# Bio-Engineered Brains and Robotic Bodies: From Embodiment to Self-Portraiture

By Guy Ben-Ary and Gemma Ben-Ary

"The cyborg is a kind of disassembled and reassembled, postmodern collective and personal self." Donna Haraway [i]

## Introduction

I believe art plays an important role in encouraging engagement with, and critical reflection on, a unique cultural moment where we are witnessing the unprecedented evolution of bio-technologies and various modes of liminal lives that hover in an ambiguous zone, defying our traditional understanding of life. Art has the potential to initiate public debate on the challenges arising from the existence of liminal lives, and the shifting forces that govern and determine life and death. [1]

I am an artist at SymbioticA, the Centre of Excellence for Biological Arts at the University of Western Australia (UWA), and have been a core researcher there since 2001. The biological laboratory is my studio where the creative process takes place, and tissue culture, tissue engineering, electrophysiology, microscopy and other biological techniques are my artistic mediums. My research is inter-disciplinary and the production of the artwork usually involves the collaborative effort of artists, scientists and engineers.

My research explores a number of fundamental themes that underpin the intersection between art and science; namely life and death, cybernetics, and artificial life. It investigates processes of transformation of bodies or living biological material from artistic, philosophical and ethical perspectives. This exploration makes use of new scientific and cybernetic technologies and processes to re-evaluate understanding of life and the human body. In my work, I use bio-technologies in a subversive way, attempting to problematize these technologies by putting forward absurd and futuristic scenarios. These strategies allow

[1] Throughout this paper, the word "I" denotes Guy Ben-Ary. However, this paper is a result of a collaborative writing effort between Guy Ben-Ary and Gemma Ben-Ary.

critical engagement with the technologies and help lure the viewers into exploring the artworks. It also draws viewers into a wider practical and ethical dialogue about the future of these technologies and their use, and forces people to re-evaluate their own perceptions and beliefs. This paper examines some of the methodologies and theories that underpin my artistic practice by using as examples, four of my major projects completed over the last decade: *MEART*, *Silent Barrage*, *In-Potentia*, and *cellF*, with some preliminary discussion of terminology, ethics and the idea of robotic embodiment as an artistic strategy.

**[fig 1]**

In 1999 I collaborated with the Tissue Culture and Art Project [2] on the development of a work entitled *The Stone Age of Biology* in which muscle cells and neurons were grown over miniaturised replicas of pre-historic stone tools[3]. This led me to the realisation that I could grow biological neural networks in-vitro, and monitor them via time-lapse photography in order to effectively visualise their growth over long periods of time.

Observing the activity of the neurons as they grew, interacted, transformed, formed new connections, and reorganised themselves spontaneously into neural networks, caused me to wonder about the internal nature of the cells, and whether I might be able to influence the cells, or interact with them in some way.  This led to finding electrophysiological techniques which offered various interfaces to the neural networks. Electrophysiology makes it possible to record and monitor the behaviour of neurons. More importantly, the electrophysiological interface gave me a glimpse into the state of the neural network and the way that individual neurons were interacting with each other. It also gave an impression of the ways that the neural networks respond to external events via stimulations. This moment in my research marks a starting point that is crucial to the development of later bio-robotic artworks. My artistic practice, from this point forward, focussed on attempting to match bio-engineered neural networks to artistic, robotic bodies, in other words, matching a 'brain' to a 'body', although this terminology is problematic and will be explored further in the following paragraph. The cultural, as opposed to the scientific, articulation of these bio technologies is at the heart of my artistic practice.

[2] The 'Tissue Culture and Art Project' are Oron Catts and Ionat Zurr, and during the years of 1999-2003 I collaborated with them. (http://www.tca.uwa.edu.au)

[3] http://www.tca.uwa.edu.au/pastIndex.html

## Terminology

The use of the words 'brain' and 'body' are in context with my artwork. It is important, at this stage, to note the difference between neural networks grown in-vitro consisting of approximately 50,000 neurons, and actual living brains, which consist of approximately 100 billion neurons, interconnected via trillions of synapses, not factoring in the complexity of thought, intent, memory and 'personality'. Thus the 'brains' of my projects are essentially symbolic. However, we use real living neurons deliberately, as a way to force the viewer to consider future possibilities that neuro-engineering and stem-cell technologies present, and to begin to assess and critique technologies not commonly known outside of the scientific community. However simple or symbolic these brains may be, they do produce quantities of data, and they do respond to stimulation, and they are subject to a lifespan. The term 'brain' when used in this paper in relation to my work, refers only to biological neural networks grown and supported in-vitro.

