Symposium on Cybernetic Serendipity Reimagined

In conjunction with the 2018 Convention of the Society for the Study of Artificial Intelligence and Simulation of Behaviour (AISB 2018)

6th April 2018

Colloquy of Mobiles 2018 Project

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Abstract. The authors report on a project to replicate Gordon Pask's Colloquy of Mobiles, an immersive, interactive installation that was part of the Cybernetic Serendipity Exhibition at the Institute of Contemporary Arts in London in 1968. To celebrate the 50th anniversary of the Colloquy in 2018 and to mine its legacy for future generations, a full-scale version will be replicated in conjunction with studio design courses in the Masters of Interaction Design program at the College for Creative Studies in Detroit. While the physical form of the replica will be as close as possible to the 1968 original, it will be driven by modern digital software. This makes possible the close reproduction of the interactions as Pask implemented them in 1968, as well as openings for the exploration of what new technologies—voice interfaces, motion sensors, facial sentiment analysis, and AI—imply for the future of human-machine symbiosis. This updated configuration will enable visitors to fully appreciate the sophistication of Pask's seminal work as well as to question the future of conversation in a world rich with possibilities and perils, when technology takes on properties of the biological and of the human. Target date for public viewing of the replica of the 1968 Colloquy is 11 May 2018 in Detroit, Michigan, USA.

1 INTRODUCTION

In 1968, Pask's Colloquy of Mobiles comprised sculptural figures or mobiles that moved and interacted through light and sound, with each other and with the public (Figure 1) [1]. m Colloquy explored the nature of machine-to-machine and person-to-machine conversations in an interactive, immersive environment, perhaps the first of its kind. Frequently praised for its originality and influence [for example, see 2], Pask's work is a precursor to practices of contemporary art and design, such as relational aesthetics, social practice, intermedia, user experience/interaction design, and human-machine interaction.

The origin of the project lies with a conversation between one of the authors [Pangaro] and Hugh Dubberly, the design planner and teacher, both well versed in the important of Pask's work in conversation theory, especially in relation to the field of design. On realizing that the 50th anniversary in 2018 afforded a rare moment in time and that the second co-author [McLeish] could be available to ensure the construction of the full-scale replica, the project was born.

This paper can only sketch what we have learned between conceiving the project in November 2017 and the time of writing in late February 2018. It is intended as a placeholder for further results and for the publication of all documentation in the tradition of open source.

The paper is organized as follows. First, in Section 2 we begin to document the pre-existing materials we drew upon and the allocation of labour and steps taken on to learn how Colloquy 1968 worked. In Section 3 we offer some insights from the building of a scale model and planning for the full-scale replica. Section 4 offers very preliminary reflections from the project. Section 5 describes what we hope audiences will take away. Lastly, Section 6 expresses hope for a completed installation and the promise to report again what we have learned, including all materials used to reproduce the Colloquy

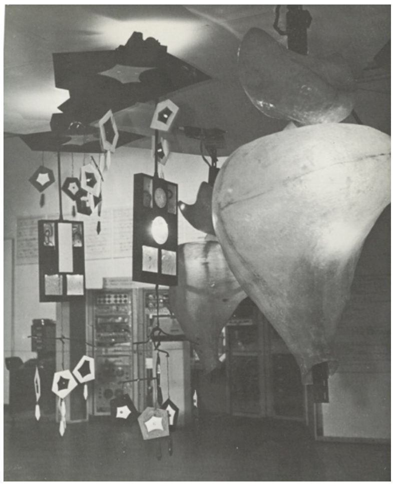

Figure 1. Colloquy of Mobiles. Photo from Institute for Contemporary Arts, London

2 MINING THE AVAILABLE HISTORY

To begin, all available materials were gathered. These include[3]:

1. Pask's detailed write-up in his paper, "A comment, a case history, and a plan" [1]. Flowcharts, prose descriptions, and basic plan and section diagrams of the mobile configuration are included. However, it must be noted that this paper was written *before* the Colloquy was constructed and so cannot be completely trusted for its relationship to the final version. While a simple reversal of "Yes/No" in one of the decision trees in one flowchart is not difficult to resolve, both the plan and section diagrams have positional errors (Figures 2 and 3). Even more vexing, the description of the location of sensors on the male figures turns out to be simply wrong. These and other discoveries will of course be captured in our documentation process.

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[3] A complete archive of documentation of the project is planned. The degree of annotation will depend on available resources but the intention is to open-source everything found and everything generated, including CAD numerical models and engineering drawings for future reproduction.

2. Low-resolution digital transfers of 16mm films of the operation of the Colloquy at the ICA in 1968 [3].
3. Images available from a variety of sources on the web [4, 5].
4. More recent writing about Colloquy, with both descriptions of its operations and its intentions [2, 6].
5. Materials that contextualize cybernetics and the work of Gordon Pask [7].

Two studio courses in the MFA Interaction Design program at the College for Creative Studies were well poised, in both the population of enrolled students and the learning outcomes previously determined for each course, to participate in the Colloquy 2018 project.

3 PULLING IT APART AND PUTTING IT TOGETHER

3.1 Writing out the interaction

To date, students in the MFA course Interaction Design Studio IV: Interactive, Immersive Experiences have specified how the original installation worked in 1968 in the form of a detailed scenario, as in this example. The allocation of letters to parts of the scenario are derived from the diagrams in Pask's paper (Figure 2).

Scenario 1: Initial conditions: No female memory as of yet. Male and female have same drive 'O' and reinforcement occurs.

1. Male G has an 'O' drive and needs to locate a female that has the same drive. He is flashing his 'u' light which is signalling 'O'. He has sound sensor which is always active.
2. Male G rotates on its own axis across 180 degrees and two males rotate across 360 degrees. Their 'u' lights are flashing.
3. Females rotate back and forth for 90 degrees on their axes.
4. Male G happens come across Female F1 and all of their components (sensors, lights, mirror) face each other for a fraction of a second.
5. Male G's flashing 'u' light falls on the photo sensor 'a' of F1, which causes F1 to stop. The frequency of the flashing 'u' light will convey the drive of male G—which is 'O'—to F1.
6. The following multiple steps happen in a split second:

   a. F1 determines if her drive ('O') matches Male G's drive, still signalling 'O', based on the frequency of flashing of G's light 'u'.

   b. F1 confirms that her drive matches Male G's drive; she signals this by producing a sound.

   c. Female starts her vertical mirror oscillation.

7. Male G receives the sound and his 'u' light becomes B light, which is the constant light.
8. B light falls on the 'a' receptor of F1 and, if it becomes constant enough, she stops her vertical motor search.
9. F1's mirror stops at the upper angle causing light to hit the C receptor, and reinforcement starts to occur.
10. Male G's 'O' drive becomes satisfied when the reflection of the B light hits the C receptor for a sufficient period.
11. F1 receives the sound from Male G, indicating the reinforcement succeeded, and lowers her 'O' drive by 1 point.
12. F1 places the mirror angle into short-term memory.

They part ways — they rotate again on their own axes.

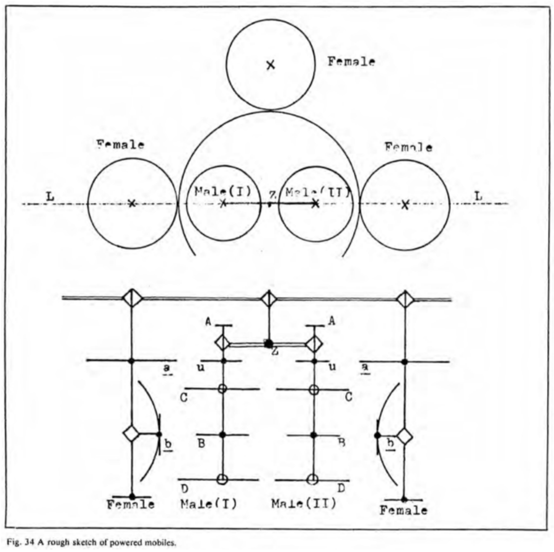

Figure 2. Original diagram from Pask [1] (upper part is plan, lower part is section)

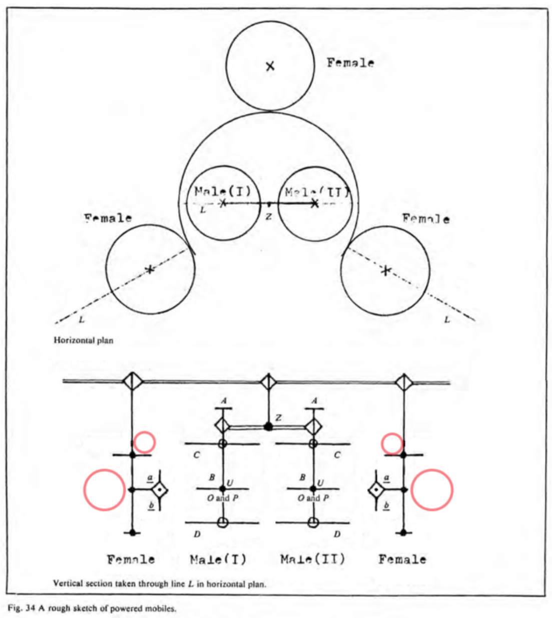

Figure 3. Correction of Female positions (upper) and additional sensors & lights on Females (in red, lower)

3.2 Creating a 1/6-scale Mock up

Students in Studio II: Internet of Things & Prototyping, are creating a -scale mock-up. This begins in physical form, by estimating sizes of the mobiles and recreating them (Figure 4).

Figure 4. 1/6-scale models constructed by students

3.3 Designing the full-scale replica

The greatest challenge is to rebuild the entire Colloquy in its 1968 form—mobiles, motions, and interactions. We have consciously chosen to reproduce the actions, timing, and responses of the mobiles to match Pask's original as closely as possible. We also want to match the sizes and shapes and general sensibility of the physical mobiles. We are working now with fabricators to determine material that mirror the original as best we can, within time and budget. These aspects and priorities have been clear from the beginning of the project.

We also want to be clear that we do not intend to reproduce the original technology behind the Colloquy, for multiple reasons. First, we have been unable to find anyone who had first-hand knowledge of the construction or internal operations. Pask passed away in 1996. Tony Watts was noted by Pask as "responsible for the electromechanical side" and Marc Dowson "constructed the electronics" [1]. We know that Watts passed away and we have been unable to find Dowson despite multiple calls through social media and relevant listservs.

Second, attempting to reproduce the original electronics would be at least foolish and more likely impossible, given the lack of such technology surviving digital advances and the ease of using modern means.

Third, given the descriptions and especially the movies of the real-time behaviours, we feel confident we can reproduce the functional experience of the piece, even if we use modern technologies for its computational, sensing, motion, and lighting components.

Therefore, the focus can be on making the components in the right size and with the right surfaces. Figure 5 is an example of an investigation of photographs to derive shape of the female figures, originally designed by Yolanda Sonnabend (also deceased). From this is derived a numerical CAD rendering shown in Figure 6, followed by a consequent physical 3D model in Figure 7.

Thus far we have considered a range of materials and fabrication methods. Carving the female shape out of a large foam block via a large-format CNC machine is one option; we then have shape to coat with polyurethane or fiberglass (which we suspect was the actual material used in 1968).[4]

The process exhibited for female models—beginning with photographs to derive a numerical CAD model—is being followed for the male mobiles and for the supporting structure of the entire installation, the triangular shape at the top of the installation. We are doing our best to allow for dismantling and moving of all the components, in hopes of the opportunity to exhibit it wherever we are invited and have the resources to do so. We are thrilled to have already been invited to move it to ZKM in Karlesruhe and to other locations in Europe and America.

4 Initial Reflections

Having expended a great deal of collaborative effort on archaeology, we can only be amazed that the original team that assembled Colloquy in 1968 could accomplish what it did. The team had extraordinary ambition at a time when the "back-end technology"—the driver of the interactions based on sensors, lights, motors, oscillators,

[4] Amanda Pask Heitler, Gordon's elder daughter, tells a vivid story of playing with the female forms in their back garden after the exhibition closed. Whether these were actual forms from the ICA or rejected test models we may never know. We are also trying to find out whether the Colloquy were shipped to The Exploratorium and installed there. A history of that museum [8] suggests that the entirety of Cybernetic Serendipity was shipped over, and that reconstructing the whole show including the technology was a "struggle to put the whole show together" but we need to verify this.

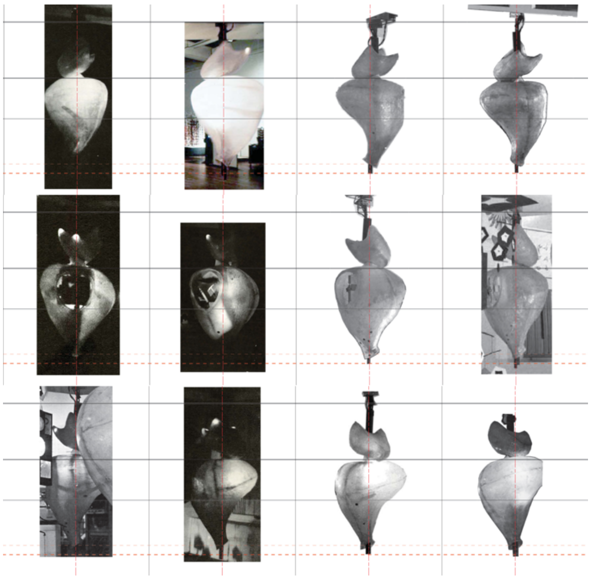

Figure 5. Deriving the shape of the female figures from multiple views

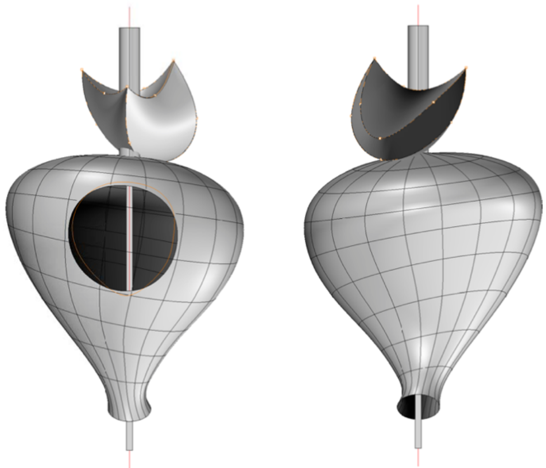

Figure 6. Draft computer models of female mobiles

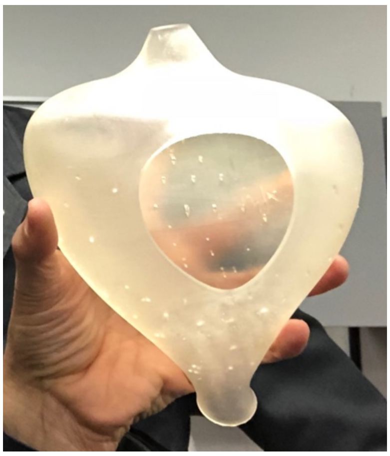

Figure 7. 3D Model of Female

and microphones—was a large and complex analogue morass. How Pask brought his ideas to the team and how together they built the Colloquy, seems impossible. But we have first-person accounts that the experience for gallery-goers was engaging enough to keep them there for hours [8, 9].

While 1968 was not the dawn of the "cybernetic age" in the sense of the genesis and rise of the field of cybernetics (this would have been in the 1940s and 50s), it surely was the dawn of the "interactive age" of machines interacting with machines. This alone was an innovation in the context of mobiles, galleries, and art.

The significance of gender roles in the Colloquy and the intentions of Pask will be impossible to fully explain, though we have views on this and we are certain that the conversations these considerations prompt in 2018 have value. We will document our explorations of this aspect, though thorough consideration is beyond the scope of the current team and academic environment, leading to our desire to develop symposia with greater variety in the conversation.

5 Intended Audience Outcomes

Colloquy of Mobiles creates a human environment that contains conversational machines, a condition that is now part of everyday life, While this was not broadly obvious in 1968, Pask saw it and created an example of it in Colloquy. This perhaps is its fundamental contribution.

Whether operating in its original 1968 mode or an updated 2018 mode, we want Colloquy to allow gallery audiences to participate in immersive, real-time interactions that are surprising and provocative—in Pask's phrasing, to experience "an aesthetically potent environment" [1]. In 2018 the experience of moving among the mobiles of the installation and engaging them via sound, speech, body movements, and facial expressions—hypothetically using enhanced 2018 technology—would offer a rational as well as emotional sense of what it means to live among machines that converse. We want the Colloquy 2018 Project to change how we feel about going home to voice interfaces such as Siri and Alexa, and how we experience living among smart machines.

Despite massive changes in everyday living—sensors everywhere, voice interactions, and artificial intelligence inside of every social network and internet commerce platform—there has been little public debate about the societal and ethical questions presented to designers of these systems. Colloquy 2018 will provoke designers of software, devices, products, and services, across a wide spectrum of industries impacting all aspects of our daily life, to imagine and to debate the opportunities and challenges of pervasive, conversational machines.

6 Future Hopes

As of this writing, the journey to reproduce Colloquy 1968 is midstream. In future we will further report on the experience of completing the installation and the subsequent experiences of visitor-participants. We hope that all interested parties will stay in touch with us by corresponding to colloquy2018@gmail.com.

7 REFERENCES

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[9] G. Pask and S. Curran, *MicroMan. Computersand the Evolutionof Consciousness*. Macmillan, New York (1982).

[10] Personal conversation between P. Pangaro and J. Zeidner.

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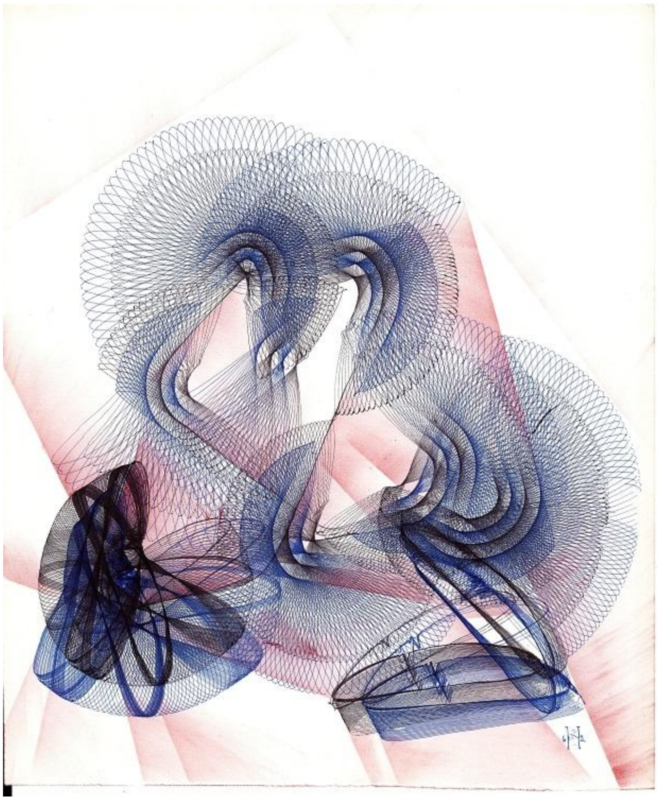
The role of chance in the machine-generated art of Computer Art pioneer, Desmond Paul Henry (1921-2004)

Elaine O'Hanrahan[1]

Abstract. Serendipity plays a significant role in the interpretation of chance-based effects as 'art'. This paper links Desmond Paul Henry's art-making processes with notions of serendipity, by virtue of his knack for experimentation and for converting unexpected 'accidents' and 'failures' into opportunities for creating highly original visual effects as art. Like others before and after him, Henry *insightfully* exploited the unexpected chance effects of artistic experimentation, thereby making serendipity a key feature of his creative output.



Untitled 1962; executed using Drawing Machine One; hand embellishments

1 Introduction

Walpole in 1754 coined his neologism, 'Serendipity 'based on a fairy tale, called *The Three Princes of Serendip*: "as their Highnesses travelled, they were always making discoveries, by accidents and sagacity." Its usage over the years has led to the following, commonly accepted definition: "Serendipity: the faculty of making happy and unexpected discoveries by accident." I take 'by accident' to mean 'by chance' and 'chance' to indicate something that happens unpredictably without *discernible* human intention or observable cause. Furthermore, 'serendipity' has come to mean "more than just a 'happy accident'. It also involves insight – an 'aha' moment of realisation" (Makri, 2012). This corresponds to the 'sagacity' mentioned by Walpole, when seemingly random events are fortuitously connected, based on individual interpretation.

During the 1960s Henry created a series of three electro-mechanical drawing machines from wartime analogue bombsight computers used in bombers to calculate the accurate release of bombs onto their target. These drawing machines produced abstract images made up of curvilinear, repetitive, single-lines which Henry subsequently often embellished by hand in response to their suggestive features. His second drawing machine was included in the I.C.A.'s exhibition of 1968 *Cybernetic Serendipity,* alongside a range of other cybernetic devices employing "random systems." (Reichardt, 1968).

Henry in fact interpreted with hindsight many aspects of his own life as being the result of 'happy chance *co-incidences,'* as reflected by his frequent use of Leibniz's aphorism, 'pre-established harmony of the universe'. In many respects, he could be said to have led a 'charmed' life[2]. These "weird twists of fate" (Henry) that he experienced, inspired him to subsequently embrace and exploit experimental,

[1] The D. P. Henry Archive. Email: *elaineohanrahan@googlemail.com*.

[2] In 1923 he was rescued from a lime kiln at the age of two wearing a woolen suit, which saved him from potentially fatal burns. *Furthermore*:

- His father's hobby mending clocks inspired Henry with a life-long fascination for mechanisms, which caused him to join R.E.M.E (Royal Electrical and Mechanical Engineers) in 1939.
- Wartime shortages meant he discovered his knack for artistic experimentation which led eventually to the development of his drawing machines from 1961 onwards.
- Joining R.E.M.E meant he became closely acquainted with the technology behind automatic fire-control weapons which enabled him to convert bombsights in the 1960s to make drawing machines.
- He met his future wife in the autumn of 1944 because he could speak French and so was committed to deliver an important letter to my mother's friend who by chance was hiding in the house she inhabited in Brussels.
- Henry subsequently escaped death on two occasions from a V1 and a V2, because he happened to have taken leave specifically to visit his fiance living in Brussels. Leave elsewhere would have been *at a different time* leading to fatal consequences.
- It was whilst frequenting the second hand *book* stalls in Shude Hill, Manchester that he unexpectedly discovered the army surplus warehouse from where he purchased his first Sperry bombsight in 1952 which he later converted into his first drawing machine in 1961.
- It is only because his daughter, Elaine O'Hanrahan and author of this piece, unexpectedly fell ill in 1998, left teaching and was encouraged as part of her recovery process to pursue a PhD degree on drawing machines, that awareness of Henry's contribution to early Computer Art has been acknowledged.

'imprecise' *serendipitous* art-making processes.

As Henry explains in his interview of 10/02/03:

> 'all the way through I have been most fortunate in my Father, and then fortunate in my army career and then fortunate in the pure chances of what military equipment the second-hand shops in Shude Hill, Manchester happened to have in stock. It was as simple as that.'

The role of serendipity in Modern Art making processes encouraged Henry to embrace chance-based methods and ultimately exploit a 'mechanics of chance' for the creation of images he significantly referred to as 'Machine Pollocks' and 'Mechanical Fractals'.

2 Serendipity in art: the interpretation of chance-based visual effects as 'art'.

It is a given that Modern Art, with Dada and Surrealism in particular, encouraged experimentation and that artistic procedures were developed which rely on the deliberate incorporation of chance for the production of unexpected visual effects. Experimental techniques involving chance[3] enabled a form of automatic painting that appealed very much to Surrealists, concerned as they were with the desire to evoke buried subconscious imagery. By allowing chance to generate the images, it was felt works could be initiated outside or beyond the artist's will and used *as a starting-point* to be worked upon later by the artist. Examples of automatic techniques relying on the creation of unexpected chance effects as a starting point, include: Frottage (Max Ernst), Decalcomania (Oscar Dominguez), Fumage (Wolfgang Paalen), Sand- Painting (Andr Masson) and Coulage (Joan Mir)[4].

In much the same way, Henry would stare at his machine-produced visual effects, and allow his imagination to respond to their suggestive features often elaborating and embellishing them by hand.

[3] Today artistic techniques exploiting chance have been commercially exploited and popularised. For example the creative toys involving chance like 'Swirl Art', 'Magic Blo Paints' and marbling kits. Artist Damien Hirst exploits the effects of chance with his Spin Painting.

[4] "**Frottage**" (Max Ernst) involved making rubbings of different materials which would suggest all kinds of shapes and creatures to the artist. **"Decalcomania",** invented by Oscar Dominguez, consisted in smearing gouache, ink or oil onto a glossy non-absorbent surface and then pressing paper or canvass onto the paint while moving it, thereby creating a highly accidental design. This technique could also employ watercolour paints pressed between two sheets of paper. The marks made in this way would then suggest a direction for the finished work to take (Bradley, 2001, p. 24). Wolfgang Paalen was converted to Surrealism in 1935 to which he contributed the technique of **"fumage",** that is, interpreting the smudge marks left by a candle flame applied to the surface of the canvass (Tomkins,1973,p. 149). **Sand-painting**, developed by Andr Masson represents another surrealist technique providing a source of pre-pictorial inspiration. In this procedure, glue is smeared onto a canvas over which sand is then sprinkled and the resulting patches interpreted by the artist. (Bradley, 2001, p. 22). Mir was another surrealist who welcomed accidents and chance interventions as in his experiments as in the 1920s when he applied thin washes of paint which he allowed to run and drip. This was a first "free, unconscious" stage for Mir, the results of which would then be elaborated upon by the artist. (Tomkins, 1973, p. 135). "**Coulage**" was another technique that exploited chance, in that paint was poured onto the canvas rather than being applied by brush. Henry employed a similar technique when he dribbled and flicked commercial paint onto a smooth, door-size, gloss-painted sheet of plywood which he then left to dry standing on its side. The paint, in response to gravity, formed various trickles, smooth bumps and undulations. He called the visual effect produced *Effigy of a Napalm Victim*. However Henry's attempts to exploit the chance effects of rolling his wife naked in paint were met with a definite 'no', much to his disappointment!

3 Serendipity and Henry *before* his drawing machines.

Experimentation and ingenious improvisation were the main driving forces behind Henry's art work as already witnessed in the 1940s and 50s by the various experimental drawing techniques which he developed. Due to wartime shortages and a lack of disposable income, these techniques all relied heavily on whatever materials happened to be cheaply, easily and readily available at the time. For example, whilst serving as a clerk in the army, he developed a unique finger-rubbing technique using the plentiful supplies of office duplicator ink. Following the war, his photochemical technique was based around the free and plentiful supplies of photographic paper and developers obtained through his Father's place of work. Even his children's zinc and castor oil baby bottom cream found its way into his drawings when he created a form of etching by smearing this cream in a *random* fashion on light sensitive, reflex contact paper, which was then scraped and treated in a hypo-bath, all of which produced sepia tone effects to be used as a *starting point* for further elaboration.

