

The Fragmented Orchestra

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Abstract

The Fragmented Orchestra is a distributed musical instrument which combines live audio streams from geographically disparate sites, and granulates each according to the spike timings of an artificial spiking neural network. This paper introduces the work, outlining its historical context, technical architecture, neuronal model and network infrastructure, making specific reference to modes of interaction with the public.

Keywords: distributed, installation, sound, neural network, streaming audio, emergent, environmental.

1. Introduction

The Fragmented Orchestra is a huge, distributed musical instrument, modelled on the firing of the human brain's neurons. This collaborative work, spanning music, art and science, has evolved from its creators' fascination with the inherent rhythms and adaptive learning of spiking neurons. The piece is made up of one central space (installed, at the time of writing, in Liverpool's FACT gallery) and 24 geographically disparate sites across the UK, acting as the neurons of a distributed virtual cortex.

Each of the sites has a "soundbox" unit installed, containing a microphone, a speaker and a computer. This streams live audio via the internet to the central installation; whenever an audio threshold is reached, the neuron corresponding to the site 'fires', causing a fragment of human-made or elemental sound to be broadcast through the gallery. The combined sound of the 24 speakers at the gallery is continuously transmitted back to each of the 24 sites.

As well as triggering a grain of sound, each firing event is simultaneously communicated to the rest of the cortex. Using a 2-dimensional spiking neuronal model [1], correla-



Figure 1. Photograph of the installation

tions in sound activity at the sites cause relationships to develop between connected neurons. The system "learns" over time how to respond to new patterns of sonic stimuli, resulting in co-ordinated cascades and and crescendos of sound.

The geographical sites were selected for their sonic qualities, with the intention of building up a portrait of the UK's varied soundscapes. These range from inner city traffic, chanting from sports stadia, the hubbub of cattle auctions, and the chatter of migrating birds, combined with incidental and performed sounds from members of the public at concert venues such as Gloucester Cathedral and Belfast's Sonic Arts Research Centre. The public, invited to play the instrument at the 24 sites, can hear the effect their playing has on the overall composition of the piece at each site and at FACT. As members of the public use the instrument, they become both player and audience of a vast and evolving musical composition extended across the UK.

This paper outlines and assesses a number of key aspects of The Fragmented Orchestra. Section 2 situates the project in its artistic and historical context; Section 3 describes the neuronal network at the core of the piece; Section 4 covers the architecture of the server that hosts the neuronal network and connects it to each of the broadcast sites; Section 5 outlines the network and communications infrastructure that hosts these sites, and the possibilities for interaction at the sites themselves; Section 6 describes the web in-

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NIME09, June 3-6, 2009, Pittsburgh, PA
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terface, which provides live access to the piece for a global audience; and Section 7 assesses the outcome of the piece and suggests directions for future work. Finally, Section 8 briefly summarises the ancestry of the project.

2. Historical Context

The Fragmented Orchestra can be partially situated in a broad heritage of nondeterministic, environmental sound works, which draw upon the unpredictable nature of their surroundings to introduce an element of chance. From the Aeolian harp to Max Eastley's sound sculptures, through Alvin Lucier's explorations of acoustic phenomena, the surrounding world frequently proves a ripe source of new auditory experiences. Alan Licht provides an excellent overview of music and the environment in *Sound Art*, in which he asserts that, fundamentally, "sound art comes from the appreciation of the total environment of sounds, both wanted and unwanted" [2, p116].

Licht also discusses the post-Futurist movement of urban soundscapes into the concert hall. Equivalently, we consider the piece as opening a set of conduits from the outside world into the gallery, through which atmospheric sound can flow. In doing so, it is dislocated from its context and subjected to a new kind of listening; rather than being filtered out as noise, short fragments of elemental sound (street noise, café chatter, the buzzing of an unattended fridge) are transformed into objects of attention in their own right. This immediate use of soundscape brings to mind the elemental works of John Cage, particularly *Variations VII* (1966), which utilised telephone lines as a new source of hidden sonic activity.

