CHAPTER 32

cellF: Surrogate musicianship as a manifestation of *in-vitro* intelligence

Vahri McKenzie, Nathan Thompson, Darren Moore and Guy Ben-Ary

32.1 Introduction

cellF 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 analogue modular synthesizer. It combines biological material with electronic circuitry, presenting a new direction in music performance and production. Advancements in biotechnology enable biological neural networks to be grown in the laboratory and outside of the body, that is, *in-vitro*. Such entities are directly linked to the human donors of their biological material, yet physically removed from any human body. At the same time, these are living entities with a degree of autonomy that grow and change with an innate vitality in response to an environment. Thus, in its autonomy and plasticity, *cellF* represents a new kind of entity that can be described as possessing '*in-vitro* intelligence', which is distinct from both natural and artificial intelligence. The characteristics of autonomy and plasticity demonstrated by *cellF*, which will be elaborated below, show not only that it is a living musical instrument, but a musician in its own right: a 'surrogate musician' who symbolically represents the human donor of its biological material. *cellF* is a music making hybridized entity: the biological neural network or 'brain' processes data, inputs and outputs, and is extended and embodied with analogue synthesizers and other electronic analogue circuitry. This paper argues that *cellF*'s autonomy as a music-maker constitutes the description of surrogate musician possessing *in-vitro* intelligence.

32.2 Origins and Development of the Work

cellF 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 posthuman sound pieces. 'Posthuman' is used not in a narrow sense that signals a hoped-for transcendence of the human body and its materiality, which fails adequately to account for the complexity of corporeal existence. Rather, we use the term as part of a broader critique of humanism and its certainties regarding the value and agency of human beings, at the expense of non-human entities. 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 Australia Council for the Arts to develop a biological self-portrait. An avid music lover, Ben-Ary wished to realize a juvenile dream and portray himself as a musician. The fact that he could not play any musical instruments was an issue addressed through Ben-Ary's creation of a biological alter ego that could live out his fantasy.

A key objective of *cellF* is to use the raw neural activity occurring in its 'brain' to produce sounds (which resemble bursts of white noise) with analogue modular synthesizers. The first step in its development was to harvest Ben-Ary's own biological material. He took a biopsy from his arm and, using induced pluripotent stem cell technology (iPSc), 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. The process involved re-programming the cell's genome back to its embryonic state using iPSc technology that was pioneered by Professor Shinya Yamanaka, who showed that the introduction of four specific genes could convert adult cells into pluripotent stem cells. The iPSc method transforms adult specialized cells into a form that is equivalent to stem cells, which are capable of becoming almost any other type of cell in the body, such as liver cells, muscle cells or neurons.

When differentiating to neurons, stem cells first transform into self-renewing and multipotent neural stem cells, and then into neurons. In *cellF*, cultures of neurons are grown in networks over a Multi-Electrode Array (MEA: a standard device that connects neurons to electronic circuitry in order to send and receive neural signals) to become Ben-Ary's external 'brain' (Figure 32.1). Human brains contain approximately 100 billion neurons, which are interconnected via trillions of synapses. *cellF*'s 'brain' contains approximately 100,000 cells, making it a symbolic brain that introduces new ways of thinking about intelligence in hybrid entities. Like a human brain, however, *cellF*'s neural network produces a large amount of data, responds to stimuli, and is subject to changes in behaviour and lifespan. Plasticity – an organism's adaptability to change – is a property of cellular, that is, natural intelligence. Plasticity in neural networks is a phenomenon 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). *cellF*'s brain exhibits change in behaviour in response to stimulations, demonstrating plasticity sufficient to entice audiences to consider the future possibilities that iPSc technologies present.

