



# Cell Space: Augmented Awareness of Intercorporeality

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Fig. 1. Cell Space

*Cell Space* is an interactive art experience that integrates collocated augmented reality, neurofeedback, and contact improvisation, challenging the conventional boundaries between audience and performer, and blending the physical with the virtual, organic with technological. Inspired by McLuhan's concept of media as an extension of the human body, and *The AR Art Manifesto's* vision of "we becoming the Media," this project reimagines participants as dynamic cells of a shared bio-digital ecosystem within the built environment. This immersive experience expands the concept of intercorporeality, moving beyond mere physical interaction to a shared bio-digital domain, thereby fostering a deeply interconnected environment of Human-Machine-Space Symbiosis. The paper contributes to the discourse on performing arts by presenting a new paradigm for applying AR and neurofeedback in contact improvisation, creating a new layer of perception and fostering

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intercorporeal interactions by reinforcing both individual and collaborative intentionality of its participants. Ultimately, *Cell Space* serves as a reflective mirror to the potential futures of our increasingly interconnected existence, encouraging participants to explore a transformative landscape that resonates with the complex interplay between their physical and digital identities and their surroundings.

CCS Concepts: • **Human-centered computing** → **Mixed / augmented reality**; **Collaborative interaction**; • **Applied computing** → **Performing arts**; **Media arts**.

Additional Key Words and Phrases: Augmented Reality, Neurofeedback, Contact Improvisation, Interactive Performing Art, Human-Machine-Space Symbiosis, Intercorporeality, Intersubjectivity, Intentionality

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## 1 INTRODUCTION

In contemporary media art, what new methods and questions are needed as the boundaries between audience and performer, physical and virtual, organic and technological are becoming increasingly blurred. *Cell Space* is an artwork at this intersection, making awareness of the evolving nature of intercorporeality. Inspired by McLuhan's idea of media as an extension of the human body [McLuhan 1994], Jess Rowland's extension to internal awareness [Rowland 2021], and The AR Art Manifesto's vision of "we becoming the Media [Torres 2016]," this concept envisions every participant as a cell within an evolving, organic spatial entity through contact improvisation. This dynamic ecosystem, reflective of Haraway's concept of the fluid cyborg [Haraway 2013], serves as breeding ground for an expanded intercorporeality, blending the physical touch of contact improvisation with shared bio-data in a digitally enhanced space.

The motivation of *Cell Space* stems from a deep inquiry into the nature of contact improvisation. This dance style requires dancers to move through unseen elements like imagination, feelings, connections with others, and the surrounding space [Koteen et al. 2008]. These aspects are crucial but intangible, particularly for beginners or even experienced dancers seeking a deeper connection with their own emotions and those of fellow participants. *Cell Space* dynamically visualizes these intangible by providing a medium through which neurofeedback technology captures the dancers' bio-data for representation, while headworn augmented reality (AR) enhances the intercorporeal experience, the "perception-action loop between the self and the other" [Tanaka 2015]. Here, AR and neurofeedback technology acts as an amplifier of perception and carefully balance the elements of distraction and immersion. This allows dancers to fully immerse themselves in the experience, concentrating on their movements and emotions.

*Cell Space* also stands as a critical exploration and a reflective mirror to our existence in an era dominated by digital interfaces and algorithmic mediation. It embodies the evolution from human-machine symbiosis to a more integrated human-machine-space symbiosis, reconfiguring societal norms and illuminating the expansive complexities of societal structures. Ultimately, it creates a tapestry of interconnectedness where individual experiences resonate within the collective.

The contributions of this paper are as followed:

First, it presents *Cell Space* as an artwork that makes awareness of the concept of expanded intercorporeality, moving beyond mere physical interaction to a shared bio-digital domain.

Second, it offers a new paradigm for applying AR and neurofeedback in contact improvisation, fostering intercorporeal interactions and being sensitive to both individual and collaborative intentionality of its participants.

