Mozart and the Mind: Brain-Music Exposition
May 19th, 2012 *The Neurosciences Institute*

Curated By: Tim Mullen, Grace Leslie
With live performances by: Stephen Prutsman and You

Précis

You've arrived at an interactive playground providing you an opportunity to engage with scientists, world-class performers, and fellow music aficionados while contemplating the intricate relationships between your brain, mind, and music.

In the outer courtyard, you'll find *MoodMixer*; a collaborative interactive experience that explores feedback loops between states of mind and music in the context of social interaction. As you and a partner each move through states of mental relaxation or focus, associated changes in your measured brainwave activity are translated into a four-channel music mixture and colored visualization. The visual and musical aesthetic at a given point in time is determined by the combined cognitive state of both participants. Thus, just as in improvisational music, some interesting social questions arise. Will you seek to cooperate closely with your partner, using musical and visual feedback to guide you both towards a unified state of mind and musical aesthetic? Or will you choose to more freely improvise and independently explore the musical landscape? The choice is yours.

Walking through the foyer, you'll find pianist/composer Stephen Prutsman performing live whilst his brain activity and neural connectivity is visualized in real-time via *BrainMovie3D* and *EEG Ocean*. "The mind is the music that neural networks play." This quote from renowned computational neurobiologist T.J. Sejnowski underscores a growing scientific consensus that studying the structure and function of vast networks of connections between brain regions is key to understanding creativity and insight, music, rhythm, language and a host of other mental processes. *BrainMovie3D* provides a window into these network dynamics by computationally modeling and visualizing information flow between different regions of Prutsman's brain as he performs live. Meanwhile, *EEG Ocean* provides an artistic interpretation of Prutsman's ongoing brain dynamics. Adopting the metaphor of "mind-as-ocean," electrical signals originating from different parts of Prutsman's brain are reconstructed and represented as waves rippling out from respective "islands" situated in a blue ocean. Neural activity associated with changes in Prutsman's mental state may emerge as salient bursts and ripple patterns in a chaotic sea of ongoing neural activity, offering a glimpse into his own mental ocean.

If you're curious about what your own brain looks like on music, the Mindo™ wearable EEG exposition allows you to visualize your own brainwaves on a tablet or smart phone. You might try *NeuroPiano*, which allows you to create simple musical compositions by fixating your gaze on the appropriate piano keys. Or create your very own *BrainMovie3D* with the Mindo-16 and decide whether your mind on Prutsman's music looks anything like Prutsman's musical mind.

Additional details are available at each installation and at: http://bit.ly/BioArt
Disclaimer: NeuroPiano is a specific example of an SSVEP brain-computer interface, which has been used repeatedly for assistive communication and control in individuals with severely impaired motor function. Although this technology is well established and perfectly safe for the vast majority of people (although some may find the flickering stimuli a bit bothersome), **we do not recommend it for individuals who suffer from photosensitive epileptic seizures.**