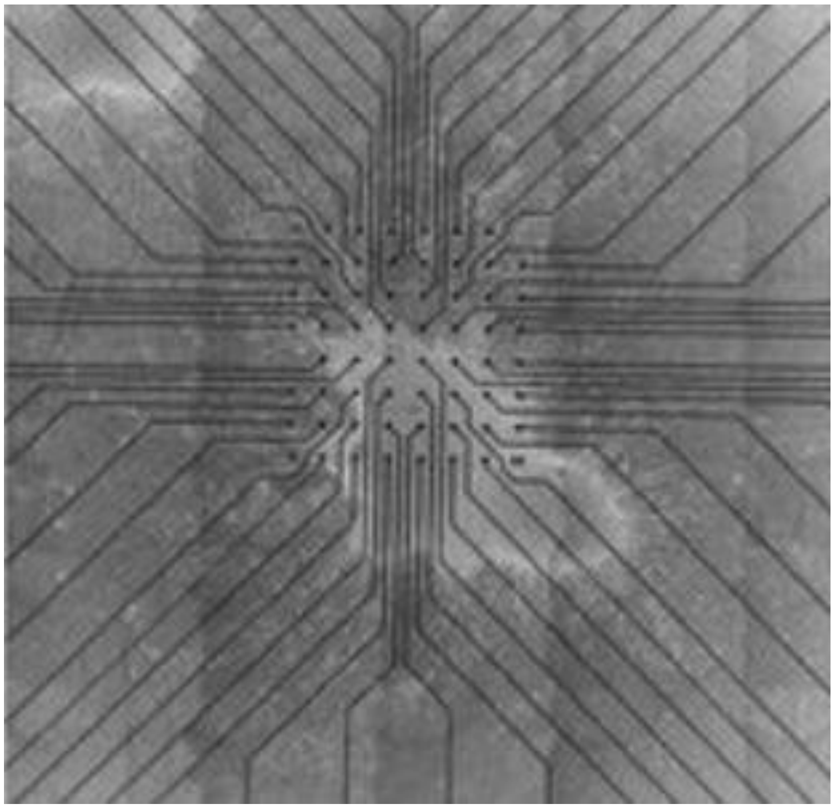

Figure 32.1: *cellF*'s 'brain': Guy Ben-Ary's neurons growing over the Multi-Electrode Array interface

The MEA dish hosting *cellF*'s neural network consists of a grid of sixty electrodes wired to an array of analogue modular synthesizers that produce sound. The activity of the neural network produces electrochemical data in pulses known as action potentials that are received by the electrodes. These electrodes simultaneously send electrical stimulations back to the neurons in the form of synthesized sound that is produced and controlled by a human musician. Thus, the system allows data to move between *cellF*'s brain and electronic analogue circuitry so that the neural network is able to respond in real time. In so doing, *cellF* demonstrates autonomy: receiving inputs and spontaneously responding to them, as with biological life. Although one is biological and the other is electronic, surprising similarities between neural networks and analogue modular synthesizers make them well matched: both systems produce complex data sets, with multiple inputs and outputs operating at micro-second speeds. Moreover, in both neural networks and analogue modular synthesizers, electrical information moves through components to produce data in the form of voltages. *cellF*'s neural interface creates a link between these two networks such that it operates as a single entity, like a body and brain working together.

cellF's neural activity produces electrical signals that are received by the MEA's electrodes, which passes them into *cellF*'s specially designed interface. The interface amplifies the signals from millivolts to volts and routs them to the synthesizers, where they are transformed into control voltages (the standard analogue method of controlling synthesizers). While the neural activity itself has no sound, the amplified electrical signals, transformed into control voltages, become synthesized sounds by patching into the modular synthesizer. Patching manages sound tone and pitch, and gate signals determine sounds as on or off; the innumerable patching options available offer a multitude of pathways for the neural data to travel and reflect the complexities of neural processes.

On one level patching choices are arbitrary and symbolic, with the patch cable connections between the different synthesizer modules offering a metaphor for synapse relationships in *cellF*'s brain that represents the activity of the action potentials.

Additionally, the team's creative decisions are revised for each performance, informed by such considerations as the nature of the performance space and the collaborating human musician, whose performance takes into account which frequencies will be received by *cellF* as a result of patching choices set up prior to performance. The configuration aims to balance unpredictability with a measured response that is akin to the interactivity occurring between improvising human musicians, illuminating *cellF*'s autonomy. For each performance, the sound is spatialized to sixteen speakers placed around the performance space, with the neural activity controlling the signal paths to each individual speaker, such that the speaker outputs spatially reflect the activity of the neurons in the MEA. This spatialization amplifies and abstracts the neural activity, offering audiences the opportunity to experience moving through *cellF*'s *in-vitro* brain in real time. *cellF* requires the project team to set up the system, but once the performance starts it operates autonomously (Figure 32.2).

