# Approaching Real-Time Granular Synthesis Feedback

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Proceedings of the Xenakis International Symposium
Southbank Centre, London, 1-3 April 2011 - www.gold.ac.uk/ccmc/xenakis-international-symposium

This paper considers the Xenakian origins of granular synthesis and presents a contemporary implementation and novel extension of this method - granular synthesis *feedback*. The aesthetic foundations of granular synthesis are reviewed and characterized by the concept of the *granular paradigm* as introduced by (Solomos 2006). Further, an implementation of granular synthesis in the music programming enviroment MaxMSP is presented. This implementation allows real-time update of the buffer content, thereby enabling granular feedback as a form of non-standard sound synthesis. As exemplifications of the principle, two feedback-scenarios are characterized and its inherent dynamics are explained. The aesthetic implications of these scenarios are discussed with respect to the debate about sonic emergence, initiated by (DiScipio 1997).

Iannis Xenakis was undoubtedly one of the most influential figures in electroacoustic music in the 20th century, pioneering in modern disciplines like sound synthesis, algorithmic composition and interface design. One of his innovations was the introduction of granular synthesis, a form of additive synthesis which "involves generating thousands of very short sonic grains to form larger acoustic events." (Roads 1988, 11) This technique was musically introduced with his 1959 piece *Analogique B* which solely employs sinusoidal grains of sound as basic sonic material. The theoretical counterpart was provided one year later in form of the article "Elements of Stochastic Music" (Xenakis 1960). More than 50 years later, grain-based sound synthesis techniques have become ubiquitous. Using flexible music programming environments (as *MaxMSP, Pure Data, Super Collider, Chuck,* etc.) they are quickly and efficiently implemented and can be run and controlled in real-time.
In this work an extension to real-time, buffer-based granular synthesis is presented. The simple but far-reaching idea is to feed back the (possibly transformed) result of the synthesis into the buffer that the synthesis reads from. Thus, the feedback gives rise to a generative, dynamic system of sound. Two exemplary scenarios of granular synthesis feedback, *direct* and *mediated* feedback, will be presented; both scenarios give rise to some kind of sonic *emergence*. The latter notion usually refers to the phenomenon of complex patterns arising out of simple interactions, as observed by many branches of science, e.g. dynamic systems theory, sociology, cognitive science or biology. Pictorially speaking, "A wondrous vine emerges when Jack plants the seed for his beanstalk, and it unfolds into a world of giants and magic harps." (Holland 1998, 1) The notion has also been related to the outcome of musical (feedback) processes. Indeed, it plays a central role in Agostino Di Scipio's critique of Xenakis's compositional methods, in particular concerning *Analogique B* and his theoretical hypothesis of *higher order sonorities* (Xenakis 1992; Di Scipio 1997). Xenakis vision was to iteratively treat complete granular structures as single grains, which is finally realized with this implementation of granular synthesis feedback.

Methodically, it is aimed to interweave music-computational, mathematical and aesthetic perspectives, in the sense of a Xenakian *alloy* of musical and scientific thought (Xenakis 1985). Whereas the first section rather takes a historical stance, computational issues of the implementation are discussed in the second part. For the study of direct feedback, an idealized mathematical point of view is chosen for it provides some systematic understanding of the inherent dynamics of the system. This understanding finally contributes to relating the scenarios' musical implications to the debate about sonic emergence.

An underlying assumption of this work is that not only whole pieces of art allow for aesthetic discussion, but that already artistic *methods* (as e.g. sound synthesis) bear aesthetic significance on their own as far as systematic questions are concerned. In this respect the paper dares to draw relations from the extension to be presented, a kind of post-Xenakian application, to the work of musicians like Iannis Xenakis or Agostino Di Scipio. The paper can in this sense be seen as a case-study in the design and aesthetic contextualization of generative music systems using the interdisciplinary work of Iannis Xenakis as a point of departure.

