# Effects of Varying Basic Affine Transformations on Scores Generated by Iterated Function Systems

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The elementary affine transformations — scale, move, shear, rotate – of a simple iterated function system (IFS) are systematically varied to illustrate the effects of such variations on a score generator based on the IFS.

This document presents a system for composing scores for Csound [6] using the deterministic algorithm for computing iterated function systems (IFS) [5], also known as the multiple copy reducing machine (MCRM) [1], and with that system demonstrating the effects of systematically varying the affine transformations that make up the Hutchinson operator of the IFS.

The motivation for this study is that an IFS is produced by recursively shrinking a set towards a fixed point using a Hutchinson operator, a set of contractive affine transformations, and this is a *global* operation in that each of the affine transformations in the operator affects the entire score. And that means that changes in the operator are not, at first sight, intuitive. The goal of this study is to make such changes *more* intuitive.

## 1 Method

The system used for these experiments is Csound [4], in which the Clang/LLVM just-intime (JIT) compiler [3, 2] has been embedded as opcodes.

In this study, scores are generated by recursively applying a Hutchinson operator 8 times to a single musical note, which actually represents a single phase-synchronous cosine grain

of sound. The Hutchinson operator simply maps the unit square to each of its four quarters. This type of grain is used because such grains can be mixed with a minimum of artifacts. This, in turn, means that viewing a spectrogram of the resulting soundfile clearly illustrates the attractor of the IFS. The durations of the grains are adjusted so that grains of the same pitch that are successive in time overlap with a minimum of artifacts.

Each score that is generated in this way is one minute long. The dimensions of the space acted upon by the operator are instrument number, time, duration, MIDI key number, MIDI velocity, and stereo pan. A single note or grain is a homogeneous column vector in this space. The operator for the initial unit square, implemented using homogeneous affine transformation matrices, is:

Listing 1: Hutchinson Operator for Unit Square.

```
/*
                                                                     */
hutchinson[0] <<</pre>
                        .5,
                                               Ο,
                         0,
                             .5,
                                    0,
                                                    0,
                                          0,
                               0,
                                   .5,
                                          0,
                                               0,
                                                    0,
                               0,
                                    0,
                                        .5,
                                               0,
                                                    0,
                               Ο,
                                              .5,
                                    0,
                                          0,
                                                    0,
                                                          0, /*
                         0,
                               0,
                                    0,
                                          0,
                                               Ο,
                                                   .5,
                                                                 p */
                                    Ο,
                               0,
                                                    0,
                                          0,
                                               0,
hutchinson[1] <<</pre>
                        .5.
                               0,
                                    0,
                                          0,
                                               0,
                                                    0,
                         0,
                              .5,
                                    0,
                                          0,
                                               0,
                                                    0,
                               0,
                                   .5,
                                          0,
                                               0,
                                                    0,
                                        .5,
                                               0,
                                                    0,
                               Ο,
                         0,
                                    0,
                                          0,
                                             .5,
                                                    0,
                                    Ο,
                                                   .5,
                               0,
                                          0,
                                               0,
                                                                  p */
                         Ο,
                               Ο,
                                    0,
                                          0,
                                               0,
                                                    Ο,
                                                          1; /*
hutchinson[2] <<</pre>
                        .5,
                               0,
                                    Ο,
                                                    0,
                                          0,
                                               0,
                         0,
                              .5,
                                    0,
                                          0,
                                               0,
                                                    0,
                                                          0, /*
                               0,
                                   .5,
                                          0,
                                               0,
                                                    0,
                                        .5,
                                               0,
                                                    0,
                                              .5,
                                                    0,
                                          0,
                               0,
                                    0,
                                          Ο,
                                                  .5,
                                               Ο,
                                                          0, /*
                                                                 p */
                                               Ο,
                               0,
                                    0,
                                          0,
                                                    0,
                                               Ο,
hutchinson[3] <<
                        .5,
                               0,
                                    0,
                                                    0,
                                          0,
                             .5,
                         Ο,
                                    0,
                                          0,
                                               0,
                                                    0,
                                                          1, /* t */
                              0, .5,
                                               Ο,
                                                    0,
                                                          0, /* d */
                                         0,
```

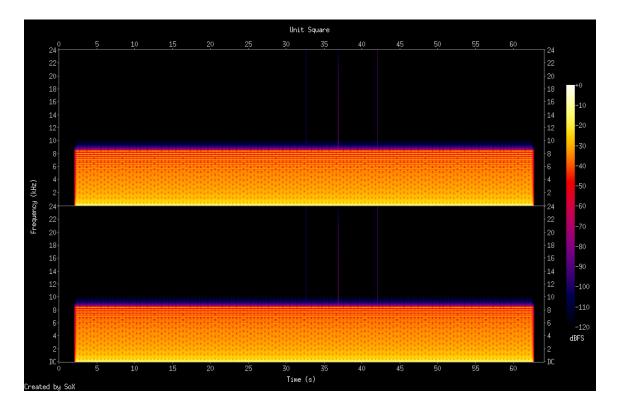


Figure 1: Unit Square.

```
0, 0, 0, .5, 0, 0, 1, /* k */
0, 0, 0, 0, .5, 0, 0, /* v */
0, 0, 0, 0, 0, .5, 0, /* p */
0, 0, 0, 0, 0, 1; /* H */
```

In this operator, the diagonals of the transformations are scaling factors, and the rightmost columns are translations.

In an actual piece, often the grains would be replaced by notes for more distinctive instruments, and pitch might be rounded off to 12-tone equal temperament. In that case, the Hutchinson operator is not iterated all the way to its fixed point, i.e. its attractor, but only far enough to produce a reasonable density of notes. And in such cases, of course, the transformations have to be set up to create some sort of musical interest, and that generally means introducing various asymmetries into the action of the Hutchinson operator.

## 1.1 Scaling

Here we present the results of varying the scaling of time and pitch, quarter by quarter.

When rescaling time, it is easy to see how the rescaling interacts with the translations in quarters 2 through 4.

Now we consider rescaling of pitch in the same way.

### 1.2 Translations

# 1.3 Shearings

### 1.4 Rotations

These are 15 degree rotations of time into pitch. Actually, they are rotation-dilations because they must include the scaling by 0.5.

