Edition (Human Factors and Ergonomics) ISBN-13: 978-1466511842. Amazon

Other Resources:

- Michael Madary and Thomas K. Metzinger. 2016. Real Virtuality: A Code of Ethical Conduct. Recommendations for Good Scientific Practice and the Consumers of VR-Technology. *Frontiers in Robotics and AI* 3, February: 1–23. http://doi.org/10.3389/frobt.2016.00003
- Jason Jerald. 2015. *The VR Book: Human-Centered Design for Virtual Reality*. Association for Computing Machinery and Morgan & Claypool Publishers. http://doi.org/10.1145/2792790
- Tony Parisi. 2015. Learning Virtual Reality ISBN: 9781491922828
- Alva Noe. 2004. Action in Perception. ISBN: 9780262640633
- Paul Dourish. 2001. Where the Action Is. ISBN: 9780262254151
- Philippe Fuchs - Appropriate use of VR headsets
- http://worldvrforum.com/product/appropriate-use-virtual-reality-head/
- Michael Heim. 1994. The Metaphysics of Virtual Reality. http://doi.org/10.1093/acprof:oso/9780195092585.001.0001
- Char Davies. 1998. OSMOSE: Notes on being in Immersive virtual space. *Digital Creativity* 9, 2: 65– 74. http://doi.org/10.1080/14626269808567111
- Philip Brey. 1999. The ethics of representation and action in virtual reality. *Ethics and Information Technology* 1, 1: 5–14. http://doi.org/10.1023/A:1010069907461
- Luca Turchet. 2015. Designing presence for real locomotion in immersive virtual environments: An affordance-based experiential approach. *Virtual Reality* 19, 3–4: 277–290. http://doi.org/10.1007/s10055-015-0267-3
- Corey J. Bohil, Bradly Alicea, and Frank A. Biocca. 2011. Virtual reality in neuroscience research and therapy. *Nature Reviews Neuroscience* 12, 12: 752–62. http://doi.org/10.1038/nrn3122
- George Lakoff and Mark Johnson. 2003. Metaphors We Live By http://doi.org/10.7208/chicago/9780226470993.001.0001
- Anton Nijholt. 2014. Playful User Interfaces. https://doi.org/10.1007/978-981-4560-96-2
- Florian Mueller and Katherine Isbister. 2014. Movement-based game guidelines. *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*: 2191–2200. http://doi.org/10.1145/2556288.2557163

Description and Assessment of Assignments

Each student is expected to contribute code for a group developed immersive environment or application. The project runs continuously all semester, the code testing the student's knowledge of the in-class lectures and reading material. The student's immersive environment will be presented in class during the last week. The student's grade will be based on the final demonstration of the group project and on the student's participation in that project and in class. Each student will maintain a personal web page detailing his or her part of the group developed immersive environment. Each group will maintain a group web page plus schedule of weekly progress. Each developed immersive environment must be fully 3D, utilize a 3D input device, display on the variety of available laboratory displays, include real-time collision detection, and behavior modeling for the autonomous characters/objects in the developed immersive world. Weekly Quiz assignments are based on learning material provided to the students

Grading Breakdown

How will students be graded overall, including the assignments detailed above. Participation should be no more than 15%, unless justified for a higher amount. All must total 100%.

Assignment	Points	% of Grade
Class participation	100	10
Weekly Quiz Assignment	200	20
Team Project Portfolio	200	20
Final Project Submission Demonstration	500	50
TOTAL	1000	100

Assignment Submission Policy

Describe how, and when, assignments are to be submitted.

Additional Policies

Add any additional policies that students should be aware of: late assignments, missed classes, attendance expectations, use of technology in the classroom, etc.