## The origins

*"All sound is an integration of corpuscles, of elementary acoustic particles, of sound quanta."*
- Iannis Xenakis, 1960

Giving a thorough account of this statement's historical trajectory, Makis Solomos denotes its underlying concept and its music theoretical and compositional consequences as the *granular paradigm* (Solomos 2006). Here, the notion of a paradigm is used in the sense of encompassing both intuition and rationality, being an aesthetic and scientific "vision of the world". It originated from Xenakis but became manifest in the work of later 20th century composers (e.g. Roads, Vaggione, Di Scipio) as well. Solomos characterizes a number of constituent aspects of the Xenakian granular paradigm of which the first two and most important are a) the wave-particle debate in physics and its transposition to music and b) the use of probabilistic models of mass phenomena in music. Both aspects aimed at "transposing" scientific thought to music theory and composition and already become apparent in Xenakis's work of the late 50th, in particular in *Analogique B*.
With the above statement Xenakis openly revealed his atomic conception of sound, corresponding to the particle standpoint of the paradigm's aspect a), while rejecting classical *wave*-based Fourier-theory.[1] The latter represented any sound signal as sums of trigonometric functions with (theoretically) infinite duration, thereby loosing any information and compositional control of continuous spectro-temporal evolution. Despite its shortcomings it was the dominant paradigm of signal processing up to that time. Being attracted by non-stationary, transient and noisy sound phenomena, the Fourier-perspective only provided insufficient representations for the sounds Xenakis envisioned. He therefore sought for alternative representations and developed a *particle*-based conception in line with the research of physicist Dennis Gabor of the 40th of the last century.[2] Although Xenakis later claimed that he developed these ideas by himself, departing from the work of Einstein (!) (cp. Solomos 2006), it seems rather plausible that Gabor's ideas somehow found their way to Xenakis via the acousticians Moles or Meyer-Eppler (compare (Roads 2004), (Di Scipio 2006) and (Solomos 2006)).

On the compositional side of the coin, Xenakis's granular "vision" becomes first apparent in his instrumental piece *Pithoprakta* (1955-56). In the bars 52-59 he composes clouds of thousands of pizzicati-glissandi of the strings. Compare (Xenakis 1992, 21) for Xenakis's graphics of that important part of the piece. For the 1958 piece *Concrete PH* for the Philipps Pavillion at the world exhibition in Brussels, he sliced by hand the tapes of recorded sounds of burning charcoal to create dense layers of crackling sonorities (Di Scipio 1998). In this sense, it can be seen as a form of early *manual* granular synthesis. Xenakis occupation with this piece brought him to further conduct musical research in particle-based methods, leading to his work on the *Markovian Stochastic Music Theory* and its musical incarnation, *Analogique A* and *B*. Whereas the former is scored for 9 string instruments, the latter employs for the first time sinusoidal grains of sound as elementary sound material. Besides the innovation in terms of the basic sound material the piece introduces recursive ordering principles to music composition. As described in *Formalized Music*, discrete Markov chains, i.e. memoryless iterative stochastic processes, are used with their transition probability matrices to structure the grain's positions (i.e. frequency, amplitude) and densities on the screens. This method corresponds to aspect b) of the granular paradigm, the use of probability theory as a technical tool in composition.
With regards to its underlying theoretical complexity, however, the piece's sonic results seemed unsatisfying to many (Di Scipio 2006). This might be a reason why Xenakis did not continue to work with this technique. Nonetheless, the piece is widely acknowledged as an important musical study, paving the way for later formalized compositions to come. With respect to the severe computational limitations of his time, Xenakis's pioneering efforts were later denoted as "heroic, labor-intensive experiments" (Roads 2004, 302)

