Surrogate Musicianship in the Age of *In-vitro intelligence*: Redefining the Live Performer

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Improvised musical performances are collaborative acts that create unique musical events specific to a particular time and space. The entities producing sound have a distinct connection to their instruments, and each other, creating an unrepeatable temporal and environmentally dependent event. Progression of this interlinked connection between body, instrument, space and time will see future technologies of live music production cease to be divorced from the biological body but, with a clearer understanding of the biological embrace of music, will become post-corporeal. The complexities and nuances that only living entities can embody will become further pronounced with advancements in biotechnology giving rise to a new kind of musical entity. This entity is physically removed from the human but is linked through new lab-based processes in which biological ‘brains’ grown outside of the donor's body *(in-vitro)* control a music making hybridized entity or specifically, a surrogate musician. This essay proposes that the future evolution of live improvised musical events will occur through advances in our increased understanding of biology and the inherent coupling of sound with the body on the hormonal and cellular level.

cellF as a living instrument paves the way to this future. It is a collaborative project at the cutting edge of experimental art and music that brings together artists, musicians, designers and scientists to create the world's first biological neuron-driven synthesizer. cellF proposes a new direction in music performance and production where electronic analogue circuitry and biological material fuse. It first premiered in 2015 in

Perth, Australia and has since been featured in numerous international festivals in collaboration with improvising musicians who perform with cellF to create post-human sound pieces.

[Figure 1. Here]

Figure 1. cellF performing at the cell Block Theatre, Sydney, 2016.

Origins

Led by artist Guy Ben-Ary, the cellF team consists of musician Darren Moore, artist Nathan Thompson and electrical engineer Andrew Fitch, along with scientists Stuart Hodgetts, Mike Edel and Douglas Bakkum. The project began in 2012 when Ben-Ary received a fellowship from the Australian Council for the Arts to develop a biological self-portrait. An avid music lover, he decided to portray one of his juvenile dreams of becoming a musician. However, there was an issue; he couldn't play any instruments. His solution was to create his own alter ego musician to live out his fantasy.

The first step in developing cellF was to harvest Ben-Ary's own biological material. He took a biopsy from his arm and using Induced Pluripotent Stem cell technology (iPSc), he transformed his skin cells into stem cells in the labs of SymbioticA: The Centre for Excellence in Biological Arts at The University of Western Australia.[i] The iPSc method transforms adult specialized cells into a form that is equivalent to stem cells that are capable of becoming almost any other type of cell in the body such as liver cells, muscle cells or neurons. The process involves re-programming the cell's genome back to its embryonic state. When differentiating to neurons, stem cells first transform into neural stem cells and then into neurons. These neural networks are then grown over a Multi-Electrode Array (MEA) dish to become

Ben-Ary's external 'brain.' Human brains contain approximately 100 billion neurons, interconnected via trillions of synapses. The 'brain' used to control cellF contains approximately 100,000 cells making it a symbolic one to entice the viewer to consider future possibilities that these technologies could present. However, these networks do produce a large amount of data, respond to stimuli, are subject to changes in their plasticity and lifespan.[ii]

With cellF, the musician and musical instrument become one entity to create a cybernetic musician. The MEA dishes that host cellF's neural networks consist of a grid of sixty-four electrodes that are wired to an array of analogue modular synthesizers to produce sound. These electrodes receive electrical signals from the neural networks (action potentials) and can also simultaneously send stimulations back to the neurons. It is essentially a read-and-write interface to the 'brain' that allows external stimuli in the form of music to be input as electrical stimuli, so that the neural network is able to respond. Neural networks produce complex data sets and analogue modular synthesizers are well suited to reflect the quantity and complexity of information via sound. Furthermore, there is a similarity in the way neural networks and analogue modular synthesizers work. In both cases, voltages are passed through components to produce data or sound. cellF's neural interface creates a continuum between these two networks.

[Figure 2. Here]

Figure 2. Guy Ben-Ary's Neural Networks grown on a Multi-Electrode Array (MEA.).

