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REPERCUSSIONS AND REVERBERATIONS: AN EXPLORATION OF WEARABLE TECHNOLOGY, DANCE, AND COLLABORATION

DIONNE, RICH ET AL
PURDUE UNIVERSITY
WEST LAFAYETTE, INDIANA

Prof. Rich Dionne
Purdue University
Department of Theatre

Ms. Kathleen Hickey, MFA
Purdue University
Division of Dance

Prof. Renee Murray, MFA
Purdue University
Division of Dance

Repercussions and Reverberations: An Exploration of Wearable Technology, Dance, and Collaboration

Synopsis:

Rich Dionne, Kathleen Hickey and Renee Murray, faculty in the Patti & Rusty Rueff School of Visual and Performing Arts at Purdue University, account their transdisciplinary research in interactive dance performance. This paper discusses the creative team's approach to the project, collaboration, and authorship. They explore the challenges of creating the technologies to support an interactive platform in live performance, the lessons they've learned from the process, and the next steps as they continue their collaboration.

Introduction: Interactive Performance in Dance

In 1966 artist Robert Rauschenberg and Billy Kluver, a Bell Telephone Laboratories engineer, collaborated to create the performance, *9 Evenings: Theater and Engineering*. This work, held at New York City's 69th Regiment Armory, featured many artists from the Judson Dance Theatre, and is arguably one of the seeds for the many collaborations amongst artists and technologists we see today (Birringer 23). Since that time, artists like Ellen Bromberg, Lisa Naugle, Geoffry Hicks and companies such as Troika Ranch, Palindrome, Chunky Move, among others, have increasingly employed the use of wearable technology and sensory devices in their performances to give performers the ability to manipulate and respond to entertainment technologies (projections, sounds and lighting) in real-time. These performance and installation pieces blur the audience-performer and performer-technology boundaries; further, they resist traditional concepts of artistic authorship and challenge the autonomy often enjoyed within traditional artistic roles in performance creation (i.e., that of the choreographer, the lighting designer, the costume designer, etc.).

In *Dance, Interactive Technology, and Device Paradigm*, Eric Mullis defines and describes interactive performance:

> Interactive performance entails the use of sensory technologies to directly affect environmental changes in real-time and in a space that is shared by audience and performer. I focus on interactive performance because it draws bidirectionally and technological mediation into sharp relief for both the dancer and the audience member. The dancer experiences a technological amplified articulation of movement and is affected by the environment that his or her movement creates, and, since the causal connection between movement and environmental output is instantaneous, the viewer can readily appreciate this interplay. The intertwining of the dancer's body, interactive platform, and environmental output creates a shared, innervated environment in which the interplay of the body and interactive technology comes to the fore (113).

Audience members attending a performance of Swan Lake typically expect the traditional music of Tchaikovsky and a narrative of the swans, the witch, and the prince. This audience and performer relationship is orthodox: viewer/performer. The dancers execute the choreography without change or the chance of improvisation. Utilizing interactive technologies can provide dancers the opportunity to develop their performance landscape, to change these preconceived ideas of the proscenium stage--i.e., the audience as viewer and dancer as performer. Dancers kinetically connected to interactive technology can directly respond to that technology, if room for variation is built into the choreography. Further, they can break the fourth wall and include the audience within the environment of the stage. Eduardo Kac coined the term "mediascape" to describe the phenomenon of performers and audience existing in a space that is no longer surrounded by their natural environment, but rather by media and interactive technologies (Naugle 8).

Incorporating interactive technologies can have a dramatic effect on how performers see themselves situated within the performance and the performance space. Dance theorists such as Johannes Birringer, Scott deLauhunta, Lisa Naugle, and Susan Kozel consider how the implementation of interactive platforms affects how dancers and audience members perceive movement. Dancers who perform through interactive platforms at times report becoming aware of how digital technology affects their performances, with some suggesting that the platform can be experienced as a partner that responds to and influences their movement as the performance unfolds (Mullis 111).

