IMMERSE

Center for Immersive Computing

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University of Illinois Urbana-Champaign
immerse@illinois.edu
immerse.illinois.edu

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Introduction

IMMERSE, the Center for Immersive Computing, at the University of Illinois Urbana-Champaign brings together expertise in immersive technologies, applications, and human experience to perform research, educate a new workforce, and build infrastructure that will accelerate a new era of immersive computing.

Immersive computing promises the seamless integration of the virtual with the physical. It includes augmented, virtual, and mixed reality (AR, VR, and MR), collectively extended reality (XR), digital twins, the metaverse, spatial computing, and earable computing. Immersive computing enables us to virtualize (digitize) the physical world as perceived by all of our senses (including visual, audio, haptic, and olfactory); to augment our physical world with virtual content and experiences; and to interact seamlessly with a continuum of mixed physical and virtual experiences.

Immersive computing has the potential to transform most human activities, including education, healthcare, science, arts, crisis response, industrial design, manufacturing, maintenance, agriculture, retail, social interactions, entertainment, and more.

Recent advances in technology and deployment through consumer products have started to unveil this potential, yet many challenges remain.

IMMERSE Thrusts

We identify the following three broad areas of challenges, which form the three thrusts of IMMERSE.

Technologies

Building immersive systems that provide comfortable, mobile, rich, trustworthy, collaborative, all day immersive experiences remains a grand challenge. Addressing this challenge will require considerable interdisciplinary research in core technology areas such as hardware/software systems (including hardware architecture, networks, programming languages, operating systems, and distributed computing), computer vision, robotics, graphics, visualization, machine learning, audio, optics and displays, sensors, and security and privacy. Furthermore, no single area provides a silver bullet, requiring an integrated approach across multiple technology disciplines for progress.

Applications

Many industries have started to use immersive systems in a variety of applications, but the transformative power of a new computing modality has historically been in the new industries and capabilities it enables; e.g., mobile and cloud computing led to industries around personal videography (Youtube) and the sharing economy (Uber). There are still many barriers today to agile, large-scale deployment of immersive applications, ranging from barriers to developing immersive content, inadequate assessment, safety, and other regulatory frameworks, and an emerging end-user hardware and system software ecosystem that has yet to standardize.

Human Experience

More than any previous change in computing modality (e.g., mainframe, personal, internet/cloud, mobile computing), the effectiveness of immersive systems is critically dependent on our understanding of the human experience and how we make meaning in immersive contexts. The real world experience is immersive, after all, and so the goal with immersive computing is to create interfaces that integrate with and augment human experience to enhance learning, efficiency, ability, empathy, etc. The success of immersive computing depends on a variety of experiential, contextual, and social aspects of the human experience, factors that are still being understood and historically not been well integrated into technology or application development. This requires bringing together work in perception science, neuroscience, psychology, design, human computer interaction, the learning sciences, security and privacy, ethics, and policy and regulation, and integrating with the technology and application ecosystems.

Increasingly the challenges within the above thrusts are interwoven, requiring interdisciplinary solutions and end-to-end system demonstrations to assess their effectiveness. IMMERSE aims to catalyze an integrative approach to immersive technologies, applications, and human experience, resulting in foundational and translational research, education of a workforce, and infrastructure to accelerate the era of immersive computing.

IMMERSE Activities

To achieve the above goals, IMMERSE brings together and enhances the substantive relevant strengths at Illinois, with an emphasis on the following activities.

Research

IMMERSE will catalyze the creation of end-to-end full system deployments for a few application domains that will serve as research testbeds to address the challenges mentioned above. These deployments will serve to motivate, prototype, and evaluate research in technologies and human experience while promoting agile deployment of real world immersive applications. More broadly, along with government, industry, academic, and philanthropic partners, IMMERSE will catalyze pursuit of large cohesive interdisciplinary research projects and provide national and international thought leadership on immersive computing.

