Sound projection as a compositional element:
The function of the live electronics in the chamber opera *Solaris*

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Solaris is based on a science fiction novel by the Polish author Stanislav Lem. It seemed logical to include mathematical principles on both the composition and in the live electronics in order to construct a specific musical atmosphere. The compositional structure, sound treatment and sound spatialisation were to provide a special ambience for the story itself. The opera consists of three parts, each of which focuses on one mathematical principle: in the First Act stochastic treatment, in the Second Act interpolation (direct connection between a starting and an ending point) and the Third Act mathematical functions (like the sine or the exponential function). These mathematical principles influenced both the instrumental composition and the electronic treatment. Many sections of the instrumental part were generated using the software "Patchwork" (IRCAM), which determined pitches and rhythms, but also the both the temporal development of the inner structure of larger sections and the transformation of musical elements within those sections. The control of different parameters during the sound treatment is based on these mathematical principles, as is the spatialisation of these sounds in the concert hall. They were processed in real time with three IRCAM sound-cards and a NeXT computer. The "Spatialisateur" (IRCAM) was used for the first time in a concert hall under live conditions.

The philosophy of the Spatialisateur program is based on a circle loudspeakers in a plane surrounding the public (see Figure 1). Every sound projection depends on two parameters: angle and distance. The angles range between 0º and 360º and the distance is simulated with the aid of a combination of volume and reverberation. This system is easy to handle for composers, but it includes more complex levels beyond the basic functions which are responsible for the high quality of the sound projection and its variability for adapting to the acoustics of different concert halls.

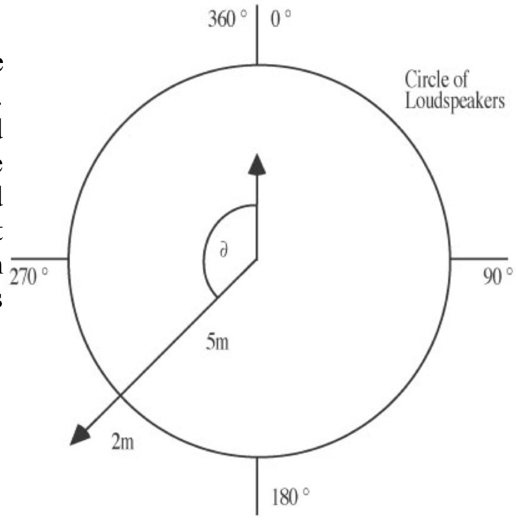


Figure 1.
The basic parameters of sound projection in *Solaris*.

The following examples will show different results of composition, sound treatment and sound projection in my opera *Solaris* with the mathematical background I described above.

The beginning of the First Act is dominated by a piano sound in the low register. The bass line was calculated in "Patchwork" by the following algorithm (the score shows the the beginning of the whole passage):(see figure 2 at the end of the text) An algorithm which calculates the values using random numbers with Gaussian distribution around the central note, here E1, provided pitches as well as durations. The order of the pitches remained as calculated, the durations were arranged in a "ritardando". The sound treatment of the piano is a combination of flanging and pitch-shifting.

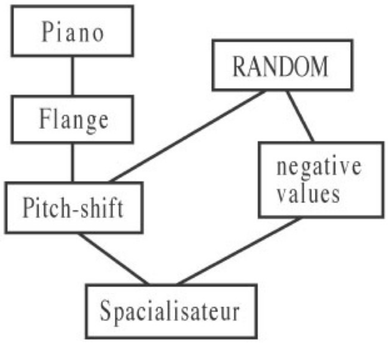


Figure 3.
The algorithm for treatment of the piano sound. In performance, the DSP (digital signal processor) of the IRCAM card constantly delivers random numbers which influence the sound of the flanging by changing the frequency of the controlling sine wave. In the same way the transposition interval of the pitch-shift is constantly modified. The new positions are reached by interpolation. Here the boundary conditions of the flanging and the pitch-shift: Flange: Frequency of the sine 0.25Hz ‹-› 0.33Hz, Feedback 0.8; Pitch-shift: Delay 5ms, Transposition -64 cents ‹-› +64 cents, Feedback 0.75.