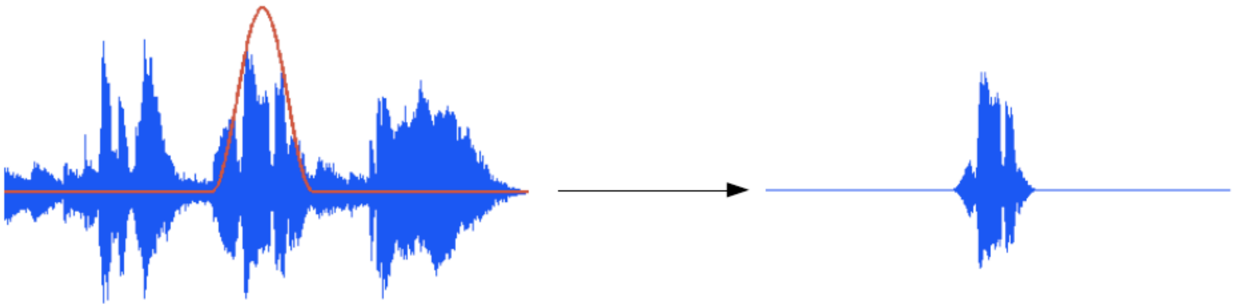

**Figure 1:** From grain-waveform (left side, blue) and grain-envelope (left, red) to the grain (right). In buffer-based granular synthesis, grains are generated by shaping a grain-waveform stored in a buffer with a chosen grain-envelope (here: Hann-window).

Departing from Xenakis's initial work on granular synthesis, composers like Curtis Roads and Barry Truax committed to the granular paradigm and further developed and popularized granular synthesis techniques from the 1970ths on (Roads 1988, Truax 1991). Roads's latest book gives an excellent overview of the field (Roads, 2004). Recently, the concept seems to have been extended and shifted towards a direction of *informed* granular synthesis. Novel contributions include Diemo Schwartz's real-time content based granulation and concatenation, where grains are ordered in a two-dimensional control-space according to different audio-features; synthesis is then based on defining a trajectory in this space (Schwartz, 2006). *Mosaicing* (Lazier and Cook, 2003) refers to the synthesis of an 'audio mosaic' based on an analysis of the employed grains and the target sound to be approximated by concatenation.

## Implementing granular synthesis feedback

A preliminary remark concerns the notion of granular synthesis as used in this paper. Regarding the systematic classification of music instruments, the German musicologists von Hornbostel and Sachs wrote almost a century ago: "Whatever object shall be ordered or systematized, it has emerged without any system and grows and changes without taking care of a notional scheme." (Hornbostel and Sachs, 1914, translated by the author).Today, the same difficulties arise for computer music instruments and methods of electronic sound synthesis as well as for the term of granular synthesis. Taking the above mentioned contemporary extensions into account while considering implementations with high level music programming environments today, the boundary between classical granular synthesis and other sample based techniques has become quite fuzzy. It seems more and more hard to decide where to draw the line between granulation and sampling. Thus, regarding the implementation, a generalized notion of granular synthesis incorporating these approaches is adopted here. These remarks might be clarified by the following description of the implementation of buffer-based granular synthesis. Its functionality ranges from the simple playback of a sound file stored in a buffer to *traditional* granular synthesis, meaning the generation of sonic events involving thousands of short sonic grains.

The implementation is realized in the music programming environment MaxMSP.[3] It is a generalization of the *granularized*-patch by Les and Zoax, which is part of the examples section of MaxMSP 5. Here, the grain waveforms are obtained from a circular buffer of arbitrary length. Default grain envelope is the Hann-window, but envelopes can also be freely defined. Figure 1 shows schematically how a grain waveform and a grain envelope generate a grain.
A *stream* of grains is defined as a collection of grains belonging to the same parameter settings. The control space for such a stream of grains is spanned by the parameters

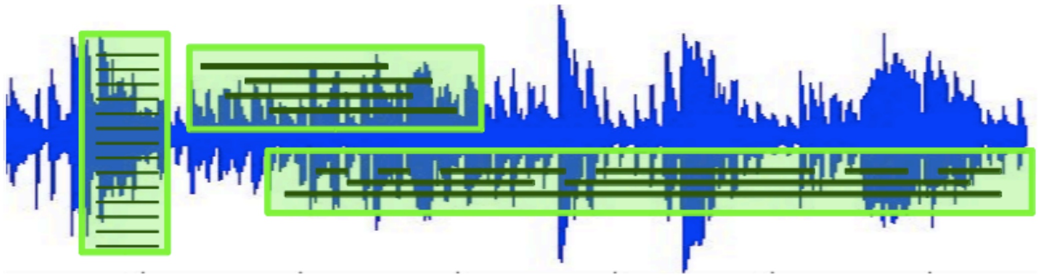

**Figure 2:** Sketch of different parameter settings of buffer-based granular synthesis. Each green box corresponds to one stream of grains. The configurations of the black lines schematically correspond to the positioning and length of the grain waveforms and number of grain layers as adjusted by the parameter settings for the respective stream.