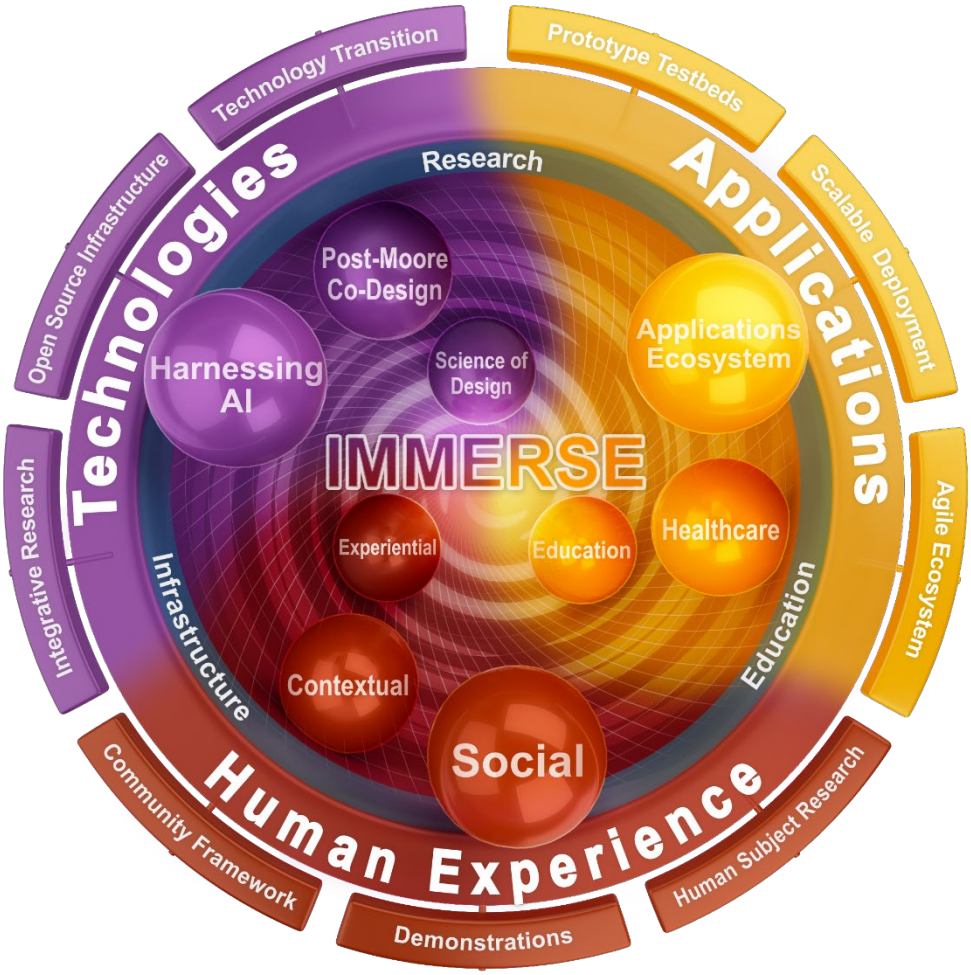
Education and workforce development

IMMERSE recognizes the need for investments in education on two fronts. First, we aim to create a workforce trained in the new immersive technologies and their use in various disciplines. IMMERSE will develop an interdisciplinary online Professional Masters degree program, with a core curriculum supplemented with concentrations in the three IMMERSE thrusts. Second, we aim to transform education itself by aggressively employing immersive technologies in courses and other instructional contexts, while guided by strong pedagogical research to optimize learning. Treating education as a key application in the applications thrust of IMMERSE, we will bring to bear work across the center for this transformation. Starting from currently available resources, we will use our immersive education deployments as our research testbeds to drive future technologies, content development tools and workflows, and assessment frameworks that will feed back to provide the next leaps in immersive education.