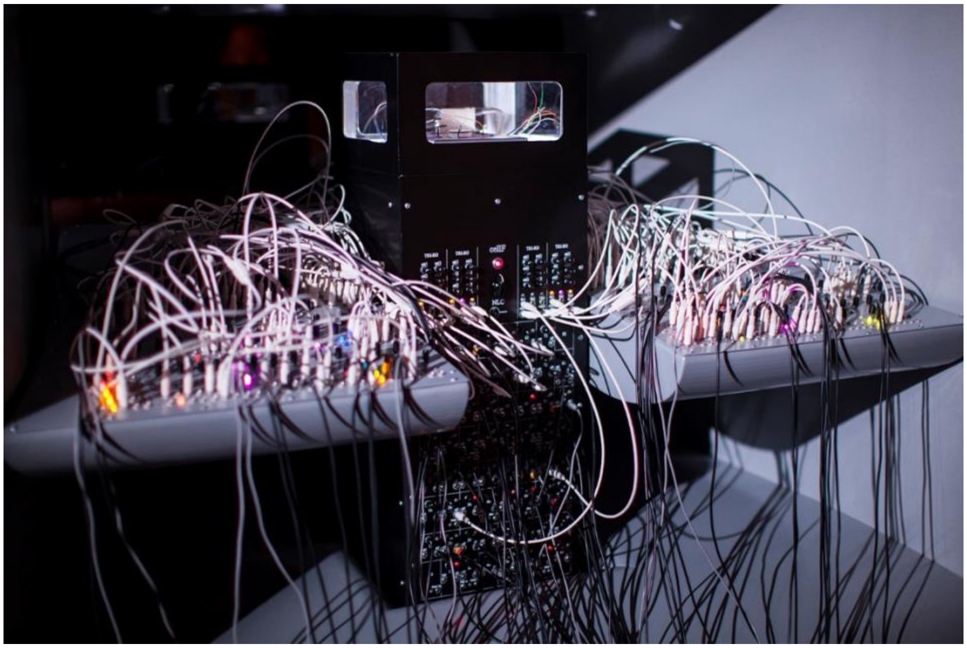

Figure 32.2: *cellF*'s neural interface and sound producing body

In order to survive and perform, *cellF* requires incubation, nutrition and an interface with its embodiment. Incubation occurs within a tightly regulated environment. 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. Human neurons grown *in-vitro* need to be fed every forty-eight hours. *cellF* is manually fed, which requires a trained person to extract and replenish the liquid ‘food’ in a completely sterile environment; sterility is of utmost importance as contamination is fatal. *cellF*’s development and ongoing existence demonstrate its autonomy, so long as the conditions required to support its life are met. *cellF*’s plasticity is evident once the system is embodied with synthesizers, which enables its transformation expressed through sound. These characteristics support our claims, which will be elaborated below, that *cellF* represents an early form of *in-vitro* intelligence. Before that, the following section will explore some of the aesthetic concerns that informed *cellF*'s design and creation.

32.3 Influences from the History of Modern Music

Composer and music theorist John Cage is significant to this project for his pioneering use of electroacoustic instruments, as well as his philosophy of composition that decoupled the score from the sound of music in performance. Cage's influential 1937 essay 'The Future of Music: Credo' echoes the declarations of Italian Futurist Luigi Russolo in claiming that noise will be an essential element in the future of music (Cox and Warner, 2001). Luigi Russolo was the first to attempt to build noise-making instruments, *intonarumori,* and argued in the Futurist Manifesto *The Art of Noises* (1913) that traditional orchestral instruments did not adequately capture the spirit of modernity nor reflect the clamour of the machine age (Cox and Warner, 2001). Russolo called for new ways of making music that incorporate 'noise-sounds', which, he argued, came into existence with the multiplication of machines. It is no longer controversial to consider any arrangement of sounds as potentially musical, and *cellF*'s use of neural noise-sound heeds Russolo's call. Yet *cellF*'s connection with 'The Art of Noises' and *intonarumori* goes beyond the use of noise as a musical element by reflecting Russolo's concerns with societal changes and the creation of instruments that critically engage with new technologies.

Where the Italian Futurists celebrated new technologies and violence, *cellF* critiques biotechnologies by using them in a subversive way. Rather than applying iPSc to more strictly utilitarian ends, *cellF* proposes an absurd and futuristic scenario in which biotechnologies are widely available. By using sophisticated biotechnologies in a playful and complex work of art, *cellF* problematizes an imagined scenario in which such technologies are ubiquitous and considered an unexamined boon. This claim is supported by the creative team's aesthetic choices. Rather than embodying *cellF* with existing instruments, the team used innovative visual and aural strategies that encourage audiences to explore the work, engage in a dialogue, and re-evaluate their perceptions and beliefs regarding musicianship. The work avoids the clinical aesthetics of the laboratory with which biotechnological arts are more usually associated, opting instead for the dark environment of a rock concert. With its large black spiral-shaped horn, *cellF*'s design aesthetically recalls the history of amplified sound and the development of twentieth century electronic instruments (Figure 32. 3).

Figure 32.3: *cellF* performing in the Cell Block Theatre, Sydney, 2016

Furthermore, a 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. In contrast with digital functionality, which symbolically represents all information in binary code, analogue information is represented in continuously variable physical quantities. Applying this preference to *cellF* has a twofold consequence; firstly, it aesthetically references twentieth century modernity and imagines a world that developed independently from the digital information age. *cellF* moves against the prevailing technoscience trends that favour artificial intelligence and computer-driven artistic practices towards the biological materiality and electrical activity that defines our existence as living entities. Secondly, an analogue approach highlights *cellF*'s intrinsically autonomous and unmediated nature. Whilst digital interfaces such MATLAB are widely used in the scientific realm to interface with neural networks, digitization requires the symbolic encoding of data. Rather, *cellF*'s neural network interfaces directly with analogue synthesizers, retaining the integrity of the neural signal and the autonomy of *cellF*'s brain. Similarly, stimulation inputs in the form of sound received from the human musician performing alongside *cellF* travel unprocessed through the interface (according to patching into the analogue synthesizers), and *cellF* responds to the stimulations it receives with a barrage of action potentials. *cellF*'s plasticity is realised, as with biological life, due to the real time changes in physical properties (in the form of electrical signals) occurring between the neural and synthesiser systems that function as a single entity.