The acoustic result is a continuous ribbon of sound which changes constantly without any periodicity. The long strings of the piano in the low register with their many partials provide a very rich sound. The sound-projection uses the same random numbers which modulated the flanging and the pitch-shift by transforming them into distance values between 4 and 8 meters (loudspeaker level: 3m). Transformations which led to higher pitches yield longer distances, those which led to lower pitches yield shorter distances. A counter-clockwise rotation always steers towards the next calculated point. As long as the rotation time itself remains constant (0.7 rotation every second), the speed of the sound-path varies in accordance to the changing distance. A possible sound-path could look like this:

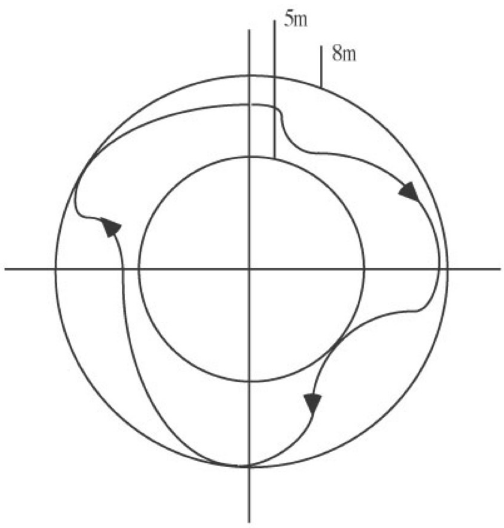


Figure 4.
A possible sound-path for the spatialisation of the piano sound.

The acoustic impression is a mirror of the compositional principle that the random treatment in the composition can be heard in the electroacoustic transformation and in the spatialisation simultaneously.

“Interpolation” is the subject of the Second Act. It influences many different parameters. A simple case is the creation of a linear scale between two different pitches with a given number of steps. Interpolation is also possible between two melodies or two different rhythms with the same number of notes. The intervals between the notes or their durations are gradually changed in a fixed number of steps. An exact documentation of the gradual transformations used in *Solaris* would require more space than can provided here, but a small example from the second scene may help to illustrate the principle. (See figure 5 at the end of text) Starting from E4 the notes A#4 and B3 are reached with semitones. Here the number of steps is different (6 and 5) and the total time has to be the same for all. Different speeds are calculated.

The following passage for flute also includes interpolation principles. The sound treatment and the spatialisation change in accordance with the musical development. The pauses between the motives give space for delays. (see figure 6 at the end of text)

This section is repeated twice in variation (the second time with viola). The algorithm of the transformation consists mainly of delays:

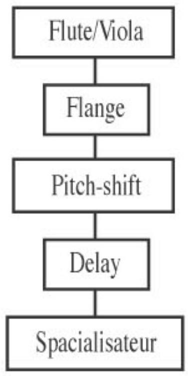


Figure 7.
The algorithm of the sound transformation of the flute passage in Figure 6. The change is audible because of the stretching or shortening of the delay time:
Flange (Filter: 200Hz ‹-› 300Hz, flange Frequency sine: 0.5Hz, Feedback 0.89).
a) (Flute) Pitch-shift (Transposition: 100 cents), Delay (Del 0 ms -› 2.0 sec. in 45 sec., Feedback: 0).
b) (Flute) Pitch-shift (Transposition: 110 cents), Delay (Del 1.0 ms -› 3.0 sec. in 30 sec., Feedback: 0).
c) (Viola) Pitch-shift (Transposition: -190 cents), Delay (Del 2.7 ms -› 0 ms. in 20 sec., Feedback: 0).

The flange and the pitch-shift provides a somewhat surrealistic impression. The sound transformation separates gradually from the origin in a), the treatment enlarges again in b) and comes back to the starting point in c).

The sound projection is done in a similar way:

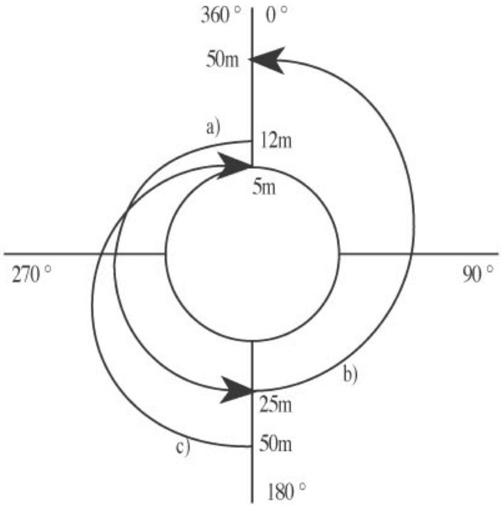


Figure 8.
The paths used for the sound projection of the flute passage in Figure 6. The actual values used for the movement are:
a) Position: 0º -› -180º, distance: 12 m -› 25 m in 40 sec.,
b) Position: -180º -› -360º(0º), distance 25 m -› 50 m in 20 sec., and
c) Position: 180º -› 360º(0º), distance: 50 m -› 3 m in 18 sec.

