Rhythmic Paradoxes and Illusions: a Musical Illustration

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Abstract
A musical composition by the author, Contre Nature (Against Nature), for percussion and computer-synthesized or computer-processed sounds, purports to musically illustrate paradoxical rhythmic phenomena. In the first movement, due to stream segregation, rhythmical figures emerge from regular beats. In the second movement, the beat is also steady, however feelings of speeding up and slowing down are provoked by mixing in varying proportions a basic beat with its rhythmic "octaves"- i.e. with beats two times, four times, eight times as fast. In the third movement, after an initial part suggesting an acceleration, one can hear beats that seem to accelerate endlessly - actually a cyclic pattern - then speeding up beats that end up slower than the initial beat rate. Examples are given of such illusory rhythmic patterns and of their musical use.

1. Introduction
I shall present here several rhythmic effects that can be considered paradoxical or illusory. These effects are called for in my piece Contre nature, for solo percussion and computer-generated tape, which will be played at the concerts of the 1997 International Computer Music Conference.

2. A beat which slows down (or speeds up) endlessly
In 1970, Kenneth Knowlton generated a beat that seemed to endlessly speed up (or slow down). He worked directly on the sound wave to achieve an ambiguous periodicity, constructing waveforms comprising periodic pulses with different periods in octave relations and with different amplitudes. If, for instance, pulses of amplitude A1 occur at instants O, T, 2T, 3T, etc, and pulses of amplitude A2 occur at instants T/2, 3T/2, 5T/2, etc, the period of the wave is T; however it becomes T/2 if A2=A1. Thus Knowlton achieved a circular deceleration by making T go from T0 to 2T0- slowing down- and at the same time increasing A2 from a small value to A1 - halving the period, thus doubling the beat rate; the rate is thus the same at the beginning as at the end, although it has been constantly slowing down.

I have realized the same effect using amplitude envelopes generated by additive synthesis. I add periodic envelopes with recurrence rates of f, 2f, 4f, 8f, etc. The amplitude of each "rate octave" is controlled separately. Thus I can achieve a synthesis such that, in 20 s, the value of f diminishes from 2 per second to 1 per second: if during the same time interval of 20 s I make the amplitude of the same component go from A to 0 and I bring up the amplitude of the 2f component to A, the beat rate has been halved, but the octave above has gradually replaced the original beat, so that one has got back to the point of departure. This process has the advantage over Knowlton’s that the combination of envelopes can be applied to any kind of wave - in fact, different "rate octaves" can even be applied to different frequency components to achieve special effects, in particular that explained below of a pattern of beats which seem to slow down when one doubles the speed of the tape on which it is recorded.

As an example, I shall play a beat which endlessly slows down, combined with a pitch which endlessly goes down. The latter paradox had been demonstrated in 1963 by Roger Shepard (Shepard, 1964) for discrete steps, and in 1968 by myself (Risset, 1969) for continuous gliding tones. (In his original article, Shepard stated that he could not obtain the effect unless a silent gap separated the successive tones). Even though the slowing down and the descent are cyclic, their combined effect can be quite depressing for the listeners, to the extent that I renounced using it as the basis of a musical composition inspired by the poem by Henri Michaux, La ralentie. The reverse process - speeding up and going up in pitch, even in a circular fashion - conveys a completely different feeling. There seems to be a strong trend associated with the sign of the derivative of the beat rate: accelerating the beat has a dynamogenic effect, while slowing it has a soothing or even depressing effect. This seems to have more impact and to hold for more listeners than a pitch ascent or descent: while some persons are very sensitive to the fact that pitch is ascending or descending, others are not. The pitch-evaluating strategy of many listeners puts a
strong weight on the spectral distribution: but brilliance, related to the frequency position of the center of gravity of the spectrum, cannot be made to increase or decrease for ever. Moreover, quite a few listeners find down- gliding pitches depressing, and a number of them mentioned that pitch glides, downward and upward, made them anxious - in several cases, they mentioned the association with sirens which they heard in anxiogenic circumstances (war bombings or ambulances in accident). The gliding circular descent is described in #513 of my 1969 Sound Catalog. The control of the amplitude envelopes producing the circular deceleration is achieved in the same way: one should simply replace the bottom oscillator by one provided with the envelope function, and scale the inputs of the tops oscillators to the appropriate values.

In my composition Contre nature, most of the third and last section centers around an endless acceleration heard on the tape: the amplitude envelopes at rates f, 2f, 4f, 8f, etc, are applied to percussion-like synthetic tones, close to some described in #400 of my 1969 Sound Catalog. The performer attempts to emulate the acceleration by following the speeding up beat: but his own pulse definitely gets faster, since it is not split and halved as the synthetic one.

3. A steady beat which insidiously speeds up

In the additive synthesis of envelopes which I described above, one can keep a steady beat but insidiously double it: this can be done by forcing the amplitude of the envelope at rate f, initially predominant, to go down gradually, and the amplitude of the envelope at rate 2f to go up gradually, so that the basic pulse seems steady while the pulse at double rate gradually takes over. This is the equivalent in the time domain of sounds made up of sine waves at octave intervals; such sounds can be made to go up gradually, so that the basic pulse seems steady while it takes 20 s to half the beat rate for all components.

I shall give a sound example of this effect, and also a compound example where at the same time an ascending pitch ends up lower, and an accelerating beat ends up slower. The effect also works in reverse. The recipe for such effects is fully given in Risset (1989).

