the new pulsar generator manual. a sound installation for synthetic voice and computer generated sounds

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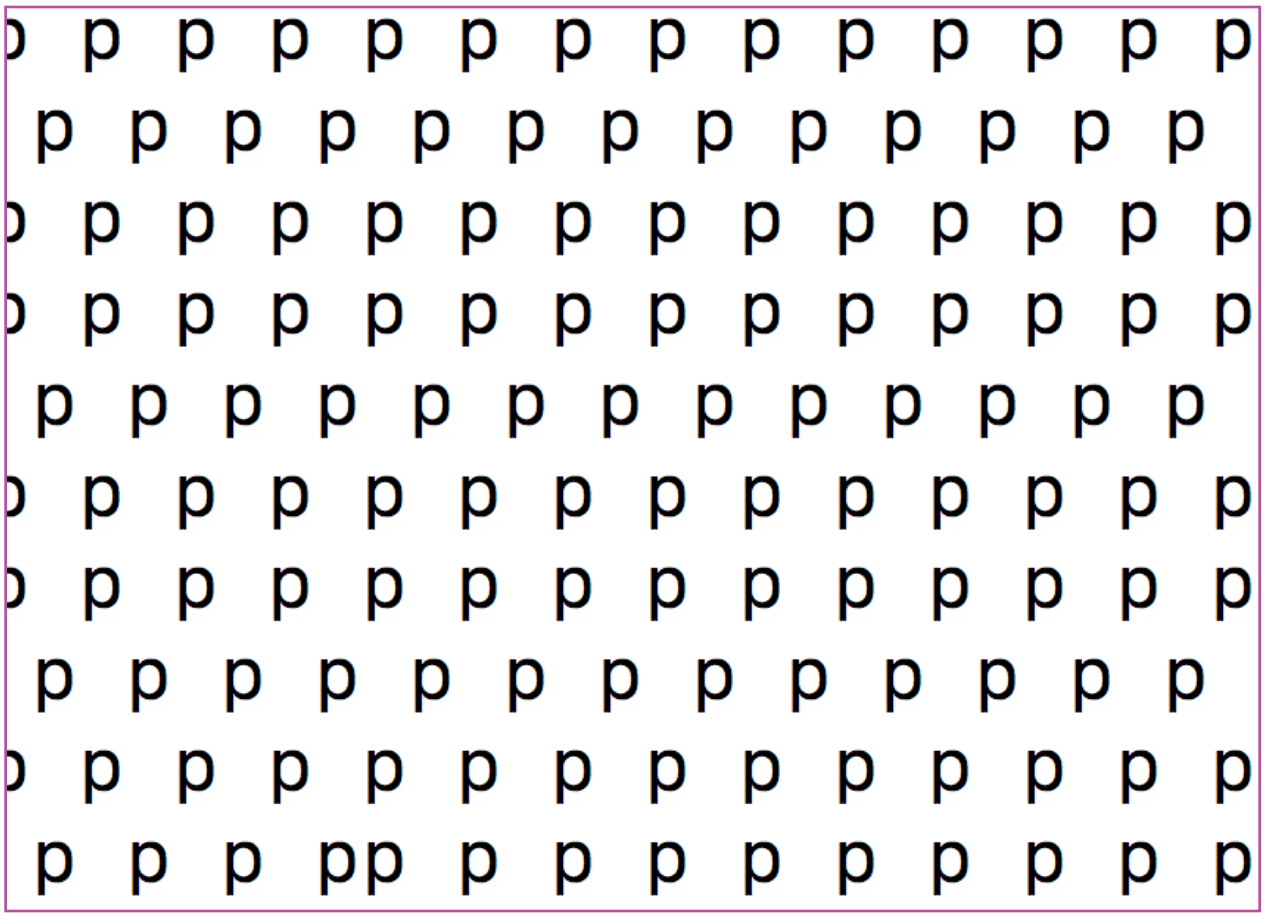
Remote Viewing presents:

The New Pulsar Generator Manual - a sound installation for synthetic voice and computer generated sounds



output of the speech synthesis HMM-model training

composition and core sound synthesis design: Marcin Pietruszewski.
HMM-based speech synthesis system (HTS): Tokyo Institute of Technology, Interdisciplinary Graduate School of Science and Engineering.
program notes: Marcin Pietruszewski with assistance from Eric Laska and Geoff Mullen

Computer Program as an Artefact

At first, the computer program is neutral and exists only in terms devoid of any reference other than to itself. The program is its function. It is a tool. It does something; it instructs a computer to perform a task. Its working is often imperceptible beyond the surface of its interface – screen based or physical - the material extension to the inner depths of its digital structure, the code. Focusing solely on a functional aspect of software limits our engagement with its wider assemblage of connotations beyond technical analysis. Beyond the functional and ostensible neutrality of its interface the software is an artefact, as Matthew Fuller points out: “software creates sensoriums” and participates in constructing “ways of seeing, knowing and doing in the world”. The software both contains a model of a world it ostensibly pertains to and it shapes the world each time it is used. The operative premise of the work ’The New Pulsar Generator Manual’ is a process of systematic engagement with complexities of the computer program as an artefact.