- *number of grain-layers (density)*
- *plackback-speed (pitch)*
- *grain amplitude*
- *(mean & variance) panning*
- *(mean & variance) duration*
- *(mean & variance) start position*

(where only the uniform distribution was implemented for the generation of the variances). Figure 2 schematically shows three different streams, each corresponding to a different parameter setting. Note that these parameters can be controlled, as usual in computer music today, with any kind of user interface sending data to MaxMSP.[4]

The parameter *number of grain layers* of a stream was implemented as a discrete analog of continuous grain density, thereby taking advantage of the computational efficiency of the *poly*∼ object. This object creates virtual copies of a simple abstraction which basically employs the *play*∼ and *line*∼ objects, to repeatedly play back the grain waveform at a given speed. The number of *active* copies of this abstraction, generating grains according to the parameter settings of the stream, is then referred to as the *number of grain layers*. The author normally uses the patch with a maximum of 24 grain layers and 12 streams. Figure 1 sketches different parameter configurations for three different streams.

To enable feedback the buffer is turned into a circular buffer by using the % ∼ (modulo)-operation (according to the respective length of the circularity) in conjunction with the *line*∼ object in the above mentioned basic abstraction. Further, the buffer content can be updated in real-time. In that case audio input is written right before the window that the grains are obtained from. Letting the grain-window slide over the buffer in real-time and feeding back the synthesis result into the buffer then allows for granular synthesis feedback. Figure 3 is a schematic drawing of that setting, where the real-time update of the buffer is the main step towards establishing a feedback loop. Two exemplary forms of this non-standard sound synthesis method are characterized in the following.

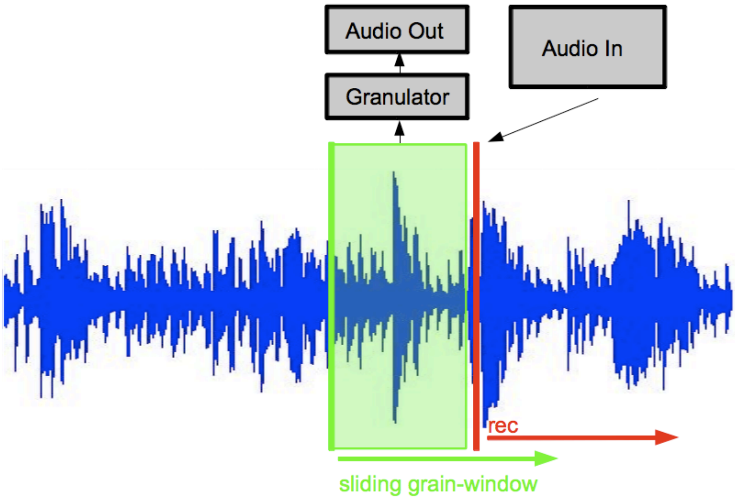


**Figure 3:** Real-time update of the buffer content enables granular synthesis feedback. The audio input is written right before the sliding window from which the grain waveforms are obtained.

# Feedback scenarios

## Direct feedback

The scenario of *direct* feedback refers to a situation where the result of the synthesis is directly fed back to the buffer that it reads from. It can be seen as a generalization of the principle of delay line granulation feedback, briefly mentioned (but not further described) in (Bencina 2006, 65).
In this scenario, a few additional processing steps are necessary to enable stable feedback. Since the parameter *playback speed* allows for transposition of the buffer content and since this operation is iterated, low- and highpass filtering must be used to prevent aliasing and low-frequency distortion of the signal.
Secondly, adaptive record level scaling must be employed to prevent level explosions (very likely to happen without). For the record level $l_{rec}$ and the signal $x$ the nonlinear heuristics is of the form $l_{rec} = -log_{10}(rms_\delta(x))$, where $rms(\cdot)$ denotes root-mean-square signal averaging with variable averaging time $\delta$. Thus, the record level is just the negative signal level in Bel. The author normally choses $1000 \leq \delta \leq 5000$ms, to obtain rather slowly varying amplitude evolutions. This choice plays an important musical role in the dynamics of the process, often leading to a certain periodicity of the amplitude-dynamics of the process.