cellF's synthesizers draw from the concepts of subtractive and additive synthesis of classic Moog, Buchla and Serge systems of the 1960s and 1970s, and include feedback systems (in which an output signal is received as an input signal, increasing resonance) in order to highlight its self-organization. These feedback systems share similarities to those devised by Gordon Mumma and David Tudor in the 1960s and 1970s that Michael Nyman (1999) describes as 'feedback-type' systems, 'whose circuitry works in a way analogous to feedback but which are also transformation devices'. The distinction here is that 'feedback-type' systems are compositional technologies producing particular musical results that are not entirely controlled by human musicians. For example, in Mumma's *Hornpipe* (1967), a horn is modified with an analogue computer that monitors the horn resonances and complements them with further resonances that cause further sound responses. Salter regards the feedback-type systems used by Mumma and Tudor as marking a critical shift in experimental music, from an emphasis on the score (and hence the composer) ‘towards the real-time manipulation of parameters, both musical as well as those made possible through electronic circuits’ (Salter, 2010). However, where Salter’s analysis points towards a new model for composition, *cellF* moves towards an autonomous system that requires minimal intervention due to the autonomous nature of biological neural networks.

Two musical projects providing important historical reference points for *cellF* are Alvin Lucier’s *Music for Solo Performer* (1965) and David Tudor’s *Neural Synthesis* (1995). To present *Music for Solo Performer*, Lucier sat motionless in a chair with electrodes attached to his head as he induced a relaxed state to produce alpha brain waves. The alpha signals were used as a sound source that was amplified through loudspeakers, which in turn controlled external percussion instruments through the movement of speaker cones or the motion of the surrounding air. Although the type of signal and musical instruments are different, both *cellF* and *Music for Solo Performer* use brain data to control instruments and render visible and audible the unseen and unheard. Tudor’s *Neural Synthesis* (1995) used integrated circuits that mimic neural activity as the central driver in an electronic feedback system. Like *cellF*, *Neural Synthesis* used the unpredictability of electronic feedback systems to determine the musical output, a process entirely different from scored music. *cellF* takes Tudor’s project to the next stage by using living biological neural networks as the source for the feedback system.

Using feedback systems in new music grew out of John Cage's radical reframing of musical composition as a means of structuring events in time (Nyman, 1999). First performed by David Tudor in 1952, Cage's *4'33"* showed that composition was a process with no determined relation to sound in performance. While Cage pioneered indeterminacy in composition by using chance processes at the level of composition, performer choice was limited (Dezeuze, 2002). The increasingly important role of performer choice in experimental music was realized in the works of Tudor, Mumma and Lucier, whose works ceded some of the authorial control traditionally exercised by composers in order to open up new musical possibilities with electronics. As with improvising musicians, where composer and performer are one and the same, their works gesture towards the self-organizing musical entities of the future. However, where decisions made by an improvising human musician are guided by training and tradition, *cellF*'s self-organizing musicianship is not. We have established that *cellF* is a musical entity, and, like a human improvising musician, both composer and performer. Emerging technologies of live music production will develop new musical genres and new instruments. Of more interest to the authors of this paper, future technologies of live music production will likely develop new relations between bodies and instruments, where robotic musicianship is one valid direction.

32.4 Influences from the Field of Robotic Musicianship

A number of Guy Ben-Ary's earlier works have been influenced by the field of biorobotics. *MEART* (2001) and *Silent Barrage* (2009) embodied rat neurons with robotics to perform artistic functions (Ben-Ary, 2014a; 2014b). Each used the movement of the robotic body to represent data. *cellF* departs from those works in two important ways: by using neurons reprogrammed from the artist's own skin cells, and through a musical embodiment that uses electricity to generate sound. Although there are no moving parts, *cellF* shares similarities with projects that deal with robotic musicianship. Bretan and Weinberg's survey of robotic musicianship describes it as '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' (Bretan and Weinberg, 2016). Robotic musicianship focuses on two areas: musical mechatronics studies the physical systems that generate sound through mechanical means, and machine musicianship develops algorithms representing higher-level musical features essential to human musical cognition. Two examples illustrate these features.