## Ethics

Oron Catts, co-founder and director of SymbioticA, claims that he feels a sense of unease whilst working with dissociated neurons, or 'bits of brains', more than with any other type of tissue. This sense of unease draws him back to the lab to try to understand exactly why such research provokes an instinctively unsettling feeling. I sympathise with this sentiment, and agree that when working with neurons, ethical questions are raised in regard to consciousness, intelligence and sentience. Questioning their ability to feel pain is valid, whilst also understanding that the neural networks currently only exist in a symbolic realm. Other ethical questions posed are: which direction will these technologies take us in the future, and what are our responsibilities? What kind of ethical boundaries will need to be established around these living entities? Catts and Ionat Zurr state that "it is important to critique the use of neurons for computational devices and the possibility of the creation of a sentient computer."[ii] Art should play an important role here; art is capable of bringing those scenarios to life and confronting the viewer, both instinctively as well as intellectually.

## Robotic Embodiment as a Strategy

The aim in embodying the brain with robotics was to highlight the liveliness of these microscopic neural networks, and to manifest their erratic existence through movement and behaviour. I was compelled to provide a manifestation for the brain by giving it a robotic body. Moreover, the electrophysiological interface allowed me to establish a feedback loop between the robotics and the biological brain, and thus create an autonomous cybernetic entity. These entities represent the fears and hopes of humanity as we enter into an unknown future with soon-to-be obsolete bodies[iii]. They illustrate, in a highly visceral manner, ideas around disembodied consciousness and intelligence. Ideas of disembodied brains are found across diverse philosophical discourse, from Plato's allegory of the cave, to René Descartes' evil demon, to cybernetic theory, and appear frequently in science-fiction. These entities might instil in the viewer a sense that science-fiction is a step closer to actualisation. In reality, the existence of these creatures is absurdly vicarious, and immediately becomes recognisable as remaining firmly within the realm of fiction.

Bio-engineering processes are in some ways similar to the process of developing robotics, and have the same three cornerstones; hardware, software and sensors. The bio-technologies that are used to bio-engineer the neural networks are:

**Hardware:** This could be better described in this practice as 'wetware'; neurons are grown and maintained in-vitro using tissue culture and tissue engineering techniques.

**Software:** Stem cell technologies, mainly Induce Pluripotent Stem cells (iPSc) which assist in reprogramming and converting cells to become stem cells, allowing them to be differentiated into any other cell type, such as neurons.

**Sensors and interface:** an electrophysiology system consisting of amplifiers connected to a specialised Petri dish, the Multi Electrode Array (MEA) hosting the living neural network. These dishes consist of a grid of electrodes that can record the electric signals that the neurons produce and at the same time send stimulations to the neurons – essentially a read-and-write interface to the brain.

**[fig 2]**

## MEART - The Semi-Living Artist

In 2000, Phil Gamblen was an artist in residence at SymbioticA, and was at that time, developing artificial muscles as part of his research into bio-mechanical processes. Conversations with Gamblen led us to the idea of providing a robotic embodiment to a bio-engineered neural network and to exploring the possibilities of creating a brain-machine hybrid or a cyborg. Together, we became interested in the manifestation of neural data via movement or robotic behaviour and later invited Dr Stuart Bunt, a neuro-scientist[4] at UWA to join the discussion, and it was he who confirmed the biotechnological feasibility of these ideas. Later still, Oron Catts, Ionat Zurr and Iain Sweetman joined the three of us to develop a project titled *Fish and Chips* that later on evolved to be *MEART - The Semi-Living Artist*[5].

**[fig 3]**

*MEART - The Semi-Living Artist* is an installation distributed between two locations in the world. Its brain of dissociated rat neurons in culture was grown on an MEA dish in Dr Steve Potter's laboratory[6] while the geographically detached robotic body resided wherever the work was exhibited, sometimes in different continents. The body consisted of pneumatically actuated, insect-like robotic arms capable of drawing on paper. These robotic arms were designed and constructed by Gamblen and inspired by natural and biological structures such as bone and muscle fibres. A camera located above the drawing captured the progress of drawings created by the neuron-controlled movement of the arms. The visual data was then sent back to the lab to instruct stimulation for the electrodes on the MEA that hosted the brain and the response to the stimulations was then sent back to the robotic arm. The geographical remoteness of the brain and body was overcome by the Internet, acting as an extended nervous system. Thus the brain and robotic body communicated with each other in real time for the duration of the artistic activity, providing a closed loop communication for the neurally-controlled semi-living artist.

