"Counter" installed in Aarhus, Denmark (© 2011, G. Drake-Brockman)

MIRRORBEINGS: ROBOT COMPLEXITY, MYTHS, AND SIMULACRA

by Geoffrey Drake-Brockman

This paper traces a speculative journey investigating the nature of "created beings" or "mirrorbeings" – machines that we make as reflections of ourselves.

ROBOT FLOWERPOTS

An origami "chatterbox" is a commonplace object. The chatterbox is familiar to us as a simple paper-folding project and as the basis for a popular children's fortune-telling game. I became interested in the chatterbox because of its universality and the intriguing lateral-shift spatial transformation it performs when operated with two hands and used in fortune-telling mode. By attaching this paper origami element to an electromechanical actuator I accidentally produced an alternate sudden inversion spatial transformation that is analogous to the transition of a flower from bud to bloom. Further development from this starting point yielded a fully robotized flowerpot. This flowerpot has a mirrored upper plate through which emerges a cloth-covered telescopic stem. When activated,

the stem grows one metre vertically before the green origami bud atop it suddenly blooms into a pink and yellow origami bloom – whilst producing a distinct "wap" sound. Soon afterwards, the bloom withers back to its flowerpot and returns to a bud state.

Floribots is an interactive collective organism consisting of 128 of these robot flowerpots with appropriate networking, electronics, sensors, and control software – it is a kind of robot garden bed that combines the familiar and comfortable chatterbox motif with a "spooky" manifestation as a huge (8m x 4m) mechanical floral arrangement that "watches you" and constantly reconfigures itself. Conceptually, Floribots was intended to stage a real-world encounter between its audience and a kind of "sci fi" tableau of co-operating mechanical plants - while provoking in the observer hopefully equal measures of disquiet and attraction.

When writing the software for the Floribots "hive mind" I drew on aspects of the behavior of my then-toddler-aged children. Accordingly, Floribots was programmed to exhibit different "moods" including the following: Reactive, Excited, Bored, Naughty, and Sleepy.

Floribots was first exhibited at the National Gallery of Australia in 2005 where it interacted with an audience of some 100,000 visitors over a four-month period. In practice, the behavior exhibited by Floribots seemed to me much more complex than its predefined moods and the transitions between them that I had programmed. Sometimes mood behaviors effectively partially overlay each other, creating new choreographic modes, whist the sound compositions played by an orchestra of 128 "wapping" paper flowers were entirely novel. The interaction between the work and its audience proved to be intense. I observed people lingering near the work for long periods and found that they would refer to the actions of Floribots as though it was a "being", rather than a mechanical arrangement of components. Floribots was voted "Peoples' Choice" of the National Sculpture Prize in 2005. It was the first time that I had made a "popular" artwork - seemingly almost by accident.

I understood the role of the commonplace object, the origami chatterbox, in making Floribots accessible to its audience - this was an intentional device. However, I felt the engagement that the work engendered with its audience via its novel behavior-patterns required more explanation. I wondered if these behaviors could be understood in terms of "Complexity Theory" (Gleick 1988). Complexity Theory investigates how relationships between parts of a system give rise to the collective behavior of that system. A sufficiently complex system can sometime self-generate novel behaviors through a process called "emergence". Along these lines, it seemed that the overall "phase space" defined by Floribots' mechanical, electrical, and software freedoms had given rise to emergent patterns and expressions - effectively allowing a created being to come into existence.

Perhaps, I thought, any sufficiently complex automaton has the capacity to become a being and exhibit novel behavior…

FLORIBOTS IS AN INTERACTIVE COLLECTIVE ORGANISM CONSISTING OF 128 OF THESE ROBOT FLOWERPOINTS

To analyze Floribots in Complexity Theory terms, I assessed it logically - that is, as a state machine. A state machine is a device with a calculable number of discreet possible conditions. Floribots has 128 flowerpots, which can be independently switched between bloom and bud modes. Thus, Floribots can be regarded as having 2^{128} (circa 10^{38})potentially different states. Given its order of complexity of 10^{38} - corresponding to many trillion trillion trillion trillion states, I postulated that the shear extent of this complexity was the root cause of its novel (emergent) "being-like" behaviors and resultant intense levels of audience engagement.

COUNTING

After my experience with Floribots, I decided to create a new automatous artwork with much less inherent complexity - to see if emergent behavior still manifested. The work I developed was called simply "Counter" and was completed in 2009.

Counter is an interactive installation in the form of a large yellow pedestrian portal that literally counts each person that walks through it. Counter has nine magnetically-actuated digits on its front and back faces and is capable of counting to one less than a billion, after which it clocks-over and returns to zero. Each time Counter's number changes; a distinct "thwack" sound is made as its magnetic display segments flip over.

Apart from its role in mapping the possibilities of mirrorbeings, the concept for Counter arises from the imperative to "be counted" or "make sure you count" that is part of liberal democratic cultural heritage. In addition, the work carries more unsettling overtones of surveillance and scientific measurement. Counter exists to perform a commonplace and straightforward act; to count. It also employs another commonplace, highly accessible, motif - in terms of being, in terms of form, a simple "doorway".