Infrastructure

The research and education activities in all three thrusts of IMMERSE require significant physical and virtual infrastructure. This includes physical lab facilities for hardware and software prototyping, user experience testing, and education, supported by state-of-the-art headsets and displays, sensors, networking, edge and cloud servers and data centers; physical and virtual facilities for collecting, developing, and curating data sets, benchmarks, and research testbeds; and prototype immersive system deployments that scale from a few to billions of distributed interacting users to enable and demonstrate our research and education mission. IMMERSE will catalyze external and internal funding efforts with various partners to develop, deploy, and maintain such infrastructure. Our aim is to enable state-of-the-art infrastructure for immersive computing research and education not just for Illinois but also make it available for the broader national and international community.

To achieve our goals, we highlight key themes and activities within each IMMERSE thrust in the rest of the document, summarized in the following figure.

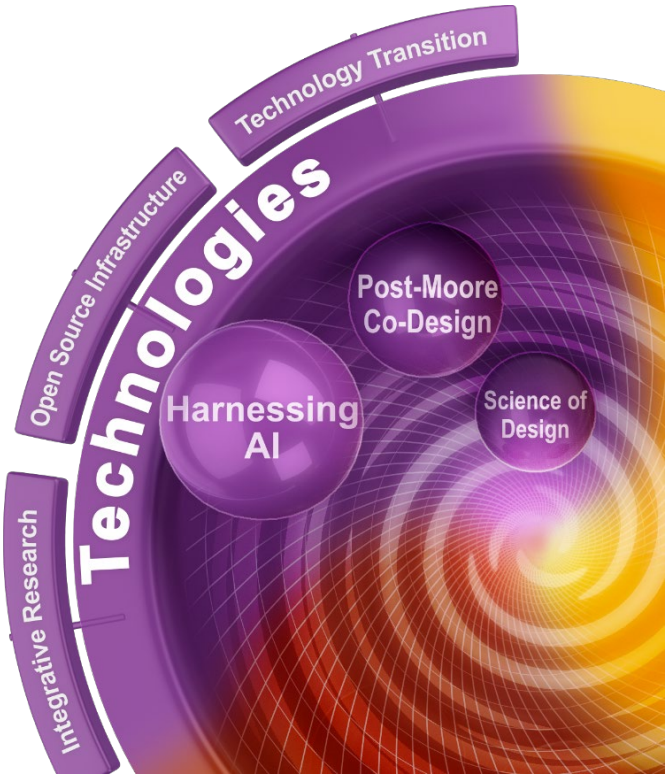


IMMERSE consists of technologies, applications, and human experience thrusts with research, education, and infrastructure activities. Each thrust highlights key intellectual themes (inner discs) and activities (outer ring) described in the rest of the document.

Technologies

To seamlessly integrate the physical and the virtual, immersive systems bring together a number of subsystems and technologies; e.g., the perception subsystem that uses a variety of sensors to determine the user's position (tracking the head, eye, hand, etc.) and what the world around them looks like; the visual subsystem that uses perception information to create photorealistic content for immersive displays; the audio subsystem that produces spatially localized sound; haptics for tactile feedback; and affective computing for emotions.

Building immersive systems that provide sufficiently comfortable, mobile, rich, trustworthy, collaborative, all day immersive experiences remains a grand challenge. For many of these attributes, there are orders of magnitude gaps between current and desired systems. Equally important, there is a dearth of metrics to holistically assess the goodness of immersive experiences, making it difficult to quantitatively measure progress or ascribe intermediate milestones towards our grand challenge.



The goals of the IMMERSE technologies thrust are: (1) to develop the technologies to address the above grand challenge for immersive systems, and (2) to develop a framework for holistically measuring the multiple dimensions of performance of immersive systems, enabling the community to quantify progress and provide a Moore's law analogue for intermediate goalposts.

Achieving our goals requires considerable interdisciplinary research encompassing core technology areas such as hardware and software systems, computer vision, robotics, graphics, machine learning, audio, optics and displays, sensors, and security and privacy. IMMERSE will foster such work by identifying critical interdisciplinary challenges and opportunities, and providing the environment to engage with them. We identify three such directions of focus below that leverage the strengths of Illinois.