Incorporation of the concept of the artefact to the discourse on the compositional work positions itself against a view which sees technology as merely a tool, neutral and not worth meaningful engagement in thinking about a “true meaning of music”. Such a view can be found in the writing of Denis Smalley, who urged the listener to surrender “the natural desire to uncover the mysteries of electroacoustic sound-making”. According to this view to “ignore the electroacoustic and computer technology used in the music’s making” is a prerequisite to a formal analysis of content and structure of music [Smalley, 1997, p.108]. This echoes the concept of “reduced listening” advocated by Pierre Schaeffer - particularly in its opposition to “causal listening” - and an idealised view that the composer’s tools are no more than a channel for an unmediated and determinate vision. With the notion of “reduced listening,” Shaeffer postulated a kind of radical “presentness” wherein only the object of present perception is attended to, rather than its object-causes or semantic referents. What is left behind, following this intentional sensory bracketing, is what Schaeffer called the “acousmatic”: the content of my perception rather than its cause. The word - itself derived from the Ancient

Greek acousmatikoi — is a reference to the name given to Pythagoras' disciples, who would listen to the master's lectures from behind a curtain. Recent developments in fields of digital media theory [Manovich, 2013; Manovich et al., 2001] and critical software studies [Fuller, 2003; Malina and Cubitt, 2008; Marino, 2006] attempt to look through and beyond this ostensive neutrality by working with the specificities of computer programs at various levels of their articulations, exploring a rich seam of conjunctions within which computation meets with its ostensible outside - users, culture, aesthetics. The challenge is to look beyond the quantifiable systemic complexity and bring the computer program back into visibility so that we can pay attention to what it is (ontology), where it has come from (through media archaeology and genealogy) and also what it is doing (through a form of epistemology), so we can understand this 'dynamic of organised inorganic matter' [Stiegler, 1998, p. 84].
The analysis proposed below has two interrelated aims: first, it is a re-drawing of a complex 'historical ecologies' [Piekut, 2014, p 212] of the pulsar synthesis technique, especially through analysis of the program's underlying synthesis paradigm and key source texts; and second, somehow originating from it, an application of the concept of computer program as an artefact and of methods of archaeology-genealogy-problematisation as a strategy for productive engagement with historically inherited technical objects. Throughout, key themes of this text are computer program as an artefact and compositional practice with historically inherited materials.

Genealogy of the New Pulsar Generator

The technique of pulsar synthesis is a powerful approach to digital sound synthesis named after a highly magnetised rotating neutron star that emits a beam of electromagnetic radiation at a frequency between 0.25 and 642 Hz [1]. Pulsar synthesis melds established principles within a new paradigm. Conceptual origins of the technique can be traced back to historical analog synthesis techniques. In its simplest form, pulsar synthesis generates a stream of electronic pulses and pitched tones akin to those produced by analog instruments

designed around the principle of filtered pulse trains (e.g. Ondioline [2], Hohner ElektroniumHarold Bode [Roads, 1996; Williams, 2016]). Karlheinz Stockhausen has used such technique in his Kontakte (1960). The vocal-like, 'glottal' characteristics of pulsar synthesis timbre can also be linked with earlier experiments in speech synthesis at the Westdeutscher Rundfunk (WDR) in Cologne by Werner Meyer-Eppler, Herbert Eimert and Robert Beyer [Eimert, 1972; Meyer-Eppler, 1949]. Pulsar synthesis, however, is a purely digital technique, and as such it acquires the power of precise programmable control and extensibility. Genealogically the technique belongs to the micro-sound and particle based category of audio synthesis techniques, a wide field of research and practice which has been covered by Roads [1988, 2004]. Aesthetically and conceptually these techniques can be classified as belonging to a larger category of non-standard sound synthesis techniques. The term non-standard has been coined by Stephen R. Holtzman to describe sound synthesis methods that are not based on an acoustical, physical, or psychoacoustic model, but instead utilise an abstract concepts of compositional organisation of sound. According to Holtzman "the non-standard approach, given a set of instructions, relates them one to another in terms of a system which makes no reference to some super-ordinated model". Such "system of relationships" serves as a formal description of sound [Holtzman, 1978, p. 1]. Within the non-standard paradigm "the computer acts as a sound generating instrument sui generis, not imitating mechanical instruments or theoretical acoustic models" [Koenig, 1978, p. 111]. The emergence of nonstandard sound synthesis systems signified an important conceptual and aesthetic shift afforded by the computer and the digital domain. The sound production became a compositional activity allowing for "the composition of timbre, instead of with timbre" [Brun and Brün, 2004, p. 189]. It permitted the ability to think composition beyond a practice concerned with a permutational combinatorics within a closed homogeneous system describable essentially by four properties of pitch, duration, dynamic marking, and instrumental timbre. Arguing from the etymology of the words composition and synthesis, which are synonymous in their respective languages of origin, one may see their difference as one of time

levels rather than of kind. Agostino Di Scipio writes, “synthesis can often be thought of as micro-level composition” [Di Scipio, 1995]. As suggested by Phil Thomson, nonstandard sound-synthesis approaches, in their “impulse towards the atomisation of musical material and control of that material on ever-lower levels,” can be seen as “microsound’s digital beginnings” [Thomson, 2004, p.210].