## 2 Discussion

As can be seen, it is challenging to predict the effects upon score generation of even simple modifications of a simple transformation in a simple Hutchinson operator. This is the other side of the great power of this method of composition.

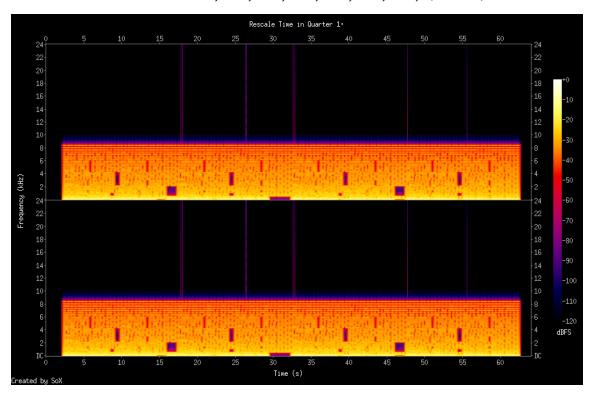
These examples do, however, show some basic principles that can be useful in music composition:

# References

- [1] Heinz-Otto Peitgen, Hartmut Jürgens, and Dietmar Saupe. "Chaos and Fractals: New Frontiers of Science". In: *Chaos and Fractals: New Frontiers of Science*. Springer-Verlag, 1992. Chap. 5, pp. 229–296. ISBN: 0-387-97903-4 (cit. on p. 1).
- [2] LLVM. ORC Design and Implementation. Available online at: https://www.llvm.org/docs/ORCv2.html. Accessed 27 September 2021. 2021 (cit. on p. 1).
- [3] LLVM. The LLVM Compiler Infrastructure. Available online at https://llvm.org/. Accessed 27 September 2021. 2021 (cit. on p. 1).
- [4] Richard Boulanger. csounds.com... almost everything Csound. http://www.csounds.com (cit. on p. 1).
- [5] Michael F. Barnsley. Fractals Everywhere. 2nd. Boston: Academic Press Professional, 1993 [1988] (cit. on p. 1).

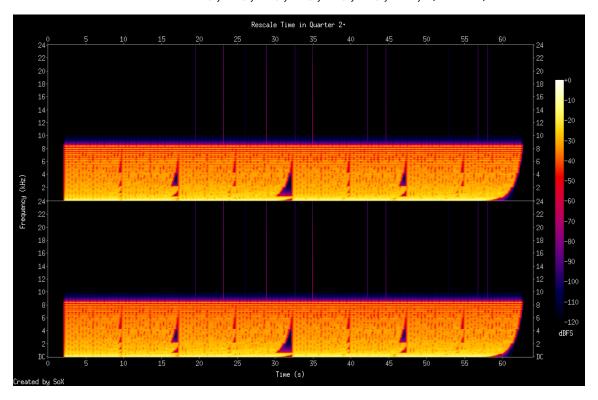
Listing 2: Rescale Time in First Quarter.

```
/*
                                  d
                                        k
                                                                 */
                                                  р
                                                  Ο,
hutchinson[0] <<</pre>
                       .5,
                             Ο,
                                  Ο,
                                        Ο,
                                             Ο,
                                                       0, /* i */
                        Ο,
                            .45, 0,
                                             Ο,
                                                  0,
                                        0,
                        Ο,
                             0,
                                 .5,
                                        Ο,
                                             Ο,
                                                  Ο,
                                                       0, /*
                                  Ο,
                                      .5,
                                             Ο,
                                                  Ο,
                             Ο,
                        Ο,
                                  Ο,
                                        0, .5,
                                                  Ο,
                                        Ο,
                                             Ο,
                                                 .5,
                                                  0,
                                             Ο,
                                                       1; /* H */
                                        0,
```



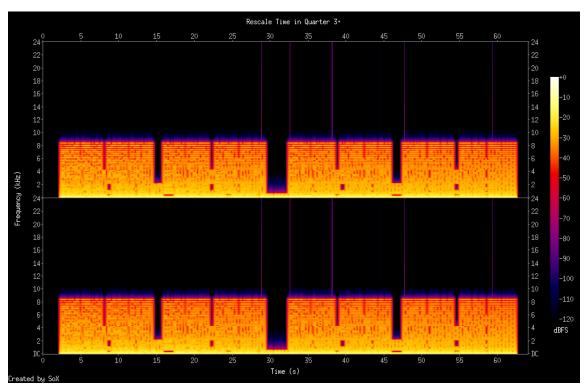
Listing 3: Rescale Time in Second Quarter.

```
/*
hutchinson[1] <<
                   .5,
                        0,
                            0,
                                         0,
                                             0, /* i */
                    0, .45, 0,
                                Ο,
                                     0,
                                         0,
                                             1, /* t */
                        0, .5,
                                     Ο,
                                         Ο,
                    0,
                                Ο,
                    0,
                        0,
                            0, .5,
                                     Ο,
                                         Ο,
                                0, .5,
                                         Ο,
                                     0, .5,
                                         Ο,
```



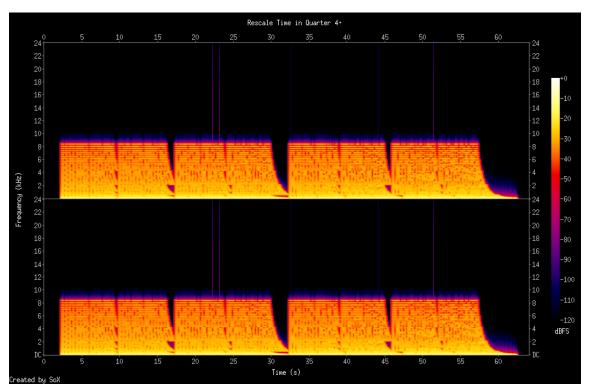
Listing 4: Rescale Time in Third Quarter.

```
/*
hutchinson[2] <<</pre>
                                           0, /* i */
                  .5,
                       0,
                           0,
                                       0,
                   0, .45, 0,
                               Ο,
                                   Ο,
                                       Ο,
                                           1, /* t */
                       0, .5,
                               0, 0,
                                       Ο,
                   Ο,
                       0, 0, .5, 0, 0,
                   0,
                       Ο,
                           Ο,
                              0, .5,
                                       Ο,
                               0, 0, .5,
                                   0, 0, 1; /* H */
```