Course Schedule: A Weekly Breakdown

	Topics/Daily Activities	Readings and Homework	Deliverable/ Due Dates
Week 1	**Content:** **1. Introduction to Immersive Technologies** 1.1 A Brief History of Virtual Reality 1.2 The five Classic Components of a VR System 1.3 Early Commercial VR Technology 1.4 VR Becomes an Industry 1.5 Reality, Virtuality and Immersion 1.6 VR, AR, MR, xR: similarities and differences 1.7 Current trends and state of the art in immersive technologies, developing platforms and consumer devices 1.7 The future of human experience 1.8 Conclusion 1.9 Review Questions	**Reading Assignment**: VR Handbook: Chapter 1 Metaphysics of VR: Chapter 8 **Writing assignment:** Choose an existing VR application and write a summary (500 words) including a personal critical reflection on its look and feel especially in relation to immersion, presence, agency and interactivity.	
Week 2	**Content:** **2. Motion tracking, navigation and controllers** 2.1 Position and Motion Trackers 2.1.1 Inside Out/Outside In 2.1.2 Tracker Performance Parameters 2.1.3 Optical - Active and Passive Trackers 2.1.4 Inertial and Hybrid Trackers - HMD Trackers 2.1.5 Magnetic Trackers 2.1.6 Mechanical Trackers 2.1.7 Ultrasonic Trackers 2.2 Navigation and Manipulation Interfaces 2.2.1 Tracker-Based Navigation/Manipulation Interfaces 2.2.3 Three-Dimensional Probes and Controllers 2.2.3 Data Gloves and Gesture Interfaces 2.4 Conclusion 2.5 Review Questions	**Reading Assignment:** VR Handbook: Chapter 2 Learning Virtual Reality: Chapter 3	
Week 3	**Content:** **3. The Human behind the lenses** 3.1. Human Perception and Cognition 3.1.2 The Human Visual System 3.1.3 The Human Auditory System 3.1.4 The Human Vestibular System 3.2 Physiology, Psychology and the Human Experience 3.2.1. Adaptation and Artefacts	**Reading Assignment**: VR Handbook: Chapters 7, 23, 26 Paper: Real Virtuality: A Code of Ethical Conduct. **Other Reading:** Metaphysics of VR: Chapter 8 Action in Perception: Chapter 1	

	3.2.2 Ergonomics 3.2.3 Ethics 3.2.4 Scientific Concerns 3.3 VR Health and Safety Issues 3.3.1 Effects of VR Simulations on Users 3.3.2 Cybersickness, before and now 3.3.3 Guidelines for Proper VR Usage 3.4 User Centered Design, User Experience and an Ethical Code of Conduct 3.5 Conclusion 3.6 Review Questions	**Writing assignment**: Find an existing immersive commercial application that you think it violates best practices and induces nausea by design. Identify what doesn't work and propose a solution (500 Words)	
Week 4	**Content:** **4. The present and the future of xR** 4.1 Areas and industries for immersive reality applications. 4.1.1 Entertainment 4.1.2 Education 4.1.3 Training 4.1.4 Medical 4.1.5 Industrial 4.1.6 Military 4.2 Use-cases, applications and production pipelines 4.2.1 From Sensing to Rendering 4.2.2 Mobile, Standalone and high- end immersive computing platforms 4.3 VR, Immersive Tech and the Society 4.3.1 Impact on Professional Life 4.3.2 Impact on Private Life 4.3.3 Impact on Public Life 4.4 Conclusion 4.5 Review Questions	**Reading assignment:** VR Handbook: Chapter 36 **Other Reading:** Handbook: Chapter 4 Metaphysics of VR: Chapter 9	
Week 5	**Content:** **5. Camera tracking and 3D Rendering for Immersive Environments** 5.1 Inside-Out Camera tracking 5.1.1 Depth Sensing 5.1.2 Microsoft HoloLens 5.1.3 Vrvana Totem 5.1.4 Low cost AR and MR systems 5.1.5 Mobile Platforms 5.2 Full-Body tracking 5.2.1 Inverse & Forward Kinematics 5.2.2 Kinect 5.2.3 Intel Realsense 5.2.4 Full body inertial tracking 5.2.6 Ikinema 5.2.7 Holographic Video 5.3 Rendering Architecture 5.3.1 Graphics Accelerators 5.3.2 3D Rendering API's, OpenGL, DirectX, Vulcan, Metal	**Reading Assignment**: Handbook: Chapter 5, 14 **Other Reading:** Learning Virtual Reality: Chapters 4, 6	

	5.3.3 Best practices and Optimization techniques 5.4 Distributed VR Architectures 5.4.1 Multi-pipeline Synchronization 5.4.2 Co-located Rendering Pipelines 5.4.3 Distributed Virtual Environments 5.5 Conclusion 5.6 Review Questions		
Week 6	**6. Modeling the Physical world** 6.1 Geometric Modeling 6.1.1 Virtual Architecture 6.1.2 Virtual Object Shape 6.1.3 Virtual Object Appearance 6.1.4 Procedural Textures 6.1.5 Advanced Material Properties 6.1.6 Procedural Objects 6.1.7 Photogrammetry 6.2 Kinematics Modeling 6.2.1 Homogeneous Transformation Matrices 6.2.2 Object Position 6.2.3 Transformation Invariants 6.2.4 Object Hierarchies 6.2.5 Scale, Perspective and Perception 6.3 Physical Modeling 6.3.1 Collision Detection 6.3.2 Surface Deformation 6.3.3 Force computation 6.3.4 Force Smoothing and Mapping 6.3.5 Haptic Texturing 6.4 Behavior Modeling 6.5 Model Management 6.5.1 Level-d-Detail Management 6.5.2 Cell Management 6.6 Conclusion 6.7 Review Questions	**Reading Assignment:** Handbook: Chapter 11 **Other Reading:** Action in Perception: Chapter 5	
Week 7	**7. Presence, Agency and Interactivity** 7.1 Augmenting the sense of Presence 7.1.1 Space and Architecture 7.1.2 The Uncanny Valley 7.1.3 Dissolving the Medium 7.2 Identity in Immersive Environments 7.2.1 Change of Identity 7.2.2 Transforming the senses 7.2.3 Extending the senses 7.3 Agency and Interactivity 7.3.1 Cybernetics, Causality and meaning making 7.3.2 Interactivity within Physical Dimensions	**Reading Assignment**: Handbook: Chapter 17, 27 **Other Reading:** Luca Turchet : Designing presence for real locomotion in immersive virtual environments	