Shimon, developed by Gil Weinberg (2017), is a robotic marimba player that improvises with a human musician; see also Weinberg's chapter in this volume. With arms and a head that mimic human communicative gestures, Shimon creates familiar, acoustically and visually rich interactions with humans. Moreover, Shimon's artificial intelligence produces musical responses that are unlikely to be achieved by humans and so facilitates a unique musical experience, which may lead to innovative musical outcomes. Shimon uses artificial intelligence to melodically respond to the human musician's movements and to learn from historical performances of great jazz musicians (Bretan and Weinberg 2016: 107). The human is the standard by which Shimon is guided, and designed to exceed, which contrasts with *cellF*'s less familiar form of musicianship. 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. The band members have an anthropomorphic appearance, with important differences: Z-Machines features a seventy-eight-fingered guitarist, a drummer with twenty-two arms, and a keyboard player that triggers notes using laser beams. The robots have collaborated with British electronic musician Squarepusher, who composed *Music for Robots* (2014) for Z-Machines to perform. The challenge for Yuri Suzuki's Studio was to design a system that could play emotionally engaging music while rediscovering conventional instruments. This, too, illustrates an important difference with *cellF*, which deliberately avoided an embodiment recalling conventional musical instruments, in order to encourage new modes of audience engagement.

Shimon and Z-Machines' musical and analytical traits, as well as their visual behaviour, extends our understanding of musicians and live music. These are non-human musicians with the ability to play music, improvise, respond and perform original and complex music, at a level that was previously considered to be sole preserve of human musicians. While each project presents a distinct approach and aesthetic style, they share a dependence on digital technologies and artificial intelligence that drives the musicians' behaviour, movements, analytical skills and ability to learn. Artificial intelligence is grounded in algorithms that are programmed by humans to mimic cognitive functions such as learning or problem solving. As is seen with the anthropomorphic appearance of Shimon and Z-Machines, and their use of algorithms that are designed to mimic human functionality, robotic musicianship is judged against the rubric of human musicianship.

In contrast, *cellF* eschews anthropocentrism in appearance and behaviour; it does not use the human as the model against which other entities are judged. Where robotic musicianship generally creates interest through the spectacle of complex moving parts, *cellF* has none. The lack of movement works against ocularcentrism, the perceptual and epistemological bias evident in Western culture that ranks vision over other senses. Movement in robotic musicianship reveals the sound production process, but with *cellF*, as with other electronic music, the sound production process is obscured. *cellF* challenges Bretan and Weinberg's definition of robotic musicianship. It generates music and demonstrates musicality through interacting with a human musician, but *cellF* is more than a machine: its body is void of mechanics and it has a 'brain' that is made of living neurons. Audiences of *cellF*'s performances with a human musician are required to interpret their experiences primarily through sound, which encourages consideration of what is new and challenging, and the future possibilities the experience suggests. It is a musical entity with sufficient autonomy and plasticity to stand in for a human musician in an improvised duet. It does so in a new way, as a living instrument existing outside of a human body, in which musical instrument and musician are one entity.

32.5 *In-vitro* Intelligence

cellF represents an interesting and provocative move away from Artificial Intelligence (AI) enquiries that dominate our current technology-focused scientific discourse. It is not an AI musical robot driven by computer algorithms; at the same time, it lacks the complexity of natural intelligence and requires a hardware body to provide stimulation for its *in-vitro* ‘brain’. As described above, *cellF*’s brain is made of bioengineered living human neurons that are grown into neural networks, interfaced such that inputs to and outputs from the networks control an array of analogue modular synthesizers, making it a wetware-hardware hybrid. ‘Wetware’ refers to the networks of neurons and other cell types that form the control systems of biological life. It is the basis of natural intelligence, which is contrasted with AI.

cellF is neither ‘naturally’ nor ‘artificially’ intelligent, yet it behaves in an apparently ‘intelligent’ way. Russell and Norvig (2009) outline four main approaches to understanding artificial intelligence that can be summarised as thinking and behaving humanly, and thinking and acting rationally. Behaving like a human, as in the familiar Turing Test (Turing, 1950), remains an accessible way to understand artificial intelligence, reflected in the anthropocentric ideals of the examples of robotic musicianship described above. In order to reach such an ideal, it is necessary to understand the underlying principles of intelligence, and this goal is pursued through cognitive modelling to enable machines to demonstrate human-like learning and problem solving. However, it is important to note that these are not the same as human intelligence, and that the principles underlying intelligence are not well understood. Thinking and acting rationally extracts the *practice* of human intelligence, which can accommodate a degree of uncertainty, into generalisable *theories* subject to mathematical modelling, known as the rational agent approach to artificial intelligence (Russell and Norvig, 2009). This is, at best, a flattened approximation of natural intelligence.

Artificial Intelligence, which in its current manifestations is more accurately described as Machine Learning, requires vast amounts of data that can be searched for patterns in order to make inferences, but thinking and intelligence are much more complex and nuanced than that. AI has achieved incredible results in situations where it is possible to acquire a complete set of rules governing any given situation. Consider the artificially intelligent computer program AlphaZero, which is able to beat any human or AI player in games such as chess and go, by learning from playing against itself more times than are possible for any other human or machine. Where older versions of similar programs had learned from historic game play (as Shimon learned to improvise by studying the historical performances of great jazz musicians), AlphaZero learned from massive calculation alone and achieved unlikely wins as a result. In information games like chess and go there is no ambiguity in the rules and what constitutes 'winning'.