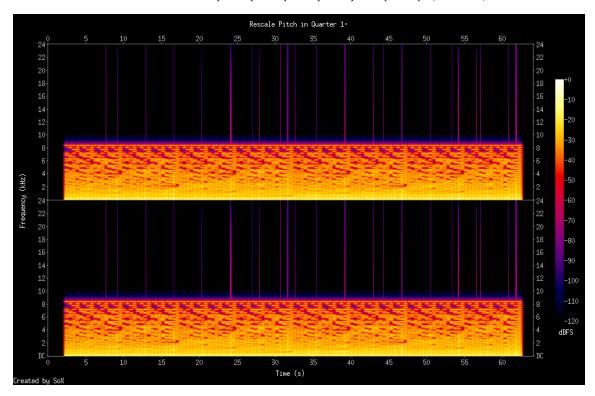
Listing 5: Rescale Time in Fourth Quarter.

```
/*
hutchinson[3] <<</pre>
                        0,
                   .5,
                            0,
                                              0, /* i */
                    0, .45, 0,
                                 0,
                                     0,
                                         Ο,
                                              1, /* t */
                        0, .5,
                                     Ο,
                                         Ο,
                    0,
                                 Ο,
                    0,
                        0,
                            0, .5, 0,
                                         Ο,
                            0,
                                 0, .5,
                                         Ο,
                                 Ο,
                                     0, .5,
                                         Ο,
```



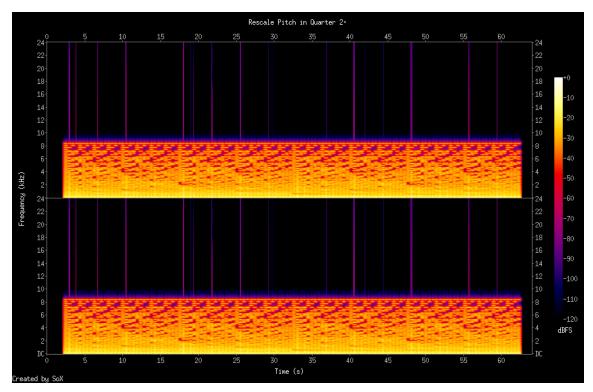
Listing 6: Rescale Pitch in First Quarter.

```
/*
                             t
                                  d
                                                                */
                                       k
                                                 р
hutchinson[0] <<</pre>
                      .5,
                             Ο,
                                  0,
                                       Ο,
                                            Ο,
                                                 Ο,
                                                      0, /* i */
                            .5,
                                            Ο,
                                                 0,
                        0,
                                  0,
                                       0,
                        Ο,
                             0,
                                .5,
                                       Ο,
                                            Ο,
                                                 Ο,
                                  0,
                                      .45, 0,
                                                 0,
                             Ο,
                                                 0,
                                       0, .5,
                        0,
                                  0,
                                       Ο,
                                            0,
                                               .5,
                                                 0,
                                            0,
                                                      1; /* H */
                                       0,
```



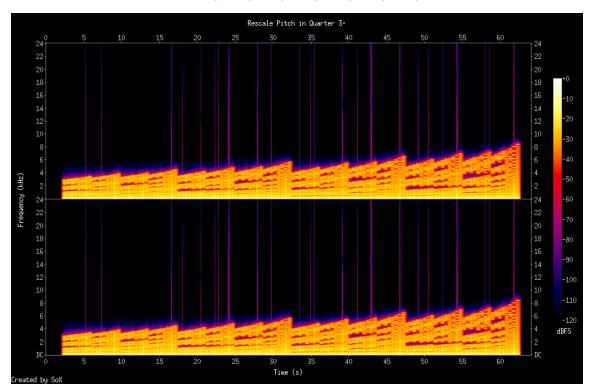
Listing 7: Rescale Pitch in Second Quarter.

```
/*
                             t
                                  d
                                       k
                                                                 */
                                                 р
hutchinson[1] <<</pre>
                       .5,
                             Ο,
                                  Ο,
                                       Ο,
                                            Ο,
                                                 Ο,
                                                       0, /* i */
                            .5,
                                            Ο,
                                                 0,
                        0,
                                  0,
                                       0,
                        Ο,
                             0,
                                 .5,
                                       Ο,
                                            Ο,
                                                 Ο,
                                  0,
                                      .45, 0,
                                                 0,
                             Ο,
                        0,
                                  Ο,
                                       0, .5,
                                                 0,
                                       Ο,
                                            Ο,
                                                .5,
                                                 0,
                                            Ο,
                                                       1; /* H */
                                       0,
```



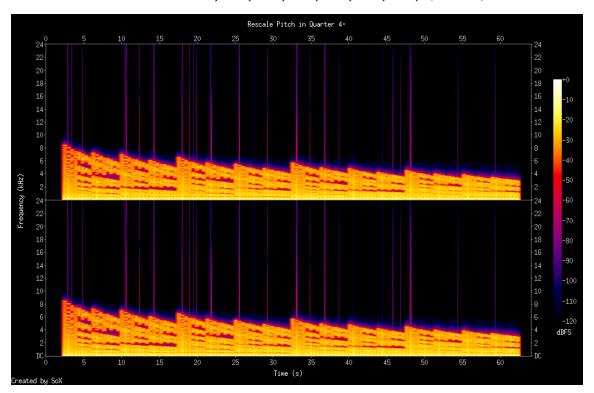
Listing 8: Rescale Pitch in Third Quarter.

```
/*
                          i
                               t
                                                           Т
                                                                      */
                               Ο,
hutchinson[2] <<</pre>
                         .5,
                                     Ο,
                              .5,
                          Ο,
                               Ο,
                                    .5,
                                          Ο,
                                                Ο,
                                                     Ο,
                               Ο,
                                         .45,
                                                0,
                                                     0,
                                                     Ο,
                          Ο,
                               Ο,
                                          Ο,
                                              .5,
                          0,
                               0,
                                          0,
                                                0,
                                                    .5,
                          Ο,
                               Ο,
                                    0,
                                                Ο,
                                                     0,
                                                           1; /* H */
```