Technology Themes

Scalable system co-design for the post-Moore era

Immersive systems will have insatiable compute requirements for the foreseeable future. The end of Moore's law and Dennard scaling means that we cannot support all of this computation in the user's wearable device within the few 100mW power envelope that would afford reasonable battery life and avoid thermal discomfort (compared to a few Watts used by today's devices). Offloading computation to the edge or cloud converts the local compute resource problem into communication and latency/bandwidth compensation problems, given the tight latency (e.g., about 20ms from head movement to visual display for VR and 5ms for AR) and large data requirements. Immersive wearables also include a variety of sensors and displays, forming a complex heterogeneous distributed system that must meet tight latency and power demands with a lightweight form factor far more comfortable than the bulky headsets of today. To support geographically distributed collaborative applications, all of these user, edge, and cloud compute platforms must form a cohesive distributed system that presents a synchronized, common world to all the users, further exacerbating the compute, latency, and bandwidth issues. The presence of always-on sensors and modification of the user's perception brings new challenges for privacy and trust. Today, there is no one silver bullet technology that can meet all of the demands of our grand challenge, demanding end-to-end codesigned solutions that consider the entire system stack including novel hardware semiconductor technologies and computer architectures, programming and runtime systems, networking, and algorithms, viewing the entire distributed platform as a unified resource that intelligently manages the inevitable system-wide tradeoffs for the best possible user experience.

Harnessing advancements in artificial intelligence to rethink immersive systems

The rapid advancements in AI are changing all aspects of algorithms and system design, making it possible to conceive of previously unthinkable functionalities. Neural algorithms have already replaced classical algorithms in several parts of immersive systems providing much higher accuracy than in the past; e. g., for eye and hand tracking. Neural Radiance Field (NeRF) driven rendering algorithms are changing how we think of the perception and visual subsystems, offering remarkable photorealism with limited content creation effort. Foundation models are enabling pipelines where text commands can be used to directly create and edit visual content, potentially removing a laborious aspect of immersive application design. Unfortunately, all of these advances require huge computational power. To exploit these AI advances in practice will require latency, bandwidth, and power aware design of AI models, continued interaction with classical techniques, and codesign with distributed hardware and system software. More excitingly, use of these models motivates a fundamental rethinking of the immersive system workflow (e.g., the relationship between the perceptual and visual subsystems), from algorithms to runtime systems to hardware design.

Science of immersive system design

If you can't measure it, you can't improve it. Our grand challenge requires multiple dimensions of performance, for many of which today's metrics are unsatisfactory and virtually all typically require tradeoffs with others. Immersive computing is ultimately about altering human perception. Metrics to assess the effectiveness of such systems must include how well they are able to integrate with and augment our sensory experiences, and considerable research is still required. These metrics must be connected to lower level, more siloed metrics (e.g., quality of 3D scene reconstruction) and frameworks for expressing the inevitable tradeoffs that must

occur (e.g., battery life vs. fidelity of the human avatar). Security, privacy, and more broadly, trust must be measurable, along with the tradeoffs they entail in compute, power, etc. It is not sufficient to develop these metrics and frameworks, but tools and methodologies to apply them and compare systems against them must be created and promoted. Today, there is little by way of standardized methodologies for holistic, end-to-end comparisons of two immersive systems. Providing such tools and methods can significantly accelerate research by providing a strong foundation for the science of design of immersive systems.

Technology Activities

IMMERSE will perform the following activities to achieve the goals of the technologies thrust.

Integrative research with end-to-end demonstrations

The focus areas described above require an integrative approach to research. IMMERSE is organized to remove barriers between computer scientists, engineers, industrial designers, neuroscientists, psychologists, UI/UX designers, and more. To this end, the center is creating physical work spaces for faculty, students, and practitioners to come together, permanently, as their main working space, as well as shared laboratory spaces with shared infrastructure to build and demonstrate new technologies research in end-to-end testbeds (described in more detail in the applications thrust). We are actively betting against the design-separately-and-combine-at-the-end philosophy, believing instead that continuous joint optimization is critical for immersive computing.