Implementing interactive platforms in live performance allows the movement of the performers (and/or other elements of the performers' performances—vocalizations, biometric data, etc.) to drive or otherwise impact the way lighting, sound, projections or other technical elements function onstage. For example, a dancer's change in pathway may directly impact the brightness, direction, color, and even movement of light on stage during their performance. Traditionally, lighting decisions like these are made by a lighting designer, whose training and experience (presumably) provide expertise in how to best support the performance through choices about brightness, direction, color, etc., Interactive technologies blur the relationship between designers and performers, giving performers a greater voice in design elements, and potentially giving designers a greater voice in choreographic decisions.

The creative directors of Troika Ranch refer to this approach of creating and collaboration with interactive technology as "slash arts." Every member of their creative team contributes to areas outside of their primary discipline (i.e. performer/ programmer/ musician). The art lives at the slash in between the traditional roles, creating a new form of collaboration (Kerpner 14). Consequently, a lighting designer collaborating on a performance implementing an interactive platform that drives or impacts the lighting during the performance is forced to wrestle with questions of authorship and autonomy: what impact will allowing dancers' movements to control the color of the lighting (for example) have on the overall impact of the lighting design? How much control of these elements can be ceded to the interactive platform before fundamental expectations of the lighting design (i.e., visibility, body-sculpting, etc.) are put at risk? Should these expectations be put at risk, and what might the result be if they are?

Choreographers Kathleen Hickey and Renee Murray and technical director/sensor network designer Rich Dionne have collaborated to explore these questions since 2015. This work—culminating in an initial public presentation in November of 2016, entitled *Repercussions and Reverberations*—challenged concepts of authorship and the relationships between designers, performers, and entertainment technologies. Dionne, Hickey, and Murray have been working since then to develop and work with technologies that gather sensory data from dancers and use that data to inform lighting and sound for live performance. This paper discusses these explorations (working with a fluid team of other collaborators); the convergence of technology, choreography, and costume; and how their research and relationship between the collaborators shifted throughout the process.

Repercussions and Reverberations

With the project, *Repercussions and Reverberations,* Dionne, Hickey, and Murray hoped to use wearable technology and a music-composition computational algorithm (an implementation of artificial intelligence research) to create a movement-based work in which the music and dance were intertwined in an ever-changing relationship and conversation. We gathered into our team of collaborators a costume technician (Rose Kaczmarowksi) exploring embedded wearable technologies in costumes and a computer scientist/musician (Jeff Evans) exploring computer-based music composition.

This group's initial conversations led to a concept that would have a computational algorithm create original sound in real-time for the performers to experience. The performers would wear biofeedback sensors measuring heart and breath rate; this data would be transmitted to the computational cluster, which would use this information to shift and change the direction of the musical composition in real-time during the performance. This ability to receive and respond to biofeedback would give the computational cluster a way to interact with the dancers on stage. Ideally, this interaction would impact the dancers' movement, which would alter the biofeedback data sent to the cluster, and in turn impact the music being generated.

A metaphor for how this bio-feedback loop would influence the composition in real-time is that of a skilled jazz musician improvising and responding to her fellow musicians. In an experienced jazz quartet, the musicians respond as much to intentional cues from each other as they do to pace, breath, mood, and other intangible cues. These cues—and each musician's responses to these cues—resonate with each other, creating a new performance each night. One goal for *Repercussions and Reverberations* was to see if it was possible to create this kind of interaction between performers and a computational cluster, and with entertainment technologies in live performance.

The following sections will describe the decisions and challenges that led to the presentation of *Repercussions and Reverberations* in November, 2016. These include the challenges of embedding wearable technologies on dancers' costumes, the decision to incorporate an artificial intelligence/computational cluster, the design of the sensor network (and the decision to attempt to collect both "active" and "passive" data from the dancers' bodies), and the simultaneous development of choreography and technology.

