

# Advancing Interactive Collaborative Mediums through Tele-immersive Dance (TED): a Symbiotic Creativity and Design Environment for Art and Computer Science

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## ABSTRACT

The Tele-immersive Dance Environment (TED) is a geographically distributed, real-time 3-D virtual room where multiple participants interact independent of physical distance. TED, a highly interactive collaborative environment, offers digital options with multiple viewpoints, enhancing the creative movement composition involved with dance choreography. A symbiotic relationship for creativity and design exists between dance artists and computer scientists as the tele-immersive environment is analyzed as a creativity and learning tool. We introduce the advancements of the interactive digital options, new interface developments, user study results, and the possibility of a computational model for human creativity through Laban Movement Analysis.

## Categories and Subject Descriptors

J.5 [Computer Applications]: Arts and Humanities; H.5.3 [Information Interfaces and Presentation]: [Computer-supported Cooperative Work]

## General Terms

Documentation, Performance, Design, Experimentation.

## Keywords

Tele-immersion; dance; choreography; Laban Movement Analysis; collaboration; shared virtual space; creativity

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## 1. INTRODUCTION

Tele-immersive Dance (TED) is the most recent evolution of the tele-immersive environment system, originally coined TEEVE for Tele-Immersion Environments for Everybody. TED

is a more specific application of the TEEVE system that is focused on supporting the creative process of movement composition. We envision TED as a new branch of performance offered within the dance paradigm. The tele-immersive environment offers real-time collaboration, multiple vantage points, and several digital options

that create a dynamic relationship between the user and the system. The most recent developments offer new digital options and graphics, an interface for structured improvisation, and a user-controlled wireless remote. The user's enthusiasm and resulting dance performances are a testament to the significant impact this system offers to performance, composition, and collaborative tasks. However, the element of creativity is not limited to the artist users. The computer science programmers are constantly improving the code and searching for new methods that could improve the picture quality and networking capabilities. There is a creativity-based challenge for both parties as the goals for the environment continue to evolve. There is a constant dialogue between the artistic users and the programmers to creatively solve problems, to build a creative environment, and to fine tune the system for interactive collaborations—we strive to understand each other's creative needs and tasks.

In this paper, we offer a documentation of the collaborative process between the computer science programmers and dancers in the continued development of the system's features. We describe the methodology behind the user studies and illustrate the technical and artistic challenges and successes that have been observed. We also illustrate the potential this system offers to create a computational model for human creativity by analyzing movement through the lens of Laban Movement Analysis, a codified system for describing and analyzing the spatial patterns and qualities of movement. It is important to place this research into context with its current and potential contributions to the artistic community of dance as well as computer science and to recognize how this collaborative, interdisciplinary research model relates to other work that is attempting to build the bridge between the inherent human mind/body creativity and the creativity behind information technology.

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## 2. OVERVIEW OF THE TELE-IMMERSIVE SYSTEM OF TED

The tele-immersive system involves multiple sites where each site contains a local 3-D tele-immersive setup that enables us to capture and reconstruct in real time the 3-D form of the dancers at each site and join them together for interaction within a virtual room (Bajcsy and Jung 2006). (Fig. 1)

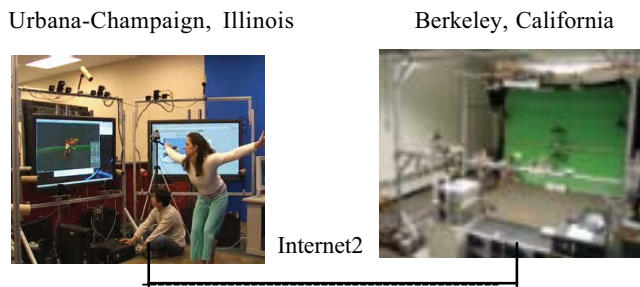


Figure 1. View of tele-immersive environment with dancer.

The main components of the system include (1) multiple camera clusters surrounding the movement area, (2) a gateway server, (3) a rendering server, and (4) displays of either or both 2D and 3D video. The network of camera clusters, which include three black and white cameras and one color camera, are mounted on a support system surrounding an open area which contains the user and allows space for the user to move and dance. The cameras simultaneously capture the actions of the user from a wide field of view. These 3D video streams are forwarded to the gateway server, the renderer, and then to the other sites. The network of cameras is connected via Gigabit Ethernet within each local site and via Internet2 to transmit the 3D streams between the geographically distributed sites. (Yang et al. 2006) Both local and remote streams are aggregated and simultaneously displayed on large 2D (Berkeley) or 3D (Urbana-Champaign) screens which represent the virtual room in which the dancers share a unified work space. (Fig. 2)

## 3. RELATED RESEARCH

### 3.1 Previous Tele-presence Dance Systems

The basic idea of collaborating with a remote partner surfaced in the performing arts circle in the late 1970's when two artists, Kit Galloway and Sherri Rabinowitz<sup>1</sup> began experimenting with geographically distributed tele-presence systems. The system which existed as an art installation piece called "A hole in the wall" enabled remote participants to see each other in a seemingly shared environment via satellite transmission, with a 1/8<sup>th</sup> second delay. Virtual environments have undergone extensive research and development in the years since this experimental excursion, and tele-communication and tele-presence systems resurfaced in the

<sup>1</sup> Kit Galloway and Sherri Rabinowitz and the Electronic Cafe can found on <http://www.ecafe.com/> which is an archived website of their performances and experimentations in the 1970's.

early 1990's as a popular research topic. The TEEVE system and what it offers through TED, is a unique system that engages the performing arts as an efficient research model supporting the development of the technology in close relationship to user needs and suggestions. The 3D tele-immersive environments in existence at the University of Illinois at Urbana-Champaign and the University of California at Berkeley feature digital options and graphics that were not possible during the early days of tele-presence.