The operations of natural intelligence, on the other hand, rely on much more than calculation and rational decision-making. The operation of natural intelligence is distributed across brain, body, and world, and 'it is in the operation of these extended systems that much of our distinctive human intelligence inheres' (Clark, 2003). As Andy Clark acknowledges, the notion of situated and distributed cognition is not new. What is particularly useful in Clark's analysis for our discussion of *cellF* is his recognition of the ways in which human brains 'dovetail' their problem-solving activities with technologies in order to form larger systems that change and evolve. We draw attention to two important features of this plasticity in natural intelligence to support our claims for *cellF*'s intelligence. The first relates to the liveness of change: it happens in real time, like a musical improvisation. More than the information feedback required for machine learning, transformation can occur because the system of natural intelligence is open to other systems in a 'complex reciprocal dance'; 'the brain tailors its activity to a technological and sociocultural environment, which – in concert with other brains – it simultaneously alters and amends. Human intelligence owes just about everything to this looping process of mutual accommodation' (Clark, 2003). The second important feature is that the other systems with which human intelligence 'dances' are different from it. The use of hand tools and the technologies of reading and writing are two of the more familiar examples of technological and sociocultural systems that have wrought immense changes to human thought, behaviour and society, as Havelock's (1963) and Ong's (2012) theories of the transition from oral to literate cultures show. We are Clark's 'natural-born cyborgs': 'Ours are (by nature) unusually plastic and opportunistic brains whose biological proper functioning has always involved the recruitment and exploitation of nonbiological props and scaffolds' (Clark, 2003). Natural intelligence has evolved within a technological and cultural world from which it cannot be definitively separated, and it is these complex relations that enable the plasticity with which natural intelligence is distinctively associated.

Neither an artificial intelligence nor a natural intelligence, *cellF* falls within a taxonomic void. In the absence of terminology that adequately accounts for *cellF*'s autonomy and plasticity, demonstrated through its capacity to make music and duet with a human musician, *cellF* is best understood as an entity possessing '*in-vitro* intelligence': an intelligent system produced by bioengineered living neural networks that function as brains outside of the body. We grant that *cellF* represents a very early form of *in-vitro* intelligence, yet the characteristics of its neural network suggest that it, or others like it, will demonstrate changes in functional plasticity, just as naturally intelligent entities do. The biological basis of *in-vitro* intelligence is subject to unanticipated change in a way that programmed AI entities are not. Artificial intelligence will achieve increasing calculation speeds, but the fundamental processes will remain the same, with a fixed material basis that constrains unanticipated change. Like naturally intelligent entities, *cellF*'s hybridity constitutes an openness to other systems that Clark and others argue supports the emergence of new intelligences: 'it is the semi-autonomous machines that hold out the best prospect of one day constituting integral parts of distributed, biotechnological, hybrid intelligences' (Clark, 2003). Neuroscientist Steve Potter (2017) claims it is inevitable that neural-synthetic hybrid entities will grow more sophisticated and find widespread applications: 'hybrid wetware-hardware intelligent things will someday be as common and as useful as digital computers are today' (Potter, 2017; Bakkum et al. 2004). As a wetware-hardware hybrid, *cellF* suggests just such an outcome, and we theorize its existence by developing a description for this phenomenon as the emergence of *in-vitro* intelligence.

Such a phenomenon suggests some exciting possibilities. Artificially intelligent entities are limited by the mathematically coded instructions they receive in symbolic language, which restrains the degree to which they can accommodate ambiguity or complexity, such as is required for emotional engagement. Emotions are too complex to be reduced to symbolic language, and are inextricably linked to specific contexts and environments. On the other hand, an entity grounded in neural networks exhibits some plasticity and so has the potential to achieve the openness to other systems and real time responsiveness required for emotional engagement. Entities with *in-vitro* intelligence demonstrate meaningful connections to human life not through human-like behaviour, appearances or thought, but through a shared cellular structure that is soft and full of salt water. Indeed, *cellF* has *direct* biological links to its donor. Its basis in biological life means that *cellF* is a living musical instrument; moreover, in its capacity to produce music and engage with a human musician in its human donor's stead, *cellF* is a musician in its own right; a 'surrogate musician'.

32.6 Surrogate Musicianship

Surrogate musicianship embodies the previously mentioned attributes of robotic musicianship – the ability to produce, analyze and generate music in response to sensory stimuli in real time – as well as combining musical instrument and musician in one living entity. Moreover, this new term offers something else: as is signalled in its name, surrogate musicians like *cellF* have direct biological links to their donors, enabling the surrogate to symbolically represent the donor, and, potentially, to stand in for the donor in other ways (Figure 32.4). Regardless of whether the donor is a musician or not, human or not, they have some involvement in the musical activities of the surrogate musician.