Open source infrastructure: benchmarks, tools, libraries

Working on large, interdisciplinary projects with real testbeds and demonstrations as key goals is easier said than done. IMMERSE will invest in personnel to assist each team with making their work compatible to a central line-of-progress. This entails fostering a culture of producing high quality open benchmarks, tools, libraries, datasets, etc., making it easier for teams on campus (and the international community) to align, integrate, and co-design towards delivering truly collaborative end-to-end research outcomes and demonstrations. Some current examples are the NIH3D Congenital Heart Library curated by our Jump Simulation center and the ILLIXR open source XR system testbed.

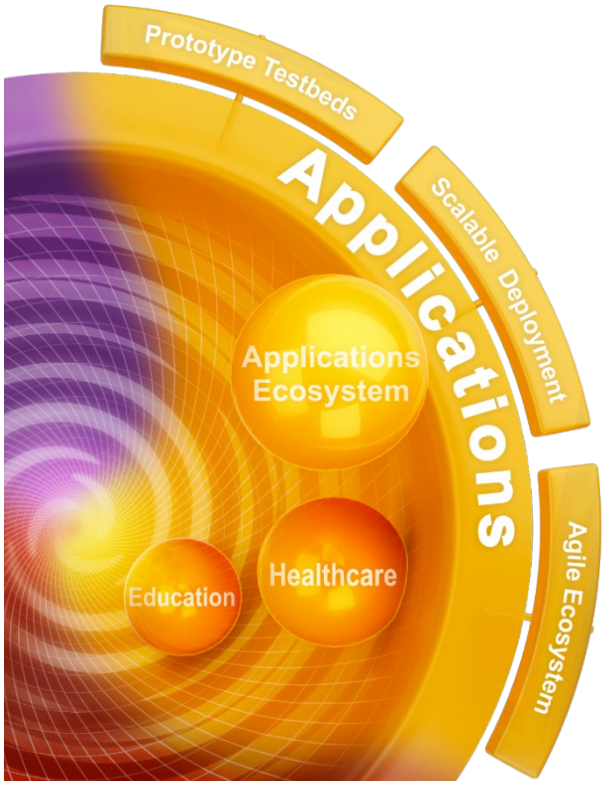
Technology transition - the last mile

Transitioning research technology to practice is a high priority. This includes active engagement and collaboration with industry as well as nurturing startups as appropriate, so our technologies are adopted by end-users, become industry standard, and displace current methods. It also includes creating community engagement and buy-in for collectively developed open infrastructure as well as new metrics and frameworks. Finally, it is a huge priority to transition our technologies through our students, including transferring our research to our considerable education activities at a rapid cadence.

Applications

Immersive computing is not just a new interface to interact with old applications in our digital world. We expect this new modality to fuel new applications and create whole new markets and business models with large societal impacts. It is difficult to predict the new killer applications and markets, but some examples that are already emerging are: hybrid meeting spaces, including for large conferences and exhibitions; applications in healthcare (see below); immersive distributed industrial design, manufacturing, and maintenance; rescue operations and crisis management such as distributed control of forest fires or mass shootings; training for defense, healthcare, and a host of disciplines; distributed and interactive broadcasts of live events such as sports and concerts; interactive scientific visualization and simulation; immersive and personalized education; robotic telepresence for surgery and health care; personalized shopping; remote site tours for real estate/vacations/construction/historical archives; immersive virtual assistants; and more.

Much research and consumer products in the immersive space have been driven by gaming, social interactions, and entertainment. While many of the fundamental research challenges are common across all immersive applications, there are several unique domain specific demands. For example, many domains cannot accept the widespread approach of ”good enough” performance, the lack of attention to privacy and security, the bulky headsets that are either tethered or have few hours of battery life, the lack of human-centered assessment criteria, etc.



A key tenet for IMMERSE is to integrate and simultaneously nurture the technology and human experience research ecosystems with the application development and deployment ecosystem.

The goals of the IMMERSE applications thrust are: (1) to drive immersive technologies and human experience research in the context of end-user applications for broad societal impact and (2) to foster an environment that enables agile development of immersive applications, specifically, as yet unimagined applications with transformative impact on their discipline.