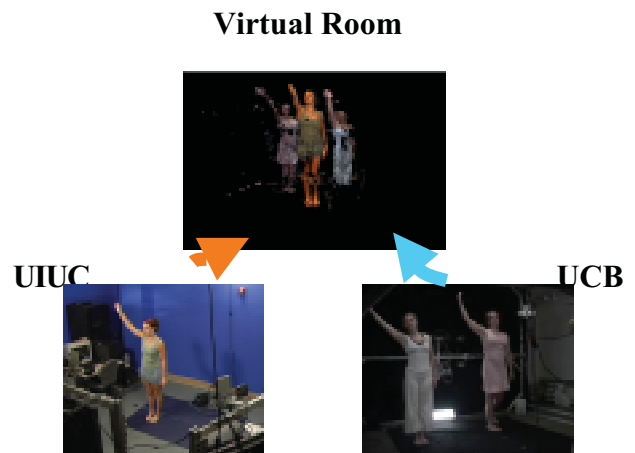


Figure 2. Illustration of the TED interface display (center image) with a representation of the local sites (UIUC, UCB).

Our system combines highly desired features for interaction including attachment-free movement, real-time interaction, multiple vantage points (that are wirelessly user controlled), and digital options that enhance and/or challenge one's movement choices. Our current research has evaluated TED as a tool for creativity, inviting users into the space to work with the digital options, observing how the tele-immersive system supports TED and how this affects their creative choices. This experimental process with the users will be described in detail in a later portion of this paper.

The TED system distinguishes itself from most existing interactive virtual environments such as Second Life by its unique features. The human forms represented on the screen are not avatars formulated by motion capture technology, but are real-time photorealistic representations of the user. There is a strong sense of the specific individual within the tele-immersive environment of TEEVE, a direct relationship of the physical form of the user to the virtual representation. There is a high level of interaction enabled by the multiple view points (one can look at the action from any perspective in the room) and the calibration of the two distributed spaces enable "visual" touch and believable "touch" moments.

### 3.2 Dance Choreography

As technology becomes increasingly accessible, the use of technology to create art is becoming an artistic philosophy in itself. Art makers are incorporating the use of video, audio and visual technologies into the creative process as well as using technology for live performances. Several theatre and dance performing arts companies create work that utilizes technology for artistic purpose and part of their artistic

identity is the presence of some technological component in the performance.<sup>2</sup> These companies consistently incorporate some form of technology in their performance work including video projections (live and pre-recorded), remote collaborators, and motion sensing. Mark Coniglio of Troika Ranch (a multi-media dance theatre group), developed and wrote a program called Isadora (after one of the founding members of the modern dance movement), which facilitates real-time interaction between live performers and the technical manipulations of the light, sound, video, and relationships of all of the above. There are also motion sensor features which enable the software to trigger an effect based on the dancer's movement and/or location.

On both the immediate (TEEVE/TED research) and broader (universal dance community) scale, the need for accessible, low-cost, efficient technologies to support dance creation and collaboration is increasing. There is an emergence of movement/technology research collaborations (and university programs that support this research)<sup>3</sup>. It is recognized that dance is an ideal platform to evaluate motion sensing and tele-immersive environments because dance movement challenges the capacity of the system to pick up motion effectively and the emotional qualities and nuances present in dance present also present a challenge as to what can be communicated through these systems. Technological advancements allow both the artist and the audience to experience the art form in a novel way.

## 4. CREATIVITY AND TED

### 4.1 Understanding Creativity within the field of Modern Dance

Within the field of modern dance choreography, how one defines and strives for creativity is an individual offering that is often reevaluated with each new work. It is generally understood that an artists' objective is to create something original. However, it is a challenge to invent an entirely new movement for the human body because, with few exceptions, it has all been done before. However, the choreographic objective is about offering a unique perspective on something the audience has perhaps seen before. Much of the creativity associated with dance composition is focused on how the choreographer can structure and present the human body moving in time and space in a manner that will either inform, challenge, invite, or entertain the viewer. This definition is not absolute.

Dance presents information in a non-narrative format that encourages abstract thought. The structure does not have to follow the linear pathway we often associate with other performance mediums such as theatre. A modern dance choreography is a publication in itself; but the language paradigm is shifted from words and grammatical structure to a more meditative, abstract, all-encompassing idea that the

<sup>2</sup> Examples of interdisciplinary technology/art performance groups include The Wooster Group and The Builder's Association. Also of interest are web forums such as [www.dancetech.net](http://www.dancetech.net).