However, The Fragmented Orchestra consciously seeks to develop a relationship with the participants: the human players of the instrument. In practice, many of these performers were accidental, being pulled in by the relayed sound at the 24 sites. These unwitting participants would begin a call and response relationship with the other 23 sites, which would often shift in nature and complexity in parallel with whatever else was being heard through the 'cortex' at that time. Other more structured and curated performances have taken place, with participants working both singularly and collaboratively. Improvisations evolved over many hundreds of miles with both spoken word performers and classical musicians. A soundbox was sited just outside the main performance/installation space at FACT in Liverpool. Here, participants often sang or spoke to the microphone and then ran in to the performance space to hear their sound ricochet around the gallery, in combination with sounds from the other sites.

Even in a situation in which a human participant is unaware of the existence of a nearby soundbox, The Fragmented Orchestra calls into question notions of musical authorship. As R. Murray Schafer asks, "Is the soundscape of the world an indeterminate composition over which we have

no control or are *we* its composers and performers, responsible for giving it form and beauty?" [3]

3. Neuronal Model

The majority of the processing of sensory information in our brains is thought to take place in the cerebral cortex, which contains a population of billions of neurons, each making thousands of synaptic connections with its neighbours. A single neuron can be thought of as a cell which generates a travelling spiking signal to these connected neighbours when the voltage on its membrane exceeds a certain threshold voltage, a process which is called 'firing' or 'spiking'. A neuron receiving several spikes simultaneously (or within a very small time-window) is likely to have its voltage pushed beyond the threshold level and will therefore in turn, send spike signals to its connected neighbours. Furthermore, connections between most neurons which cause spiking signals tend to become potentiated and those which do not become depleted, a phenomenon known as 'Synaptic Plasticity'. The dynamics of millions of such adaptive, interconnected neurons thus provides an extremely rich behaviour, especially on a collective level of description (for a comprehensive introduction, see Gerstner and Kistler [4]) and patterns of firing regularly occur in groups of neurons. This is illustrated in Figure 2, taken from a mathematical simulation of a group of 1000 coupled neurons. For an example of such collective firing behaviour, see [1].

The neurons are numbered on the ordinate y-axis (with neuron number 1 at the bottom, and neuron number 1000 at the top) and the time, which runs from zero to 1000 milliseconds (or one second), is on the x-axis. This is therefore a simulation of one second's activity of this group of 1000 artificial neurons. Every time a neuron fires, a dot is placed on the graph at the appropriate time on a line horizontally drawn from that particular neuron. The dots on the graph can thus be regarded as firing 'events'. In the particular graph shown, because of the plasticity of the neural connections, many of the events are centred in four bands, which appear as a pulse or 'wave' of spiking events in real-time.

The spiking events are indeterminate (not predictable in advance) but are certainly not randomly distributed, and, as is the case with the above scenario, can be highly correlated. A rhythmic pattern such as the one pictured above is likely to be connected with the 'polychronous' firing of a particular group of neurons [1], in which the firing of a particular neuron generates a sequence of events which stimulate a large number of neurons, which form a closed group with the connections between these neurons being reinforced through repeated firing of the first neuron (the group of neurons fire not in synchrony but with polychrony). It is the musicality of these sequences of firing events, or rhythms, which we are interested in. In our research (see, for example, Miranda and Matthias [5], Grant et al [6], Matthias and Ryan [7]) we have started to look at what happens when

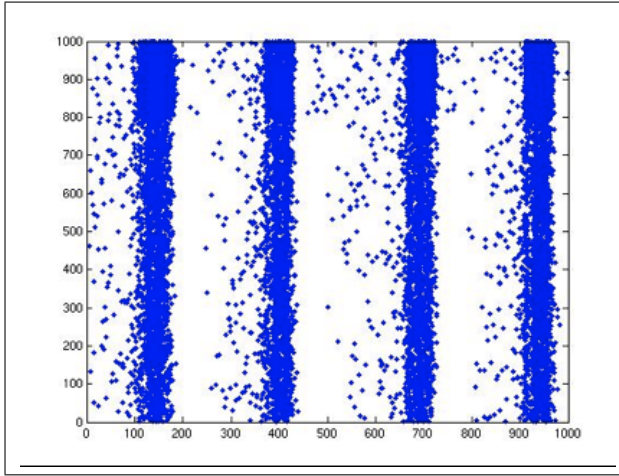


Figure 2. Spike timing graph. $x = \text{time (ms)}$, $y = \text{neuron index}$.

each firing event is represented by a sonic event.