## 2 RELATED WORK

Augmented Reality (AR) is expanding the boundaries of intercorporeality in interactive art. Adrien M and Claire B utilized real-time body gesture adaptation, transforming the traditional stage and offering audiences a novel experiential journey [Bardainne [n. d.]]. This transformation of space and body interaction is further explored in Universal Everything's *Fluid Bodies* exhibition, where neuroarchitectural techniques redefine motion and form, offering a new perspective on the interaction between performers [Özdamar 2019]. Building on these foundations, *Cell Space* elevates the concept by creating a shared augmented experience that encapsulates both the audience and performers within its realm.

Further exploring social and physical connectivity, *Body RemiXer* emphasizes immersive technology's capacity to enhance social connections and intercorporeal relationships [Desnoyers-Stewart et al. 2020]. *Cell Space* harnesses AR to enhance this experiential depth, improving a balance between distraction and immersion to create an engaging environment.

The incorporation of neurofeedback in performances adds a deeply personal layer to this interaction. *Noor—A Brain Opera* elevates this concept by integrating brain-computer interface with opera, fostering a collaborative spectacle between performers and audience [Nijholt 2019]. *Enheduanna* explores the realm of multi-brain computer interfaces, enhancing interactive experiences in performing spaces and facilitating a deeper connection between one performer and two audiences [Zioga et al. 2017]. Alongside *GROUPTHINK*, these works underscore the field of interactive neuroscientific art, highlighting a shared, entangled experience between humans and machines [Hossaini et al. 2022]. *Cell Space* takes a step further by merging multi-agent neurofeedback with AR, enabling the visualization of a collective inner state and creating an immersive experience.

Additionally, COOP HIMMELBLAU's *Astro Balloons* represent an early exploration of human-machine-space symbiosis. Using biofeedback, these installations create personalized introspective spaces, challenging traditional boundaries between self and environment [Siegal 2002]. Expanding this concept to an urban context, *Feedback Vibration City* envisions a cityscape constantly reshaped by its inhabitants' bio-signals, illustrating the dynamic interplay between humans, technology, and environment [Feireiss et al. 2022]. *Cell Space* extends these concepts by employing AR and biofeedback to merge physical and virtual realms, transforming space from a mere backdrop to an active, responsive participant in the artistic experience.

## 3 CONCEPTUAL FRAMEWORK

### 3.1 Expanding Intercorporeality: Beyond Physical Interaction to Shared Bio-Digital

*Cell Space* extends the notion of intercorporeality, traditionally understood as the interplay between the body's social nature and social relationships [Csordas 2008], into a shared bio-digital domain. This paradigm shift resonates with McLuhan's view of media as a human body extension, where technology becomes a core component of our sensory and cognitive experiences [McLuhan 1994]. Here, intercorporeality is not merely about shared physical space but a shared being, where participants' organic vessels of experience interact with and influence a real-time digital environment, reflecting profound interconnectedness [Haraway 2000].

Augmented visuals in *Cell Space* create a new layer of perception, establishing a tangible presence of space and relationships through intercorporeality, bridging the gap between individual subjective experiences and collective awareness. Meanwhile, the visualization of bio data, extending the dimension of intercorporeal awareness by highlighting the physical and emotional connections between dancers. This facilitates a unique affordance for dancers to acknowledge and actively respond to each other's presence, invoking the interplay of intercorporeality and intentionality [Searle 1983].

### 3.2 From Human-Machine Symbiosis to Human-Machine-Space Symbiosis

Reflecting on Lev Manovich’s *The Poetics of Augmented Space* [Manovich 2010], *Cell Space* explores human-machine-space symbiosis, where space itself becomes an augmented participant. This shift is propelled by the integration of AR, which elevates the awareness of space as an active, responsive entity. AR in *Cell Space* transcends its role as a medium for visual enhancement to become a profound integration tool, weaving human, machine, and space into a unified, interactive organism. AR does not just overlay digital information onto the physical world; it weaves together the fabric of the physical and the virtual, creating a new “In-Between Space” [Torres 2016].

Embracing the vision articulated in *The AR Art Manifesto*, *Cell Space* embodies the future where “we become the Media” [Torres 2016]. Participants are not mere observers or interactors within this space; they are integral components, influencers, and co-creators. This reflects a nuanced adaptation of Marshall McLuhan’s insight: “We shape our space, and thereafter our space shapes us” [Culkin 1967], where technology is seamlessly integrated into our lives and living spaces, becoming an extension of our being and transforming the way we interact with our environment.



