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Atomic Noise

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Published in:
Organised Sound

Publication date:
2005

Document Version
Publisher's PDF, also known as Version of record

Atomic noise

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Stochastic, unvoiced sounds are abundant in music and musical sounds. Without irregularities, the music and sounds become dull and lifeless. This paper presents work on unvoiced sounds that is believed to be useful in noise music. Several methods for obtaining a gradual change towards static white noise are presented. The random values (Dice), random events (Geiger) and random frequencies (Cymbal) noise types are shown to produce many useful sounds. Atomic noise encompasses all three noise types, while adding much more subtle variations and more life to the noise. Methods for obtaining a harmonic sound from the noise are introduced. These methods take advantage of the stochastic nature of the model, facilitating a gradual change from the stochastic sound to the noisy harmonic sound. In addition, the frozen noise repetitions are shown to produce unexpected pitch jumps with a potentially useful musical structure.

1. INTRODUCTION

Noise, understood as unvoiced sounds, is used in many musical situations, from the abundance of cymbals and hi-hats in rhythmic music to the granular music of modern computer music. This paper offers a review of methods that can be used to create noise and harmonic tones from noise. As noise music (Hegarty 2002; Sangild 2002) consists of sounds, mainly unvoiced, that have little association to existing sounds, this work is focused on advancing the technology to produce such sounds in real time.

Noise is inherent in all musical sounds, including the human voice. Without noise and random fluctuations, most sounds are dull, lifeless and synthetic, and noise can indeed add a wide variety of *tone* qualities to a harmonic sound. Noise is an important part of much twentieth-century music, including the *musique concrète* of Schaeffer, the stochastic (random) processes of Xenakis, and the random selection of grains in granular synthesis. Today, noise is used in staggeringly loud noise music (Fact Index 2004), and in soothing pure white noise (Pure white noise 2004).

Three types of noises and irregularities can be identified: random values (Dice noise), random events (Geiger noise), and random frequencies (Cymbal noise). The distribution of the random events, or the random frequencies, determines how many components are produced; few render a sound reminiscent of the name with which the noise type has been dubbed, while many render a sound perceptually close to static white noise.

An all-encompassing noise algorithm, atomic noise, can produce almost all types of the pure noises, while permitting all kinds in-between, sounds with even less natural associations. While atomic noise is believed to be useful to many contemporary musicians, in particular in the noise music community, several atomic noise extensions are proposed for obtaining a variable harmonicity. In particular, the periodic distribution of frequencies and atomic onsets allows a gradual subtle change between stochastic and voiced sounds. Atomic noise is also shown to produce many potentially interesting crescendo effects. An *étude* has been made in collaboration with a composer to investigate the musical aspects of the atomic noise sounds.

2. NOISE IN MUSIC

The distinction between noise and tone has been clear for a long time. Helmholtz (1954: 8) states: 'The sensation of a musical tone is due to a rapid periodic motion of the sonorous body; the sensation of noise to non-periodic motions'. Schaeffer (1966: 517) found that: 'the white noise is the exact opposition of the harmonic sound, since it occupies the entire spectrum'. In between the harmonic sounds and the white noise, Schaeffer placed the cymbal, group of cymbals, group of gongs, bells, etc., and chords. In modern classifications (Bendat and Pirsol 1986), the 'random' data are separated from the deterministic data and classified as either stationary or non-stationary. The mpeg 7 audio description (ISO/MPEG 2001) distinguishes between harmonic and percussive, coherent and non-coherent, and sustained and non-sustained sounds.

As to the sensory pleasantness of noise, Zwicker (1999) tested tonality (a feature distinguishing noise and tone quality of sounds) versus sensory pleasantness (a complex sensation that is influenced by elementary auditory sensations such as roughness, sharpness, tonality and loudness) and found a strong dependency, indicating that band-pass filtered noise with large bandwidth has low relative pleasantness, as compared to sinusoids and band-pass filtered noise with low bandwidth.