The IMMERSE center currently includes work in a variety of application domains, including healthcare, education, performing arts, industrial design, architecture, scientific visualization, civil engineering, games and entertainment, and more. IMMERSE has identified the following themes of focus for the applications thrust: the application domains of healthcare and education (due to their potential for broad impact and our strengths at Illinois) and an integrated applications ecosystem for agile deployment of immersive applications across all domains.

Application Themes

Healthcare

Immersive technologies are already being used in a variety of healthcare scenarios, including medical imaging, surgical planning, intra-operative applications, mental health therapy, telemedicine for bridging geographical gaps for remote and rural consultations, and medical training using digital twins and simulation, with substantial data showing improved outcomes. Nevertheless, there continue to be significant barriers, ranging from technology barriers to stringent assessment and regulatory procedures to patient privacy standards (e.g., from the Food and Drug Administration or FDA and HIPAA in the US). While some of these barriers are common to many immersive application domains (e.g., dealing with network latency and bandwidth for remote healthcare), others are unique to the needs of the healthcare industry. For example, many of the above medical applications require a level of accuracy in registration and rendering that is far more precise and higher fidelity than needed in social interactions and entertainment driven applications.

Education and training

Immersive technologies can transform education and training, eradicating geographical barriers, lessening inequities, removing safety hazards in some training, providing deeply experiential learning, and enabling collaborative learning and training at a large scale. Immersive classrooms enable immersive historical reenactments, interactive scientific experiments, and cultural explorations that make learning engaging and unforgettable. Illinois has a long history of using immersive technologies in education, including in archaeology, electrical engineering, dance, medicine, etc., as well as pedagogical research in how humans use, experience, and benefit from immersive learning. Nevertheless, significant barriers remain in creating content, scalable delivery, collaborative and remote education, preserving privacy, and pedagogical assessment and improvement.

Integrated applications ecosystem

The true promise of immersive computing will likely be revealed from extending current applications and developing applications not imagined today. Catalyzing such applications requires an integrated development and deployment ecosystem that makes it easy for small groups of students, staff, and faculty to quickly prototype and develop immersive applications across current and emerging domains. Similarly, it is also challenging to transition new technologies and assessment criteria into developing systems and applications. An integrated ecosystem that democratizes these processes can be vital for innovations in multiple disciplines.

Application Activities

IMMERSE will perform the following activities to achieve the goals of the applications thrust.

Prototype end-to-end testbeds for healthcare applications

IMMERSE will catalyze the development of end-to-end testbeds that deploy specific challenging applications from the healthcare domain. These testbeds will serve to drive and prototype new technology research from the center, demonstrating new capabilities in the healthcare domain. The research will push the frontiers of hardware, system software, networking, distributed systems, AI, perception, haptics, rendering, audio, and end-to-end system codesign and optimization. The testbeds will enable evaluation and assessment in various human experiences and regulatory contexts. Healthcare domain-specific content authoring and editing workflows will enable rapid deployment. New open source benchmarks, datasets, and evaluation methodologies along with open source hardware and software will be made available to the international community to drive further research and development. Specific Illinois strengths that underlie this work are the Carle Illinois College of Medicine (CI MED), the first engineering-based college of medicine preparing physician innovators, and the JUMP simulation center, an emerging leader in healthcare simulation and a collaboration between CI MED and local healthcare organizations such as OSF Healthcare, funded through the JUMP ARCHES endowment. The ultimate goal is to create new capabilities for healthcare while pushing the frontiers of current technologies.