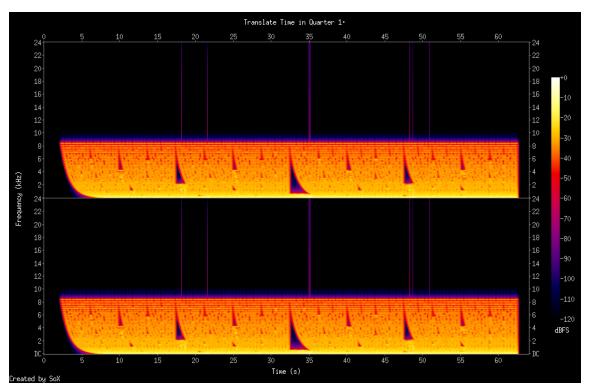
Listing 9: Rescale Pitch in Fourth Quarter

```
/*
                          i
                               t
                                                          Т
                                                                     */
hutchinson[3] <<</pre>
                         .5,
                               Ο,
                                     Ο,
                              .5,
                          Ο,
                               Ο,
                                    .5,
                                          Ο,
                                               Ο,
                                                     Ο,
                               0,
                                         .45,
                                               0,
                                                     0,
                          Ο,
                               Ο,
                                          Ο,
                                              .5,
                                                     0,
                                                    .5,
                          0,
                               Ο,
                                          0,
                                               0,
                          Ο,
                               Ο,
                                    0,
                                               Ο,
                                                     0,
                                                           1; /* H */
```



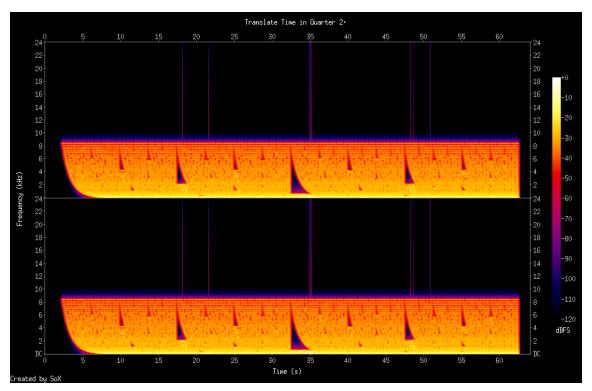
Listing 10: Translate Time in First Quarter

```
/*
                                  d
                                                                 */
                                       k
                                                 p
hutchinson[0] <<</pre>
                       .5,
                             Ο,
                                  Ο,
                                       Ο,
                                            Ο,
                                                 Ο,
                                                      0, /* i */
                        Ο,
                            .5,
                                  0,
                                            Ο,
                                                 0,
                                       0,
                        Ο,
                             0,
                                 .5,
                                       Ο,
                                            Ο,
                                                 Ο,
                                                      0, /* d */
                                  0,
                                      .5,
                                            Ο,
                                                 0,
                             Ο,
                                                 0,
                        Ο,
                                  Ο,
                                       0, .5,
                                                      0, /*
                                       Ο,
                                            Ο,
                                               .5,
                                            Ο,
                                                 Ο,
                                                      1; /* H */
                                       0,
```



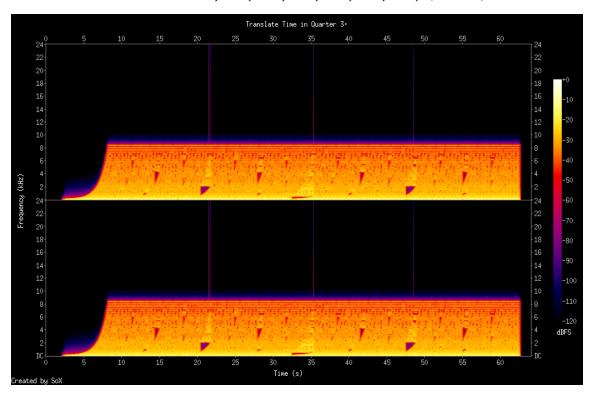
Listing 11: Translate Time in Second Quarter

```
k
                                             p
hutchinson[1] <<</pre>
                      .5,
                            Ο,
                                0,
                                     Ο,
                                          Ο,
                                               Ο,
                                                    0, /* i */
                          .5,
                                0,
                                          Ο,
                                               0,1.1, /*
                       Ο,
                                     0,
                            0,
                               .5,
                                     Ο,
                                          Ο,
                                               0,
                                                    0, /* d */
                                0,
                                    .5,
                                          Ο,
                                               0,
                            Ο,
                                               Ο,
                       Ο,
                                Ο,
                                     0, .5,
                                                    0, /*
                                                    0, /* p */
                                     Ο,
                                          0, .5,
                                              0,
                                          0,
                                                    1; /* H */
                                0,
                                     0,
```



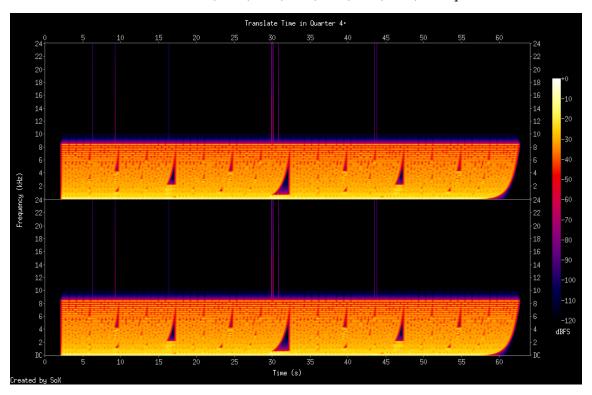
Listing 12: Translate Time in Third Quarter

```
/*
                             t
                                  d
                                                                 */
                                       k
                                                 p
                                                      0, /* i */
hutchinson[2] <<</pre>
                       .5,
                             Ο,
                                  Ο,
                                       Ο,
                                            Ο,
                                                 Ο,
                        Ο,
                            .5,
                                  0,
                                            Ο,
                                                 0,
                                                     .1, /*
                                       0,
                        Ο,
                             0,
                                 .5,
                                       Ο,
                                            Ο,
                                                 Ο,
                                                      0, /* d */
                                  0,
                                      .5,
                                            Ο,
                                                 0,
                                          .5,
                        Ο,
                             Ο,
                                       Ο,
                                                 0,
                                  Ο,
                                                      0, /*
                                       Ο,
                                            Ο,
                                                .5,
                                            Ο,
                                                 Ο,
                                                       1; /* H */
                                       0,
```