The duration of the movement is always shorter than that of the delay change. This way, the final position of the spatialisation can be reached before the las motive has been played.

The fascination of this passage lies in the congruence of the sound transformation and the movement in space. The flute (viola) is located in front of the audience. When the transformation leaves the original sound, the transformed sound leaves the location of the player. The same happens at the end in the opposite direction.

The Third Act is partly dependent on mathematical functions. Figure 12 shows the use of two exponential functions which generate pitches and durations. (see figure 12 at the end of text) In this example, acceleration and diminution of the intervals are simultaneous, and we perceive musical congruity, which is actually an illusion. While listening to this passage, we associate an increasing curve with smaller values, but in fact it is exactly opposite: the small values in such functions are at the beginning and then constantly increase. In another scene, sound transformations are generated with sine-functions. The pulsation controls the delay time and produces glissandi up and down.

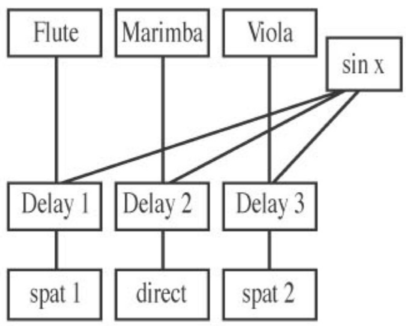


Figure 10.
The algorithm for controlling three delay-times with a single sinusoid.
The actual values used are:
Delay1: 300ms —› movement between 100 ms ‹-› 500 ms;
Delay2: 900ms —› movement between 700 ms ‹-› 1100 ms;
Delay3: 600ms —› movement between 400 ms ‹-› 800 ms;

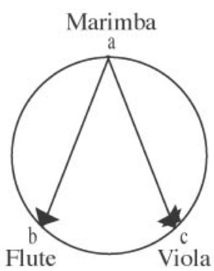
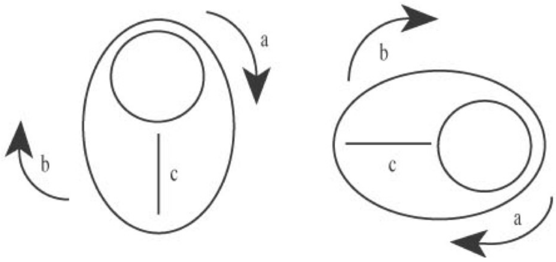


Figure 11.
The pattern of sound projection of the flute and the viola music from Figure 10.

In the first section the delays are faded in, then the sine-function increasingly influences the transformation between -200 ms and +200 ms of the central delay-time and then the rising and falling glissandi begin. In a third passage an increasing feedback of the delays provide more density and more transpositions. The instruments play motives which also symbolise the sine-function, so that the principle of the transformation is represented by the music itself. (see figure 9 at the end of text) The sound projection here is easy. During the whole process (90 sec.) the effects of flute and viola are moved in a straight line through the space: flute a -› b, viola a -› c, the marimba remains in a. My original wish to move the sounds with sine-functions as well had to be abandoned. The second processing was too complex to allow recognition of complicated simulated movements in space. The solution described above is perceptible as a process where the space is gradually included in the musical action. A sound movement controlled by a sine-wave can be heard in another scene, where continuous music patterns from the piano are projected as follows:

Figure 13.
The projection of the piano controlled by sinusoidal movement: Movement a is the rotation of the sound, movement b is the rotation of the ellipse a/b=3/1, and movement c is the change of distance (from 3 to 20 m).



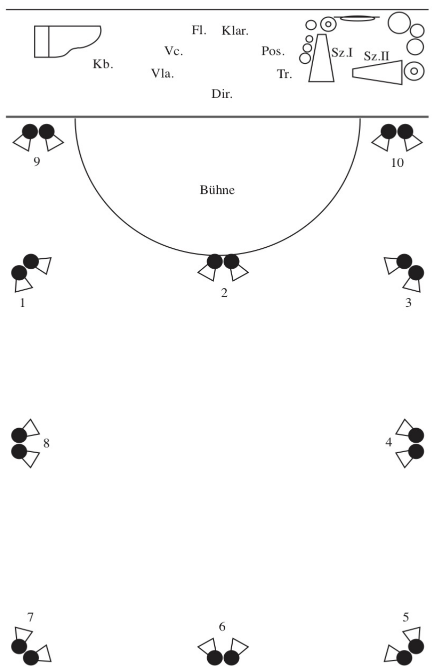
Because of the pulsation of the sound movement the acoustical impression of speed becomes dominant. The approaching and departing sound in combination with the rotation simulates an acceleration and deceleration of the movement. The impression of changing speed is supported by the combination of maximum tempo and closest distance. In addition the whole process accelerates in two steps:

a: 1 circle in 10 sec. -› 1 circle in 3 sec. over 102 sec.,
b: 1 circle in 30 sec. -› 1 circle in 9 sec. over 102 sec.,
a: 1 circle in 3 sec. -› 1 circle in 1 sec. over 106 sec.,
b: 1 circle in 9 sec. -› 1 circle in 3 sec. Over 106 sec.

