SONIFICATION OF THE FISSION MODEL AS AN EVENT GENERATION SYSTEM

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ABSTRACT

I am proposing an event generation system for sonification purposes, where a simplified chain reaction model known as nuclear fission in physics is used. The basic background of the fission model, mapping of parameters as sonic entities and technical aspects of the realization procedure are presented.

1. INTRODUCTION

1.1. Sonification of event generation systems

Algorithmic composition and sound synthesis in computer music has intensively employed mathematical models. These models have been introduced in order to generate several types of data streams for compositional and synthesis control sources. In particular, micro-sound generation methods in computer music need to deliver immense data flow in order to build macro-structures.

The control sources of data flow can be stochastic laws [1], chaotic functions [2], Cellular Automata models [3], genetic algorithms [4][5], terrain data, physical models and nature events [6] etc., which could create dynamic event generation systems from deterministic to non-deterministic and linear to non-linear results. The mapping could be applied to both the time and frequency representation of sound. The granular distribution in time domain gives us the micro-sound composition tool, termed granular synthesis, which has been inspired by the quantum representation of sound in physics devised by D. Gabor in 1947 [7]. The additive synthesis, which operates in the frequency domain, can benefit from different mapping of sources according to the needs of intensive data flow for modification of each partial in sonic spectrum [8].

Looking to the past, we see that the idea of distributing sonic events in sound space was first realized by Iannis Xenakis, starting with his work “Achorripsis” (1957) and then followed by his "ST" series of compositions [1]. He proposed the utilization of probability functions and invented the stochastic composition. "Stochos" is an example application, which permits us to attain the micro-sound time level event generation and in addition provides multiple control sources working in parallel in order to manipulate the sonic parameters on any event time level, by using the stochastic synthesis mapping [9].

The granular synthesis pioneers C. Roads [10][11] and B. Truax [12] have created event generation systems where the application assigns specific features for each sonic event. C. Roads “Cloud Generator” (CG) software is an example of how the user can control the event distribution process which creates clouds of grains, filling up a sound space changing in time.

We consider each event in an event generation system as mapped as a sonic entity or a sonic vector dimension in sound space. The sonic vector should at least have time information about onset and duration of the following event for an accurate definition in time-space. Iinformation like pitch, intensity, spectral or spatial data could be assigned in order to define further dimensions of this vector. With the sonification process we can further modify the data flow or mapping structure for compositional purposes.

1.2. About the fission model

Fission was discovered in 1934 when Enrico Fermi irradiated uranium with neutrons and believed he had produced the first transuranic element [13][14]. In a nuclear reaction laboratory experiment, a beam of particles of type x is incident on a target containing nuclei of type X. After the reaction, an outgoing particle y is observed in the laboratory, leaving a residual nucleus Y. We write the reaction as

$$x + X \rightarrow y + Y \, . \tag{1}$$

Mostly, the heavy residual nucleus Y loses all its kinetic energy (by collisions with other atoms) and therefore stops within the target. Since a nuclear reaction takes place under the influence only of internal forces between the projectile and target, we expect the reaction to conserve *energy*, *linear momentum*, and *angular momentum*. In nuclear reaction experiments, usually two basic properties of the particle y; its *energy*, and its probability to emerge at a certain angle with certain energy is measured. The latter implies also a *reaction probability*, which leads to different energy states having different probabilities. Furthermore, the compound nucleus after the impact decays to $y+Y$ in different ways, which is also based on purely statistical considerations. Within this stochastic nature, we can interpret this process as a dynamic system.

In the process of fission, a heavy nucleus, such as that of uranium, splits into two lighter nuclei. It is expected that most of the fission energy is transferred to the fragments. In fact, 80 percent of the energy released in fission does appear as the kinetic energy of the fragments and the remaining 20 percent appears as decay products and kinetic energy of neutrons emitted in the fission process. Each neutron can initiate another fission process, resulting in the emission of still more neutrons, followed by more fissions. A typical fission nuclear reaction is:

$${}^{235}_{92}U_{143} + n \longrightarrow {}^{93}_{37}Rb_{56} + {}^{141}_{55}Cs_{86} + 2^{n} \, . \tag{2}$$

We can assume each neutron life as an event and, therefore, we can extract additional parameters for the mapping system. It is assumed that the velocities of the nuclear particles are sufficiently so that one can use the non-relativistic kinematics approximation.

We consider a projectile *x* moving with momentum P_x and kinetic energy K_x. The target is at rest and the reaction products have momentum P_y and P_Y. The particles *y* and *Y* are emitted at angles θ_y and θ_Y with respect to the direction of the incident beam. Figure 1 illustrates this reaction. We assume that the resultant nucleus *Y* is not observed. Assuming that *X* is initially at rest, we have:

initial energy = final energy

In a real fission reaction, the average number of neutrons produced is greater than one, making the chain reaction possible. The two neutrons emitted in the fission process are prompt neutrons. They are emitted at the instant of fission. About 1 percent of the neutrons in the fission process are delayed neutrons emitted following the decays of the heavy fragments.