Neuro-engineers usually make robots that perform utilitarian tasks such as navigating, however, *MEART* was given the very non-utilitarian purpose of being an artist. It allowed us to engage viewers in discussion about the future use of neuro-engineering technologies, and to raise questions about the nature of semi-living entities, that may potentially be conscious, sentient, or creative in the future. Throughout its public exhibitions *MEART* had a specific task - to draw portraits of viewers. *MEART* explored the cognitive dimensions of 'seeing' and converged what it sees into representation. Thus the optical element, the digital camera, instructs the mechanical element, the robotic arm, how to draw via the interpretation of the wet element, or neurons. Unlike human artists, there is no knowledge in the arm itself[iv].

[4] Dr Bunt has a lab in the school of Anatomy & Human Biology, UWA and was then the scientific Director of SymbioticA.
[5] The collective who developed *Fish and Chips* and *MEART* was known as the SymbioticA Research Group.
[6] Dr Steve Potter is an Associate Professor in the Laboratory for neuro-engineering at Georgia Tech, Atlanta, USA. Potter and his then-PhD student, Douglas Bakkum, were our scientific collaborators and played a major part in the development of *MEART.*

After exhibiting *MEART* and the portrait series a few times the work was developed further. Douglas Bakkum, a PhD student in Potter's lab at that time, who worked closely with the team on the development of *MEART*, suggested changing the task given to the neural networks. He observed that human portraits are of a complexity that the neurons may not be able to cope with, and that a simple geometric shape such as a square might be better. At the same time I was in conversation with Bulgarian artist, Boryana Rossa, who was writing a text juxtaposing *MEART* with Malevich's famous Suprematist artwork, *Black Square*. She wrote "*Black Square* is considered to be the beginning of a new and redefined art form. The Suprematist paintings are projects for, and instruments of, a new universe and a new system of the world. The Suprematist canvases were sign-projects, containing images of the technical organisms of the future Suprematist world. *MEART* is a real futuristic organism, an organism existing in reality, a realized project of the futurist's and Suprematist's dreams."[v]

Following conversations with Bakkum and Rossa, the team decided to engage *MEART* to reproduce *Black Square*. The visual properties of the work were a factor in this decision, as well as the conceptual value of the artwork, as a continuation and contribution to this significant work and its place in art history. A video camera, the sensory input and the 'eye' of *MEART*, was set up to observe a video recording of the painting, captured in the Tretyakovsky Museum, Moscow. By reducing the input to the neurons to a simpler shape, *MEART*'s task was made simpler, and it was able to cope with the data more efficiently. This allowed for an examination of the relationship between input and output, and the possibility of detecting behavioural patterns. This outcome satisfied many criteria, both scientific and artistic. *MEART* was a proof of concept, showing that it was possible to create a coherent feedback loop between the bio-engineered brains and a robotic body, and to use the artistic processes as a metaphor to raise questions about the potential of semi-living entities to be emergent or creative.

**[fig 4]**

Paul Vanouse describes *MEART* as presenting "a collage of contradictions that are designed to create cognitive dissonance in its viewers, and it forces them to re-evaluate their own perceptions and beliefs. Its authoritative complexity simultaneously convinces us of its technological re-engineering of cognitive processes, while also calling attention to just how far it has strayed from generally held conceptions of life, intelligence or creativity. *MEART* is the ultimate Cartesian dualism; a machine body completely removed from its brain and to complicate matters even further the brain has been reconstituted in vitro from its cellular components."[vi] This accurately describes our aims for *MEART* and underlines the way in which the artwork serves to assist the viewer in engaging in a critical reflection on notions of life and sentience.