The treatment of the piano sound ranges from the natural sound at the beginning to huge descending glissandi at the end.

Installation in the hall for the first performance of *Solaris* at the *Munich Biennale:*

Figure 14.
For the world premiere during the festival *Munich Biennale* the musicians and the conductor were located behind the stage. (see Figure 14) The influence of the acoustic sound of the instruments on the live-electronic sound transformations and the spatialisation was minimal. The Spatialisateur program used the loudspeakers 1 – 8 to provide a continuous change from one loudspeaker position to the next during a gives sound movement. The instruments were amplified and played over loudspeakers 9 and 10. The sound was placed in the stereo panorama according to their position in the hall (e.g. the piano to the left, the percussion to the right). The singers used cordless microphones which were played over loudspeakers 1 and 3 and supported by loudspeaker 2 to balance the centre.



Due to the fact that the hall was rectangular and not a perfect square, The Spatialisateur had to be adapted to the hall. For example all previously produced distances were adjusted to give a similar acoustic impression to that in the studio. Allowances were made for the reverberation of the hall as well as the new dimensions of the loudspeaker circle.

Finally, it should be mentioned that many of the parameters of the software which control the different effects of the Spatialisateur program are relative. Distances are perceived very subjectively. The acoustical impression of 5 m distance can be controlled by a value of 12 m in the software and vice versa, depending on the nature of the sound. The timbre of the sound itself and the amount of time the listener needs to recognise the movement of a sound are very important factors in this regard. It seems that sound movements in space are more difficult to perceive than the classical parameters in music. Therefore, in *Solaris* polyphonies of sound movements were kept straightforward and high speed sound movements were cautiously introduced. The genre opera already offers an immense amount of sensual information of different kinds, so that the Spatialisateur program was only used for very special scenes. That made this kind of sound treatment appear logical and seemed to broaden the resources of dramatic expression for the whole conception of *Solaris*.

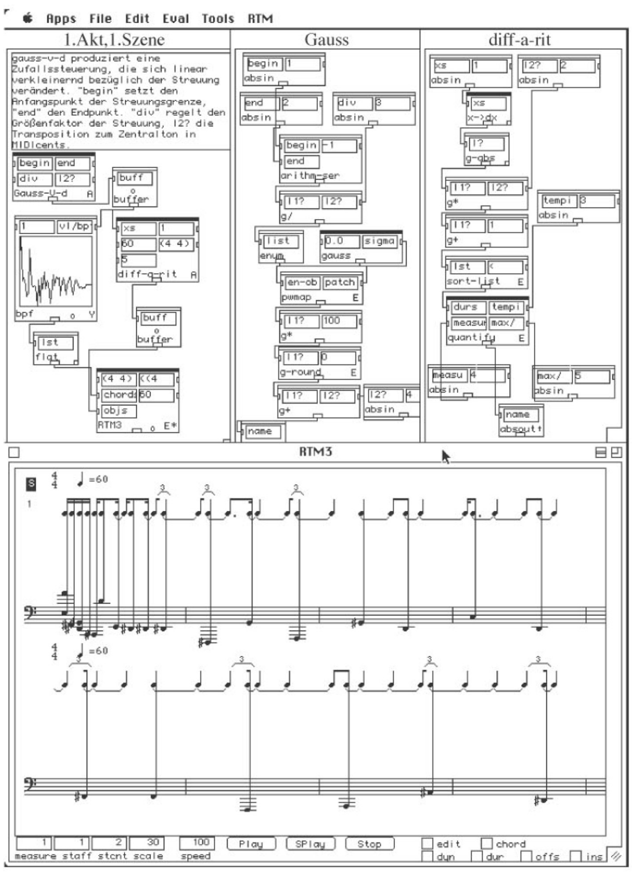


Figure 2.
The Patchwork algorithm for the bass line in the first act of *Solaris*.