Sound

The data from the neural activity provides the basic building blocks for the production of sound which resembles bursts of white noise. The fundamental objective of cellF is to use neuronal data to control analogue modular synthesisers, but this raw neuronal data by itself would arguably not be able to evoke the potential for the self-determinant emergence of the system. Thus, data is converted into control voltages to transform the action potentials (neural data) into synthesized sound. The patching of the modular synthesizer reflects the complexities of neural processes by offering a multitude of pathways that the neural data can travel. The patch cable connections between the different modules are a metaphor for synapse relationships in cellF's 'brain' that aim to both represent the activity of the action potentials and transform them. Additionally, the sound is spatialised to sixteen speakers placed around the performance space with the neuronal activity controlling the signal paths to each individual speaker. This spatialisation reflects the activity of the neurons on the MEA offering the sensation of walking through cellF's *in-vitro* 'brain' in real time.

cellF's synthesizer draws from the concepts of subtractive and additive synthesis of classic Moog, Buchla and Serge systems of the 1960s and 1970s, and includes feedback systems to highlight its self-determination. These feedback systems share similarities to those devised by Gordon Mumma and David Tudor in the 1960s and 1970s which Nyman (1999: 101) describes as 'feedback-type' systems 'whose circuitry works in a way analogous to feedback but which are also transformation devices.' Salter regards the feedback-type systems used by Mumma and Tudor as a critical shift from the emphasis of the score (and hence the composer) 'towards the real-time manipulation of parameters, both musical as well as those made possible through electronic circuits' (2010: 197). Rather than ushering in a new model for composition as suggested by Salter, cellF's aim is to create an autonomous system that requires minimal intervention.

The musical project with the closest links to cellF was David Tudor's Neural Synthesis (Warthman 1999), which used integrated circuits that mimic neural activity as the central driver in a chaotic electronic feedback system. cellF takes Tudor's piece to the next stage by using living biological neural networks. Neural Synthesis is also parallel in terms of using the unpredictability of chaotic electronic feedback systems to determine the musical output as opposed to scores or improvisation. This approach grew out of John Cage's chance operations and was also realized in the works of Tudor, Mumma and Alvin Lucier (Nyman 1999). cellF embraces this approach to suggest self-organizing musical entities in the future. cellF still requires the project team to set up the system but once the performance starts it operates autonomously. This approach puts the focus of cellF as the music maker as opposed to an instrument at the will of the composer.

cellF also references Alvin Lucier's 1965 work 'Music for Solo Musician' (Nyman 1999: 106) in which Lucier sits motionless in a chair with EEGs attached to his head as he induces a relaxed state to produce alpha brain waves. The alpha signals are used as a sound source and amplified through loudspeakers. Additionally, the signal is also used to control external instruments such as percussion through feedback-type triggering systems and stereo tape recorders that have pre-recorded versions of the alpha rhythms. Interestingly, Lucier's original vision for the piece included the alpha waves controlling whole environments that could include lights, TV's or radios paralleling cellF’s immersive spatialization of sound. Although the type of signal and sound producers are different, the use of brain signals or data to control instruments is shared highlighting the relationship between the ‘brain’ and the ‘body.’ The focus on manifesting the unseen and unheard into the visible and audible is shared in both works.

In John Cage's 1937 prophetic essay 'The Future of Music: Credo' (Cox & Warner 2001: 25), Cage echoes the declarations of futurist Luigi Russolo and composer Edgar Varese in stating that noise will be an essential element in the future of music. Russolo was the first to attempt to build noise-making machines and stated in the 1913 Futurist Manifesto (Cox & Warner 2001: 10-11) that traditional orchestral instruments did not adequately capture the spirit of modernity nor reflect the clamour of the machine age. He found orchestral instruments limited in timbre and called for new ways of making music that can incorporate ‘noise-sounds’ which he argued came into existence with the invention of machines. cellF places the use of neuronal noise, a primordial source, as a musical element at the forefront of sound production. However, cellF's connection with Russolo's noise-making machine, the *intonarumori,* is not only the use of noise as a musical element but also to reflect societal changes through the creation of instruments that comment on new technologies.