The basic posture of work with the New Pulsar Generator is a model of absolute compositional control over all parameters of the synthesis process. When working with the program, the user is confronted with a clean slate, a tabula rasa; the system is mute and to generate sound it requires input. The whole aspect of compositional labour – requiring the user to specify objects from the microstructure of sound (*pulsaret* waveform, envelope), its dynamic development in time (tables for fundamental and formant frequency, amplitude and spatialisation path) and to the overall form of the composition (duration, presets) – should be seen as an intentional aesthetic and conceptual stance. Such model refers the Cologne School of Electronic Music centred around WDR and serial techniques developed by composers such as Karlheinz Stockhausen and Gottfried Michael Koenig. In its most radical guise, this approach entails using no material that is “given” from outside. No musical instruments, no recorded samples: Every feature right down to the micro-level is the outcome of a choice. It was with respect to this that Karlheinz Stockhausen wrote of “every sound” as “the result of a compositional act” [Stockhausen, 1963, p.142] and Herbert Eimert et al. [1958] coined a term “absolute composition” through which “real musical control of nature” can be asserted.

At the level of sound microstructure, the user specifies the pulsaret waveform and a shape of the envelope, which together can be thought of as an elemental timbre of the program. At a higher level of organization, the user operates a set of graphs for fundamental and formant frequency, amplitude and spatial position, drawing shapes – lines, curves, and points – on a value (vertical) versus time (horizontal) axis. The underlying design paradigm of the program favores a flexible work between two strands of conceptualization: the inductive – a bottom-up glueing of the elemental into the global – and a deductive – a top-down carving of the whole into smaller parts.

As such the New Pulsar Generator might be described as a system of ‘transparent stratification’ rendering entirely open for a pendular process of differentiation and reintegration of sound materials and forms at all the levels of temporal organisation. Such bi-modal processes problematize the duality between form and material: the same object can be conceived as material or form (substance or container) depending on the level of investigation. Through its graphic parametrisation of synthesis data and systematic approach to composition across multiple temporal levels - an attempt at fusion between micro and macro scales - the program relates to another historical piece of compositional technology - UPIC (Unité Polyagogique Informatique de CEMAMu) by Iannis Xenakis. The instrument operationalized a multiscale approach to sound composition within a standard user interface. An incessant interpolation between temporal resolutions of the micro, meso, and macro scales constituted a vital feature of the vision behind UPIC. Such uniform treatment of composition data and objects at every level mobilized a creative grafting across and between temporal resolutions, a dialectical couplet of local and global perspectives [3].
The following section defines a basic synthesis model of The New Pulsar Generator program.

Fundamental Circuit

A basic circuit of pulsar synthesis consist a pulsaret waveform, envelope and pulsaret train (repetition of pulsars). A single pulsar (Figure 1) consist of an arbitrary pulsaret waveform *w* with a period *d* followed by a silent time interval *s* which renders a total duration of a pulsar as:

$$p = d + s$$

where *p* is the pulsar period, *d* is the duty cycle and *s* is period of silence.

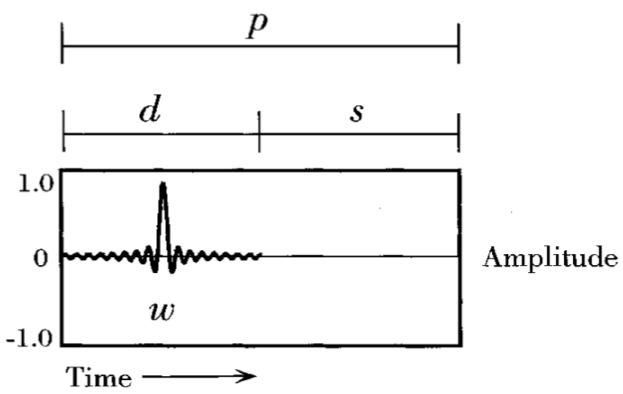


Figure 1. A single pulsar consisting of a pulsaret waveform *w* with a period *d* followed by silent time interval *s*. Source [Roads, 2004].

The repetition of *p* forms a pulsar train (2) which can be described as the rate of pulsar emission with a period of:

$$fp = 1/p$$

and the frequency of the duty cycle as:

$$fd = 1/d$$

Typical ranges of *fp* are between 1 Hz and 5 kHz, the typical range of *fd* is from 80 Hz to 10 kHz. In pulsar synthesis a value of both *fp* and *fd* is independent and can constantly vary.