The reaction speed is about 10^{-20} s. In reality, the space between the uranium atoms is huge compared to the size of the colliding particles, so that there must be sufficient conditions for the reaction process not to die out quickly. It is very likely that the neutrons do not hit any target.

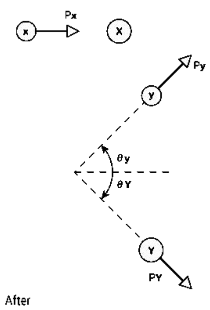

Figure 1: *Collision kinematics*

For our model we make the following considerations. At first we restrict the conditions of the system for the purpose of having a basic prototype. We assume that every reaction creates two prompt neutrons, which is the case for a chain reaction. Then we watch for their collision time, location and speed vectors. For the time being, we neglect the effect of the delayed neutrons, which occur after a very long time through the decay products compared to the fission reaction time.

1.3. The rules of the model

For our sonification model we created a 3D space filled with the target atoms. In this experiment, we choose a size in three dimensions of $400 \times 400 \times 400$. For making the calculation process much easier, we locate all the target particles on the integer coordinates, so that we have 64 million atoms resting in our space.

We define the collision rules such as there will be two new particles created with every collision. Each of them will have a speed vector V_p. Using this information, we can calculate when and where their collision with the next target will occur. If they do not hit any target, they might go out of our space and feedback from the opposite site of their point of leaving. We are free to set these rules, since this is a virtual model. Every atom after the reaction becomes a by-product, which cannot be part of another reaction. In summary, we need to know the following parameters:

- The collision coordinates **Cx, Cy, Cz**
- The 3D speed vectors of the 2 new particles after the collision **Vp1, Vp2**
- The event life **t1** and **t2** as the two neutrons life durations.

Having set these parameters, we can apply a mapping for the sonification of this system. We could simply assign an oscillator loaded with the mapping parameters for each event for this task.

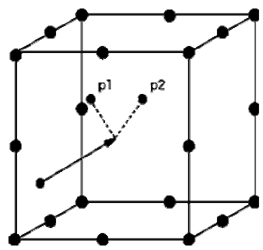

Figure 2: *Collision and creation of new particles in the net.*

2. SONIFICATION PROCESS

The realization of this model and the sonification process has been implemented in Csound. The source file can be found at `http://perso.wanadoo.fr/sinan.bokesoy/fission.csd`
The following considerations apply:

a) The initial parameters are assigned to their initial values. We inject the system with two initial neutrons at a specific location (px, py, pz) and also two speed vectors (vx, vy, vz) and (vx2, vy2, vz2). Each time the program calculates the collision parameters; the new particles call up again the same collision calculation block, while updating the distribution of particles in space.

b) Using integer numbers for the coordinates in this model brings enormous ease and speed for the calculations. There we compromise some features like preservation of momentum in the reaction kinematics. For each new particle, a randomly calculated velocity value is assigned in the range (0-5). The resolution of the numbers is one digit after the decimal point: 1.4, -0.2 or 0.6, for example. Therefore, if we know the departure point and the velocity of the new particle, we can immediately calculate its collision point with atoms. The program routine looks after whether there exists a target or not at the calculated point.

c) After each collision, the target at the collision point will be cleared in the 3D space and, namely, its corresponding table in the program. This happens by calculating the index value of the target coordinate to reach the correct array address in the table, which should address 64 million points. The table size limit in Csound is 16777217, therefore we use multiple tables to link them as one large table.