Organised Sound **10**(1): 75–81 © 2005 Cambridge University Press. Printed in the United Kingdom. doi:10.1017/S1355771805000695

Noise and irregularities are common in many musical instruments. Indeed, without irregularity, the sound produced by most musical instruments would become synthetic, lacking the life that is necessary to produce an enjoyable sound. Noise is found in its purest form in some percussive instruments, and in particular in the unvoiced consonants of the human voice. In addition, wind instruments, such as the flute, have an additive noise component. Struck and plucked string instruments, such as the piano and the guitar often have unvoiced plucking and striking noises, whereas the bowed instruments have aperiodicities that add to the quality of the instruments.

In music, the Futurists proposed, without success it seems (Chadabe 1997), a series of instruments, the *intonarumori* that produced *rumbles*, *whispers*, *creaks* and other noises. Schaeffer went on to collaborate with Pierre Henry on *musique concrète*, in which recorded sounds, many of them unvoiced, were used in the compositions. Stockhausen and others used electronic generators, sinusoids and white noise in their early works. Another composer, Xenakis, used stochastic processes in both compositions and creation of new sounds. The distinction between composition and sound events has been blurred in granular synthesis (Roads 1988), a method in which long music pieces can be obtained by random summation of time- or frequency-shifted short (10–50 ms) grains, often extracted from a short sampled waveform using a random selection and manipulation process.

The use of noise has been further enlarged by two recent trends. In noise music (Fact Index 2004), adapts such as Japanese Merzbow, or Caspar Brötzmann, use noise played extremely loud in a generally rather static way. 'Noise music becomes ambience not as you learn how to listen, or when you accept its refusal to settle, but when you are no longer in a position to accept or deny' (Hegarty 2001). This stands in full opposition functionally, if not otherwise, to the use of noise to create 'relaxation and calm, promoting sleep, and blocking annoying noises . . .' (Pure white noise 2004).

3. SYNTHESIS OF NOISE

For the purpose of this paper, three types of noise have been used: random values, pulses at random intervals, and summation of sinusoids with random frequencies. These noise types are called Dice, for the random values, Geiger, for the pulses, and Cymbal noise for the summation of sinusoids. These types are believed to be the purest form of noise generation. When enough pulses, or sinusoids, are generated, all three noises are virtually indistinguishable. The interesting part occurs when there are few pulses, or few sinusoids, in which cases the static noise breaks up into individual pulses, for the Geiger noise, and separated sinusoids, for the Cymbal noise. The noises obtained with the Dice, Geiger or Cymbal methods are extremely static, even with few pulses/sinusoids. The same noise types can be obtained using the atomic noise presented below, but without the static behaviour of the sound.

3.1. Distribution

Distribution affects how likely a value is to occur. Common distributions are uniform, in which all values are equally likely, and Gaussian, in which the probability function is bell-shaped. In this work, if nothing else is stated, a Gaussian model is assumed. This signifies that the values are normal-distributed, that is, it is more likely to have a value around the mean than a value far from the mean. The Gaussian-distributed noise is defined by its mean value and its standard deviation (corresponding to the level). These values are called the first and second moment, where the third moment is called skewness, and the fourth kurtosis. An illustration of the four moments of the Gaussian distribution is given in figure 1.

Distribution has not been found to have a large influence on the sound. Although the difference between a uniform and a Gaussian distribution may be audible, it is somehow difficult to perform controlled experiments because of the subtle difference. Skewness and kurtosis are also believed not to have a large perceptual effect.