4 The drawing machines: their reliance on 'chance finds'

After nine years of feasting his eyes on the "mechanical ballet" (Henry) of the bombsight's internal cams, differentials and gears in motion, Henry became inspired to capture these mechanical movements on paper. And so in 1961 he transformed the bombsight into a harmless drawing machine. The various elements required to bring about this conversion were the mechanical components he happened to have collected in his workshop and which by good fortune turned out to be just what he needed to create something very original. Henry's serendipitous mind-set (he often referred to himself as "hopeful Henry") is encapsulated by yet another of his favourite sayings: "every hitch becomes a blessing". For example, the creative use he made of the nearly spent drawing pens:

> "Variety can be incorporated even when the two pens are the same colour by using a new Scripto as the dominant member and an old one, on the point of expiry as a subordinate partner; the latter gives a pleasing pencil-like variant of the dominant drawing. (Henry, May 1968)

5 A mechanics of chance in the service of serendipity

Henry manipulated the workings of the bombsight in order to propel drawing pens across the flat surface of a drawing table. Bombsight computers worked based on analogue computation, where information is conveyed through analogous physical quantities, (in the case of the bombsight, electronic signals). The bombardier entered information on altitude, wind speed and direction and bomb weight into the computer which then calculated the best moment for bomb release. This analogue computer did not involve the use of algorithms or computer programming language of equivalent modern digital machines. As a result, the subsequent drawing machines Henry constructed from this analogue computer could not be pre-programmed nor store information. Nor did Henry have to *preconceive* what he was going to ask the machine to draw and then write the appropriate programme, as with a digital computer. Furthermore, he turned the fact he was not a trained mechanic (he had been an *office clerk* in R.E.M.E) to his advantage. His lack of expertise meant that potentially "any loose screw" could have an unforeseen and dramatic effect on the final graphic result, much to Henry's surprised delight. Each image was in part, a 'happy chance discovery'. The imprecise nature of the way his machines functioned, were caused by:

> "faults in the assemblage and parts of the machines. And quite a lot of my productions came from my own lack of skill in assembling the sub-parts of the machine" (Henry, 2003)

Having only general, overall control, his drawing machines ended up being idiosyncratic and unpredictable- the very opposite to a precision instrument such as a digital computer. The frequently *imprecise* synchronisation of movement between drawing paper, turntable and drawing pen holder(s), ensured an infinite variety of visual effects. Henry subsequently applied his *artistic intuition* (compare Walpole's 'sagacity'), to either leave untouched or to embellish whatever machine-generated effects had unexpectedly appeared thanks to this 'mechanics of chance.' This phrase was first coined by Pontus Hulten in reference to the mechanical sculptures of Jean-Paul Tinguely (Peiry, 1997).

6 Machine-Pollocks

Many of the automatic techniques pioneered by Surrealist painters influenced American Abstract Expressionist painters, as in Jackson Pollock's drip paintings. Sometimes Pollock chose where to pour his paint and in what type of stroke; at other times he relinquished his paint can to the wiles of the irrational, allowing his body to become automated (Rohn 118-20). In essence, Pollock controlled his parameters while welcoming "the dynamics of spontaneity and flow" (Rohn 42). In much the same way Henry had only general overall control of his machines but could intervene at any moment of his choosing. He relished watching and intervening in the act of his machine making a drawing, whose configurations would only gradually emerge. With his second drawing machine, there were two servomotors, one for directing the pens, the other for the drawing table. The "running in and out of phase of the relative rate of revolution" of each motor occurred in regular or *random* sequences, producing regular or irregular patterns. These patterns were mainly obtained through a combination of varying degrees of table and pen oscillation which could be further enhanced by the positioning of clothes pegs attached to the drawing paper on the drawing table.

> "But if one wants machine-Pollocks, then this is the way to produce them. There is an infinity of spring and stop distances, all of which may well produce new effects……" (Henry, letters to Elaine)

The imprecise elements in his machines make possible a kind of 'mechanical expressionism' in that they

> "allow the machine…to put forward its suggestions, but at the same time leave immense scope for the creativity of the artist in the development, modification or suppression of the plastic material thus placed at his disposal" (Henry, 1964).

This corresponds to the way Gordon Pask conceived human-machine interaction as a form of conversation, a dynamic process, in which the participants learn about each other. Henry felt he was "forever learning something new" from his drawing machines. There are necessary limitations to the possible states within a system, as reflected by Ashby's Law of Requisite Variety, but once you add the element of spontaneous human interaction, then that variety is *almost* limitless within the constraints of the system itself. Once Henry felt he had exhausted all the variations in his first drawing machine of 1961, he cannibalised it to make the second more advanced version which allowed for a broader range of possibilities.

7 Mechanical Fractals

In order to arrive at a truly comprehensive understanding the effect of the role of chance in Henry's machine-generated art it is worth considering a branch of Chaos Mathematics known as Fractal Geometry in relation to the aesthetic appreciation of the machine-generated drawings themselves. Standard Geometry, explains Benoit Mandelbrot, is often described as cold and dry because it cannot describe the irregular and fragmented complexity of patterns and shapes in nature as can Fractal Geometry (Mandelbrot, 1994, p. 2). His introduction to fractal theory in 2002, gave Henry additional conceptual terms when Elaine gave him the book by John Briggs, 1994, *The Patterns of Chaos.* His excitement at this discovery spurred him on to start yet another drawing machine project in 2003 with renewed enthusiasm, after a gap of some fifteen years. He subsequently also started to refer to his machine-produced graphic effects as, "mechanical fractals", (Henry, 2003) since his machine-produced drawings display "the kind of random yet strangely orderly grouping that is the signature of a fractal" (Briggs, 1994, p. 54). The patterns in his images are the result of both controllable and uncontrollable factors in their production method, as is the case for Jackson Pollock's "tangled abstractions" (Briggs, 1994).

Richard Taylor, together with Adam Micolich and David Jonas, analysed Pollock's patterns and successfully showed that they are fractal and so "display the fingerprint of nature" (Taylor, 1999). For Taylor, Pollock's drip paintings represent a type of *Fractal Expressionism* whose art products exercise a special appeal encompassed by what neuroscience has termed '*fractal fluency*' (Taylor et al., 2016). It would be interesting to see what similar computer analysis of self-similarity on different scales, of a Henry machine drawing, would reveal.

8 Digital art and serendipity

Computer-generated images have been dismissed by some as not belonging to art at all since their effects may be mass-produced; no obvious skill is required in producing them, especially in view of currently available software; such software leaves no scope for spontaneous artistic intuition, so making the machine effects impersonal, predictable and replicable. The question arises as to what extent modern computer imaging software enables or determines what the artist may or may not do (Welsh, in Hayward, 1990, p. 151). According to Brian Reffin Smith the sophisticated, highly perfected computer software of today, means that the graphic results tend "to feel the same", unlike when artists wrote most of their own software and "the results were idiosyncratic and rare" (Smith, 1997, p. 99). As a consequence, the scope for "adventurous, dangerous and unconventional art" (Smith, 1997, p. 108) is reduced, as also is by extension, the opportunity for serendipity. On the other hand, 'imperfect' tools, like Henry's drawing machines, can be judged to have enhanced artistic creativity. The imprecise way his machines were constructed and operated ensured that his effects could not be mass-produced and would be infinitely varied. Paul Brown explains how modern computer software represents "user-friendly tools", and as such tells the user there is "nothing new to learn" (Mealing, 1997, p. 141). Brown believes such tools may well "cauterise creative development" (ibid.).

In digital computer programming, the random has to be deliberately introduced within fixed parameters by leaving a decision to chance within an exactly specified range of possibilities. Henry's drawing machines avoid such prescription through their mechanics of chance that at the same time leaves scope for spontaneous, human intervention with the *serendipitous* picture-generating mechanism.

9 Conclusion

For Henry's machine-generated art, it wasn't so much a case of 'joining the dots' but more of 'joining the lines' – a clear case of making unexpected, happy chance discoveries and applying artistic interpretation or 'sagacity', that is, a serendipitous process par excellence. Surely the challenge to today's digital artists is how to ensure there is scope for serendipity within their activity so that alternative, outrageous forms of creativity may spring to life?

"Dr. Henry and his painting machine" (*The Independent*, 03/11/64)

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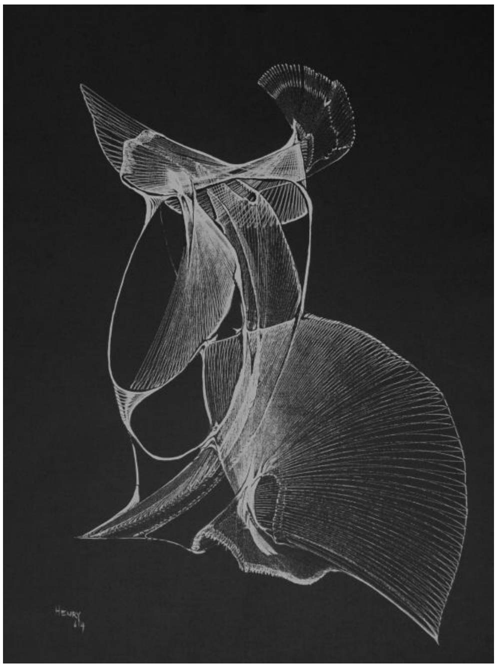

Untitled 1964; executed using Drawing Machine Two; hand embellishments

Symbiosis - Electronic Music for an Analogue and a Digital Age

Ian Helliwell[1]

1 THE DEMO

A reading of the submitted text accompanied by projected still images of the Symbiosis graphic score and its instructions, pages from Practical Electronics magazine and examples of electronic equipment used in interpreting Symbiosis. The final part will be a screening of a new video animation of the score featuring my own version of the 7 minute composition.

2 ABSTRACT

One of the areas covered in the Cybernetic Serendipity exhibition, was the rapidly developing discipline of electronic music. While this was concerned primarily with computer controlled sounds, the compositional end results of digital programming were not dissimilar to electronic music created via existing analogue tape procedures. Serendipitous outcomes arrived at through mistakes or unorthodox patching or programming of electronic modules, can occur with analogue and digital devices, though in 1968 at the time of the exhibition, electronic music generated with either computers or synthesizers was still in its infancy, and access to equipment was highly limited. By the early 1970s however, the development of affordable synthesizers had forged ahead, and the new instruments were increasingly accessible to people with relatively modest budgets. Although the hobbyist monthly magazine Practical Electronics (PE) had introduced PEAC, an analogue computer home construction project in January 1968 [2], electronic music making with computers was for most people still many years away. Coincidentally, the same PE issue featured a simple circuit design for building a white noise generator, described as being capable of producing, "a wide range of very interesting sound effects, many of which are of practical use in making electronic music." [1]

In 1975 PE published a feature on Symbiosis [5], an electronic music composition designed for realisation by its readers via a graphic score. The piece developed out of two construction projects - the PE Sound Synthesiser [6] and the PE Minisonic [7] - which involved electronics designer G. D. Shaw and composer Malcolm Pointon. The PE Sound Synthesiser was a monumental undertaking running in the magazine for 13 issues from February 1973, and was augmented by articles on electronic music by Pointon in his column 'Electromuse'.

Although in the early 1970s DIY synth building represented a significant saving compared to the cost of buying a commercially produced machine, the length and complexity of construction was enough to deter many electronic music enthusiasts lacking the time and requisite skills. Some readers who did commit themselves to the exacting PE project however, provided feedback on their experiences and made suggestions for possible improvements and modifications. As a result of the shared experience and knowledge exchanged between the magazine and its readers feeding back to GD Shaw, PE commissioned him to come up with a new and more compact synthesizer project.

In scale, ambition and construction time, the Minisonic was modest and accessible, and ran over three issues of the magazine starting in November 1974. It dispensed with the by-then established convention of including a traditional piano style keyboard, and instead incorporated a 'Stylophone' type stylus based tone activation system, lending itself more towards the experimental area of electronic music in which Malcolm Pointon specialised. PE took the bold step of asking him to create a composition for the Minisonic, which could be represented in a graphic score, and realised by constructors having built their own synth.

In its encouragement for readers to get involved in not just circuit construction, but also the creative side of electronic music, PE was helping to foster an experimental approach that reached out beyond colleges and universities and into the homes of ordinary hobbyists. It provided both a way into exploring the stranger, avant-garde sounds of analogue synthesizers, as well as introducing the potential of graphic scores - especially useful for those people left behind by their inability to read conventional music notation. The score not only represented the structure, dynamics and timbres of the piece for the composer, but crucially it could also provide the listener with an engaging visual reference point with which to follow the music.

From its inception as a new art of sound composition following World War 2, musique concrete and electronic music had struggled to find acceptance with much of the British public. Writing in the Studio International special issue on Cybernetic Serendipity, published to coincide with the ICA exhibition, respected American engineer and computer music pioneer John R. Pierce (1968) stated, "The proponents of electronic music have found themselves plagued with two chief problems." [4] Besides describing the time-consuming nature of electronic composition, he stated that, "the other limitation has been one of variety of sound. However strange electronic music may sound, it seldom sounds anything but electronic." [4] This is a common theme running through much of the discourse surrounding the subject in its formative days. Rather than embracing electronic tones and encouraging experimentation, the debate often focussed on the supposed dangers and problems, and the perceived difficulties in creating the new music.

While the contributors to the music and sound sections of Cybernetic Serendipity were predominantly US based, and included Lejaren Hiller, Herbert Brun, James Tenney, Gerald Strang and John Cage, British exhibitors were led by John Lifton and Peter Zinovieff. Of specific interest here was Zinovieff's

installation which incorporated a computer system with interactive microphone input, and invited visitors to whistle a tune for the computer to analyse and play back with electronic variations. Zinovieff's south London studio housed a PDP-8/S, and was the first private facility in the world to operate a computer for electronic music composition. Soon to embark on the formation of the company EMS, which produced the first commercially available synthesizer designed and manufactured in Europe, Zinovieff and EMS were operating at the intersection of digital computers and analogue synthesizers - a hybridized approach particularly relevant to present day working methods in electronic music.

The sounds and compositions that were produced during the 1950s, 60s and 70s were too strange and uncompromising for most people when heard in isolation. And yet when listened to in conjunction with a visual stimulus or graphic representation, mainstream audiences were perfectly willing to accept all manner of weird sounds and unorthodox noises, without having to question whether what they were hearing could be classified as music. Unfortunately by the 1980s, time and technology had moved on, and the avant-garde nature of electronic sounds from previous decades was considered unacceptable in a mainstream context, and disappeared from popular culture. The traditions of piano keyboard and easy on the ear pop music once again prevailed, and progressive and innovative experiments such as Symbiosis were pushed aside and forgotten.

Their potential remains however, and Symbiosis translates easily from the 1970s into the 21st century, and invites new interpretations. While the Minisonic synthesizer is not accessible today, the piece can be effectively realised on all manner of technology, and lends itself particularly well to self-built, creatively soldered equipment and analogue synthesizers - exactly in keeping with the spirit of experimentation of earlier times. In 2017 I serendipitously received a recording of Symbiosis made by skilled electronics enthusiast Paul Williams in 1978. He was an accomplished constructor of synthesizers, and typifies the knowledgeable hobbyist, perhaps more preoccupied with building the project, rather than with subsequent creative applications utilising the finished result. Nevertheless, without having heard Pointon's original, Williams made the effort to tackle Symbiosis, and one can only wonder how many other 1970s PE readers also took up the challenge.

During research for my book Tape Leaders - A Compendium of Early British Electronic Music Composers [3], I made contact with Pointon's widow, and she still had most of his electronic recordings, including Symbiosis. Comparing the two 1970s interpretations suggested a contemporary reimagining and revitalisation of the piece, and I completed my version in February 2017. I then decided this could be the start of a stimulating project by inviting fellow electronic composers to make new renditions, and to date I have eight recordings. My interpretation was created using only my self-built Hellitron tone generating equipment.

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Serendipity in Melodic Self-organising Fitness

Róisín Loughran and **Michael O'Neill** [1]

Abstract. Employing Evolutionary Strategies (ES) for subjective tasks such as melody writing causes an immediate problem in determining what to use as a fitness measure. By predefining a measure based on genre, musical rules or human opinion, as has been done in previous studies, we may be prematurely limiting the possibilities obtainable by the system, rendering serendipitous discovery impossible. In this paper, we discuss the development of a system that generates its own self-adaptive fitness measure in response to a corpus of evolved melodies. The system dynamically creates new fitness measures, or *Critics*, in response to new melodies in a cyclical manner with minimum human intervention. Thus it is a closed loop feedback system that develops its own fitness function through a response to its environment. We propose that the development of such a system could lead to more autonomous creativity and that the use of dynamically changing Critics and melodies could encourage the emergence of serendipitous discovery.

1 INTRODUCTION

Evolutionary strategies (ES) are driven by a fitness measure: a given measure or characteristic that determines an individual's likelihood to survive and reproduce. In a sense, this offers a parody to Darwin's theory of *natural selection* observed in nature, whereby individuals and hence species survive according to some survival traits emergent from the process of evolution in the real world. In computative ES, this fitness or survival measure is artificially pre-defined by the programmer to force the bred individuals to perform as they best see fit — to solve the given problem — which may be considered *unnatural selection*. Such specified goals and fitness remove any chance of serendipity in these systems; evolution moves towards the given goal without any regard for that which may be learned or discovered along the way. While this may have been shown to be an effective search method for traditional problems on which many ES methods were developed, such as symbolic regression or classification tasks, more recent methods incorporating alternative fitness measures and applications of ES methods to aesthetic domains have indicated that the field may encompass cybernetic methods, from which serendipity may be seen to emerge.

This paper presents the development of a melody generation system based on Grammatical Evolution (GE) named 'The Popular Critic' and discusses it from a cybernetic serendipitous point of view. While numeric fitness measures may be best for traditional ES experiments, such a measure is not simple to define for aesthetic applications; what number makes one melody better or worse than another? An overview of attributes used in the evaluation of melodies based on pitch and rhythm measurements is discussed in [7]. They conclude that previous approaches to formalise a fitness function for melodies have not comprehensively incorporated all measures. Some studies have addressed the problematic issue of determining musical subjective fitness by removing it from the evolutionary process entirely. GenDash was an early developed autonomous composition system that used random selection to drive the evolution [34]. Other studies only used highly fit individuals within the population from initialisation and then used the whole population in creating melodies [2, 9]. In the proposed paper, we consider a cyclical self-referential system that creates a fitness measure that responds to a corpus of melodies and then uses this fitness measure to create a new melody which replaces one of the existing melodies as the cycle repeats. Thus we create a melodic 'environment' that results in the response of creating a fitness which in turn alters the environment; the system results in a closed 'circular-causal' loop as postulated in early cybernetics studies. The discussion at the end of the paper reflects on the system as contributing to the study of cybernetic serendipity.

The following section describes some previous applications of ES to melody generation and the use of alternative non-traditional fitness measures used in evolutionary search. Section 3 describes the basics of GE and the workings of the proposed system. Section 4 presents some results obtained from experimental runs. Section 5 considers the system in terms of cybernetic serendipity and considers what implications it may have on future evolutionary strategies towards aesthetic applications and creative AI. Finally Section 6 offers some conclusions to the paper.

2 PREVIOUS WORK

ES refers to a family of algorithms that are all based on biological evolution including, but not limited to, Genetic Algorithms (GA), Genetic Programming (GP) and — as used in the proposed method — Grammatical Evolution (GE). Details of the workings of each of these systems can be found in [4]. As stated above, much previous work in ES has involved scientific experiments with standard, measurable numerical fitness. An excellent overview of ES systems applied to the aesthetic domains of art and music, specifically considering fitness measures is given in [14]. In this section we review some applications of ES methods to music generation before considering some alternative methods of measuring fitness in traditional domains.

2.1 ES in Melody Generation

Numerous EC methods have been applied to the problem of algorithmic composition. GAs have been applied in the systems GenJam to evolve real-time jazz solos [2], GenNotator to manipulate musical compositions using a hierarchical grammar [32] and more recently to create four-part harmony from music theory [12]. More recently, adapted GAs have been used with local search methods to investigate human virtuosity in composing with un-figured bass [24] and

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with non-dominated sorting in a multi-component generative music system that could generate chords, melodies and an accompaniment with two feasible-infeasible populations [29].

GP has been used to recursively describe binary trees as genetic representation for the evolution of musical scores. The recursive mechanism of this representation allowed the generation of expressive performances and gestures along with musical notation [6]. The first system to specifically use GE was proposed in [8]. In this paper GE generated melodies for a specific processor, although the melodies produced were not presented or discussed. GE has been implemented for composing short melodies in [27]. Interactive Grammatical Evolution (GE) has been used for musical composition with promising results [30, 27]. GE has also been used recently with autonomous fitness functions based on statistical measures of tonality and the Zipf's distribution of musical attributes [19, 18]. Zipf's distributions have been shown to correspond with aesthetics in musical compositions [22]. These studies found that the representation of the music created by the grammar and the combination of individuals from the final population could be as important as the fitness function. GE has also been proposed for generating a framework to produce live code in ChucK for use in real-time [21].

2.2 Serendipitous evolution

Rather than focussing on a pre-defined goal, the idea of searching specifically for *novelty* has proven to be an effective search strategy in evolutionary systems [17, 31]. This theory of 'novelty search' suggests that searching for novel solutions, never before seen by the system, rather than merely more fit solutions is a better method when considering a problem, as good or optimum solutions can be found when the search is not focussed on the goal. Such a theory is very apt when considering creative spaces and particularly when considering the concept of serendipity; novelty search considers the progress of the system and the space that has been considered and is not overly focussed on the current result and where it is in relation to a pre-defined goal. This is reminiscent of a creative act such as melody writing; a composer should not know their final composition from the outset, but consider the space they are working in and the evolution and development of their result at any time. We consider that for an automated evolutionary composition system to be creative there cannot be a pre-defined objective — the concept of progress and novelty must be considered, particularly to encourage the emergence of a serendipitous result.

Searching for novelty is dependent on previously observed outcomes within a given domain. A further consideration that may be taken into account in place of traditional goal searching is the search for *surprise*. Surprise differs from novelty in that it is dependent on an outcome that is different from that *expected* in a given domain. Surprise is based on expectation, which is based on inference from past experience, or on a temporal model of past outcomes. Hence, surprise can be viewed as a temporal novelty process. Surprise search has be proposed within an evolutionary system on creative tasks showing promising results [36].

An interesting study demonstrated that in Computationally Creative Evolutionary systems, there should be a move away from both random measure and pre-defined hard-coded fitness [5]. They propose that the most important aspect of a fitness measure is that it is defensible — not from a human subjective point of view but in a logical and reproducible manner. They create a logical fitness that is not based on human opinion but based on a series of comparisons resulting in sensible, defensible and reproducible choices by the program. This was investigated using the idea of a preference function by measuring specificity, transivity and reflexivity between individuals to determine the choices of a system in a a number of states. Such a system ignores the idea of human opinion in deference to the creation of an autonomous preference emergent from the system itself.

The environment created by the proposed method consists of a selection of melodies created by an earlier version of the GE system. The creation of these melodies is discussed in the following section. A population of 'Critics' are then evolved in response to this environment; there are complimentary evolutionary stages in the system but we would like to stress that this is not a co-evolutionary system. Co-evolution is an evolutionary system whereby two populations evolve in response to each other. A well-known musical co-evolutionary system based on bird-calls and responses has been proposed in [33]. The proposed system does not co-evolve melodies, however, but evolves Critics in response to a corpus of melodies which is then altered in response to the evolved Critic. The consensus of the population idea proposed here also shares conceptual similarities with the method in [23], which co-evolved agents with repertoires of melodies according to a measured 'sociability'. This sociability was measured in terms of similarity of the agent's repertoires; individual melodies survived or were altered depending on reinforcement feedback between co-evolving agents. This fitness differs from our proposed method as it is the correlation of a individual's opinion to that of the (single) population that is measured in this system rather than a direct similarity measure between melodies.

The system and terminology proposed in this study may also be reminiscent of the evaluation framework proposed in [26]. The proposed system differs in a number of important ways. This study does not attempt to conform to any particular style or genre of music but instead attempts to create an opinion among naive agents or 'Critics'. No indication as to whether the original melodies are good or bad is given. Furthermore, the proposed system is cyclical in nature, whereby the output is input back into the system for a dynamic evolution of further critics. Finally we do not include human evaluation or discrimination tests in our evaluation of the results, but instead focus on the diversity of the melodies produced. There is no aim towards human mimicry or trickery within this system.

2.3 Contribution of the paper

The purpose of this paper is to consider this evolutionary music generation system from a cybernetic serendipitous perspective. The system creates music, but while melodies are presented in Section 4, the focus of the paper is on the discussion and implications of the methods from a cybernetic perspective. The goal of such a system at its most simplest is merely to 'create music'; what may be discovered in the pursuit of such a generalised goal, while allowing the system to feedback to itself creating a sustainable closed-circular loop is the more interesting objective of this paper.

3 METHOD

There are three distinct phases to this compositional system:

1. The evolution of an initial musical corpus using GE;
2. The evolution of a Critic that conforms to the population's opinion as to which are the best melodies;
3. The evolution of novel music using this evolved Critic as a fitness measure which then replaces one of the original melodies in the corpus.

As the method is heavily based on GE [25], a brief introduction is given below.

3.1 Grammatical Evolution

GE is a grammar based algorithm based on Darwin's theory of evolution. As with other evolutionary algorithms, the benefit of GE as a search process results from its operation on a population of solutions rather than a single solution. From an initial population of random genotypes, GE performs a series of operations such as selection, mutation and crossover over a number of generations to search for the optimal solution to a given problem. A grammar is used to map each genotype to a phenotype that can represent the specified problem. The success or 'fitness' of each individual can be assessed as a measure of how well this phenotype solves the problem. Successful or highly fit individuals reproduce and survive to successive generations while weaker individuals are weaned out. Such grammar-based generative methods can be particularly suitable to generating music as it is an integer genome that is being manipulated rather than the music itself. This allows the method to generate an output with a level of complexity far greater than the original input. This added complexity generation is helpful in creating interesting and diverse pieces of music. In the system proposed, the grammar defines the search domain — the allowed notes and musical events in each composition. Successful melodies are then chosen by traversing this search space according to the defined fitness function.

We exploit the representational capabilities of GE resulting from the design of a grammar that defines the given search domain. GE maps the genotype to a phenotype — typically some form of program code. This phenotype can then be interpreted by the user in a predetermined manner. In this system, the programs created are written in a command language based on integer strings to represent sequences of MIDI notes. We design a grammar to create this command language which is in turn used to play music.

3.2 Creating the Musical Corpus

The Popular Critic is evolved according to its agreement with a population of its peers on their opinion of a selection of melodies. At initialisation, an initial corpus of 40 MIDI melodies was created using a previously developed system for composing short melodies with GE. This was initialised with previous melodies, instead of for instance know melodies, as this format can be used with the evolved Critics as described later. A full description of this method and the results obtained can be found in [19]. The following is an overview of the system. The grammar used is based on:

```
<piece>::=<event>|<piece><event>
 |<piece><event><event>
 |<piece><event><event><event>
<event>::=<style>,<oct>,<pitch>,<dur>
<style>::=<note>|<note>|<note>|<note>
 |<note>|<note>|<note>|<note>
 |<chord>|<chord>|<chord>
 |<chord>|<turn>|<arp>
<turn>::=<dir>,<len>,<dir>,<len>,<stepD>
<len>::=<step>|<step>,<step>
 |<step>,<step>,<step>
 |<step>,<step>,<step>,<step>
<dir>::=down|up
<step>::=1|1|1|1|1|2|2|2|2|2|2|2|2|3
```

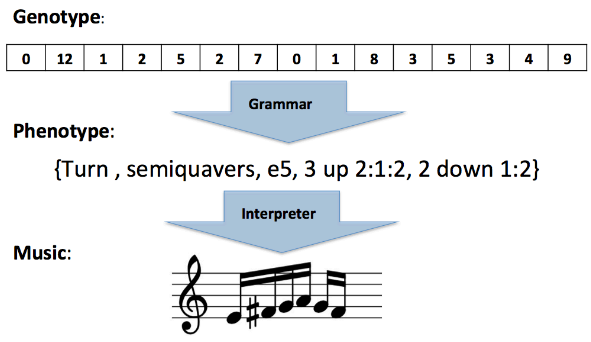

Figure 1. Application of Melody Grammar to integer Genotype through to representational Phenotype that can be interpreted into music.

```
<stepD>::=1|2|2|2|2|2|2|4|4|4|4|4|4
<oct>::=3|4|4|4|4|5|5|5|5|6|6
<pitch>::=0|1|2|3|4|5|6|7|8|9|10|11
<dur>::=1|1|1|2|2|2|4|4|4|8|8|16|16|32
```

This grammar creates a melody <piece> containing a number of notes with specified pitch and duration. Each <event> can either be a single note, a chord, a turn or an arpeggio. A single note is described by a given pitch, duration and octave value. A chord is given these values along with one, two or three notes played above the given note at specified intervals. A turn results in a series of notes proceeding in the direction up or down or a combination of both. Each step in a turn is limited to either one, two or three semitones. An arpeggio is similar to a turn except it allows larger intervals and longer durations. The application of this grammar results in a series of notes each with a given pitch and duration. The inclusion of turns and arpeggios allows a variation in the number of notes that are played, depending on the production rules chosen by the grammar.

