Hummingbird: Live Theater Adventure Empowering Collaboration in Virtual Reality

Daria Tsoupikova
University of Illinois Chicago, School of Design
datsoupi@gmail.com

Sai Priya Jyothula
University of Illinois Chicago, Computer Science
saipriyajyothula@gmail.com

Arthur Nishimoto
University of Illinois Chicago, Computer Science
anishi2@uic.edu

Jo Cattell
Kaleidoco
jocattell@gmail.com

Andrew Johnson
University of Illinois Chicago, Computer Science
ajohnson@uic.edu

Lance Long
University of Illinois Chicago, Computer Science
llong4@uic.edu

ABSTRACT

Hummingbird is an innovative, award-winning performance engaging participants in active storytelling that bridges live theater and collaborative interaction through virtual reality (VR). Hummingbird's story celebrates courage and coming of age through the eyes of a gutsy teen who must outsmart her mother's egotistic boss and survive a dangerous new technology in a live, immersive adventure. Developed at the University of Illinois Chicago by faculty and over 30 students from the departments of Computer Science and Design in partnership with professional theater producers, directors, actors, videographers and composers, this project advanced interdisciplinary collaboration, provided a unique learning environment and broadened the research experience for several cohorts of students. Over 500 people attended Hummingbird's performances at the Tony Award-winning Goodman Theatre's New Stages Festival, Chicago Children's Theater and SIGGRAPH 2022 in Vancouver, Canada, with over 200 active VR participants. In each performance, five VR participants actively collaborate with each other and a lead actor within the VR adventure, contributing problem-solving, collaboration and teamwork, while a greater audience simultaneously follows the virtual performance aspects on a large video wall in real-time. Discussion sessions and audience evaluations followed each performance, informed the Hummingbird team on script, design and interactivity to improve future performances. Through qualitative analysis of audience experiences and insights from our collaboration, we discuss key considerations and design recommendations for integrating VR with live theater. Hummingbird demonstrates how VR can revolutionize theatrical storytelling by enabling traditional theater to narrate epic stories that were once considered too ambitious for traditional stage by extending live theater and making VR accessible to a broader audience. This project serves as a prototype for successful partnerships between non-profit theater and interdisciplinary research institutions to increase opportunities for cross-disciplinary student education.

CCS CONCEPTS

• **Computing methodologies**; • **Computer Graphics**; • **Graphics systems and interfaces**; • **Virtual reality**; • **Applied computing**; • **Arts and humanities**; • **Performing arts**;

KEYWORDS

Virtual reality, Storytelling, Theater, Multi-user, Performance, Interdisciplinary Collaboration, Design Process

1 INTRODUCTION

The origins of immersive theater emerged from 19th century pantomime and later musical performance. In contemporary immersive theater, the stage is removed and audiences are immersed within the performance itself. Critically acclaimed immersive theater works such as "Sleep No More" by Punchdrunk performed in New York's McKittrick Hotel [1], and "Don't Look Back" by Dream Think Speak, a UK-based company [2], create experiences in which audience members are guided by live actors. Blast Theory explored location-based art and mixed reality through their interactive pervasive urban chase game "Can You See Me Now?" [3] and multitude of participatory forms in their other projects including performances, installations, mobile and online technologies. Many recent experimental theater performances involve active audience participation through captivating narratives, in which audiences choose where they want to go, what they want to see, and when they want to leave.

Over the last six decades, virtual reality (VR) has explored the engagement of participants through interaction and collaboration. Groundbreaking works such as Jeffrey Shaw's Legible City installation, invited participants to explore virtual cities visualized as three-dimensional words and sentences while riding stationary

Figure 1: Participants interact as a team in the Orchard scene during the Hummingbird performance.

bicycles [4]. The active physical pedaling encouraged a journey of reading by choosing the path to create combinations of texts and spontaneous conjunctions of meaning. Maurice Benayoun's CAVE project, World Skin, armed immersed participants with cameras in the Land of War [5]. The action of taking photographs of the war scenarios extracted these violence scenes from the universe of the installation as if a layer of skin was being torn off, questioning the way mediated images of human horrors appear neutralized in news media.