Rather than being limited to a more narrative-driven artwork that uses existing instruments, cellF was created to reflect bio-political issues concerning the future use of stem cells and the potential of bio-engineering brains by offering contestable futures and opening them to a public debate. As opposed to the Futurists that celebrated technology, machinery, violence, youth and industry, cellF is critiquing bio-technologies.

It uses them in a subversive way, attempting to problematize them by putting forward absurd and futuristic scenarios. Visual and aural strategies are employed to help lure viewers into exploring the artwork in a manner that draws them into a dialogue about the future of these technologies, and encourages them to re-evaluate their own perceptions and beliefs.

The fascination with the inventive modernity that created the gramophone, the intonarumori and early electronic instruments has instilled itself within the project through eschewing the digital in favour of the analogue. This approach has a twofold consequence; firstly, aesthetically referencing turn of the century modernity, imagining a world which developed independently to the information age and secondly, to highlight the ‘autonomous’ nature of the project. Digital interfaces such MATLAB are widely used in the scientific realm to interface with neural networks. The digitization of the project would have created another step in the translation of data which the project team wanted to avoid and thus the neural networks were interfaced directly with the analogue synthesizers. The team also wanted to move in opposition to the prevailing trend of artificial intelligence and computer-driven artistic practices towards biological materiality and electricity, which defines our existence as living entities.

[Figure 3. Here]

Figure 3. cellF’s synthesizers and neural interface patched for performance.

In vitro **intelligence vs artificial intelligence**

cellF’s ‘brain’ or wetware is made of bioengineered living human neurons that are grown into neural networks *in-vitro* over a specialized interface that allows input and output to and from the networks. The signals from the neurons are used to control an array of analogue modular synthesizers making it a wetware/hardware hybrid. It is not an artificial intelligence based musical robot that is driven by computer algorithms nor could it be seen as being controlled by natural intelligence. This distinction is important as cellF falls within a taxonomic void. We propose to refer to it as an entity that is controlled by '*in-vitro* intelligence'; intelligence that is produced by bioengineered living neural networks that are grown and function as 'brains' outside of the body.

cellF is a move away from the mainstream artificial intelligence narrative prevalent in today's technology-focused discourse. Neuroscientist Steve Potter (2017; Bakkum et al 2004), claims that the inevitable path to hybrid neural-synthetic entities will be paved in the future, predicting the same outcome that cellF suggests; the emergence of *in-vitro* intelligence. Potter is 'confident that hybrid wetware-hardware intelligent things will someday be as common and as useful as digital computers are today.' cellF as a 'wet-alogue' synthesizer is one possible application for hybrid neural-synthetic entities. Once it has been assembled, it performs autonomously; there is no programming or computers involved, only biological matter and analogue circuits.

Can a sound machine induce emotion in a human listener if it is algorithmically coded to mimic a human feeling? Will *in-vitro* intelligence enable us to elicit the same type of responses that a human musician can? Electronic dance music has arguably shown that machine created music is able to elicit emotional responses but the difference is that machines are used as tools and not as agents of music production. If the intent of instruction is imported from other frameworks will its fidelity and purpose be enough to hold our interest? Machines may well learn to generate sound, but can they evoke an emotional response in an audience increasingly aware of its existence and heritage? Hard coded devices with 'lifelike' properties may eventually be too overclocked to meet our needs and expectations. Much like emulating photographic filters to satisfy our nostalgia, embedded bias may emerge to become too difficult to ignore. The question remains; can instruments with the ability to learn through artificial intelligence make unique music in response to the moment or would it be derivative of the encoded decisions made in the past and would it hold long standing appeal to humans who are hard-wired to crave new experiences?