3.2. Random pulses

Random pulses distributed evenly in time are heard as a ticking noise, reminiscent of a Geiger counter, when the number of pulses is low. Pierce (2001) differentiates between slow random pulses, which are heard separately, pulses at a rate of a few hundred per second, which are not all detected individually, and pulse rates above this, where a smooth noise is heard and no individual pulses are perceivable. In Geiger noise, the sound at time t is calculated as

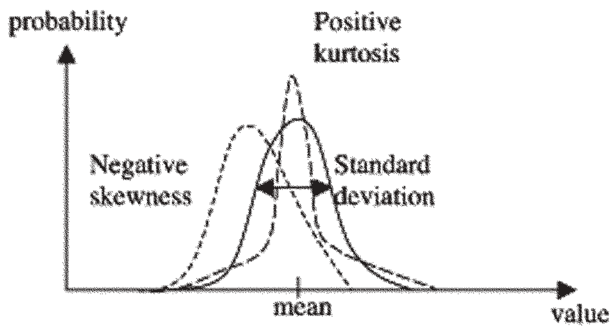

Figure 1. The parameters of a fourth moment Gaussian distribution model. The plots illustrate what probability a certain value has.

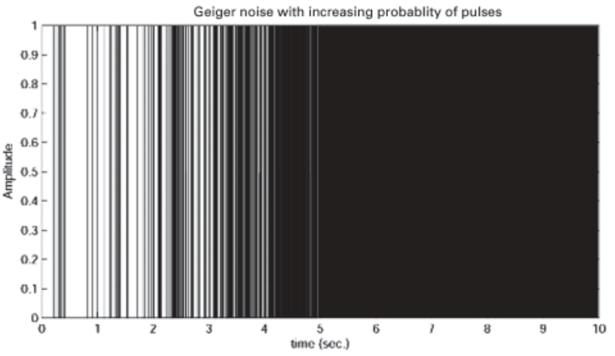

Figure 2. Geiger noise, with pulse probability going from 0.0002 to 0.001, corresponding to between approximately 9 to 44 pulses per second at a sampling rate of 44,100 Hz.

$$s(t) = \begin{cases} 1 & \textit{if} \quad r_t > p \\ 0 & \textit{otherwise} \end{cases} \tag{1}$$

where r_t is a random sample and p is the probability that a pulse occurs at time t.

The pulses used here are of a single non-zero value, and they are distributed randomly in time. As more and more pulses are added (p is decreased), the individual pulses are no longer perceived, but instead the sound becomes unvoiced. This occurs at approximately 1,000 pulses per second. An illustration of such a sound can be seen in figure 2. If the pulses consist of more than just an impulse, they can be located in time. Richard, d'Allesandro and Grau (1993) used resonant waves called formant-wave-functions (FOF) (Rodet 1986), with a random onset time, to synthesise, in an analysis/synthesis context, naturally occurring musical noises.

3.3. Random sinusoids

The summation of a large number of sinusoids with random frequencies evenly distributed on the frequencies also renders an unvoiced sound, if the number of sinusoids is high enough. As the sound resembles that of a cymbal for a relatively low number of sinusoids, this noise generation method is called Cymbal noise. In Cymbal noise, the sound $s(t)$ is calculated as

$$s(t) = \sum_{k=1}^{N} \sin(2\pi\omega_k t + \varphi_k). \tag{2}$$

The frequencies ω_k and starting phases φ_k are random values between zero and one, and $-\pi$ and π, respectively. Assuming the distribution of ω_k is uniform, the resulting sound approximates that of Gaussian white noise, when the number of sinusoids, N, is large enough. An illustration of the resulting sound can be seen in figure 3.

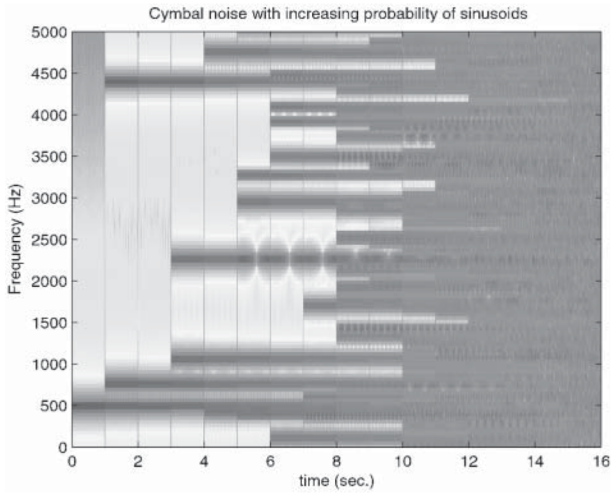

Figure 3. Spectrogram of Cymbal noise. The number of sinusoids is increased from five to 4000.