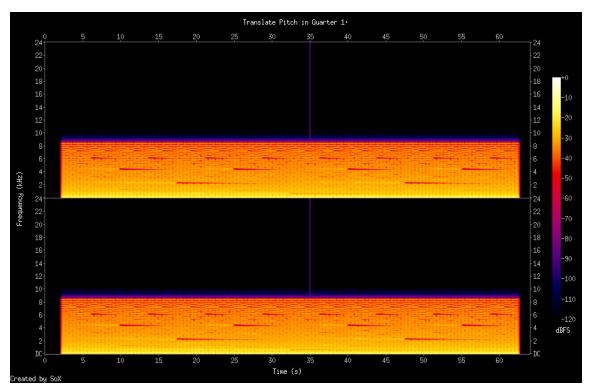
Listing 13: Translate Time in Fourth Quarter

```
/*
                                                         Т
                         i
                              t
                                                                   */
                              Ο,
                                   Ο,
hutchinson[3] <<</pre>
                        .5,
                                         Ο,
                                              Ο,
                                                   Ο,
                                                         0, /* i */
                             .5,
                                              0,
                              Ο,
                                  .5,
                                         Ο,
                                              Ο,
                                                   Ο,
                                       .5,
                                                   0,
                                              0,
                                             .5,
                                         Ο,
                                                   0,
                              Ο,
                         0,
                                   0,
                                         0,
                                              0, .5,
```



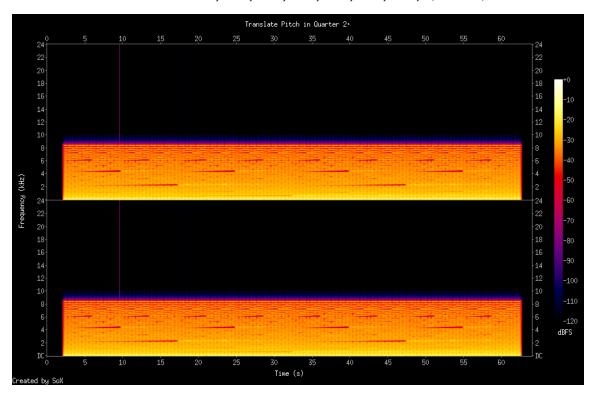
Listing 14: Translate Pitch in First Quarter

```
/*
                             t
                                  d
                                        k
                                                                 */
                                                  p
                                                  Ο,
                                                       0, /* i */
hutchinson[0] <<</pre>
                       .5,
                             Ο,
                                  Ο,
                                        Ο,
                                             Ο,
                        Ο,
                            .5,
                                  Ο,
                                             Ο,
                                                  0,
                                        0,
                        Ο,
                             0,
                                 .5,
                                        Ο,
                                             Ο,
                                                  Ο,
                                                       0, /*
                                  0,
                                      .5,
                                             Ο,
                                                  0,
                                                      .1, /*
                        Ο,
                             Ο,
                                       Ο,
                                           .5,
                                  Ο,
                                                  Ο,
                                                       0, /*
                                        Ο,
                                             Ο,
                                                .5,
                                                       0, /*
                                             Ο,
                                                  Ο,
                                                       1; /* H */
                                  0,
                                        0,
```



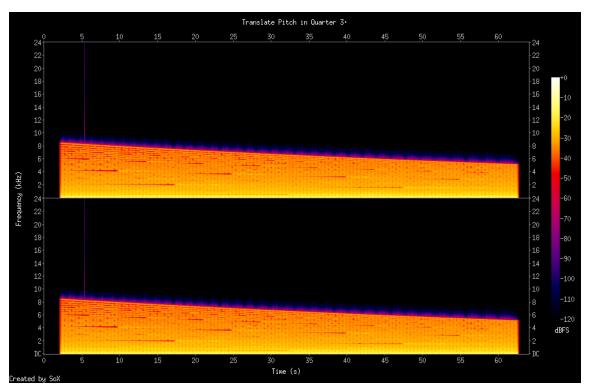
Listing 15: Translate Pitch in Second Quarter

```
/*
                              t
                                   d
                                        k
                                                                  */
                                                  p
hutchinson[1] <<</pre>
                        .5,
                              Ο,
                                   Ο,
                                        Ο,
                                             Ο,
                                                  Ο,
                                                        0, /* i */
                        Ο,
                             .5,
                                   Ο,
                                             Ο,
                                                  0,
                                        0,
                        Ο,
                              0,
                                 .5,
                                        Ο,
                                             Ο,
                                                  Ο,
                                                        0, /*
                                   Ο,
                                       .5,
                                             Ο,
                                                  0,
                        Ο,
                              Ο,
                                        Ο,
                                            .5,
                                   Ο,
                                                  0,
                                                        0, /*
                                        Ο,
                                             Ο,
                                                 .5,
                                                        0, /*
                                                  0,
                                             Ο,
                                                        1; /* H */
                                        0,
```



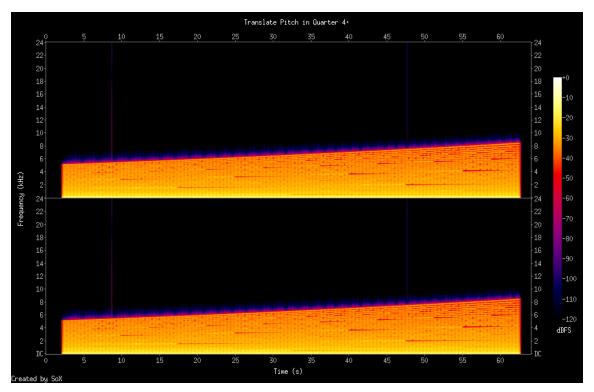
Listing 16: Translate Pitch in Third Quarter

```
/*
                             t
                                  d
                                                                 */
                                       k
                                                 p
hutchinson[2] <<</pre>
                       .5,
                             Ο,
                                  Ο,
                                       Ο,
                                            Ο,
                                                 Ο,
                                                      0, /* i */
                        Ο,
                            .5,
                                  Ο,
                                            Ο,
                                                 0,
                                       0,
                        Ο,
                             0,
                                 .5,
                                       Ο,
                                            Ο,
                                                 Ο,
                                                      0, /* d */
                                  Ο,
                                      .5,
                                            Ο,
                                                 0,
                                                      1.1,
                                                             /* k */
                        Ο,
                             Ο,
                                       Ο,
                                          .5,
                                                 Ο,
                                  Ο,
                                                      0, /*
                                  Ο,
                                       Ο,
                                            Ο,
                                               .5,
                                                      0, /*
                                            Ο,
                                                 Ο,
                                                      1; /* H */
                                  0,
                                       0,
```