Contrary to the pervasion of machine learning, we envision a move to 'wet-tech' based instruments where life support systems facilitate a conducive environment for these entities to exist. However, can a living surrogate musician illuminate and extend music making while being detached from human physicality? cellF has shown that there are several things that are needed for this to eventuate; incubation, nutrition and interface. A surrogate musician will need a tightly regulated environment in order to survive and perform. This vessel can be called a bioreactor or incubator. Human neurons need 100% humidity at 37 degrees Celsius with ambient gas levels of CO_2 at 5% as well as near darkness or very low UV light. A purpose-built bioreactor as small as a pack of cards can supply this environment but consideration needs to be made for CO_2 tanks, power supplies and access for manual or automated feeding.

Human neurons grown outside of the body need to be fed every forty-eight hours and sterility is of utmost importance as contamination is fatal. Manual feeding requires a trained person to extract and replenish the liquid 'food' in a completely sterile environment. An automated system would be the best solution but this would increase complexity. cellF’s interface retains the integrity of the neuronal signal by limiting mediation and keeping it in the analogue realm, likewise the stimulation inputs from human musicians' sound maintains untranslated elements of their source. It is imagined that reading and responding to this kind of super-positional state will improve in resolution with advancements of lab-on-a-chip type components (Mobini et al 2019). Developments in the stability, regulation and automation of the incubation, nutrition and interface systems will need to be advanced in order to create self-determinant systems.

In-vitro intelligence and artificial intelligence are not neutral technologies, they are inherently political, so it is important we engage with them in a constructively critical way. How can they be used to further a healthy sympathetic relationship among individuals? cellF is a step towards an understanding of both the impending implications and the wild possibilities this technology holds. When we work with technology we are also engaging in a political act, we are reflecting on the use of devices from our techno-centric society and our inferred position in the new extended public sphere (Boeder 2005). Conversely, when straddling both art and science realms we posit questions about the most primordial aspects of what it means to be human. The discourse can go even deeper towards an understanding of how we got here and where we are going (Schulkin and Raglan 2014); this is what live music can and should do. Complicated machines need years of careful study before they can be used effectively. Is it not then logical to apply this knowledge to ourselves with the potential assembled within us over billions of years? In improvised music, musicians try to reassemble an emotional and intellectual puzzle in which the instruments present the means to understanding this enigma. Live interactions such as these show heightened activity in the motivation, reward, and pleasure regions of the human brain, significantly, ‘when subjects are performing mutually cooperative tasks that are rewarding, require empathy and an appreciation of social context and another person's feelings, there is increased activity in . . . several specific regions in the prefrontal cortex' (Harvey 2018). At a meta level, high-interdependent tasks where two or more humans who experience social flow (Walker 2010) while participating in a cooperative altruistic act such as improvisation (Rogers 2013), release high levels of oxytocin; the hormone that emotionally binds people (MacDonald 2010). Keeler et al (2015) found that 'circulating levels of the hormone oxytocin were found to be increased only under conditions in which singers were asked to improvise together.'

This binding of the participants is important when considering, among other things, the societal dilemmas we have faced in the past that we face today and increasingly will do into the future. The release of these hormones among musicians and audience members during live music events, not only improves the social bond in that particular time and space but it also increases the potential for the live improvised performance to be further nuanced and aligned to the participating entities' mental state. Music and biotechnology can have exciting far reaching benefits and surrogate musicians are well positioned to accelerate this via a merger between these elements. We suggest that the instrument itself be more closely aligned with the body in order to offer fluid symbiosis between the two.

Ethics

In the 21st century we are witnessing a unique cultural moment where the unprecedented evolution of bio-technology opens the path for the creation of various modes of liminal lives that defy traditional understandings of life. The existence of these liminal lives are practically and philosophically challenging. cellF attempts to problematize these emergent bio-technologies' influence on the shifting forces that govern and determine life, death and sentience. We are able to deconstruct, manipulate and re-assemble the microscopic building blocks of life in completely new ways and our bodies are malleable and fragile.