3.4. Random values

The random values (Dice) method of creating unvoiced sounds is the most common method today. By using a new, uncorrelated, value at each time sample, an unvoiced, uncoloured sound is obtained. The distribution of the random values is not very important, perceptually. This can be verified by, for instance, changing the number of quantisation steps of the sound. As the number is decreased and approaches two, no perceptual difference has been found. Although this was an informal experiment with only two participants, this result indicates that the Geiger noise, which consists of only binary samples, is perceptually very close to the Dice noise, given that the number of pulses is high enough. As for the Cymbal noise, the distribution approaches a normal distribution by the central limit theorem; the Cymbal noise is also perceptually very close to the Dice noise, given a large enough number of sinusoids.

3.5. Atomic noise

Three synthesis methods of noise have now been identified, and indications that the three methods are perceptually very close under certain assumptions have been given. The three methods are Dice noise, with random values, Geiger noise, with pulses at random times, and Cymbal noise, with random frequencies. As the components of the Cymbal noise have, in theory, infinite duration, while the components of the Geiger noise have infinitesimal duration, it is hard to find an equivalence between the two. However, if the notion of random value, time and frequency is retained, the noise types can be obtained by summing a large number of sinusoids with random amplitude and frequency, multiplied by a Gaussian

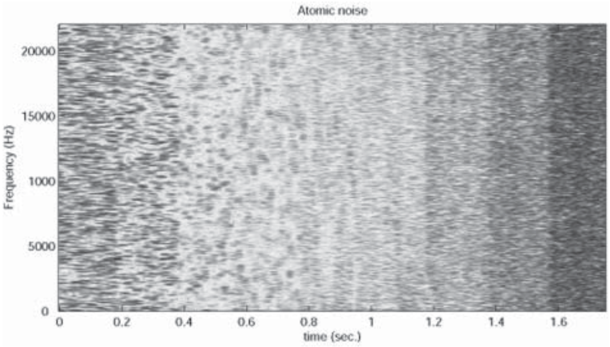

Figure 4. Spectrogram of atomic noise. Probability $p = 0.1$ and standard deviation σ of the Gaussian decreases from 1,000 to 0.1 logarithmically.

shape with random standard deviation at random starting times,

$$s(t) = \sum_{k=1}^{N} a_k \cos(2\pi\omega_k t) \cdot e^{\left(\frac{t-t_0}{\sigma}\right)^2}, \quad (3)$$

where the amplitude a_k is a random variable with a Gaussian distribution with mean μ_a and standard deviation σ_a, the frequencies ω_k are random values as in the Cymbal noise, t_0 is the onset time, and σ is the standard deviation of the Gaussian. N is the number of atoms, but atomic noise can also be created in the same manner as Geiger noise (equation 1) by inserting a new atom at time t_0, if the random value drawn is greater than the probability threshold p. As σ approaches zero, the corresponding signal has small duration and large bandwidth, thus approaching Geiger noise. As σ increases, the sinusoids have more duration and less bandwidth, and the signal approaches Cymbal noise. A spectrogram of atomic noise, for a medium probability of atoms, is shown in figure 4.

The atoms of atomic noise can be used to create any kind of sound, if the parameters of the model are chosen with care. Gribonval, Depalle, Rodet, Bacry and Mallat (1996) used the high-resolution matching pursuit method, basically a greedy algorithm, to estimate the parameters to resynthesise musical sounds. Miner and Caudell (2002) used wavelets to synthesise noise in virtual environments. The current work is mainly devoted to creating noise with no associations to existing sounds, however. Therefore, no parameter estimation and no parameter structure useful when trying to obtain naturally occurring sounds have been attempted.