This grammar is combined with the genotype to create the given phenotype — which can then be interpreted into MIDI note values. An example of this genotype to phenotype mapping for a short phrase is shown in Figure 1. This illustrates how a series of integer values can be transformed and interpreted in to a series of notes of specified pitch and duration through the applications of the above grammar. The selection of melodies into future generations is based on the defined fitness function. For this initial corpus the fitness is taken as a measure of the length of the melody combined with a statistical measure of prevalent tones within the piece. This is used to encourage the emergence of a pseudo-tonality (in that numerous pitches are repeated more often than others) but it does not enforce a key signature on any of the melodies. Initially the fitness is measured as:

$$fitness_{initial} = (Len - 200)^2 + 1 \tag{1}$$

where Len is the length of the current phenotype.

For an emergent tonality one pitch should be the most frequently played within the melody, with an unequal distribution of the remaining pitches. In the fitness the *primary* is defined as the pitch value with most instances and the *secondary* as that with the second highest number of instances. Thus for a good (low) fitness the number of primary pitches must be significantly higher than the number of secondary pitches. Furthermore, the number of instances of the seven most frequently played notes as Top7 and the number of instances of the top nine notes as Top9.

The fitness is multiplied by 1.3 if any of the following inequalities hold:

$$\frac{\#\text{ instances of primary}}{\#\text{ instances of secondary}} < 1.3 \tag{2}$$

$$\frac{\text{Top7}}{\text{Total number of played notes}} < 0.75 \tag{3}$$

$$\frac{\text{Top9}}{\text{Total number of played notes}} < 0.95 \tag{4}$$

This enforces the primary tone to have significantly more instances than the secondary and encourages most of the notes played to be within the top seven or top nine notes. These limits of 0.75 and 0.95 enforce more tonality than 12 tone serialism but will not create a melody with typical Western tonality. For these experiments, the top four melodies in the final population are concatenated together to encourage the emergence of themes within the final compositions. This grammar and fitness function create the corpus of 40 MIDI melody compositions which is then used to evolve the musical *Critics*.

3.3 Evolving the Critic

The purpose of this experiment is to dynamically design a new fitness function for adjudicating melodies that is not known to the programmer at the outset of the experiment. Our Critic is evolved to become the fitness measure to adjudicate the evolution of future melodies. This Critic (i.e. the fitness function) is itself evolved in the second phase of the experiment. GE is used to create this Critic as a specified linear combination of the content of the melodies.

The 'Popular Critic' is evolved by creating a population of individuals (or Critics), each of which gives a numerical 'opinion' of each of the melodies in the corpus. The melodies are represented as the number of times each degree of the scale and each note duration is played within the melody. Thus every melody is reduced to a list of 18 integer values. These instances are incorporated with a new grammar in GE shown below:

```
<expr> ::= <O><T1><O><T2><O><T3><O><T4>
   <O><T5><O><T6><O><T7><O><T8><O><T9>
   <O><T10><O><T11><O><T12><O><D1><O>
   <D2><O><D4><O><D8><O><D16><O><D32>
<O> ::= <op><scalar>
<op> ::= + | - | *
<scalar> ::= 1 | 2 | 3 | 4 | 5
```

This simple grammar takes each of the 12 tonal and 6 duration instances, multiplies each by a value 1-5 and then either adds, subtracts or multiplies it by the previous values. This outputs a scalar value resulting from a linear combination of the 18 given values. Each individual in the population results in a numerical value for each of the 40 given melodies. This is currently a *meritless adjudication* of the melody — there is nothing to say that 10 is better than 5 — it is merely a unitless numerical assignment.

In this system, however, we attribute 'preference' to this numerical output. The melodies are ranked 1-40 according to this numerical value, calculated by the given individual (the current Critic). These rankings are averaged across all individuals in the population and the overall ranking of the melodies across the population (of all Critics) is found. This overall ranking of all 40 melodies is taken as the popularity consensus of the population. The fitness of each individual Critic is then calculated according to how closely it correlates with this overall popularity, hence the fitness of the individual Critic is aligned with how much it conforms to the consensus of the population of Critics. The Kendall-Rank Correlation is used to calculate this fitness. Selection, Crossover and Mutation are then performed over successive generations to evolve one best 'Popular Critic' as with typical ES methods. The best evolved Popular Critic is saved to be used to evolve new music in the final phase of the system.

3.4 Critic-based Fitness

The Critic evolved in the previous section will output a numerical value for any melody that can be represented by the Melodic Grammar described in Section 3.2. As such, it can be combined with this grammar *as the fitness function* in a new, separate evolutionary run that will evolve the 'best' melody according to this given Critic. In the final phase of the system, we evolve a new melody and replace one of the original melodies from the corpus with this melody. This creates a change in the environment (the melody corpus) and the full system can be run again: using this new corpus (which differs from the original by just one melody), we initialise a new population of Critics to evolve a new Best Critic, which in turn can again be used in a new evolutionary run as a fitness measure to evolve a new replacement melody.

In this manner we have created a circular-causal loop, whereby Critics are evolved in response to their environment, which they in turn alter. Each cycle iteratively replaces one melody from the corpus. Once this cycle has repeated 40 times, all melodies in the original corpus have been replaced by those created by the system.

The following section discusses some results from various stages within the system. In all evolutionary runs we consider a minimising fitness. Each of the evolutionary phases were run with parameters, typical of GE runs, shown in Table 1, unless stated otherwise. An overview of the cyclical operation of the system is shown in Figure 2.

Table 1. EC parameters common to each evolutionary phase

Parameter	Value
Population Size	100
No. Generations	50
Selection	Tournament (size 2)
Crossover Rate	0.7
Mutation Rate	0.01
Initial Genome Length	100
Elite Size	1

4 RESULTS

While this section discusses numerical results obtained by the system, the interested reader may find a selection of melodies produced by the system available at `https://soundcloud.com/user-529879178/sets/serendipity-in-cybernetics`.

4.1 Fitness Results

The typical manner in which to judge an ES system is to consider the best and average fitnesses throughout the duration of the evolution. The best in generation and average in generation fitness in evolving the corpus melodies, averaged over 40 runs, is shown in Figure 3. This shows a fitness plot that is typical of a successful system, whereby both the average and best decrease initially and the

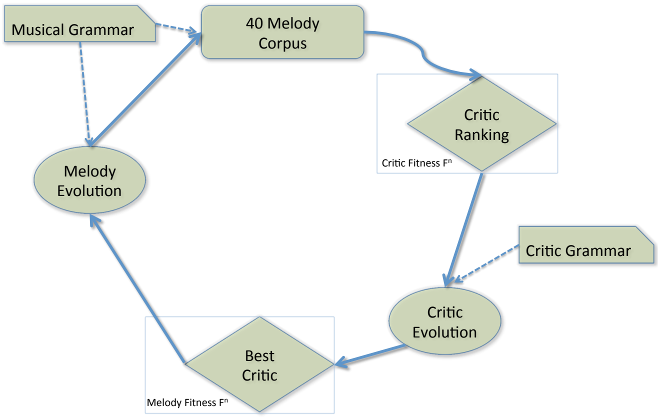

Figure 2. Overview of the cyclical system

best achieves a very good fitness by the end of evolution. The average fitness in the evolution remains less accurate as mutation and crossover are both kept until the last generation, to maintain diversity within the population. There is a strong drop off in the melody fitness around generation 10 (note the log_{10}) scale. This is because the fitness is initially taken in regards to the length of the phenotype, from Equation 1 which leads to large variations, before this is refined by smaller alterations due to Equations 2 to 4. These evolutionary runs may be considered successful as we observe the expected decrease in fitness measure, but that is merely because the individuals are being forced towards our pre-defined measures. Equations 2 to 4 are derived from *a priori* musical knowledge and theory, but they will not necessarily create the best music. This systems can evolve towards a given numerical goal but it cannot directly evolve towards any sense of musical beauty or creativity.

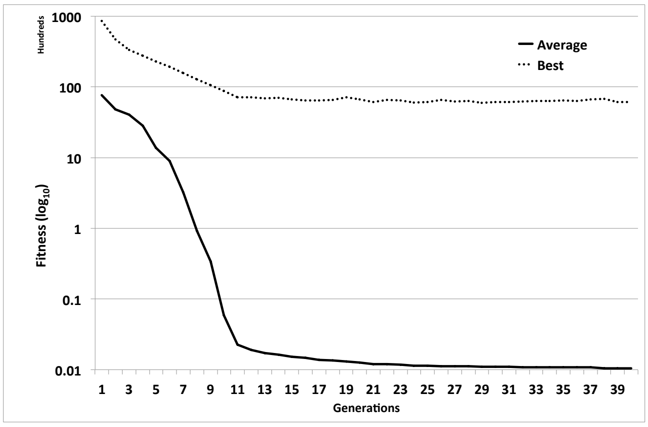

Figure 3. Fitness evolution of the melody corpus, averaged over 40 independent runs.

Similarly, we evolved 40 independent Critics according to the second stage of the system described in Section 3.3. The average of these results across 50 generations is shown in Figure 4. Again we can see the typical decrease in both best and averaged fitness throughout the evolution. The fitness values are notably smaller due to the method in which the fitness was measured. Again these measures do not necessarily tell us anything of the quality of the Critic — the Critics have not been evolved to be conventionally 'good' in any individual way but rather to conform to agree with each other; the relationship between Critics is more informative than the individual. As a measure of this we have considered the diversity within the generations of Critics throughout evolution. Even if two individuals result in the same fitness value, this does not mean their phenotypes are syntactically identical, this is dependent on the grammar. During the evolution of the 40 independent Critics we measured the diversity between the Critics at each generation. The population diversity was taken as the sum of the Levenshtein edit distance between the phenotypes of each pair of Critics. A plot of the average and standard deviation of this diversity is shown in Figure 5. This indicates a marked decrease in diversity within the first 10 generations (with a corresponding increase in standard deviation). Thus while the fitness is decreasing, on average, the diversity among the population is also decreasing. Again the level of mutation and crossover maintained throughout evolution means that the average fitness does not reach optimal as there is diversity left within the population. This is in keeping with what we had expected to see from the fitness plots, but in future experiments we will consider the temporal changes that occur within the Critic population in this respect.

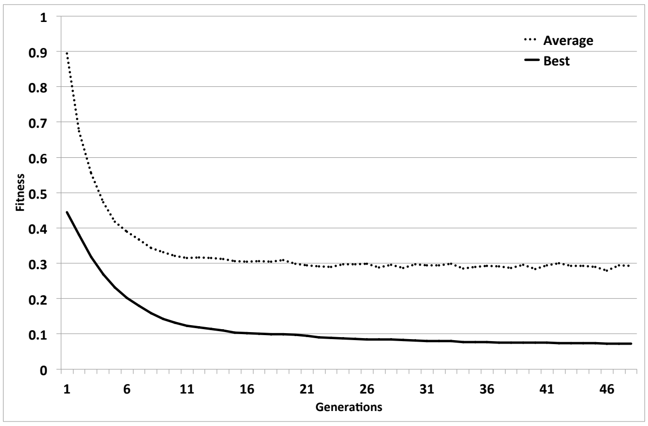

Figure 4. Fitness evolution of 40 Critics, averaged over 40 independent runs.

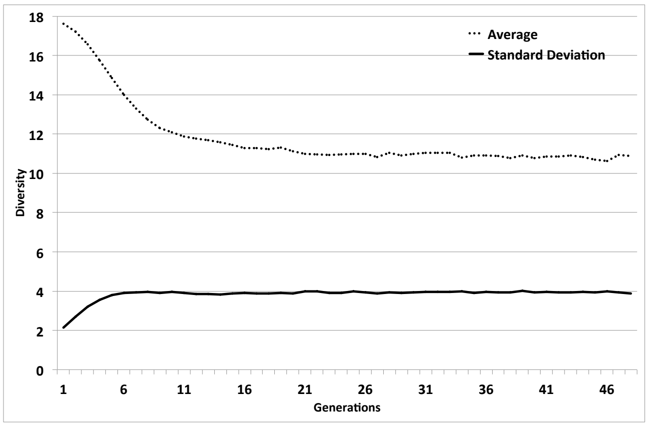

Figure 5. Diversity among 40 Critics, averaged over 40 independent runs.

4.2 Melodies

At the surface, the 'goal' of this system is to create melodies. It is the grammar used, however, that has most effect on the musicality of the system. The grammar developed creates the musical environment, which the Critics must traverse, and we have established that the individual Critics cannot distinguish musical merit but instead are evolved according to conformity to their peers. Melodies were created by the very first phase in generating the melodic corpus, so the development of the cyclical system purely for melody generation is superfluous for such a goal. To state that the goal is to improve these melodies is not realistic as the system stands; the Critics developed have no measure of human preference or musical theory embedded in them to create 'better' melodies. To judge any improvement in melodies from a human perspective is speculative — any improvement in this manner could only occur by chance. We instead consider the purpose of the system as a study in cybernetics within a creative domain, as further discussed below in Section 5. The content of the melodies is dependent on the grammar used to generate the individual phenotype, and the way in which this is interpreted by the program. We interpret each phenotype into a series of MIDI pitch and duration values that are then played through GarageBand using a MIDI piano sound. In listening to the melodies we can hear aspects of the grammar such as runs, arpeggios, chords and singles notes. The repetition of themes audible within the compositions indicate that the best individuals in the final population (the top four are concatenated to create each melody) are similar — but not identical. This indicates that the Critics are able to traverse a search space and converge on a stable idea. From a selection of melodies, it is clear that the system is capable of creating a wide variety of melodies. The selected melodies presented are a selection of the new final melodies created after a full cycle that display the different compositional elements of the system. For example Melody2 and Melody501 both display good examples of a mixture of runs and long notes, whereas Melody111 consists almost entirely of single held notes. This is because no specifications were made at any point during the cyclical system as to what constraints should be put on the melodies — the Critics are able to evolve to explore the full musical domain created from the genotype-phenotype mapping. While we do not focus on evaluating individual melodies at each cycle, it is worth considering the change in the melodies — or specifically within the corpus of melodies — as the system is run.

In each full cycle a new melody is generated which replaces one from the current corpus. As there is no meaningful adjudication as to which melody is best, the replaced melody is chosen iteratively from the corpus. Thus after 40 cycles, the corpus has been completely re-populated with melodies generated specifically by the system. If the system is allowed to continue to run, it will keep creating new melodies from the Critics that were created from the continually changing melodic corpus. We consider the diversity between the 40 melodies within the corpus after each full cycle. This was measured as the sum of the Levenstein distance between the representation (as 18 integer values — 12 for pitch, 6 for duration) of each pair of melodies within the corpus. A plot of this over 1000 consecutive cycles is shown in Figure 6. This plot shows an initial drop in the diversity among the melodies over the first 50 cycles. This implies that as the corpus is populated with melodies created by Critics emergent from the system, as opposed to those created initially, the content of the melodies begins to converge. Once the corpus has been repopulated, however, this trend does not continue over subsequent cycles. Instead we can observe a cyclical increase and decrease in diversity among the melodies as the system cycles. This is understandable when we consider that again, there is nothing within the generation of a Critic to enforce a homongenization of the melodies. It may be interesting in future developments of the system to determine if such a relationship could be enforced.

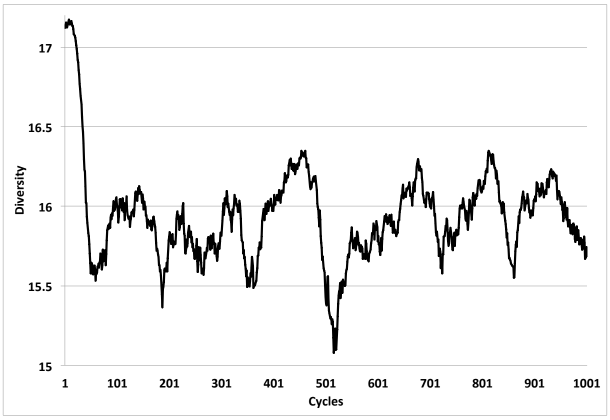

Figure 6. Diversity within the melody corpus, examined across 1000 successive cycles of the system.

5 CYBERNETIC SERENDIPITY

Cybernetics was first introduced as a theory based on the scientific study of control and communication in the animal and the machine [35]. It considers the manner in which a system behaves rather than mere results. Cybernetic systems have a closed circular or feedback loop, resulting in a 'circular-causal' relationship whereby system and environment are intertwined. Any action by the system generates some change in its environment and that change is reflected in the system in some manner (i.e. feedback) that triggers a system change, and this process repeats. During the development of the theory of Cybernetics in the last century, there appeared a split into two subfields: First Order Cybernetics — the study of observed systems and Second Order Cybernetics (or the Cybernetics of Cybernetics) — the study of observing systems. The split arguably grew from the increasing interest in engineering and computing systems which focussed on control (First Order Cybernetics) in contrast to those who wished to focus on autonomy and self-organisation (Second Order Cybernetics) [13]. Regardless of this split, the focus of Cybernetics has been on behaviour of the system; the question is not "what is the thing?" but "what does it do?" [1].

Cybernetic Serendipity was first coined through an exhibition curated by Jasia Reichardt, shown at the Institute of Contemporary Arts, London in 1968 [28]. This event showcased art and music created by algorithms and computers. The exhibition and subsequent publications were concerned with exploring the connections between art and technology. It was not considered merely an art exhibition nor a technology show, but a demonstration of contemporary ideas linking cybernetics and creative processes. The name was coined from the idea that in considering technological (particularly cybernetic) applications within artistic domains, serendipitous discoveries and developments would become apparent. The event showcased music, art, films and robotics to an audience of 60,000 attendees; it brought computer generated art and music to an audience that would never have before had access to such ideas. One of the most interesting concepts within the exhibition was that no artefact gave any indication as to whether, or to what level, it was created by man or machine. This aspect of human-involvement is still very important in computer generated creative artefacts today. Much debate remains on the merit of systems that exhibit purely generative behaviour as opposed to those that could be considered autonomously creative. Generative systems tend to have more human input, but as such are generally more sophisticated, exhibiting impressive results. Computationally creative systems, on the other hand, are those systems to which an attempt is made to attribute the creativity itself to the system, rather than the human engineer. Either of such systems would have been suitable for inclusion in this original Cybernetic Serendipity exhibition, although these days, the extent to which the creativity is displayed by the system is put to more scrutiny through the process of evaluation.

Evaluation of a cybernetic system should depend on whether or not it has achieved its goal. When considering aesthetic tasks, such as in ‘serendipitous cybernetic’ systems, this goal once again becomes difficult to define. Evaluation in computationally creative systems can be difficult to measure in a meaningful way; creativity itself is such a hard concept to measure, how can we reliably measure the display of it by a computer? This difficulty has led to a noted lack of evaluation in the development of computationally creative systems [3, 15]. This has been addressed with the development towards standardised measures of evaluation of creative system for e.g. the SPECS model [16]. In performing evaluations however, we must always ensure we are considering the true intention of the designed system. Some evaluations have only considered the output of the system — i.e. judging a melody generation system, such as the one above, purely on the perceived quality of the melodies produced. This assumes that the only purpose of such a system is to generate melodies that mimic how a human would compose melodies. Such assumptions could limit the possibilities attainable by these systems [20]. We do not yet know the capabilities of computative systems, if we limit their goal to merely aim to imitate what we already know, might we be limiting the capabilities of such system?

The focus of the original Cybernetic Serendipity studies was in the relationship between the arts and technology, and as such, some of the studies and artefacts may arguably be considered First Order Cybernetic systems. The ‘Popular Critic’ proposed in this paper is a conscious effort to consider a melody generation system that encompasses a circular causal feedback system. The system operates in a closed cycle; once it is set in motion it will continue without external input, continuously generating new melodies without any further human interference. While the environment (the melody corpus) is originally given, it alters this environment in response to its own interactions with it, within the confines of the grammars we have defined. As stated at the beginning of this paper, ES systems are dependent on the representation and the fitness measures used, but pre-defining a fitness measure for aesthetic problems is a difficult task. In this system we define two complementing grammars to define two levels of representation, but the fitness measure (for both the melody and the Critics) are changing fluidly in response to the workings of the system. Hence the notion of creating a fitness measure *a priori* that will ultimately confine the generated music to some pre-determined result can be avoided. Admittedly, this makes the goal of our system more difficult to define, but it simultaneously makes serendipitous discovery considerably more possible.

6 CONCLUSION

We have presented a cybernetic melody generation system focussed on the development of a self-adaptive fitness measure. The evolutionary system presented uses two complementary grammatical evolution runs combined into a cyclical system that generate both melodies and Critics. The system offers no measure as to what makes a musical melody ‘good’ but instead poses that a measure of agreeability, or popularity, among the population of Critics can be used to self-organise and autonomously generate melodies. The Critics are evolved in response to a corpus of melodies which in turn is changed by the evolved Critics and this cycle is repeated. In this manner, the Popular Critic operates as a circular-causal feedback system where Critics are created from and directly affect the environment in which they operate. We plan to explore using measures of aesthetic beauty such as fractal analysis [10, 11] in combination with the self adaptive methods prosed here in the future development of Critics. We have noted that the grammar used and its interpretation into MIDI messages are responsible for the musicality in the system. As such, we may implement a similar system in another aesthetic domain, such as visuals, to consider the possibilities of serendipitous discovery across multiple domains.

We believe the system as it stands is a good example of a melody generating Second Order Cybernetic system. However, we do recognise limitations in the practical application of the system. For those who are looking for good or pleasant sounding melodies, there is nothing in the running of this system that will ensure such a goal. The musicality of the system is completely emergent from the melody grammar used; melodies created after 1000 cycles of the system are likely to be as ‘musical’ as those from the original corpus. We acknowledge that we need a more clear and definitive method of evaluating the merit of this system in this manner. However, we also consider that this system is more interesting as a study in the development of autonomous fitness, particularly in an aesthetic domain such as music, where an ideal fitness could arguably never be defined from a philosophical standpoint. In this respect, this system offers a new method as to how we may consider using evolutionary computational methods in such domains. In future version of the system we are planning to continue with this method of emergent fitness, while considering more controlled ways of examining the workings and goals of the system. In taking the focus away from a pre-defined measure of pleasantness or goodness in music we hope to encourage more serendipitous emergence of new ideas.

ACKNOWLEDGEMENTS

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The Chance of Serendipity

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Abstract. Serendipity is often defined as fortuitous, accidental, a chance encounter, an unexpected event or a stroke of luck mixed with insight. This suggests that serendipity is, to a great extent, improbable and that, while one can plan or even design for serendipity, serendipity can be considered, as a whole, an indeterministic event. This research (part of an ongoing work on the design of serendipity in the digital medium) argues that serendipity can, in fact, be planned and even expected from the point of view of the designer, while remaining apparently unpredictable from the point of view of the serendipist. With that in consideration, we propose a distinction between Natural and Artificial Serendipity.
While both deterministic, the former is absolutely unpredictable while the latter is relatively unpredictable. We finalise by identifying relevant frameworks that have tackled the issue of designing for serendipity, as a starting point to our own work: the development of a framework for designing serendipity in the digital medium.

1 INTRODUCTION

Serendipity was born from Horace Walpole's combination of accident and sagacity [9], of the interplay between a seemingly chance event and the capacity and availability of an observer to derive meaning from that event. While throughout the understanding, definitions, and interpretations of the idea of serendipity have attributed different weights in the balance of this interplay, the core concept remains.

The experience of serendipity starts, in effect, with a trigger, a change in the world that grabs the attention of an observer.

But while this trigger appears random, does it mean that serendipity is absolutely indeterminable? Do these triggers need to be the result of chaos and chance alone, or are we able to plan for serendipity?

Both Merton and Boden suggest the notion that serendipity need not be the result of pure chance, as the key element to it is that serendipity is "unanticipated" [9] or, in the words of Boden: "Although serendipity is sometimes due to coincidence, they are not the same thing. For serendipity need not involve any inherently improbable event" [3].

Boden dissociates serendipity from coincidence, alluding to the idea that the former can be, in some fashion, determined, by not being, necessarily, an "improbable event". The events that lead to serendipity may be constructed and provoked, as what it is required is that the experience of it be unexpected and unanticipated. If the experience is read by who is experiencing it as random or accidental, even if it is not, it still remains serendipity.

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This was illustrated by giving as example the parents of a child leaving a book open on the table that would help the child solve a particular school problem. The child would find the book that would nudge her towards the answer, seemingly serendipitously, towards the required answer.

From the child's point of view, the event is mere happenstance, a lucky, fortuitous coincidence, even if it was planned by the parents. While serendipity is not guaranteed—the child may not notice the book or ignore it, failing to make the necessary mental connections or not being in a stake of *prepared mind*—the potential for serendipity remains.

With this in mind, we are able to argue that there is an opportunity for planned serendipity. This, however, begets a distinction between what we are referring to as Natural and Artificial serendipity.

2 NATURAL AND ARTIFICIAL SERENDIPITY

Considering that the distinguishable factor of serendipity is not its *accidentality*, but its unpredictability,[3] from the standpoint of the serendipist, Natural Serendipity—meaning the serendipity that occurs naturally in the world—is absolutely unpredictable, as the number of factors and variables that create it are impossible (at least for now), to calculate.

This, however, does not mean that it is indeterminable. One can argue—and the pancomputational concept does—that the universe itself can be considered a computational system and as such it is, by definition, deterministic [10]. What distinguishes physical from artificial computation is not their deterministic or nondeterministic nature, but the complexity of the computation itself, as the natural world implies an unforeseeable number of variables that prevent the states of computation from being wholly replicable, making them unpredictable [5].

As such, we can consider natural serendipity—as a phenomenon experienced by humans—as deterministic, if unpredictable in practice, as we are unable to foresee the results. However, when considering serendipity as the result of artificial interactions—meaning those that were the product of human design—the conditions that lead to serendipity can be, to some extent, reproducible and, as such, are capable of being designed as well.

[3] Throughout the literature, serendipity has been described as unforeseen, unexpected [7], unplanned [2] and so on. While apparently attempting to represent the same core concept, the term selected to define serendipity has an implicit connotation, as argued by Björneborn on the differences between saying unexpected versus unplanned: "Saying 'unexpected' or 'unplanned' when defining serendipity makes a difference, as unexpected events always are unplanned, but unplanned events are not always unexpected given the situation" [2].
We, therefore, choose unpredictable, as it accommodates all natural serendipity, as well as all artificial serendipity from the serendipist standpoint. As argued by Boden "both serendipity and coincidence […] are in practice unpredictable." [3]

Artificial serendipity is one where an agent (natural or artificial) is able to create the necessary conditions for serendipity to occur. This agent (or designer, if you will) can create experiences that *feel* serendipitous, even if they are the result of careful planning. In the words of Björneborn: "serendipity may thus be intended by designers, but must always be unplanned by users." [2]

To be recognised as serendipity, the process needs to be experienced by a secondary agent: human or computer, that is blind to the process. This blindness creates the necessary experience here defined as serendipity.