Since the era of enlightenment, philosophers have attributed the human brain with a great deal of importance as the primary organ that determines life or death. Ancient Egyptians and Greeks saw the heart as the primary organ that determined life, while early Christians and Hebrews believed life was indicated by the breath. However, when automated processes (breathing/circulation) were separated from sensation and volition (that was determined to be based in the brain), the move towards defining the brain as the pivotal organ of where life resides in the body began. Thus, with Descartes's famous declaration 'I think therefore I am', western philosophy established the anthropocentric belief that thinking is required before any living being can be granted human status. This distinctly modern philosophical paradigm placed the brain on a pedestal, and clearly marked the thinking brain as the primary signifier of individual existence or personhood within modern western culture. By literally creating a live 'brain' that controls a robotic body, cellF raises interesting questions regarding why we still seem to be ruled by an antiquated and distinctively modern historical form of personhood, and in turn, with cellF we ask: What does it really mean to be alive and be human in the 21st century?

CellF uses processes capable of transforming bodies or living biological material and makes use of new cybernetic technologies to re-evaluate our understanding of life and the human body. cellF addresses a ‘new materialist’ question, underpinned by the belief that artistic practice can act as a vector for thought. What is the potential for artworks using biological and/or robotic technologies to evoke responses in regards to shifting perceptions surrounding understandings of life, death, sentiency, and the materiality of bodies?

It is important to note that when working with living neurons, ethical questions are raised in regard to consciousness, intelligence and sentience. Questioning the neurons’ ability to feel pain is valid, whilst also understanding that the neural networks we work with currently only exist (as ‘brains’) in a symbolic realm. The question is, what happens in the future when their existence exceeds symbolism with advancements in technology? cellF attempts to initiate public debate regarding these possibilities and critique our belief that advancements in technology are deterministic. Other ethical questions that are relevant when working with neurons grown *in-vitro* are; what directions will emergent bio-technologies take us in the future, and what are our responsibilities to the liminal lives we create using these technologies? What kind of ethical boundaries will need to be established around these entities? Catts and Zurr (2003) state that 'it is important to critique the use of neurons for computational devices and the possibility of the creation of a sentient computer.’ Artworks using neurons, such as cellF, have the potential to evoke responses in regard to shifting perceptions surrounding the understanding of ‘life’; confronting the viewer, both instinctively as well as intellectually, and question the liveliness of the differential categories of life and death, human and non-human.

[Figure 4. Here]

Figure 4. Guy Ben-Ary's Neuronal cells at day 10 for differentiation.

Robotic musicianship

Ben-Ary's previous works MEART (2001) and Silent Barrage (2009) embodied rat neurons with robotic bodies to perform artistic functions (Ben-Ary 2014a,b.). cellF departs from his previous works by using neurons reprogrammed from his own skin cells. The embodiment of the neurons took a turn away from robotics that manifest data via movement towards a musical 'body' that uses electricity to generate sound. Although there are no moving parts, cellF still shares similarities with projects that deal with robotic musicianship.

In their article, 'A Survey of Robotic Musicianship' (2016:100-109), Bretan and Weinberg define this type of musical project as encompassing 'the construction of machines capable of producing sound, analyzing music, and generating music in such a way that allows them to showcase musicality and interact with human musicians.' They add that the robotic musicians usually employ artificial intelligence for identifying higher-level musical features essential to human musical cognition. Robotic Musicianship focuses on two primary areas; musical mechatronics, which are the physical systems that generate sound through mechanical means; and machine musicianship, which are generally algorithms representative of cognitive processes. The research into robotic musicianship is growing rapidly in current times and there are a large number of approaches and methods for the production of robotic musicians. Shimon and Z-machines are two examples of such projects.

Shimon, a project developed by Gil Weinberg (2017), a professor of musical technology at Georgia Tech, is an improvising robotic marimba player that is designed to create meaningful and inspiring musical interactions with humans. The robot uses artificial intelligence algorithms to produce acoustic melody-driven improvised music.