Counter has 10^9 potential states, making it hugely less complex than Floribots as a state machine. In addition, unlike Floribots - which can transition between states in multivalent and open-ended ways - Counter has only one transition available: "to increment". Despite being crippled in terms of its relative complexity, Counter has proven surprisingly capable of engaging its audience. The work has been installed four times in temporary outdoor exhibitions, three times in Australia and once in Denmark. Each time the work has counted around 2 to 300,000 pedestrians, with its final installation at Bondi in Sydney taking it over one million aggregate interactions.

Two arguably emergent behaviors have manifested repeatedly in all four of Counter's installations; phenomena which I term the "pedestrian vortex" and the "decimal effect". A pedestrian vortex forms when a group of people form a circular queue to continuously file through Counter's archway and keep it "clocking over" as it counts each individual over and over again. It turns out that being counted repeatedly is sufficiently attractive for this formation to spontaneously occur every time that Counter has been exhibited. The decimal effect is a heightened level of crowd engagement and excitement as Counter approaches a large power-of-ten clock-over point, such as 10,000 or 100,000. At such moments some jostling to "be the one" occurs and a loud spontaneous cheer will typically arise from the audience.

Prototype robotic origami flowerpot (© 2005, G. Drake-Brockman)

I think that the most interesting, possibly emergent, behaviors of the Counter installation are not its mechanical state changes in isolation, but the combination of these transitions with audience behaviors. Thus, the true complexity of the created being system includes not only the 10^9 states inherent in Counter's electronics but the much larger "phase space" of its 300,000-per-exhibition human audience. The ultimate complexity of such an automatous artwork becomes difficult to fix, given the demonstrated capacity of Counter to "grow" its phase space by absorbing state-potential from its human audience.

Based on my experiment with Counter, I conjectured that even simple automata have the propensity

"Floribots" responding to its audience (© 2005, G. Drake-Brockman)

to "borrow" additional state-potential from their audience, so that they too can achieve emergence.

BINARY AUTOMATA

If an automatous artwork as simple as Counter can develop emergence, how simple can the system get, while maintaining this propensity? To investigate, I decided to address the logical limit of state machines. Accordingly, the next work in this series, titled "Clockwork Jayne" has just two states.

Clockwork Jayne consists of a life-size fiberglass ballerina figure mounted on a faceted mirror base enclosing a clockwork mechanism that can rotate her. Clockwork Jayne was modelled on prima ballerina Jayne Smeulders of the West Australian Ballet, who heroically posed for over three hours standing "en pointe" while a full body-cast was made. When this work's clockwork mechanism is wound up, the ballerina pivots slowly and a tune plays quietly until the spring winds down. The work draws on another commonplace motif; children's clockwork music boxes with ballerinas that pop-up and spin in front of a mirror when you open the lid. As a simple rotating clockwork, this automaton has just two logical conditions: wound-up, and unwound.

When Clockwork Jayne was exhibited, despite her extreme simplicity as a state machine, yet another self-generating audience behavior was apparent: Clockwork Jayne would prompt her gallery audience to form into an orderly queue – a long line of people patiently waiting for the experience of winding her up and watching her gradually unwind.

In observing this binary automaton, with a level of inherent complexity surely too low to permit emergence from within, I still noted an artwork/audience interaction that was arguably emergent. My interpretation, consistent with my earlier conjecture, is that artworks are able to grow behaviorally by acquiring state-potential from their human audience.

The motivation for humans making their state-potential available to an automaton, however, requires further explanation. In the case of Counter the act of enumeration itself seems sufficient to prompt deep audience engagement with an abstract, conceptual work. I see a parallel with the use of a commonplace motif in Floribots; just as flowerpots are familiar and attractive, so is the very act of counting. It seems that humans are generally attracted to automata based on commonplace motifs and motivated to share state-potential with them. In the case of the ballerina automaton Clockwork Jayne however, my view is that it's principally the device of anthropomorphism that binds the audience

"Counter" with a "pedestrian vortex" (© 2011, G. Drake-Brockman)

so closely to these human-shaped artworks. Humans are universally attracted to representations of themselves, and the intensity of this reaction is magnified exponentially when the representation moves, and even more importantly reacts to them. With the boost provided by anthropomorphism, it seems that even binary automata can achieve emergence.

VARIABLE RELIEF

Having explored the limit of low-complexity automata, an alternate wing of investigation suggested itself – that of automata even more complex than the 2^{128} states of Floribots. Accordingly, I created a "spatial robot" called "Headspace".

Headspace draws on the ancient artform of relief sculpture, but updates the traditional carved stone format to a matrix of 256 motorized polished aluminum rods. Each rod can independently move back and forth by about half a metre, allowing the overall grid to assume a wide range of relief topologies. Headspace is effectively a "variable relief" sculpture.

Headspace is fully autonomous; possessing four motion sensors with which to detect human presence and an on-board software algorithm to regulate its behavior. This Headspace "mind" is loaded with three-dimensional scan data from the faces of over 600 schoolchildren, and the rod matrix is able to adjust its relief profile to represent these faces, as well as morph between them and perform various geometric transitions. As a variable-portrait system, Headspace is capable of human representation - like Clockwork Jayne – and thus is also, in a sense, anthropomorphic.