4. A beat which slows down endlessly, yet which ends up slower

In 1968, I synthesized a continuous tone that seemed to go down in pitch yet ended up higher than it started. The recipe is given in #514 of my 1969 Sound Catalog. While all octave components glide down in pitch, the upper ones are reinforced at the detriment of the lower ones, so that the centroid of the spectrum goes up. This is a conflicting situation where two distinct cues for pitch, usually correlated, are divorced, namely tonal pitch (identical or closely related to pitch chroma or pitch class) and spectral pitch (identical or closely related to pitch height or brilliance). In 1975, I obtained in a similar fashion the effect of beats that seem to slow down yet that are clearly faster at the end. I used basically the same process as in the endlessly speeding beat, but I changed the amplitudes and the recurrence rates of the components at different paces: for instance, in 10 s, the amplitude weight shifts from one component to the component one rhythmical octave above, while it takes 20 s to half the beat rate for all components.

In Contre nature, the last minute of the tape part in the third and last movement consists of such a beat which constantly speeds up, yet which ends up much slower than it started. The instrumentalist endeavours to follow the acceleration of the tape without gradually halving the rate: he quickly reaches very high speeds, thus he has to resume his acceleration from a slower starting beat.

5. A pattern of beats which slows down when one doubles the speed of the tape recorder

In 1986, I demonstrated a pattern of beats which appears to slow down, for most listeners, when on doubles the speed. This effect is described in detail in Risset (1986); it is an extension of the pitch effect of a tone that seems to go down in pitch when all its component frequencies are doubled (Risset, 1971).
The initial pattern of beats consists of stretched rhythmical octaves applied to frequency components in exact octave relation. For instance, on a sine wave at frequency 100 Hz, one applies an envelope at a recurrence rate of 1 per second; on a sine wave at frequency 200 Hz, one applies the same envelope at a recurrence rate of 2.1 per second; on sine wave at frequency 400 Hz, one applies the same envelope at a recurrence rate of 4.4 per second; and so forth. When the speed of the tape recorded is doubled, all frequencies and all recurrence rates are doubled. However, the listening experience for most listeners is that of a slowing down of the rate. This can be understood if one takes into account the conditions in which the ear can appreciate "temporal coherence" (Van Noorden, 1975): in a situation of stream segregation (Bregman & Campbell, 1971; Bregman, 1990), the listener can appreciate temporal relations precisely within a stream, but very poorly across different streams: it is hard and often impossible to recognize the temporal order of two successive elements when they are segregated in different streams. In the latter case, the rhythmic comparisons between the initial sound and his speed-doubled variant are performed locally, not globally. Now, on the 200 Hz component, the beat rate is 2.1 per second for the initial sound and 2.0 for the second one; on the 400 Hz component, the beat rate is 4.4 per second for the initial sound and 4.2 for the second one; and so on. Thus, the local comparisons concur in giving the impression that the beat rates are slower in the speed-doubled version of the sound.

6. "Virtual" rhythmic figures

This effect is not called for in the composition Contre nature, but it clearly demonstrates that the perceived rhythmic patterns do not depend solely upon the timing of auditory events. Rhythmic figures can arise from stream segregation phenomena: Such figures can be said to be phenomenal, illusory or "virtual": they have the virtue to induce specific rhythmic figures appreciated by listeners. This relates to the tendency of perception to group notes in certain ways.

Thus the first movement of Contre nature presents rhythmical patterns induced by stream segregation - even when the time interval between successive sounds stays the same. The segregation is provoked by the differences between successive sounds. Differences are introduced first in terms of spatial localisation; then in terms of amplitude; then in terms of pitch and timbre. The faster the speed, the stronger the segregation: thus, when certain motives are repeated faster and faster, the rhythmic feeling can change as new rhythmic figures stem out of the growing segregation.

One should note that rhythms induced by stream segregation are often used in music. Shima Arom (1984) has demonstrated its importance in African rhythms. David Wessel (1979) has given a striking example where segregation based on timbral differences completely changes the perceived melodic and rhythmic patterns. In his sixth piano Etude, György Ligeti has resorted with great ingenuity to segregation to enable the performer generate rhythmic relations that seem inhumanly complex (for instance 5/7): the performer plays fast regular sixteenth notes, but every 5th and 7th note stand out because of their melodic position and/or because they are stressed. I have used this process in the end of the first section of Contre nature, but I used segregation through timbral differences, which Ligeti could not do in a piano etude.

7. Conclusion

The composition Contre nature illustrates the complexity of rhythmic perception: the perceived rhythmical structure depend upon other factors than the mere timing of auditory events. Although such phenomena seem to go against the physical nature of the sound - the objective timing of events - they in fact reveal certain processes of auditory perception, demonstrating the complexity of the psychoacoustic relation. Insofar as music is meant to be heard, this psychoacoustic relation must be taken in account by computer music practitioners to fully exploit the potential of the medium and to ensure that the relations specified between the physical sound objects map into the desired perceived musical structures: Contre nature exemplifies this in the rhythmic domain.

References

Note

The "recipes" for the discussed rhythmical patterns are given in the article or in the following references. Some of these references include sound recordings. The author plans to publish a book with recipes and recordings of auditory illusions as well as other aspects of computer sound synthesis design: the above-mentioned phenomena will be included in this publication.