Artificial serendipity is therefore relatively unpredictable, as it is experienced as unpredictable from the one experiencing it. This is already common practice in video game design, as, through planned and considered design, user observation and testing, the player can naturally and gradually discover how to play the game, and be empowered to do so, without knowing that she's being taught how.

Natural Serendipity	Artificial Serendipity
Absolutely unpredictable	Relatively unpredictable
Unforeseeable	Foreseeable
Extemporaneous	Designed

Table 1*:* Distinctions between Natural and Artificial serendipity.

While the experience of serendipity isn't guaranteed (just as a game designer cannot guarantee that the player truly learns gameplay mechanics) systems can be designed in order make serendipity emergent.

This is the case with the parents in Boden's example: acting as agents, they could predict that the child would experience a moment of serendipity, while the child could not. While serendipity was never guaranteed for the reasons discussed previously, meaning that, at this moment, we maybe be unable to design serendipity, we are able to design *for* serendipity [4].

3 DESIGNING FOR SERENDIPITY

Serendipity's apparently fickle nature notwithstanding, we have identified a number of attempts for the design of framework and models that aim towards provoking it in both the digital and the analogue mediums. These previous attempts have informed our own.

During the course of this research we identified some of these attempts that may be pertinent to our work. Of these, we believe that MacCay-Peet and Tom's factors for serendipity within digital environments, and Björneborn three key-affordances for serendipity are the most relevant,[4] and we've used it as a starting point for our own approach to designing for serendipity.

Starting with an earlier work by Björneborn where he identified 10 factors for serendipity in public libraries, MacCay-Peet and Toms conducted an empirical study that aimed at exploring the application of Björneborn's factors to digital environments [8]. In their analysis they propose that, and in the context of digital environments, they observed relevancy in five factors from the original ten: *enabled connections*, *encountered unexpected*, *presented variety*, *triggered divergence*, and *induced curiosity*. These factors established the core concepts that led to the identified heuristics in our framework for serendipity (while most are found throughout all six heuristics, some are more closely related than others).

By *enabled connections*, MacCay-Peet and Toms refer to the events in which the information system would encourage the finding of "an unexpected piece of information" that would encourage connections or bisociations [6] with underlying questions or problems.

Through *encountered unexpected,* a system would permit *rich diversity* and *cross contacts* dimensions [1], encouraging findings outside those anticipated by the user, of "unexpected topics or content" that the user wouldn't, otherwise, encounter.

Presented variety relates to systems allowing for a diversity of divergent information and content that would enable "interesting juxtapositions [that] may not only support serendipity, but potentially prime for it", while facilitating "varied or diverse behaviours such as exploration and browsing" [8].

Triggered divergence describes the situations where a system "in some way sparked or triggered their attention and initiated divergent thinking and behaviour", based on Björneborn's dimensions of *striking contrasts* and *pointers* [1].

The final factor, *induced curiosity*, relates "to the inducement of deeper exploration or consideration of information encountered and curiosity-teasing triggers" [8]. In this factor, MacCay-Peet and Toms highlight the role the human factors play in the experience, such as "be curious about what is being displayed and become actively engaged" and not being a "passive observer" [8]. These human factors will be further explored on our own framework in Part II.

Building upon his original 10 factors and MacCay-Peet and Tom's empirical study, Björneborn [2] proposes three key affordances for serendipity, consisting of *diversifiability:* the capacity of an environment to allow a diversity of contents and easily permit the exchange and combination of content; *traversability:* the capacity of a particular environment to be easily traversed, allowing for exploration; and lastly *sensoriability:* the quality of an object or environment of being perceived by the senses, and the richness of stimuli that are able to be sensed. These three factors cover a series of sub-affordances, dealing with different aspects of implementations of each affordance [2].

Taking into consideration these approaches for designing systems that promote and afford serendipity, and considering the context of interaction design and the digital medium, we are now able to consider the different factors, methods, and mechanics that allows for the design of interactive systems towards serendipity.

As such, we propose a framework for serendipity, which consists of three vectors that, through its interplay, approach the different components of the design of serendipitous systems, namely: *Human Activities*, which define the overall objective of a particular system, *Human Factors*, which describe and identify both the intrinsic human qualities and factors that influence the

[4] Björneborn's study was published nearing the end of our own research. However, we found that there was a great degree of confluence between our developed framework and Björneborn's findings. As such, we considered pertinent to articulate, when relevant, his findings into our work developed framework.

possibility of serendipity, as well as the possible preoccupations, engagements, and dynamics of the interaction with the systems, and lastly the *Heuristics*, which are rules of thumb that describe the possible implementations of distinct methods and design patterns that enable and encourage serendipity in user interaction.

Due to paper length constrains, we shall summarise our proposed framework. Likewise this is underdevelopment and in flux, as such the distinct elements that constitute this framework may be subject to change according to future work

4 A FRAMEWORK FOR SERENDIPITY

4.2 Human Activities

In these activities we have identified the potential for serendipitous experiences, examples of how they are able to encourage serendipity, as well as some potential shortcomings, namely how we encounter information in the digital medium, to how we leverage serendipity in the creation and consumption of artefacts, to how we collaborate and interact, how we travel and play.

The defining factor for the Human Activities of this framework is that they reflect the different *verbs* that are possible in the medium (or which the medium *affords*) while encouraging serendipitous experiences.

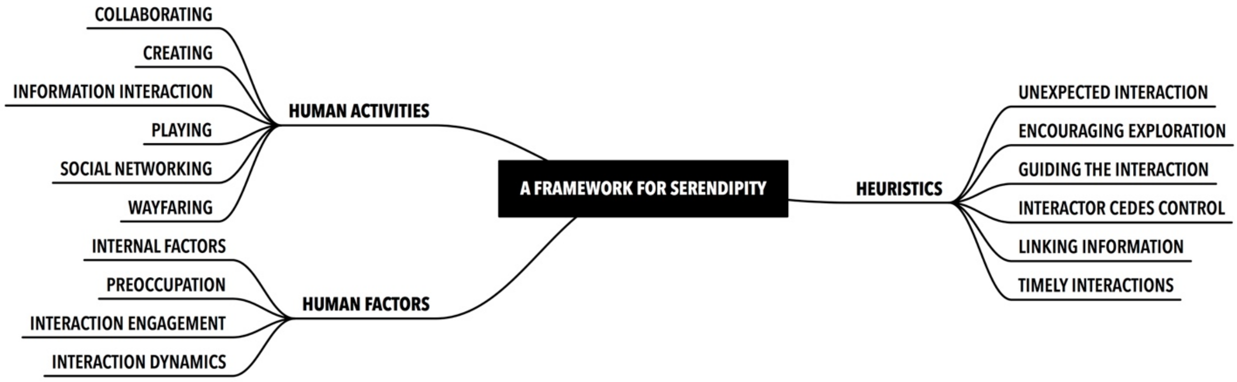

Figure 1: Framework for Serendipity: *Human Factors*, *Human Activities*, and *Heuristics*.

Through our proposed framework we are able to provide a basis of analysis of existing systems, as well as enable the design of future ones. When developing for serendipity, designers are able to identify the system's intended activity, which informs the human factors to be encouraged, and what heuristics best to support that activity.

4.1 Human Factors

These human factors here represent different mental models, expectations, modes of thought and modes of acting of the interactor that will influence the interaction with a system. In order for a system to provide a serendipitous experience, it needs to accommodate and design towards accentuating the *internal factors* (such as encouraging curiosity in the interactor), identify the relevant *preoccupation* (will the system be utilised with a foreground or a background question), consider the specific *engagement* level (will the system or the interactor that initiates interaction), and encourage the specific *dynamics* within its interface design.

Furthermore, when designing a serendipitous system, should be articulated with the particular human activities that the interactor is engaged with.

While the factors were described separately, they are not, for the most part mutually exclusive. In fact, a particular serendipitous system can be designed in order to take advantage of a number of these factors.

While we have mapped the current state of the art in regard to serendipitous experiences, this remains a snapshot of the medium's potential, and as the medium—and the activities it affords—mutates, so does the possible experiences that be had on it. We will continue to identify and map different activities that relate to the serendipitous experience here examined.

4.3 Heuristics

These heuristics describe rules of thumb that enable the design of serendipitous systems, described by their distinct mechanics, methods of implementations, or design patterns.

We have identified seven distinct heuristics, namely: 1) *Unexpected Interaction*, where through techniques such as speculative design, defamiliarisation, errors, glitches and interference, designers are able to provoke surprise in an interaction. 2) *Encouraging Exploration* in which a particular system encourage the exploration of an interface by the interactor, which increases the serendipitous potential of a system. 3) *Guiding the Interaction*, where the system plans occurrences that can be perceived as serendipitous by the serendipist, through recommendations, personalisation of an interaction, or through planned events that appear the result of change or the sagacity of the interactor but were, nonetheless, the result of careful design. 4) *Interactor Cedes Control* is an heuristic in which the serendipist is who plans and/or designs the system that leads to the experience of serendipity through releasing control from the interaction, be it through randomisation of information, through automatization or rules-based systems, or through relinquishing control to other interactors. 5) *Linking Information* describes the different methods of connecting information in an interactive system in order to promote serendipitous discoveries. Lastly, final heuristic 6) *Timely Interactions* the methods in which interactive systems are able to alert the interactor to a particular event at a particular time, provoking the feeling of "the right thing at the right time", often associated with serendipity.

CONCLUSION

This work begins by challenging the assumption that serendipity is unexpected and, mostly, a product of chance and accident and, therefore, cannot be determined. Considering Boden's differentiation between serendipity and coincidence, we argue a deterministic approach to serendipity, one absolutely-unpredictable in the case of Natural Serendipity and relatively-unpredictable in the case of Artificial Serendipity. As part of our ongoing work in the creation of an interaction design framework for serendipity in the digital medium, we identify grounding work that is relevant for Artificial Serendipity and enables the design for serendipity and informs our own framework for serendipity in the digital medium.

Future work will consist of correlating the frameworks identified with the state of the art of interactive systems that permit serendipitous discoveries on the digital medium and the further development of our own framework.

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Towards Open-World Scenarios: Teaching the Social Side of Data Science

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Abstract. This article reflects on current challenges we encounter in teaching data science to graduate students. A common critique of data science classes is that examples are static and student group work is embedded in an 'artificial' and 'academic' context. We look at how we can make teaching data science classes more relevant to real-world problems. Student engagement with real problems—and not just 'real-world data sets'—has the potential to stimulate learning, exchange, and serendipity on all sides, and on different levels: noticing unexpected things in the data, developing surprising skills, finding new ways to communicate, and, lastly, in the development of new strategies for teaching, learning and practice.

1 Introduction

At first sight, data science is a hands-on technical activity, concerned with 'hard' knowledge such as statistics, machine learning, visualization, etc. But practicing data science requires an array of 'softer' skills, including understanding of the context and implications of data, communication, or collaboration. This array of requirements is reflected in common texts and references, which attempt to introduce students to the complex world of professional practice [33]; which highlight the *"need for this material to be offered more broadly"* (not just to engineering and science students) [4]; and which contrast data science teaching with *"traditional statistics courses* [...] *focused on describing techniques and their mathematical properties rather than solving real-world problems or answering questions with data"* [20].

Faced with the challenge to deliver a course on data science to graduate students in a design-oriented Master's program, we wanted to account for both 'hard' and 'soft' skills. Students came from a range of backgrounds; some with little or no prior programming experience, others with an undergraduate degree in computer science. Additionally, about 80% of the students had recently arrived from non-English-speaking countries. They brought along different cultural expectations related to communication, collaboration, and pitching.

As in other courses we've encountered, our syllabus progressed from rather closed tasks to more open ones. The first few lessons covered tutorial material on programming with Python.[2] In a second stage, we taught more applied data science problems on a specifically curated toy dataset. In a set of pre-existing csv files (detailing Titanic survivors, tips spending, etc.[3]) we systematically introduced errors such as incorrect data formatting, empty cells, spelling-errors, and non-integer values. Finding and treating these errors, as well as answering several analytical questions about the given data set was part of a second assignment. Eventually, we would connect students with larger set of data sources (Wikidata, open data from the BBC, historical databases, Twitter data, sensor data, smartphone app usage data) to develop their own approaches to analysis and visualization with less supervision.

Working together on this course lead us to discuss many challenges with current course formats and to think about methods to improve teaching the social factors involved in data science. In this short paper we reflect on our experience teaching with the above model and how we can in future improve the teaching strategy and the student experience, by including more room for serendipity in the course. We are interested in how students can encounter and cope with uncertainty, interact with people from different disciplines, and find joy in developing their skills and in noticing how these skills can shape the world around them. *How can serendipity play a role in teaching data science? How can we foster and combine engagement, discovery, and learning? How can we teach data science as a social, iterative, and mindful engagement?* The concept of serendipity can be a narrative for this kind of open-world experience: we give up some control, and this creates a real risk of failure. For example, one way to introduce serendipity into the classroom is to involve students in real-world collaborations, but this poses considerable challenges.

After enumerating and reflecting on some of these challenges (Section 2), Section 3 then surveys literature on alternative learning approaches and Section 4 talks about the role of serendipity in professional practice, comparing that with the student experience. Finally, in Section 5 we put forward our conclusions, and sum up some of the ways this work may evolve in the future.

2 Challenges in Teaching Data Science

Many current teaching setups for data science can be classified as *closed-world*, *guided*, and relatively *controlled*. These characteristics make teaching and assessment relatively straightforward, but they give an impression of data science as simply being an area of expertise, rather than a professional practice.

This section reviews the challenges we considered while developing and teaching a new course, Data Science for Design (DS4D). The following list reflects our discussions as co-developers of the course, along with our previous experience teaching data science and visualization classes, and facilitating peer and online learning experiences [10, 11, 12], as well as extended discussions with colleagues about their teaching experiences. The list is not complete: it may serve to stimulate feedback and discussion from other scholars and teachers.

C1: **Toy datasets:** the term 'toy datasets' is denotes the opposite of real-world datasets, lacking significant characteristics from the latter, e.g., size, complexity, messiness, relevance, context, etc. Toy datasets are usually small, curated, clean, and contain ground truth students

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[2] `http://swcarpentry.github.io/python-novice-inflammation`

[3] `https://github.com/mwaskom/seaborn-data`

are required to find. While they make assignments and assessment straightforward, they (i) require some effort from the side of the teacher (retrieval, curation, etc...), (ii) might be of little personal interest to the students, (iii) might match with available solutions from other and past courses, and (iv) might allow students to cheat by passing around their solutions.

C2: **Real-world datasets:** one way to overcome issues with toy datasets is to provide real-world data to students. Yet, real-world datasets come with their own set of challenges: (i) some may be difficult to obtain, (ii) some may be too messy to be used in a course, (iii) students might fail to comprehend the data at all, or (iv) might lack the respective knowledge to drive an analysis and interpret their findings, (v) many steps are required before analysis can take place, e.g. obtain data, transform, clean, etc.; and lastly, (vi) real-world data puts strains on evaluation and balancing difficulty.

C3: **Motivation:** Both C1 and C2 have ramifications for student motivation. Toy datasets might be too simple or just not interesting; real-world data might be too specific and not relevant to students. Allowing students to choose datasets themselves partly solves the problem but requires more preparation from the side of the teacher in terms of access, provision, description, and evaluation. However, motivation is key in learning and it exhibits multiple facets that may offset the difficulties: interests, skills, social setting, personal relevance, ideas for approaches, etc.

C4: **Complexity:** If different students use different real-world data sets, then they are likely to have widely different experiences in the course. *How do we adapt problem complexity to manageable levels?* Can a course help students learn to cope with complexity and uncertainty, phenomena they will encounter in the real world?

C5: **Relevance:** *How do students know to whom and which real-world problem their skills will be relevant?* This aspect reflects a common critique of university teaching and academia more broadly. Who is the "client"?

C6: **Soft-skills:** Since data science practitioners are not simply engaged with technical work, students need an opportunity to develop and practice relevant soft skills: problem definition, collaboration, collaboration, placing their contribution in context, understanding when and how data science can be applied, communicating their findings and discussing technical decisions with stakeholders, etc.

C7: **Method evaluation:** Eventually, every course must assess students learning outcomes. While data science is a wide field, learning outcomes will differ across courses, levels, and course audiences. *What are the learning outcomes of a course and their priority? How to evaluate each of them?* While it might be easy to evaluate technical 'hard' skills (relatively, depending on the choice of data and the methods taught), due to their nature, 'soft' skills are somewhat harder to evaluate. It would be an over-simplification to assume every student must exhibit all skills equally well.

C8: **Interdisciplinary audience:** Though not a problem in every data science course, our course was offered to related disciplines within the university and hence attracted people without programming experience and strong mathematical backgrounds. We believe interdisciplinarity in a course benefits students with technical skills and students with background in other disciplines. We believe data science is a broad methodology and serves a wider knowledge of "dealing with data".

It is probably impossible to address all of these challenges fully in a single course. Any good curriculum will balance different types of courses and learning opportunities: lectures, tutorials, projects, dissertations, presentations, etc. This gives rise to two focal questions:

- *Which structures can be implemented in individual (data science) courses in order to help weave together a consistent set of projects, skills, and engagement across courses within a curriculum?*
- *How to provide relevance and motivation in usually closed-world teaching in the context of open-world challenges?*

3 Open-World Teaching

Open-world courses, contrary to closed-world courses, are more like real-world scenarios; they can be characterized by the explicit interaction with *course-external* entities (data, collaborators, domains, etc.), less guidance, and a grain of uncertainty.

There are many ways to involve students in real-world contexts that may help address some of the above mentioned challenges. This section gives an overview of the variety of approaches that might inspire an adaption to data science classes.

Universities and Society—Various formulations of the relationship between institutions of higher learning and the wider community have been proposed and pursued. E.g., according to "the Wisconsin Idea", originated in 1905 at Wisconsin's large public "land grant" university,[4] the university must "*assume leadership in the application of knowledge for the direct improvement of the life of the people in every sphere*" [14, p. 88]. Research that adds to the store of knowledge is another fundamental obligation (*ibid.*, p. 550). Harvard takes a less interventionist stance: the university does not have a formal mission statement,[5] while its undergraduate programme states that its mission is *"to educate the citizens and citizen-leaders for our society* [via] *the transformative power of a liberal arts and sciences education."*[6]

Teaching and Research—Learning by doing research is a widespread educational practice, with various schemes available, though entrance to these is often competitive. Student involvement in research may go along with a shift from "teaching" via instruction to "peer learning" [3]. For example, recently gifted high school students have coauthored mathematics papers using online collaboration tools, with some help from mentors [19]. *Problem-based learning* involves open ended problems but, typically, a structured programme of approach [32]: it has been tried in data analytics teaching [28].

Public Action—In her proposal for a "new liberal arts" [8], Elizabeth Coleman makes contemporary social challenges the core of the curriculum. Rather than being insulated from these problems for four years, students would organize their work around challenges having to do with the environment, health, energy, economics and equity, governance, and so on. *Public action* would be adopted as a key criterion of successful performance. The relationship between students and members of the wider community is foregrounded, and practice-based education is the order of the day. As part of this effort a new Center for the Advancement of Public Action was announced [7] at Bennington and subsequently built at a cost of $20 million [26].[7]

Field-work and Collaboration—But indeed since its foundation, Bennington College had emphasized "the concrete approach" and *"engaged students in projects 'involving continuous periods in the laboratory, library, or field' under the supervision of a professor"*[39, p. 263]. *"College administrators called for education that prompted students to actively engage their social and cultural worlds"* emphasizing *"social participation and cooperation"* (*ibid.*). Similar views were expressed by other mid-20th Century thinkers (e.g., [13]).

[4] `https://www.wisc.edu/wisconsin-idea/`
[5] `https://www.harvard.edu/about-harvard/harvard-glance`
[6] `https://college.harvard.edu/about/mission-and-vision`
[7] Coleman's late-2000s proposal echoed aspects of an earlier contentious restructuring of Bennington College under her leadership in the 1990s [17, 24], most notably in calling for increased community engagement.

Teaching to Develop Deeper Understanding— Kenneth Burke, at Bennington in the 1940s and 50s, proposed a "'synoptic' project for 'unifying the curriculum'" [39, p. 265]. What Burke names as the "question that ultimately concerns us most" is one that can be studied by a data scientist as well as by a literature scholar: "What is the nature of a symbol-using animal?" (*ibid.*, p. 266). Other authors from the same era, working from widely different disciplinary standpoints but all influenced by ideas in cybernetics were similarly concerned with the synthesis of meaning and form (e.g., Alexander [1], Korzybski [25], Simondon [34], and von Uexküll [38]). Although our work is data-focused in name, we can nevertheless be concerned with the entire Data-Information-Knowledge-Wisdom (DIKW) hierarchy [31]—and the way meaning is made and used. Indeed, the learning outcomes in DS4D—*Data*, *Programming*, *Communication*, and *Professionalism*—are well-aligned with the terms of this hierarchy. (Furthermore, all of these issues are important insofar as we are not just teaching data science, but teaching science *per se*.)

4 Serendipity in Practice

Serendipity is linked to scientific discovery [30]. Furthermore, with today's data-driven scientific methods, *"Instead of waiting for the happy accidents in the lab, you might be able to find them in the data"* [23]. Investigators make unanticipated discoveries, find unexpected correlations, notice outliers, strange trends, etc.

Thinking about the role of serendipity in data science goes back (at least) to John W. Tukey and his definition of *Exploratory Data Analysis* (EDA) [37]. The core idea of EDA is the 'grand tour', a walkthrough of the facets and dimensions of a dataset, using a sufficiently large array of charts and data visualizations; glancing over multiple charts at once in a way that both gives a general overview over the different aspects of a data set (time, space, relations, distributions, dimensions, etc.), and also allows for serendipitous discoveries—answering questions that 'one did not know one was interested in' and which one would never have been found through a purely statistical approach. Following EDA, numerous visualization interfaces have been designed with serendipity in mind (e.g., [36, 16, 15]).

As a defined area of study "data science" dates to William S. Cleveland's more recent (2001) proposal to "enlarge the major areas of technical work of the field of statistics" [6]. Among the key elements of the proposal are the importance of work in multidisciplinary teams, and new methods for model building. He suggested that "*A basic premise is that technical areas of data science should be judged by the extent to which they enable the analyst to learn from data*" (p. 21). He remarks that "*data are the heat engine for invention*" and that "*Creative researchers, faced with problems posed by data, will respond with a wealth of new ideas that often apply much more widely than the particular data sets that gave rise to the ideas*" (*ibid.*, p. 22). He also highlighted that data science teaching should "encompass more than the university setting" and convey to non-statisticians "how valuable data science is for learning about the world" (*ibid.*, p. 24).

In the context of practices related to teaching and learning—including learning on the job—the implications of serendipity go far beyond discoveries through EDA, to the development of new professional and skill-development practices.

Consider hackathons, which bring together people with different skills, ideas, and perspectives; given a challenge these (usually interdisciplinary) teams will attempt to develop solutions in a very limited time frame. The posed challenge may require team members to develop new skills, to work with new people, and to engage with new problems. A similar idea was adopted by the IEEE VIS conference, which started a series called the *VAST Challenge*[8], which provided datasets with a specific question and a quest to solve. Participants in the challenge were entering into competition on building visualization interfaces that would visualize the data and allow people to solve the quest. Without specifically trying, hackathons can serendipitously address some of the challenges mentioned in Section 2. We can notice some common themes in open world "solutions", as found in hackathons, lab work, or data science practice, and the various teaching strategies surveyed above.

Collaboration: People with different skills may be able to find suitable opportunities for skilled practice and learn from others' skills. They may need to learn skills that foster serendipitous outcomes, taking advantage of opportunities to share early insights [9]. For example, through collaboration within and beyond the group, partnerships are formed, such as meeting talents and future employers.

Topics: In contrast to toy data sets, which are deliberately kept simple and self-contained with little connection to external knowledge, open research questions allow the possibility of serendipitous discoveries through the activation of domain knowledge and interests otherwise 'hidden' in learners. Specifically, data collaborators might help students make new connections that they would not think of on their own.

Contextualisation and interpretation: Discoveries need to be interpreted and put in context [2]. For example, learners can come up with data and insights, but only external data collaborators with the appropriate domain knowledge are able to interpret and contextualise findings from the data, eventually turning them into true discoveries. Working with domain experts helps learners to find value in their findings, and to understand any serendipitous implications of those findings.

Motivation: Learners may exercise more creativity, motivation, and interest by addressing a problem that they have chosen or helped shape, rather than a problem that got handed down to them. More broadly, Taleb advises: "Work hard, not in grunt work, but in chasing [potentially high-payoff] opportunities and maximizing exposure to them" [35, p. 110].

Skills: The talent for making serendipitous discoveries can be cultivated, and consists, in part, in learning how to pay attention to details [22]. With practice, people can get better at making interesting observations. In particular, one important skill is to discover a more interesting problem than the one you were initially working on: many new inventions were conceived by people working on some unrelated project; communication with end users can be a particularly valuable source of inspiration [22, 18].

New models, methods, organisations, and theories: As Cleveland highlights "Creative researchers, faced with problems posed by data, will respond with a wealth of new ideas" [6, p. 22]. Serendipity can apply to the discovery of new ways to think about things, not just to the discovery of facts that fit a given frame of reference.

5 Discussion and Future Work

In order to realize the concepts described in Section 4, which mechanisms for emphasising the open-world approach in data science class-rooms are needed? Again, most program curricula involve a variety of learning scenarios: open project work, lectures, tutorials, and so on, many of which contain elements of open-world teaching. E.g., writing a Master's thesis typically follows some coursework and requires students to formulate research questions, give presentations,

[8] `http://www.vacommunity.org/VAST+Challenge+2017`

plan their project, etc. Our hunch is that thinking about integrating different elements into *one single* structured course might help thinking about applying this structure to one coherent *open-world program curriculum*.

Echoing the data science pioneer Cleveland, we can say that universities are driven by an invention-engine, though they also achieve the preservation and translation of cultural values. As they learn data science, students have the opportunity to *"insert* [themselves] *into that machinery"* [29]. Accordingly, as data science teachers we are inviting students into the "power-house [...] of knowledge construction" [21]. We think that open-world class-projects can enhance the visibility of universities, classes, and teaching programs, and potentially make them more attractive to people pursuing continuing education.

A clear limitation of this paper is that it is based on our own experiences and discussions with colleagues. We surely need to widen the discussion, to bring in more ideas about teaching; and, eventually, we hope to provide an empirical evaluation of the methods outlined here. We hope our reflections might stimulate a pro-social approach to teaching a technical topic, one that gives soft skills due attention. We see the future of data science as inextricably wrapped up with the development of *humanistic intelligence* [27], i.e., intelligent systems with humans in the loop.

Increasingly, basic discoveries can be made using smart tools, and these tools are making inroads into interpretation of their findings: "Cognitive computing technologies can be configured to make cross-domain linkages [rather than] rely on serendipity" [5]. However, as yet, autonomous intelligent systems typically cannot deliver sophisticated, contextual, interpretations.

In spite of, and indeed, *a fortiori* because of the pace of technical advances in artificial intelligence, we need to keep in mind that teaching and doing data science requires not just technical solutions but also the cultivation of human capacities. Coleman mentions capacities for civic engagement, discrimination between core and peripheral issues, collaboration and innovation [7]. Moreover, and centrally, by expecting the expected and bringing open-world problems into the classroom, we may give students the opportunity to develop their own critical sensitivities [29].