Headspace is vastly more complex than Floribots. Each rod in the Headspace matrix may be moved between 256 discreet positions, so the overall system has 256^{256} or about 10^{616} states! When Headspace was placed on permanent exhibition at Christ Church Grammar School (Perth, Australia), I noticed novel, unanticipated behaviors manifesting in terms of interference between its disparate subsystems, and apparent layering of algorithmically discreet matrix behaviors. So Headspace also exhibits emergent behavior - as we may have expected given its very high level of complexity. In addition, Headpsace has proven to be exceptional in terms of its audience engagement, although mostly online. In fact, more than 160,000 people have viewed the Youtube video of Headspace – considerably more than have physically attended any of my gallery exhibitions.

COSMIC CONNECTIONS

Although Headspace is a permanent installation, it is located inside a building and its physical audience is restricted to students and staff at one particular school. I speculated that there could be other audiences and sources of state-potential available to a suitably optimized robotic artwork. The opportunity to investigate this possibility arose with a commission to create an external artwork for the NEXTDC Data Centre, in Malaga, Western Australia. The resulting work is titled "Readwrite" - and is activated by stimuli of primarily extra-galactic origin.

Readwrite is an autonomous robotic artwork some 10m in length, with 24 pneumatically-actuated "flipping" elements arranged in a grid, mounted on the front elevation of the data center. Motion sequences on Readwrite are triggered by the detection of charged "muon" particles. Muons are terrestrial cosmic rays generated in the upper atmosphere by interactions with high-energy particles originating from distant supernovae and the accretion disks of supermassive black holes in active galactic nuclei. Readwrite has four muon detectors – with one mounted at each corner of the artwork. When a "cosmic ray" hits one of the corners of the piece, a propagating wave of flipping elements begins from that point.

The Readwrite control algorithm is based on a heavily modified version of the Floribots code-base, and retains elements of the emotional modes of that work - which were originally modelled on the behavior of my sons at toddler-age. Given this, although Readwrite is lower in complexity at a mere 2^{24} or ~10^{7} states, it is not surprising that some of the propensity for emergent behavior first noted in Floribots remains evident. Indeed, Readwrite has been observed to perform overlapping choreographies and mid-flip reversals which can be interpreted as emergent behavior patterns. In terms of audience reaction, Readwrite's location - high on a building on an arterial road in an industrial precinct - means that little local impact is readily apparent - bar the occasional car slowing down to get a better view. Thus, it seems that Readwrite is unlikely to be able to borrow much state-potential from its human audience. However, perhaps its ultimate complexity as an automatous system extends to its network of extra-galactic connections - which could give rise to considerable additional emergent potential. A caveat however, is that the cosmic conversation in which Readwrite is involved is fundamentally reactive rather than interactive in character - due to large distances (millions of light years) extending the feedback time from its extra-galactic interlocutors beyond the likely endurance of the work.

ROBOT MYTHOLOGIES

I noted previously that the Clockwork Jayne, and Headspace automatous artworks employ the compositional device of anthropomorphism – that is, they mimic the physical appearance of a person. Extrapolation beyond the notion of anthropomorphism led me to wonder what it might be like for a created being to not just look, but to be, like a person - to delve into the realm of the "anthropo-onlological". I anticipated that even deeper levels of audience engagement should be possible with this approach, with yet greater potential for human phase space to be "shared" with an automaton. I decided that an investigation of this possibility would best be made via an ongoing dialogue between a real person and a made person - somewhat in the tradition of a Turing (1950) Test. I have collected a set of pre-existing frameworks for such conversations that I call "robot mythologies".

My list of candidate robot mythologies includes widely known stories about made beings, such as: Mary Shelly's (1818) Frankenstein - the creature who becomes jealous of its creator; Pinocchio (Collodi 1883) - the wooden boy who wants to be real; Rachel - the replicant who thinks she's a real woman (Dick 1968); Terminator - the robot from the future that becomes a surrogate father figure (Cameron 1984); Golem - the clay being from Jewish mythology that is animated by an inscription but cannot itself talk; the Tin Man - who yearns for a heart to fill his empty chest (Baum 1900); and the robot doppelganger of Maria who unleashes lust-driven chaos and stirs dissent throughout Metropolis (Lang 1927).

Perhaps the most emotionally-charged robot myth is Coppelia, as it deals specifically with romantic love and attraction. Coppelia is a story about a clockwork girl, who is mistaken for a real girl by a boy who falls in love with her.

PERHAPS THE MOST EMOTIONALLY-CHARGED ROBOT MYTH IS COPPELIA, AS IT DEALS SPECIFICALLY WITH ROMANTIC LOVE AND ATTRACTION

The story thickens further when the clockwork girl is in turn impersonated by a real girl, jealous of the boy's affections. Coppelia is a ballet, with music by Saint-Léon, Nuitter, and Delibes, based on a story by Hoffmann (1817). It was first performed in Paris in 1870, and since then has become part of the classical ballet repertoire and is staged frequently by ballet companies around the world. Because the Coppelia story deals with issues at the edge of humanity - machines interchangeable with persons, love and attraction in flux at this boundary - I decided it was fertile ground on which to develop an automatous artwork dealing with the crux of the created being issue.