The different noise types (Dice, Geiger and Cymbal) can be created by using equation (3). The values for the frequency distribution, standard deviation and amplitude mean and standard deviation are given in table 1. It is difficult to obtain exactly the same perceptual effect as given above, as there is more change

Table 1. Parameters of atomic noise that create the different noise types.

Noise type/parameter	ω_k	σ	p	μ_a	σ_a
Dice	–	<0.1	>1	–	–
Geiger	–	–	–	1	0
Cymbal	–	>100	–	1	0
Symbiosis	–	≈ 10	–	1	0

in atomic noise than in pure Cymbal or Geiger noise. If p is increased above 0.15, approximately, the noise approaches white noise. The symbiosis noise is a mixture of the noise types, giving perceptual associations to all three.

4. MUSICAL APPLICATIONS

While the algorithms presented so far are potentially of great interest to the noise music community, white noise does not hold the same interest for everybody in the music community. Experiments have been conducted to obtain a crescendo effect, where one of the parameters of the atomic noise is increased rapidly, and a harmonicity effect, by using a random variable with a distribution that enhances the tonal quality of the noise. Obviously there is an infinity of possibilities when using temporal envelopes, or time-varying filters. Using the atomic noise model, a music piece has been made, '*Etude Blanche*' (Jensen and Georges 2005).

4.1. Tone from noise

Although the purpose of this paper is to provide tools for the creation of near-static noise with little correlation to known sounds, this section will describe methods for obtaining a harmonic signal from noise. A harmonic signal would normally sound more like a musical instrument, but in this work, harmonicity is obtained while retaining the stochastic nature of the sound, thereby avoiding too much resemblance to natural sounds. A harmonic signal can be obtained from noise through many methods. Here we take advantage of the methods used to create the signal, and amplify selected time or frequency areas in order to obtain a voiced sound. Another method consists of repeating the unvoiced signal, which renders a useable voiced signal. This repetition method can be used on any signal, but when using noise, the perceived note is dependent on the noise signal in ways that create unexpected note jumps when increasing or decreasing the repetition rate, creating an interesting, unexpected effect. Other methods for obtaining a pitch sensation from noise, as stated by Roads (1996), include amplitude modulation, or delay and add noise (comb filter noise).

4.1.1. Periodic distribution

Since Geiger noise would become harmonic if the probability of pulses were to increase at periodic times, and similarly, Cymbal noise would become harmonic if the probability of sinusoids increased at periodic frequencies, a periodic distribution for the stochastic signals is proposed here. This periodic distribution is based on a triangular window, raised to the w^{th} power:

$$p(x) = \Lambda \left| x - \frac{x_0}{2} \right|^w, \quad 0 \le x \le x_0. \tag{4}$$

The x parameter corresponds to time in Geiger noise, and to frequency in Cymbal noise. Λ is the normalisation necessary to obtain a power density function. p is now repeated for the duration of the sound in Geiger noise, and until the Nyquist frequency in Cymbal noise:

$$p(x + x_0) = p(x), \quad x < x_{MAX}. \tag{5}$$

The stochastic variables corresponding to the Geiger impulse onset time or the Cymbal sinusoid frequency are now found by the change of variable method (Bendat and Pirsol 1986). The peak-to-valley parameter w determines how much harmonicity there is in the sound, $w = 0$ renders a stochastic sound, while increasing w increases the harmonicity.

The periodic structure of Geiger noise is difficult to visualise. The time-domain plot generally shows only uniform distribution, and the spectrogram demands careful tuning of the window size to allow an observation of the periodicity. An example of Geiger noise with increased harmonicity can nonetheless be seen in figure 5. The relative strength of the upper harmonics seems to increase with the harmonicity weight w.

Harmonic Cymbal noise is created using a periodic function that increases the probability of having a sinusoid at the harmonic frequencies, using equations (4) and (5). This function gives the same strength to all partials, as can be seen in figure 6.