3.1. The Fragmented Orchestra

In the case of The Fragmented Orchestra, each event is transformed into a short sample of sound streamed from one of the 24 sites. The cortex is tiny, consisting of just 24 neurons, but is sufficiently large to achieve many complex rhythms and collective firing behaviours. Each site is represented by its own neuron, which is also stimulated by the sound from that site. The samples of sound are relayed in real-time and last between 30 milliseconds and 2 seconds. We have adapted a mathematical model of biological neuronal networks developed by Eugene Izhikevich and others [1], which is one of many models of spiking neuronal networks which are based on a simplification of a model developed by Hodgkin and Huxley in the 1950s [8]. These models are essentially electrical in nature and consider the relationships between the flow of ions across cell membranes and the flow of voltage signals between the cells. In a sense, we have created a hybrid organism, involving 24 cortical neurons which are also all crude sensory neurons (they are stimulated by the ‘volume’ of the sound). This tiny organism is then distributed across the 24 sites and transformed into a musical instrument.

One of the essential attributes of the musical interface is the relationship between the stimulation of the neuron by the audio in the site and the plasticity in the neuronal network. If the amplitude of the audio in a particular site causes the neuronal membrane voltage to exceed a certain threshold value, the neuron associated with that site will fire. This will cause ‘spike’ voltage signals to be sent to all of the other neurons (we have an all-to-all topology), which may also fire if their membrane voltage is above the threshold. Furthermore, a synaptic plasticity algorithm [1] ensures that causal firing is encouraged by the enhancement of corresponding inter-neuronal connections.

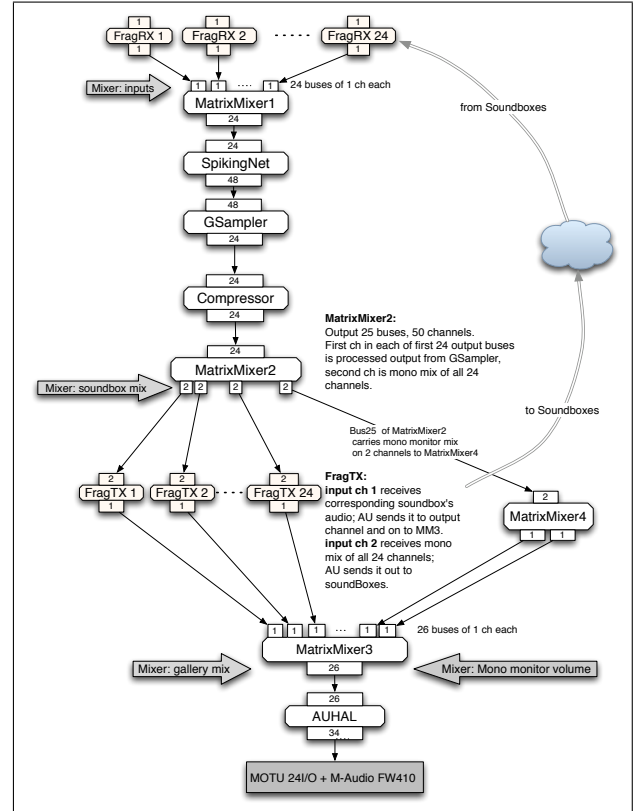


Figure 3. Server architecture

The interplay between the stimulation of the neurons by external forces and the network dynamics associated with synaptic plasticity is particularly interesting. The resulting temporal firing dynamics have the potential to be much more correlated and sophisticated than, say, a pink noise generator exhibiting scale-symmetric correlations. There is, however, a trade off to be considered: heavy stimulation knocks the system out of its ‘settling’, and so a very stimulated network has less chance of exhibiting the correlations in rhythmic dynamics associated with the global and long-term operation of synaptic plasticity.