Scalable delivery of in-person and online immersive education and training

Illinois already offers several courses with immersive content, but these are currently small scale, built-from-scratch, in-person offerings using diverse workflows. A recent development is the Studio from the Games Studies and Design program which offers project management and development services for immersive content development consistent with state-of-the-art industry practices. Enduvo, an Illinois born startup, provides solutions for medical training. IMMERSE will work towards enabling such resources on campus to develop scalable workflows that enable rapid development of immersive course content. To meet the challenges of course delivery, initial efforts will focus on in-person classroom facilities with state-of-the-art off-the-shelf systems and small scale collaborative experiences. In parallel, we will deploy prototype research testbeds that enable scalable collaborative and distributed online learning experiences. This combination of production systems and research testbeds will provide a unique environment for driving immersive technology advances firmly integrated with state-of-the-art pedagogical assessments to enable the benefits of immersive education and training.

An agile immersive applications ecosystem

We focus on healthcare and education to exploit the current strengths of Illinois. The ultimate goal is to leverage the resulting advances in technologies, human-centered assessment mechanisms, content authoring workflows, deployment platforms and testbeds, and physical facilities to create an agile ecosystem that fosters the growth of new and as yet unimagined applications to deliver on the transformative potential of immersive computing. The Studio program described above will serve as a starting point to scale to our long-term goal.

Human Experience

As the field of immersive computing rapidly progresses, its transformative applications and experiences are unfolding across all aspects of human lives. This rapid evolution necessitates a framework that not only considers the experiences of the users of technologies and applications, but also delves deeper into the nexus of intricate societal impacts and the broader human ecosystem.

We propose Human Experience as a broad, holistic term encompassing experiential, contextual, and social processes.

The goals of the IMMERSE Human Experience thrust are to establish a multifaceted research platform that explores human interactions with immersive technologies within an expansive, yet human-centered, ecosystem. This encompasses not only the assessment of individual-level user experiences and psychological impacts but also the scrutiny of wider societal issues, such as governance, regulation, sustainability, and ethics. The ultimate aim is to provide a comprehensive framework that fully captures the myriad human and societal implications arising from advancements in immersive computing.

Human Experience Themes

Experiential Factors

We aim to unify Human-Computer Interaction (HCI) and Human Factors research in the realm of immersive computing, leveraging the extensive expertise in social and behavioral sciences available at Illinois. Our goal is to define how immersive technologies influence human cognition, learning, perception, emotions, attitudes, and behaviors. We intend to deeply explore user-centered design, sensorimotor effects, as well as the psychological and physiological impacts of extended reality experiences. In doing so, we expect to set new benchmarks for the evaluation and design of immersive interfaces.

Contextual Factors

Immersive computing, far from being an isolated entity, is interconnected with and adapts to various contexts. We aim to explore immersive computing beyond its immediate applications, directing attention to the broader contexts that shape these technologies. By scrutinizing the unique challenges, opportunities, and ethical considerations in sectors such as healthcare, education, and entertainment, we intend to inform best practices. Our goal is to establish these guidelines within a broader societal and ethical framework, drawing from a

multidisciplinary perspective, and to incorporate these insights early in the technology and application development stages.

Social Factors

Immersive computing is deeply interwoven with social dynamics, influencing relationships, culture, and society as a whole. We aim to investigate the social dimensions of immersive computing with a nuanced, comprehensive lens, focusing on its ethical, cultural, legal, and societal implications. Our inquiry extends to privacy concerns, data security, and digital ethics. Importantly, we give special attention to a new form of digital divide. This divide is not merely about access but also encompasses disparities in adoption and differentiated usage patterns of emerging technologies like AI and immersive computing. We also probe into the potential unintended biases or discrimination that may be embedded within these advanced technologies. Our commitment is to guide the development of immersive computing in ways that uphold both individual and collective rights, foster inclusivity, encourage diversity, promote collaboration, and safeguard privacy.

Human Experience Activities

IMMERSE will achieve the goals for the human experience thrust with the following activities.

Build a community to lead a Human Experience framework

IMMERSE will bring together researchers and practitioners from multiple disciplines such as design, psychology, anthropology, education and others to accelerate the development of a human experience centered framework to shape the emerging technologies and applications for immersive computing. The goal will be to form a community of practice that will publish and disseminate a series of guidelines and metrics related to human-centered design, privacy, accessibility, diversity, ethics, and legal implications in immersive computing, similar to, for example, the Ethics Guidelines for Trustworthy Artificial Intelligence and the Assessment List for Trustworthy Artificial Intelligence (ALTAI) published by the European Commission.