**Art and science collaboration**

The mode of collaboration which was set up with Steve Potter and Douglas Bakkum was unique in that both the artists and the scientists were fully engaged in the development of the project, and explored the same questions from different perspectives. In an early e-mail, Potter writes "Your project is very exciting to me for a number of reasons. It is very similar to mine, in hardware and goals. It combines art and science, and I am very interested in both and their overlaps. It addresses an important aspect of my work that I have had a very hard time addressing: How should the lay public think about these things?"

Oron Catts, in an interview with Emma McCrae in 2006, described the collaboration between the artists and scientists in *MEART* as being a true collaboration; in other words, both parties engaged and explored possibilities, rather than exploiting the skills of the other for their own purposes.[vii] Whenever *MEART* was exhibited, there were always two parallel experiments being conducted. One side of the experimentation was the artistic, cultural exploration by the artists, and the other was a scientific experiment recording data and drawing conclusions in alignment with Potter's own research. The scientists tried to increase their understanding of the fundamental mechanisms that underpin the behaviour of embodied neural networks in-vitro.

One notable finding for the scientists was related to Potter's research into the way neurons behave when growing in vitro. Potter writes "We noticed that a culture that was being used to control *MEART*, after days of receiving stimulation fed back via the internet from its video camera eye, began to calm down, showing less and less epileptiform activity. We found we could quell the barrages of activity in all of our cultured networks by sprinkling low-frequency pulses of electricity across the network, delivering via the substrate electrodes."[viii] Interestingly, this discovery, made by observing one of *MEART*'s cultures responding to specialised stimulations, was one of the focal points of *Silent Barrage*, a subsequent project with the same collaborators.

## Silent Barrage

In 2006, Gamblen and I were invited as research fellows to Dr Steve Potter's lab, one of the eight laboratories for neuro-engineering in the Coulter Department for Bio-Medical Engineering at Georgia Tech. This proved to be a pivotal development which provided a significant advancement in both the creative and technical aspects of our work. The outcomes of the research, alongside Steve Potter, Douglas Bakkum, Riley Zeller-Townson and Peter Gee[7], eventuated in the production of a major project and artwork entitled, *Silent Barrage*.

Up until 2006, communication between the artists and the scientists in the Potter laboratory was based purely on email exchange, so it was a remarkable experience for us to finally access the lab, and become part of the scientific environment of our collaborators. *Silent Barrage* is similar to *MEART* in its basic architecture; a cybernetic entity that is assembled from a bio-engineered brain that grows over an MEA interfaced to a robotic body. However it has a different narrative and set of aesthetics, and the development and creative process during *Silent Barrage* also differs from *MEART*. Being in Potter's lab allowed us, the artists, close proximity to the brain. We began to understand the brain better, and become acutely aware of its fragility and the complex process involved in growing and nurturing it. As well as this, we became familiar with the experiments being conducted by the scientists, and these interactions were creative triggers that led to the development of some of the essential narratives that underpin *Silent Barrage*.

During the residency in the Potter lab my aim was to focus on learning about the process of growing neural networks on to the Multi Electrode Array (MEA) interface. The phenomenological experience of making a brain in Potter's lab, coupled with experimentation with new ideas for robotic embodiment, being conducted at the time by Gamblen, led us to develop the aesthetics of *Silent Barrage*. We realised how important the MEA dishes are to the scientists; each scientist had their own dishes, and each had developed a unique relationship with them. An email from Potter in 2001 sums it up; "(we were) a bit reluctant to 'anthropomorphize' them, and that naming them was my idea […] The name goes with each dish, which usually serves for several successive cultures, usually lasting several months, and in one case, for about two years. […] It is difficult not to feel the cultures are 'alive' since we use many of the same terms we use for living animals, say, like 'feeding', 'growing', 'keeping warm', and that the behaviour of the cultures is complex and dynamic, as is the structure. We

[7] When Douglas Bakkum graduated and left the Potter Lab, Riley Zeller-Townson took his place in the *Silent Barrage* team. Peter Gee, an engineer, also joined the team. Both were instrumental in the development of *Silent Barrage*. Dr Nathan Scott, an engineer, and Brett Murray, a programmer, also assisted in the production of the work.

go through hours if not days of 'mourning' if a workhorse culture dies from getting infected or other mishap. And the excitement of seeing a new culture fire great signals for the first time must be like seeing your baby take its first steps.”

