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Title: Transformation of Buddhist Mandalas into a Virtual Reality Installation

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Abstract

Technology can translocate traditional art into interactive, immersive experiences. At the Asian Art Museum of San Francisco, we transformed Tibetan Buddhist mandalas into a 3D virtual reality mandala installation. Further, we externalized an analog of the meditative experience by recording electroencephalograms that dynamically modulated the visual scene. Using neurofeedback, fluctuations in the alpha power drove the intensity of the fog obscuring the mandala. This creates the illusion of clearing the fog with one's mind in a meditation-like state. The collaboration demonstrated how technology intended for scientific use may be adapted to an artistic installation that enriches the visitor experience.

<1> Museum-Academic Partnership

Virtual reality (VR) adaptations of art pieces are a modern cornerstone of museums of this time. One can take a VR experience of the *Mona Lisa* at the Louvre [1]. The Dalí museum created a surrealistic immersion into Dali's world in *Dreams of Dalí* [2]. In essence, these are novel ways to experience exhibits that heighten the intimacy with the artworks. What is rarer is a transformation of the exhibit that blends the extant with the generative—to create a new piece of VR art that is born of the original works yet has a distinct phenotype. By □witching medium, emergent properties are found in artistic progeny. The Asian Art Museum of San Francisco embraced the challenge of utilizing VR to enhance the exhibit *Awaken: A Tibetan Buddhist journey toward enlightenment.* By partnering with researchers at Santa Clara University, the diverse team created a VR installation inspired by the mandalas of the exhibit and integrated elements of the exhibit story that were not possible in a traditional experience. We will show how this installation affected the experience of museum goers.

The other side of this story is the challenge of the scientist reaching the public. In the research world, the default is to stay insular to one's discipline. However, in many arms of science, such as neuroscience, communicating the philosophy and facts to the broader community must be a central goal. The science may inform values and attitudes that drive personal or social decision-making and acceptance of potential medical or behavioral interventions. There are clear examples of this two-way engagement model [3] in recent collaborations between artists and scientists. *A-Me* adapted AR neurosurgical tools to communicate the relevance of localization in the brain in the context of memory [4]. The installation *Mental Work* probed the question of separation of man and machine by using extracted signals from electroencephalograms (EEG) to control geared machines inspired by the Victorian era [5]. *My Virtual Dream* pulled together the social nature of being by taking collective EEG from 20 people to generate a live musical performance and dynamic dome projection [6]. The latter two works, took advantage of the principles of neurofeedback, which trains a user to modify their brain activity. The work presented here also uses neurofeedback. We link neurofeedback to meditative practices by using brain signals to modulate the VR experience. By making this link, we can show how neurofeedback may be used therapeutically in a manner similar to meditation.

Out of these motivations, *Mandala Flow State* (*MFS*) was born. The museum's and researcher's needs were both met through the mind meld of the neurofeedback VR installation. The following sections will describe the inspiration, design, and outcomes of the installation.

Figure 1. Traditional and VR mandala designs. Mandala of Vajrabhairava (image courtesy of Asian Art Museum of San Francisco) and *Mandala Flow State*. The inspirational design elements may be seen in architecture, motifs, and color scheme.

<1> *Mandala Flow State* Design

In *MFS*, the user is directed to relax while concentrating on the mandala that is revealed from its center and the music that progresses deliberately through the experience. The mandala and the soundscape are intended to promote focused relaxation. The scene is covered in a thick fog filter. The clearing of the fog is linked to the EEG signals that correlate with focused relaxation. This element acts as the neurofeedback informing the user of the change in brain activity. In conjunction, the feedforward and feedback elements are analogous to the visualization and shifting mental state of meditation, respectively.

