PLASTICITY: NOISE, CORRELATION AND INTERACTION

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Abstract

This paper introduces the interactive and performative installation artwork, Plasticity (Jane Grant, John Matthias, Nick Ryan and Kin) and its software engine the Neurogranular Sampler via a journey through the synchronized pendulum clocks of Christian Huygens, entrainment in dynamical systems, and correlations and noise within neuronal networks. I examine ways in which the public are 'playing with noise' in the artwork and suggest that the public engagement with the work is closely connected to the fact that the dynamics of the artificial neuronal network lie at the borders between synchrony and randomness.

Keywords: installation Art, Performativity, Neuronal Networks, Plasticity, The Fragmented Orchestra, Dynamical Systems, Noise, Synchronisation.

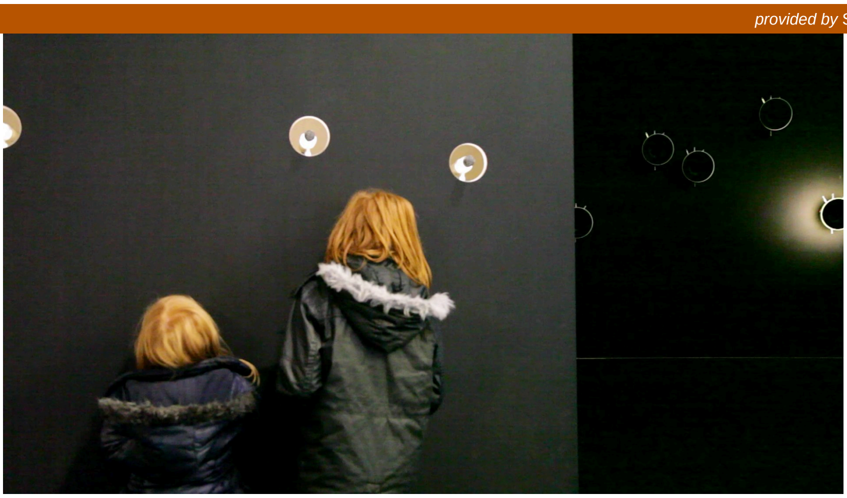

Fig 1. Visitors to 'Plasticity' at the onedotzero 'Adventures in Motion' Festival make sounds into the microphones which are re-triggered by the firings of an artificial neuronal network accompanied by flashing LED lights at firing events in the adjacent gallery space. © Jane Grant, John Matthias, Nick Ryan and Kin. Image by Avril O'Neil.

Introduction

In the artwork, *Plasticity* (Jane Grant, John Matthias, Nick Ryan and Kin), visitors to a gallery installation space are invited explicitly to 'perform'. That is, they are invited to participate in the work by making noises into several microphones installed into a wall in the gallery. Following this noisemaking, lights light up around the microphone, which is followed by the lighting up of LED ribbon around various loud speakers a few metres away accompanied by fragments of the noisemaking, now disembodied from the noise-maker and scattered across the speakers. These fragments of sounds and light, the viewer/listener/noisemaker is told, are triggered by the firing of artificial spiking neurons which exist in the computer behind the wall; the rhythms of the sounds and the patterns of light are artificial neural reconfigurations of the original human-made sounds.

When *Plasticity* was installed in the BFI Southbank as part of the onedotzero 'Adventures in Motion' Festival, London in November 2011, hundreds of people delighted in interacting with the work (you can see a documentary video of it here [9]). After being questioned by the artists, many members of the public typically said that they didn't really know what was happening, but that it was 'cool' and also that there was a certain fascination with the fact that there was a kind of 'brain' within the computer. There was also something else at play here. Members of the public continued to 'play' the instrument. The sounds and lights coming back from the instrument are not randomly generated, but consist of rhythmic patterns generated by the interactions between the artificial neurons in the software. There is a fascination in playing with these rhythms, the rhythms at the borders between randomness and synchrony, especially when the sources of the sounds are made by the public themselves. In this paper I will begin to explore the reasons behind this fascination, beginning by discussing Christian Huygens, continuing with an explanation of ideas of noise and correlation, and ending with a brief description of Polychronisation in Neuronal networks.

Synchronisation

In 1654, whilst in bed with influenza, the Dutch physicist Christian Huygens discovered that the two pendulum clocks fixed to a common support onto his bedroom wall would synchronize into an exact contrary motion after a short period of time, no matter what the initial phases (positions) were within the clock's oscillatory cycle. This phenomenon, now known as 'synchronisation' or 'entrainment,' wasn't fully understood until the late twentieth century [1] but has now become one of the fundamental principles within our understanding of dynamical systems (things that interact and move). Furthermore, many natural systems exhibit this phenomenon, including the synchronous flashing of fireflies and the circadian rhythms of animals [2]. If we begin with a number of completely independent (that is, uncoupled) oscillators which start at randomly chosen initial phases, then these oscillators will continue without changing their cycles. However if there is an interaction between the oscillators, no matter how small, then entrainment is likely to occur. Huygens' pendulums, for example, were sending vibrations to each other continuously through a common wooden support –if the two pendula had been fixed to opposite walls, then there would have been no coupling.