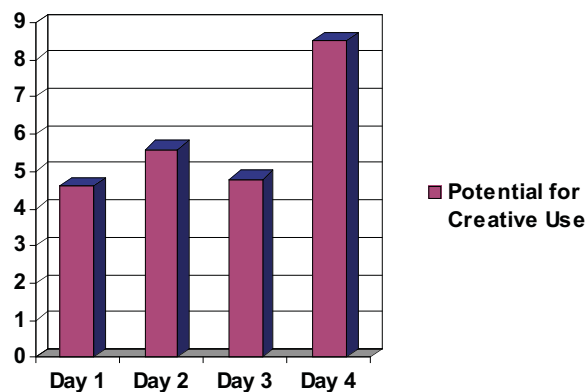
<sup>3</sup> Arizona State University: [www.dance.asu.edu](http://www.dance.asu.edu) offers a Masters Degree in Interdisciplinary Digital Media and Performance

choreographer invents and defines. In dance, we often talk about the "world" a choreographer creates within the context of a specific work. Realities are established and a movement vocabulary is developed (a unique set of recognizable movements that can be associated with a specific choreographer or a specific choreographic work). The challenge for many choreographers is to find that new, unique perspective, to clearly define this new "world" they are attempting to create, and to develop a movement vocabulary that supports the overarching imagery that becomes the performance work itself.

### 4.2 TED as a Creative Tool for Choreography

Our interest in the tele-immersive system as a tool for dance relates to the fact that TED occurs in the tele-immersive space that exists between the real and the surreal. It is a virtual world but it is the dancer's real-time, physical form moving and interacting within the space. With the help of the digital options such as size manipulation or dancing with self, the dancer is able to accomplish things in the tele-immersive environment that are physically impossible in the real world. Yet, even the impossible acts are grounded with a strange sense of reality because it is actually the dancers' true form, not an avatar or other representation, displayed on the screen. The delay is so small (<100 milliseconds) that it does not become an inhibiting factor.

**Graph 1. This graph shows an increasing potential for creative use was perceived by the users throughout the duration of the study. The specific question was "What potential for creative use does the TED system offer on a scale of 1 (does not do much) to 10 (expands creative potential)?"**



In fact, we have had some feedback from the dancers that the slight delay is a valuable feature because it allows time for the dancer to think about what comes next.

TED is an invaluable tool for generating movement that is unique in both form and context. The mind and body are transposed, and the result is often something outside of the typical movement vocabulary of that dancer or choreographer. (Table 1) The experience of moving in the TEEVE system makes TED totally unique. The altered sense of self offers the

much sought after new perspective mentioned above and opens the door for a new way of seeing the self, of feeling the self, and of dancing with another person that may help with the creative process. The TED system has been evaluated as a tool for creativity for dancers during a pilot study funded by the NSF. The results of this study will be presented in the following section.

### 4.3 Composer/Choreographer Collaboration

We invited creative individuals from modern dance and music to test the system for its use as a creative and compositional tool. Assistant Professor of Dance, John Toenjes, is the Musical Director for the Dance Department and teaches a course which brings together composers and choreographers for a collaborative process of making dance and music as a joint compositional study. This semester, we invited the members of his class into the tele-immersive lab to make movement and experience TED. The tele-immersive software itself was in the process of many changes but we wanted to work simultaneously with users to help define priorities and needs for these improvements.

Two groups, A and B, were invited to spend a total of 8 hours (four separate two hour sessions) working in the TED space. Each group consisted of two dancer/choreographers and one musician/composer. We created a syllabus and provided an orientation session to help familiarize the users with the lab and the TED interface. Their creative objective was to create a 10 minute structured improvisation dance accompanied by a supportive sound score. Each experimental session was documented with video camera and a log book as well as daily questionnaires about the user experience (specific questions and answers from these questionnaires are provided within tables throughout the paper), the importance of certain features, and asking for feedback about improvements/adjustments were the most important. The culminating project was showcased during the April 2008 Tech Summit, a special event at the Krannert Center for the Performing Arts in Urbana-Champaign featuring technology based artistic tools and performance groups.

## 5. A FUNCTIONAL RELATIONSHIP: TECHNOLOGY AND ART

### 5.1 Divergent Objectives, Convergent Results

An interesting phenomenon surfaced during the process of the art/computer science collaboration. Observing the prioritized goals of the artist versus the scientist reveals fundamental discrepancies that we believe contribute to a dynamic collaboration. Expanding on the reflections of Ted Kirkpatrick<sup>4</sup> during a discussion about a collaborative work called *Touch* we have also come to an understanding of the differing primary objectives of art and science. The two

primary goals in science include: 1) repeatability and 2) timelessness. It is important in science and technology that one can achieve the same outcome each time the experiment is performed. It is also important that the theory, statement, or technology can be consistent and hold true over time. What is true today must be true tomorrow. In art, the priority lies in 1) responsiveness and 2) the ethereal. A spontaneous relationship must exist between the performer and the audience with the ability for real-time, unpredictable reactions. No performance is ever exactly the same nor is it expected to be. The transience of (performance) art is part of its design but also part of its dilemma for preservation and documentation. The crucial moment of art is the instance in which it occurs, which is understood to be a unique, fleeting moment in time. However seemingly dichotomous these objectives initially appear, the goals overlap. In fact, the primary objectives of one tend to indicate the secondary objectives of the other. For example, in dance, the goal is to train the body to accomplish a task consistently (a pirouette, for example), to understand the mechanics of the movement in order to reliably perform it. In computer science, artificial intelligence systems strive to reproduce the spontaneous unraveling of human dialogue but it is a challenge to make a protocol for spontaneity. This overlap creates enough common ground to unify the research, but enough healthy tension to push development and new ideas. We also offer the interdisciplinary nature of our research team as a model for future research in multiple fields because of the diversity of ideas and the comprehensive and integrated possibilities that arise.