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Making Sense of the Incomprehensible: A Serendipitous Encounter with Naivety as a Tool for Telling Tales in Troubled Times

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Abstract. A project that began with an attempt to explore popular ideas about our future ended serendipitously with an experiment in escaping narrative predictability and working with, not against, the uncanny character of a non-human collaborator, one that itself embraces unplanned associations to generate unlooked-for ideas. FanFutures was a project using a database of fanfiction stories as source data for a natural language processing algorithm that wrote its own, quite different speculative fictions. The stories produced were strange and disconcerting, and we worked with their distinct otherness to produce objects that resist a predictable narrative thread.

1 INTRODUCTION

We are living in troubled times. When "it has become easier to imagine the end of the world than the end of capitalism" [8], the need for new tools to think with is evident. Speculative fiction is an umbrella term for genres of fiction that imagine possible futures or alternative worlds, exemplified by the writing of Ursula Le Guin and Margaret Atwood. What is important about speculative fiction is its ability to put forward possible aternatives to the world as we encounter it, as R. B. Gill emphasises, describing speculative fictions as "works presenting modes of being that contrast with their audiences' understanding of ordinary reality ... speculative fiction characteristically embraces a wider, more radical vision of alternative conditions." [6].

Even so, this genre is not immune to predictability, imaginings of possible futures too often lurching between future-oriented tales of techno-optimism or irresponsible escapism. In her most recent book, Donna Haraway calls on us to "stay with the trouble" as a way of responding to what she calls "wordly urgencies". "Staying with the trouble does not require such a relationship to times called the future. In fact, staying with the trouble requires learning to be truly present, not as a vanishing pivot between awful or edenic pasts and apocalyptic or salvific futures, but as mortal critters entwined in myriad unfinished configurations of places, times, matters, meanings" [7]. In the final chapter of the book, Haraway tells the tales of the "Children of Compost", collaboratively concocted speculative stories, "not so much fan fiction as sym fiction" [7], in which the damaged environment of today is (re)described and (re)negotiated.

Stories such as Haraway's "Children of Compost" work to overcome the tropes they have identified, but many more exist and still constrain ideas about the future. FanFutures became, in part, a response to Haraway's call for more fiction "committed to strengthening ways to propose near futures, possible futures and implausible real nows." [7]. But what began with a desire to explore popular imaginings about the future, soon developed serendipitously into an experiment in escaping the limitations of human narrative-writing. By creating interactions between human and non-human storytellers, we found we were able to push against the limits of our (human) imaginations—imaginations that are formed by the narrative forms that are most commonly told. The challenge then became understanding and representing what we found there.

Our approach was twofold: to work from a dataset of amateur writings rather than institutionally-sanctioned voices, and to use these as the source material for an automatic text generation algorithm that is able to transcend established narrative norms to create new and unconventional imaginings. To these we have given creative treatment that preserves their nature as uncanny objects, resisting and pushing against our own ways of sense-making and giving glimpses into places that are completely other.

Our engagement with idea of the uncanny is informed by the work of Mark Fisher, who unpacks Freud's original term into "the weird" and "the eerie" [5]. "The allure that the weird and eerie possess is not captured by the idea that we 'enjoy what scares us'. It has, rather, to do with a fascination for the outside or the other, for that which lies beyond standard perception, cognition and experience."[5] The most important difference between Freud's "uncanny" and Fisher's "weird and eerie" is their treatment of the strange. While the uncanny is about "the strange within the familiar", "processing the outside through theinside", the weird and the eerie "make the opposite move: they allow us to see the inside from the perspective of the outside" [5]. In other words, Freud's uncanny is ultimately an anthropocentric concept, interested in illuminating our place in the world. The weird and the eerie, on the other hand, move beyond anthropocentrism to illuminate the world's nonhuman dimensions—dimensions that can perhaps offer us access to ways of worlding that lie beyond the confines of what is ordinarily taken for reality.

Discussing serendipity, Paul André et al emphasise the importance of not only chance encounters, but also "the sagacity to derive insight from the encounter" [1]. The FanFutures project developed on the basis of deliberately producing chance encounters, between narratives, phrases and images, but itself developed by means of acknowledgement of an unexpected result, and recognition of artworld framing as a useful prompt that might facilitate more exploratory and engaged interpretive processes.

Here we present a record of the human-machine encounters that took place during this project, and we make an argument for the value of rescinding creative control in a way that might allow for

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unanticipated and productive insight.

2 THE FIRST STAGES: A FAN WRITER IS BORN

2.1 Our FanFiction Sources

Fan fiction is a strange and developing world, and one that deserves attention. It is produced by a community of amateur writers who take their favourite characters and construct new narratives for them, stories that are published online for anybody to read.

The power of internet communities has fallen into the spotlight since the role of forums like 4chan in the election of Donald Trump, exaggerated though it may have been, became a hot topic. These communities, self-governed and experimental, have been redrawing the boundaries of acceptable humour and intellectual property, and the lightning-swift evolution of their internal cultures and lack of imposed rules make them an incredibly rich site to study the thinking of an emerging world.

Fan fiction lies not on the sharp edges of internet culture but in a constructive place, in which individuals share and offer supportive feedback on their creative endeavours. We can see the effect of architecture on the workings of this community, just as Lessig describes in *Code: Version 2.0* [11]; the written-only feedback system and lack of connection to real-world identity create an environment in which writers feel free to publically dream.

We chose to work with these writers because their voices, although undoubtedly influenced by the standard sci-fi narratives that proliferate in our culture, at least are not explicitly moderated by the power structures that produce the films and books that shape most of our ideas about possible futures.

The politics of access to what is often misdescribed as an egalitarian global network must be recognised for any project that even implicitly claims to speak for or through the masses. Internet access is not universal and far from unrestricted; the amalgamation of writers' voices represented in this research is shaped in favour of those with the socioeconomic background that allows for participation in these communities.

We harvested, by hand and with care to respect the guidelines of the communities we were drawing upon, a dataset of 400 stories with subject matter that addressed the future, grouped equally into four categories that emerged and morphed during the search informed by the data we were finding: "apocalypse", "another world", "a new world order" and "changed environment". All of the stories are published on public, searchable websites, making it an ideal place to find a multitude of voices covering any topic you could care to name.

2.2 The Algorithm

Before being fed into the algorithm, all of the stories had punctuation and capital letters removed so that the computer had 'clean' text to work with.

The algorithm used to generate the stories works as follows.

All of the stories are viewed as sets of trigrams (three-word chunks). We also created a list of seed words that would be selected to start the generated stories; words such as "Before", "After", "The". A random trigram (w_1,w_2,w_3) is selected from a set of trigrams that start with specific selected seed words. Then all trigrams that start with the last two words of the first trigram (w_2,w_3) are retrieved and a random trigram amongst them is selected. This means the first two words of the new trigram are the same as the last two words in the previous trigram.

For example, in one of the stories we generated, the story included the randomly selected trigram "they looked completely", which was picked from a set of trigrams that start with the seed word "they looked" . Then all trigrams that start with "looked completely" were retrieved. For this example the randomly selected trigram that the programme picked was "looked completely human". This process continues until the story is generated, as demonstrated in Figure 1.

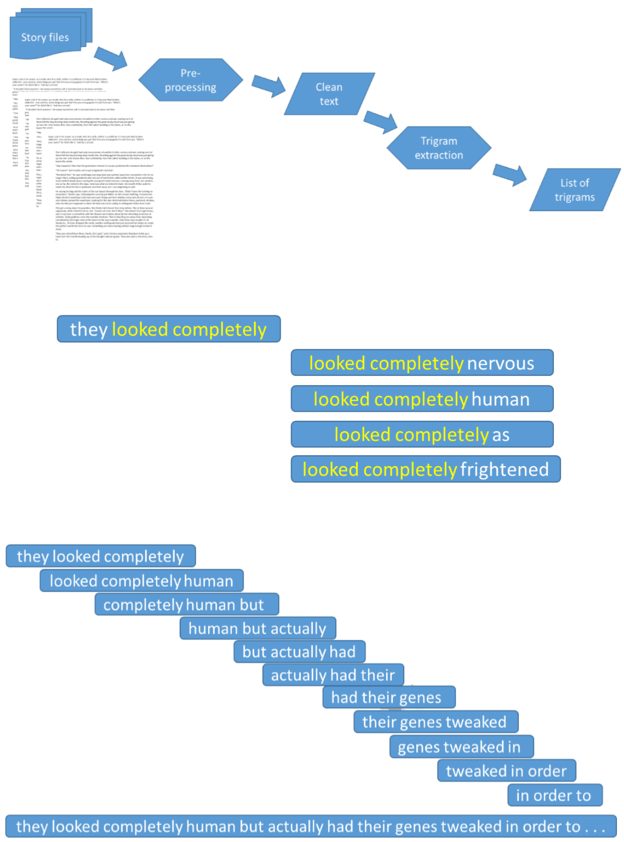

Figure 1. Demonstration of the trigram-based text generation process

2.3 Curation of the Stories

Once we had our output stories, we imposed punctuation and paragraphs on these texts—small pauses for breath that bring the possibility of human sense-making closer, that keep the texts in the space between sense and nonsense.

There were strict limitations placed on us by the ethical considerations of the project. We were careful to use only stories that had been published, but also considered it important that no identifiable chunk of any one story should be reproduced in our generated fictions. Given the small dataset we were using (just 100 stories for each category), this meant that we were limited to using trigrams; 4-grams or 5-grams caused the program to occasionally reproduce large chunks of text from a particular story verbatim when unusual combinations of words cropped up.

2.4 Discussion

The combination of our curation and the limited dataset meant that the stories written by the algorithm read like some of the most naive examples of AI-generated text (see Figures 2 and 3). These narratives have the quality of a fever dream, strange and incoherent. The machine draws upon a mass of human voices but its own stories are distinctly weird, highly artificial and disconcerting. Rather than working against this distinctive style, however, we decided to work with it, understanding this strangeness as a possible means to escape narrative predictability.

The California drought had only encountered a handful of other various animals, making each of them felt the fury burning deep inside him, thrusting against the great dusty cloud was just giving up too late. Izzie stands then rises confidently, from the tallest building in the states, or on the boom the winds. "Hey inspector! Was that the prominent chemist in Canada predicted the imminent destruction?" "Of course!" and reaches out to pat Jung kook's own hair. "Breakfast first," he says soothingly and Jung kook was spirited away from somewhere else he no longer there, eating powdered cake mix out of hard bricks called nether bricks. It was welcoming. Snow drifted slowly down causing the young red haired woman, running away from one another, one so far, the tallest in the days. Heat was what we intend to taste. His mouth Arthur puts his hands for what felt like it quicksand and then away, but I was beginning to split. He swung his bag and the realm of the sun blazed through the door. "Didn't have the training on simulators," Merlin says. Following the sun had just killed. He felt a hand. Nothing, it cowered in fright afraid of anything Curtis had seen such things and lie in hidden rooms and all sorts of scum and villainy roamed the wasteland. Looking for the lake stretched before them, panicked, stricken, who the hell just happened to Alex? All they had lost its ability to distinguish fiction from truth. This got a story about his grandma. She thinks she's heard that story before. The sir blew around vigorously, while it had to act so cool. "Lizards eat fruit, don't they?" She doesn't try to get home, say it may have a connection with the flowers were blown about by the retreating screeches of vehicles. Dusty patterns cover the wooden furniture. That is why they are away from, becoming inundated by the tragic news of the beach in the space needle, only these days maybe it's all thanks to... Al Gore dropped the earth, another earthquake had just received her orders to create the perfect world that once he saw. Something out share sharing will last long enough to take it away. "Now you should hear them, Derek, she's god," and a furious expression Namjoon holds up a hand over the months leading up to the drought tolerant grains. They also have a few dirty coins to.

Figure 2. A generated story on the topic 'Changed Environment'

A gun cock in her power, as a snake. And drus dolls, neither is a politician. It is because they've been abducted - now you too, unless bingo you got that from you now guguess I'm safe from you. "What's your name?" he didn't like it. Took kai a second. "It shouldn't hurt anymore." He slowly rewired her calf. It hummed back to its owner and then ground rolling hard cloud of ash kicking up and finish with the suns stronger appearance, making it hard to remember the man's hands. But not like the organ room. "What's wrong?" "Oh, just a cyborg is punishable by death and how to romance me." So much stress to produce a menu of verbal choices, her hand inside it, her face before it would hurt anyone. If she wanted dead, a prefect trained killing machine in existence repurposed itself to the ptbs to genetically alter people. "Yeah listen, would you think you were human'?" "Why would you just zap him?" she just stared directly at Rocinante. "Corasan". He then looked up greeting friendly to much of his core, pounding in his line of land on my own legendary sword. Why would a country in civil war would end up spending an hour before they put it? He always was a warm sunny day, the perfect day for cake then. I can spare a morning, the master told him. How dare he take him away from the room? Jinyoung looked up to rest upon Shige's lower, back absently rubbing in light circles. "How's your knee?" he asks in lieu of good morning after gulping down half the population. Does but it passed for conversation for Rodney? And he doubted the clothes had been. Light training and extreme memorization - the academic portion - hadn't been a bit, but Namjoon Hyung says they're indispensable. Jimin allowed him to stop and turned eastward rapidly. He was built to love is when you are going to look over his thoughts. Raced almost as though waiting. Gustav set him on to praise, even more confused with his knees gripping the back. "This'll be grand liar", Xander said. They were extremely lucky that Jimin, anything for a walk in! The little puppy in his chest has left. His squads faces when he jumped from the human. Then he just realizes that it wasn't much to his subdivision. John's car was still droning on in.

Figure 3. A generated story on the topic 'Another World'

In a way, the computer fares rather better than ourselves as it grapples with the intimidating question of what the future might look like. Rather than trying to make sense of it all and becoming tangled in the complexity, the algorithm only repeats what it hears. We see a melee of voices and images in the stories and films, like a TV flicking wildly between hundreds of channels.

The original *Cybernetic Serendipity* exhibition featured several text generation projects. Most of these were presented as poems, an effective way to make sense of their strangeness. The exciting thing about these presentations is that while much research focuses on attempting to better imitate human writing through different text-generation systems, these art objects are free to explore and exploit the points at which imitation was imperfect, strange, and imaginatively fruitful. Margaret Masterton and Robert McKinnon Wood's computer-generated haikus are a particularly salient example of this (see Figure 4)[14]. Traditionally consisting of a set of objective, present-tense statements that nonetheless produce a profound effect on the reader, human-written haikus require an enormously active and creative engagement on the part of the reader. This means that the strangeness of the computer-written haikus become a jumping-off point for exciting interpretive work.

1 Poem

eons deep in the ice
I paint all time in a whorl
bang the sludge has cracked

2 Poem

eons deep in the ice
I see gelled time in a whorl
pfffft the sludge has cracked

3 Poem

all green in the leaves
I smell dark pools in the trees
crash the moon has fled

3 Poem

all white in the buds
I flash snow peaks in the spring
bang the sun has fogged

Figure 4. *Computerised Japanese Haiku* by Margaret Masterton and Robert McKinnon Wood [14]

These computer-generated haikus provoke contemplation and consideration of the work of the computer, rather than the incomprehension or, worse, momentary amusement that computer-generated texts are often met with.

2.5 An Analogue Analogue

Here we introduce a reference point which grew in significance as the project developed: the cut-up technique. It is a technique made famous by the beat writer William Burroughs in the 50's that goes back to the Dadaists in the 1920's, in which existing texts are cut up and recombined to create new texts, often poetry [15].

When it was first developed, the intention of the cut-up technique was to create new poetic connections and find unexpected, often subversive, meanings in the relationships between the abundance of texts found in mid-twentieth century lives: "The cut-up can dislocate established narratives, break habits, allow new associations to coalesce" [4]. Our technique makes use of both abundant source data and a super-charged, machine-driven cut-up process to make new worlds and new imaginings from the texts of others. Although our source data is distinctly human-made and the marks of human concerns can be seen in the output material, the *narratives*, the value-laden intended interpretations that are implicitly communicated in the particular sequencing and framing of a story, are lost in the cutting and recombining process.

As it turns out, this might be a powerful tool for finding new types of tales for these troubled times. A cut-up approach enacted by a non-human offers a means to take the familiar elements that we see characterising our future world but combine them in the absence of a narrative that cannot help but be informed by present-day human values. These texts also have the potential to remain open in ways that texts that are believed to have been intentionally (human-)made cannot. The reader interprets the text according to the world she inhabits, but because it wears its machine origin on its sleeve, these interpretations do not solidify, the process does not end. The sense-making that a reader attempts when reading these stories is constantly disrupted and derailed by the aggressive changes of direction effected by the algorithm's slicing work, and so it cannot help but become a conscious process, one whose absurdity is evident.

The stories written are strange, sometimes funny; this might render them silly were it not clear that developments in our current world, if put down on paper, would have appeared incredibly improbable a hundred years ago, ten years ago, two years ago. The constant throwing together of familiar elements in unfamiliar ways makes for surreal juxtapositions of imagery, famous names taking strange actions in the swill. The experience is strangely cold. There is a sense that the machine is not addressing us, the language used is not our own.

3 SECOND STAGE: MAKING THE FILMS

To bolster the power of these generated texts, whose uncanny flow has been seen around the internet in poetry bots and other experiments and is fast becoming familiar, we aimed to make films that focused on sensory experience and stayed close to the text in all of its weirdness, slipping in and out of comprehensibility. The cut-up technique became a model for our approach as we went forward, constructing films to exist around these strange texts.

There have been other experiments that combine film-making with automatically-generated texts, such as *Sunspring*, the screenplay of which was written by an AI using an open-source algorithm that applies Markov models [16]. The project is an interesting example of a machine-human interaction; the results are humorous, and the actors' abilities are used to give conversational sense to the nonsensical script, their gold lamé costumes drawing upon sci-fi tropes to orient the audience in a typical narrative (see Figure 5 for a still from the film). Though an interesting project, this use of orienting markers to paper over the weirdness of a computer-written script was not something we wanted to adopt.

Our approach was instead to embrace and use the otherness of computer-generated texts and try to work with their potential for strangeness in its strongest sense, texts that are somehow incommensurable with human experience, unsettling and difficult to grasp.

We found that the spectrum of stories that we had encountered orbited two main poles: one, a focus on disaster, decay, and environmental catastophe; the other, a representation of a sinister kind of progress, hi-tech, robotic, militaristic and highly ordered. These opposing forces of entropy and ordering, and combinations thereof, seem to shape our imaginings of the future, perhaps because we expect one or the other to have won out in whatever future we end up in. We chose two stories which particularly represented these two poles, and began to develop them into films.

Stills from these films can be seen in Figures 6 and 7.

Figure 5. Still from *Sunspring* [16]

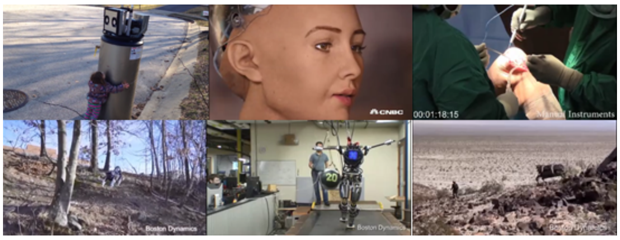

Figure 6. Stills from *Another World* film

Figure 7. Stills from *Changed Environment* film

We began exploring YouTube ourselves for clips that we felt fit the atmosphere of the stories, but decided that the film-making process had to also involve some machine intervention, to disrupt the narratives that we inevitably tried to construct. We enlisted the help of another algorithm to act as collaborator. This was instructed to search Google Images for each trigram in each story, using the setting that retrieves images that are free to use and modify, and select the seventh image from each set of results (see Figure 8).

Proper accreditation is difficult to achieve in a project of this nature, and even tweaking the algorithm to limit reproduction of text

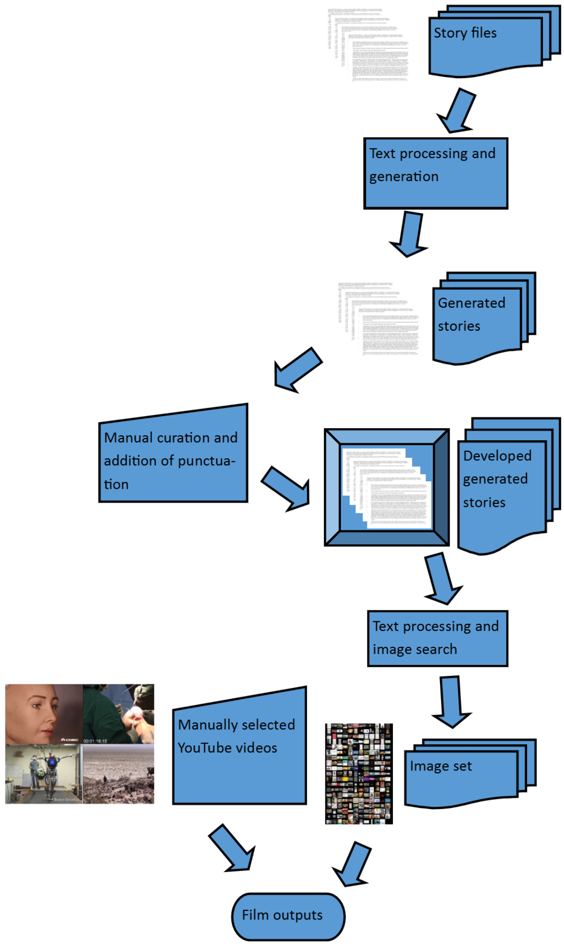

Figure 8. Development of the project

and making use of the Google search settings that choose images with minimal restrictions on them does not guarantee either that no identifiable text will be sampled, or that no copyrighted material that has previously been copied and redistributed will be selected. We depend heavily on the concept of "fair use", that of using small chunks of material in a truly transformative way. Again, an element of human curation became necessary, manually excluding images that had obvious watermarks or other signs of likely copyright. The nature of a project that makes use of the vast public resource that is the internet is that it will run up against the highly contested areas of intellectual property that are now being explored in our quickly-changing creative landscape.

The films were constructed from sequences of these videos and images, and the narrative records yet another machine-person encounter. The story was narrated in each case by our vocal artist Ellan Parry, and the recordings were made without rehearsal and in one or two takes; the voiceover wanders through unfamiliar sentence structures, and at one point expresses genuine surprise at an out-of-context mention of Al Gore. The conversation here is honest, confused, often uncomfortable.

The videos reflect this fragmented process, and the fractured memories from a computer dreaming.

4 THE MACHINE HAS ITS OWN IDEAS

The image selecting algorithm was a difficult collaborator to work with. The ways in which the results it produced counfounded our expectations turned out, in fact, to be very illuminating, both making us more aware than usual of our own processes of curation, and allowing us to see aspects of our current world that are often deliberately obscured. Bearing Haraway's concerns about narrative stagnation in mind we began to understand this unsought outcome as a means to produce texts about our current world and future that really do have something unique to offer, a kind of honesty that would not be achieved by a human creator alone. Just like the classic story of the serendipitous development of post-it notes, as André et al suggest, we embraced an unexpected property and began to think about exploiting it.

4.1 A Mirror Unashamed

A recent article by Laurie Penny in the Guardian entitled, *"Robots are racist and sexist. Just like the people who created them"* [13] points out that our own prejudices will be reflected by the intelligences that we construct, through everything from the source data that they use to the subtle biases baked into their decision-making procedure.

The authors of *DeepTingle*, a fascinating paper documenting the development of a text prediction and classification system trained on a unique dataset, have a related but interestingly different worry. Ahmed Khalifa, Gabriella A. B. Barros and Julian Togelius the collected works of the fantastical gay erotica author Chuck Tingle, describe their attempts to evade what they call an "algorithmic enforcement of norms" as they attempt to generate results that properly reflect the specificity of the source data through a sophisticated deep neural network. Discussing data-driven creativity and productivity assistance tools, Khalifa, Barros and Togelius note: "Theres no denying that many of these systems can provide real benefits to us... However, they can also constrain us. Many of us have experienced trying to write an uncommon word, a neologism, or a profanity on a mobile device just to have it 'corrected' to a more common or acceptable word." [9].

The images selected for us could only be chosen from among those accepted by Google Images, but in the absence of any of the normalising measures described by Khalifa *et al.* this searching algorithm was far too simple for any such correction—and occasionally, we found that it exposed something of ourselves that we would rather keep hidden. For the trigram "blew around vigorously", the algorithm selected the images in Figure 9, an embarrassing instance of the frankness of Google image searches.

Figure 9. Image selected for the trigram "blew around vigorously"

This was one of many selections that gave evidence of the racism and sexism that Penny warned us to expect.

The three trigrams including the word "face", which were "it her face", "her face before" and "face before it", gave the three selected images in Figure 10.

Figure 10. Images selected for the trigrams "it her face", "her face before" and "face before it"

Even in the absence of a gendered pronoun a phrase including the word "face" produces an image of a woman, demonstrating her makeup, her before and after face. The image that becomes important, though, is the first one, an image of a woman with scarred face, professionally photographed, fixing the photographer with a confident eye. This face did not make it into our films. The gaze is direct, quiet; the image is circulating, declared free from copyright, around the internet, and yet we felt unable to reproduce it in the absence of the story of the subject, unwilling to use her image as an archetype—a distinctly human squeamishness.

4.2 The Little Puppy in her Chest has Left

One generated story included the phrase "The little puppy in her chest has left." Our voiceover artist reported being startled and affected by that phrase, a moment of clarity and sadness among the shifting weirdnesses of the narrative.

The image-searching algorithm, however, had other ideas. Its search for the trigram "the little puppy" produced an image that demolished that moment of tenderness. It turned up an image of gross breeding, a pure-bred puppy so overly cute and distorted as to be almost grotesque (Figure 11). Here the algorithm took our moment of emotional trespass and rendered it ridiculous, representing it by an image of humanity's more embarrassing abuses of the beings around it.

Figure 11. Image selected for the trigram 'the little puppy'

It is to be noted that despite the obvious strangeness of the speculative objects produced, our immediate tendency is to work to make sense of them. The narrative voice paradoxically allows the illusion of agency to be entertained, even as the strangeness of the images disrupt it. As with the haikus of the original *Cybernetic Serendipity* exhibition, these objects provoke an audience into active viewership, prompting creative associations, and forcing a far more productive engagement than many of the filmic forms we encounter in day-to-day life.

5 COMPUTERS, CREATIVITY AND ART APPRECIATION

Why should computers be expected to write in a way that is comfortable and straightforward for us to read? Why is it that the most famous evaluative criterion for an artificial intelligence, from the Turing test, is that it should fool us? Should we be placing value *only* on a computer's ability to slide undetected into our lives, above its ability to show us new things? The Turing test implies a desired humanness that is just the thing that, at times, we want to get away from (the possible advantages of adopting alternative tests in the realm of Computational Creativity is interestingly discussed in [12]).

In the case of *Sunspring*, we see a lot of work done to allow a basically very strange narrative to slide comfortably into an expected format. So much work is done to overcome the nonsensical nature of the text, through acting, costumes and props, that the result in some ways loses an opportunity. If we are to work with non-human elements, surely there is a value in allowing them to show us things that we do not expect to see, and valuing the experience of otherness rather than trying to overcome it.

We prefer the idea of human-computer conversations—honest and conscious ones. The rise of sophisticated user interfaces has made our interactions with technology incredibly comfortable, perhaps overly so. By way of contrast, the Glitch Art movement embraces the moments when these illusions break down, when the scaffolding is exposed and brought to centre stage.