Fig. 2. Opening phase in Cell Space





Sensor	Indicator	Parameter	Relationship
Heart rate sensor (Integrated in EEG headband)	HR	Flash frequency	HR(Low)  HR(High)
EEG	Attention	Brightness	AT(Low)  AT(High)
	Relaxation	Color	RE(Low)  RE(High)
	Pressure	Voronoi weight	PR(Low)  PR(High)

Fig. 3. Neurofeedback Mechanism of Cell Space

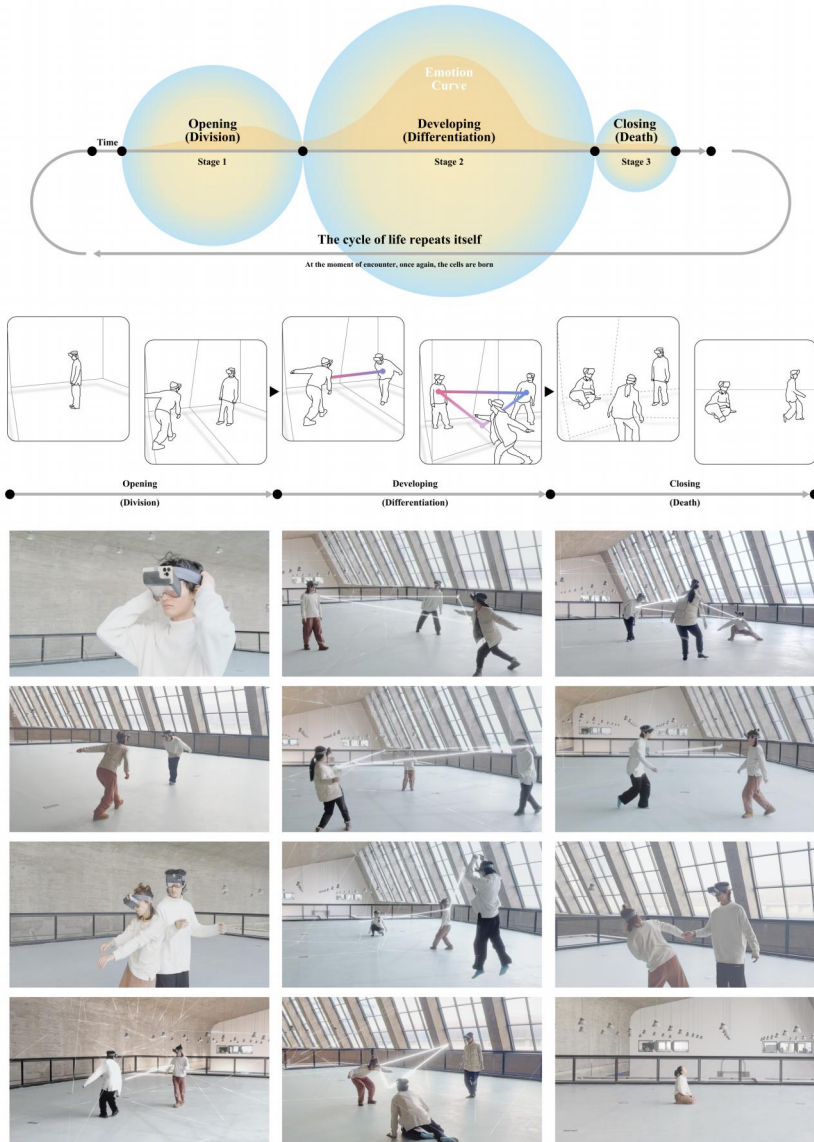


Fig. 4. Phases of Contact Improvisation

## 4 EXPERIENCE OF CELL SPACE

### 4.1 Interaction design

*Cell Space* integrates collocated augmented reality and neurofeedback within a field spanning 10x10x5 meters. Designed with a minimalist aesthetic, the visuals are crafted from dots and lines, coupled with subtle lighting effects. This design achieves a balance between distraction and immersion for dancers, enhancing the essence of the intercorporeal experience through shared experiences and mutual awareness.