Figure 32.4: *cellF* performing with defunensemble, Science Centre Heureka, Helsinki, 2019

To consider the term ‘surrogate musician’, it is useful to look at one of the situations with which it forms an analogy, that of surrogacy in human reproduction. This is a form of assisted reproductive technology in which a woman carries and gives birth to a baby on behalf of someone else. Gestational surrogacy involves the surrogate being implanted with an embryo via in-vitro fertilisation, so that the surrogate is entirely genetically unrelated to the donors of sperm and egg. Traditional surrogacy uses donated sperm and the surrogate’s own egg, so that the resulting baby is genetically related to the surrogate. Tracing the relevant terms of reproductive surrogacy in the context of *cellF* aligns Guy Ben-Ary, as the donor of biological material, with the role of the genetic parent. *cellF* is incubated in a fully technologized manner, eliminating the role of the 'surrogate mother' in this scenario. The resulting 'child' is *cellF*, the 'surrogate musician'. The experience of the child that results from a surrogacy arrangement is an under-researched area; a systematic review revealed methodological limitations and uncertain results (Söderström-Anttila et al., 2016). Risks relate to the child's knowledge of their origins and the implications for their developmental psychology, and long-term health outcomes that are inextricably linked to that of the genetic parents, which may include the surrogate mother. As with all analogies there are limits to this one, and many of the issues that arise with reproductive surrogacy are not relevant here. (These include legal complications regarding the different laws pertaining to surrogacy in different jurisdictions; ethical issues that relate to the situation of the surrogate mother and her right to enter into an altruistic or commercial arrangement, and the justice of such arrangements; psychological issues impacting the surrogate mother such as feelings of loss upon separating from the surrogate child.) Other issues arising in reproductive surrogacy are relevant and can hint at the debates that will emerge as biotechnologies develop, becoming more sophisticated and readily available.

Surrogate musicianship is a relational term that alludes to the connections between donors and surrogates, not unlike that between parent and child in our analogy. Reproductive surrogacy prompts consideration of the multiple meanings of parenthood, which can be separated into genetic, biological, and social dimensions. It is clear that Ben-Ary is genetically related to *cellF*, and the case of reproductive surrogacy shows that genetic parents experience a strong sense of connection to, or 'ownership' of, their surrogate child (Healey, 2015). Biological parenthood is a category that alludes to gestation (Gheaus, 2018) and the connections between babies and the surrogate mothers who have grown them from their own biological material, even if the egg was genetically unrelated. The distinction between genetic and biological parenthood is not clear cut, and the resulting medical and emotional connections between surrogate mother and baby are not well understood. Yet, given the significance the *cellF* project places on materiality, where biological and naturally intelligent materials and processes are awarded a significance different from that of artificially intelligent materials and processes, reproductive surrogacy offers a useful model for imagining our responsibilities to future hybrid entities.

The concept of social parenthood is salient in the case of *cellF*'s surrogate musicianship, and the lessons of reproductive surrogacy illuminate the symbolic connection between *cellF* and its donor. The use of surrogacy as an assisted reproduction technology by infertile and same sex couples (or other family groupings) definitively shows that reproduction is not the same as parenthood. Reproductive technologies in general reveal our understandings of what is 'natural' as a culturally constructed category. It is conceivable, then, that the bonds between entities like *cellF* and their donors of biological material, as well as others who contribute to their creation and care, will be powerful enough to guide human investment of time and resources. Furthermore, social notions of parenthood draw us away from the legal framework of rights, which does not universally apply to the intended or surrogate parent, let alone to entities such as *cellF*, towards a framework of social justice and the responsibilities we hold in living together, at a domestic level and at a broader ecological scale.

Despite its limitations, then, reproductive surrogacy assists us in imagining ways to consider how hybrid entities like *cellF* cannot be separated from broader considerations of fairness and justice in social relations. The use of the term ‘surrogate musician’ in describing *cellF* strategically assists us in imagining the significance of the bonds between biological donor and the new entity that results, bonds that are likely to strengthen as the entities develop. Furthermore, the complexities of human assisted reproductive technologies offer a useful lesson that illustrates the ways in which the human desire for kinship can spur the development of new technologies that races ahead of legal, social and ethical resolutions. To complete this section, we will touch on some potential scenarios arising from surrogate musicianship, and their implications for new music.

cellF plays with a human musician, but a surrogate musician may perform alone or with other surrogate musicians; different manifestations of the same surrogate might play simultaneously in different locations. A human musician could create an external surrogate with their own biological material (or, for that matter, with biological material from any other living being), as the non-musician Ben-Ary did with *cellF*, and engage in musical activities with their own surrogate musician. The future may see musicians offering their cell-lines to preserve their musicality after death. Surrogate musicianship might allow future generations of such entities to not only generate music and demonstrate musicality by interacting with human musicians, but to interact with other surrogate musicians via a cultured interface that includes other cell types along with neurons. For example, it is conceivable that cochlear hair cells could be interfaced to stimulate a neural network through vibrations, opening further avenues for creative inputs and outputs. The possibilities are as diverse as the potential donors themselves.