<2> *Awaken's* Mandalas

The *Awaken* exhibit applies a narrative-based model to present the art of Tibetan Buddhism. The visitor is prompted to take exhibit title's challenge and break the fourth wall by entering the world of the gallery and experiencing a sampling of the extensive traditions in Tibetan Buddhism. One critical piece of this journey and the exhibit are the mandalas—a visual guide in meditation practices. In essence, a mandala is a geometrically delineated map of the visionary environment traveled in meditation. Each element of the design is representative of the deity's universe. Architecturally, a mandala design has an embedded series of squares and circles aligned to the four cardinal directions and centered on a vertical axis. The central point is symbolic of the deity that oversees the entirety of the universe. In practice, the in-depth symbolism of the mandala promotes learning the tenets taught by the deity. The projected purpose of the mandala is to recreate that universe in one's mind via meditative practices.

The mental discipline to "draw" the mandala in one's mind is only possessed by a few. Rather it is an aspiration for most practitioners and simply unfathomable to novices. Without an attainable bridge to the endpoint, most people simply walk away. Visualization technology, like VR, may serve as that bridge and be able to lead in people who would otherwise be discouraged.
From the exhibit, the Mandala of Vajrabhairava [7] was selected as the inspiration piece for *MFS* because it most vividly captured the architecture and design motifs that could be replicated in the VR design (Fig. 1). This work has multiple layers of circles and squares. There are motifs symbolizing indestructibility (vajra), pristine awareness (flames of fire), and mental purity (lotus petals). The color scheme embolizes the bold hues of the Tibetan art work. A true mandala is three dimensional, though typically represented on a flat surface. We applied these characteristics to the VR mandala design.

<2> VR Mandala Design

In designing *MFS*, we adopted the abstract and architectural elements of the traditional mandalas yet did not attempt to appropriate the overt religious symbolism and iconography. The 3D mandala had seven layers of circles and squares built from repeated design elements (Fig. 1). The design elements were created procedurally in Substance for novel geometric patterns. Traditional Tibetan motifs were selected from original sources with creative commons licenses. The environment and UV mapping were modeled in Maya. Unity was used as the hub of the animation, geometry and signal processing as well as driving all of the interaction and timing.

The mandala was gradually revealed through a growing circular aperture. As the mandala progressed, the central point was pulled to greater depths to create flow, distance and make space in the scene for the additional layers. The full mandala filled the visual scene by 180° and required looking up, down, right and left to see the edges giving the illusion of being inside the mandala universe. These features contributed to the immersivity that could not otherwise be achieved without VR.

<2> VR Music Design

<3> Rationale

The music was written with the intention of guiding the viewer into a meditative state. The music also drew upon proven methods of music meditation and healing. While there are many inspirations for this piece, the most significant inspirations were Tibetan music and modern minimalism. It was essential to create something that could have repetition and shift using Tibetan and Western instrumentation, while not overpowering the visuals. The music helped to promote the immersion into the VR environment by masking ambient noise and involving more senses in the experience.

<3> Composition

The piece was written primarily in Logic Pro X, with the majority of the parts being composed in MIDI and the remainder were found audio recording or live recorded audio. The piece is composed with piano, erhu, gong, Tibetan singing bowls, traditional flutes including the Chinese Xiao and Japanese Skakuhachi flutes, bass, synth, Chinese Ruan Moon guitar, and vocals. The piece is in 4/4 time and at a Moderato tempo of 94 BPM. The music aligned with the VR time course such that there was a three stage progression (Fig. 3): (1) Opening/Groundwork, (2) Piano/Focus, (3) Piano and Traditional Instruments/Ending.

The opening stage represented the acclimation and calibration period. The 90-second stretch introduced traditional Tibetan instruments and laid a color and texture palette. Two lines—melody and responsorial phrases—interacted, resulting in a call and response, further drawing the listener into the *MFS* conversation and dimension. The participant transitioned into the main experience with a ringing singing bowl and decrescendo to the gates of the mandala.