### 5.2 Technological Limitation as a Creative Tool

Contributing further to the efficiency of the performance research model utilized in TED, we experience a continuum of creative work time throughout the development of the software. The dancers are able to take advantage of what the system offers, despite the technical limitations which remain the focus for improvements from the computer science perspective. Factors such as low frame rate, delay, incomplete images, ghosting, and jittering are actually considered useful compositional limitations that challenge the dancer to come up with a creative solution. The result is a very integrated process for developing the code that supports the tele-immersive system. As the dancers work in the virtual space, testing the graphics and other digital options, they are able to provide immediate feedback to the computer scientists, pointing out what features are the priority for a high level of performance and what features are actually useful in their current state. In fact, it has been requested that some of the effects considered undesirable by the computer scientists, be retained as a digital option even when that feature is corrected. This has helped shape the research agenda, creating an environment that is a rich bed of research for both parties throughout the process.

Also, in dance composition courses, the assignment will often involve a limitation. It is part of the creative problem solving to generate an original solution to a limitation which can range from determining the music, the level of body placement (high, medium, low level), or deciding that you can never use your left arm. These limitations define the parameters that the choreographer must work within and provide a foundation that

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<sup>4</sup> Assistant Professor of Computing Science at Simon Fraser University, Ted Kirkpatrick (in collaboration with Henry Daniel and Richard Vaughan) presented a performance research project investigating Creation and creativity at the Body Spaces International and Interdisciplinary Workshop March 14-16, 2008.

begins to define the “world” of that specific choreography as mentioned earlier. It is actually quite a challenging task to enter into an empty studio with no preconceived notion of what to explore choreographically and just make a dance. Not many choreographers choose to work this way.

### 5.3 Glitch Art

Art is often inspired by error, whether it is human flaw, natural disaster, or a happy accident. As mentioned in the previous section, the artists using the TED system are often drawn to the imperfections of the image displayed or a digital option gone awry. We have been advised by the artistically inclined users that a totally perfected system may not be as creatively inspiring and that it would be advantageous to retain some of the imperfect qualities as digital options. Improving the visual quality and the data compression is of primary importance from the computer science perspective, and this greatly expands the possible uses of the Tele-immersive system (remote medical surgery assistance, physical therapy, etc). However, from the artistic point of view, it has become apparent that retaining some imperfections is a highly desirable option.

**Table 1. Technical Errors identified as Desirable Digital Options within TED.**

Description of Desired Effect	Translation to Digital Option
“choppy, images skipping parts of the movement trajectory”	Make a digital option that automatically drops frames (reduces frame rate)
“blotchy, large, color blocks so you can’t see physical features of the person”	Make a digital option that is a pre-set to the size parameter of pixels or the zoom function (zoom in all the way)
“hole in the body/scattered image”	Make a digital option that limits the available bandwidth or compression so that some data is lost

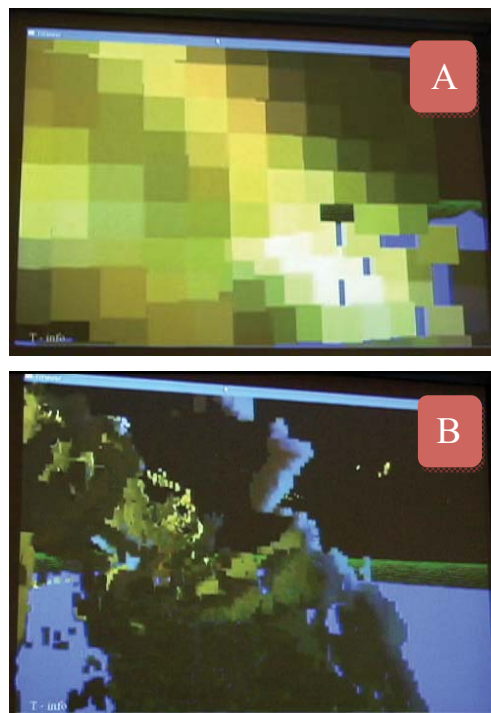
An informal art movement called Glitch Art, an offshoot of sound glitch, is inspired by computer crashes and digital errors. Whether it is taken seriously by the art world or not, (there is actually a book due in September 2008 titled “Glitch: Perfect Imperfection”), it demonstrates how technology is influencing and merging with art at every developmental level. The philosophy behind glitch art resonates with the approach dancers are using in the TED system: it finds value in the collaboration of technology and art at every step of the way. It is about creative problem solving with current options and limitations which reveal new uses for technology that might not have been discovered had the collaboration been postponed or introduced when the technology was more stable or highly evolved. The glitch art element within TED has been a valuable realization for the computer scientists involved in this project because it illustrates an important part of the spontaneity of the creative process of making dance. For example, during one session with dancing with self, the bottom cameras were synchronized a few seconds delayed from the top cameras so there was a split body from upper and lower with the torso moving ahead of the legs. The programmers

were about to stop the session to reboot but the dancer said “Wait! This is great!” and continued to make a comical study of movement with the upper and lower bodies disengaged.