Recently, the virtual reality field has offered theatrical group experiences such as CAVE: Making Collective Virtual Narrative, that invited dozens of co-located viewers in a passive "lean back" shared virtual narrative [6]. Hearts and Minds, the Interrogation Project [7], a previous performance by our team, was a multiuser, immersive narrative designed for CAVE2 virtual theater that brought to life testimonies of American veterans. With its focus on visceral narrative, audiences were not given any agency to actively participate in the story. Carry Me Home, the cutting-edge live and VR real-time circus performance enabled viewers from all over the globe to join remotely via VR [8]. Gumball Dreams by Ferryman Collective is a guided VR theater experience with a live actor playing multiple roles engaging three remote participants on a fictional story led by an ancient creature on a foreign planet [9]. Although these VR projects bring innovative perspectives on collective VR narrative experience, they mostly provide passive individual engagement for audiences and do not offer a team of participants collaborative, collective agency over their actions and outcomes. The desire for active participation motivated us to create Hummingbird to address this gap. In this paper, we describe the collaborative team, processes, and production of Hummingbird performance and how it merges live theater and collaborative interaction in VR, engaging participants in active storytelling.

Hummingbird's novelty is merging live theater and VR with the goal of providing active agency to a group of participants focusing on real-time collaboration in VR. Hummingbird builds on concepts of live theater and collective VR by merging live theater (with professional actors, costumes, music, effects, props) and VR (with full immersion, interaction and responsiveness) allowing active participation with the actors, plot lines and story. Hummingbird's audience does not simply observe the performance but become participants actively collaborating throughout the entire experience. They directly interact with each other, the actors and the story and play an active role in the creative process of the work. Each person must participate for the story to move forward. Hummingbird creates a space where each participant is able to work independently but must also recognize the importance of working with the other people in their group. We designed the story to be driven by collaborative interaction performed by the participants together. Research has found that shared virtual environments give their users a greater sense of presence in the shared space than other collaborative mediums [10]. Synchronized collective gross motor functions such as collaborative physical gestures trigger changes in the virtual story of Hummingbird.

This project bridges art, science, and live theater in a collaborative research effort between computer science and design faculty and students at the University of Illinois Chicago (UIC) Electronic Visualization Laboratory (EVL) and Chicago theater directors, actors, videographers and producers. The project provided a unique opportunity for more than 30 students to participate in the professional theater production and the development of Hummingbird. Hummingbird's premiere was adapted to comply with COVID-19 restrictions, following pandemic safety guidelines for health check, masks, distancing, sanitizing and maximum audience capacity. Despite these difficulties and limitations, all performances were fully booked and well received.
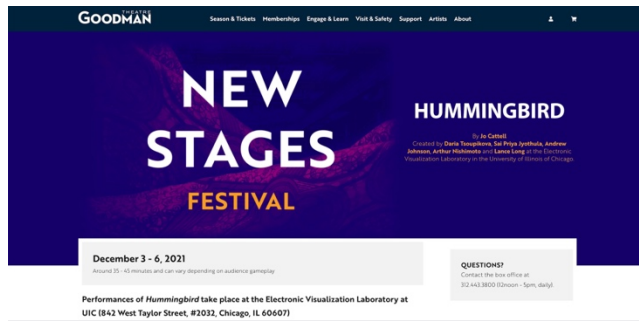
Figure 2: Hummingbird premiered in the Tony Award-winning Goodman Theatre New Stages Festival, which showcases innovative and ground-breaking theater works.

Figure 3: On arriving, the audience is greeted by a G-Corp lab assistant who requests that they wear a lab coat, and instructs them on the experience.

In this performance, the virtual world is only a part of the bigger performance rather than the experience in itself. Hummingbird demonstrates how VR can enable live theater to tell epic stories that have previously been too big for the theatrical stage, providing opportunities for live theater to explode beyond the walls of the theater venue.

Our project encouraged stronger theater engagement among the tech-savvy youth audience, many with little exposure to live theater, while still engaging a general audience. There is a great interest by theater communities to utilize new technology with live performances. However, technology development requires financial support that is difficult within the non-profit theater sector. Hummingbird's collaboration between Goodman Theatre and UIC serves as a prototype for such partnerships.