4. Server Architecture

The neural network itself is hosted by a Mac OS X server located at the installation site. The server application takes the form of a graph of Audio Units, which handle the network streaming as well as the sound processing. The core of the audio processing is handled by two units, one containing the spiking neural network, and the other containing the granular sampler.

The network is based upon the Izhikevich model outlined above [1], taking its input from the physical network of audio sources plus its internal “noise”. For each of these neurons, the unit sends two streams of data onwards through the chain, the first carrying the audio signal, the second con-

taining spiking events generated by the neural network in response to both the direct stimulus to that neuron, and to activity elsewhere in the network.

The granular sampler is in many ways typical of this kind of unit: it selects ‘grains’ of sound from the input, of lengths varying from 30ms up to a second or more. These grains are output in a rearranged and layered form, with the extent of this rearrangement dependent on the chosen system settings.

The important difference with this granular sampler is that the timing and density of the grains is determined by the activity of the neural network, which in turn is partially determined by sonic events at the soundboxes (‘partially’ because the complex internal dynamics of the neural network mean that its behaviour is very far from a simple mapping of input to output).

A graphical user interface to the server application allows the parameters of the system to be modified in real-time. Amongst others, these include the spiking threshold for each neuron, the output volume of each channel, and an adjustable per-channel delay buffer, from which the sampler can draw grains, introducing a temporal ‘shuffling’ effect to reorder the input. However, these parameters are not intended for frequent modulation when the piece is running; rather, they are intended as a way to fine-tune the initial parameters of a generative system, ensuring that the density of output is not too low or too great. The subsequent operation should primarily be governed by the internal neural plasticity.

5. Soundbox network

The Fragmented Orchestra is fundamentally a distributed system, comprised of an interconnected network of communication nodes. Given that these sites are scattered throughout the length and breadth of the UK, it is entirely reliant on the availability of a network infrastructure that is capable of transmitting audio data in real-time over a great distance. Indeed, this kind of project has only been rendered technically feasible in recent years, courtesy of the rapidly accelerating rate of consumer-grade internet connectivity.

The architecture of The Fragmented Orchestra’s network is illustrated in Figure 4. The central server, which performs the neuro-granular processing, is located in the gallery space at FACT. This is connected via the internet to the 24 soundbox sites, each of which has a sufficiently fast broadband connection to relay audio streams in both directions in real-time.

This installation must be operational 24 hours a day, throughout its 3-month duration, so it is also vital that this software is as stable and resilient as possible. It must be able to cope with significant network delays and outages and must be configurable on a per-site basis according to specific needs; for example, one site must be scheduled to reduce its volume at night to avoid disturbing nearby residents. Moreover, due to the geographical dispersion, we must be able to

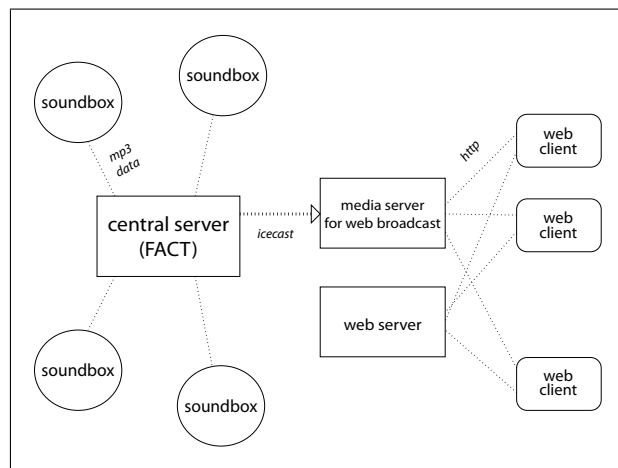


Figure 4. Network architecture

comprehensively configure and control the system remotely. Given these requirements, a piece of software to perform these tasks was written from scratch, developed over several months and thoroughly tested for reliability and stability.