Having described the necessary 'safety belts' for implementing direct granular synthesis feedback - a procedure based on iterative application of relatively simple operations on the signal - questions concerning the systematic behavior of this kind of feedback loop arise. By taking a closer (theoretical) look at the inherent dynamics of the system with regard to the parameters playback speed and amplitude, some systematic understanding the system's properties shall be achieved.
Let us therefore consider the evolution of the *(playback-velocity, amplitude)*-pairs in the case of two streams of grains with different velocities $\alpha$ and $\beta$. The granulation operation (denoted by $L$) acting on the input signal $x$ can then be written as

$$(Lx)(t) = x(\alpha t) + x(\beta t). \tag{1}$$

Note that this simply corresponds to playing back the buffer at speed $\alpha$ and $\beta$. It is then easy to

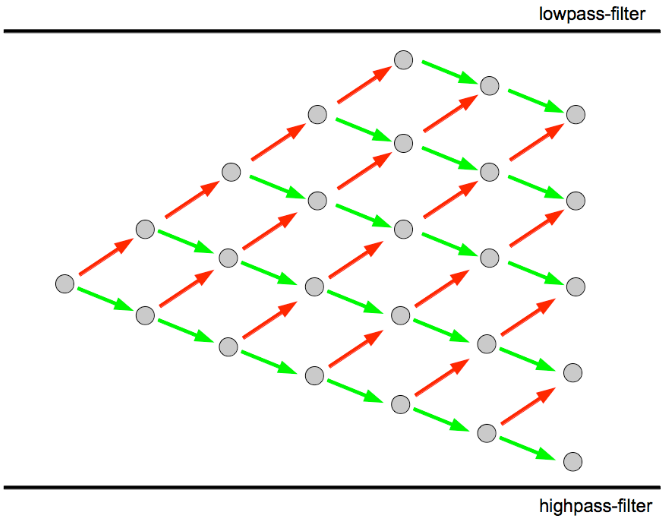


**Figure 4:** Schematic evolution of a playback-speed (pitch) lattice. The red and green arrows correspond to the transposition operations of two different playback-velocities.

see that feedback, i.e. iterative application of $L$ leads to

$$(L^n x)(t) = \sum_{i=0}^{n} \binom{n}{i} x(\alpha^{n-i}\beta^i t). \quad (2)$$

Thus, we obtain a set $C_n$ of *(playback-velocity, amplitude)* pairs at the n-th iteration:

$$C_n = \left\{ \left( \alpha^{n-i}\beta^i, \binom{n}{i} \right) : i = 1, \dots, n \right\}. \quad (3)$$

Consequently, the iteration leads to a kind of *lattice* of playback-velocity coefficients with amplitudes determined by the binomial distribution. This lattice is only of relevance as far as its playback-velocities together with the buffer content generate audio components in the hearing range (in practice: low-& highpass-range). Figure 4 sketches the temporal evolution of this lattice in the relevant range.
To prevent the lattice (and therewith the synthesis result) from 'migrating' out of the hearing range, we need $\alpha = \frac{1}{\beta}$, i.e. the coefficients being symmetrically distributed around the playback speed 1 and maximum amplitude coefficient. Since the binomial approaches the normal distribution in the limit, we theoretically obtain an invariant pitch-amplitude structure in the limit. This limit should then be an eigenvector of the operator L, technically speaking. That being said, the "empirical" observations concerning the sonic convergence might appear less unexpected.

As a demonstration of this principle of two different playback velocities generating a process, Figure 5 shows the spectrogram (using a Hann-window of window length 1024 and overlap 4) of an example of the transformation of a finger snap to a harmonic stationary sound of 30 seconds length (for sound examples see: http://kaisiedenburg.net/publications). Its playback velocities are 0.5 and 2, and at about the half of the example, the number of grain layers was increased. The time-frequency visualization clearly shows that the transient snap-sounds (vertical lines) are transformed into harmonic sounds (horizontal lines) in the end, corresponding to a musical transformation from rhythm to (stationary) timbre.