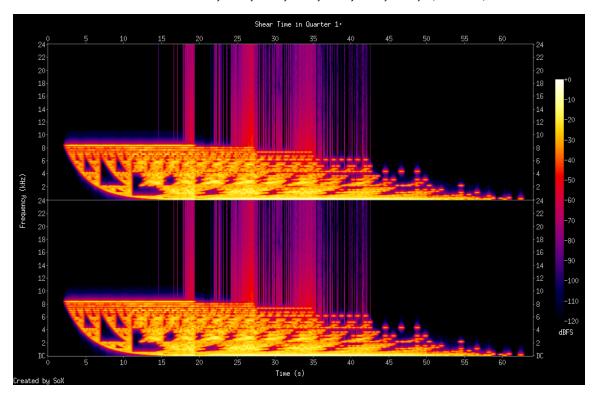
Listing 17: Translate Pitch in Fourth Quarter

```
/*
                            t
                                  d
                                                                */
                                       k
                                                 p
                                                Ο,
                                                      0, /* i */
hutchinson[3] <<</pre>
                      .5,
                            Ο,
                                  Ο,
                                       Ο,
                                           Ο,
                        0,
                           .5,
                                 0,
                                            Ο,
                                                 0,
                                       0,
                        Ο,
                            0,
                                .5,
                                       Ο,
                                            Ο,
                                                 Ο,
                                                      0, /*
                                 0,
                                     .5,
                                            Ο,
                                                 0,1.1, /*
                            Ο,
                        0,
                                  Ο,
                                       0, .5,
                                                 Ο,
                                                      0, /*
                                 Ο,
                                       Ο,
                                            0,
                                               .5,
                                                      0, /*
                                            Ο,
                                                 0,
                                                      1; /* H */
                                  0,
                                       0,
```



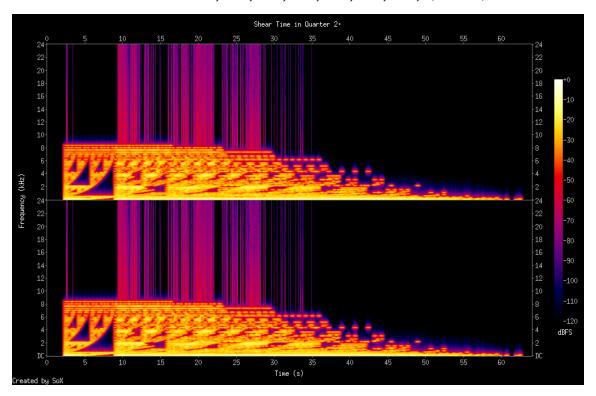
Listing 18: Shear Time in First Quarter

```
/*
                                                    p
                                                   Ο,
hutchinson[0] <<</pre>
                        .5,
                              Ο,
                                    Ο,
                                              Ο,
                                                         0, /* i */
                                         Ο,
                         Ο,
                             .5,
                                    Ο,
                                              Ο,
                                                    0,
                         Ο,
                              Ο,
                                  .5,
                                         Ο,
                                              Ο,
                                                    Ο,
                                        .5,
                                              Ο,
                                                    0,
                              Ο,
                                         Ο,
                                             .5,
                                                    0,
                                                  .5,
                                                   Ο,
```



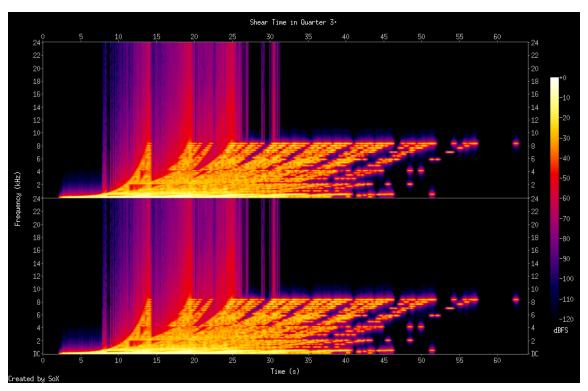
Listing 19: Shear Time in Second Quarter

```
/*
                                                                    */
                                                    p
hutchinson[0] <<</pre>
                        .5,
                               Ο,
                                              Ο,
                                                    Ο,
                                                          0, /* i */
                                    0,
                                         Ο,
                         Ο,
                              .5,
                                               Ο,
                                                    0,
                                    0,
                         Ο,
                               Ο,
                                   .5,
                                         Ο,
                                               Ο,
                                                    Ο,
                                        .5,
                                               Ο,
                                                    0,
                               Ο,
                                             .5,
                         Ο,
                                         Ο,
                                                    0,
                                                   .5,
                                                    Ο,
```



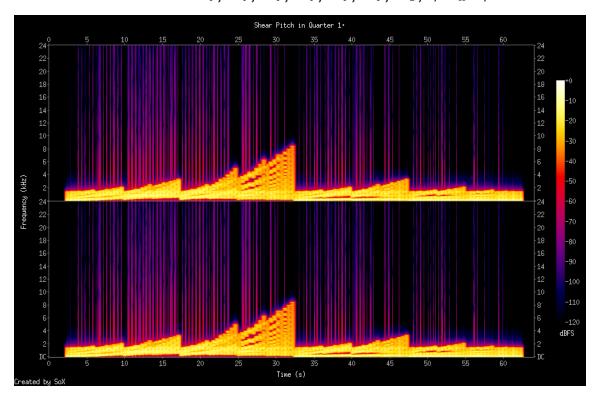
Listing 20: Shear Time in Third Quarter

```
/*
                                                                 */
hutchinson[2] <<</pre>
                       .5,
                             Ο,
                                  Ο,
                                        Ο,
                                             Ο,
                                                  Ο,
                                                       0, /* i */
                        Ο,
                            .5,
                                  0,
                                             Ο,
                                                  Ο,
                                        1,
                        Ο,
                             0,
                                 .5,
                                        Ο,
                                             Ο,
                                                  Ο,
                                      .5,
                                             Ο,
                                                  0,
                             Ο,
                                        0, .5,
                                                  Ο,
                                             Ο,
                                                .5,
                                                  Ο,
                                                       1; /* H */
```