THE COPPELIA PROJECT

The Coppelia Project involves the creation of a troupe of four life-size autonomous robot ballerinas who are able to learn and perform dance movements and interact with each other and their audience. The Coppelia Project is inspired by the story of a clockwork girl in the ballet Coppelia, whilst also drawing on the commonplace metaphor of clockwork music boxes, like the Clockwork Jayne artwork.

The Coppelia Project robots are optimized narrowly as ballerina robots or "dolls". They can spin "en pointe", while moving their, arms, head, and waist. However, they cannot walk and their hands do not have grippers to pick things up. The Coppelia Project dolls are taught ballet movements

"Headspace" depicting a facial profile (© 2010, G. Drake-Brockman)

by having their arms, head, and torso physically moved through a ballet sequence by a ballerina trainer. An onboard computer captures the motion so it can be replayed later in various dance move combinations. Realization of The Coppelia Project required custom-developed electronics and software to enable real-time ballet motion capture and replay – a solution for this requirement was developed and integrated with the assistance of roboticist David Veerman.

The mechanical articulation of the Coppelia dolls was the result of an extensive research and development exercise undertaken with Jayne Smeulders of the West Australian Ballet. Jayne assisted in establishing the biodynamic requirements for ballerina movement by demonstrating the classical ballet positions (fig 10) and the paths of the limbs in transition between these states. Jayne also acted as the model for the robots, each of whom shares her body shape and facial appearance.

In terms of its complexity, The Coppelia Project has quite a large phase space and thus ample potential for emergence. Each of the four dolls has 18 independent axes with 12-bit position resolution on each, allowing $4{,}096^{72}$ distinct conditions of the system - which equates to 2^{864} or about 10^{260} states. This is lot more complex than Floribots, but still much less so than Headspace.

My goal with The Coppelia Project is to create "mythically charged" automata – a group of interactive, self-determined, expressive machines – that once set free, operate independently to explore questions at the edge of humanity. Specifically: are machines interchangeable with persons? What are the patterns of love and attraction at this boundary? I see The Coppelia Project as a kind of staged confrontation between humanity and its technological alter-ego. The dolls are "blanks" that are energized by their programming to mimic the elegant movements of human dancers, but they are imperfect in their attempts at human grace. Another stark difference between people and robots is that people are unique, while robots are manufactured goods and can be made on a production line. To emphasize this distinction, the Coppelia robots will perform as a group of four identical machines.

Currently, just one Coppelia doll – believed to be the world's first full-size robot ballerina - has been assembled. This first doll – named "Lilas Juliana Areias" (fig 11) - gave her debut solo performance to an audience of special guests at an exhibition at my studio in 2013. Parts for the other three robots are in various stages of assembly, so the piece overall remains a "work in progress". When fully realized, I hope

to use The Coppelia Project as the basis for a yet more ambitious work integrating human and robot dance in a new ballet stage production.

My selection of the Coppelia theme was made decisive by a fascinating aspect of this ballet when viewed on-stage. In a Coppelia production one sees a beautiful and graceful ballerina "hamming it up" to deliberately move like a clunky robot. We know when we see this performance that the clunky robot being imitated is meant to be a real girl who is pretending to be a clockwork girl, who has been mistaken for a real girl. Why not, I thought, add yet another layer of irony to this intrigue by making a robot to imitate the human ballet dancer? In contemplating this stack of one thing pretending to be another thing, which is in turn pretending to be yet another thing, I am reminded of the concept of "simulacra" as articulated by the cultural theorist Jean Baudrillard (1981) – a key concept which I will return to shortly.

PHYSICALITY

All of the artworks that I have described to this point are mechanical robots in some sense. Each of them incorporates moving elements, occupies tangible space, and has mass. These features crucially distinguish them from "virtual" or computer-generated ("CG") constructs. Occasionally I have even had to point this out to a viewer of, for example, an online video of Floribots who has mistaken the clip they have just watched for a CG animation, rather than documentation of a real-world robot. Whilst recognizing that creating purely-virtual agents is an alternative approach to the created beings agenda, it is not the one I chose to pursue in this body of work.

"Readwrite" performing a sequence triggered by a cosmic ray z(© 2014, G. Drake-Brockman)

Thus, the autonomous robot artworks I have described are digitally activated but realworld-manifested; unlike virtual beings - which are fully digital in both activation and realization.
In building robotic artworks I'm motivated by a desire to make digitally-activated pieces that directly and physically intervene in the human world. I have avoided making CG artworks due to a view that merely virtual artistic constructs work "the wrong way around". That is, virtual artworks invite humans to enter into their machine-mediated space, while I prefer that such works should directly manifest into our everyday human sensory reality. Only by manifesting in human terms do I find it plausible to credit such creations as fully adequate conversational partners, as true mirrorbeings. I see a stark contrast between the vivid physicality of humans – with our beating hearts and bodies that displace volume and have mass – compared to the relative corporeal impoverishment of the screen interfaces most typically used to display virtual constructs. Each of the created beings I have examined is thus steadfastly real and firmly tangible. They are, in every case, physicality, made of "stuff", just like us...