The next stage was the body of the VR experience, which was divided into subsections. The first section (2 minutes) was centered around a piano ostinato with vocal and synth. While the ostinato had few shifts throughout the piece, slight changes in rhythm acted as subtle cues for the listeners to remain focused on their journeys. The sparsely interspersed singing bowls and gongs reminded listeners to re-center and focus their thoughts. The addition of the erhu added complexity to the following section by shifting the balance. The erhu re-entered over the piano, marking the first moments of coexisting traditional instruments and preceding section. The piano and erhu decrescendo where a sweep against a tam-tam was heard. This led to the final stage in which both the first two sections are combined.

The final stage aimed to pull the participant out of the VR experience. Here, all instruments are reunited. This time, the piano ostinato is providing a rhythmic center. The erhu once more takes the melodic lead where the Ruan provides a harmonic base. Now, the flute provides a counter-melody to the erhu. Once more, drones in the low flute and bass provide a unifying strand. Playing in harmony, the piece grows in intensity before a final singing bowl is struck. Here, the piece closed with a windswept effect that was coordinated with the dissolution of the completed mandala.

<2> Neurofeedback System

<3> Rationale

MFS demonstrates the principles of neurofeedback. In brief, neurofeedback is the externalization of brain signals into a perceptible form for the purposes of modulating thought and behavior [8]. Neurofeedback is a closed loop system in which the user is the central point. The measured brain activity signal is transmitted to a computer, which then processes the signal to convert it to a control parameter for an output, such as a visual graded cue. The user attempts to change the stimulus representing the specific brain activity in a directed manner. The user improves over many sessions by maintaining the prescribed level of brain activity for longer durations in each session. While various ways of measuring brain activity are possible, we chose to use EEG for our system for its accessibility and physical compatibility with VR headsets.

The foundation of neurofeedback therapy is based on an analysis of the frequency spectrum of brain activity at specific EEG channels [9]. Cognitive neuroscience research has shown that particular profiles of relative frequency band contribution to the total brain activity are reliably associated with stereotyped mental states. In our application, we made use of the EEG pattern for focused relaxation. This mental state is associated with low autonomic arousal and strong attentiveness to internal thoughts processes or external stimuli [10]. Focused relaxation is marked by elevated alpha power in multiple brain regions, including anterior frontal cortices. In studies of mindfulness-based meditation, increased alpha power is found during the meditative state [11]. The empirical evidence indicating a reliable connection between anterior frontal alpha and spontaneous and induced states of mental relaxation lead to our selection of this metric for our neurofeedback system. *MFS* is designed to promote focused relaxation through the sensory experience and to model the modulation of alpha power via the neurofeedback signals. In theory, the learning that occurs in the neurofeedback sessions transfers to real life circumstances, such that a person is better able to maintain or induce a calmer disposition and clearer thinking when needed [12]. As an enhancement to the museum-goers experience of *Awaken*, our system aimed to externalize the guided imagery of meditative visualization of Tibetan mandalas.

<3> Data Flow

The neurofeedback system is diagramed in Figure 2. First, the Muse EEG device detects electrical brain activity and transmits data via Bluetooth to Muse Direct on the computer. Muse Direct will then output processed data from the raw EEG on the selected parameters. We used absolute alpha (8-13 Hz) power from AF 7/8 channels. Muse Direct sends messages to Unity extOSC. Next, the data is sampled through a 10-second sliding window, the mean and standard deviation are calculated, and then scaled by a difficulty factor. Lastly, the data is passed through a sigmoid function creating outputs from 0 to 1. This becomes the input to control the neurofeedback parameter in Unity. This processing ensured smoothly varying change in the control parameter for the density of the fog shader in real time. An increase in alpha signal proportionately decreased the appearance of the fog.