1.1 Concept and Aesthetics

Hummingbird is a live theatrical adventure that questions identity, humanity's relationship with technology, and coming of age in a digital society. The story celebrates these ideas through the eyes of a courageous teen Aya, who must outsmart her mother's narcissistic boss Gerard and survive dangerous new technology in a live, immersive adventure.

The audience enters the theatrical space as visitors to Gerard Corps Laboratory where they discover laboratory elements that are also clues for the experience, such as a bird wing anatomy, programming code, danger signs, banners, and display screens; all designed to further immerse the audience in the research laboratory atmosphere. Gerard invites them to take part in an experiment and introduces Aya. All audience members including observers and VR participants get the same introduction to the story by actors and move through the same physical sets. VR participants discover that they have inadvertently volunteered to test the new technology, Hummingbird Tech, or HBT, that can transfer a human soul from one body to another through a three-stage process: destabilization, purification and awakening. Fitted with HBT devices (Oculus Quest headsets) they progress further into the narrative, turning into avatars in a shared virtual environment where they can actively collaborate in the story. The observers follow along with the performance in the virtual world on the large video wall co-located with the VR participants in real-time.

Gerard, a cyber ghost obsessed with immortality, has captured Aya's mother, Deni. In order to save Deni, participants must collaborate and successfully overcome the challenges in three virtual scenes – Underworld, Orchard and Giant Statue. In Underworld, a dark magical cave, participants must reveal hidden drawers through the use of illuminating stalactites to enter the next world. They find themselves outdoors and underwater in Orchard and must release the flood water through collaboration. In Giant Statue, participants are lifted into the sky on the hands of a giant statue where they transform into Hummingbirds with the power of flight. Only if all participants work together, they can escape Gerard, the digital world, and save Deni.

The aesthetics of Hummingbird are inspired by Japanese Ukiyo-e paintings from the 19th century, known as "pictures of the floating world," which prioritized outlined forms and gradient colors. These paintings, which were on display at the Chicago Art Institute served as references for the design of the virtual scenes and guided collaboration between theater producers, designers and developers.

1.2 Interaction and Collaboration in VR

Hummingbird premiered in the EVL's Continuum [11] due to the COVID-19 closure of the Goodman Theatre. This sensor-rich research space provided a 20' x 10' touch screen display wall, 8K passive stereo display wall, and a surround sound audio system. The room was divided into different sections - a 20' x 20' main "stage" for VR participants, audience seating, and space for the production team. Development of the multi-user interaction began with a prototype – a blueprint test in which we reenacted the written narrative with virtual objects (ex. trees) physically mapped in the EVL's Continuum using cardboard props. VR participants used an Oculus Quest VR headset with embedded hand tracking that enabled multi-user interaction. Hand tracking allowed the use of natural gestures for grabbing and touching, often prompting comments such as "How do you track my hand, I am very amazed by it." Multi-user interaction, untethered social interaction, and collaborative exploration of the plot lines was enhanced using virtual avatars.
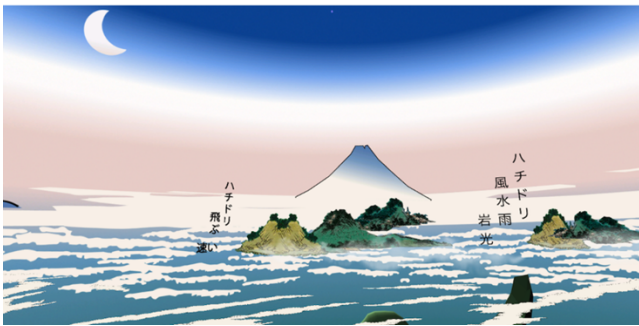
Figure 4: Hummingbird scenes Orchard (top) and Statue (bottom).

Figure 5: Early concept sketches (left) served as references for design of the virtual scenes (right).