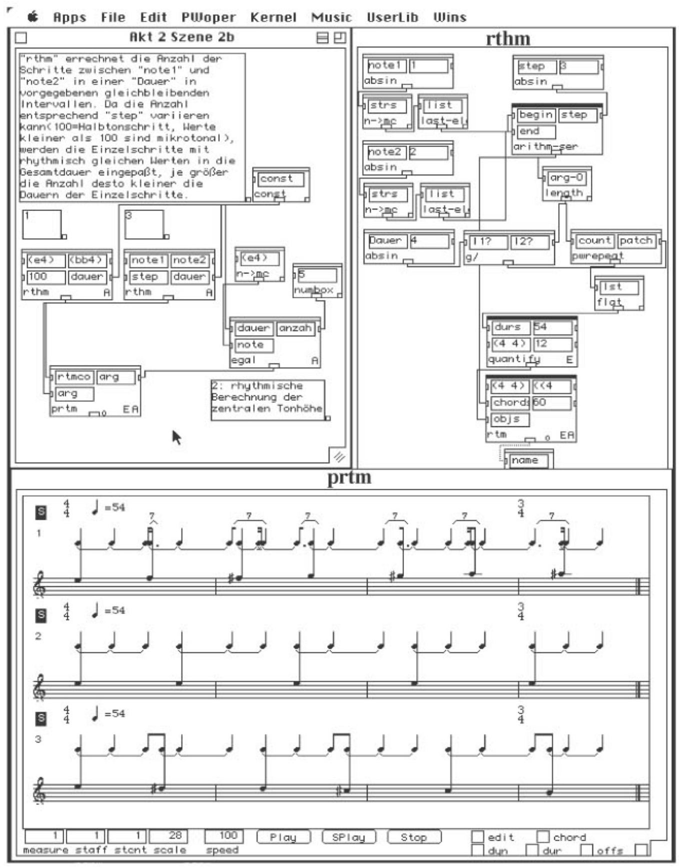


Figure 5.
A Patchwork algorithm for interpolation taken from the second scene of Act Two.

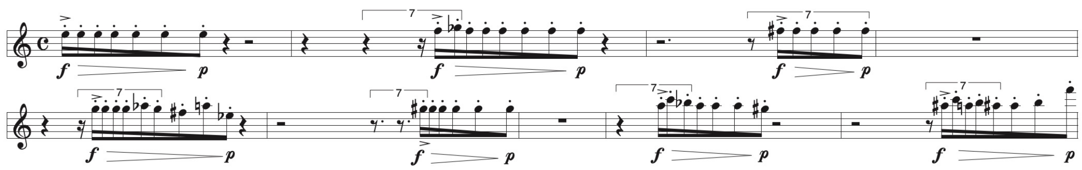


Figure 6.
A short passage for the flute showing rests for the added delay.

Figure 9.
An instrumental excerpt from Act Three showing the representation of the sine function in instrumental voices.

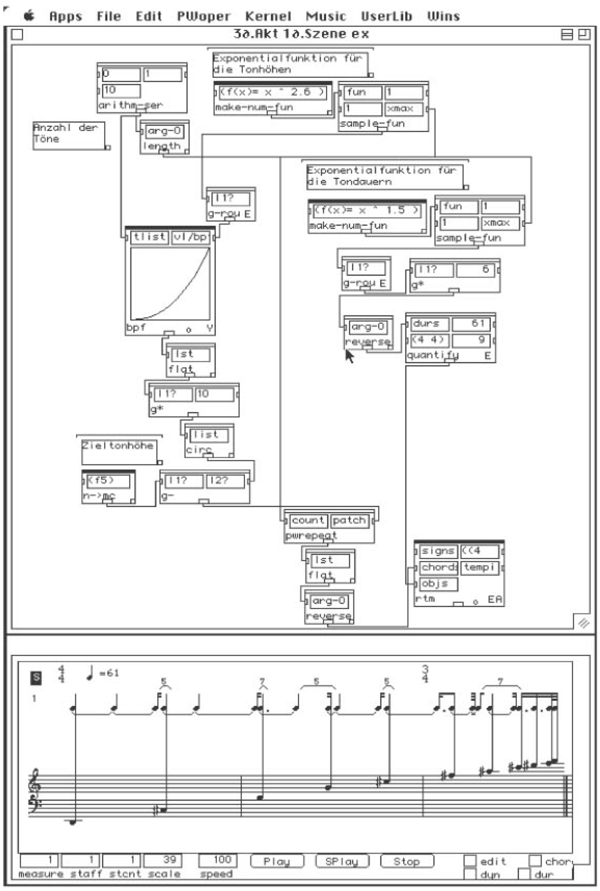


Figure 12.
A Patchwork algorithm which uses exponential functions to generate pitches and durations in Act Three of *Solaris*.

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