Infrastructure to develop and demonstrate the Human Experience framework

The IMMERSE healthcare and education prototypes and production environments described in the applications thrust will provide a rich infrastructure in which to conduct human experience research for immersive computing. Conversely this infrastructure will serve as an integration point to drive and demonstrate human experience driven technologies and applications.

Human subject research for immersive computing

IMMERSE will support and accelerate processes for human subject research for immersive computing at Illinois. For example, IMMERSE will support physical laboratory spaces that make available technologies related to data capture and analysis to support human-centered empirical research, and create common guidelines for such work based on established immersive human experience driven metrics. IMMERSE staff will also work with our Institutional Review Board (IRB) to help them understand the unique attributes of doing human subjects research in immersive computing contexts, and share information with researchers about how to design a study to receive IRB approval.

IMMERSE Faculty and Staff

Name	Affiliation
Laura Shackelford	Anthropology
Fitsum Abede	Applied Research Institute
Matthew Bramlet	Bioengineering
Brad Sutton	Bioengineering
Praveen Kumar	Civil & Environmental Eng
Matias Carrasco Kind	College of Business
Jamie Nelson	College of Business
Vishal Sachdev	College of Business
Dejan Trencevski	College of Business
Mike Yao	College of Media
Irfan Ahmad	College of Medicine
Carlos Brown	College of Medicine
Mark Cohen	College of Medicine
Mae Vogel	College of Medicine
Tarek Abdelzaher	Computer Science
Sarita Adve	Computer Science
Vikram Adve	Computer Science
Nancy Amato	Computer Science
Chris Fletcher	Computer Science
Saugata Ghose	Computer Science
Brighten Godfrey	Computer Science
John Hart	Computer Science
Kris Hauser	Computer Science
Julia Hockenmaier	Computer Science
Sebastian Kelle	Computer Science
Steven Lavalle	Computer Science
Sasa Misailovic	Computer Science
Klara Nahrstedt	Computer Science
Jim Rehg	Computer Science
Eric Shaffer	Computer Science
Elahe Soltanaghai	Computer Science
Deepak Vasisht	Computer Science
Shenlong Wang	Computer Science
Jina Kang	Curriculum & Instruction
Mike Tissenbaum	Curriculum & Instruction
John Toenjes	Dance
Jennifer Cromley	Educational Psychology
Robb Lindgren	Educational Psychology
Mark Hasegawa-Johnson	Electrical & Computer Eng
Raluca Ilie	Electrical & Computer Eng
Rakesh Kumar	Electrical & Computer Eng
Radhika Mittal	Electrical & Computer Eng
Romit Roy Choudhury	Electrical & Computer Eng
Craig Shultz	Electrical & Computer Eng
Abigail Wooldridge	Indust & Enterprise Sys Eng
Jim Kendall	Industrial Design
Suresh Sethi	Industrial Design
Lisa Bievenue	Informatics
Daniel Cermak	Informatics
Judith Pintar	Informatics
Katryna Starks	Informatics
Christopher Lueg	Information Sciences
Michael Twidale	Information Sciences
Christopher Ball	Journalism
Caroline Cao	Jump Simulation Center
Kim Inki	Jump Simulation Center
Shandra Jamison	Jump Simulation Center
Wendy Rogers	Kinesiology
Randy McCarthy	Mathematics
Kalina Borkiewicz	National Center for Supercomp Apps
Rob Kooper	National Center for Supercomp Apps
Eric Kurt	Scholarly/Media Commons
Jake Metz	Scholarly/Media Commons
Niloufar Emami	School of Architecture
Amber Schultz	Siebel Center for Design
Rachel Switzky	Siebel Center for Design
Pasquale Bottalico	Speech and Hearing Science
Scott Neale	Theatre
Alex Cabada	University Library
Megan Sapp-Nelson	University Library