## 6. DIGITAL OPTIONS

### 6.1 Overview of Digital Options

One of the unique features of the TED system is the Digital Options that have been developed to facilitate creativity. These



**Figure 3. Examples of “glitch art”— desirable artistic effects that are actually technical deficiencies or errors. In photo A, the default setting was accidentally written in to the code at a high zoom level. In photo B the dancers are purposefully manipulating zoom with the Wii and taking advantage of the low frame rate which causes the image to scatter.**

options include the use of a Wii remote control for camera position, new graphical objects and interface, Dancing with Self, and Size Manipulation. There are other ways to manipulate the image and manually create digital effects which are specific to an individual session and based on current limitations and context.

These options were discussed in the section on Glitch Art. There are many digital effects that surface because of technical error or deficiency but these are not considered official digital options because they are not fully controlled. Eventually, these accidents can also be provided as a digital option that can be consistently generated by the system. In this section, we will discuss the Digital Options that are reproducible and exist as options on the new interface. And although the Digital Option may be reproducible, the way the user chooses to work with it creatively will be completely novel.

## 6.2 Wii Remote Control

The Wii remote control was introduced this year as an alternative to manually adjusting the point of view with a mouse. The Wii was an ideal option as a programmable tool because of the wireless Bluetooth communication interface, its lightweight design, and because of the motion sensing built in accelerometers (Tamai et al. 2007). The Wii offers two control modes: camera mode controls the point of view and object mode controls the graphical objects.

The Wii allows the user to control the virtual camera perspective (the audience perspective) without having to leave the space or limiting movement (i.e., bending down to adjust the mouse). The Wii remote had a two-fold advantage for the users. Not only does it allow the users to seamlessly zoom in and out and pan the room with the touch of a button but because of the motion sensing capabilities, the wii bridges the virtual and reality world THROUGH movement. By tilting the device up/down/side/side the changes in the point of view are directly related to the users movements.

This was highly valued by the users and was identified as a pivotal moment for considering the TED system a useful creative tool because of the heightened physical connection to movement (through the camera point of view) in the virtual world. The Wii view allows the user to intuitively manipulate the virtual camera and graphical objects providing additional movement to what is seen on the display because not only the user herself is moving, but also the point of view is moving and adding to a sense of space and direction. (Table 2)

**Table 2. Questionnaire: “What is unique about working in the TED environment**

“(The TED setup) allows the person behind the camera to be the author who dictates the point of view of the audience (viewer). The Wii enables this same kind of control. For the user, there is this parallel experience of being behind the camera (being the Wii controller) and at the same time being the performer.”--Laura

## 6.3 Graphics and New User Interface

A new interface was developed to allow the dancers to build a structured sequence of digital options for their dance session. An open timeline allows the user to drag and drop the icon for a specific digital option (see Figure 5).

The user can then click on the edge of the icon and drag the digital option to a desired length of time. In this way, the user builds a structured series of digital options that will support the creative movement exploration of their dance choreography. In Figure 5, the dancers are utilizing the graphical object called “terrain” to float their heads in space. Other graphics included stars that floated at varying speeds in the virtual space and could be used as a choreographic tool either to make movements that touched the stars or avoided them, for example.

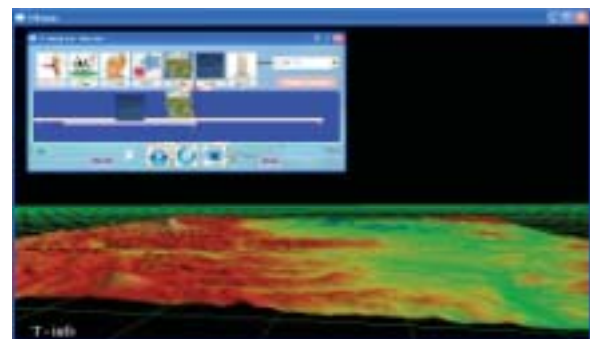
There were also some rotating objects such as a camel and a cow but they were not as useful to the user because they did not provide a high level of interactivity; they were somewhat self-

contained in comparison to the terrain which was an environment

that lent itself to interaction and had texture and varying colors (red, green, blue) that could be affined with moods and atmospheres desirable for inspiring dance movement.



**Figure 4. The Wii Remote control is lightweight and its motion sensing accelerometers provide an ideal movement-based-relationship between the physical world in the lab and the virtual TED world.**



**Figure 5. These images show the dancers in the virtual space, looking at the interface. Choosing the graphical objects and how long each would last in the timeline was the first step of**

building a structured improvisation sequence they would then interact with during performance.



**Figure 6.** This image shows how the dancers were able to play with size and position themselves utilizing the Wii remote control within one of the graphical objects, the terrain (both the blue and colored terrain are pictured here layered on top of each other).