If we take one pendulum and measure its position from the starting point as it moves and plot that position against time on a graph, then the plot would look like a sine wave. An alternative way of representing an oscillator is within a description called 'frequency space,' for which the frequencies of a collection of oscillations are plotted on a Cartesian *x*-axis with their contribution to the whole signal plotted on the *y*-axis. For a single pendulum, this representation would look like a single spike at the frequency of oscillation; a frequency which is determined by the weight and length of the pendulum.

If we measured the positions of a collection of many uncoupled pendula and added all the positions together to make a combined signal, the signal would look very noisy (it would fluctuate a lot) as it would be made from an addition of oscillators with randomly connected phases. A random signal (for which there is no temporal correlation between one moment and any other) is represented in frequency space as 'white noise' in which all frequencies of the signal contribute an equal part. A graph of the power of the contribution of frequency, or amplitude, against frequency therefore looks like a flat horizontal line for a white noise signal.

If we watched the change in this frequency space description for a group of identical coupled pendula, from initial

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random starting points evolving to an entrained 'pulse', then we would see a gradual change from a horizontal line to a single spike. The speed of the change depends upon the strength of the coupling. It is possible to witness (and listen to) the phenomenon of the entrainment of several mechanical oscillators using several identical mechanical musical metronomes, a plank of wood and two drinks cans [3]. If the metronomes are put on a table and started at arbitrary phases, and then placed on a piece of wood which is balancing on the two drinks cans, then the metronomes very quickly change their phases (but not their frequencies) to beat together. When one listens to the rhythms caused by the metronomes' beaters, one hears a transition from a set of almost random clicks to a (nearly) single pulse. The two extremes of this situation are not particularly interesting –our brains quickly stop listening to and 'filter out' random signals, however there is an enormous temporal range of rhythmic activity between these two temporal extremes mediated by interaction between all kinds of oscillators; natural and otherwise.

Self-Organised Criticality

In the examples above, the interactions act as a dynamic filter to gradually change the random signal into a correlated one. Turning on an interaction, even a tiny one, changes the temporal dynamics radically. Here we make a connection with many theories of the interdependent roles of correlation, noise and interaction in physical interacting systems [1]. The theory of self-organized criticality [4], in which a toy computer sand-pile model is perturbed by dropping virtual sand grains at randomly chosen positions and times, is one such example. The grains of sand in Bak, Tang and Wiesenfeld's computer model are allowed to fall onto a flat regular lattice 'surface', landing either onto a vacant lattice point or onto a lattice point already occupied by a 'grain'. The only rule in the simulation is that if the relative size of adjacent towers of grains becomes larger than three (say) then the next grain that lands onto that tower has to topple onto any one of the nearest-neighbour lattice points. This leads to a simple dynamic of growth and avalanche in which the system quickly becomes stable at a point at which all of the 'hills' of sand are at their critical angle to form the next avalanche. Moreover, Bak, Tang and Wiesenfeld measure the number of grains per second (or grain current) which topple over the edges of the digital surface. This signal is not a random signal but is 'coloured' by the correlations that have been imprinted from the very simple dynamical rules in the toy model.

When we analyse the power contribution of the frequencies in the grain current signal (which indicates when the sand grains are falling off the digital surface) we find that we do not get a white noise signal. The resulting graph has a functional form which falls as 'one over the frequency'; a ubiquitous natural form of noise called 'One over *f*' or 'Flicker' noise. This process of introducing functional form into the power spectra of noisy signals is often referred to as 'colouration', and is used in engineering as a method of probing the dynamics (and interactions) of physical systems. The noisy signals in coloured noisy patterns which have this kind of form (often referred to as 'power law') have a scale symmetric structure, which means that patterns in the signal are repeated over many length scales in a kind of fractal symmetry and for this reason are also often referred to as 'fractal noise'. Such noise patterns are found within many diverse natural systems including fluctuations in the luminosity of stars and the fluctuation of cars travelling in highway traffic [5]. It is important to realize that the motivation of Bak, Tang and Wiesenfeld's work was not to study the physics of sand-piles, but rather to examine universalities of the physical laws of the dynamics of driven interacting complex systems.

Plasticity

Noise is ubiquitous and indeed necessary in biological neuronal systems and in many theories and experiments is interpreted as a driving force to keep these natural systems 'buoyant'[17], enabling them to explore many energetically possible dynamical states rather than being confined to single solutions [16]. Neuronal systems are also susceptible to entrainment but typically lie within the interesting dynamical area between randomness and correlation [6]. In the example of the interacting penudula, the interaction is a continuous one. The pendulum clocks on Christian Huygen's wall were continuously interacting through the support on the wall. The interaction within Neuronal networks is not continuous but is referred to as 'pulse coupled'. Each neuron interacts with the others by sending spike signals (a temporal pulse of around a millisecond) along long tubes called 'axons' to connect with the other neurons at a junction called a 'synapse'. The spiking rhythms of the cortical neurons contain all of the information carried between connected cortical neurons in our brains.