MoodMixer

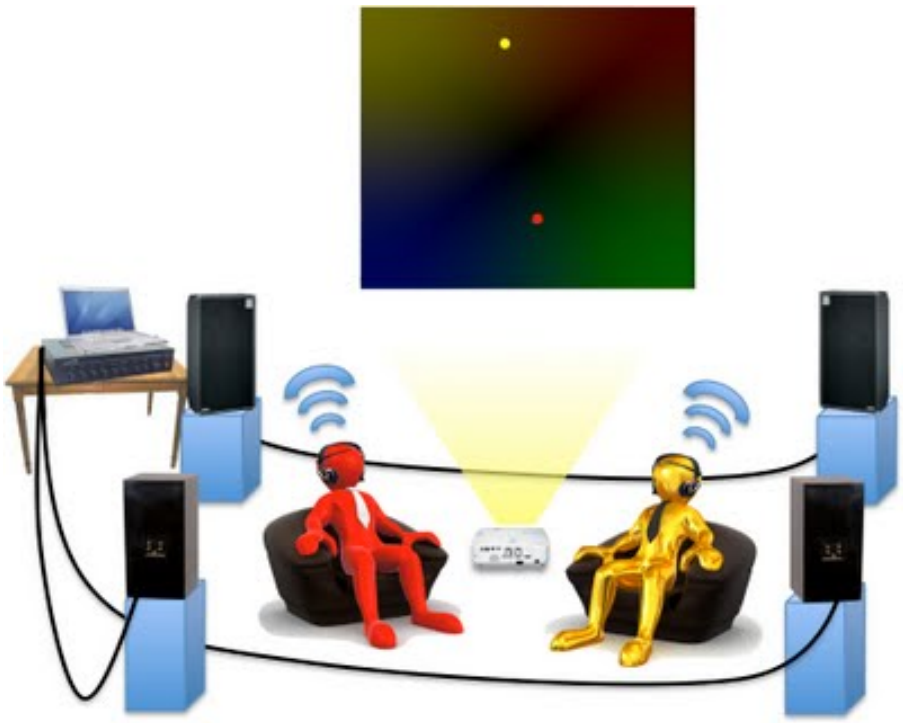
Created by: Grace Leslie and Tim Mullen

MoodMixer is an interactive installation in which participants collaboratively navigate a two-dimensional music space by manipulating their cognitive state and conveying this state via wearable electroencephalography (EEG) technology. The participants can choose to actively manipulate or passively convey their cognitive state depending on their desired approach and experience level. The music composition continually conveys the participants' expressed cognitive states while a colored visualization of their locations on a two-dimensional projection of cognitive state attributes aids their navigation through the space. MoodMixer is a collaborative experience that incorporates aspects of both passive and active EEG sonification and performance art. See [1] for a more detailed discussion of the technical design of the installation and its place in collaborative sonification aesthetic design within the context of existing EEG-based music and art.

Tonight's MoodMixer installation uses a new automatic music generator to produce a composition reminiscent of John Adams' piano piece *Phrygian Gates* (1977-8). The software randomly chooses notes from a set scale and repeats them to create slowly evolving loops, hallmarks of Adams' minimalist style, of which *Phrygian Gates* is a prototypical example. The scale begins in A Lydian, then shifts to A Phrygian, and then cycles around the circle of fifths, to E Lydian, E Phrygian, and so on. Several aspects of the music are manipulated to match the participants' cognitive states, primarily tempo and mode, as these are thought to be the features which most determine a piece of music's emotional expression [2]. One participant is able to increase and decrease the tempo of the piece based on their level of relaxation, while the other participant influences the overall texture of the piece by expanding and contracting note lengths based on their level of focused attention. Participants also have the option of jumping to the next key in the cycle by blinking their eyes. No two performances of the composition sound the same, given the unique contributions of each participant, and the pieces always evolving structure.

[1] Leslie, G. and Mullen, T., (2011) MoodMixer: EEG-based Collaborative Sonification. Proceedings of the International Conference on New Interfaces for Musical Expression. Ed. A.R. Jensenius, A. Tveit, R.I. Godøy, D. Overholt. ISBN: 978-82-991841-7-5
[2] Gabrielsson, A.; Lindstrom, E. (2001). "The influence of musical structure on emotional expression". *Music and Emotion: Theory and Research*: 223–243.

A schematic of one version of the MoodMixer Installation in use.



The Musician's Mind

In the foyer, you'll find acclaimed pianist and composer Stephen Prutsman performing/improvising live on the keyboard while wearing a high-density (128-electrode) EEG headset. His neural activity is being visualized in real-time via a pair of complementary, yet distinct, visualization displays: *EEG Ocean* and *BrainMovie3D*.

EEG Ocean

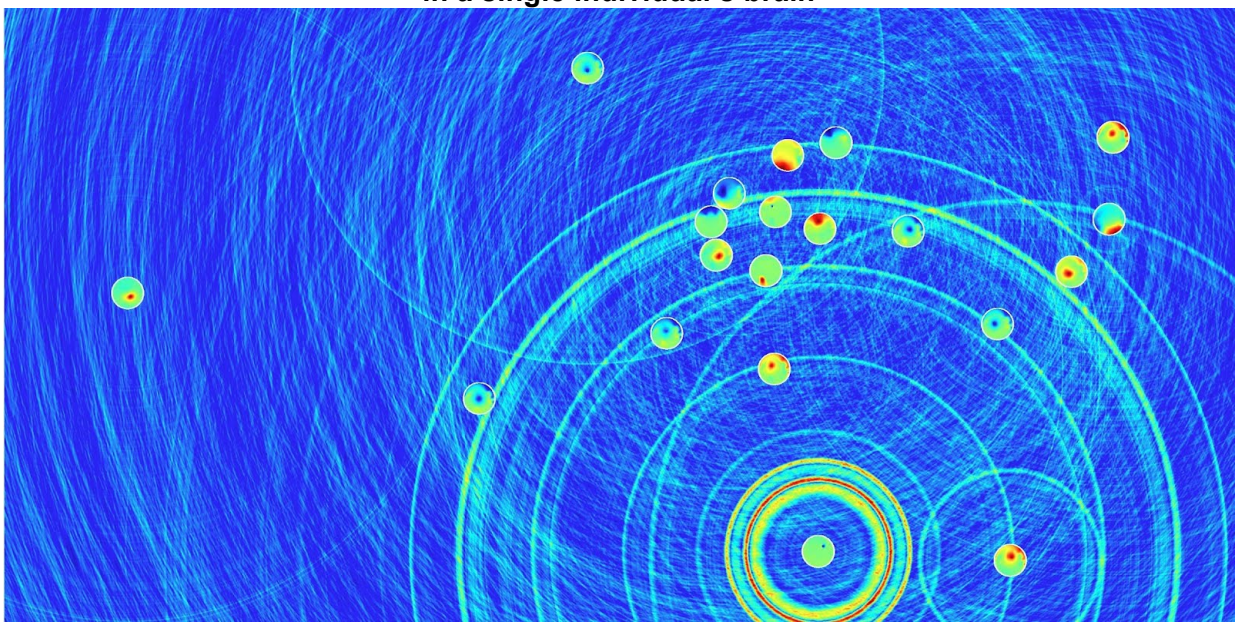
Created by: Nima Bigdely-Shamlo and Tim Mullen