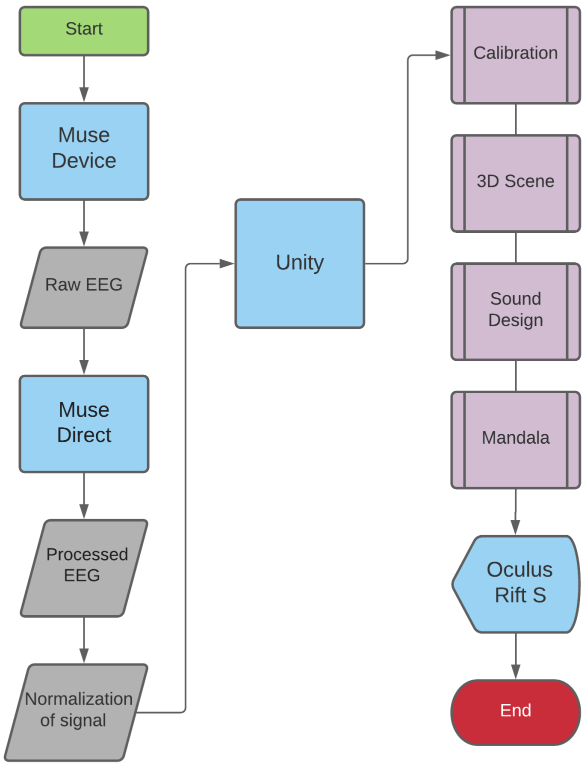

Figure 2. Data Flow. The brain activity is measured by the Muse headset, relayed to Muse Direct program, which processed the raw data to meaningful signals. Prior to input to Unity control parameters, the signals were normalized. The VR experience built upon the 3D scene, mandala, sound design, and neurofeedback calibration of the fog. The application is delivered to the user on an Oculus Rift S.

<2> User Experience

An overview of the experience is charted in Figure 3. The experience starts with the interior column of a Buddhist temple, where users were given the opportunity to acclimate and the EEG to a calibrate. A singing bowl chime signaled the start of the experience. From the center of the field of view, the mandala emerged and retreated farther in depth as the progressive layers of mandala were revealed. During the core of the experience, the user would try to relax and the appearance of the fog would indicate the level of relaxation. When the mandala reached its fullness after six minutes, it was swept away.

For the purposes of visualization in the installation, the raw EEG and the relative alpha power for AF 7/8 was displayed using Muse Lab. The graphs were displayed alongside the participant's VR experience for museum visitors to watch, in essence peering into the experience and mind of the participant. The simulcast engaged museum visitors widely, creating a more communal experience.

Our observations on the session activity are from our general impressions of and user feedback from the sessions. Our team noticed that novice users of VR did not attend to the fog modulation; rather were in an exploratory state in the novel experience. Consequently, the fog fluctuated without a pattern and stayed relatively thick as they were not in a state of focused relaxation. Other users expressed that they could not detect a connection between their efforts and the fog. In response, we explained that the ability to do so is reliant upon greater practice, just like meditation. This gave the opportunity to explain how neurofeedback works. In rare instances, a seasoned mediation practitioner would try out our system. Impressively, those who came into the experience with a strong ability to induce a state of focused relaxation, did reduce the level of fog for noticeable periods (30-60 seconds). This antidotal observation points in the direction of the technical accuracy of the system design. That is, focused relaxation is correlated with greater alpha power and that the derived standardized score changes the fog density to a perceptible level. The collective insights from the diverse array of visitors elicited discussions with the designers, which is the essence of the two-way model of engagement.