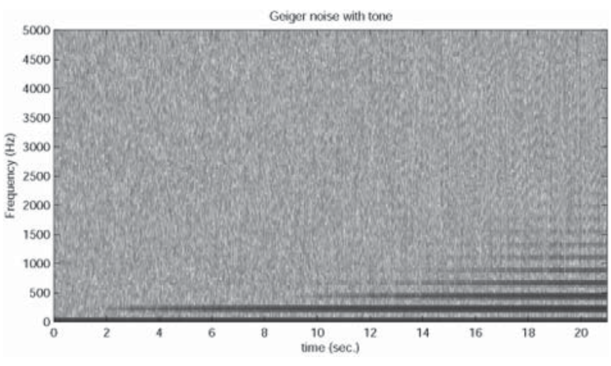

Figure 5. Example of increasing harmonicity in Geiger noise. The harmonicity index w is increased from 0 to approximately 8 exponentially.

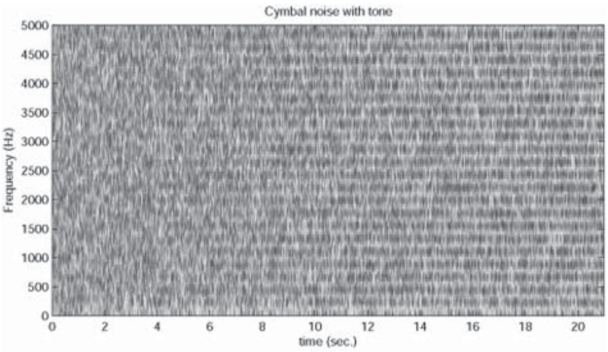

Figure 6. Harmonicity obtained by increasing the probability of sinusoids at the vicinity of the harmonic frequencies. w is increased exponentially from 0 to approximately 8.

4.1.2. Frozen noise repetitions

Another method of obtaining tone from noise was introduced by Warren (1999). He used repeated static Gaussian noises (frozen noise) to show the perception of infrapitch (very low frequency pitch). His conclusions (on Vol. 10's *Organised Sound* CD) are that repetition of frozen noise segments renders a w*hooshing*, *motor boating*, and *noisy pitch*, dependent on the repetition rate. For the low infrapitch (2 Hz), a collection of *rattles*, *clangs* and other *metallic types* of sounds may also be perceived, in addition to the *whooshing* sound. This repeated frozen noise is created by setting the first samples to random values, and then repeating these values:

$$s(t) = \langle rnd \rangle, \quad 0 \le t \le t_0, \tag{6}$$

$$s(t + t_0) = s(t). \tag{7}$$

$\langle rnd \rangle$ is one random value drawn from a stochastic distribution. For large t_0, an infrapitch may be perceived with other structures being perceived simultaneously, while for small t_0, a noisy pitch is perceived, the timbre of which is determined by the actual random samples. If the repetition rate is slowly decreased, from for instance 1 s to 10 ms, an interesting effect can be perceived at approximately 30 ms repetition rate, where the note perceived starts to jump between different overtones. This effect is not without traditional musical meaning, as the notes generally have a simple almost-integer ratio. An example of repeated frozen noise can be seen in figure 7.

There are now three possible ways of obtaining a harmonic sound from the different noise types: the periodic distribution in time of Geiger noise that creates a sound with gradually more relative energy in the higher overtones as the harmonicity weight is increased; the periodic distribution in frequency of Cymbal noise that creates a sound where all harmonics have gradually more energy as the harmonicity