Wearables on Dancers

Repercussions and Reverberations provided an opportunity to explore and develop wearable technologies appropriate for deployment in dance performance. Using and embedding wearable technologies in a dance setting presents special challenges. Dancers' bodies experience a variety of extremes of stretching, contracting, spiraling, twisting, and bending. Dancers' movements often involve traveling into and out of the floor, and interacting with other dancers' bodies in unexpected ways and places (i.e., back to back; hip to shoulder, knee to back, etc.). Garments worn by dancers (and, by extension, the wearables embedded in those garments) need to be robust enough to stretch, contract, twist, flex, and survive a variety of impacts against different surfaces. Additionally, they should not restrict dancers' movements in any of these ways. Finally, inevitably the garments worn by dancers directly influences the visual impact of the dancers' work; therefore, they must visually support the intentionality of the choreography and the dancers, not distract or even contradict it. These challenges became the most important aspect of the work of Kaczmarowski (and, later, of Courtney Frederick, who joined the project as an additional collaborator interested in the aesthetic design of costumes integrating wearable technologies). Additionally, these challenges informed Dionne's work selecting sensors and developing the methods for collecting and sharing data with the computational algorithm.

Artificial Intelligence/Computational Algorithm

From the beginning, it was important to the team of collaborators to allow for chance, indeterminacy, and improvisation between the performers and the interactive platform. To accomplish this, the team--with Evans--explored the possibility of incorporating a computational algorithm/artificial intelligence in the interactive platform. This would enable the system to do more than simply make a direct connection between the dancers and the entertainment technologies in use; rather, the dancers would inform the music being composed, but be unaware of the exact impact the choreography would have on the music. This would introduce an element of surprise to the interaction.

A number of performers and artists have incorporated wearable technologies into their creative work. Notable among them is Imogene Heap, whose Mi.Mu gloves allow her to interact with music composition, sampling, and synthesizing software through the movements of her hands. These gloves incorporate flex/bend sensors and inertial measurement units to interpret hand orientation and transmit this information to a computer for processing. This processing is completely under the control of the performer; each action and movement has an expected and purposeful result.

Our goal was to transcend beyond predictable and intentional control of sound, lighting, or projections. Instead of predictable responses from the music, the movement, heart rate, and breathing of the dancers would operate in a kind of improvisational call and response with the computational algorithm, resulting in a new and fresh experience each performance.

Collecting Both Active (movement) and Passive (biofeedback)

Initially, the team intended to utilize a number of different sensors to detect active (i.e., from intentional movements of the dancers) and passive (i.e., from involuntary responses) data. Just as a tight jazz improvisation responds to active gestures, vocalizations, and instrumental performances as well as to the passive communication of mood, tempo, and feel, we hoped to create an environment where the computational algorithm would be able to respond both to intentional movement and passive biometric data.

To accomplish this, we planned to outfit each dancer with a variety of active and passive sensors. The active sensors included three-axis accelerometers (located at wrists and elbows) and a three-axis gyroscope sensor for measuring rotational velocity (located at mid-back on the torso). The passive sensor comprised a heart- or pulse-rate sensor, to be located at the neck, fingertip, or earlobe.

Sensor Network Design

Dionne selected an Arduino Lilypad USB as the microcontroller that would communicate with the sensors on the dancer's body. The Lilypad USB is easily programmable, features large connection pads suitable for making connections via conductive thread, and is washable; these factors drove the selection of the Lilypad USB for the project. Given the number of sensors and the long distances signal would need to travel, the designer opted to utilize an I2C serial bus for connecting sensors to the

Lilypad USB. This selection meant that four conductive paths (positive, negative, data signal, and clock signal) ran from each sensor location back to the microcontroller.

Additionally, the Lilypad USB on each dancer communicated with an XBee wireless transceiver over a serial connection. Each transceiver connected to a self-healing Zigbee mesh network coordinated by an XBee transceiver located offstage, connected to a central computer acting as a “hub,” collecting the data from all of the dancers. The program on each Lilypad USB polled the sensors for new data every 250 ms (0.25 seconds) and transmitted the data over the XBee transceiver.

At the central computer, custom software (programmed in Processing) collected data sent by XBee radios on each dancer. This data originally was to be repackaged as MIDI messages for transmission to the music composition computational algorithm. By the time of performance, this data was instead sent to moving light fixtures via DMX-512A to control pan, tilt, and color (intensities of red, green, and blue).