This has a number of key features, most of which are configurable for each soundbox.

Network connection monitor. The state of the network connection is continually monitored by a dedicated thread, whose job it is to destroy stale connections and re-open the connection as rapidly as possible.

Data buffering. When the client first successfully makes its audio connection to the server, it prebuffers around 10 seconds of audio data. This ensures that a backlog of audio is always available in case of network jitter or lag.

Audio cache. The data buffer also serves a secondary role: if the network connection is lost altogether, the contents of this buffer are output from the speaker on a continual loop (and similarly at the network reception point at the server-side). Thus, some representative sound can continue to be played whilst awaiting the return of network connectivity.

Outage monitor. A system-wide scheduler is operational to reboot the computer in the worst-case scenario of an unrecoverable network outage or other nonfatal system failure.

Due to the infrastructure’s foundation on consumer broadband lines, which do not provide a consistent, guaranteed level of service, the buffering described above is a necessary feature to prevent frequent cut-outs in the audio stream. This introduces an element of latency to the interaction at soundbox sites; a sound event is not echoed back for several seconds or more. Though not intentional, this serves to

accentuate the vast distances travelled by the audio signals over the geographical network.

Indeed, a fundamental part of the character of interacting via The Fragmented Orchestra is found in this latency. As part of a set of performances taking place based upon the project, a relationship developed between the Bristol Watershed site and the site at Belfast's Sonic Arts Research Centre, resulting in a distributed, collaborative performance mediated through The Fragmented Orchestra. Both parties had to evolve structures and strategies that dealt both with the fragmentation of their overall contribution and the time delay relative to their performance partner.

In the programme for the first performance of his piece *Variations VII*, John Cage discusses this class of novel, technically-induced situation: "The technical problems involved in any single project tend to reduce the impact of the original idea, but in being solved they produce a situation different than anyone could have pre-imagined." [9].

5.1. Interactivity at the Sites

A sonic event at one of the sites will be fed into the neural server system; after a delay equal to twice the network buffer size, the output of the neural network will then be output from the loudspeaker at the site. Based on this feedback loop, a visitor to one of the sites can 'play' The Fragmented Orchestra as an interactive instrument, perceiving their actions as mediated through this chain of pathways.

This simple call-response behaviour itself seems to provoke a significant amount of engagement with a public audience; there is a great fascination in the process of creating a sound and hearing its echoes return, having travelled through a web of routes spanning the nation. However, there is a greater degree of reactivity throughout the network than is immediately evident. Because of the interconnected nature of the neural network that governs the audio spike timings, audio events at one site can implicitly become associated with those at others, based on dynamic correlation patterns between the sites. As the system continues to run, and more of these connections evolve, this results in sound events at one site triggering those at another in synchrony – an audible example of the "pulse" or wave phenomena described in Section 3.

It is consequently possible to create an auditory cascade of events, the effect of which is akin to hearing echoes of sound from the recent past in distant corners of the country. In a learning system such as this, each event does not only have an immediate effect but also has consequences for the long-term behaviour of the system.

6. Web Interface

For those unable to visit the sites that make up The Fragmented Orchestra's physical architecture, the piece can be accessed using a web interface designed and developed for the purpose [10]. The interface is an Adobe Flash applica-

tion, based upon the sparse, geometric aesthetic that characterised the installation's visual identity, and integrated with the rest of the website content. Indeed, the interface is the first content that the user is presented with, foregrounding the content of the piece above the supporting information that the remainder of the site provides; it was the intention to create an immediate, immersive experience, free of visual distractions and focusing the visitor on the sound of the work.

The experience itself is markedly different to that of visiting the exhibition site, though modelled on a similar concept. The user is presented with a network of nodes, each corresponding to a soundbox site, joined together by lines in a similar way to a diagrammatic neural network. A minimal set of control buttons enables the user to pause the piece, add and remove nodes, and switch to a full-screen display mode. No other visual elements are present, with the exception of a visual aura surrounding each node to indicate its sound state.