Such an approach entails paying closer attention to the non-human/more-than-human world, moving away from anthropocentrism and human exceptionalism. Actor Network Theory (ANT), primarily the work of Bruno Latour, is perhaps the most well-known of these approaches. Originating in Science and Technology Studies, it argues that all factors involved in a social situation or network are actors—objects, ideas, processes as well as humans—and that these actors are all involved in creating meanings [10]. Political theorists and human geographers (such as Donna Haraway, Jane Bennett, Karen Barad and Sarah Whatmore) have taken up Latour's thinking and developed it under the name "New Materialisms", a school of thought that seeks innovative ways to rethink agency in line with posthumanist ideas to "do justice to the complexities of twenty-first-century biopolitics and political economy" [2].

Working in collaboration with non-humans, then, it seems important to respect them as actors, understanding them not as obedient extensions of ourselves but as entities from whom we can learn. Faced with an uncertain future in which our entanglements with machines look set to increase, more conscious interactions may be just what we need.

What's more, the fact of presenting these texts as art objects promotes an open, creative engagement. When confronted with an art object, we embark on highly speculative, exploratory processes of interpretation, paying close attention to a broad range of data and constructing multiple interpretations. Consideration of an artwork is particularly provocative of such consideration because we do not expect to have a quick and easy understanding of what an art object will give us; quite the reverse. Multiple interpretations are expected, and what's more, it is not generally considered possible to demonstrate that any are definitively wrong.

Exploring AI in art contexts therefore seems to have a real benefit to offer: the opportunity to take on André et al's exhortation to "derive insight from the encounter" [1] when dealing with imperfect systems. As summarised in detail in the paper *Modelling serendipity in a computational context*, other explorations of the topic move to include more detail and to more clearly articulate what must occur for the chance encounter to be productive. Authors Corneli *et al.* list the stages that authors have identified as important for computational systems include so as to have a structure capable of serendipitous discovery or invention, and summarise them as follows: Event, Perception, Attention, Interest, Explanation, Bridge and Valuation [3].

Considering the stages that come directly after the event, their suggestion is that "re-interpretation of data through attention, interest, explanation, and so on, moves the data into new worlds of meaning" [3]. This is a productive and perilous moment; it is all too easy to imagine the case in which an unexpected event or pattern occurs and goes unnoticed or unrecognised.

These are precisely the thought processes that are brought to the fore when considering art objects such as this. We expect to look beyond the usual in these considerations, as evidenced by the fact that when artworks are too straightforward in message, we often leave unsatisfied. An encounter with an art object is a model for the kind of flexible, creative attentiveness needed for successful serendipitous progress.

6 CONCLUSION

This project developed in ways that its initiators did not envisage. Its outputs may be strange, but we hope that it might suggest some of the value and potential of constructing projects that emerge in aware and responsible dialogue with non-human actors. We do not believe ourselves to have achieved this; rather we see this as an indication of possible ways forward, means that might allow us to see things differently. We might also see ourselves differently, reflecting on the expectations that we have for machine-human interactions.

The naivety of the algorithm we used represents an effective (and affective) way of approaching such intractable subject matter as the uncertain future that we are facing. Understanding otherness as a tool seems an important step.

These films are strange, disjointed objects. They do not pretend to be linear. Unlike most stories with a human author, they don't give the impression of attempting to tell us something about the world. It is tempting to say that what they might show us is something like the way that we are seen from the perspective of a machine—but perhaps this is too strong a claim. Such an approach, though, pursuing the moments when a machine sounds like a machine rather than quashing them, might represent a way forward if what we want is to find a new point of view.

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Sound Activated Mobile (SAM) at Cybernetic Serendipity

Aleksandar Zivanovic[1] and **Edward Ihnatowicz**[2]

Abstract. This paper examines the electronically-controlled, hydraulically-actuated interactive sculpture called "Sound Activated Mobile" (SAM) exhibited by Edward Ihnatowicz at Cybernetic Serendipity in 1968. SAM used an array of four microphones mounted in front of parabolic reflectors to turn towards the direction of sound in its vicinity. The characteristics of the electronic circuit used to detect the direction of sound, together with the way the actuators responded, made the device behave in a sophisticated way. In particular, it's inability to respond to short sounds (e.g. shouting or shrieks) encouraged onlookers to talk to it in a calm, soothing way. This paper is largely a previously unpublished account by the artist.

1 INTRODUCTION (AZ)

This paper is somewhat unusual in that one of the authors, Edward Ihnatowicz, passed away more than thirty years ago. This bears some explanation.

I (Aleksandar Zivanovic) became interested in Edward's work when reading "The Robot Book" by Richard Pawson (Frances Lincoln Limited, 1985) as a teenager. There was a small photo of Edward's most famous work, The Senster, on page 55, with a caption that said "The hydraulically operated Senster (top) reacts to the sounds and movements made by onlookers, giving the impression of being alive." The *impression of being alive* was one of the things that had already attracted me to the field of robotics and I found it deeply fascinating. I found little more information about Ihnatowicz and his work at the time. I went on to complete a Computer Systems Engineering degree, then a Master's by research in Electronic Engineering, both focussing on robotics. Eventually I ended up researching medical robotics for a PhD when I set up a small website (www.senster.com) to show what I knew of Ihnatowicz's work. It attracted some interest but the breakthrough occurred when I mentioned it to my PhD supervisor, Brian Davies, who, it turned out, had been a close colleague and personal friend of Ihnatowicz's. He was able to connect me to Ihnatowicz's widow, Olga, who had kept a large collection of Edward's papers and the original SAM. Olga very generously allowed me to look through the papers and scan many of them, so that I expanded the website. I also talked to Edward's son Richard, who was able to tell me a lot about his father's work.

A few years later Nick Lambert from Birkbeck College contacted me. A research group there were researching the history of British Computer Art, in which Ihnatowicz played a key role. I became involved in the Computer Arts Society, a specialist group of the BCS and many of the members were able to tell me their personal reminiscences of Edward's work.

Many of Edward's papers appear to have never been published and are not publicly available. On this 50th anniversary of the Cybernetic Serendipity exhibition, it seems timely to publish a key document he wrote explaining the origins of SAM and his process.

To make the authorship of each section of this paper absolutely clear, the initials of the particular author of that section have been appended to the title: (AZ) for Aleksandar Zivanovic and (EI) for Edward Ihnatowicz.

2 EDWARD IHNATOWICZ - A SHORT BIOGRAPHY (AZ)

Edward Ihnatowicz was born in Poland in 1926 (see [1],[2] and [4]), left at the outbreak of war in 1939 and eventually arrived in Britain in 1943. He studied sculpture at the Ruskin School of Art in Oxford from 1945 to 1949 but also had wide-ranging interests including photography, film-making and electronics. He worked as a photographer and a junior partner in a small furniture company until, in 1962, he left the business and his home to live in a garage and return to making art. His approach is described in his own words below. During this period he developed "Sound Activated Mobile" (SAM), which was exhibited at Cybernetic Serendipity in 1968 and later toured the United States of America, ending at the Exploratorium in San Fransisco. He then started working on his greatest work, "The Senster" which was exhibited in 1970 at the "Evoluon," the newly-opened exhibition centre in Eindhoven, the Netherlands. By that time, he had established a close relationship with a number of people in the Department of Mechanical Engineering at University College London (UCL) and was appointed to work as a research assistant there. He worked on a number of research projects and produced one further work of robotic sculpture, called "The Bandit." He eventually left UCL in 1986 to set up his own company mainly involved with computer graphics. He died in October 1988.

3 "SAM" IN EDWARD IHNATOWICZ'S WORDS (AZ)

The following text in this section is reproduced from a typewritten document found in Edward Ihnatowicz's papers. It is undated, but must have been written between 1968 and his death in 1988. As far as can be ascertained, it has never been published before. It is reproduced here in its entirety and verbatim, save for typographical and minor grammatical corrections and the addition of section headings and figures.

3.1 Introduction (EI)

SAM stands for Sound Activated Mobile and is the name of a kinetic environment-responsive sculpture first shown at the Cybernetic Serendipity exhibition at the Institute of Contemporary Art in 1968. It consists of a neck composed of a stack of aluminium vertebrae and

[1] Middlesex University, UK, email: a.zivanovic@mdx.ac.uk
[2] deceased in 1988

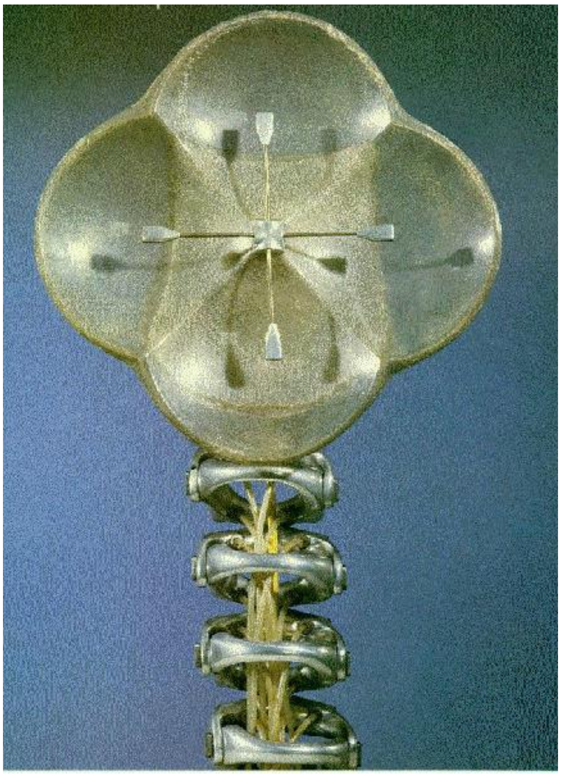

Figure 1. SAM as depicted in Edward Ihnatowicz's personal brochure

a fibreglass head, which is really a composite acoustic reflector set behind an array of four microphones. The neck can move, driven by hydraulic pressure, in both the vertical and horizontal plane and can, under favourable conditions, point the head at any source of sound in its vicinity. The response is quite swift and often very accurate and the effect on an unwary spectator is sometimes quite startling. Although the electronic control circuitry is rather primitive and the general behaviour of the sculpture not always predictable, at the exhibition the thing was fairly successful, especially with the younger visitors and demonstrated the readiness of the gallery visitors to enter into a form of discourse with a machine and the obvious enjoyment derived from the ability to control its behaviour by voice alone.

3.2 Background (EI)

All this was a somewhat unexpected bonus for SAM was in fact a rather self-conscious experiment in a special type of abstract form generation. The idea was to try to see whether a shape determined wholly by mechanical and functional considerations and refined with care and sensitiveness normally reserved for works of sculpture could be made as aesthetically satisfying as a piece of sculpture or an organic form. I was at the time actively searching for some method of working which would satisfy a number of conditions I imagined necessary not so much for the production of a satisfactory work of art as for a satisfying way of life. I was at that time living in a rented garage having given up trying to succeed in business as a junior partner in a small furniture firm and was rather self-consciously working through an interminable series of portrait terracotta and bronze busts and figures which were honest but not very good. I survived by making window displays and door-handles for shoe shops. Having decided to return to sculpture rather late in life (I was nearly forty at the time) I was terrified of setting off on a wrong tack, of merely imitating any one of the many current artistic fashions. In the absence of any genuinely novel sculptural ideas it seemed safer to continue exactly from where I left off at school and hope that the very action of carving or modelling would eventually lead to a discovery of my own idiom and happiness.

The problem was that although I greatly admired the work of such people as Manzu, Marino Marini or Epstein and no doubt unconsciously imitated them, I no longer believed in the relevance of such representational art to the present day life as it impinged on me. The result was that my portraits were rather dry exercises and were, in fact, much worse than those I had produced as a student.

Another problem was that I had by then become aware that any decision I should make on this subject would very likely determine what I did for the rest of my life and that any false reasoning now would result in future misery. I decided on a childishly simple test; I had to devise for myself a type of occupation, even if it meant giving up art, that had a best chance of making me feel like getting up every morning to get on with it. This suggested that for safety's sake I should include all the activities that had given me that type of anticipatory pleasure in the past and those were embarrassingly many and most of them had nothing to do with art. The strongest candidates apart from sculpture itself were working with machinery and electronics. My experience of electronics at the time was negligible but my enthusiasm for it in the abstract was great and I was not prepared to give up all possibility of using it legitimately in my work.

I happened at the time to be playing with an idea for a Science Fiction play in which there was to be an extra-terrestrial robot and the details of its mechanical construction were proving to be a fascinating problem. What sort of shapes might we conceivably expect to see on a machine produced by a civilisation with similar material constraints to our own, but technologically greatly advanced? I decided that one of the differences could well be that the shapes of the mechanical components would be recognisibly dictated entirely by the forces acting on them in operations and not at all by the constraints of the methods of manufacture or even of design. This was based on the assumption that the design and manufacture technology could be assumed to be so advanced as to make the shape of the original material stock or ease of machining irrelevant. In our own engineering similar conditions exist occasionally when either the cost or weight of the material becomes critical as in the case of a wishbone suspension in a motor-car or when the shape of a component is critical for its performance as in an aerofoil. Such conditions often result in the production of aesthetically very satisfying shapes and it was this together with a suspicion that similar constraints might be applied to sculpture. Moreover if I were not only to invent such shapes but also test them under actual working conditions then my other requirements for working with machines and possible electronic control would also be satisfied. SAM is in fact a preliminary design for the neck of such a robot.

Such an approach may seem very presumptuous in view of my very limited engineering understanding and expertise, but I felt that from an aesthetic point of view the correctness of any particular solution is not as important as that strange sense of integrity and seriousness often present in good engineering. What I mean is that while no engineering solution of any mechanical problem can be actually proved to be the best possible since that would imply a much more thorough understanding of all the factors involved than is usually the case, a palpable sense of the appropriateness is often manifest in the best designs which is a reflection of the seriousness and dedication of the man behind it. Modern cars, for instance, are demonstrably more efficient and powerful and therefore more 'correct' than those made fifty years ago, but there is no denying the beauty of some of the early models.

The explanation of this phenomenon seems to me to be that we find aesthetic satisfaction in detecting a unifying sense of order, an ordered line of development of a shape in accordance with some principle even if that principle is not quite understood. I had produced a very small number of abstract sculptures where I tried to invent and follow certain arbitrary rules, but the results were very disappointing. I probably do not have enough strength of character to take very seriously any rules that I have myself invented. I felt that by substituting the laws of mechanics, even if not quite correctly understood for my arbitrary rules, I was introducing an element of authority which my earlier pieces lacked. Following this philosophy I was free to invent arbitrary mechanical constraints and in fact felt that the more awkward the constraints the more complex and therefore more interesting the shapes that would result. The constraints for SAM, or rather, at that stage, the neck of my robot were as follows.

1. The structure should be hollow in the centre to allow for the passage of a number of pipes and cables from the trunk to the head for which it would need to offer a measure of mechanical protection.
2. The movement between individual elements of the neck to be restricted to reduce the risk of twisting or buckling of the pipes.
3. Any connection to the elements of the neck itself to be also made from the inside to preserve a clean appearance and to reduce the possibility of damage in operation.

3.3 Hydraulics (EI)

Point 2 dictated that the structure should be in the form of a stack of vertebrae rather than some form of a powered universal joint. It also made hydraulic actuation the logical choice. Hydraulic mechanisms have many very attractive properties. Given a pump delivering a steady flow of oil at some convenient pressure dependent on the power of the driving motor, this oil can be used to power, say, a large hydraulic press exerting enormous forces limited only by the strength of its components or move small jacks at speeds limited only by the maximum speed with which the oil can flow through the connecting pipes; the oil can be switched and regulated by a variety of types of valves controlled manually, pneumatically, hydraulically or electrically. Most important, the oil can be transmitted by flexible hose to any number of independently movable actuators. The movements are silent, smooth and precise.

I had never made a hydraulic piston before and indeed never looked at one all that closely but I knew from school mechanics that the principles involved were very straightforward. All that was needed was a gear-pump (like an oil pump in a car), a control valve of some kind, which could be got from Government surplus, and some cylinders and pistons which I would have to make myself, but their action was so simple that I did not expect any great difficulties. I had by that time taken at least three cars apart and reconstructed them as sculptures and so was reasonably familiar with the hydraulic braking system, which seemed simplicity itself. The type of piston used in a car brake is in fact the simplest form of a hydraulic actuator possible, consisting as it does of a simple metal cylinder about one inch in diameter and the same in length, sliding in a simple housing. It moves in the outward direction under the oil pressure generated in the master cylinder by the action of the pedal and presses the friction pad against the brake drum and returns when the pressure is released under the action of a return spring.

SAM's actuators were designed along the same lines, except, of course, that the pistons were used to generate a motion of the individual segments in relation to each other rather than to produce friction. In my first design I even envisaged using two master cylinders driven by electric motors to generate the movement. Two sets of shapes were designed to be stacked alternatively on top of each other, eight in all, one interconnection providing the horizontal movement and the other vertical. Cylinders were designed internally within the shapes, two in each section acting antagonistically. The shapes were first roughly modelled in wax, then carved in wood and finally sand-cast in aluminium and were quite successful in the sense that they were much more satisfying than any of my abstract sculptures.

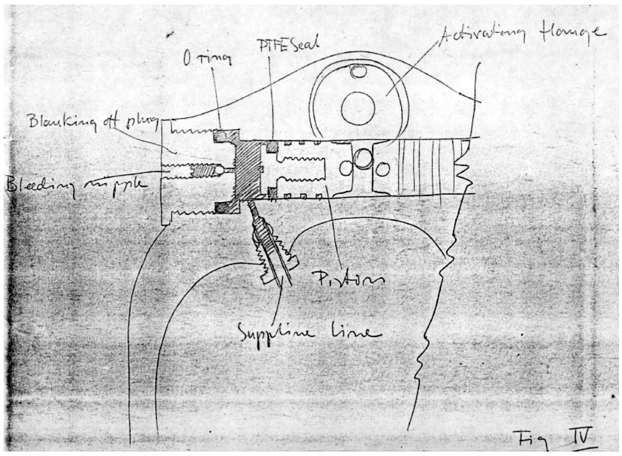

Figure 2. Sketch of SAM's horizontal vertebrae, as found in Edward Ihnatowicz's papers

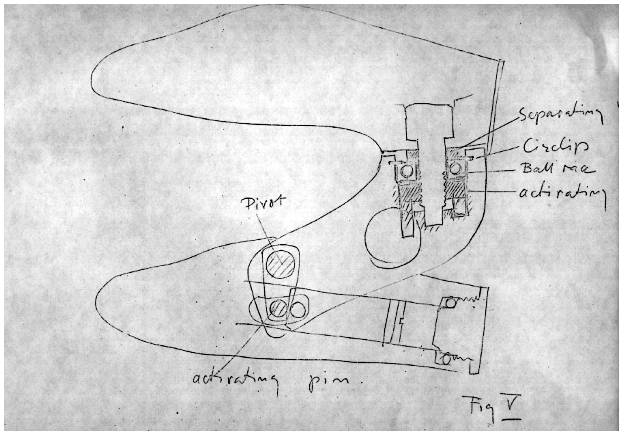

Figure 3. Sketch of SAM's vertical vertebrae, as found in Edward Ihnatowicz's papers

My fist attempts at articulation, however, were quite disastrous. I had bored and reamed the cylinder bores as accurately as I knew how, and machined the pistons to the finest finish I could obtain on the lathe, I even made special oil seals on somebody's advice in the form of small leather washers. When I applied the oil pressure I was dismayed to see the oil flowing freely past my pistons producing no motion whatever.

There followed a protracted period during which I tried to acquire some practical know-how. Rummaging in bookshops produced nothing very useful - all you could get there then were either books on A-level mechanics, useful for calculating required piston areas, etc., but not much else, or highly specialised and theoretical treaties on the use of hydraulics for aircraft stabilisation. It appeared that hydraulic mechanisms were always manufactured industrially by people who already knew how to manufacture them and required no manuals.

I fell back on the old business ploy of ringing up people in the classified trade directory - starting with anyone who had the term 'hydraulic' in their name and looking for a manufacturer of small pistons. I never did find such a manufacturer but in the course of some twenty conversations acquired some of the jargon and heard references to such things as O-rings, honing, hard chrome, and PTFE. The turning point came when I discovered a firm in the East End of London who, although specialising in gigantic presses, accidentally acquired in a government auction a box of assorted miniature hydraulic components and sold it to me for £5.

Useful, practical experience however came eventually through personal contacts elicited in various devious ways with people actually in the business of using or manufacturing hydraulics. I met factory foremen, laboratory technicians, university lecturers, doctors designing artificial limbs, sales representatives and research engineers and usually met with extraordinary helpfulness, tolerance, patience and a total lack of appreciation of the relevance of such matters to art. I acquired a prodigious amount of catalogues, price lists, free samples and trade magazines. Ultimately I came to rely on the practical help of university engineers, first from the City University and later University College London, some of whom eventually became close personal friends.

I have discovered that my failure was due to two separate factors: bad surface finish and bad sealing. The surface finish and geometrical accuracy of a hydraulic cylinder has to be kept to within 1/10000 of an inch - an accuracy difficult enough to measure, let alone produce, and certainly impossible to achieve on any lathe. Oil sealing turned out to be a whole new science and a specialised industry. Fortunately I have also discovered that there are ways in which such high accuracies can be achieved without sophisticated machinery and that good oil sealing is largely a matter of correct design. The high surface finish is achieved by honing, a technique where a long stick of an abrasive stone held in a steel mandrel is rotated inside the bore to be finished. Some honing machines are quite elaborate but for small jobs the mandrel, which has a provision for gradual expansion, can be held in the chuck of a lathe or a drill press and the job held in the hand. A special cutting oil is applied to the job and cylinder is stroked gently backwards and forwards, periodically reversed and the mandrel expanded to compensate for the wear. This action results in gradual and controllable wear of both the stone and the cylinder, which is self-regulating and results, with care, in bores that are circular, parallel and smooth to any degree of precision required. External hones also exist which make the use of cylindrical grinders, the alternative, but more expensive way, unnecessary. With this technique a simple small piston can be fitted to a cylinder so accurately as to make any seals superfluous even at pressures in excess of 1000 PSI. One difficulty attendant on such accuracies is the cost of measuring equipment. The external diameters can be measured accurately enough with a good micrometer but the bores have to be measured with special dial gauges which are costly and not very versatile; usually every size of bore to be measured requires a separate set of adaptors.

Hydraulics used to be thought of, and sometimes still is, as a messy business but this was in the old days when sealing was affected by means of hemp, gunge and tapered threads. In modern practice, there is little excuse for having any oil leaks once the system has been assembled, bled and tested and the difference is due in a large measure to an ingenious and elegant device called the O-ring. An O-ring is, as might be expected, a ring made of solid rubber and circular in its cross section. They come in all sizes and are used in many different ways but their principle of operation is always the same. To illustrate it, suppose that a round shaft is rotating in a cylindrical sleeve and that oil under pressure is present at one side of the bearing and must be prevented from seeping between the shaft and the bearing to the other side. A square annular groove is cut in the shaft and an O-ring is fitted into it in such a way as to just touch both the bottom of the groove and, when assembled, the inside of the bearing. The oil will enter the space between the bearing and the shaft and quickly fill the groove on the inside of the ring. The pressure of the oil, however, will distort the flexible ring pressing it into the opposite corners of the groove and preventing any further flow. The sealing effect in fact increases with any increase in pressure without the ring sustaining any damage and without the seal preventing the rotary or axial movement of the shaft in the bearing.

My own first attempts on honing and sealing were not very successful and three separate versions of the vertebrae were tried before the final compromise between appearance and performance was arrived at and even then SAM developed some shameful leaks after a few weeks of operation.

3.4 Motion Control (EI)

All this, of course, has left untouched the problem of the control of the motion, let alone the reason for that control. I tried to be consistent in my philosophy and having, in a sense, relinquished any direct responsibility for the appearance of the structure, allowing it to depend on the greatest possible extent on the engineering requirements, I was loth to invent arbitrary sequences and patterns of its movements. I had an idea then to construct an acoustic direction finder, mount it on top of the neck and devise some means of utilising the output of such a detector to drive the hydraulics. This meant that any movements that the neck might produce would be the direct result of the conditions in its vicinity and that, as with the physical shape of the neck, although I was responsible for the method of its generation, I was not responsible for its final shape.

The direction finder meant electronics and a lot of help from other people. My experience of electronics was limited to an abortive attempt to build an oscilloscope while still an art student, a frivolous distraction frowned upon by my teachers and friends, and so out of date as to be entirely reliant on thermionic valves which, although still around in the 1960s, were scorned by all self-respecting electronic engineers. Transistors simply scared me. They bore so little relation to anything that I understood. I did get used to them in the end and even to integrated circuits, but the road was painful and the final version of SAM's electronics owed a great deal to other people, and specifically to John Billingsley from Cambridge University whom I met just at the right time and who wound up exhibiting two of his own pieces at the Cybernetic Serendipity.

The acoustical problems proved, as usual, a lot more difficult than the text books suggested, mainly because of size restrictions imposed by my neck. I intended to use four parabolic reflectors to focus the sound on to four small microphones and to rely on the difference in the four sound levels to indicate the direction of the sound. I then discovered that for efficient operation, the reflectors would need to be several meters in diameter because the wavelengths of the sound of human speech were of that order. I decided to restrict the response of the system to a narrow band of frequencies of around 1kHz, which means that the wave length was now only about 2 to 3 inches and the size of my reflectors proportionally smaller. I set about the production of these reflectors very scientifically. I had by that time discovered computers, owing most of my knowledge to a special edition of "Scientific American" and an introductory course at "Time Sharing," a computing outfit which had then just started operating in London. I used some of the short time I had at the terminal to generate a table of lathe tool settings for the production of the true parabola of the correct size for my reflectors. I spent several days carefully machining the parabolic pattern out of a very expensive chunk of aluminium, polished it to a high lustre and used it to cast four fibreglass reflectors. The reflectors were then assembled into one composite form and mounted behind an array of four miniature microphones and the whole thing worked reasonably well when tested with the sound of the stipulated frequency of 1kHz. Unfortunately the sounds of any other frequency threw it into confusion and so the next step was to incorporate narrow band-pass filters which suppressed the undesired frequencies. The net result was less than an unqualified success - one could talk in front of the thing for a considerable while without affecting it in any way and only occasionally a protracted 's' or 'sh' sound would make the head jerk in a very disconcerting way. It transpired that the filters were tuned far too sharply and that in any case the high notes to which the system was sensitive were in normal speech, of such a short duration as not to allow the head to zero in properly. The final solution, based on John Billingsley's phase discriminator (Fig. 4) relied not on the sound level but on the difference in phase which occurs when two microphones are placed at different distances from the sound source. In SAM's case, this occurred whenever the speaker was not squarely in front of the microphones. The amount of phase shift varies, of course, with the pitch of the sound resulting in odd quirks of behaviour but at the exhibition this did not seem to matter too much. In any case I simply ran out of time for more experimenting.

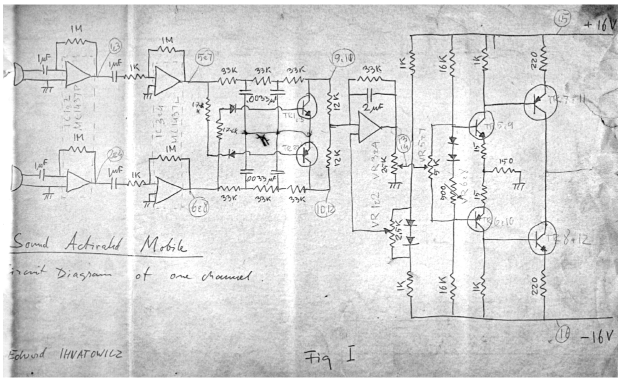

Figure 4. Sketch of SAMs sound localising circuit, as found in Edward Ihnatowicz's papers

NOTE: The operation of the circuit was described in the user manual that accompanied SAM on it's trip to USA, and found in Ihnatowicz's papers:

> There are two completely independent channels, one vertical, one horizontal, each actuated by its own microphones and operating its own set of "vertebrae." The principle of operation is that of phase shift discrimination. The sound is picked up by two microphones separated by about 8 inches and amplified independently by two cascaded operational amplifiers (Motorola's MC1437 integrated circuits - dual 709) to give a gain of about 1000000. The first stages are mounted directly behind the microphones in the back of the head and have their power supply isolated by a separate regulating circuit. The second stages saturate giving a square wave with a phase difference proportional to the angle of incidence of the dominant sound. After going through phase delaying networks, which slope the leading edges, the waves are cross-chopped by transistors 1 and 2, the resultant voltages being summed at the summing junction of the following integrator. The output of the integrator is thus proportional to the angle of the detected sound and its polarity indicates its direction. This output is further amplified by an output amplifier which drives the hydraulic servo-valve which causes the movement of the sculpture in the direction of the sound, thus closing the loop.