Costume Technology and Impact on Network Design

The team wrestled heavily with the question of “what drives the design” of the costumes from the outset of the project. Embedding sensory technologies throughout a dancer’s body and incorporating wearables inevitably impacts costume design decisions, from what fabrics are selected to what silhouettes are created, from how fabrics flow and drape to how stretchable they can be. From the beginning, the team knew we wanted to avoid any aesthetic that appeared somehow “cybernetic”--i.e., with obvious cables and wires or other “sci-fi” visual tropes. However, we also wanted the audience to be aware of the fact that the dancers’ bodies were interacting with entertainment technologies on stage. Balancing these desires became an ongoing challenge.

Initially, Kaczmarowksi and Dionne explored methods of incorporating the wiring required for the sensors directly into the costume. This meant looking for ways to have the garment itself serve as the technological infrastructure for the sensor network. Early experiments with conductive fabrics, conductive threads, and wearable microcontrollers and sensors yielded positive results in the costume shop. This suggested a two-layer approach to the costume design: a “base layer” bodysuit, which would incorporate the sensor network, and an outer “design layer” which would sit on top and provide opportunity to explore different design and aesthetic choices. By separating the “infrastructure layer” from the “aesthetic layer” of the costume design, we hoped to reduce the amount to which the design of the costume was dictated by the electronics. The bodysuit layer would incorporate conductive fabrics and threads, minimizing its visual impact.

The first version of the bodysuit was built around a dark grey, long-sleeved unitard. One-quarter-inch-wide strips of conductive fabric were sewn on the unitard from ankles and wrists to the middle of the back. These strips of conductive fabric formed the "wiring harness" of the sensor network. Each strip terminated at wrists and ankles in a single metal snap; these snaps provided a way to both physically and electrically connect sensors to the network on the bodysuit. Similar snaps were sewn at the middle back, to allow for connecting the microcontroller, wireless radio, and gyroscope sensor. (Using snaps as mechanical and electrical connections for sensors and microcontroller/radio bundle (the "brain") solved two key problems: how to make it possible to change sensors, if we desired, and how to make the bodysuit washable.)

While initial sensor network tests in the costume shop (with the bodysuit "on the hanger") were successful, testing in the rehearsal studio revealed significant problems. A skin-tight bodysuit needs to stretch as dancers move; stretchable conductive fabrics were chosen for the conductive infrastructure of the bodysuit because of this. However, the conductive fabrics, when stretched to the extremes required by the movement of the dancers, exhibited increased electrical resistance. This caused significant (and unacceptable) dropouts in communication throughout the sensor network--and necessitated a redesign of the bodysuit.

Imagine an arm outstretched, palm down. Draw a line from the top of the wrist, along the arm, around the outside of the elbow, and up to the shoulder. When straight, that line may be around 24 inches long; when you bend your elbow, that line gets longer by an inch or so. Draw the same line along the inside of your elbow instead of the outside, and it'll be about 24 inches; but, when you bend your arm, it will get shorter by a couple of inches.

This illustration demonstrates the fundamental design challenge of the skin-tight bodysuit: the electrical pathways along the suit needed to be able to change length significantly to accommodate the dancer's movements. Conductive fabrics could not stretch enough--nor could conductive threads. Using conventional wires--which don't expand--meant incorporating wires long enough that they wouldn't need to stretch. However, this meant dealing with all of the extra wire when that length wasn't needed. This pushed the design of the garment away from a skin-tight approach to a "blousier" one, which could incorporate longer lengths of wire. Even so, wires extending to the wrists and ankles continued to break and snap through to just before the performance, necessitating the need to cut all but the gyroscope sensors (conveniently located at the middle back, near the "brain") for the November presentation.

Choreography and the Impact of Simultaneous Development

All artists involved in *Repercussions and Reverberations* started developing their component of the project roughly around the same time. Hickey and Murray began their movement research while Evans explored computational algorithms and Dionne and Kaczmarowski experimented with sensors, embedded wearable technologies, and wireless data transmission. This simultaneity initially appeared both necessary and beneficial: for example, selecting sensors without knowing the movement seemed counterintuitive, and developing the movement without knowing what sensors might be used seemed counterproductive. However, this simultaneity also introduced challenges in the development of the project.