However, in a new work-in-progress titled "Parallax Dancer", I have begun to question some of the pretexts I have just set out, and experiment with an artistic manifestation that does not restrict itself to manipulation of physical matter, but which might still qualify as a created being of an alternate modality. In doing so, I have made a foray into the realms of virtual reality (VR) and augmented reality (AR), in an attempt to build a realworld-embedded nonreal automatous agent. That is - a virtual artwork that solves the human interface problem I perceived, by directly manifesting into everyday human sensory reality.

INVERTED IMMSERSION

In the field of virtual reality, a frequent objective is to create simulated environments that are "immersive" – that effectively surround the participant with visual stimuli from all potential viewing angles. This can be achieved using headsets, multiple video projectors, or rooms completely tiled with display surfaces. Such approaches are viewer-centric, and of-

ten require concessions to participate - like donning special viewing apparatus and temporarily "leaving the real world behind". In the Parallax Dancer project I set out to explore whether an inverted approach to immersion is feasible – one that is object-centric, uses no special worn or handheld viewing apparatus, and integrates fully into the real world. This approach is consistent with the concept of augmented reality - but differs from most implementations in that no personal viewing device is required and it aims to surround a virtual object with output, rather than surround a viewer with input. As I have noted, in most of my work I have pointedly avoided purely virtual outcomes. I was not satisfied with artistic constructs that I felt were "stuck inside the machine", along with the fairly "clunky" interfaces required to view them. Whether the inverted immersion strategy resolves my concerns will become apparent when the Parallax Dancer project is fully realized.

"Parallax" refers to the way that the appearance of objects differs as the angle of view changes. Using the parallax effect, it is possible to create an illusion of three-dimensionality, without relying on stereo vision. Viewing a virtual object with stereo vision usually requires special glasses or a head-mounted display - paraphernalia that I wanted to avoid the need for in this project. A parallax-based illusion of three-dimensionality can be achieved without such viewing apparatus if the spatial location of the viewer is known. The power of parallax can be appreciated with a simple visual experiment: Close one eye… with the remaining open eye have a look around your immediate vicinity, move your head from side to side slightly and note how this conveys

"The Coppelia Project" - "Lilas Juliana Areias" (© 2014, G. Drake-Brockman)

three-dimensional (3D) information about your environment. Even with stereo vision disabled, parallax allows humans to apprehend a very accurate 3D map of the world. In my opinion, parallax is even more important than stereo for human 3D perception, and this is why humans who are blind in one eye can still navigate and operate spatially.

Parallax Dancer is a "spin-off" from, and conceptual compliment to, The Coppelia Project. The "Dancer" in Parallax Dancer is the same ballerina, Jayne Smeulders, who is the model for the mechanical Coppelia robots. At the beginning of the process, Jayne's body was laser-scanned in various ballet poses by the Headus scanning bureau at Fox Studios in Sydney (Fig 12). Phil Dench of Headus then undertook post-production work on the scan data to create a fully articulated,

surface textured, ballet dancing, real-time-generated, 3D animated model of Jayne. He also wrote code to continuously render four parallax-corrected views of the resultant animated 3D ballerina model. This software system, referred to as the "rendering engine", is interfaced in realtime to a viewer-tracking and ballet control system separately developed by a group of graduate engineering students from the University of Western Australia, led by Bradley Byrne. Currently the Parallax Dancer (fig 12) system is operational in prototype form and is undergoing optimization and tuning. The concept for Parallax Dancer is a development from an earlier work called the "Quadrascope" – made in collaboration with Richie Kuhaupt as part of the Chromeskin project (National Sculpture Prize 2001, National Gallery of Australia).

Parallax Dancer is intended for installation in a gallery - where a continuously improvised ballet sequence will be danced by its virtual ballerina in response to the movements of people in its audience. Parallax Dancer will physically consist of a rectangular display-prism made out of four portrait-orientation 165cm video screens. These screens will be set edge-to-edge, facing outwards, and supported on a rotating dais in the middle of the room. A machine vision system will track the locations of viewers in the gallery, and select a "privileged viewer", such that when they look at the display-prism they will see a parallax-corrected view of the dancing ballerina (Jayne), located in its center. This view will remain parallax-corrected from the viewer's perspective - even as they walk around the room. The privileged viewer will also be able to see 'past' the ballerina, to a scene generated to match the background of the room, behind the render-prism. If there are multiple simultaneous viewers close to the installation, then some of them will see a distorted view. The system will be able to 'hop' between privileged viewpoints and support two privileged viewers simultaneously.

Like its twin; The Coppelia Project, Parallax Dancer is a scaled-up extrapolation of a commonplace automaton - the child's clockwork ballerina music box. Both projects are also machine copies of Jayne Smeulders - but using very different technological strategies: One is based on robotics, the other uses a type of virtual reality. The two projects are also linked via the powerful Coppelia mythology - with its evocation of love, sex, and the potential for passionate human/mechanical relationships. I hope to eventually see them both running side by side, to allow a comparison to be made between the two beings and to gauge the intensity of their interactions with audiences.