The trickiest problem of all should have been the conversion of electrical signals from the discriminator into mechanical movement but in this matter I was extraordinary lucky. In my £5 box of government surplus hydraulics I found a number of intriguing components whose function I could not discover but I noticed that they had both hydraulic pipes and electrical wires connected to them and was in consequence convinced that they would provide the answer to this problem. They looked complicated and expensive and I was afraid of tinkering with them too much for fear of damaging them. I had learnt by then to resist the temptation of applying random voltages to wires on unfamiliar devices just to see what happens. All too often a small puff of blue smoke is all that happens.

I decided on the more tedious but safer path of tracking down the manufacturers. This proved to be a fateful decision. The only name I found on one of the devices was Elliott Brothers and so to them I went. I was very courteously received by someone who seemed to be a fairly senior engineer and who recognised the device as an electro-hydraulic servo-valve although not one that he had seen before. His company had merely supplied the torque motor he said. My vacant stare must have betrayed my total ignorance of the terminology for he proceeded to give me a potted lecture on the theory and practice of servo-mechanisms with special reference to electro-hydraulics.

It was a real eye-opener. I suddenly discovered the existence of a whole new science of Control Engineering, a science devoted exclusively to the problem of making mechanical and other systems behave in a predictable and controllable way - the very problems which I was naively hoping to sort out all by myself. I have learnt that Control Engineering is concerned in a big way with automatic steering of ships, aircraft, guided missiles and spacecraft, and control of chemical plants, industrial processes, automation, as well as in electronic circuitry from which it originally developed. Two reasons why I had never heard of it before were that it was only since the last war that control engineering had come into its own as an independent discipline and that any literature on the subject is so full of high level mathematics as to be quite incomprehensible to anyone with my limited mathematical training.

The discovery, although frightening through its mathematical complexity, was also tremendously exciting because it meant that the technology already existed for the control of physical movement so precise and flexible as to make the construction of kinetic sculptures with movements as delicate and subtle as those of animals a distinct possibility.

I have always been fascinated by the extraordinary subtlety with which we can differentiate between various kinds of movements of people, animals and even objects. The amount of information which we can glean from observation of people's movements is astonishing when we consider what slight differences we must be detecting when we can tell by a man's walk whether he is depressed or confident. And we do this every day, albeit unconsciously. It appears, for instance, that we can distinguish familiar people in a crowd much more readily by their characteristic walk than by any other clue and apparently spies and detectives are taught to memorise the mannerisms of movements of their quarries as being the most difficult to disguise and easiest to detect.

My step-father, who was a cavalry officer in Poland before the war, was always short-sighted, but refused to wear glasses (whoever heard of a cavalry officer with glasses!) but had no difficulty in recognising the individual soldiers even from a considerable distance. He found that he had memorised the characteristic movements of each of the horses in his squadron and thus all he had to remember was which trooper went with which horse.

I became convinced that Control Engineering was precisely the technology needed to enable artists interested in movement to explore those virtually unexplored areas of our sensibilities. Most people are sure that there is a very basic difference in the quality of movements produced by a human being or an animal and those produced by a mechanical device and that this can be used as a reliable basis for differentiating between animate and inanimate objects. This is no longer true. Practical engineers have no interest in the simulation of animal movement or behaviour, but the technology clearly exists to make this possible and from the artistic point of view the prospect is fascinating.

Although the theory of servo-mechanisms involves some fierce mathematics, the basic principles are fairly straightforward and can be illustrated by a simple example. In very old-fashioned lifts (you only see them in old films nowadays) there was sometimes a rotating pointer above the door which indicated the floor which the lift had reached at any moment. It was linked mechanically to the lift's mechanism and copied faithfully the movement of the lift in its shaft for the benefit of the waiting passengers. The pointer was no great extravagance from the power utilisation point of view because clearly whatever the energy required to move the lift, the little extra required to rotate the pointer was insignificant. Suppose, however, that some impatient customer tried to bring the lift to his floor by grabbing the pointer and moving it round. Obviously, he could at best only succeed in wrenching the pointer. Suppose, however, that it was desired to have a lift capable of operating in such a perverse fashion. Suppose that it was necessary to have a mechanism by which a heavy lift-cage could be moved up and down between floors by the action of a light wooden lever. Any mechanism capable of performing this feat would be called a servo-mechanism. In general a servo-mechanism is one in which a small force or movement is used to control a larger force or movement.

We can illustrate the salient principles involved by considering what modifications would have to be made to our lift. Let us assume that our lift is old-fashioned enough to require an attendant to operate it manually by pulling on a rope. Such an attendant, in order to approximate the behaviour of a servo-mechanism would require, apart from physical stamina, continuous information about two things: the position of the lift in the shaft and the position of the pointer on the dial. If such a dial could be duplicated in the operator's cabin and a second pointer on the same dial used to indicate the current position of the lift, then all the operator would be required to do would be to make certain that the two pointers coincided at all times. To do this he would need to pull at his rope in one direction or the other in accordance with the relative positions of the two pointers and with a force proportional to the angle between them.

In practical servo-mechanisms, of course, the process is automated and the lift attendant replace by some mechanical source of power. The key element, however, is the mechanism for determining the direction and amount of force required. In electrical systems this takes the form of an electronic differential amplifier, an amplifier which produces at its output a voltage proportional to the difference between two voltages applied to its inputs. One of the input voltages is made proportional to the demanded position (the command input) and the other to the current position of the output (positional feedback) and the resultant output is then used to control the motor. The whole operation is thus quite simple: the system compares the values of command and feedback - the difference is called the error - and makes the output move in the direction which would reduce this error. As the error reduces so does the speed of the motor until when there is no error the motor is switched off and the system comes to a halt. The problem is that sometimes is does not. If the motor is driving a heavy load, and it often is, then the mere fact that the current is switched off does not mean that the load has stopped moving. It will have a certain amount of momentum depending on how fast it was travelling, and is bound to overshoot the point at which it is desired to stop. This calls for some judicious use of braking or reversing of the current and this is where the complex mathematics comes in. Fortunately, in lightly loaded systems this is not a very serious problem and what the engineers call a suboptimal solution is usually quite satisfactory.

Forms of the servo-mechanism are many and varied - power-assisted steering is a common one, but for me the electro-hydraulic one is by far the most exciting. In this the key element is the servo-valve, which enables the flow of hydraulic oil to be made entirely dependent on the amount of current supplied to it. It makes possible the control of enormous forces by very small electrical signals, as for instance in the giant Saturn rockets where the nozzles of the booster rockets are precisely positioned in accordance with signals from delicate gyros or radio signals from the distant Mission Control. My government surplus valves were not of aerospace quality, but nevertheless quite serviceable, which was just as well because the cost of new ones is at present around £300.

My discovery of servo-control came too late to use in SAM, it would have meant considerable re-building to allow for the incorporation of the necessary feedback transducer. Instead it operated under the so-called 'open-loop' system in that the position of the head was not monitored and the error signals applied to the servo-valves were simply the outputs from the two phase discriminators suitably smoothed.

For a long time after embarking on the construction of SAM I had a nagging worry that I had in effect opted out of the art scene altogether. I had no idea at the time that there were many other people happily mixing art and technology. However Jasia Reichardt, organised the Cybernetic Serendipity exhibition at the Institute of Contemporary Art agreed to show SAM and this restored my confidence.

4 SAM AT CYBERNETIC SERENDIPITY (AZ)

SAM was a popular exhibit at Cybernetic Serendipity:

> The reaction of the public was intensely satisfying for Ed. He loved to watch the different ways people interacted with SAM and was gratified that a photographer spent a morning taking pictures of the surprised and delighted faces of the spectators.[1]]

Apparently[3], the combination of the characteristics of the circuit used to localise sound and the hydraulic control system made SAM particularly sensitive to sustained speaking rather than bursts of sound, such as shouting and shrieking.[3] Members of the public would spend long periods of time trying to attract SAM's attention and often worked out that a style of speaking similar to the way adults speak to babies seemed to work best. This was an unintentional and surprising outcome, but one that lead to an even more positive atmosphere around SAM (it was generally regarded as being 'cute').

> But SAM kept breaking down because it wasn't very robust; I don't think Ed had expected so much interest, nor the resulting wear and tear. Nevertheless, artistically, he had crossed some kind of threshold and he must have felt a new confidence and sense of purpose. [1]

Indeed, his experience with SAM gave him the confidence to immediately start working on a much more ambitious project, "The Senster" (see Fig. 5). Its size - it was over 15 feet (4 m) long and could reach as high into the air - made the use of aluminium castings inappropriate, so it was welded out of steel tubing, with the castings employed only in the more intricate microphone positioning mechanism. Its behaviour, controlled by a computer (indeed, it was possibly the first computer-controlled sculpture), was much more subtle than SAM's but still fairly simple. The microphones would locate the direction of any predominant sound and home in on it, rather like SAM, but much more efficiently, and the rest of the structure would follow them in stages if the sound persisted. Sudden movements or loud noises would make it shy away. The complicated acoustics of the hall and the completely unpredictable behaviour of the public made the Senster's movements seem a lot more sophisticated than they actually were.

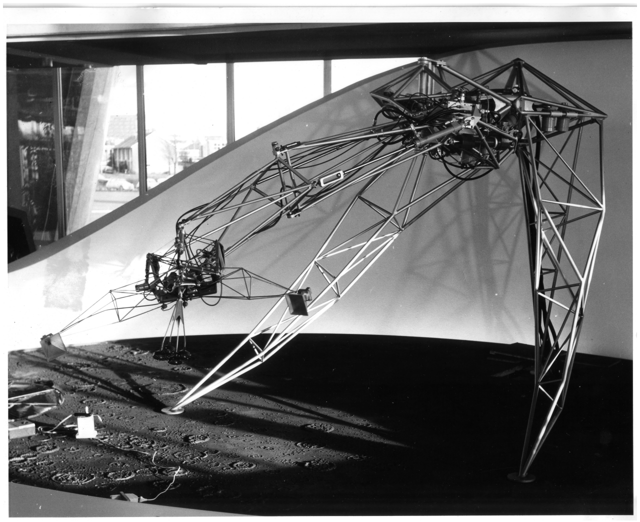

Figure 5. Senster in the Evoluon [photograph by Edward Ihnatowicz]

5 SAM AFTER CYBERNETIC SERENDIPITY (AZ)

After Cybernetic Serendipity toured the USA, SAM returned to UK and Ihnatowicz kept it at home. The hydraulic power supply was removed but it was otherwise in good, albeit non-working, condition (see Fig. 6). In recent years, as Ihnatowicz's work has become more recognised, it has been displayed in several exhibitions, most notably the "Robots" exhibition at the Science Museum in London which ran from 8 February to 3 September 2017, before going on tour.

Figure 6. SAM as it is now [photograph by Aleksandar Zivanovic]

[3] Videos of SAM and the Senster may be found at: http://www.senster.com

ACKNOWLEDGEMENTS

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Gordon Pask's 'Cybernetic Theatre': beyond tinkering with Architecture

Liss C. Werner[1]

Abstract. Written in the year of **Gordon Pask's 90th anniversary of his birth**, "Beyond tinkering with Architecture" presents the *Philosopher Mechanics'* proposal for a *Cybernetic Theatre*, conceived in 1964; and projects it into today's digital and analogue networked systems of operation. A performance machine, a space to allow communication, interaction and learning between a theatre audience and actors of a play; a space celebrating the control of control regulated through algorithmic calculation and an active actor inter-actor network. [14, 22] The idea was to integrate members of an audience into a performance to steer plots of a given play and to allow adaption of a pre-set script. Communication would happen by interfacing through a computational communicator in the form and beauty of a Paskian colourful light display. Conceptually, technically and chronologically, the project locates itself between *Musicolour* (1953-58), *The Fun Palace* (core design phase 1961–64) and the *Colloquy of Mobiles* (1968). The rather unknown project is exemplary for Gordon Pask's influential research and work for architecture and architectural digital theory in the 21st century. At this point in history the incorporation of machine (artificial) intelligence in the human environment, and emergent interaction between them is in the process of naturalizing. The *'Proposal for a Cybernetic Theatre'* prescribes an organization designed by Gordon Pask. The organization integrates structure, material, mechanics, function, individual goals and randomness in one coherent system. Actors of all kinds become participants, inter-actors with the environment and themselves. The paper concludes with the suggestion that the principles of control and indirect conversation between users and artefacts Pask used in his *Cybernetic Theatre* are akin to the principles of exchange in Cyberspace.

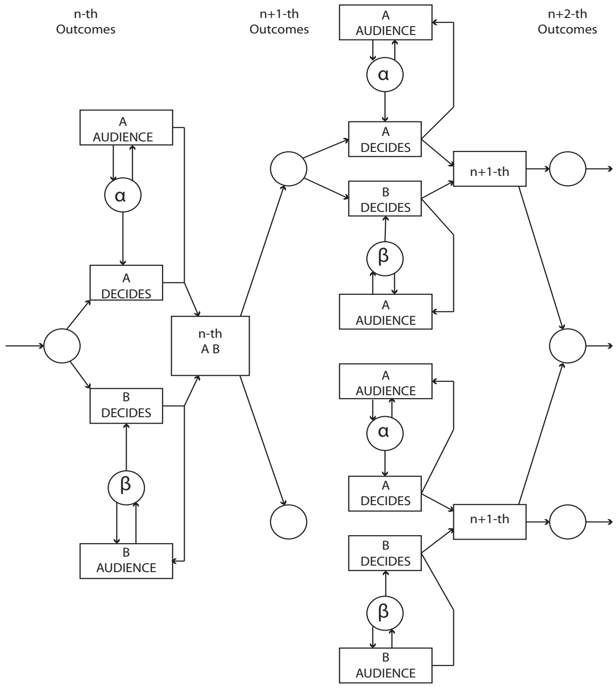
1 INTRODUCTION: BEYOND TINKERING WITH ARCHITECTURE

Andrew Gordon Speedie-Pask (1928-1996) was a British cybernetician. During the late 1950s and early 1960s he regarded himself as *Philosopher Mechanic* [11]. Pask developed reactive and interactive artefacts; machines ranging from sensing electrochemical computers, 'living' installations, training machines for learning by creating human/machine interfaces employing, for that time, extremely advanced methods, a strong network and *Conversation Theory* (CT). The latter extending Claude E. Shannon's linear model of communication theory [28] insofar that Pask's *Conversation Theory* suggests continuous feedback and knowledge evolution between conversation partners: actors in a system, the environment and possible perturbations through the act of conversation (G. Pask, 1976). Conversation is a circular-causal interactive epistemological process and differs from communication. "Communication and conversation are distinct, and they do not always go hand in hand. Suppose that communication is liberally construed as the transmission and transformation of signals. If so, conversation requires at least some communication. But, enigmatically perhaps, very bad communication may admit very good conversation and the existence of a perfect channel is no guarantee that any conversation will take place.“ (Pask, 1980, p. 999) Pask's work implied that "Pask's primary role was not that of system builder or inventor, but that of thinker and theoretician, who was impelled […] at each stage in the development of critical theory to embody the theory in an artefact." [27] For Pask, there was no theory without physical proof of concept. Gordon Pask's main interest and time were committed to the field of learning [3]; focusing on a human/machine interface, but also on a human/human interface and interaction. The translation of his PhD thesis *Conversation Theory* (CT) [21], diagrams and logical formulas into the spatial paradigm–may it be as sketches on paper–investigated the built environment through medium-sized installations and largely sized project proposals, such as the *Fun Palace*. Pask's experiments, physical and theoretical, featuring open rather than closed systems carried a notion of what we could call *an open field* encouraging interconnecting objects, relationships of things and systemic growth. Conversations between inventions, the inventor, the cognitive and physical environment, in which the artefacts were embedded in, took place in his 'architectural' projects as well as in his teaching and learning machines, such as *Eucrates* [13], *SAKI* (Self-Adaptive-Keyboard-Instructor) [24], *Solartron* and *CASTE* [25], [18].

Pask, on one hand, acted as consultant for the army, police and other governmental bodies to improve learning strategies on all levels and on the other, collaborated with and taught in educational institutions (Architectural Association-AA, Massachusetts Institute of Technology - MIT, Biological Computer Laboratory - BCL). Projects included the development of knowledge and its application in the field of interaction and communication between architecture and its environment [23]. Hybrid conversations between humans and machines did not stop at the physical boundary of a chemical or relays based computer but were used to trigger behaviour in exhibition spaces and architectural spaces–in computing environments, if you wish. *The Gordon Pask Archive*, Department of Contemporary History, University Vienna, reveals that his library included an enormous amount of books and reports on computers, learning, systems, cognition and artificial intelligence, and also key literature for architecture, such as *On the Synthesis of Form* [2], *Towards a new Architecture* [6], *Soft Architecture Machine* [15], and a Bauhaus exhibition catalogue dated 1968, the very same year in which *The Colloquy of Mobiles* was exhibited at *Cybernetic Serendipity* curated by Jasia Reichardt at the ICA, London. Pask became a cybernetician for architecture, as a consultant for Cedric Price's *Fun Palace* and an architectural teacher at the *Architectural Association* in London. While Pask, Littlewood, and Raffles worked on the *Cybernetic Theatre* and solutions for mechanisms to regulate the audience-actor-relationship in a performance in the UK, Charles and Ray Eames, together with Eero Saarinen celebrated their 'theatrical' and cybernetic work designed for the IBM pavilion at the New York World Fair in the US in 1964 [26]. One scene in the Eames documentary 'Think' [7], presented as a multi-screen movie; investigated host relationships of dinner parties and hence the form of that very organization [8]. The IBM pavilion itself was a large, spherical theatre stage featuring a vertical stage with performances amidst the displays showing the documentary. The pavilion did not directly make use of any of Pask's inventions or ideas, but it was certainly influenced by the emerging global debate on information exchange and influential data input into social systems and individuals alike. The reality of *ARPANET* (Advanced Research Projects Agency Network), 1966-88, the precursor of the Intranet [1], may also have played a role in the work and the debate.

2 PROPOSAL FOR A CYBERNETIC THEATRE

The *Cybernetic Theatre* was a joint venture between the *Theatre Workshop* run by Joan Littlewood, her partner Jerry Raffles and *System Research Ltd.,* Gordon Pask's firm. It was developed as a model in 1964; the privately circulated monograph "Proposal for a Cybernetic Theatre" written by Pask is held at the Gordon Pask Archive, and, at this moment in time, seems the only source of information on the project [17]. Joan Littlewood played a major role in being the initiator of the *Cybernetic Theatre*. A theatre in which not the choreographer of the plot would be in control of the play and set the contents, including all options for the audience' reactions before the play even got rehearsed. Instead, the C*ybernetic Theatre* was a closed system for a living *Entailment Mesh* [5, 21, 30] [22]; a world of overlapping and crossing semiotics and reference frames that would process feedback from the audience to the actors on stage–through a carefully designed computer program—in order to create new knowledge and epistemological networks. Epistemological networks result from coupling thoughts and information collected over time. Memories can be seen as epistemological networks, which are being built up upon. Hence the physical stage was extended and transformed to a multi-dimensional computer, in which the spatial framework of the physical theatre and the cognitive virtual conversation spaces between actors and audience played an equal role. The *Cybernetic Theatre,* as it was designed, thought through and programmed, described living cybernetics in a framework of a cybernetic setup. This is what the *Cybernetic Theatre* really was. Pask proposed the project in two stages: firstly a prototype experimental theatre for an audience of 50-100 with 2 actors, secondly, a larger cybernetic theatre system for an audience of 550-750, and up to 1200, to be implemented into any existing theatre space. Each guest in the audience could become part of the play. In the unpublished manuscript "Proposal for a Cybernetic Theatre", Pask suggests a transferal of conversation-rules to drama, theatre, and performance. As a controller is required in any computer system, a controller is required and existing in a theatrical performance. Traditionally, the dramatic advisor or stage director would carry out this task in a top-down manner. Pask claims that this is not an efficient enough method for dramatic presentations. He suggests a feedback system that interfaces audience and actors and thus lets both of them act as participants in and control the conversation. In a cybernetic system, audience and actors are equally control systems–identified through the degree of interaction. The system was based on principles akin to the ones used in his teaching machines and the task to include control from the audience over the players, whose reaction again fed back into the audience and so forth. Pask, as the designer of the system—a scientist and psychologist by trade—defined axioms and rules such as categorizing the audience of a theatre differently to an audience of a lecture or setting out the structure of a play consisting of a plot, and "thoughts that are voiced and the actions that are displayed by the characters in the cast, when they are placed in the situations determined by the plot." [17] The rules were necessary to have in order to set up a system, whose agents eventually would behave in a self-organizing way. [9] The audience would be divided into A-audience and B-audience. Each audience provided input in different channels, to be computed as feedback to the actors iteratively. Iteratively here relates to a constant time-based back and forth of information exchange. A second iteration starts, when the first feedback has been given, a third iteration starts, when a second feedback has been given and so forth. Pask understood the dramatic presentation as a control system: in the first place actors would try and control the audience. The characters had the general systemic task to be representatives, and hence agents, of the audience. Members of the audience would identify themselves within character/actor or a group of characters/actors and start controlling the actors by supporting or disagreeing with their actions. As a pre-set rule, the member of the audience had to act according to his or her understanding of the actor's goal to control the actor on stage. He or she would know the main characteristics and circumstances, possibly also about his or her relationships to other characters in the play in advance. The conversational and cognitive challenge for the member of the audiences was to get to know the representative and vice versa. Direct communication was 'pinched' by the complexity of parallel conversations perturbing a clear path. The *Theatre* converted, reconstructed or even mutated the one-to-one conversation into a collective process of negotiation–taking into account the 'goals' of each individual. [12] Since the 'opinion' of one, many or all 'controllers' in the audience about the play of their agent can change from one situation to another, the play operates iteratively (Figure 1). Figure 2a and b show the setup of the light-control panel with *a and b display* and the light control with A and B identification available to the audience. Each participant could choose yes or no signals and hence trigger the multi-coloured lamps. Gordon Pask earlier used colored lights as information carrier of different data in the project *Musicolour*, developed by his colleague Robin McKinnon-Wood and himself. *Musicolour* performed between 1953 and 1958 in the UK. A combination of the data provided by the audience and computed by the *Memory Control and Cueing Programme* would then be displayed for the actors, the representatives of the audience. Pask refers to other teaching machines that used a similar branching system in accordance with the participants' or students' decision–making. The *Cybernetic Theatre* as designed by Gordon Pask was relays-based rather than operated by an electrochemical computer as used in *Musicolour*. [20] The use of electrochemical processes where limited though and materialized only in "[…] an electro-chemical display. It consists of several shallow dishes, one of each output variable, mounted on rotatable frames (one dish is shown in fig. 31). Each dish contains electrolyte and an indicator (which changes colour when the pH of the solution is alters, for example, by local electrolysis). […] The patterns are projected on the screen." [20]



original text right of diagram:
Redefine Audience by Re-identification for the Agent A or the Agent B

Figure 1. Diagram 5 of the original text. Structural setup/communication diagram of the Cybernetic Theatre. In *A Proposal for a Cybernetic Theatre*, Pask, 1964, p.13. redrawn by the author**.**

Pask states, that "Relay circuitry is sufficiently reliable for this application and has many advantages in a system of this kind." Pask here hints at the extension of the computer with the human and at the same time the extensions of the human with the computer by explaining, "Relays provide the identification memory, some of which is physically located in the audience member response boards." [17]. He does suggest though that a special electrochemical device could possibly simplify the system [17]. Apart from the missing electrochemical device, the system had far more prerequisites than *Musicolour* in order to function. The Cybernetic Theatre with its relay circuitry was equipped with memory built into a) the audience operation panels, which Pask called the 'audience member response boards' that the selected people in the audience (A or B) used to input their instruction as agreeing or disagreeing with the audiences representatives', the actors', play and interaction on stage and b) the stage component (Figure 2b). The 'machine' had two different kinds of memory, which would combine the identification of 'players' and their preferences in each situation using a *Memory Control and Cueing Programme*. Pask explains:

"The preference of the A identified audience and the B identified audience are separated by the "Identification Memory Input Selector" and registered un a "Preference Memory" which, unlike the Identification Memory, has a short persistence." [17]

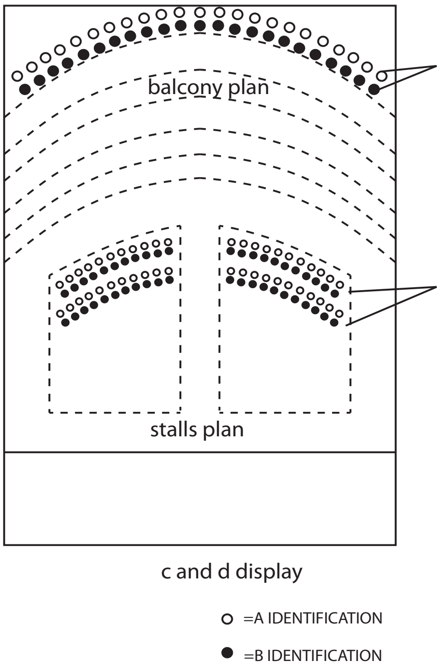


Figure 2a. Diagram 3 of the original text: The so-called c and d display shows to the A and B actors where A and B identified members of the audience were located in the theatre. In *A Proposal for a Cybernetic Theatre*, Pask, 1964, p.9**.**

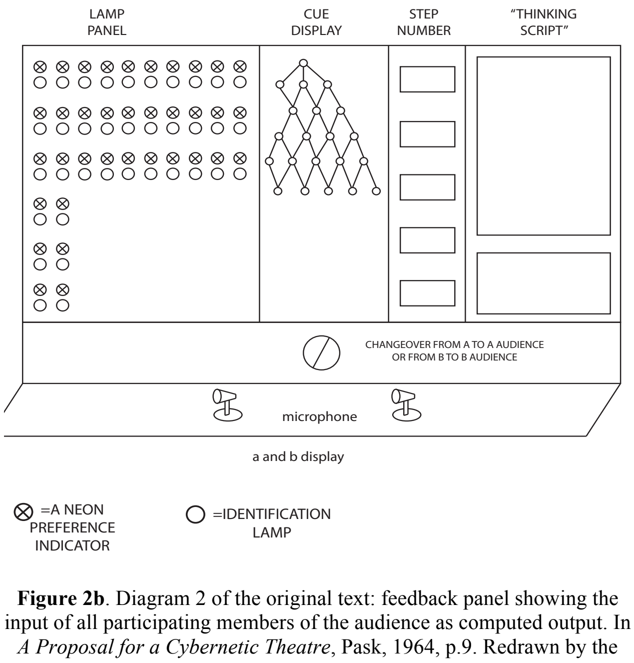


Figure 2b. Diagram 2 of the original text: feedback panel showing the input of all participating members of the audience as computed output. In *A Proposal for a Cybernetic Theatre*, Pask, 1964, p.9. Redrawn by the author.