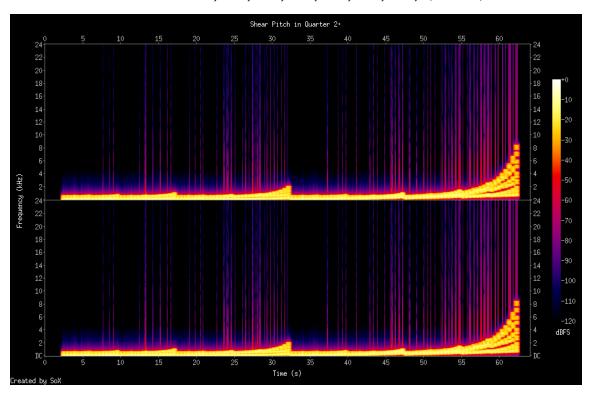
Listing 21: Shear Pitch in First Quarter

```
/*
                                                    p
hutchinson[0] <<</pre>
                        .5,
                              Ο,
                                         Ο,
                                              0,
                                                    Ο,
                                                         0, /* i */
                         Ο,
                             .5,
                                    0,
                                         0,
                         Ο,
                              Ο,
                                   .5,
                                         Ο,
                                               Ο,
                                                    Ο,
                                        .5,
                                               0,
                         Ο,
                              Ο,
                                                    Ο,
                                         0,
                                             .5,
                                                   .5,
```



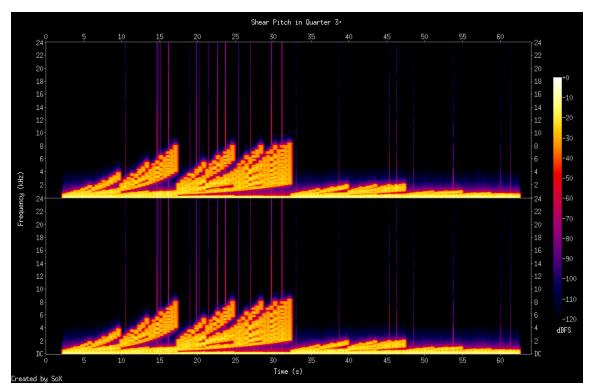
Listing 22: Shear Pitch in Second Quarter

```
/*
                                         k
                                                                    */
                                                    p
hutchinson[0] <<</pre>
                        .5,
                              Ο,
                                    Ο,
                                         Ο,
                                              Ο,
                                                    Ο,
                                                         0, /* i */
                                              Ο,
                         Ο,
                             .5,
                                         Ο,
                                                    0,
                                    0,
                         Ο,
                              Ο,
                                   .5,
                                         Ο,
                                               Ο,
                                                    Ο,
                              1,
                                        .5,
                                               Ο,
                                                    0,
                                             .5,
                                                    Ο,
                         Ο,
                              0,
                                         Ο,
                                    0,
                                               Ο,
                                                   .5,
                                                    Ο,
```



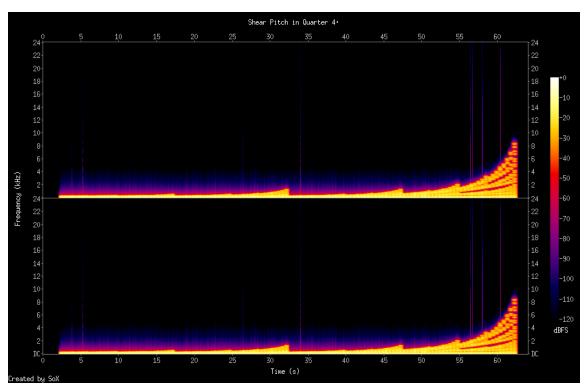
Listing 23: Shear Pitch in Third Quarter

```
/*
                                                                   */
                                                   Ο,
hutchinson[2] <<</pre>
                        .5,
                              Ο,
                                   Ο,
                                        Ο,
                                              Ο,
                                                        0, /* i */
                         Ο,
                             .5,
                                   Ο,
                                              Ο,
                                                   0,
                                        0,
                         Ο,
                              0,
                                  .5,
                                        Ο,
                                              Ο,
                                                   Ο,
                                       .5,
                                              Ο,
                                                   0,
                                        Ο,
                                            .5,
                         Ο,
                              0,
                                   Ο,
                                                   0,
                                             Ο,
                                                 .5,
                                                   Ο,
```



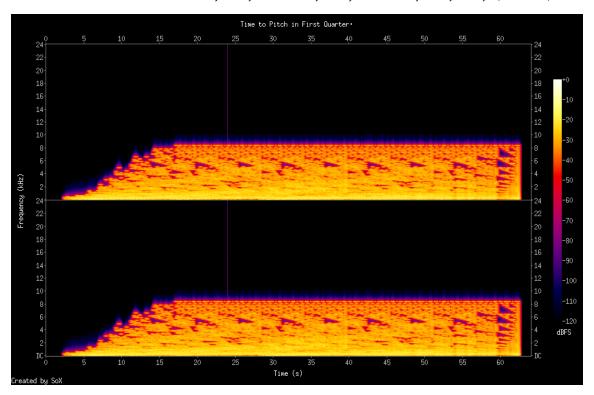
Listing 24: Shear Pitch in Fourth Quarter

```
/*
                                 d
                                      k
                                                               */
                                                p
                                                Ο,
hutchinson[2] <<</pre>
                      .5,
                            Ο,
                                 Ο,
                                      Ο,
                                           Ο,
                                                     0, /* i */
                       Ο,
                           .5,
                                 0,
                                           Ο,
                                                0,
                                      0,
                       Ο,
                            0,
                                .5,
                                      Ο,
                                           Ο,
                                                Ο,
                                                     0, /* d */
                                 0,
                                     .5,
                                           Ο,
                                                0,
                       0,
                            0,
                                 Ο,
                                      0, .5,
                                                Ο,
                                                     0, /* v */
                                                     0, /* p */
                                 Ο,
                                      Ο,
                                           Ο,
                                              .5,
                                           Ο,
                                                0,
                                                     1; /* H */
                                 0,
                                      0,
```