## 6.4 Dancing with Self

Another compelling digital option is dancing with self. This option is valuable as an exercise in movement memory (the dancer must memorize the movements of the previously recorded session on order to anticipate and choreograph effectively with the interactive recording). (Figure 7)

It is an interesting choreographic tool because it allows the dancer to accomplish the impossible and have two “selves” with the option of unison or individual movements. This can be used as a device to create a solo (working with two bodies and then removing one for the actual performance, leaving a sense of the second body because the movement choices were made with that second body present)



**Figure 7. Dancing with Self.** In this instance, the dancer who is pulling the hair is the pre-recorded version and the dancer being pulled is reacting live.

## 7. THE TELE-IMMERSIVE DANCE (TED)

### EXPERIENCE: TECHNICAL AND ARTISTIC

The following sections explain what technical changes we are focusing on improving and how this translates into the digital

options for the user. We continue to present direct quotations from the users from questionnaires filled out directly after working creatively in the TED system. These excerpts are presented as tables throughout the following sections. As mentioned earlier, the technical metrics that come from the system as “limitations” actually provide the context for creativity. The dance that evolves is directly related to the current limitations of the technology (i.e. the bandwidth, compression, processing power, etc.).

## 7.1 Technical Issues for Computer Science

### 7.1.1 Challenges

Realistic tele-immersive environments pose many different challenges that can be categorized in 3 groups: camera challenges, content challenges and networking challenges. The camera challenges come from the problem that current technology of 3D cameras does not provide enough capture area to cover the body of a person completely, therefore multiple cameras are required. Multi-camera environments require precise spatial and temporal synchronization. The second category of challenges is related to the huge bandwidth requirement for the TI data streaming. Finally the networking challenges involve multi-stream coordination due to the common large bursts at routers in the current Internet infrastructure, synchronization of multiple 3D streams, transport protocol selection and QoS guarantees including high throughput, low delay, and low synchronization skews.

### 7.1.2 Implementation

Each tele-immersive environment consists of multiple cameras that capture the scene in 3D format and multiple displays that present the aggregated virtual space to users in real time. We introduce service gateway as a streaming component in each site, which collects local streams from the cameras, and distributes them out to the other sites. It also aggregates remote streams across the Internet, and forwards them to the local displays for rendering. All these components work in high coordination and synchronization to enable interactivity among remote users, with a rate of 7-12 frames per second (fps). The 3D data combine the depth and color information, and are rendered in point cloud format. We use motion JPEG to compress the color map and zlib to compress the depth map. The compression ratio is about 50% on average.

### 7.1.3 Graphics and Interface

One of the most important features of TED software is the ability of adding graphical objects to the scene in a time adaptive way. We used FLTK library to build a user interface which has time control capability. Moreover, for graphical object handling we use OpenGL in VC++ environment. The 3D terrain used for this scene was among the free models available on the internet. Moreover, we use Maya to convert 3D file formats to the format that we could use. Currently there are very few objects added to the scene. For rendering the objects we used the GPU by the OpenGL commands. This way the

program doesn't tremendously slow down because of showing various 3D objects in the scene.

The design of the timeline interface uses the drag and drop feature. The user can choose the object from the available icons and drag it onto the timeline. When the object is released, the interface automatically assigns a time schedule to it, which is independent of other objects in the timeline. After that, user can change the timing feature by dragging the ends with the mouse. Another feature is that the user is able to see the picture of the object on the timeline which is very helpful for fast understanding of the timeline.

Having used the FLTK library we have made this user interface capable to be used on most of the available operating systems. In fact, any platform supporting C++, OpenGL and FLTK can use our software. This way a wide variety of people are able to use this platform.

## 7.2 Technical Issues for the Dancer/Choreographer

### 7.2.1 Depth Perception

One of the challenges when interacting with a remote partner is achieving believable "touch". There is an adjustment period for a new user to get acquainted with what we call "visual touch". In order to give the illusion of sharing the same space in the virtual world, one must develop a sense of touch through a visual calibration of the virtual kinesphere. In Figure 8 it is possible to see the high level of believable interaction that is possible within TED. Achieving a high level of believable interaction requires some adjustment to moving in the system. One must rely on the visual feedback instead of the kinesthetic feedback that is typical of dance partnering in a normal studio space. In the virtual world, one can either choose to adhere to the rules of physical space or defying them by walking through the partner.

### 7.2.2 Frame Rate/Bandwidth/Time

The currently implemented code includes a new interface and graphics which slow down the processing capabilities. This means the dancers speed of movement is dictated by the processing power of the gateway computer. In order to fully capture a movement trajectory, one must move at a slow pace. However, the dancers enjoyed playing with this limitation because they were able to "create" the effect of choppy, scattered images by moving quickly. The dancers described the experience of moving within

the TED environment as a transformation into actually reported a decreased awareness of their physical, real world. It is described as an "out of body experience", as a "transition into another dimension."

Because the limited frame rate requires the user to move at a slower pace (allowing the system to capture, stream, and render the image on to the 3D display) when projecting onto a screen at a remote performance site as with the Krannert Center Tech Summit, there are bandwidth limitations to consider. The available bandwidth to stream from the Computer Science building to the Krannert Center is 290 kilobits per second for audio and 350 kilobits per second for video, which creates a slightly "choppier" look to the movement.