For musical use, all synthesis parameters can be controlled in real-time. In case of the pitches, the adaptive record level scaling enables the relaxation of the above theoretical constraint of inverse

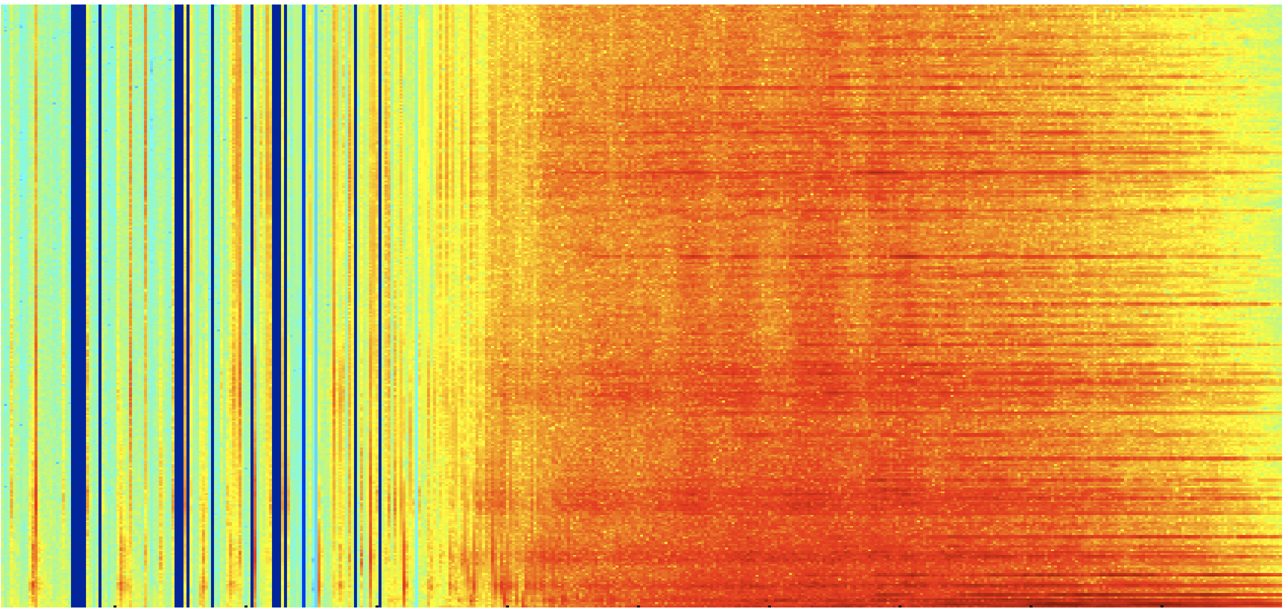

**Figure 5:** Spectrogram of the evolution of a finger-snap as a demonstration of the process dynamics. A Hann-window of length 1024 and overlap 4 was used. Playback-velocities are 1/2 and 2, the process-duration about 30sec. The effect of heightened density in the middle of the example is caused by an increased number of grain layers.

playback speed coefficients such that the system's property of stable evolution is still guaranteed. However, the properties of the unfolding of the process can be subverted by playing around with the real-time parameters. For example, diminishing the variance of grain start position and grain length leads to *almost* synchronised grains which cause combfilter effects, again effecting the sonic evolution drastically. These combfilters with its spiky impulse responses amplify certain harmonic components strongly and suppress all others. In effect this leads to a sonic limit which is of very harmonic, organ-like tone-color, without audible noise contributions.
The playback-velocities (pitch) as well have great impact on the process evolution, since they determine the form of the *harmonic lattice*, i.e. the unfolding of the playback velocities (pitches). While inverse pitches lead to a stable sonic limit (as suggested by the above argument), other pitch combinations will give rise to constant sonic flux. Thereby, the process can give rise to Shepard-tone-like sound transformations, meaning a sequence of sonic events which perceptually seems to rise or fall infinitely.
Conclusively, direct granular synthesis feedback gives rise to a dynamical system of sound. Operations on the local level determine the overall properties of the musical unfolding. This clearly resembles "Xenakis's gesture [which] aimed at generating, by one and the same process, both complex timbral entities and the overall form of the work, so that the passage between micro- and macro-structure is rendered continuous." (Di Scipio 1998, 219).