Specific attention was brought to design collaborative tasks encouraging multi-user interaction (e.g. all avatars should simultaneously use pickaxes to break down a stone wall). The script writer was tasked with including interactivity (both individual and collaborative) as part of the story to avoid Ludonarrative dissonance. An

Figure 6: Color coded avatars representing each participant as they interact with each other in the Underworld scene.

additional challenge was to create a compelling narrative that also gave participants' agency and the ability to make their own choices. We focused on the design of interpersonal interaction and team tasks, such as passing objects to each other or translating parts of a puzzle. This required all the VR participants to join in their efforts and motivated them to support each other. Multiple levels of interaction were available, including discovering the sounds made by origami animals, talking to trees and flowers, opening drawers, and even arm wrestling with trees. Participants can independently discover, but are also required to work as a team to move the story forward and overcome obstacles.

We trained professional actors in navigation, control, and interactions in the digital environment. This is a live participatory experience, so Hummingbird focuses on interaction, not only with the virtual world but with the actors. The actor is there to assist, not provide answers, but ultimately to empower the audience members to find their own solutions and share what they discover.

2 DESIGN AND DEVELOPMENT

"I'm out of sight
    Without the light
    All work as one
    To chip the stone
    So you'll get out
    Once you turn me about"

The design of props, costumes, and digital screens were inspired by Japanese origami characters, traditional Japanese costumes, and Haiku poetry. We engaged Japanese education specialists and native speakers to advise on the accuracy of poems and phrases used in the virtual and physical designs. The avatar design was inspired by transitions between Japanese characters "flying", "human", and "bird" to celebrate transformation. The virtual avatars accurately reflect physical participants' heads and hands, which is especially important for collaborative interaction.

More than 20 design students contributed to the exhibition by providing typography, visualization, sketching, and production skills for posters, banners, mugs, lab coats, floor stickers, digital screens, backdrops and the overall identity. Vector graphics were used to hand draw background and sky sets, with nearby objects being hand painted. Finally, we designed a custom framework for creating black outlines to style the virtual scene. The Continuum lighting infrastructure was appropriately calibrated and strip lights

Figure 7: Poster designs for Gerard Corporation and Hummingbird performance announcement.

Figure 8: VR participants interact in the Orchard scene while observers watch their interaction on the large screen.

were added to mark the dimensions of the interactive space, aid tracking and enhance the performance identity.

2.1 Sound and Videography

A New York-based Japanese composer wrote music inspired by Japanese folk instruments and traditions. Inspired by her own cultural heritage, she based her composition on traditional music found at Japanese festivals and historic cultural events, resulting in a distinctive and cohesive score.

The performance audio was split into environmental and local channels. The environmental channel provided background sounds for participants and observers using speakers located throughout the room. VR participants were provided a local channel independent to each headset and corresponding to their position in the virtual scene. Balancing and harmonizing these channels to complement each other symbiotically involved significant effort.

We used Isadora by Troikatronix to produce visual videography effects in real time for all screens. Isadora provided multichannel audio and video control, cueing, blending, routing, and projection mapping. We interfaced Isadora's video and audio processing engine to work with our Unity server to create real-time versatile videography.

2.2 Development and Technology

Our computer scientists iteratively developed a number of custom systems and tools to streamline production. The centralized Unity server coordinated all scene information, participant locations, and interactions between all VR headsets and display walls. A dedicated chat server reinforced communication between the actor, VR participants, and the audience observing the VR world from the two display walls.

The first of two control interfaces allowed the actor to trigger variations of events and dialog triggers from within their VR headset. The second interface (Figure 9, right) enabled the stage manager to perform similar actions in addition to monitoring the state and progress of each participant. This allowed the team to utilize both on and off-stage perspectives to customize the performance for each group of participants.