During this residency we observed that the scientists spent days upon days looking down the microscope, observing the cultures and using many different visualisation techniques to illustrate the events that continuously occur in the MEA dish. It became apparent that the dish was a microscopic arena for a neuronal performance. It was at this point that we decided to create a ‘parallel magnified immersive space’ within which the robotic body could perform. We tried to create a space evocative of the MEA so that viewers could walk through *Silent Barrage’s* brain and thus experience its complexity and chaos.

As the viewer approaches the space housing the robotic body of *Silent Barrage,* thirty two robotic components can be heard and seen, as they move vertically up and down the columns of PVC piping. At 2.4m in height, these columns tower above the viewer and are arranged in a grid-pattern across the gallery floor. As the robotic parts navigate the columns, they leave traces around their circumference with a pen pressed against sheets of paper wrapped around each column. These drawings are the robotic body’s translation and representation of information received from the bio-engineered brain hosted on one of the MEA dishes in the Potter Lab. But the origin of the mark-making has another layer of complexity because the audience plays a crucial role; there is feedback between the audience and the neurons. The viewers are invited to step into this immersive space and move around the chaotic robotic objects, and through their presence in the space, the viewer communicates directly with the neurons. Cameras are located on the ceiling to capture the movement of the audience, and this information is fed back to the brain as stimulations. In response, the neurons produce their own electric signals that are then fed back to the robotic objects to enact their kinetic choreography and mark-making activities, and draws further attention from the viewers. This process occurs in real time. The drawings on the poles are unique to each individual neural network, and more importantly, they trace and record the interaction between the viewer and the brain.

**[fig 5]**

The scientific research conducted in Potter’s lab during the residency in 2006 inspired us and became central to the development of *Silent Barrage*. The scientists were researching specialized stimulations in order to calm unwanted bursts, or barrages of activity, to try and enhance the functional plasticity in the cultured neural networks. In other words, they discovered that once the neurons formed a network over the MEA, they showed spontaneous epileptiform activity; a similar thing happens in the brain of a patient experiencing an epileptic seizure. These barrages of unwanted neural activity may originate due to lack of sensory input and disturb the neural network with the processing of data. Potter and his research team managed to overcome this problem by sending specialized stimulations to the networks to calm them, and enhance their functional plasticity, increasing the possibility for learning.[ix] These experiments contributed to our vision of multiple robotic objects arranged in an immersive environment in which we ask the viewers to generate stimulations to the neurons by moving through this environment. Thus the viewers, in a symbolic and poetic way, are helping cure the dysfunctional brain from its epileptic properties by walking through the space and being among the poles. The viewers help to 'silent' the 'barrage'.

**[fig 6]**

## In-Potentia

In 2008 the media became saturated with news of the development of a new stem cell technology known as Induced Pluripotent Stem Cells (iPSc). The 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.

In layman's terms, the iPSc method transforms adult specialised cells into a form that is equivalent to stem cells, which are capable of becoming any other type of cell in the body (skin, liver, muscle, neuron, etc.). The process involves re-programming their 'software' (genome), and coaxing them back into their embryonic state.

Initially, iPSc was hailed as the technology that would help resolve some of the ethical dilemmas associated with embryonic stem cell harvesting, but it is now clear that it merely transformed the ethical landscape of this field of research. Not only are there increasing concerns regarding the relative ease with which iPSc cell samples could potentially be taken from us, without our knowledge or consent, but more specifically, there are increasing concerns regarding the ethically loaded potential for iPSc technology to be used in the derivation of gametes; human reproductive cells, ie. sperm and oocytes.

The discovery of this biological alchemy intrigued me. I realized how malleable and fragile our bodies are; how we are able to deconstruct, manipulate and re-assemble the microscopic building blocks of life in completely new ways.

Around this time, I had a conversation with Boryana Rossa who criticised artists using the biological material of other species, and she questioned the ethical aspect of this practice and why human material could not be used. I had to concede that *MEART* and *Silent Barrage* both relied on mouse and rat neurons grown over the MEA interface, a standard scientific practice. Human brain cells were at this point out of the question, as there is no way to harvest brain cells from a living creature without causing it fatal harm. iPSc technology offers a way to safely use human cellular material. By hacking into the cell's software, it is possible to manipulate the genetic make-up of the cells and from there craft the building blocks necessary for the creative process. By re-programming human skin cells, it seemed that I would be able to create a brain from scratch, in a sense.