In literature and film, across western and eastern cultures alike, we find instances of the metaphor of the mind or consciousness as an ocean or sea. From a phenomenological perspective, one can appreciate the reference to the seemingly limitless expanse and dynamic nature of one's imagination and inner mental world -- a vast ocean at times calm and serene while at other times animated, tumultuous, chaotic, raging. But the metaphor also has physical truth. In fact, 78% of the brain is water and electrical activity generated by clusters of neurons in the brain rapidly propagates in a wave-like fashion through this conductive medium. These weak electrical currents traverse tissue, bone and skin to be measured by electrical sensors on the scalp using electroencephalography (EEG). The activities and interactions of these neural generators -- or "sources" -- of EEG activity are dynamic and ever-changing, reflecting one's constantly changing thoughts, perceptions, and actions.

EEG Ocean borrows from the metaphor of mind-as-ocean in an effort to visualize complex brain dynamics in a manner that is at once scientifically informative, intuitive, and aesthetically engaging. Sources of EEG activity are algorithmically reconstructed from scalp EEG data using Independent Component Analysis (ICA), and each source represented as an "island" in a blue ocean. The estimated electrical activities of these sources over time are represented as waves "rippling" out from their respective source-islands. The color and geographical topography of an island corresponds to the projection map of its respective source onto the electrodes (e.g. the source's "scalp map"). In principle, a single frame of an ongoing *EEG Ocean* movie can represent the collective activity of a large number of sources over a long period of time, allowing a viewer to identify and appreciate complex patterns of neural activity emerging on a local or global spatiotemporal scale. For instance, repeated patterns of activity or oscillations, infrequent bursts or evoked activity, inter-source synchronization, or other structured phenomena may particularly stand out against the chaotic backdrop of ongoing neural dynamics.

Details on the algorithm are available at: http://www.antillipsi.net/research/EEGOcean

A frame from an *EEG Ocean* movie depicting up to 12.5 seconds of activity from selected EEG sources in a single individual's brain



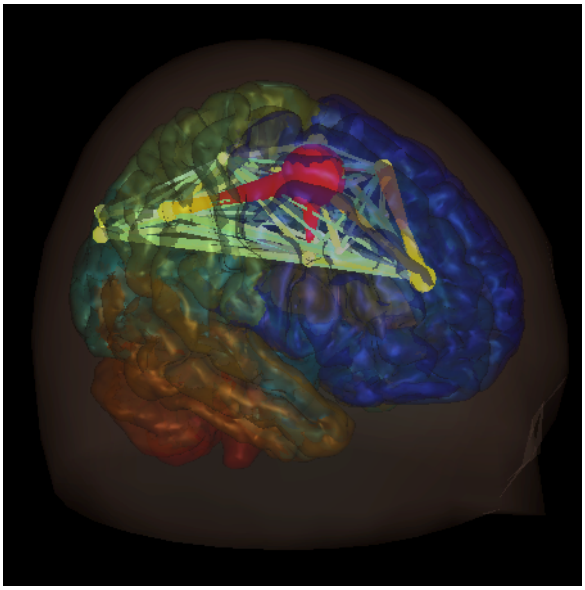
BrainMovie3D

Created by: Tim Mullen and Arnaud Delorme, with contributions from Christian Kothe and Alejandro Ojeda