Hickey and Murray began their movement research by creating a series of task-based improvisational scores geared at intentionally altering breath and heart rates. These improvisations focused on physical exertion through time. The choreographers developed movement experiments based on sustaining a speed of motion for a specific duration of time: slow, moderate, or quick movement executed during scores ranging from one to five minutes in length. After attempting each score, they documented their breath and heart rates.

Through these improvisations Hickey and Murray started to shape the content and movement vocabulary of the work. The choreography developed a theme of a shifting, evolving landscape. The two dancers sent ripples and waves past each other causing wakes and turbulence to flow through each other: a gust of wind created from a strong slashing gesture by Murray thrown in the direction of Hickey, influenced Hickey to respond with a lighter fragmented gesture reaching out in the same direction. The dancers physically called out to each other. One motion initiated a chain of movements that the duet performed creating a gestural conversation. The ideas of change, influence, and impact appeared throughout the choreography. Once the team layered the sensor network onto the dance, the choreographers expected to fold the computational cluster into this conversation about these themes of impact and influence.

Dionne and Kaczmarowksi attended rehearsals to fit the wearables on the dancers, to attempt to collect data, and to witness the development of the choreography. This process provided Hickey and Murray with feedback about how their collaborators were reading the dance at each stage of its progression. This feedback helped shape the content and trajectory of the work while giving the other collaborators an opportunity to become active participants in shaping the choreography. Although data was collected in these rehearsals, it was primarily used to understand the functionality of the sensory networks on each dancer.

Hickey and Murray did not have the opportunity to rehearse with the computational algorithm since Evans was constructing it simultaneously to the development of choreography. Consequently, Hickey and Murray continued to develop movement material without knowing how it would impact and influence the computational algorithm. The choreography was forced to develop based only on information Dionne and Evans provided about how they expected the computational algorithm to interact with the dancers.

As will be discussed below, eventually the computational algorithm needed to be abandoned during the development of the project. At this time, two lighting designers, Allison Newhard and Megan Turnquist, were brought on board. Newhard and Turnquist worked with Hickey and Murray to develop a lighting design that would support the developing themes of impact and influence, and with Dionne to allow for moving light fixtures to respond to the sensor networks on each dancer. However, because the rehearsal space was not equipped with moving light fixtures, Hickey and Murray confronted the same challenge of inaccessibility they struggled with regarding the computational algorithm. They were forced to continue to develop movement based on information Dionne, Newhard, and Turnquist provided on how they expected the technology to interact with the dancers--rather than with actual interactions with the technology.

The lack of space to explore the interaction between dance and light restricted the work of the choreographers. Hickey and Murray therefore chose to create three fully choreographed works to perform at the November 2016 presentation of *Repercussions and Reverberations*, rather than works that left room for improvisation with and response to the lighting technology. Because of this choice, Hickey and Murray restricted the dancers' freedom within the performance to respond to the immersive media, losing the bidirectional relationship between dancers and moving light fixtures.

Description of AI development

Jeff Evans drove the incorporation of the computational algorithm that would compose the music during the performance. From the outset, though Evans expressed confidence that we would be able to accomplish our goals, he was plagued by setbacks related to the maturity of research in appropriate computational algorithms. These setbacks included difficulty finding/developing algorithms capable of learning and generating music appropriate for the choreography being developed, that could operate at the required speed to be viable in live performance without significant latency, and that could integrate data transmitted from the dancers effectively.

Initial tests of music-composition algorithms, while perhaps musically interesting, were not appropriate for live performance. These algorithms demonstrated an ability to recognize patterns from the training scores used to teach the algorithm "what music is," and to restructure and reorganize these patterns in interesting ways. However, the results these algorithms would output were not easily recognizable as music--at least not music that could be incorporated into the choreography being developed by Hickey and Murray.

There was evidence of improvement in the samples Evans shared with Dionne, Hickey, and Murray over time. However, the rate of improvement--of machine learning--was rather slow, suggesting that it would take some time to "train" the algorithm sufficiently to function as a musical collaborator in a live setting. Adding to this concern was the rate at which the different algorithms responded to new data and information. In most cases, there was significantly latency, suggesting the call and response nature of the relationship between choreography/dancers and music we sought would be difficult to create in real-time in a live setting.