In collaboration with Dr Kirsten Hudson, Mark Lawson and Dr Stuart Hodgetts, I produced *In-Potentia*, a speculative, techno-scientific experiment using disembodied human skin cells and diagnostic biomedicine equipment. This project allowed me to experiment, for the first time, with the new technology and to learn how to carry out the iPSc technique. In this project, the iPSc technique was redeployed to create a liminal boundary creature of animate and inanimate matter.[x] We deliberately set out to problematize the new iPSc technology and selected human foreskin cells, which can be easily purchased from on-line scientific catalogues. These were selected as a starting point to learn the iPSc technique, with the aim of reprogramming them into stem cells, and then into brain cells. We aimed to highlight the absurdity of the scenario; to reverse-engineer foreskin cells, and from this material, create a living 'brain'. In fact, the project was affectionately given the working title of 'Project Dickhead'.

**[fig 7]**

The brain of *In-Potentia* was encased within an incubator-like robotic body which served to keep it alive, as well as to present the exalted new technology on a pedestal. The Robotic body was designed using an 18$^{th}$ Century aesthetic, as a way to denounce the era of enlightenment and the associated pomp of new scientific discovery. The phallic, somewhat steampunk incubator was custom-made from hand-blown glass and polished timber panels, with aged brass fittings. This elaborate encasing concealed a bio-reactor that automated the process of feeding and clearing wastage from the living brain cells. There was also a DIY version of an MEA that converted the electrical activity from the brain into an unsettling sound-piece. In this work, unlike *MEART* and *Silent Barrage*, there was no feedback loop or interaction with the brain. We placed the brain on a pedestal, presenting it with the indifference of a museum specimen, or a piece of jewellery; something to be viewed, behind glass, feted, admired, and perhaps even feared.

Since the era of enlightenment, philosophers have attributed the human brain with a great deal of importance as the organ that determines life or death. With Descarte'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 placing a live, male 'brain' on a sculptural robotic pedestal that has been informed by the aesthetics of 18th century scientific paraphernalia, *In-Potentia* raises some interesting questions in regards to why we still seem to be ruled by an antiquated and distinctively modern historical form of personhood, and in turn, with *In-Potentia* we ask: what does it really mean to be alive and be human in the 21st century?[xi]

*In-Potentia* has the ability to symbolize our worst nightmares as it threatens accepted and clear-cut categories of the human body. This work serves to challenge definitions surrounding embodied material wholeness, and provokes many more questions than answers in the viewer. In this artwork we ask, what is the potential for artworks to activate responses about shifting perceptions surrounding understandings of 'life' and the materiality of the human body? And what does it mean artistically, philosophically and culturally to make a living biological brain from foreskin cells?

## cellF

**[fig 8]**

In 2012 I was awarded a Creative Australia Fellowship from Australia Council for the Arts to create a new project, a cybernetic self-portrait, entitled *cellF*.

*cellF* is a progression of the past fourteen years of research conducted through various projects involving robotic embodiment and bio-engineering. This project is a continuation of my interest in problematizing new bio-technologies and contextualising them within an artistic framework. The fellowship allowed me the time and space to develop this idea and at the current time of writing, *cellF* is still under development.

The project has been divided into two parts; the first, which posed enormous challenges with biological protocols, was to reprogram my own skin cells taken from a biopsy and to transform them into neurons to create a functional neural network, an external brain independent from my body. The second part has been to develop a robotic body to interface to this external brain so that they work in synergy, including a real time feedback loop and in many ways this biological self-portrait follows the same hardware, software and sensors formula as the other projects.

In 2012 I had a biopsy taken from my arm, and cultivated the skin cells in vitro in the labs of SymbioticA at UWA, then froze them cryogenically and shipped them to Barcelona, where I collaborated with Dr Michael Edel.[8] In Barcelona, with the help of Edel, I reprogrammed the cells using iPSc and created stem cells, which began to differentiate and were pushed down the neuronal lineage until they became neural stem cells. These were frozen and shipped back to SymbioticA, where I, in collaboration with Dr Stuart Hodgetts[9] began to develop a protocol to fully differentiate them in an MEA dish. Working with Edel and Hodgetts is another example of a close collaboration with scientists where both parties benefit from the research; the scientists are using the artistic cells for scientific purposes and this project has allowed them a unique opportunity to do so.