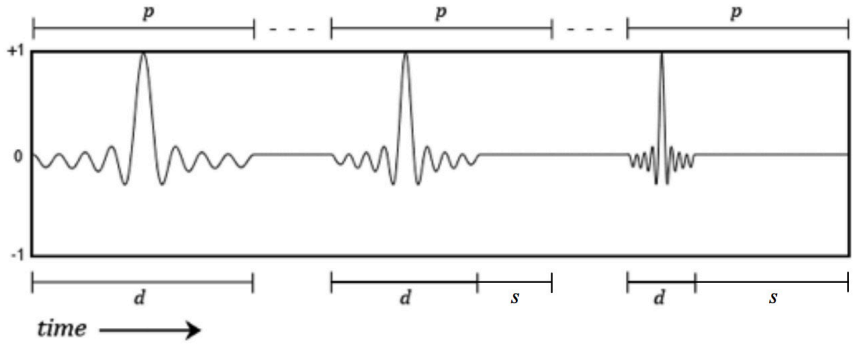


Figure 2. Pulsar train. Source [Roads, 2004].

As Figure 2 displays the d:s ratio varies while p remains constant - in practice, both the rate of pulsar emission and the duty cycle can be simultaneously manipulated according to independent control inputs. This is a special case of pulsar synthesis design. A rate of emission below 18 Hz generates rhythmic pulses. Between 18 and 30 Hz output flutters between discrete and continuous texture. Above about 30 Hz it fuses into an audio tone. The technique operationalises the notion of rhythm with its multi-temporal affordances as a system of interconnected patterns evolving on multiple timescales. The pulsaret waveform w can be of any waveform shape (1.3). In simplest cases pulsaret waveform can be formed by a fixed synthetic type: the sine, saw and square. Complex variants include waveforms generated by time-varying signals or extracted from a sampled sound.

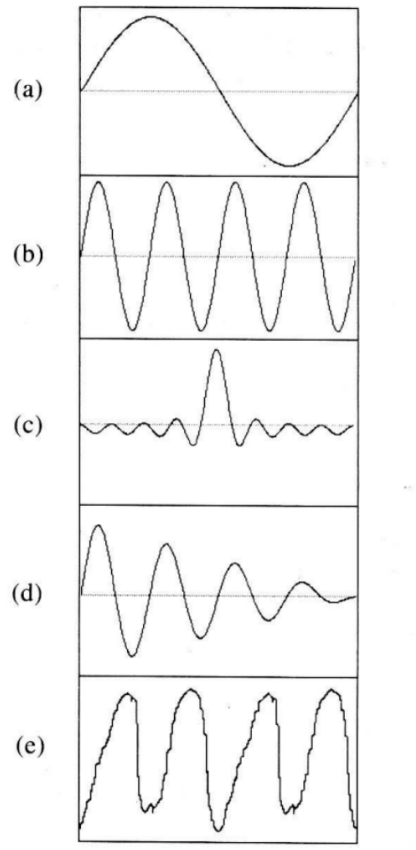


Figure 3. Examples of pulsaret waveforms. In practice any waveform can be used. a) sine; b) multicycle sine; c) gaussian limited sine; d) multicycle sine with exponential decay; e) pulsar rotation path Source: [Roads, 2004].

An essential feature of pulsar synthesis model is the pulsaret envelope. The pulsaret envelope limits in time the pulsaret waveform and can be of any shape (Figure 4). The envelope strongly affects the spectral content of the pulsar stream [Roads, 2004, p. 146]. A rectangular envelope (Figure 4(a)) produces a broad spectrum with strong peaks and nulls for any pulsaret. An envelope with a sharp attack and an exponential decay depicts a well-established formant synthesis configuration corresponding to FOF and Vosim techniques. An important generalisation in above synthesis model is that the waveform w and envelope v can be of any shape. This consist a special case of pulsar synthesis.