Coupled with the specifically composed audio for this environment and the constantly moving perspective thanks to the wii remote control, the dropped frames were actually a desirable effect the dancers were able to anticipate and work

with. One of the composers created work that was inspired by the limited frame rate and "holes" in the image. She was especially drawn to the sporadic and fleeting images composing her sound score "in response to the visual image that is depicted on the screen." This is a prime example of how the tele-immersive system, even in it's currently evolving state is able to provide creative stimulation and inspiration to the user.



**Figure 8. The ability to create believable remote interactions is demonstrated in the above series of pictures. The two dancers in photos above are at different locations but are interacting in real time within the Tele-immersive environment.**

**Table 3. Questionnaire: "In what ways did the TI system change your relationship and/or awareness of yourself and your physical environment?"**

January 2008:

"I'm noticing a different awareness, somewhat like an out of body experience."-Laura

"In reality, you are still moving, but we forget our physical reality and focus on the 3-D. I feel like our body exists in the 3-D virtual environment, rather than the real world."-Young Sun



### 7.2.3 Graphics and Interface

There are some graphics that are more useful choreographically than others. We received a lot of feedback about the graphics and the interface from the dancers and recognized that the Wii remote control was the most highly desired option, followed closely by the ability to change point of view. (See Graph 2) Because these two options allow for the dancers to interact with space and provide a texture and context to the environment, they influenced their movement and were therefore most useful for creative movement exploration.

There was a strong request for a more specific time measurement on the interface which would allow more control and specificity when added a feature. They wanted to have the time code revealed so they would know exactly how long they were dragging out a digital option to be. This is especially useful when working with music and attempting to time a graphical change to a change in the music.

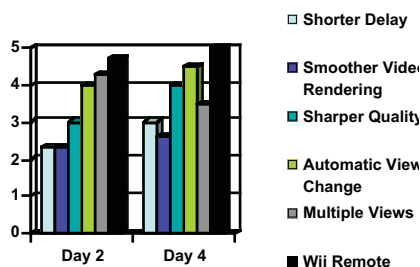
### 7.2.4 Limited Space

The dancers also expressed some concern about the limited space available in the lab. Although when translated onto the large screen during the final performance, it was observed from the viewer's perspective that the dancers actually portrayed a very expansive sense of space and that it seemed their virtual world was never-ending. The Wii remote control contributes to the ability to give this large sense of space to the virtual world because with its ability to move and "see" the room, it compensates for the dancer's lack of ability to actually cover space. It can create distance between the perceived viewer (the camera) and the dancer by going close and far away and therefore adds a strong spatial element even though the physical dancer may only have a limited area.

### 7.2.5 Color

There are limitations to the colors that can be worn. Trial and error revealed that pastels and patterns work the best. Because of the blue subtraction background on the wall the color blue will recede from the image (black also seems to have this effect although it looks more like a shadow). This is another example of how the dancers were able to take advantage and use a technical limitation as a jumping off point for creative problem solving. One could create a solo that is actually a duet with one person who remains "invisible". This would allow the physical element that is difficult to accomplish in the virtual world to become more prominent. A trio would actually appear as a duet if one person was invisible and would introduce an element of weight sharing if two the invisible person shared a physical space with one of the two "seen" users.

**Graph 2. The users prioritized on a scale of 1 through 5 (Five was highly desirable) the digital improvements they**



**desired after a two hour work session on two separate occasions.**

### 7.2.6 View Change/3D Display

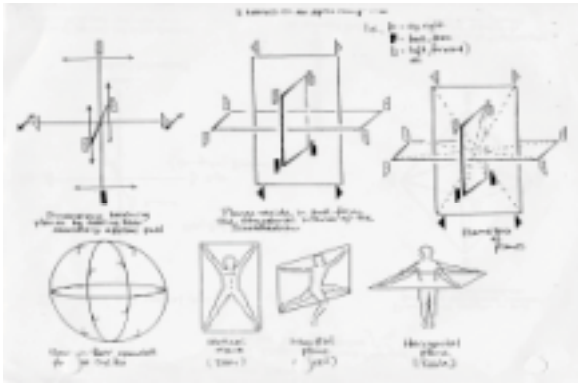
The ability to change the point of view is a highly valued component of TED for the users. This is one of the features that provides the dancers with the ability to "feel" the space in the virtual world. Being able to zoom and pan and view this on a 3D screen gives the true sense of volume to the dancer's body and interactions with a partner. This feature was also ranked highly desirable (see Graph 2).

## 8. TED: THE NEXT PHASE

The TEEVE system has proven to be a useful choreographic and compositional tool, inspiring novel movement and providing an interesting means for collaboration and music composition as well as a new form of dance, TED. The recent developments indicate there is potential for further development of the TEEVE/TED system to help build a computational model for human creativity through LMA and as an archival tool for recording movement.

### 8.1 Computational Model for Human Creativity

There is significant interest from both the artistic and computer science community to capture human movement in a highly specific, detailed manner which could then be translated into a computational model. We have begun preliminary studies attempting to capture Effort life through motion capture. The ultimate goal is to map out human movement using Laban Movement Analysis, which is a method for analyzing the specific qualities, shapes, and dynamics of movement and revealing the relationship between function and expression. There are four main categories in LMA: Body, Effort, Shape, and Space. (Figure 9). We are beginning our research with Effort. There have been studies analyzing through LMA the Effort Life associated with gesture (Zhao, 2001) but the application was more focused on computer animations and obtaining an accurate understanding of human movement in order to reproduce it in animations. We investigate computational models of LMA inside the tele-immersive system in the form of geometric cloud points and subsequently extracted geometric features and dynamic motion models in order to manipulate the LMA readings internally (essentially "teach" the computer to respond to the users movements) The internal creativity process in the tele-immersive system, executed through instantiation of digital options, is modeled via the compositional framework.