	7.3.3 Interactivity beyond Physical restrictions; the Super Hero effect 7.4 Physical Computing 7.4.1 IoT and sensor networks 7.4.2 Rapid Prototyping 7.5 User Performance Studies 7.5.1 Test-bed Evaluation of Universal VR Tasks 7.5.2 Influence of System Responsiveness on User Performance 7.5.3 Influence of Feedback 7.6 Conclusion 7.7 Review Questions		
Week 8	**8. Sound in Immersive Environments** 8.1 Evolution of Sound Systems 8.1.1 From mono to stereo to surround 8.1.2 Object Based Sound 8.1.3 Ambisonics 8.1.4 HRTF 8.2 Sound Design Basics 8.2.1 Sound as Information 8.2.2 Earcons 8.2.3 Impact of Sound in Objects and Actions 8.2.4 Natural vs Real Sound	**Reading Assignment**: Handbook: Chapter 13 **Other Reading:**	
Week 9	**9. Medical Applications of xR** 9.1 Areas of Application 9.1.1 Behavioral Therapy 9.1.2 Exposure Therapy and PTSD 9.1.3 Training 9.1.4 Rehabilitation 9.1.5 Virtual and Augmented Surgery 9.1.6 Virtual Anatomy 9.1.7 Triage and Diagnostics 9.2 The role of FDA 9.2 Conclusion 9.3 Review Questions	**Reading Assignment**: Handbook: Chapter 45	
Week 10	**10. VR Applications in Manufacturing** 10.1 Productivity Enhancement Platforms 10.1.1 Virtual Prototyping spaces 10.1.2 Virtual collaborative working spaces 10.1.3 Augmented and Virtual Assistance 10.1.4 Telepresence 10.2 Applications of VR in Robotics 10.2.1 Robot Programming 10.2.2 Robot Teleoperation 10.3 Information Visualization 10.3.1 Oil Exploration and Well Management 10.3.2 Big Data Visualization	**Reading Assignment**: Handbook: Chapter 21 **Writing Assignment:** Write a short assessment of your immersive application so far. How safe is it for commercial use? What is your target group and how will it improve their intended experience? How can you improve it if you had the resources to bring it to market?	

	10.3.3 Volumetric Data Visualization 10.4 Product Liability and Social responsibility 10.4.1 Innovation as continuity vs disruption 10.4.2 Entrepreneurial Design for Societal Progress 10..4.3 Legal Responsibilities 10.4 Conclusion 10.5 Review Questions		
Week 11	**Advanced Topics in VR -** Highlights from recent papers on immersive environments.	**Project Assignment:** continue to enhance your immersive environment.	
Week 12	**Advanced Topics in VR -** Highlights from recent papers on immersive environments.		
Week 13	**Advanced Topics in VR -** Highlights from recent papers on immersive environments.	**Project Assignment:** continue to enhance your immersive environment.	
Week 14	**Advanced Topics in VR -** Highlights from recent papers on immersive environments.		
Week 15	**Advanced Topics in VR -** Highlights from recent papers on immersive environments.	**Project Assignment:** continue to enhance your immersive environment.	
FINAL	Final Presentations	**Final Project Demo & Write up** - Student critique Instructor feedback	Date: For the date and time of the final for this class, consult the USC *Schedule of Classes* at www.usc.edu/soc.

Statement on Academic Conduct and Support Systems

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Section 11, *Behavior Violating University Standards* https://scampus.usc.edu/1100-behavior-violating-university-standards-and-appropriate-sanctions. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the *Office of Equity and Diversity* http://equity.usc.edu or to the *Department of Public Safety* http://adminopsnet.usc.edu/department/department-public-safety. This is important for the safety of the whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. *The Center for Women and Men* http://www.usc.edu/student-affairs/cwm/ provides 24/7 confidential support, and the sexual assault resource center webpage http://sarc.usc.edu describes reporting options and other resources.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.html provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information* *http://emergency.usc.edu* will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.