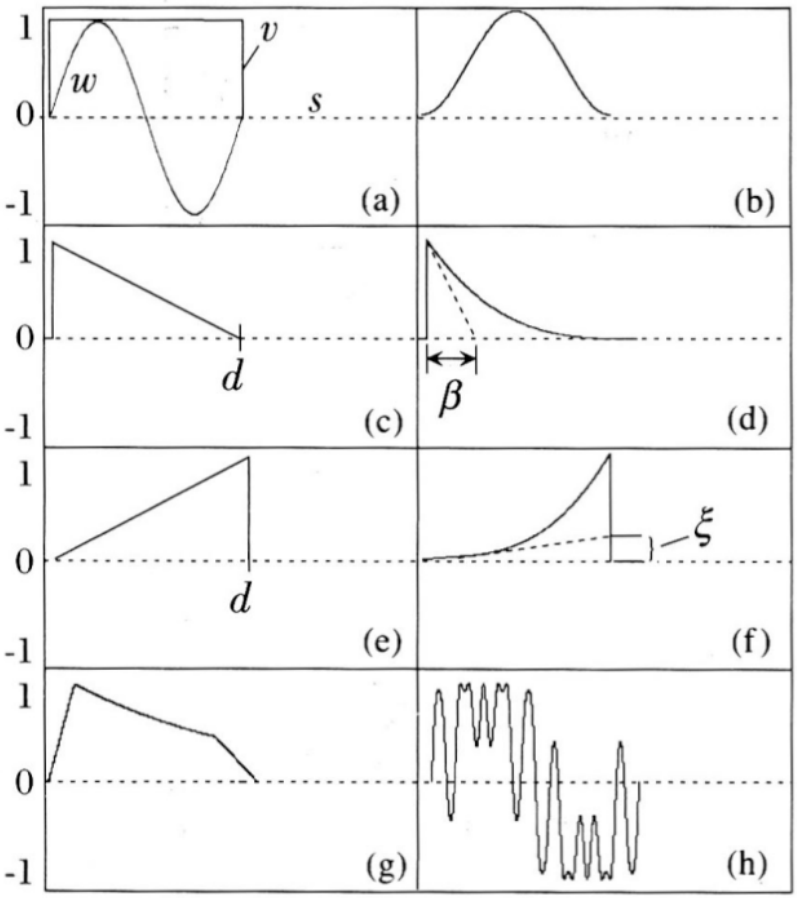


Figure 4. A standard catalogue of pulsar envelopes: a) rectangular; b) gaussian; c) linear decay; d) exponential decay; e) linear attack with duty cycle *d*; f) exponential attack; g) FOF envelope; h) bipolar modulator. Source: [Roads, 2004].

The Artefact

Subrata Dasgupta defines the artefact as “a useful thing that is produced or consciously conceived in response to some practical need, want or desire” [Dasgupta, 1996, p. 9]. The artefact is “a thing” not “an object” [4]. This choice of terminology is deliberate. The “thing” signifies the indeterminate, not yet crystallised status of the object, its not-yetknown constitution. It is an invitation to discover, explore, and sense, to get to know what future this “thing” enhances. To consider the “thingness” of the computer program is to unpack its constituent complexity, to traverse a network of discourses activated through its working. From this perspective, the artefact case to be fixed and stable. Instead, it tends towards a mobile and unstable. In short, it moves from the one to the many. Fernando Zalamea observed this process in the context of the object of new mathematics: “Determinate ’entities’, firmly situated in one absolute, hard and fast universe, do not exist; instead we have complex signic webs interlaced with one another in various relative, plastic and fluid universes” [Zalamea, 2019, p. 272]. Such a perspective immediately resonates with a mode operative within creative practice with its exploration of “boundary objects” [Borgdorff, 2012, p. 177] and entities whose ontological and epistemological nature depends on the context in which they appear. The New Pulsar Generator program, as with any other piece of human-made technology, does not function in a vacuum. As Anne Sauvagnargues [2016] points out:

> A tool or a machine should not be studied in isolation without taking into consideration the milieu of individuation that surrounds it and allows it to function. No machine or technical tool exists by itself ... they only function in an assembled milieu of individuation, which constitutes their conditions of possibility: there is no hammer without a nail, and thus the interaction between a multitude of technical objects makes the fabrication of hammers and nails possible, while also forming the conditions of their utilisation and the practices and habits associated with them [Sauvagnargues, 2016, p. 186]

Artefacts are complex conglomerates of things and composition of “components, which are continuously rearranged and reassembled in their specific modes of appearance throughout history” [de Assis, 2018, p. 107]. Artefacts are “like organisms, they manifest evolution” [Dasgupta, 1996, p. 114]. Any artefact is surrounded by the knowledge that is prior to its emergence and also by the knowledge that appears only after the artefact was made. The moment of “doing” or design of the artefact is itself a knowledge-rich, cognitive process. Furthermore, artefacts themselves are also knowledge - their design embodies and encapsulates many operational principles. To find a way of accounting for, understanding, and crucially, working with this multiscalar thing is an important challenge requiring new tools for thought, and ways of holding different kinds of account together. In approaching this topic, Dasgupta formulated a concept of systemic complexity. Referencing Herbert Simon’s work “The Architecture of Complexity” [Simon, 1991], Dasgupta argues that “a system ... is said to be complex if it is composed of a large number of parts or components that interact in nontrivial ways” [Dasgupta, 1996, p. 113]. Systemic complexity has a purely quantitative character, it grasps what the artefact is, but it does not tell us how the artefact assumed its form, nor does it give any clues about what it might produce in the future. A key notion of Dasgupta’s reflection on artefacts is that beyond systemic complexity there is another kind of complexity within human-made things - “the richness of the knowledge that is embedded in an artefact” called “epistemic complexity” and which “consist of the knowledge that both contributes to, and is generated by, the creation of an artefact” [Dasgupta, 1996, p. 116]. It is both formation of the artefact and process of being informed by its working. These complex objects with their myriad of references can be viewed as assemblages. To assemble some thing is to fit together the separate component parts of it. The concept of assemblage captures “the function of synthesis of disparate elements” [Alliez and Goffey, 2011, p. 11] and it is a useful tool that explains the mutations, transformations, and re-configurations of complex systems. With its interplay between structure and contingency, organisation and chance, the assemblage “can be seen as a relay concept, linking the problematic of structure with that of

change and far-from-equilibrium systems” [Venn, 2006, p. 107]. What is currently being referred to as assemblage theory (see Buchanan [2015]; De Landa [2010]; DeLanda [2016, 2019]) is a composition of diverse approaches in the human and social sciences with a more or less explicit link to foundational work of Gilles Deleuze and Félix Guattari on the concept of agencement [5].