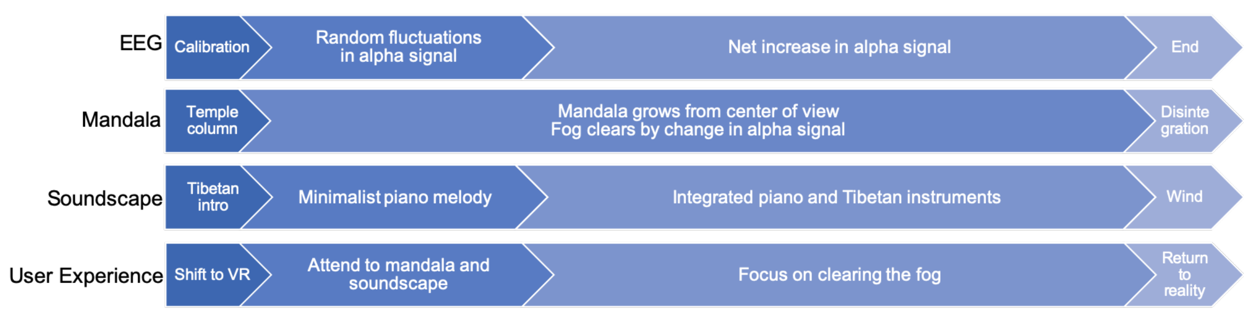

Figure 3. Idealized user experience. Parallel processes that create the holistic user experience are the EEG-based neurofeedback signal, the mandala progression and the accompanying soundscape.

<1> Participant Feedback

We collected survey results from 44 participants on four dates in February 2020 (Fig. 4). For more than half the participants, this was their introductory experience with VR. This showed the museum installation was an effective manner to introduce emerging technologies to the public. Of those who viewed the exhibit prior to our installation, 89% found a moderate to strong connection between the two. This synergy was a primary goal for the museum and was largely achieved by this evidence.

While the relaxation state of participants mostly stayed the same (51%), a large segment (39%) reported increased feeling of relaxation afterwards. Given the first-time exposure to the experience and the public setting, we find this outcome encouraging. To dice apart what is working and what is not, we look to the survey of VR features. Overwhelmingly, participants liked the music as well as motifs and geometric designs. The pacing, immersivity, and color features were split in preference, which gave direction for redesign for future versions.

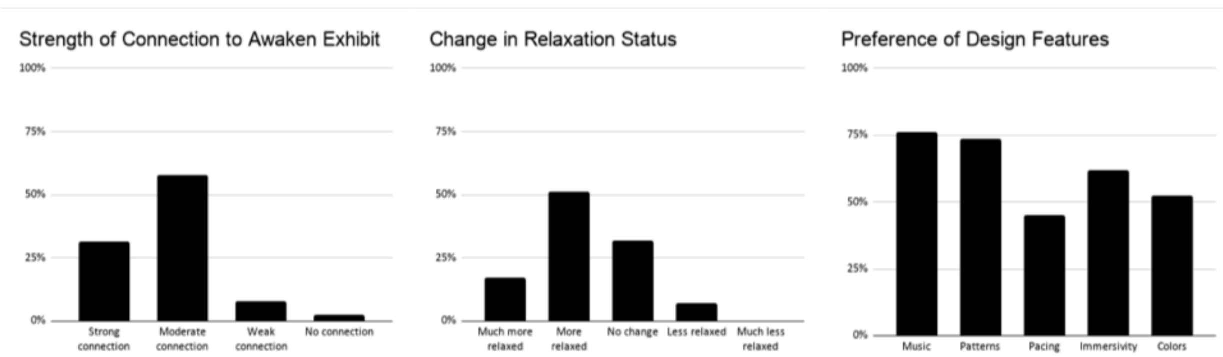

Figure 4. Participant Feedback on *Mandala Flow State*. Percent of respondents for each item are reported.

<1> Conclusion

Our goals were to (1) attract a more diverse pool of visitors to the Asian Art Museum, (2) enhance the museum-goers experience of the *Awaken* exhibition, and (3) educate the public on the topic of neurofeedback. We achieved all of these marks. Many people came expressly to participate in *MFS*, as they were interested in the interactive VR experience. This brought more people through the museum doors who would then explore the museum widely. Specifically, more people came to *Awaken* and found more meaning in their walk through of the gallery. People who watched or participated in the installation reported that a genuine connection with the theme of the exhibit. Through this connection, the makers of *MFS* provided many people a first-time exposure to VR technology and neurofeedback applications. The partnership supported the needs of both parties and created an experience that could not have been done individually.

Acknowledgments

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12. Refer to [9].

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