Neurofeedback mechanisms visualize emotional states through indicators such as "pressure," "relaxation," and "attention," derived from the brainwave data of the dancers, influencing the space's visual elements in real time (Fig. 3). This visualization of bio-data extends intercorporeal awareness by highlighting the physical and emotional connections between dancers. In our design, the "pressure" indicator influences the weights of Voronoi cells, assigning larger weights to cells corresponding to higher pressure levels. This results in a noticeable visual effect of push, as the distance between the cell's surface and its center is determined by the weight of the cell relative to that of its neighbors. The "attention" indicator is represented by the brightness of the Voronoi frames, where increased attention levels intensify the brightness. For the "relaxation" indicator, a range from high relaxation to low relaxation is remapped into color gradients from blue to red. The visual representation of cells and linkages flashing in accordance with the frequency of "heart rate" assists dancers in becoming aware of each other's heartbeats. This approach reinforces the concept of intentionality with the dancers' interactions, enabling them to consciously engage with the augmented reality environment as a collective.

*Cell Space* emphasizes inclusion, inviting participants from diverse dance backgrounds to engage with the intersection of technology and movement. It offers an intuitive affordance for dancers to realize and actively respond to each other's intentions through a new layer of perception created by bio-sensing technology and augmented visuals.

## 4.2 Phases of Contact Improvisation

At the heart of *Cell Space* is Contact Improvisation (CI), a dance form that examines the body's relationship and physical connectivity between dancers. We conceptualize three phases—Opening (Division), Developing (Differentiation), and Closing (Death)—that reflect the life cycle of cells and the fluidity inherent in digital entities (Fig. 4).

*Opening (Division):* Mirroring the division stage in cell life, the opening phase in *Cell Space* involves the initial contact and exploration between a leading dancer and a participant. They engage in duet exercises like rolling point of contact, maintaining a tactile connection that rolls or slides across their bodies (Fig. 2). Each new participant represents a new cell, collectively exploring touch, weight, and movement within the shared space, embodying the start of this bio-digital life cycle.

*Developing (Differentiation):* In this phase, dancers expand their range of movement and interaction, echoing the biological process of differentiation. The metaphor extends to the digital realm as real-time neurofeedback influence each dancer-cell's characteristics, such as weight, frame width, color, and brightness. This stage is a dynamic exploration of individuality within a collective context, where each dancer-cell exhibits unique attributes reflective of their inner state.

*Closing (Death):* The performance culminates in the closing phase, where the brightness and color of each cell gradually fade, and the structures dissolve. This dissolution represents the end of the life cycle but also signifies transformation and rebirth. This reflective period encourages participants to slow down and internalize their experiences, contemplating the ephemeral yet profound nature of their interactions within "Cell Space."

## 4.3 Participant Roles

*Cell Space* accommodates various levels of participation and accessibility, defining three primary Participants: Immersants, Spectators, and Bystanders (Fig. 5).

*Immersants:* As primary participants, immersants are dancers equipped with headworn augmented reality headset HoloKit, ensuring their connection to the performing space and other

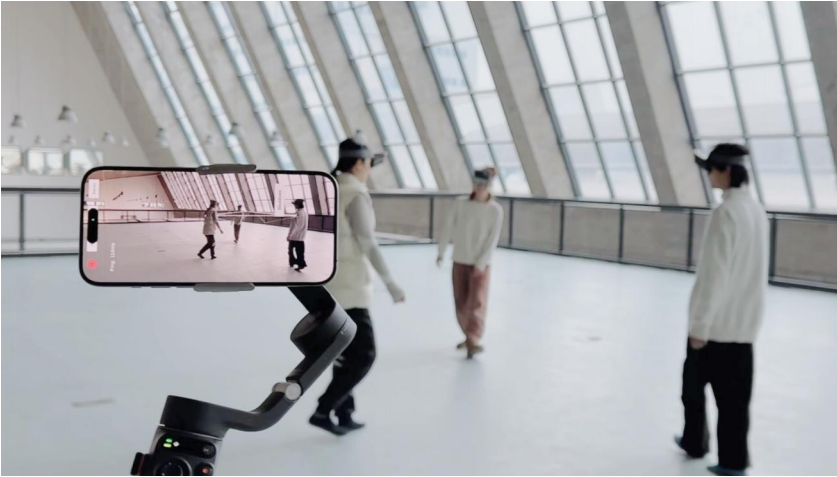


Fig. 5. The spectator is using an iPhone to view the "In-Between Space" of *Cell Space*.