Shimon is capable of collaborating and playing in real time with human musicians excelling in changing musical styles through improvisation techniques. It is an anthropomorphic robot that creates familiar, acoustically rich, and visual interactions with humans. Moreover, it analyses music based on computational models of human perception and generates algorithmic responses that are unlikely to be played by humans. When collaborating with human players, Shimon can therefore facilitate a musical experience that is not possible by any other means, inspiring players to interact with it in novel ways, leading to innovative musical outcomes.

Z-Machines (2018), a project by Yuri Suzuki Design Studio, is an all-robot band built to perform beyond the capabilities of the most advanced human musicians. It features a 78-finger guitarist, a drummer with twenty-two arms, and a keyboard player that triggers notes using laser beams. The robots are programmed to play with strong efficacy which captured the attention of British electronic musician Squarepusher, who collaborated with Z-Machines on a project entitled 'Music for Robots.' Yuri Suzuki states that the challenge was to design a system that could play emotionally engaging music while rediscovering conventional instruments.

Shimon and Z-Machine's musical and analytical traits as well as their visual behaviour extends the definition of live music where non-human musicians play, improvise, respond and perform original and complex music at a level that was previously considered to be solely human. Although they are very different in their approach, methods and aesthetics, they are similar in their dependency on digital technologies and artificial intelligence. Their ability to demonstrate musicality, expressivity and artistry when improvising is directly related to their artificial ‘brain’. This ‘brain’, composed of algorithms and computer hardware, drives the robot’s behaviour, ability to learn, analytical skills and movements. Artificial intelligence is usually considered to be algorithmic-based intelligence expressed by machines as opposed to natural intelligence displayed by humans and animals. These algorithms are coded by humans to mimic cognitive functions such as learning or problem solving. cellF expands the definition of robotic musicianship through creating a system with a ‘body’ void of mechanics and with a ‘brain’ made of biological living neurons. Surrogate musicianship embodies the previously mentioned attributes of robotic musicianship but has direct biological links to its donor, whether they are musicians, non-musicians or non-human to be directly involved in musical activities.

Eschewing conventional robotics alleviates the numerous technical challenges that accompanies projects that aim to either imitate or enhance human musicianship. In addition, a project focused on robotics would ultimately be judged against the rubric of human musicianship. One of the goals of cellF is to place the audience and human performer in a position of encountering a new method of sound generation to encourage questioning and reflect on the ramifications of future musical and societal possibilities it poses. The absence of movement and the obfuscating of the sound production process forces the viewer to address how cellF works, challenging their own definitions and thoughts about what it represents and the future possibilities it suggests.

Surrogate musicianship

Surrogate musicianship gives rise to the possibility where *in-vitro* entities may manifest some inherited musical traits of the donor's biological material while also being able to produce, analyze and generate music in response to sensory stimuli in real time. Surrogate musicians could also display artistic expressivity of their own and be able to interact with other musicians via a cultured interface including but not limited to, neurons. It is conceivable that retinoids and cochlear hair cells could also be interfaced, further opening other avenues for creative inputs and outputs. The possibilities are potentially as diverse as the donors themselves, with the human musician being able to create an external surrogate to engage in musical activities with their own or biological material from any other living being.

When musicians improvise, they communicate through the sound of their instruments being manipulated by their bodies and gestures. We refer to these as the communicative pathways. These pathways will shorten as biological technology advances and the performer-surrogate overlap to eventually merge, potentially bringing closer the participating biological entities and human musicians. This overlap can be experienced with cellF where human collaborators have a direct connection to the neural activity of another entity through using the sound they produce as stimulation. In particular the intricacies and chaos inherent in live sound transactions and the production of cellF's sound from the very element that the neurons produce. The path of communication between performer and instrument is free from render and becomes an 'open wire' where we can observe and question our physical inhabitancy. cellF's live performances asks the viewer to critically assess the technology we invite into our lives and how it can potentially change us.