The immediate territory outlined by the work on and with the New Pulsar Generator can be viewed as an assemblage which displays two types of complexity. On the systemic level, there is the computer program - packaged as a standalone application with its graphic interface consisting of sliders, buttons, knobs, data plots, etc. All of these can be considered as the surface - a visible,material extension to the inner depth of the computer program - the source code [6]. The source code, the textual form of the programming language, represents another kind of complexity. It is a textual layer with its syntax, objects of the programming language with unique attributes and behaviours, classes of objects with methods establishing the logic of interaction between them [7]. Crucially, the New Pulsar Generator program has an observable, perceptual dimension - it sounds. The sounding extends the site of exploration further to incorporate the study of mapping between the representation of data and acoustic properties of the program’s output. The program produces a unique set of sounds; interfacing a particular sound synthesis model (i.e., pulsar synthesis) it parametrises the audible. As pointed by Matthew Fuller, beyond the realm of the functional, the computer program creates sensoriums and participates in constructing “ways of seeing, knowing and doing in the world” [Fuller, 2003, p. 19][8]. “Computers and software are not just technology but rather the new medium in which we can think and imagine differently” [Manovich, 2013, p. 13].

An engagement with particular qualities and propensities of the New Pulsar Generator program as a humanmade artefact permits to look beyond its immediate form - as packaged functionality, the application with an interface and a set of fixed interaction points - and explore different types of knowledge, design, and aesthetic concepts activated via systematic experience of its operation.In this context, the concept of archaeology as proposed by Michel Foucault, becomes a helpful

methodological tool. As Clare O'Farrell describes, "Archaeology is the term Foucault used during the 1960s to describe his approach to writing history. Archaeology is about examining the discursive traces left by the past to write a 'history of the present'. In other words archaelogy is about looking at history as a way of understanding the processes that have led to what we are today" [O'Farrell, 2005]. In this sense, archaeology, is a perspective of looking at the past from the present, with the aim of better situating/understanding the present. Archaeology sketches out a boomerang-like route: from the present to the past, and back from the past to the present. It does not aim at disclosing "how things were" but rather "why things are what they are" now. Archaeology as defined by Foucault:

> Archaeology does not try to restore what has been thought, wished, aimed at, experienced, desired by men in the very moment at which they expressed it in discourse... it does not try to repeat what has been said by reaching it in its very identity. It does not claim to efface itself in the ambiguous modesty of reading that would bring back, in all its purity, the distant, precarious, almost effaced light of the origin. It is nothing more than a rewriting: that is, in the preserved form of exteriority, a regulated transformation of what has already been written. It is not a return to the innermost secret of theorigin: it is the systematic description of a discourse-object [Foucault, 2013a, p. 139-40]

In the context of a discussion on the New Pulsar Generator program as an artefact, archaeology consists of selection and isolation of singularities - identifying sources and retrieving them for further work as models. The term "model" covers a vast array of meanings, running the gamut from the model as an ideal to artists' models. "Model theory" in logic is the study, at a very abstract level, of structures of "objects" and their "relations." These objects may be concrete physical objects — the chairs in my office — or, more frequently, abstract objects—the natural numbers. In biology, individual living organisms, specially bred mice, for example, are called "models". Within the study of science and technology, the term "model" has

a wide variety of meanings, many of which — the majority perhaps — are not material but conceptual Hesse [1965]. These isolated sources then become subject to analysis and comparative research. Appropriate design solutions, innovations and transmissions of ideas over time are studied in terms of genealogy. This stage calls for a hermeneutic approach, where both the surface (interface) and depth (source code) of the program are interpreted and compared. Genealogy draws lines of reference between the artefact and other fields of thought and practice.

Crucial in this context is the act of problematisation. Problematisation happens by constructing new and experimental arrangements based on sources and models identified and explored in the first two phases. The artefact as “discoursive-object” is not to be merely described but needs to be productively engaged with and re-situated. Michel Foucault has called such process problematization.

> Problematisation doesn’t mean the representation of a pre-existent object, nor the creation through a discourse of an object that doesn’t exist. It is the totality of discursive or non-discursive practices that introduces something into the play of the true and false and constitutes it as an object for thought [Foucault, 2013b, p. 257]

While the labour of archaeology and genealogy mediates what things are, problematisation searches for new modes of productively exposing them. Modes that, as well as retrospectively facing into the past, orients us to the future and creatively project things anew.