dancers without isolation and with negligible latency. They also see augmented cell structures and links between dancers, enhancing their awareness of the collective "cell" shaped by proximity and mental states. Additionally, Immersants wear Flowtime biosensors to track heart rate and EEG signals, translating their emotions and mental changes into visual elements within the cell space.

*Spectators:* Equipped with AR headsets or handheld devices, Spectators view the performance in real-time, observing the augmented cell structures and interconnections from a first-person perspective. They can enter the performing field, transforming from passive observers to active participants, blurring the boundaries between themselves, the dancers, and other spectators.

*Bystanders:* Those without devices can still engage with *Cell Space* by watching through a monitor screen, offering a third-person view of the immersive experience. This allows a broader audience to appreciate the complex interplay of connections and movements within the performance.

## 5 TECHNICAL REALIZATION

*Cell Space* is developed as an iPhone app in the Unity3D game engine, designed to run on multiple iPhone 15 Pro devices with the HoloKit X - a smartphone-based head-mounted stereoscopic AR headset [Interactive 2024], and multiple EEG headbands. The system architecture is illustrated in Fig. 6.

### 5.1 Procedural Generation for Cells

The cells in *Cell Space* are generated procedurally based on the real-time spatial data and bio-data of the dancers. To achieve real-time generation at 60Hz on mobile devices, an efficient 3D Voronoi generation framework [Rycroft 2009] is employed.

The dancer's positions are considered as sites in a 3D-version Laguerre-Voronoi diagram [Aurenhammer 1987]. This diagram partitions the Euclidean space into polyhedron cells defined by a set of spheres. The Laguerre-Voronoi diagram can be seen as a weighted version of the Voronoi diagram, where each site has a weight added to its distance before comparison with other sites. The linkage between dancers is generated from the dual triangulation of the Voronoi diagram, as shown in Fig. 6 Step 3.