Intriguingly, I note that the underlying technology of Parallax Dancer - the rendering engine, viewer tracking system, and display prism – has the potential to be a "universal object". Given the right data-set, the device will be capable of rendering any object, static or moving, as a 3D virtual representation embedded into a real environment. In a sense, this could be the "last sculpture" as it will be capable of becoming, essentially, anything.

As a virtual ballerina system, I think that the state machine complexity of Parallax Dancer's 3D animation - without parallax correction - may be approximated to that of a single doll from The Coppelia Project - which has $4{,}096^{18}$ or about 10^{65} distinct conditions. Assuming two privileged viewpoints are tracked with 10-bit resolution on azimuth, inclination, and distance - parallax correction will increase the state space for the artwork by a factor of some 10^{18}, taking it to circa 10^{83}. This number is considerably less than 10^{260} that I calculated for The Coppelia Project – which has four robotic dancers, rather than a single virtual one.

However, if considered as a universal object, the state machine complexity of the rendering and tracking system of Parallax Dancer would be vastly higher. Any general calculation of the state potential of such a system has to rely on pixel-states – leading to unrealistically-high complexity measures, as many theoretically-discreet pixel states are not distinguishable by human viewers. Nonetheless, as an exercise, I have performed a calculation based on the broadest parameters - the theoretical state capabilities of four screens running at 4K resolution with 10-bit color depth – which would give such a machine the potential for well over $10^{298598400}$ states. The preposterously large and somewhat untrustworthy number provides a hint at the seductive power of the virtual approach to creating beings.

COMPLEXITY INFLATION

I have analyzed the inherent complexity of the automatous artworks that I have made by regarding them as state machines. I generalized from this a pattern where the novel behaviors that characterize created beings arise spontaneously from highly-complex automatous systems. In many instances however, the ultimate complexity of these systems seems to be inflated by an injection of state-potential from their audience. I found that

audiences are prepared to "lend" phase space to an automaton were that artwork has first offered to "bind" with them in some way. I have noted that this offer to bind can be expressed in the following ways:

• Using a commonplace motif; such as a flowerpot for Floribots or enumeration for Counter.

• Anthropomorphism; looking like a ballerina for Clockwork Jayne, or taking on the facial appearance of a school-student for Headspace.

• Occupying the public realm; like Readwrite - which is installed alongside a arterial road, in a major industrial district of Perth.

• Making a mythic connection; like The Coppelia Project.

I have also touched on a possibility beyond this anthropocentric structure, where other audiences and sources of state-potential could become available, in terms of the extra-galactic stimuli to which Readwrite reacts. With Parallax Dancer I have investigated the enormous potential complexity of virtual beings, free from the limitations of the physical; or by extrapolation to the universal object, from any limitations at all. However, the primary circumstances that I have found which engender complexity-inflation all seem very much about humanity, or "us", in the following ways:
• Commonplace – being familiar to us.

• Anthropomorphic – looking like us.

• Public – being present with us.

• Mythic – being part of our story.

So, is an investigation of the way that created beings emerge via such exchanges with humanity, ultimately just another way of looking at ourselves, by apprehending mere copies or representations of us? To answer this question adequately I refer further to the work of Jean Baudrillard.

SIMULACRA

To me, Baudrillard (1981) is the primary authority on the nature of technological simulations, copies, and representations. He has examined the historical and cultural development of these phenomena and has identified three orders of simulacra:

• First order; where objects are unique and each representation is a clear counterfeit of the real and is recognized as merely a place-marker for the real.

• Second order; where mass production and widespread availability of mechanically produced copies cause distinctions between representation and original to begin to break down.