We developed a custom character animation and dialog tool to animate 2D and 3D characters, such as the talking crab, flowers, and rocks. Figure 9 (left) shows the animation script which mapped
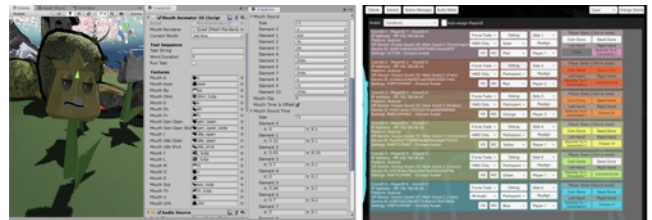

Figure 9: VR The 2D Mouth Animation Tool (left) and Stage Manager User Interface (right)

Figure 10: Cinema Face Cap Unity Plugin (left), Animation Alignment App in Unity (center), Final VR scene (right)

facial animation sprites with the appropriate timestamp in the audio file.

To bring Gerard's actor performance into VR, we developed a workflow: capturing his facial expressions using Kinect for Windows, converting them to 3D model animation using Cinema Face Cap, and synchronizing them with the dialog audio using a custom C# Unity alignment tool (Figure 10). This tool was also used to preview multiple performance takes with various Gerard models, aiding the director and the production team in selecting the optimal performance and appearance for Gerard.

All custom systems and tools were developed using the Unity game engine, C# scripting, Javascript, and node.js. The art assets were designed using Autodesk Maya, Blender, and textured using Adobe packages, with additional tools and assets provided by the Unity Asset store.

3 PERFORMANCES, AUDIENCE EXPERIENCE AND DISCUSSION

The first performance premiered as part of the Chicago's Tony Award-winning Goodman Theatre New Stages Festival, showcasing innovative and ground-breaking theater works [12]. Prior to the public premier, we staged 8 performances as a workshop in June 2021 under COVID-19 restrictions for a limited group of invited youth. Following the success of the June workshop, ten public performances were held on December 3-6, 2021 within EVL (due to the COVID closure of the Goodman Theatre). Following the premiere, the performance content was further revised to run on a private wireless network for portability and adapted into a stand-alone module capable of supporting external onsite presentations. Our team worked on the augmentation of the interactive experience, software and system updates, videography, and overall project animation and interaction improvements. The stand-alone performance was exhibited at the SIGGRAPH 2022 Immersive Pavilion in Vancouver [13] and Chicago Children's Theatre [14].

More than 40 Hummingbird performances were attended by over 500 people, including over 200 active participants. Each performance included 5 VR participants that actively interacted in the outcome of the story wearing a VR headset, and up to 25 observers, passively watching the performance play out, observing both the actors and participants and the VR experience presented on a large screen video wall. All performances were fully booked by the end of the ticket release day. Each performance time was approximately 45 minutes depending on the audience's engagement followed by a 10-minute Q&A discussion and a short survey to gauge the audience's experience. Quantitative data from both VR participants and observers including story engagement, collaborative participation, experience with VR technology, enjoyment and interest in live theater and VR theater was obtained through questionnaires. Qualitative information was obtained through the Q&A discussions. The survey included structured multiple-choice questions using a Likert scale, and unstructured questions where the participants were encouraged to reply at length to provide their comments and feedback. The data from these surveys, along with observations by the researchers and audience, were used to assess the audience engagement and functionality of the hardware and software components of the performance, and to make improvements prior to bringing the performance forward to the next phase of production.

Most of the audiences reported that they enjoyed watching/participating in Hummingbird (100% of VR participants and 78.8% of observers). The majority felt they were part of the story (67%), notably VR participants felt increased engagement over observers (94.8% vs 45%). An overall majority of participants appreciated collaborating with other participants inside VR (93.7%). In response to our question regarding the experience, the majority had positive connotations: fun (78%), interactive (67%), exciting, creative, beautiful, intuitive, awestruck, dreamlike, fully committed to story, wondrous, breath-taking, stimulating, gorgeous! sensoric! suspenseful, exhilarating, and inclusive. Many comments were positive: "What a wonderful journey!", "a wonderful combination of creativity and emerging tech", "I felt very close as a bird!", "I love interactive theater, and this was fabulous". Negative comments focused on improvements that could be made to the system, such as lag, network

Figure 11: *Hummingbird* **poster and performance in Chicago Children's Theatre.**

glitches, graphics optimization and common VR side effects. These were addressed by developers and actors in subsequent shows.