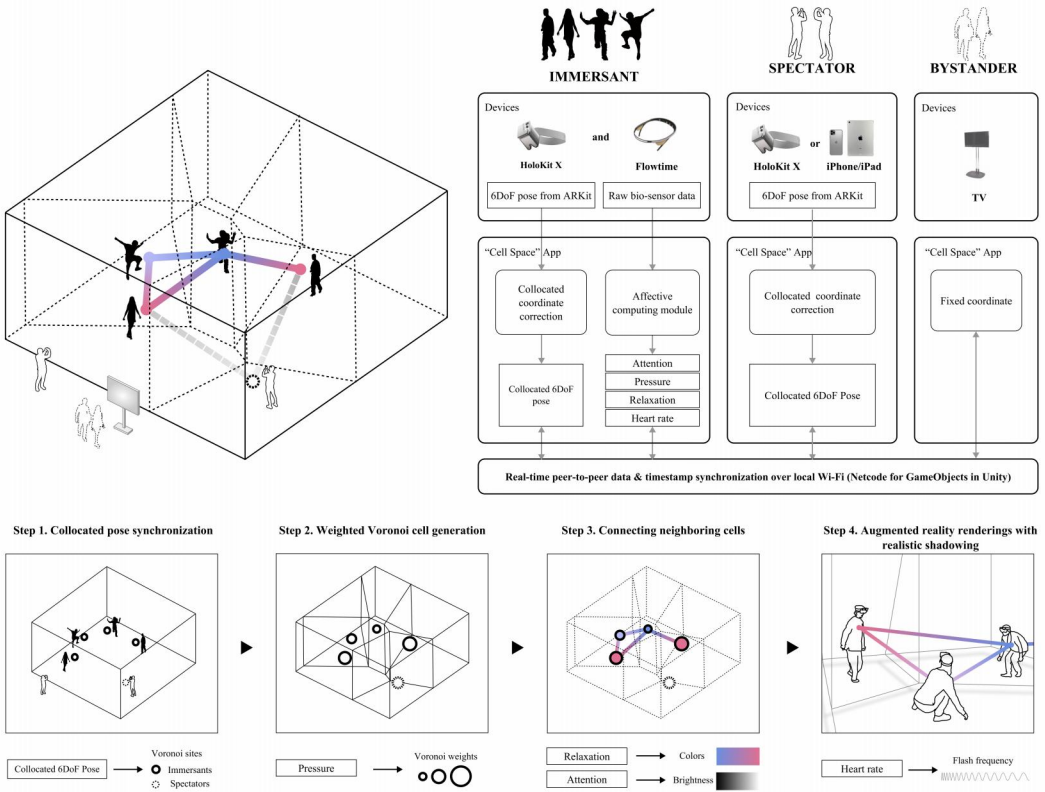


Fig. 6. Illustration of the system

These procedural generation techniques allow for the creation of dynamic and visually appealing cell structures in real-time, closely tied to the dancers’ positions and bio-data, enhancing the immersive experience in Cell Space.

### 5.2 Spontaneous Collocated Multiplayer Mixed Reality Framework

The system employs a spontaneous collocated multiplayer mixed reality framework, which is built upon the technology outlined in the methodology of InstantCopresence [Hu et al. 2023]. This framework utilizes a host-client architecture within a local network. It calculates the timestamp offset of each connected client device in relation to the host device and synchronizes the coordinate systems of all nearby devices. This synchronization guarantees that all devices showcase identical virtual content at the same physical location. As a result, the system enables instant sharing of the mixed reality experience without requiring an internet connection or pre-scanning of spatial maps.

In Fig. 6 Step 1, the collocated 6DoF poses of each participant are mapped to Voronoi sites, with each participant representing the center of a cell within the Voronoi diagram.

### 5.3 Neurofeedback

To integrate bio-data into the experience, heart rate sensors and EEG devices from [Flowtime 2024] are employed to capture and translate participants’ bio-data into emotion indicators via an affective



computing module. The EEG headband, equipped with eight sensors, measures the brainwaves of dancers, capturing EEG signals from both left and right channels. This device is capable of detecting brain activities ranging from  $-2\mu\text{V}$  to  $2\mu\text{V}$ . The headband connects to our application, developed with Unity and Flowtime's SDK [Flowtime 2023], through Bluetooth. It transmits the raw data to Flowtime's Emotion Cloud for processing. The Emotion Cloud analyzes this data and returns indicators of attention, relaxation, and pressure, which range from 0 to 100, at intervals of every 600 milliseconds. These indicators are subsequently utilized to dynamically modify various mesh parameters in the visualization.

## 6 CONCLUSION AND FUTURE WORK

*Cell Space* represents a leap in the realm of contemporary media art, blurring the boundaries between audience and performer, physical and virtual, organic and technological. By merging collocated augmented reality, neurofeedback, and contact improvisation, this artwork redefines the concept of intercorporeality and provides a platform for exploring the dynamic and symbiotic relationship between humans, machines, and the spaces they inhabit.

Building on this foundation, future endeavors may include:

- Implementation of responsive spatial audio: Introducing a soundscape that reacts to the participants' movements and bio-data, amplifying the immersive experience and fostering a deeper connection between participants and the space.
- Integration of Bio-sensors for Plants: Adding bio-sensors for plants to incorporate an ecological dimension, enhancing understanding and appreciation of our interconnectedness with the broader web of life.
- Incorporation of Environmental Sensors: Embedding sensors to detect changes in the environment like temperature and moisture, enriching the performance's context and highlighting the impact of these factors on our lives and perceptions.

As *Cell Space* evolves, it will continue to push the boundaries of performing art, inviting participants to reflect on their place within the larger ecosystem and the potential for technology to enhance and deepen our understanding of that relationship.

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