**[fig 9]**

[8] Head of the Laboratory for Pluripotency, University of Barcelona
[9] Director of the Spinal Cord Repair Lab, University of Western Australia

In parallel to the biological work carried out in Barcelona and Perth, I also spent time considering the very important artistic aims of the project; namely, what sort of robotic body will I give to myself? My decision is based on a long-standing passion for music, a juvenile dream that is shared by many - to be a rock star.

I plan to embody my external 'brain' with a sound-producing 'body' comprised of an array of analogue modular synthesisers. The aesthetics of the synthesiser, which are similar to that of an electrophysiological laboratory, fits my vision perfectly. Furthermore, there is a surprising similarity in the way neural networks and synthesisers work in that in both voltages are passed through the components to produce data or sound. There is also a practical consideration, the neural networks produce large and extremely complex data sets, and by its very nature, the analogue synthesiser is well suited to reflecting the complexity and quantity of information via sound. The finished artwork is still on the design table however my plan is to embed the synthesisers into a sculptural object that will also house a mini bio-lab that hosts my external brain.

Essentially this robotic-sound artwork can be seen as a cybernetic musician. The intention is that the artwork will be performative, and that human musicians will be invited to play with *cellF* in a series of special one-off shows. The human-made music will be fed to the neurons as stimulations, and the neurons will respond by controlling the analogue synthesisers, and together they will perform live, improvised sound pieces.

Dr Douglas Bakkum[10] has returned to collaborate again with me and will be assisting in developing the interface software and other modules that are required to connect the MEA to the sound producing body. Andrew Fitch[11] will custom-design the synthesisers specifically for this project while Dr Darren Moore[12] will work with me on the aesthetics of the sound.

**[fig 10]**

Moore and I are interested in contextualising the work from a musical perspective and in conversation, Moore referred to several examples. The futurist, Russolo, in the early 1900's, wrote about the art of noise and was interested in expanding the sonic palette to include noise and noise-making machines; conceptually ahead of its time and not fully realised by others until the 1950's and 60's when synthesisers became more commonly used in music. John

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[10] Dr Bakkum is currently a group leader at the Department of Biosystems Science and Engineering, the ETH Zurich.
[11] electrical engineer from Perth, aka nonlinearcircuits
[12] experimental musician and lecturer at Lasalle College of the Arts in Singapore

Cage's *4'33"*, also known as 'the silent piece', was an important work in the conceptual development in the field of experimental sound-art; it emphasised the noise of the environment around the performance and the non-musical aspects around the music. David Tudor, in the 1990's, combined the engineering of electronics with the inspiration of biology and developed a synthesiser that was controlled by an artificial computer coded 'brain', not made from biological matter, but closely resembling one in its activity and intention and used it to composed and play a series of works titled *Neural Synthesis Nos. 6-9.* In other words, Tudor's artificial neural network simulated the way real biological neural networks operate using a computer code and wired this to a synthesiser to create sound. *cellF* builds on these precedents, and in particular it takes Tudor's vision a step further from using an artificial neural network and making use of a real biological neural network to play electronic music.

**[fig 11]**

**Conclusion**

The four artworks presented in this paper, *MEART*, *Silent Barrage*, *In-Potentia*, and *cellF*, highlight the way in which my experimentations have focussed on matching robotic bodies to bio-engineered brains. *MEART* was a cybernetic entity exploring notions of creativity and emergence. *Silent Barrage* allowed viewers proximity to the brain via a robotic interface. *In-Potentia* responded to breakthroughs in iPSc technology to create a brain and place it on a robotic pedestal. *cellF* gathers all this work together, and will culminate in a robotically-enhanced performance of my own biological material; a self-portrait. My intention is to create strongly subversive projects that problematize emerging biological innovations and technologies, and critique them from a cultural perspective rather than a scientific one. In each, there has also been a desire and a deliberate attempt to set up absurd scenarios that suggest possible, contestable futures, in line with post-humanist theory and to contribute a cultural voice to a scientifically-biased discourse. My work is an exploration, posing more questions than answers, through which cybernetic technologies and processes and asks us to re-evaluate our understanding of life, the human body, sentience, and personhood.

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[i] Haraway, D (1991) A Cyborg Manifesto: Science, Technology, and Socialist-feminism in the Late Twentieth Century. Simians, Cyborgs and Women: The Reinvention of Nature, pp 82-149.

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