Importantly, the majority of participants indicated a willingness to attend other VR theater productions in the future (89.6% of VR participants and 70.3% of observers) and other live theater shows (without VR) after trying Hummingbird (81.7% of VR participants and 68.8% of observers). Distinctly active VR participants felt increased motivation over observers. The audience inquired about future shows, sharing their excitement, and expressing enthusiastic support.

Discussions during Q&A sessions focused on the user's engagement in collaboration and sharing ideas and inspirations for collaboration empowering mechanisms. The takeaways of these conversations informed the iterative revisions of the subsequent performances including empowerment of collaboration, interaction, and VR environments. For example, the majority of participants enjoyed grabbing objects: "I enjoyed interaction and wished I could interact with more items," and suggested practicing picking up objects: "Maybe a little more tutorial time practicing picking up objects would help". In response we implemented an introductory VR scene "Construct", in which individual participants could practice grabbing origami animals prior to collaborating in team interaction. Discussions during Q&A sessions showed that participants enjoyed the show and collaboration: "fun collaborating and good guidance", "participants totally engaged, fascinating". Sense of teamwork was noted, indicating the impact of collective interaction.

The observers split into two groups: one valued passive observation without wearing VR headsets: "Observation itself was interesting". Notably, parents of invited youth expressed high appreciation for participating specifically as observers, as this role allowed them to understand why their children are engaged in VR. "It was eye-opening to watch my kid experience inside VR". The opportunity to be co-located with their children on stage, without wearing a VR headset, gave them a deeper understanding about the motivation of their children as active participants in the story. The second group inquired about more involved participation: "Make the audience included", "Maybe the audience could also be an "outside force"". Our future plans include development of interactivity engaging the observers to actively collaborate with VR participants.

4 CONCLUSION

Hummingbird explores new ways of extending VR as a medium for live theater and technology in ways that have not been previously

possible, capitalizing on immersive theater, VR/XR artworks, and pervasive adventure games, paving the way for a new interdisciplinary theater of the future. As theaters grapple with attracting younger crowds, there is a growing interest to utilize technologies with live performances. Hummingbird contributes to exploring how VR can extend traditional theater, making VR art more accessible to a broader audience. The performance pushes the boundaries of active collaboration by giving audience agency and active control over their actions. The research and development of this project can be adapted to other performances by other artists to develop VR theatrical experiences.

Our team successfully collaborated on the development and staging of Hummingbird VR theater performance. We described our collaborative research and development processes as well as tools we designed for production. These tools and processes advanced our creative work and enabled design of the interactive audience's experience bridging traditional theater approach with VR development. For the team, the success of Hummingbird opened new avenues of exciting collaboration between design, computer science, and theater to elevate the appreciation of live theater and to contribute to the advancement of storytelling through the use of innovative technologies. It is our goal to inspire young people and professionals to use the advanced technologies for the creation of cultural content that promotes accessibility, integration, and social change.

Findings from Hummingbird performances that were observed, reported and analyzed provide insight into interactive collaborations as well as research outcomes and development of hybrid VR+live theater experiences. In particular, our findings suggest that while the active participants in VR are obviously more engaged than the passive observers, the majority of the observers responded positively to the observed interactions within the VR experience compared to traditional theater.

Analyzing the audience experience revealed the positive impact of Hummingbird on participants' interest in both VR theater productions and traditional live theater shows. Active engagement in VR was associated with heightened motivation, compared to observers. Moreover, parents of invited youth appreciated their role as observers without VR headsets, gaining insights into their children's VR engagement and deepening their understanding of their children's active participation in the story.

Hummingbird proved incredibly successful in engaging diverse audiences despite multiple COVID-19 pandemic challenges and limitations. We look forward to expanding the project to diverse audiences and continuing to work with youth.

Hummingbird shows how VR can enable live theater to narrate epic stories previously regarded as too grand, too ambitious and too unrealistic for the traditional stage, extending live theater and making it more accessible to a broader audience. The research and development of this project can be adapted to other performances by other artists to develop VR performances. Hummingbird's collaboration between the non-profit theater sector and research institution serves as a prototype for such partnerships.

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