As illustrated in *Plasticity*, we exploit a musicality of these spiking rhythms and the fact that they generally lie within a rich temporal dynamic domain in many of our installations and musical works in which recorded and live sounds are controlled and re-triggered by an artificial spiking neuronal network [7, 8, 9, 10]. Neuronal systems are noisy, and this noisiness is exploited in many spiking neuronal models such as the biologically plausible cortical model, the Izhikevich model [10] which drives the neurons with an external noisy current assumed to be representative of a signal from the thalamus. The interactions between the neurons act as a dynamic filter to introduce many correlations in the signal in a similar way to the much simpler digital sandpile described earlier. Our interactive sound installation, *Plasticity* [9], drives many Izhikevich neurons with a noisy signal but also with the participative sounds made by visitors to the Gallery through a number of microphones. Visitors play with the noise. The output sounds become correlated by the correlations within the initial sounds made by the noisemaker and also by the interactions between the neurons in the software which affect the relative timing of the firing events which cause the re-triggering of the sound. Clearly a statistical frequency space description of the output sound signal in a work such as *Plasticity* would be an inadequate way of describing the work from an experiential point of view. What the public performing the work find interesting are the individual rhythms generated in the software which produce unpredictable (though not randomly generated) phrases which last a few seconds, mixed with the rhythms and timbres of the sounds made by the participants over smaller durations, which are captured in the fragments of sound. The *Plasticity* installation is partly driven by a multichannel version of an audio unit which we have developed called *The Neurogranular Sampler* [10]. In this software, an artificial Izhikevich neuronal network takes grains of sound from live sound input and retriggers them upon neuronal firing events, which are controlled by the parameters on the instrument's interface within a single computer. The firing patterns output form the software are the rhythms of

‘Polychronisation’ [11], in which the imaginary and the memorial are linked with sensory perception and the dynamics of the spiking neurons.

Polychronisation

The idea of polychronisation follows from Izhikevich’s [12] two-dimensional reduction of the Hodgkin-Huxley electrical model of a neuron [13], which has the voltage on the neural cellular membrane as the main physical variable. In a network of artificial Izhikevich neurons, a spike signal is sent from a neuron along an axon to the synapses of all its connected neighbours when the voltage on its membrane reaches a certain threshold voltage. On reaching the neighbours, these spikes transfer a voltage commensurate with the strength of the synaptic coupling at the post-synaptic neurons. The strengths of the synaptic couplings are not fixed, but change according to a process that has become known as ‘Spike-Timing Dependent Plasticity’ or SDTP [14]. In STDP, the strength of the coupling is increased in the case of causal spiking (one spike precedes another) and depressed in the reverse case, mediated with an exponential temporal functional form. The phenomenon of Polychronisation follows as a result of the interplay between the STDP and the introduction of axonal delays into an artificial neuronal network. An axonal delay is simply the transit time of a spike from the neural cell body to the synapse of a connected neuron. Crucially this introduces the spatial into the calculation of the neurodynamics, an element surprisingly neglected until very recently in computational neuroscience. When a neuron in an artificial Izhikevich cortex is regularly stimulated to fire by either a sensory signal or by a spike signal from another connected neuron, it sends spikes to connected neurons which become reinforced through the process of STDP –a kind of Hebbian learning [15]. In this way subgroups of neurons become Polychronised (firing together in a group but not at the same time) and it is the pattern of the firing sub-group which represents the signal pattern for the initial stimulation. Izhikevich’s idea introduces ‘simple memory’ into this scenario by suggesting that the re-firing of the polychronised group of neurons evokes the original stimulus within our imagination.

In the work *Plasticity* and within the *Neurogranular Sampler,* it is the polychronised rhythms which scatter across the speakers in the gallery and from the instrument respectively, and the changing of the neural circuitry becomes a method to change the out-coming sonic rhythms. If one takes a set of identical artificial neurons and removes any synaptic plasticity within the model, the spikes rapidly entrain in a similar manner to the connected metronomes or Pendulum clocks which Huygens noticed. That is, the spikes all occur at very similar times across the network (rather like a spasm or seizure) and this is perceived as a pulse within the context of the sonic artworks if the duration of the live sounds triggered by the firing times is small. It is interesting to note that if we change the neural circuitry by introducing synaptic plasticity (such as Spike-Timing Dependent Plasticity STDP, for example) into this pulse-like behavior, the result is to de-correlate the activity [6]. We can therefore introduce synaptic plasticity as a control mechanism, a method of changing the dynamic activity within the network, which in turn controls the temporal dynamics of the sonic output.

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