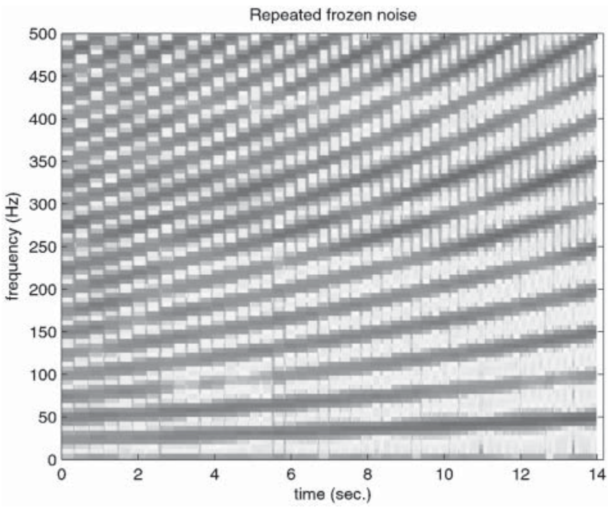

Figure 7. An example of the repeated frozen noise. The repetition rate is varied between 25 to 50 Hz.

weight is increased; and repeated frozen noise that creates a noisy pitch at fast repetition rates and a pitch that sometimes jumps between the overtones, in an interesting and unexpected way, for slower repetition rates.

4.2. Crescendo effects

Crescendo effect occurs when one, or several, atomic noise parameters are changed within a short lapse of time. This gives a timbral change to the sound that can be explored in a musical context. The obvious choices of parameters to change are probability p and standard deviation σ. For a large value of p (>0.2), the noise approaches white noise, and no crescendo effect is obtained. Similarly, for a small value of s, the atoms get so short that no tonal components are audible. Examples of four short crescendo sounds are shown in figure 8. A crescendo effect can also be obtained with harmonicity weight. By changing the weight rapidly, a sound with transient harmonic structure is created.

4.3. *Etude Blanche*

In collaboration with composer Laurent ‘Saxi’ Georges, a musical piece has been produced (Jensen