Consider the space that the nodes inhabit as a 2D plane. Each node conceptually outputs a live audio stream from its site to a limited area around it in this plane; the user then plays the role of a 'listener' within this space, whose position is determined by the mouse cursor. The amplitude and stereo panning of each of the nearby nodes is then modulated in real-time to create the impression of virtual sound-source positioning, with the analogy that the user is moving through the 2D space between this network of speakers – in much the same way that the visitor to the physical installation configures their experience of the work by moving between the speakers. This technique was tested and developed for *AtomSwarm* [11], an earlier performance piece by Daniel Jones, and was found to be a deceptively effective way to immerse the listener within the space of the composition itself.

Here, however, it is possible to add, remove and reposition nodes at will, so the user can select their own palette of sound sources from the array of varied sites. A choral performance at Gloucester Cathedral can thus be combined live with street sounds from Bristol, transforming The Fragmented Orchestra into an interactive instrument that can be used to create novel and unique compositions by members of the public.

It is critical to state that we view the website as complementary to the physical installation rather than as a strictly alternative method of experiencing the piece. Though efforts were made to optimize the immersiveness of the interface, it is a radically different experience to the cocoon-like physical immersion of the 24-channel surround system, whose embodiment excludes all other sensory stimuli to allow for complete focus on the sonic affects.

A common observation made by visitors to the installation is that the piece benefits from listening at various times of day at night. Given that the gallery is only ordinarily

open during daylight hours, it is here that we feel that the 24/7 web access point succeeds in genuinely broadening the scope of the piece.

7. Conclusion and Future Work

At the time of writing, one month remains of The Fragmented Orchestra's 10-week tenure at FACT. The public response has been overwhelmingly one of curious engagement; much of the the broadsheet coverage [12] has tended towards the explanatory rather than the critical, outlining the concepts, context and architecture behind the system. However, as is recognized by this article, the experience of the installation itself is actually wholly intuitive and uncomplicated; without any technical interface as such, the visitor is left simply to wander between the 24 ceiling-hung speakers, configuring their own unique experience of the installation through their location.

Timing is also critical: it quickly becomes apparent that, as David Stubbs notes in *The Wire* [13], the sonic signature of the UK – and thus the installation – alters significantly according to the time of day, with inevitable early-morning lulls, lunchtime buzz and chatter, and a greater number of intentional performances towards the evening. Though this does mean that the qualities of the experience will vary wildly according to the sound events at each of the sites, this is also one of its most rewarding features. As Stubbs comments [13]:

“So fitful and sporadic are these sounds that it's left to chance just how well you'll be rewarded from your visit here - but there is a strange, radio ham's delight when, for instance, the sounds of a kid's party in a London gallery break down the wires, unspoiled even in this era of media supersaturation.”

8. Origins of the Project

The Fragmented Orchestra was conceived by artist Jane Grant, physicist, musician and composer John Matthias and composer Nick Ryan. Network and server engineering were coordinated by Daniel Jones and Tim Hodgson respectively, and the project's visual identity was enabled by the London-based Kin Design. The Fragmented Orchestra was awarded the PRS Foundation New Music Award 2008, whose funding part-enabled its realization.

Its concepts and technologies arose from a web of related projects. In 2004, John Matthias and Eduardo Miranda, based at the University of Plymouth, developed the Neurogranular Sampler [5], an instrument which triggers grains of sound from prerecorded sound files when artificial spiking neurons fire in an Izhikevich network. These initial experiments formed a large part of the piece *Cortical Songs*,

written by John Matthias and Nick Ryan [7], which was released on Nonclassical records in 2008. In this work, artificial spiking neurons control a set of lights, which flash when the neurons fire. The score is a combination of instructions to performers following flashing events, and conventional notation. At the same time, Jane Grant and Tim Hodgson further extended the Neurogranular Sampler, concentrating on larger grain duration, high firing density, and the creation of a working interface for the instrument. The instrument formed the basis of Jane Grant's video/audio work *Threshold* [14] which merges the spike timings with the sound of voice and breath.

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