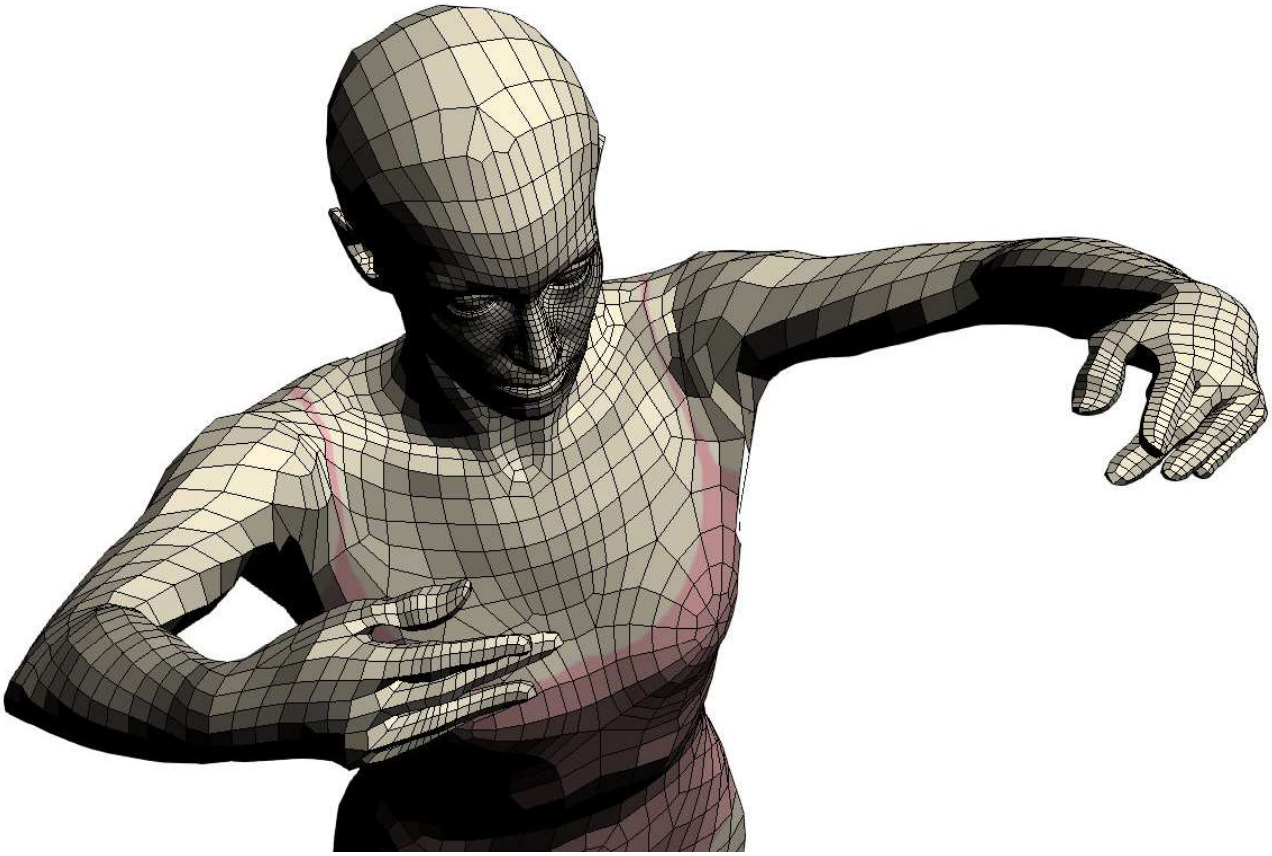
• Third order, where the distinction between reality and representation vanishes. In the third order of simulacra, which roughly corresponds with the world we now inhabit, Beadrillard says that we experience a precession of simulacra; that is, the representation precedes and determines the real. How can The Coppelia Project, or its sister work Parallax Dancer - where I aim to make anthropo-onlological automata, be reconciled with this undermining of the ultimate reference – humanity – on which the constructs are founded? The apparent model for these automata is of course "us" – human beings. We are unique, natural, imperfect, people; who possess agency – that is, we have volition, capability, and motivation. It seems obvious that to the extent that an automaton begins to seem like a being it is because it seems like a human.

However, Baudrillard explains that, in general, the real, authentic, and original – in this case the true human - has been dissipated by the "precession of simulacra". In making this observation, I think Beaudrillard hints at a yet more interesting interpretation of where "true humanity" might now lie. It seems to me that our collective nature has come to reside in the very layering of the simulacra-stack that we have built up around ourselves. This "stack" is no longer ordered from most authentic to least, but is like a loop, perhaps akin to the "pedestrian vortexes" that spontaneously form to cycle through the aperture of Counter.

By analogy; the defining photographic portrait of our time has shifted from the stiffly-posed formal tableaus of a century ago, to a digital "snap" of a teenager in the very act of taking a "selfie". In this context, The Coppelia Project and Parallax Dancer contribute to the definitional process - by adding further layers of simulation to the simulacra-stack, and possibly even extending the system laterally by acting as a simulacrum of an entire stack of simulacra. Indeed, I think that such referent-less human simulacra systems now constitute the most useful "us" available for artistic examination.

CONCLUSION

In this paper, I have described how commonplace motifs such as origami chatterboxes, doorways, and music boxes have been used as the basis for a series of unexpectedly-behaving and deeply engaging automatous artworks. I have analyzed the emergent behavior



Parallax Dancer Prototype system

exhibited by these automata in terms of the inherent complexity of each artwork, and examined how they can sometimes acquire additional complexity and potential for emergence by effectively borrowing "state-potential" from their human audience, and possibly elsewhere. I have noted the role of anthropomorphism in intensifying the engagement between audience and robot, and looked at the potential for robot mythologies to extend this engagement.

Beyond the physical "traditional robots" that are the principle focus of this paper, I examined an outlier-being to help map the limits of my complexity-based analysis of automata. The inverted immersion virtual being Parallax Dancer led to speculation about the possibility of a universal object with the potential for off-the-scale complexity.

I have touched on the notion of simulacra to help understand the cultural context of automatous artworks that seem like beings. We humans naturally tend to see ourselves as the primary originals confronting our secondary simulations in the form of such creations; but Baudrillard reveals that our position as originals is no longer privileged. Any claim that we are the first and special beings – in a milieu characterized by pervasive practices of re-representation, multiple duplication, and perfect copying - has been deeply undermined.