In the 19th century it was widely accepted that the mind was comprised of various mental faculties, each housed in a separate brain region. The size of a brain region allocated to a given faculty was thought to reflect one's propensities or skill in that faculty. As such, by measuring the size of various brain regions -- or more specifically the indentations and protrusions of the encapsulating skull bone -- a phrenologist could deduce the total sum of one's personality and character. While modern neurological advances have long since led to the dismissal of phrenology as a pseudoscience, neuroscientists and neurologists widely accept that different regions of the brain are specialized for different functions. However, when we measure neural activity during cognitive tasks using electrophysiological techniques, we see complex spatiotemporal patterns of dynamic activity as multiple functional regions appear to activate and process information -- both serially and in parallel. One compelling theory of brain organization posits that cognitive information processing is subserved by dynamic patterns of information flow (connectivity or integration) between functionally specialized (or segregated) units. Under this view, the key to understanding the mind-brain complex relies not only on understanding the functional roles of various brain regions, but -- perhaps even more importantly -- it relies on understanding the structure and functional dynamics of the vast plexus of interconnections between various brain regions.

BrainMovie3D seeks to provide a window into the dynamic brain in the form of a three-dimensional representation of an individual's brain activity and network interactions. Functionally distinct sources of measured EEG activity are isolated using ICA and localized within the brain volume. An adaptive sparse vector autoregressive model is fit to these source time-series (Group Lasso, using the ADMM solver). This model captures temporal dynamics and multivariate interactions between these sources. From this we compute a measure of frequency-domain multivariate Granger Causality (directed information transfer) between sources, which allows us to visualize a dynamic network in the three-dimensional brain volume. By continually updating the statistical model and associated visualization based on data collected in real-time from an individual, one can gain insight into and appreciation for the ever-changing patterns of information flow and dependencies between specific brain regions. Along with many other uses, such technology might also be used to improve cognitive function in neurofeedback training, helping one modulate -- and over time, strengthen or weaken -- specific functional or effective dependencies between brain regions.

A BrainMovie3D frame showing transient information flow in a network of localized EEG sources



MindO & Cognionics Wearable EEG Demos

Contributed by: Yu-Te Wang, Lun-De Liao, Chin-Teng Lin, Tzyy-Ping Jung and Mike Chi with contributions from Christian Kothe, Arkadiusz Stopczynski, and Tim Mullen

Recent advances in microchip fabrication and sensor technology have made it possible to reliably and cheaply measure neural activity using wearable EEG sensors (e.g. mobile and lightweight, wireless, gel-free, "plug-and-play"). Concomitant advances in computing power and signal processing algorithms have led to significant improvements in the ability to isolate weak electrical currents, generated from coalitions of neurons in the brain, from the many other intrusive sources of electrical "noise" generated from eyes and muscles, surrounding electrical devices, and the sensors themselves. These advances, combined with powerful statistical machine learning algorithms, are making it possible to learn mappings between complex cognitive and sensorimotor states and information derived from EEG signals recorded from people in natural environments, performing everyday tasks. This is enabling us not only to expand our understanding of the human mind and develop improved clinical care, but also to develop new ways of allowing people to communicate thoughts, intentions, and emotions to the external world. Perhaps equally exciting, are the many new possibilities for exploring relationships between the inner mind and the external world in the context of music, dance, and other performing arts; for instance, exploring feedback connections between the neural activity and mental states and behavior of performers and audience.

Some of this cutting-edge EEG technology, developed jointly by researchers at UC San Diego and National Chiao Tung University in Taiwan, as well as at Cognionics (San Diego) is available for you to interact with. Feel free to don one of the wearable EEG headsets and within a matter of seconds, visualize your own brainwaves, BrainMovie3D, or real-time LORETA source reconstruction on a tablet, smart phone, or laptop. You can try some interactive brain-computer interface (BCI) demos, including a "NeuroPiano" wherein you can create simple musical compositions by fixating your gaze sequentially on the appropriate keys. Each key flickers at a unique frequency and focusing one's attention on a specific key generates a neural response at the same frequency (a "steady-state visual evoked potential" or SSVEP). This response can be measured every second and used to select and play the note associated with the attended key.

Caution: The NeuroPiano and other SSVEP demos are specific examples of an SSVEP brain-computer interface, which has been used repeatedly for assistive communication and control in individuals with severely impaired motor function. Although this technology is well established and perfectly safe for the vast majority of people, **we do not recommend it for individuals who suffer from photosensitive epileptic seizures.**

Three examples of current MindO wearable EEG headsets designed and built by Dr. Chin-Teng Lin and his associates at National Chiao-Tung University in Taiwan.

Acknowledgements:

We owe a deep debt of gratitude to all those who have contributed hardware, ideas, and time to the demos exhibited at this years Mozart and the Mind – without them, this would not have been possible.

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