Notes

[1]. Pulsars are phenomenal objects: rapidly rotating neutron stars that send out beams of radio waves which, like lighthouse beams, sweep around the sky as the star rotates. They are amazingly precise timing devices that can be used as clocks for testing relativity theory and may be used for timekeeping and navigation. With a diameter of only about 15 kilometres and a density comparable to that

of the nucleus of an atom, they also provide a laboratory for some extreme physics. Pulsars appear to ‘pulse’ since the beam of light they emit can only be seen when it faces the Earth. The discovery of pulsars by Jocelyn Bell Burnell is considered to be one of the greatest astronomical discoveries of the twentieth century. See Burnell [1984]. These conceptual origins of the technique found its way back as a productive means in the field of sonification which in a broad sense is concerned with auditory representation of data Hermann et al. [2011]. In 2009, the composer Marcus Schmickler together with the programmer Alberto de Campo and astronomers Dr. Michael Geffert (Bonn University’s Argelander Institute for Astronomy) and Dr. Kerstin Jaunich (Deutscher Musikrat) worked on a set of astrophysical data sonification pieces. Among them was one devoted to astrophysical pulsars. See http://piethopraxis.org/projects/bonner-durchmusterung/

[2] See the demonstration of Ondioline by its inventor Georges Jenny https://www.youtube.com/watch?v=hy5w7Fz0pDo

[3] An in-depth analysis of correlation between UPIC system and pulsar synthesis is a subject of an article I have written for a forthcoming publication by the Center for Art and Media Karlsruhe (ZKM) and the Centre Iannis Xenakis (CIX)

[4] The origins of the conceptualisation of “thing” can be traced back to George Kubler’s “The Shape of Time: Remarks on the History of Things” [1962]

[5] As an important side note, it is worth mentioning somehow problematic English translation of French word agencement as assemblage. Such translation problem has been highlighted by Eric Alliez and Andrew Goffrey: “although the French agencement is something that might be said of the way in which elements on the page of a magazine are put together, of a palette of colours or of the arrangement of furniture in a room, in the use that Deleuze and Guattari make of it, it also conveys an active sense of agency as being what some or other entity does, a precious indicator of the constructivist horizon within which it operates. The term ’assemblage’ does not really convey this crucial nuance of agency, even while it does capture the function of synthesis of disparate elements rather well” [Alliez and Goffey, 2011, p. 10-11]. Thomas Nail [2017] and Manuel DeLanda [2016] point out,

etymological origins of both words span out of completely different roots. While the French agencment comes from the verb agencer - to arrange, to lay out, to piece together, the English assemblage comes from French assemblage, which in both languages means joining of two or more things, pointing to a resulting product rather than the process itself

[6] Hans Dieter Huber proposed a notion that code is a deep structure that instantiates a surface of the program, see: http://www.hgb-leipzig.de/ARTNINE/huber/writings/jodie/indexe.html. The relationship between the deep and surface structure of the computer program is paradigmatic in the design of and practice with The New Pulsar Generator

[7] The systemic complexity - the artefact's whatness - can be seen as the neutral layer which exists only in terms devoid of any reference other than itself. This view corresponds to Andrew Feenberg's "instrumental theory" of technology as described in Feenberg [2002]. Within the instrumental theory paradigm," technologies are tools ready to serve the purpose of their users. Technology is perceived as a neutral - without valuative content of its own "[Feenberg, 2002, p. 6]

[8] The code and output can be considered in a generative relation, as in the Whitney Artport CODEDoc exhibition. since each "enter project" button was located at the end of the different programs, viewers had at a bare minimum to pass their eyes over the artists' code as they scrolled to the bottom to reach the link to the visual display . Viewers were thus prompted to consider where they located cultural , artistic, and institutional value: with the code (instruction sets for translating a message from one symbolic form to another), execution (machinic process), or output (object). See: https://www.whitney.org/exhibitions/codedoc. CODeDOC show was curated by Christiane Paul (September 2002). A related text "The Fine Art of Appropriation" (UCSB, 1997) by Robert Nideffer's, which met university requirements for a printed and bound MFA thesis by submitting the HTML code used to produce his visual artwork and therein posing compelling questions about code as both mechanism and object of knowledge

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Biographical Note

Marcin Pietruszewski (born 1984) a composer and researcher.He is engaged in sound synthesis and composition with computers, exploring specific formal developments in the tradition of electroacoustic music and contemporary sound art, as well as extra-musical domains of auditory design, computational linguistics and psychoacoustics. He works across performance, multimedia installation and radio productions probing the dynamics between the formalism of synthetic sound and its material realisations.

He has collaborated extensively with musicians and composers - e.g. , Marcus Schmickler (performed and recorded Schmickler's Demos for choir , chamber quintet and electronics), Tristan Clutterbuck (fancyyyyy) , Jules Rawlinson and Lauren Sarah Hayes. Recent projects include a collaboration with Florian Hecker and a graphic design company NORM from Zurich.