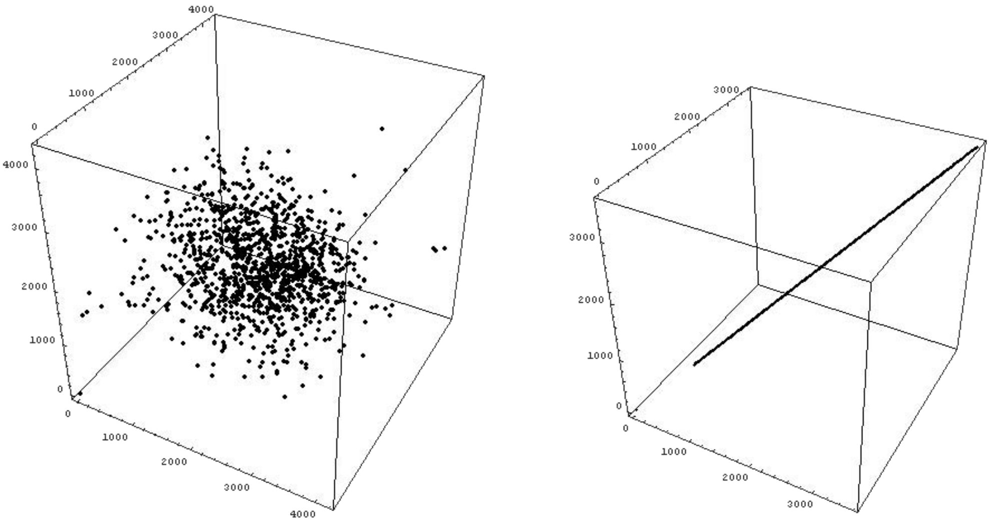

Figure 4: *Visualization of collisions data in two different experiments*

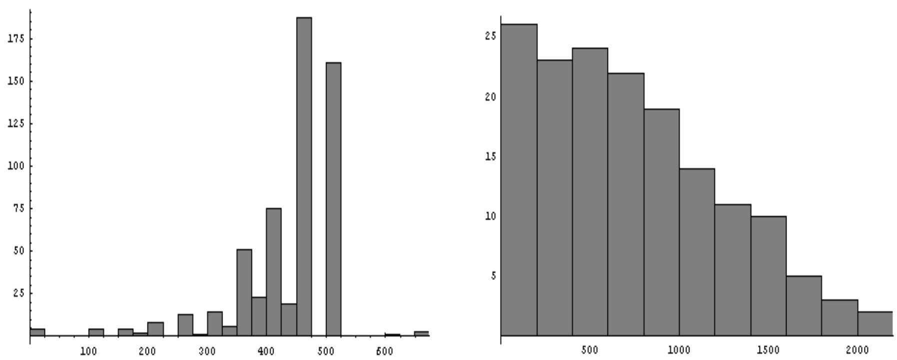

Figure 5: *Histograms for the onset time distributions of the experiment*

d) Also the coordinates of each collision **xc, yc, zc** and **xc2, yc2, zc2**, their velocities **vx, vy, vz** and **vx2, vy2, vz2,** the particle life durations **time1** and **time2,** and the collision onset times are written in their corresponding tables.

e) A recursive routine updates the tables and looks for new collisions and generates the information. At the end we obtain 7 parameters ready to map for each event.

f) Each event is calling the instrument definition in Csound with using the 'event' opcode. Besides the onset time, which is the collision time, the neutron life duration **time1** and **time2** accurately define these events in time space.

xc	*yc*	*zc*	*vx*	*vy*	*vz*	*time1*
f1	*f2*	*f3*	*g1*	*g2*	*g3*	*dur*

Table 3: *Parameter mapping*

Table 3 shows how to map the collision coordinates and the neutron speed components to frequency and intensity parameters of 3 oscillators. Their duration is determined by neutron life (time1). One could use another set of oscillators and assign time2 as their durations and distribute them with the collision coordinate mapping in the stereo field.

The scaling of source and destination parameters in the mapping can be adjusted at will. Certain scale factors help us understand the evolution of the process more clearly.

Figure 4 shows the collision data of two experiments. The rules for the speed vector calculations are different. The first experiment, plotted on the left, shows a distribution of collisions where the speed vectors are assigned randomly for the particles. The second experiment, plotted on the right, shows a distribution with the velocity vector of the first particle fixed to 1, 1, 1 and of the second particle to -1, -1, -1 always. These experiments show the extreme conditions of between disorder and order of this dynamic system. Figure 5 shows us the histogram data of the onset time distributions for the experiments above.

The parameters supplied as tables could also be fed to a 3D modeling software in order to visualize the dynamic system in 3D environment and gain better understanding of the motion of the particle system. This basic model was a simplified version of a fission model and did not use the following known features of the fission model:

- Considerations on preserving energy, angular and linear momentum in the reaction
- Delayed neutrons produced by the by-products
- The prompt neutron number was fixed as two, but could be changed
- The distribution of resting atoms were fairly regular and just on the integer coordinates

The last two conditions were introduced in order to increase the speed of calculation, which is not in real-time.

3. CONCLUSIONS

We tried to bring up a simplified a model of nuclear fission for sonification purposes and explained an example mapping process. The chain reaction creates event data and has been mapped with Csound as instrument parameters.

The sound examples that can be found at `http://perso.wanadoo.fr/sinan.bokesoy/ex1.mp3` and at `http://perso.wanadoo.fr/sinan.bokesoy/ex2.mp3` give a quick idea about the onset time distribution in the chain reaction. Since the collision coordinate of one axis was mapped to the pitch, the change of the granular pitch gives an idea about the distribution of the collisions.

Many different mapping trials can be performed with the rest of the parameters. I found that the model produces strong realistic images of explosions or thunder events. It would be useful for future expansions to use the data output of the model for convolution implementations [15]. In this way, the model can be employed to process other sounds, which gives a digital audio effect quality. What we have done here, as first step, is to interpret the particles of this fundamental reaction as acoustical quanta. Controlling acoustical quanta makes it necessary the use of automated systems with high-level control features such as the presented sonification model [1]. We extracted the macro parameters of control from the fission model here, which are derived from elemental laws of nature.

A system capable of responding to the input parameters in real-time is the goal; triggering multiple reactions at the same time on different coordinates would also be very interesting. Only then we could consider the model as a sonic instrument and as a compositional tool or a real-time effect system, which has the ability to interact with the real-time input parameters and feedback processes. In order to achieve this, other programming environments than Csound, like the new Java implementation of Max/MSP, will be considered as the next step.

4. ACKNOWLEDGEMENTS

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