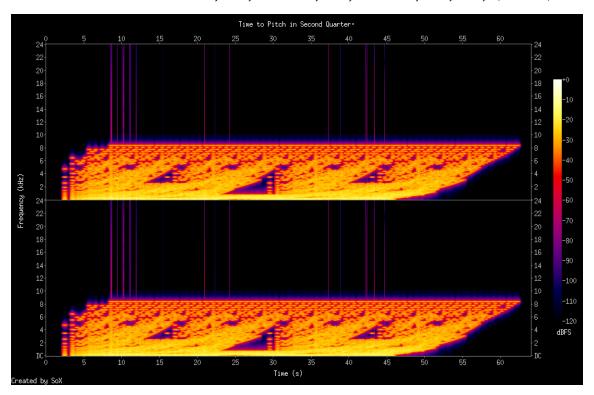
Listing 25: Time into Pitch in First Quarter

```
/*
                           t
                                     d
                                          k
                                                         p
hutchinson[0] <<</pre>
                      .5,
                                          Ο,
                                                    Ο,
                                                         Ο,
                                                             0, /* i */
                           Ο,
                                     0,
                           0.482,
                                                    Ο,
                                                         0,
                       0,
                                     0, -0.129,
                       Ο,
                           0,
                                    .5,
                                          0,
                                                    Ο,
                                                         Ο,
                                                             0, /* d */
                                     Ο,
                       Ο,
                           0.129,
                                          0.482,
                                                    0,
                                                        0,
                           Ο,
                                                   .5,
                                                         0,
                                                             0, /* v */
                       0,
                                     Ο,
                                          0,
                       Ο,
                                                    0,
                                                       .5,
                                                             0, /* p */
                                     0,
                                                        0,
                                                    Ο,
                                                             1; /* H */
```



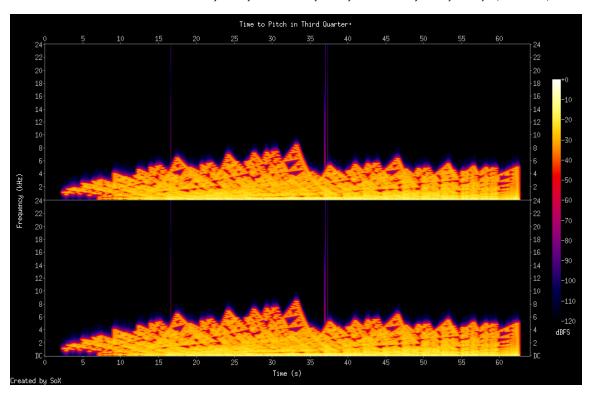
Listing 26: Time into Pitch in Second Quarter

```
/*
                                      d
                            t
                                           k
                                                          p
hutchinson[1] <<</pre>
                      .5,
                                           Ο,
                                                     Ο,
                                                          Ο,
                                                               0, /* i */
                            Ο,
                                      Ο,
                            0.482,
                                                     Ο,
                       0,
                                      0, -0.129,
                       Ο,
                            0,
                                     .5,
                                           0,
                                                     Ο,
                                                          Ο,
                                                               0, /* d */
                       Ο,
                            0.129,
                                      Ο,
                                           0.482,
                                                     0,
                                                          0,
                            Ο,
                                                    .5,
                                                          0,
                       0,
                                      Ο,
                                           0,
                       Ο,
                                                     0,
                                                        .5,
                                      0,
                                                         0,
                                                     Ο,
                                                               1; /* H */
```



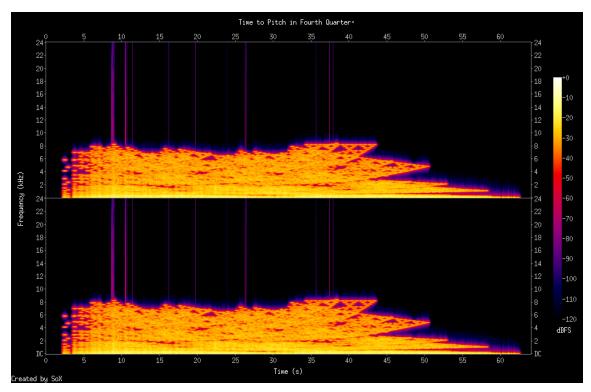
Listing 27: Time into Pitch in Third Quarter

```
/*
                                      d
                            t
                                           k
                                                         p
hutchinson[2] <<</pre>
                      .5,
                                           Ο,
                                                    Ο,
                                                         Ο,
                                                              0, /* i */
                            Ο,
                                      Ο,
                            0.482,
                                                    Ο,
                                                         0,
                       Ο,
                                      0, -0.129,
                       Ο,
                            0,
                                     .5,
                                           0,
                                                    Ο,
                                                         Ο,
                                                              0, /* d */
                       Ο,
                            0.129,
                                      Ο,
                                           0.482,
                                                    Ο,
                                                         0,
                            Ο,
                                           0,
                                                   .5,
                                                         0,
                                                              0, /* v */
                       0,
                                      0,
                       Ο,
                                                    0,
                                                        .5,
                                                              0, /* p */
                                      0,
                                                         0,
                       0,
                                                    Ο,
                                                              1; /* H */
                                      0,
```



Listing 28: Time into Pitch in Fourth Quarter

```
/*
                                      d
                            t
                                           k
                                                          p
hutchinson[3] <<</pre>
                      .5,
                                      Ο,
                                           Ο,
                                                     Ο,
                                                          0,
                                                               0, /* i */
                            Ο,
                                                     Ο,
                                                          0,
                        Ο,
                            0.482,
                                      0,
                                         -0.129,
                       Ο,
                            0,
                                     .5,
                                           Ο,
                                                     Ο,
                                                          Ο,
                       Ο,
                            0.129,
                                      Ο,
                                           0.482,
                                                     Ο,
                                                          0,
                                                    .5,
                                                          0,
                                                               0, /* v */
                       0,
                            0,
                                      0,
                                           0,
                       Ο,
                                                     0,
                                                         .5,
                                      0,
                                                          0,
                                                     Ο,
                                                               1; /* H */
```



[6] Barry Vercoe, John ffitch, et al. *Csound*. Available online at: http://csound.com. Accessed April 22, 2021. 2021 [1985] (cit. on p. 1).