If the surrogate musician symbolically stands in for its donor, as we have argued, these scenarios present performance contexts that engage the imagination in new ways. Surrogate musicians also have direct biological links to their donors, allowing us to consider the possibility that *in-vitro* entities may manifest some inherited musical traits from their donors of biological material. If a human musician is improvising with their own surrogate, their shared cellular material might lead to them making similar responses to stimuli; it is conceivable that such a scenario will produce innovations in improvised music.

32.7 Concluding Discussion

Western philosophy has long understood the world from an anthropocentric perspective that values human life, as entities with large brains and sophisticated cognition, above other kinds of life, and uses the thinking brain as the primary signifier of individual existence and sentience. Moreover, anthropocentric perspectives use the human as the analogic basis for rational arguments regarding unfamiliar biological species or processes. New scientific discoveries increasingly show the error of such thinking, where the threats posed by anthropocentric perspectives for ecological systems more broadly ultimately threaten human life as we know it. Particularly relevant here are those discoveries that reveal species and processes that fall between accepted categories. For example, Coley and Tanner's (2012) illumination of misconceptions in biological thinking discusses programmed cell death and disturbances in ecosystems as normal phenomena that, as a result of anthropocentric perspectives on ‘death’ and ‘disturbance’, are thought of as undesirable.

Biology as a field of enquiry is constantly engaged with trying to understand what ‘life’ is; some characteristics are accepted, while others challenge our preconceptions. Just as new scientific discoveries challenge accepted definitions, artworks using neurons have the potential to shift perceptions surrounding our understanding of ‘life’. *cellF* fulfils some of the accepted characteristics of life, such as being composed of cells, growing and adapting to an environment, and responding to stimuli. Other characteristics are harder to categorise. *cellF* depends on technological support to sustain its life, but human brains too develop neat links with technologies in order to form larger systems that change and evolve. *cellF* is not a surrogate child in the common sense, but it is genetically related to a specific human being. Cognitively and genetically, humans have much more in common with non-humans than anthropocentric perspectives have traditionally allowed. *cellF* challenges audiences to rethink categorical assumptions regarding what is considered human and non-human, biological and technological, living and dead.

This paper answers Eduardo Kac’s call for ‘a new critical vocabulary to meet the intellectual challenge’ posed by living artworks like *cellF* (Kac, 2007). We have argued for the significance of *cellF*’s biological materiality as fundamental to our use of the new terms *in-vitro* intelligence and surrogate musicianship. *cellF*’s current and future plasticity, its adaptation to change, is founded upon the biological basis of its neural network. We contrast this with the fixed material basis of artificial intelligence, where proper functioning depends upon the stability of its constituent metals, metalloids, alloys and plastics. Although the synthesizers and other electronic circuitry with which *cellF* is embodied are not cellular, both its neural network brain and analogue synthesizer body create and receive electrical information. These analogue systems come together in *cellF* to create music that is an expression of physical phenomena occurring in real time, in contrast with artificial intelligence that plays out a complex set of pre-arranged instructions.

Future manifestations of *in-vitro* intelligence will produce surrogate musicians that will neither be driven by chance nor determined by instruction, but spontaneous and extemporaneous. The complexity and speed of information pathways will facilitate their capacity to perform nuanced operations in real time, in response to audible, and potentially visual, stimuli. These living entities will be both the instrument and the musician, with a seamless flow from input to output. The biophysical and electrochemical pathways in self-organizing biological entities allow information flows that synchronize much faster than occurs in similar-scale structures made of materials like silicon and metal. The constituent materials of instruments are significant; an instrument made of metal produces a different tone to one made of wood. Surrogate musicianship allows us to speak of the different output of sound between a musician made of dry plastic, alloy and electricity from the expressivity of one made of wet, organic materials. Furthermore, surrogate musicians will offer a unique musicality that is accorded to their biological materiality and the consequent relations between surrogates and donors.

As a new framework of music production, surrogate musicianship will change the approaches of human musicians. The future evolution of new music 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. We are able to deconstruct, manipulate and re-assemble the microscopic building blocks of life in completely new ways; human bodies are more malleable that ever before. The potential and ramifications for these biotechnologies extends beyond music. As an engaging and provocative experimental artwork that applies iPSc and neural interfaces for aesthetic purposes, *cellF* opens discussions concerning the future use of stem cells and the potential to bioengineer brains. By showing audiences beyond the scientific community what is possible, the artists and the work ask questions about the use and misuse of biotechnologies, and how and why they are applied. In so doing, the technology is problematised, rather than simply celebrated. *cellF* invites us to grapple with these questions, while the stakes are quite low, in an attempt to initiate public debate and to critique a position that considers technological progress a necessary good. As our use of the terms '*in-vitro* intelligence' and 'surrogate musician' show, emerging biotechnologies pose difficult questions about what counts as a life, and what sorts of lives matter.

32.8 References

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