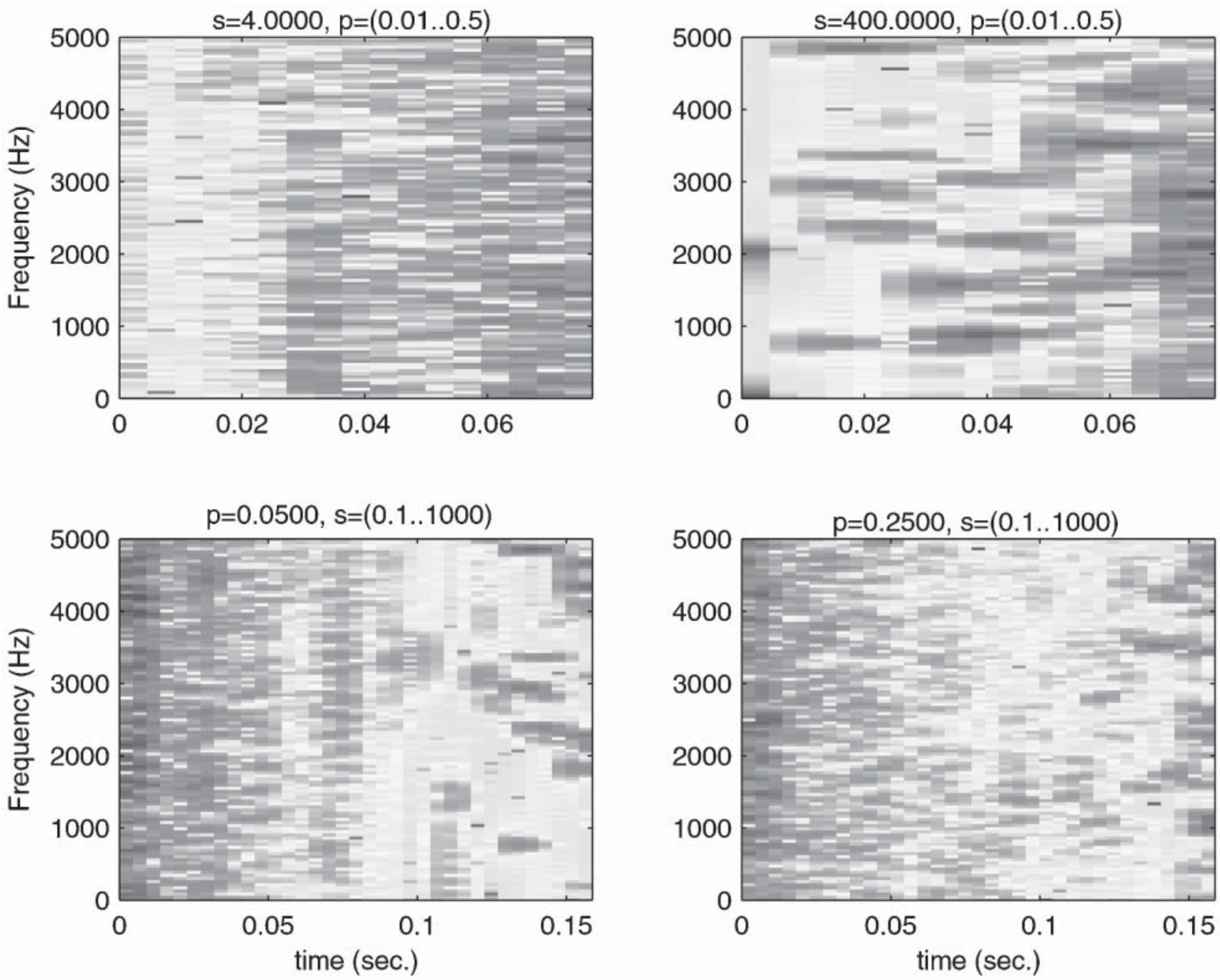

Figure 8. Examples of crescendo effects in the atomic noise.

and Georges 2005). The piece consists uniquely of sounds created by the atomic noise model, subjected only to minor volume and panning effects. The piece, which is an *étude*, explores the limits of the atomic noises, mixing slowly evolving non-harmonic tones with ragged noise and repeated frozen noise, finally showing the possibilities of mixing a number of mainly unvoiced sources with varying degree of pleasantness. By introducing some of the atomic noise types at the beginning of the piece, and furthermore retaining the focus through the slowly repeating frozen noise and other rhythmic structures, cues are given that enable the separation of the atomic noises. By using rather extreme atomic noises with varying degrees of tonality including, for instance, almost stationary sinusoids or near-tonal impulses, an effective dissociation between the tonality and sensory pleasantness is achieved. This enables, in combination with the rhythmic and structural effects, the creation of a music that gives a wide variety of emotional signals that produce states of relaxation, nervousness, even stress, and also curiousness and relief.

5. CONCLUSIONS

This paper has presented the technology necessary to create a wide variety of unvoiced sounds that, because of the lack of associations to existing sounds, are susceptible to being used in noise music. Three noise types are initially identified: Dice, Geiger and Cymbal noise. These noises, while ultimately having the same white noise stationarity, still encompass a wide range of static sounds, including random clicks and summation of sinusoids with random frequencies.

A method of obtaining all kinds of noise, while reducing the somewhat boring static behaviour of the pure noise types, is dubbed atomic noise. Changing the means of the atom probability and width in atomic noise allows one to create a wide range of stochastic sounds. These sounds do not have any correlation with naturally occurring sounds, and this is exactly what can make these sounds useful in noise music. Atomic noise provides several ways of creating near pure white noise, producing interesting effects useful in soothing or overwhelming music.

The atomic noises, or the pure noise types, are subjected to several methods of obtaining a sound with a variable harmonicity. The distribution of frequencies, or atom onsets, is made periodic, which produces a harmonic sound while retaining much of the noisy aspect. The variable harmonicity weight allows a gradual change from stochastic to harmonic sound.

Another method of creating voiced sounds from noise, repeated frozen noise, has been shown to produce some unexpected and interesting effects. Indeed, while increasing the repetition rate, at some repetition rates the perceived pitch jumps up and down in almost-integer ratios, producing a musically interesting melody.

Finally, crescendo effects have been produced giving novel and interesting onsets in musical situations. Sound examples of the different noise types are presented, along with a short musical piece, on the *Organised Sound* CD.

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