The act of improvisation requires acute openness and abandonment of expectation to bypass conscious thought and access instinctive reactions. Human to non-human improvisations will need a latent free system in order to reach human-level response times. Akin to the unbiased receival of sound by the unborn making sense of its environment, we see the divergent thinking methods of human curiosity as the ingrained arbiter of progress, value and intent. Linking seemingly unrelated elements with intent is in particular what makes human creative work unique, a move away from pre-emptive hard logic systems may lay the foundations for advancement in this area. An artificial intelligence driven agent is a tabled episode of pre-arranged instructions whereas an *in-vitro* agent responds organically to stimuli. *In-vitro* intelligence will produce surrogate musicians that will neither be chance orientated nor deterministic but spontaneous and contemporaneous. These living entities will be both the instrument and the musician; seamlessly flowing from input to output, extending our ability to listen and forcing us to reconsider the borders of humanity.

Several musicians that have played with cellF have commented that although their performance was unlike any other musical collaboration that they had experienced, that there was a definite connection and clear interaction from the neurons to the musician’s stimuli. cellF’s configuration for performances aims to balance unpredictability and measured response akin to the interactivity between human musicians. Author Darren Moore recalls cellF following a similar improvisational arc in response to his drumming giving form to the performance with definite sections. For Moore and other collaborators, the sensation was that the neurons were listening and responding to ideas in a way not dissimilar to performing with other musicians, yet in a unique way. Surrogate musicianship could offer a different pathway for improvisational interaction rather than aiming to be human-like making the choice to engage with surrogate musicians an aesthetic one.

The constituent materials of the machine are perhaps more important than are credited. As an instrument made of metal produces a different tone to one made of wood, the differences in the makeup of the musician will also affect the output of sound. A musician made of dry plastic, alloy and electricity will have markedly different expressivity to one made of wet, organic materials. Furthermore, the structure will embody the processes specific to its history. The biophysical and electrochemical pathways in self-organizing biological organisms allow fast information flows that synchronize at a macro-scale level much faster than could occur in similar-scale structures of materials like silicon or metal. The complexity and speed of information pathways at both the micro and macro levels will facilitate the surrogate musicians' capacity to perform hyper-nuanced operations in real time in response to audible, and potentially visual, stimuli.

[Figure 5. Here]

Figure 5. cellF performing with Darren Moore (drums) and Clayton Thomas (bass) at the cell Block Theatre, Sydney, 2016.

Conclusion

The potential and ramifications for these bio-technologies extends beyond music. As cellF broadened the application of iPSc and neural interfaces from their original intentions, the developments in bio-technology will force us to ponder what makes us human and where the boundaries of this term exist. cellF is positioned to redefine our understanding of live performance through questioning 'who' or 'what' can be involved in improvisational practices. Additionally, by creating a new framework of music production, the very act of interacting with surrogate musicians inevitably changes the musical approaches of human musicians.

The surrogate musician has the potential to enter into live improvisational contexts possessing complexities that are not governed or controlled by us but are from deep within us. As experienced musicians are able to access their subconscious processes to get them into ‘the zone,’ surrogate musicianship may offer a fast-track to this process, making it a regular state rather than an ethereal intangible quality. The future may see musicians offering their cell-lines or their completed surrogate musician to enter into performative contexts without the need for the donor to be present. This paper proposes the emergence of in-vitro intelligence; a central element in the creation of the surrogate musician and predicts its integration into the production of music and sound but also beyond that, into our daily lives. Entities that extend the possibilities of music production beyond the limitations of the human body like cellF, reinforce the biological importance of improvised music and are a harbinger of future trends in robotic and surrogate musicianship, forcing us to question what it means to be human in the 21st century.

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[i] iPSc technology was pioneered by Professor Shinya Yamanaka who showed that the introduction of four specific genes could convert adult cells into pluripotent stem cells. Yamanaka was awarded the 2012 Nobel Prize, along with Sir John Gurdon, for the discovery that mature cells can be reprogrammed to become stem cells.

[ii] Plasticity in neuronal networks is a phenomenon that is well established in the neuroscience community, and one that is thought to play a very large role in learning and memory (Wagenaar et al 2006).