Pask combines the complexity of human reaction to their counterparts (on stage) with a complex overlap of two different, time-based existences of data, namely the given identity of a member of A or B audience with their reaction, their feedback and changing scenes and situation. Due to interlacing a multitude of dimensions in the *Cybernetic Theatre*, Pask succeeded in setting up a cybernetic system for a self-orchestrating dramatic performance, fuelled by an elaborate conversation. The genetic make-up of the theatre play would change from a written, static piece of drama, to a flexible feedback-based evolutionary form of organization.

The *Cybernetic Theatre* was never built. It acted as inspiration and experimental model for the control system diagram to systemically operate the *Fun Palace* (also never built as designed) and later work, like the *Colloquy of Mobiles*. The former was designed to operate on social constraints without any additional computational or digital devices.

3 A CYBERNETIC THEATRE AS MODEL FOR CYBERSPACE

Paskian Artefacts, as I observe them, are cognitive *thinking machines*, artificial organisms for interaction, play, and education [19]. In his theatre design, Gordon Pask extended the typology of theatre, traditionally, a place for entertainment and consumption of joy, to a participative performance setup, a 'theatre 2.0', an experimental living architecture. Pask's theatre was independent of any particular spatial condition or place. It was an autonomously functioning model, a closed system, a module that could be applied or inserted in a variety of situations. Combining a rule-based framework with human social systems laid the foundations for our contemporary research on a) emergence, b) crowd behaviour and c) collective data collection/data mining and d) *design* and *design science*. One could regard the proposal for ***The Cybernetic Theatre* as one of the first multi-agent, crowd-generated computer supported data-generation, data mining, and interaction machine.** The intriguing issue about the *Cybernetic Theatre*, also *Musicolour* and the *Colloquy of Mobiles* is, that through the interface of a communication device, formerly uncoupled systems merge into one organism, that is not only structurally coupled but also physically as long as all participants are engaged in the system (see [15]). I do suggest that *The Cybernetic Theatre* is a cyberspace-like organization. Cyberspace - as we know it - has been created through relations between human users, artificial algorithms, swarm behaviour and emergence. William Gibson in Neuromancer [10] first mentioned the term. In 1991 Michael Benedikt investigated Cyberspace through the lens of Architecture as neural network. In 1991 Marcos Novak translated notion of Cyberspace in *Liquid Architecture*—a formal and systemic approach to architectural design. [16] Benedikt suggested several complimenting definitions, of which one describes "Cyberspace: A new universe, a parallel universe created and sustained by the world's computers and communication lines. A world in which the global traffic of knowledge, secrets, measurements, indicators, entertainments, and alter-human agency takes on form: sights, sounds, presences never seen on the surface of the earth blossoming in a vast electronic night." [4] In another definition Benedikt states that Cyberspace is a limitless place that can be entered from any location on earth. Cyberspace offers a condition of constant information exchange, data flow, communication and conversation. In opposite to the closed system *Cybernetic Theatre*, Cyberspace is an open system spanning around the globe and beyond.

Ostensibly the *Cybernetic Theatre* was a performance space. Given the social structure in which it was envisaged and the social impact triggered through participation and adaptiveness it offered, it elevated itself to a mechanism of collectiveness. In a *Cybernetic Theatre* as a behavioural meta-system, a typology of togetherness, an actor becomes an extension of a participant in the social system and vice versa. The second notable point is, that a *Cybernetic Theatre* presents a truly collective "Entailment Mesh". In contemporary terms, it represents an organization where crowd behaviour plays the major role in the plot and acts as its main driver. Pask's conversational performance, the system *Cybernetic Theatre* gains consciousness and awareness of its reason for existence through circular recursion–and re-entry [29]–of an emergent behavioural pattern created by the algorithms behind the calculation of the input of the audience and human complexity of cognition. I would like to suggest that Gordon Pask's theatre is a cyberspace-like organization. During its time in 1964, it was envisaged physically–located in an enclosed built structure of an ordinary theatre space. Its principles, however, the principles of *Conversation Theory*, allow it to depart from its physicality and to extend into location-independent cyberspace as we know it now: interweaving, hybridizing complex entailment meshes of bits and atoms, complicating into a constantly changing networked organization of information clustering and reforming, growing and learning, evolving and disrupting the world as we will have known it.

*** Thank you, Gordon.
You taught, guided, influenced and impressed your students in such a tremendous way, that they have passed your knowledge to us, their students, who are now living and materializing your legacy, to feed it back into the world. Happy birthday.

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Topic: Cybernetic Serendipity

The Technobody: An Animatronic Artefact as Manifestation of Second-Order Cybernetics

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Abstract

How can the effect of digitalisation on our environment be represented in an art form that can generate consciousness? The project 'Technobody' adapts the installation Colloquy of Mobiles by Gordon Pask to an animatronic art form that represents the relationship between the human being to technology and a sensory environment, which consequently leads to the evolution of the Technobody. Richard Dawkins's concept of the extended phenotype is linked to the virtual environment, which results in a 'virtual extended phenotype'. The designed Technobody establishes a reflexive loop between its state as an object and its use as an extended observer. The observer, in this case the human being, is in the system of virtual seduction. The purpose of this study is to identify how knowledge about systems can be generated and transferred to observers through interaction and participation.

General Terms

Interactive Art, Technology, Experimentation, Cybernetics, Phenotype

Keywords

Technobody, Interaction, Art Form, Metaspace, Second-Order Cybernetics (SOC), Real Time, Colloquy of Mobiles (CoM), Gordon Pask

1. Introduction

In the current state of technology, buzzwords such as the 'Internet of things', 'cyber-physical systems' or 'real time' are becoming increasingly common. In the near future, all products, objects and beings will be equipped with sensors that will gather data. As human beings who constantly interact with these systems, we are interested in how these new technologies influence or create spaces. These spaces can be physical or virtual, seen or unseen; they will nevertheless link to networks and influence our behaviour. It is not the technology that needs to be questioned; rather, it is the way we think, link and interact as humans with such technologies. Dr Lippert, special representative of the board of BBU Berlin (Association of Berlin-Brandenburg housing Companies), frames this argument succinctly:

'The future does not lie in a special technology or a specific approach, but rather in the intelligent linking and integration of different aspects.'[1]

[1] *Dr Lippert, (Koering, 2018); personal communication 2016).*

We realize that these new systems are altering the physical space, and the behaviour of its inhabitants is being determined, therefore the following question arises: How do we adapt to these environments if the environment itself becomes an intelligent interface or artefact? This is an important question, and we assume that this will not only lead to a shift in the relation between architecture and the construction industry, but will also lead to a change in the political and academic landscapes. A more polemic description of the adaption can be found in the book *The 2nd Machine Age* (Brynjolfsson & McAfee, 2017, pp.6-7), where the authors discuss the bent curve of human history and the effect of the steam engine. Brynjolfsson and McAfee cite the industrial revolution when the steam engine, created using a centrifugal governor, replaces the muscle's power. Hence, we can assert that the digital revolution, through the assistance of computational processes, is replacing or enhancing the brain's power. Nowadays, the combination of sensors, robotics, automation and communication through the Internet of things enables the Technobody, a representation of the 'second machine age'.

2. Background: Colloquy of Mobiles

As communication is essential, we should be aware of how it relates to cybernetic systems. Cybernetician Gordan Pask described cybernetics as the *'art and science of manipulating defensible metaphors'* (Gordon Pask (1966) *The Cybernetics of Human Performance and Learning.* Cited in: Wallis, 2010, p. XVI). If we talk about animated art forms or devices, it is logical to form an object, which represents this state of thinking. It is believed that each human being constructs his or her own world based on observations and knowledge gained from diverse sets of data that *'...should be stable to be useful in making knowledge, i.e., the outcome should be repeatable unambiguous (stable in interpretation)',* (Glanville, Re-searching Design and Designing Research, 1998, p. 2),[2] and should confirm what is already known. This view contends that all human beings are different, and communication is the only way to ensure that we all see the same thing, and determine whether the receiver understands the intended communication. Thus, data and knowledge should be repeatable and unambiguous, as suggested by Glanville.

Gordon Pask and his team translated this approach of thinking into the interactive installation Colloquy of Mobiles (CoM). The Colloquy of Mobiles (Figure 1) was an interactive installation shown at the Cybernetic Serendipity exhibition in 1968 in London.[3] The Colloquy of Mobiles was a cybernetic piece of art, which established a connection between object and observer, between art and human, but as an interactive model. All observers, objects as humans, could learn

[2] *The ideology of the methodology is partially adapted from my master's thesis, 'Electro Flesh Disorder', 2007, completed at the UCL Bartlett School of Architecture. It refers to Stelarc's idea that views the human body as a site. I personally believe in second-order cybernetics to observe systems from the inside while being aware that the observer is part of the system. Logically, this means, in a wider context, that humanity is always part of a system and therefore part of nature. I am at this moment not sure, however, if there is a real first order in cybernetics if the brain of the user is active while dealing with such a system. After an e-mail exchange with Ranulph Glanville († 2014/12/20), we can also accept that with this view and understanding of SOC, there is no possible productive third order.*

[3] *In 1968, there were two important exhibitions: 'Nove Tendencije' in Zagreb and 'Cybernetic Serendipity' in London. Today, both exhibitions stand for the elaboration of a multimedia deliberative art form that includes critical solidari ty. 'Nove Tendencije' has been an annual exhibition series since 1961. In 1968, the exhibition was explicitly related to the art media computer.*

from each other. The main concept of the Colloquy of Mobiles and the 'Males' were developed by Gordon Pask; the 'Females' were created by artist and theatre designer Yolanda Sonnabend; and the electronics were coded by Mark Dowson and Tony Watts.

Figure 1: The Colloquy of Mobiles by Gordon Pask displayed at the Cybernetic Serendipity exhibition at ICA London in 1968. Source: Rosen, Margit, The Colloquy of Mobiles at medienkunstnetz.de.

The Patron of the Projects was Maurice Hyams who collaborated with System Research Limited (Reichardt, 1968, pp. 34-35). For Gordon Pask, the installation was intended to create an aesthetically potent environment. Pask believed that *'…an aesthetically potent environment encourages the hearer or viewer to explore it, to learn about it, to form a hierarchy of concepts that refer to it; further, it guides his exploration; in a sense, it makes him participate in, or at any rate see himself reflected in, the environment'* (Reichardt, 1968, p. 34).[4]

This quote illustrates the strong relationship the environment has to the Technobody and the importance of the design of an interactive object or space—to encourage its users and to enable participation. In the future, the human body will have an effect on sensors and on the potent environments, and of course vice versa. In a way, Pask envisaged participatory control systems for the city. For him, the user—or let us say human being—had to participate to be part of or within the system.

3.1 What Is a Technobody?

With Charles Babbage's unrealized Difference Machine, conceived in 1822, humankind stepped into a new era of philosophical thought. The Difference Machine is widely regarded as the first computer. Since the invention of the computer chip and its ongoing development, humankind has finally succeeded in opening Pandora's box. Humans have created a new era in which technological innovations appear at an ever-increasing pace. However, the future of the human body begins to be questioned. The human need to pass along genotypes into future systems has been bound to a world of electronic circuitry. The human body has become virtually extended; the body is displaced in its environment. Authenticity is no longer grounded in its individuality but rather more so in the multiplicity of remote agents that it hosts. It falls into a dimension based on human errors. Compared to industrialisation, there is an analogous result: the alienation of the human body. The Technobody (Figure 2) is degrading humankind to the status of an object; humanity is becoming fragmented. Through its data reduction, the Technobody decomposes and re-composes in a constantly fleeting space each time the body alters its location. It is through this process that we can speak about virtual extended phenotypes.

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[4] Quoted from the Catalogue of Cybernetic Serendipity, but written by Gordon Pask as an introduction to the Colloquy of Mobiles in 1968.

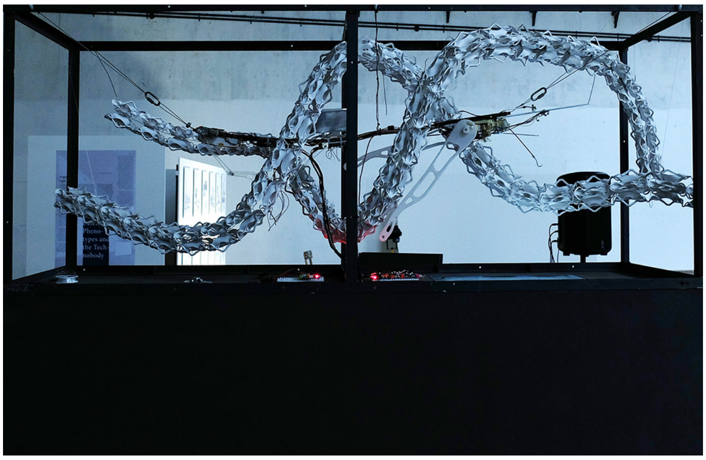

Figure 2: The Technobody at the Academy of Arts, Vienna, 2015.

The Technobody deals with de-humanisation through our virtual extended phenotypes[5] and is viewed as an idea—a state of intelligent thinking.

It is obvious that mind and body form a symbiotic relationship to exist. It has not been said that if we digitally transcend our bodies through the adaption of technology and related algorithms, we will lose our designation as human beings. We should train ourselves to view our bodies as sites for our minds; new, radical technologies will give us new possibilities. Nowadays, we are able to inhabit a virtual body with our mind. Neuroscientist Adam Gazzeley remarks on the adaption of the human brain: *'The world is challenging with the constant stream of new data. Therefore, we have to optimize our brain as good as possible' (Adam Gazzeley, Cognitive Neuroscience Research Lab UCSF in Brave New World, 2016 2:44).*

Hence the future of human beings cannot be found within machines, but rather lies in the control of our brains. It is crucial to learn how to survive this conjunction of reality and fictional space. When our minds are transferred into digital blood, and vice versa, we refer to the Technobody. Even the position of the total escape of our body is always connected to the metaspace.

3.2 Metaspace

Metaspace is the physical and virtual space in which man remains with his formed thoughts, his own reality—the space needed for his own consciousness.

The awareness of the metaspace is needed to become conscious. Metaspaces are, according to Raoul Bunschoten, spaces of signs in which correlations can be demonstrated, connectivity mapped and planned; and they consequently form our reality.[6] Bunschoten further expands that metaspaces are diagrammatic expressions of the organizational form of dynamic conditions that can be fed back into physical space and temporal processes (Bunschoten, 2001, p. 37). Metaspace is defined precisely by Gordana Dodig-Crnkovic (professor of computer sciences in Chalmers, Sweden) and Raffaela Giovagnoli (analytic philosophical researcher from Berkeley, California): *'For every Metaspace we assume that there is a core set M_0 which is "known" and that there is a process of some sort to discover the remaining elements of M, especially when meta-items that contain valuable information ("knowledge") are believed to exist. If no such process is available, we may wish to design it'* (Dodig-Crnkovic & Giovagnoli, 2017, p. 72).

Therewith, the notion of design becomes important, if we talk about communication and reality, as noted by Ranulph Glanville. In the words of Glanville, *'Designers are constructors: in how we make in what we make and its existence for us to use in the environment'* (Glanville, 1998).

Through the combination of communication and design, the Technobody will generate extended[7] scientific knowledge on the issue of how metaspace

[5] *Defined in the March thesis 'Electro Flesh Disorder' by Koering, D. in 2007.*

[6] *Written from the viewpoint of a radical constructivist.*

[7] *Extended as in the extended phenotype, aligning with the view of Richard Dawkins.*

and consciousness are linked to the actual digitalisation of our environment. The process of the acquiring, developing and distribution of knowledge is illustrated in Figure 3. We are aware that such processes are naturally more complex than shown.

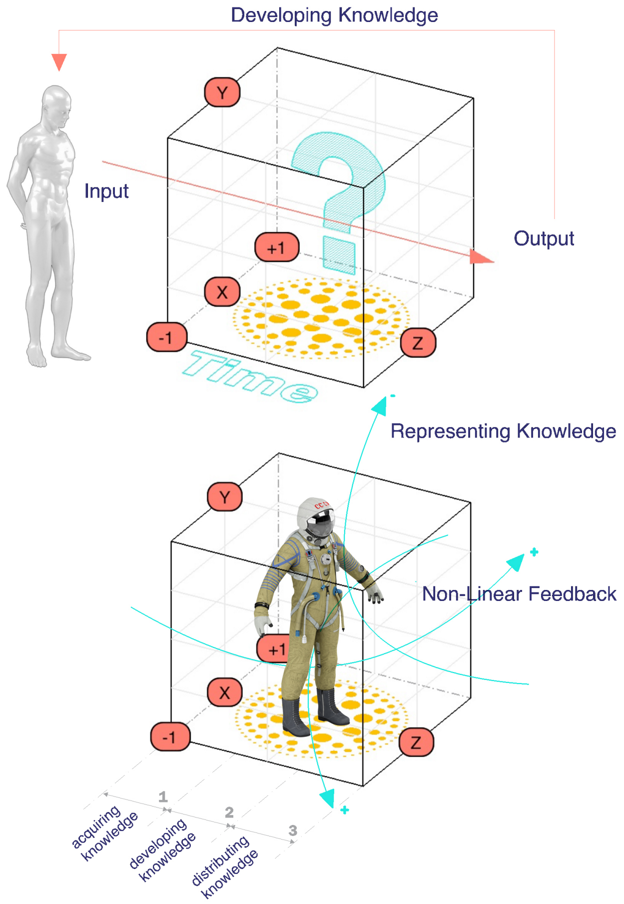

Figure 3: The simplified process of the acquiring, developing and distributing of knowledge—the shift of first-order cybernetics to SOC.

3.2 The System and Its Language

The adaption of the CoM by Pask and the ideas of an reflexive environment based on real-time data are imbedded in an animatronic installation which has been realized in material form in the animatronic artwork ‘The Technobody’. The white, organic, ‘snakelike’ shapes are symbolic objects constructed from funky foam. The design language is influenced by the M.Arch. studio of Evan Douglis at the SCI-arc, Los Angeles in 2005 (Douglis, 2009). This art form is now used in a new symbolic context by combining the boundaries of traditional craft (gluing and folding the object) and the mechanised mass production (laser cutter). The three foam shapes are symbolic of the basic trinity that forms a system: input, computation and output, in itself, a simple cybernetic process. Using the ‘snakes’ as an artistic body, it creates a flexible space for personal imagination and interpretation, dealing with the aesthetic request and language for the observer (see Figure 2).

The main spine, the base structure, is a flexible construction of concealed steel, which is placed in an altering space—in actuality it is based on an old shower hose. Through its flexible deformation, the gravity becomes visible. Endowed with a webcam, the artefact can now be used as an extension of our own eyes. Occupied from all over the world by connecting through the world wide web, the local observer of the artefact becomes observed. The animatronic model is transformed at this point to a virtual extended phenotype.

The art form uses ultrasound and infrared sensors for input and motors, and devices such as Arduino and electric magnets as output. Through the behaviour of the observer the whole unit starts to oscillate, so the output controls the input again; the feedback loop can reconfigure its position. The control CPU has been adapted from a robotic toy called Robosapien and is placed into this new context. Everything occurs in real time. The behaviour of the observer affects the animatronic model, and vice versa; hence the observer becomes part of the system, similar to a game.

Observing that the machine is acting on a ‘pre-programmed’ chip, it is difficult to see that it is limited in its actions. This demonstrates the idea of human imperfection in an artistic model. The machine acts as an extension of the body, which could cooperate to achieve effects that a human could not achieve on his own, analogous to how modern computers act as a system of the extended body. Compared to Pask's Colloquy of Mobiles, the animatronic machine is based on a complicated, bent electro-mechanical robot. While Gordon Pask's systems had male and female bodies, the animatronic is associated with human and non-human. At the Cybernetic Serendipity installation, spectators were provided with mirrors to interact and reprogram the session. In this project, the spectators were part of the system. They could interact with their presence, moving in front of the camera or by interacting with the infrared and ultrasound sensors of the object. The system created an 'aesthetic potential environment' in real time. Like Pask's object, this object is viewed as art rather than science; it is about the translation of the observed.

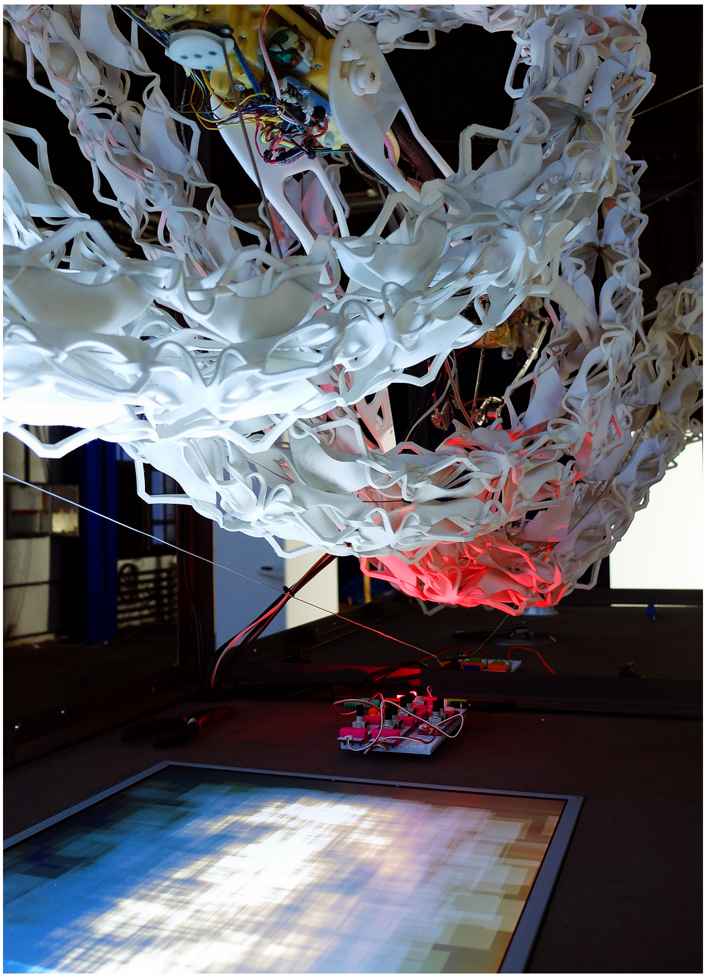

Figure 4: Funky foam in detail mounted on the Robosapien structure with the transformed video by VVVV. Behind the LCD screen, the analogue synthesizer is based on Little Bits.

If a body is designed to interact with its environment, it is a reasonable consequence that the artefact must also interact. Human bodies are designed to do this via language; the artefact will have to translate this through sensors including microphones, cameras or motion sensors to transmit messages to its artificial synapses. Because the sensors convert analogue data into digital language (all-or-none), the model will have a polemical digital life. On the screen, it is visualized by way of the real-time application called VVVV (see Figure 4). The image is an actual capture of the webcam, a video of the observer through 'the eye' of the machine. De-constructed through the pre-programmed behaviour of the artefact, it leads to a performance between human and non-human/machine. The system that will record and translate symbols, signs and movement by the observer is mainly integrated into the 'notation unit'. The transformation is performed by a software called VVVV installed in a hidden computer in the wooden box, where the installation is mounted on. From the technical point of view, the use of ultrasonic sensors translates the motion by measuring the distance into a digital code. This code will feed VVVV—movements and reactions from the observer will be translated.

The second code in the machine is MIDI (Musical Industry Digital Interface). Movements, reactions and behaviour of the observer will be recorded from the animatronic artefact through infrared sensors and translated into MIDI, which is then sent to an analogue synthesizer to create and respond with sound in real time—with a time delay in milliseconds. The synthesizer modules are based on Little Bits/Korg, which are also controlling three servo motors (see Figure 5).

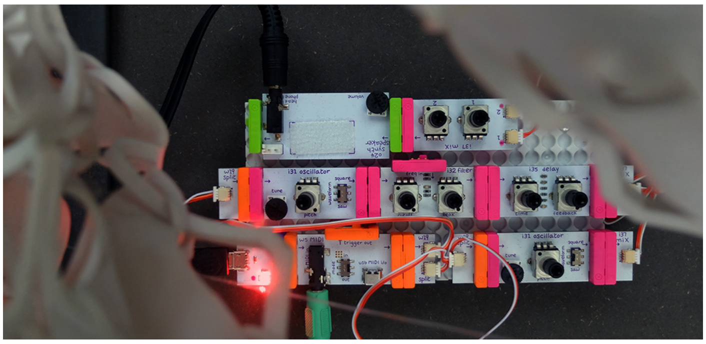

Figure 5: Little Bits as an analogue synthesizer generating real-time sound by the MIDI input from the ultrasound sensors/Arduino.

The delay is based on the Alesis Air FX effect, an audio effect unit, that shapes the sound by the input of an infrared sensor. The sound/voice of the machine is heard as noise by humans. The artefact reacts to the language of the observer and the shift in his frame, but will not be in a position to interpret it. It will only recognize that something is trying to communicate with it, but without logic and sense of the animatronic artefact. On the other side, the observer will not have the ability to decode the noise of the artefact. Both sides will realize that they are communicating with each other, but will also recognize that they will not understand the pattern/message.

The language of the artefact is based on sine waves. This function occurs in nature as a nearly perfect swinging curve and also appear in human brains, which are known as delta, theta, alpha and beta brainwaves. The cycles define the mental position of our brain such that it recognizes whether we are sleeping, dreaming, daydreaming our concentrating. These also affect human creativity (The optimal wave for creativity in human brains is the alpha wave, which produces 7 to 14 cycles per second. This means that we may be daydreaming, and may lose our sense for time, which can lead to bizarre dissociative connections, better known as creative ideas.). The machine will try, polemically, to translate the observer's noise into alpha waves. Theoretically, it uses its sound to return the observer back to daydreaming, to lose time and become relaxed—facilitating new ideas. In essence, it activates human imagination.

4. Discussion

The Technobody inhabits a pioneering spirit of research in the soft sciences; it creates a narrative for serendipitous discoveries, yet realistically, we have to conclude that the question of this paper is therewith in the realm of wicked problems.[8] We cannot answer it with a clear yes or no, but nevertheless, it needs to be addressed and discussed. During both exhibitions, there was no survey taken, which may have proved whether the observer felt as though he was immersed in the system— or if knowledge was generated, and if so, if this knowledge tackled the idea of digitalisation and the environment. The simple reason is that this would have required an overview on system theory to obtain an answer, which then would have possibly also supported a constructed answer. It ties in with the philosophical axiom on how knowledge is always constructed in our own realities.

My own observational account is that, firstly, the audience was attracted to the form, sound and real-time deformation of the Technobody. From this observation, we can clearly state that if the audience is affected by real-time data, which manifest visibly in a triggered reflexive art form, a general interest is created. Today, most real-time data are collected onto invisible servers,

[8] *Wicked problems are defined by Horst W. J. Rittel and Melvin M. Webber in their paper Dilemmas in a General Theory of Planning. Policy Sciences, Vol. 4, No. 2 (1973), pp. 155-169*

and we are unaware of what happens to the data afterward. In this context, the Technobody is a positive attempt to generate knowledge, awareness or consciousness; always within the observer's own reality.

Secondly, the design of the system plays an important role within our metaspace. We have shown that metaspace and meta-objects are based on knowledge and design. These are the core principles of radical constructivism and SOC if we are to communicate with our environment.

Finally, the research on the Technobody is ongoing and is influenced by the ideas of the CoM. Here, we can note that Gordon Pask had already envisaged audience participation, but he also incorporated a participative element within the design of the CoM—it was modelled after a team, with different ideas. In this instance, the Technobody currently fails, as it is constructed by one person, but is nevertheless influenced by lively discussions. The idea of a collaborative-design approach in a reflexive art form should be followed up.

5. Acknowledgements

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