The collaborative team quickly began to suspect that these challenges would make the incorporation of a computational algorithm in the November, 2016 presentation challenging at best, if not impossible. Evans research further revealed he was unsure how we would best be able to introduce the data collected from the dancers' bodies to the algorithm. Given this combination of challenges (and the challenges with embedding the sensory technology detailed above), with much regret the team opted to give up the computational algorithm aspect of the project, and focused instead on using the data collected from the dancers to control the movement, intensity, and color of moving light fixtures.

Performance/ Presentation

Saturday through Wednesday of the week leading to the presentation was the first opportunity to work with all of the technologies, the sensor networks, the costumes, and the dancers all at the same time. Dionne, Newhard, and Turnquist worked through troubleshooting the wearables communicating with the sensor network and moving light fixtures. Two moving light fixtures were positioned upstage center on the stage floor, while one moving light fixture was positioned stage right and one stage left both hanging offstage above the audience. The computer running the "hub" software and the wireless network coordinator transceiver were positioned offstage.

The sensor network reliably communicated with the dancers and moving light fixtures for the first time at Thursday night's technical rehearsal, and a fully-functional and responsive sensor network directed the movements of four moving light fixtures during both Friday and Saturday performances. The sensor networks collected data from the three-axis gyroscopes embedded in the costumes of both dancers. Two moving lights communicated with Hickey's sensor network "brain" and two moving lights communicated with Murray's "brain."

As an initial concept test of an interactive platform, this November presentation demonstrated that the project was promising, but would need more time and perhaps changes in the development approach. The connection between dancer and lighting instruments was apparent, most effectively so during solos, when the duet performed a dramatic shift in texture and speed together, or during slow motion movements. When both dancers traveled quickly through the space or performed large quick movements for an extended period of time, however, the four moving light fixtures received data changing more rapidly than the fixtures could track, causing them to move quickly, change color frequently, and appear detached from the dancers' actions.

The moving light fixtures responded to the movements of the dancers, and the connection between the dancers, the sensory networks, and the lighting technology created a heightened environment for the dancers and audience to experience during the performances. The connections between dancers and lights read as vague during some sections of the choreography; further, because Hickey and Murray were forced to restrict the choreography by eliminating room for improvisation there was little opportunity for the dancers to respond to what the lighting technology was doing. However, there was a clear call and response happening between the dancers (calling) and the lighting technology (responding) throughout the performance.

Lessons Learned/Next Steps/Conclusion

Through the project, *Repercussions and Reverberations*, Murray, Hickey, and Dionne hoped to explore notions of authorship, the convergence of choreography and technology, and the relationships amongst collaborators through the use of interactive technology in performance. The presentation of their work (and that of their collaborators Jeff Evans, Courtney Frederick, Rose Kaczmarowski, Allison Newhard, and Megan Turnquist) in November of 2016 brought revelations (both exciting and disappointing) and indicated new directions for their work in the future.

Questions of authorship materialized most directly through the technology of lighting. Newhard and Turnquist struggled with what it meant to "design" the stage with lights in which the dance itself also shaped the lighting. Because of this, Newhard and Turnquist ultimately decided to change their title to lighting coordinators throughout the research process. They were not in full control of the lighting design due to the four moving light fixtures connected to the sensor network. Since the moving light fixtures were responding to the dancers and receiving data from the sensor network the choreographers and sensor network designer also had a hand a creating the lighting design of the project. Newhard and Turnquist therefore focused on creating a subtle lighting design that supported the choreography, the moving lights and dancers. However, they had to give up full control of the visual aesthetic of the lighting, accepting visual moments that may not have matched their vision of the lighting for the piece.

The moving light fixtures responded to the movements of the dancers and created a heightened environment for the dancers and audience to experience during the performances. The pan and tilt of the moving light fixtures--particularly those positioned directly over the audience--caused audience members to be illuminated at different times during the performance. At times audience members found themselves part of the visual picture of the performance, visible to other audience members. Clearly, the audience experienced an immersion into the landscape of the performance, altering their relationship to the dance.