**Figure 9. Sample of LMA space configurations and the associated symbol (describing the sagittal, horizontal, and vertical planes and the direction of movement).**

The framework supports dynamic configuration and composition of functional entities, changes in algorithms to be executed, inclusion of dynamic sets of data to stimulate the process of dance creativity, and reallocation based on user needs.

## 8.2 Archival Tool

As mentioned earlier, one of the important qualities of performance art, and especially dance, is the ethereal, fleeting nature of its existence. And this is partly true because dance is not expected to ever be performed the same exact way twice because of emotional and contextual reasons. However, there is value placed on accuracy and repeatability of intention. Preserving dance has remained a great challenge for this reason. There are three main methods for documenting and preserving dance. The first is the most widely used: video. Although this method has many advantages including accessibility, ease of use, and a relatively high level of picture quality, but it only captures that one show, complete with flaws, and it is a challenge to duplicate the details and nuance when learning from 2D video.

Moreover, the 2D video does not provide a spatial information or alternative points of view. The second option is that choreographic works are passed down by the choreographer to a specially appointed person who knows the work inside and out and is given the rites to recreating that work. The third option is Labanotation, a very complex and intricate system of symbols and codes that represent every imaginable body formation and movement pathway. This method is extremely time consuming and because there are only a limited number of people who can actually read and write this code, it is not very practical to use. It could take hours and pages to accurately notate a short but complex five minute phrase.

We are proposing the TED system as a solution to this issue. Preserving a historical solo within the TED system would allow a new dancer to view it from different angles and learn it in a perceived shared space with the original dancer, a much more efficient way to learn movement. This would enable greater accuracy with detail and positioning of the body's limbs and torso.

## 9. CONCLUSION

Tele-immersive Dance is a unique form of dance that utilizes the TEEVE system for creativity with the human form. Just as dance for the camera evolved as a new form of dance with increased accessibility of video equipment and editing software, TED promises to become a new era in dance (and performance art) as we continue to develop and construct a portable system for tele-immersion. With TED, the dancer creates in an equipment-filled lab but could perform on a New York City rooftop. Although it is challenging to evaluate creativity or determine what metrics indicate its success or failure, the testimonials and the visual result of just four sessions indicate a high level of creative thought and the process resulted in a worthwhile compositional study according to the users and the audience. TED offers a new way to communicate through movement, influences the creative process, and almost becomes a third collaborator itself (Table 4). The user's enthusiasm and constructive critiques allowed us to recognize what needs to change and retain what is valuable so we can continue developing this highly immersive, collaborative, creative environment.

**Table 4. Excerpt A from Creative IT logbook**

Excerpt January 2008:

“(TED) almost became another person one has to consult with in collaboration, someone else's opinion and ideas that must be taken into account.”-Cheryl

“The presence of the 3-D screen was strongly felt—almost like it was another person in the room, collaborating, offering an opinion as to what could happen next in the creative process.”

This system thrives on creativity in every sense of the word: the dancers, the system itself, and the programmers. Our future plans include building the computational model, making the system portable, and expanding to multiple sites which would enable a three-way (or more) interaction.

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## 11. REFERENCES

- [1] Bajcsy, R., Jung, S-H., 2006. Learning physical activities in immersive virtual environments, *IEEE ICCVS*, New York City, NY.
- [2] Zhao, Liwei, 2001. Synthesis and Acquisition of Laban Movement Analysis Qualitative Parameters for Communicative Gestures, *Thesis Dissertation in Computer and Information Science*, University of Pennsylvania, PA.

- [3] <http://project.arts.ubc.ca/bodyspaces/>
- [4] Yang Z., Wu W., Nahrstedt K., Kurillo G., and Bajcsy R., Viewcast: View Dissemination and Management for Multi-party 3D Tele-immersive Environments, *Proc. of the 15<sup>th</sup> Annual ACM International Conference on Multimedia*, 2007
- [5] Sheppard, R., Wu W., Yang Z., Nahrstedt K., Wymore L., Kurillo G., Bajcsy R., and Mezur K., New Digital Options in Geographically Distributed Dance Collaborations with TEEVE: Tele-immersive Environments for Everybody, *Proc. of the 15<sup>th</sup> Annual ACM International Conference on Multimedia*, 2007.
- [6] Nahrstedt K., Bajcsy R., Wymore L., Sheppard R., Mezur K., *Computational Model of Human Creativity in Dance Choreography*, Association for the Advancement of Artificial Intelligence, 2008.
- [7] Tamai M., Wu W., Sheppard R., Kamali M., and Nahrstedt K., *Wii View: A View Control Interface for 3D Tele-immersive Environments*, IEEE ICME, Hanover, Germany, June 2008.
- [8] Wolfram, Eric. *Virtual Dance: technology can help create and promote dance, but it doesn't replace the physical body. Or does it?* Dance Magazine, February 2003