### Mediated feedback

The scenario of mediated feedback refers to a musical situation where the feedback loop includes an external mediation. This is for example easily realized by diffusing the granulator's output by loudspeakers and using a microphone as real-time input source for the buffer. The result of the synthesis is then externally mediated by a performer, a space or any kind of sonic transformation. A well known example of such a mediation is Alvin Lucier's *I am sitting in a room* in which in controlled feedback loops the resonant frequencies of a room are excited by a voice. This situation turns out to be a special case, that is, easily realizable with the presented implementation (note that a generalized form of granular synthesis is considered here, including the case of *very* long grains).

I used the system in improvisatory settings with instrumental performers focussing on musical feedback. The real-time update of the buffer used for the synthesis creates a musical situation where the material of synthesis and performer can be continuously mutually adapted, leading to a strong sense of homogeneity of the sonic material. I also employ intermediate scenarios where both processes, direct and mediated feedback, are running at the same time. Then the question arises which sphere dominates the other: Are the internal dynamics of the process stronger than external influences (as contributions of an instrumentalist into the system), that is, are they robust to external interventions?[5]

### Sonic emergence

After having set up his basic hypothesis about the granular nature of sound (as outlined above), Xenakis continued by envisioning sonic objects of higher orders:"Suppose that each point of these clusters represents not only a pure frequency and its satellite intensity, but an already present structure of elementary grains, ordered a priori. We believe that in this way a sonority of a second, third or higher order can be produced." (Xenakis 1992, 47) Interestingly, the scenario of direct feedback resembles Xenakis vision about how to arrive at higher order sonorities quite closely, treating whole configurations of grains as elementary grains. As it was seen, the simple iterated application of granulation gives rise to sonic convergences, as for example leading from noise to harmonic timbre. The major difference remains the ordering principle of the grains: while Xenakis uses in *Analogique B*, so to say, *stochastic* feedback (using iterative stochastic procedures, alias Markov chains), the presented direct scenario employs *deterministic* granular feedback as a means of sound transformation.
Agostino Di Scipio has taken up the Xenakian notion of higher order sonorities but doubted whether Xenakis's methods were suited to generating these. As he notes, "the limit of Xenakis' mechanisms lies in the fact that they hardly bring forth an *evolutive* flow in sound matter and determine the emergence of 2nd-order sonorities." (Di Scipio 1997, 176). Di Scipio neither wants to criticize the particular arrangement of grains in *Analogique B*, nor does he think the piece's "failure" lies in the computational limitations of its time (which is a strong claim). His critique is rather concerned with the particular ordering principles Xenakis employed: "stochastic laws seem to prevent the emergence of a higher structural level; they seem not to be capable of bringing forth those 'sonorities of second order' Xenakis expected to achieve." (Di Scipio 1998, 219)[6] While this might hold true for the particular stochastic method for ordering the grains as employed in *Analogique B*, it certainly does generalize to the whole class of generative stochastic algorithms in music-computation. An example for this is Xenakis's *dynamic stochastic synthesis* as realized in his late electronic works *Gendy3* (1991) and *S.709* (1992). This method of synthesis operates on the lowest possible level, i.e. the sample level, by organizing interpolated sample breakpoints with the means of random walks. However, Xenakis's sonic results certainly inhibit emergent forces. As described in (Hoffmann 2009), the particular stochastic composition of the program (or *modeling* in scientific language), that is, the way how chance is framed, is what finally determines the essential properties of the *GENDYN*-sound.
Di Scipio is as a composer committed to granular composition, especially striving for the emergent formation of grains without being interested in stochastic ordering principles (in so far abandoning aspect b) of Solomo's granular paradigm). As a constructive conclusion of his discussion of *Analogique B*, he proposes his concept of *audible ecosystems* as a seemingly more constructive approach to sonic emergence (Di Scipio 1997, Meric and Solomos 2008). He considers an *eco*system (in contrast to merely a *system*) to be created by the "recursive coupling of an autonomous system with its ambience." (Di Scipio 2003, 273) Concerning the musical implications of such systems he writes "[...] sound is the interface. All processes or equipment involved, including microphones and loudspeakers, are uniquely vehicles or transformers of sonic information. As finally perceived by listeners, sound bears traces of the structural coupling it is born of." (Di Scipio 2003, 275) Relating these descriptions to the ones about mediated feedback, one can conclude that the latter is at the core of such an ecosystemic approach.
The scenario of direct feedback proved to give rise to some kind of sonic emergence without being coupled to external influences. On the other hand, it was argued that the use of stochastics