He has presented his works at various venues and festivals around the world, including: CTM/Transmediale, Berghain, the Institute of Contemporary Arts (ICA) in London, the Irish Museum of Modern Art (IMMA) in Dublin, MUMUTH in Graz, Klangkupolen (KMH) in Stockholm , the Center for Arts and Media (ZKM) Karlsruhe.

He is active as a lecturer of computer music and creative coding practice at the Reid School of Music (Edinburgh College of Arts , Edinburgh University). He also writes about topics of computer music history, aesthetics and philosophy.

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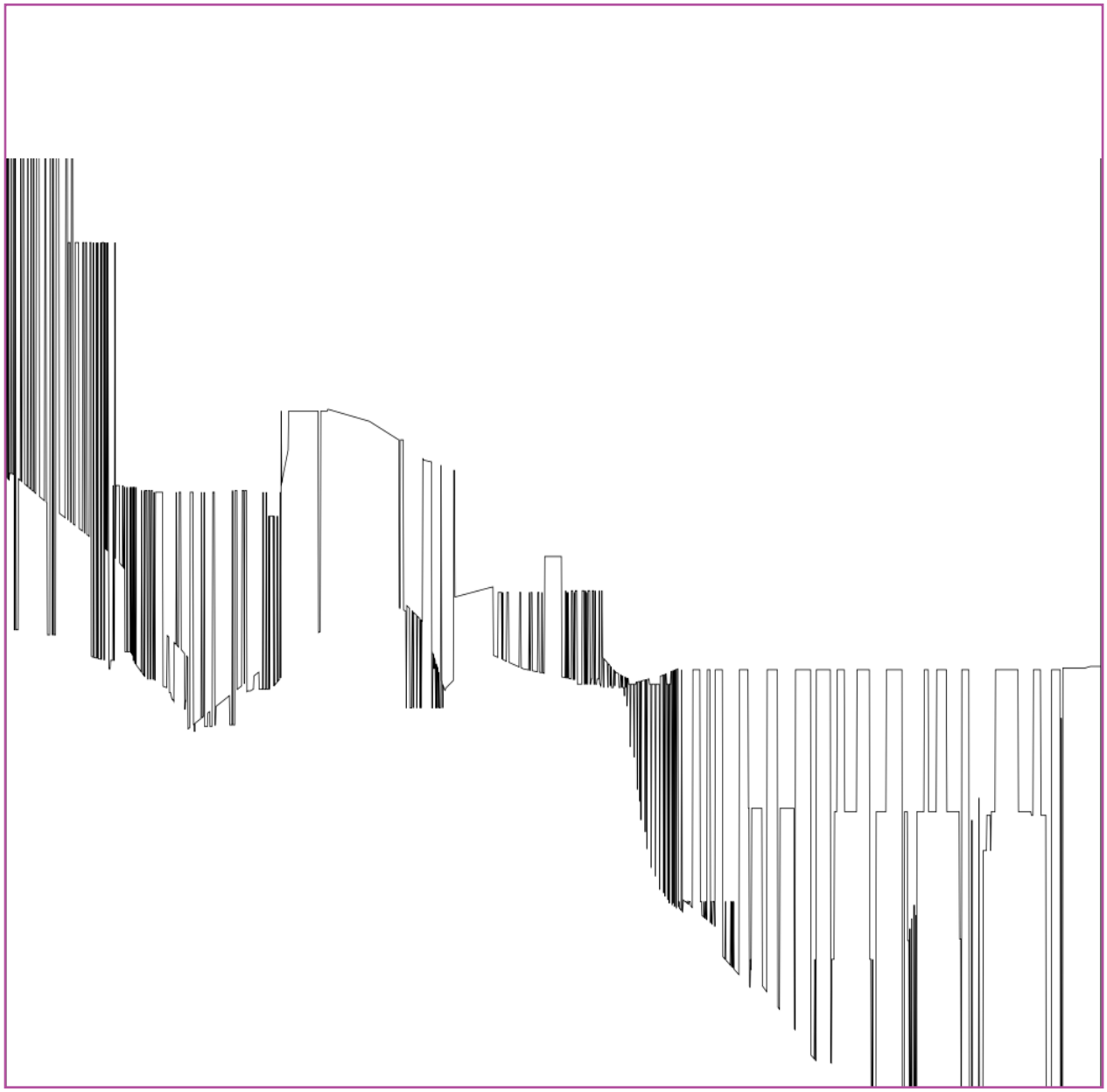
Acknowledgments

The artist would like to thank Remote Viewing (Eric Laska and Geoff Mullen) for the invitation to present 'The New Pulsar Generator Manual'. Curtis Roads and Florian Hecker for technical and conceptual advice on the New Pulsar Generator program. The staff at the Center for Speech Technology Research (CSTR) at Edinburgh University for advice on building the synthetic voice model. Alicja Pawluczuk for love and care. Andrew Johnston for ongoing support and encouragement.



a single pulsaret waveform from the New Pulsar Generator editor