In many of my works I include a reflective element - a mirror. For example, every Floribot has a mirrored base-plate, and The Coppelia Project dolls have mirror-polished aluminum skeletons. These inclusions are deliberate, as I see every created being as a kind of mirror, a "mirrorbeing". The implication is that the relationship between creator and created is ultimately reciprocal. Via the precession of simulacra our creations reveal in us aspects of an "inverse Pinocchio" – the boy who wishes he was wooden. In a similar vein - via confrontations with automata - we may also see reflected our various propensities as jealous creatures, speechless golems, and beautiful clockworks.

I have made automatous artworks utilizing a progression of artistic devices from commonplace inclusions to mythic allusions in pursuit of ever-deeper audience engagement and greater opportunities for emergence. It seems that the resultant "mirrorbeings" are imitating us, while we in turn imitate them - and that the greatest potential for emergence arises from the pooled phase space of us and our creations. Further, we have seen hints that even further potential may be tapped from the very phase space of the cosmos, and from the disembodied world of the virtual.

■ GEOFFREY DRAKE-BROCKMAN

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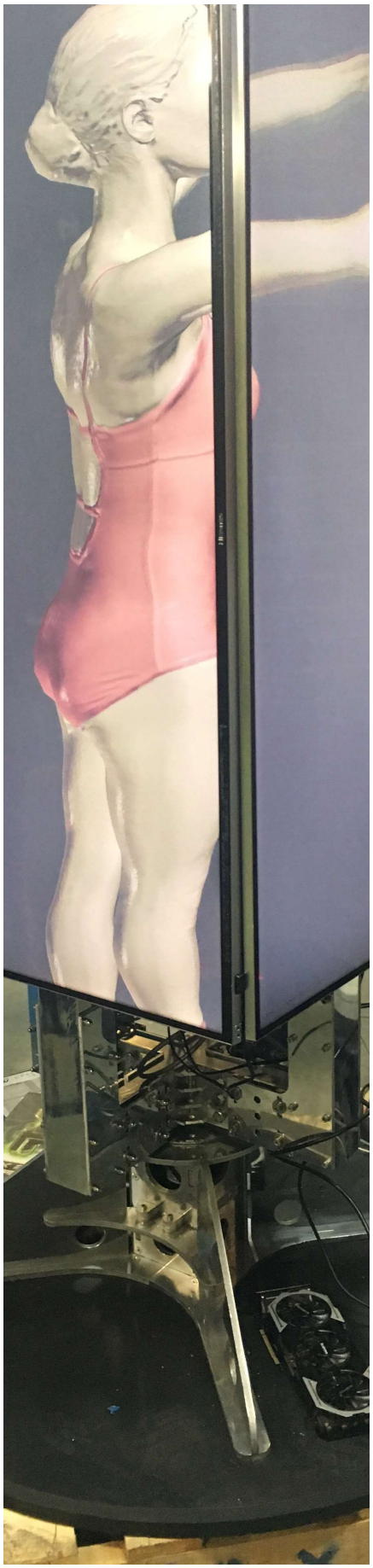
Notes:

i - A phase space is a coordinate space in which all possible states of a particular system are represented, with each state of the system corresponding to a unique point in the coordinate geometry of the space.

ii - Spatial Robots are reconfigurable environmental machines that are optimized for altering their shape in response to stimuli. They may be considered to be a sub-branch of interactive architecture.

iii - The Coppelia Project has been assisted by the Australia Council for the Arts, The Western Australian Government through the Department of Culture and the Arts, The West Australian Ballet, and the many generous contributors to its crowd-funding campaign.



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GEOFFREY DRAKE-BROCKMAN IS A CYBERNETICS ARTIST SPECIALIZING IN LARGE-SCALE PUBLIC INSTALLATIONS. GEOFFREY HAS BEEN EXHIBITING SINCE 1986, WITH SHOWS IN PERTH, SYDNEY, MELBOURNE, CANBERRA, DENMARK, NEW YORK AND LONDON. MAJOR EXHIBITIONS INCLUDE THE LINTON AND KAY (2016), NATIONAL GALLERY OF AUSTRALIA IN 2001 AND IN 2005, SINGAPORE ART MUSEUM (2010) THE BIENNALE OF ELECTRONIC ARTS PERTH (2002), THE PERTH INSTITUTE OF CONTEMPORARY ART, (2007), SCULPTURE BY THE SEA, BONDI, COTTESLOE, AND AARHUS/DENMARK; (2001 - 2014), AND COLLABORATIVE CONCEPTS IN NEW YORK (2002). HIS PUBLIC COMMISSIONS INCLUDE THE ELEVEN-METRE-TALL ROBOTIC SCULPTURE TOTEM AT THE PERTH ARENA, THE COSMIC RAY-ACTIVATED AUTOMATON READWRITE AT THE NEXTDC DATA CENTRE, AND THE INTERACTIVE LIGHT SCULPTURE SURFACE AT THE PERTH CHILDREN'S HOSPITAL. GEOFFREY WAS BORN IN WOOMERA, SOUTH AUSTRALIA IN 1964 AND IS BASED IN PERTH, WESTERN AUSTRALIA. GEOFFREY HOLDS A BSC IN COMPUTER SCIENCE AND A MA IN VISUAL ARTS