in sound synthesis per se do not prevent emergence, as exemplified by the *GENDYN*-program. Conclusively, neither the coupling of a system with its surrounding, nor the abandonment of stochastic algorithms seem to be a necessity for establishing sonic emergence, as proposed by Di Scipio. In this sense, his critique appears to be biased towards his own vision of ecosystemic composition. Chance can be properly framed, likewise non-coupled deterministic feedback systems can be domesticated. These examples support the point of view that it is rather about the particular configuration of musical feedback loops that enables or prevents the emergence of systemic higher-level properties.

## Conclusion

This paper described a pathway for approaching granular synthesis feedback. The granular paradigm was therewith once more extended in the direction of feedback and emergence. The paper presented the method of granular synthesis feedback, its aesthetic origins and characterized two musical scenarios featuring a kind of emergent feedback. Concerning the question about sonic emergence, the discussion of the scenarios' dynamics hopefully contributed to a more differentiated perspective on the debate.
Future work will include most importantly the musical exploration of this novel non-standard technique via composition and improvisation. That will be one attempt of many to once more fulfill Xenakis's prophecy: "The basis of the timbre structures and transformations will have nothing in common with what has been known until now." (Xenakis 1992, 47)

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## Notes

[1]From a formalized point of view, classical Fourier-analysis considers signals to consist of superpositions of trigonometric basis functions. A Fourier expansion of a $2\pi$-periodic signal $s = s(t)$ is thus of the form

$$s(t) = \sum_k c_k e^{2\pi ikt} \tag{4}$$

where the $c_k$ are a sequence of complex coefficients. The main problem of this kind of representation is that it can only represent (and thus also generate) stationary signals. In most tasks in signal processing today, the Fourier expansion is consequently replaced by a *Gabor*- or *Wavelet*-expansion which considers signals as sums of collections of functional "atoms" of short duration.

[2]The so called Gabor transform is a generalization of the well-known short-time Fourier-transform (and its visual outcome, the spectrogram). It provides reasonably good time- and frequency-localization at the same time, therewith allowing for the analysis and synthesis of time-variant signals. An arbitrarily precise expansion in terms of time- and frequency is impossible because of Heisenberg's uncertainty relation. In terms of modern mathematical language, any signal $s$ can then be written as

$$s(t) = \sum_j \sum_k c_{k,j} T_k M_j g(t) \tag{5}$$

where $g$ denotes the functional building block ("acoustic particle"), and T and M denote the operators shifting $g$ in time and frequency. The set of expansion coefficients $c_{j,k}$ is also called the *Gabor-matrix*. This formula is a modern generalization of Denis Gabor's proposal of the 40th of the last century to use Gauss-functions as atoms $g$ in this kind of representation (Gabor 1946). Today, the field of time-frequency- and Gabor-analysis is an evolving area of research, involving contributions from mathematics, engineering and computer science. It lays the groundwork for many important questions in musical signal processing, e.g. signal-adaptive time-frequency representations. See e.g. (Mallat 2009) for an introduction.

[3]Please contact me, if you are interested in the basic patches.

[4]I have already used different settings of keyboards and other touch pads for the control of the pitches. For the other synthesis parameter I use standard slider and knob controls. It seems desirable, however, to make as many as possible parameters accessible via only one control interface.

[5]"Convergence Zone", a piece developed by saxphonist Alex Hofmann and the author, musically explores this kind of direct and mediated granular synthesis feedback. It is premiered in June 2011 at the festival *next_generation* at ZKM, Karlsruhe. Other explorations are about to follow...

[6]Di Scipio is apparently referring to the concept of *weak* emergence, where the emergent higher level patterns are unexpected, but can be explained in terms of the lower level interactions of the system, as e.g. in the case of the growths of a beanstalk. This can be differentiated from the concept of *strong* emergence: "truths concerning that phenomenon are not deducible even in principle from truths in the low-level domain." (Chalmers 2006, 244) Chalmers considers the phenomenon of consciousness as the only existing example for strong emergence.