The abandonment of the computational algorithm resulted in a loss of the bi-directional, improvisational relationship between the dancers and the technical elements that was originally planned for. As a result, Hickey and Murray did not achieve a fully interactive dance performance (at least as defined by Eric Mullis). While the work could be described as fully *immersive* in the new media landscape of wearable technology, it was not truly *interactive*. However, although the connections between dancers and lights read to some audience members as vague or ill-defined during some sections of the choreography, there was a clear call and response happening between these two dancers and the moving lights throughout the performance.

Dionne, Hickey and Murray are currently working on the next phase of *Repercussions and Reverberations* and rebuilding the technology based on the lessons learned in the first iteration of the project. We identify four questions that need to be explored based on the presentation in November of 2016. First, how do we enable a more improvisational call and response between dancers and technology? Second, how can we encourage a greater feeling of authorship over the interactive technologies that might typically fall in their domain (i.e., moving lights within lighting design; music within composition; etc.) while maintaining an interactive aspect to them? Third, how can we embed technologies within costumes in a way that has even less of a visual impact? Finally, how do we enable the choreographers to become familiar with what data the sensors collect and the possibilities of that data in the interactive environment?

To address the first question--how do we enable a more improvisational call and response between dancers and technology?--Dionne is exploring methods of incorporating chance or unpredictability into the data collected from the dancers. The first approach to this involves convolution: creating an algorithm that combines the data collected from the dancers with other data sets to create a third, new data set. For example: *Repercussions and Reverberations* built on images of rippling water; for each performance, we might combine the data from the dancers with a set of data about the tides on the day of performance (i.e., water level over time). This would result in a data set that would have unpredictable results for the performers each night. This unpredictability would provide something to which the dancers could respond, creating a bi-directional call-and-response loop.

Another approach Dionne is exploring to introduce unpredictability to the interaction on stage involves a convolution with a different data set. Rather than pull in a data set from an outside source, Dionne is looking at developing programming that would allow for using the data collected from one sensor on a dancer's body to be convolved with the data from another sensor--for example, using the data from a flex sensor on a dancer's elbow to modify the data collected from a flex sensor on that dancer's (or another's) knee. This method would not only introduce unpredictability from the perspective of the dancers, but also allow dancers to impact the way other dancers sensor data is utilized, increasing the possibilities of interaction not only between dancers and the technology and but between dancers and other dancers.

We believe that the fact that data collected from the sensor networks on each dancer directly commanded the movement and color of the moving lights drove much of the sense of loss of authorial control for the lighting designers in the November, 2016 presentation. To address this concern, Dionne is developing a version of the custom "hub" software that collects the sensor network data, and then distributes that data over an Ethernet connection to a closed network via OSC (Open Sound Control) messages. This will allow designers in different disciplines (i.e., lighting, sound, music composition, scenery automation, etc.) access to the data and the opportunity to decide from moment to moment in a performance how that data is used. They might assign a particular sensor stream they receive to the red color of a specific light in one moment, and then assign that same stream to the intensity of all of the top light in the next, and in a third, not utilize that data at all.

As the first phase of R*epercussions and Reverberations* made clear, the needs of electronics embedded in garments are often diametrically opposed to the visual aesthetic and the needs of the garment to accommodate a dancer's movement. In this context, the greatest issue is the non-stretchability of electrical wiring. To address this, we are actively exploring smaller components and finding ways to reduce the length of the conductive pathways between sensors and each dancer's network "brain." (The shorter the pathways, the less stretch is required.) Although this raises concerns about wireless network congestion, this thinking may lead us to incorporating more (and smaller) "brains"--including wireless transceivers--on each dancer's body.

Finally, to ensure the choreographers are not working in a vacuum and have a clearer sense of what the interactive platform is and what it might be capable of, we are focused on building the technology first so that the choreographers and dancers can experience an immersive rehearsal environment. In addition, we are installing components of the interactive environment (i.e., lights, sound components, etc.) in the rehearsal studio. Through this immersive rehearsal environment the choreographers will learn how to communicate with the sensor network through movement and light while expanding and reframing the conventional roles of choreographer, dancer and designer.

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