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Scambi fushi tarazu: A Musical Representation of a *Drosophila* Gene Expression Pattern

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Abstract: The term Bio-Art has entered common usage to describe the interaction between the arts and the biological sciences. Although Bio-Art implies that Bio-Music would be one of its obvious sub-disciplines, the latter term has been much less frequently used. Nevertheless, there has been no shortage of projects that have brought together music and the biological sciences. Most of these projects have allowed the biological data to dictate to a large extent the sound produced, for instance the translation of genome or protein sequences into musical phrases, and therefore may be regarded as process compositions. Here I describe a Bio-Music process composition that derives its biological input from a visual representation of the expression pattern of the gene *fushi tarazu* in the *Drosophila* embryo. An equivalent pattern is constructed from the *Scambi* portfolio of short electronic music fragments created by Henri Pousseur in the 1950s. This general form of the resulting electronic composition follows that of the *fushi tarazu* pattern, while satisfying the rules of the *Scambi* compositional framework devised by Pousseur. The range and flexibility of *Scambi* make it ideally suited to other Bio-Music projects wherever there is a requirement, or desire, to build larger sonic structures from small units.

Keywords: *Scambi*; *fushi tarazu*; *Drosophila*; BioArt; BioMusic; Music; process composition

Introduction

The Western classical music tradition has, at least since the time of Beethoven, emphasised the primacy of the composer – the *Werktreue* tradition (Goehr 1989). Most aspects of a musical performance will be described in detail on the score, from the choice of notes to the volume, tempo, phrasing, attack and even expression. The interpreter, whether musician, singer or conductor, has limited scope for insertion of their own individuality. Consequently, one of the hallmarks of a great interpreter of Western classical music is the ability to perform the difficult trick of expressing personal individuality without disrespecting the wishes of the mighty *auteur* composer.

The dominance of the composer began to be undermined in the mid-20th century. Within the avant-garde, interest increasingly developed in the possibility of creating completely non-*auteur* kinds of music, dispensing with any need for the genius of a master composer. In John Cage's words: "Beethoven was wrong. *Beethoven was wrong*!"[1] The idea of music as an unfolding process became fashionable. Of course composition, even by the greatest genius *auteurs*, had always followed certain conventions, obeyed certain expectations of taste. Some of these already contained the seeds of the idea of process music within them. For instance, the rules of serialism allow the composer total freedom of authorial power at the beginning of the note row, but choices shrink dramatically as the end of the row approaches, indeed by the 11th note there are only two options and none for the final note. The composer begins with a flash of inspiration but within the space of 12 notes, ends as slave to the process.

The concept of musical processes began to crop up in widely varying genres within late 20th century classical music. Minimalists devised sets of rules to build up complex patterns from very simple materials, creators of aleatoric music used computer algorithms or other chance-generating processes to force unpredictable sound combinations, and practitioners of intuitive music began to use graphic scores and text instructions to provide frameworks for collective improvisation. This efflorescence of processes within composition inspired the compilation of taxonomies to guide analysis of exactly what process composition meant, to whom, and how (Nyman 1999, Christensen 2004).

A pioneering example of process music is Henri Pousseur's *Scambi* from 1957 (Pousseur 1959). In many respects *Scambi* is like a game: it has a set of 32 fragments ("sequences") of electronically generated sound of either 30 or 42 seconds in length, and it has rules about how those sequences may

[1] Reported by John Ashbery, quoted in Ross, A. (2007). The Rest Is Noise: Listening to the Twentieth Century. New York, Farrar, Straus and Giroux. p. 483

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be put together. Pousseur created the sequences by cumulative manipulations of white noise, applying filters and thresholds of various kinds to select the sounds he liked. If, as Stravinsky once said, "composition is selective improvisation"[2], Pousseur exemplified this approach in creating *Scambi*. The initial filtering of the white noise produced unpredictable consequences, but subsequent treatments refined the output bringing it within a more conventional compositional authorship. The rules that Pousseur then defined for assembling the sequences relate to the most euphonious connection of the end of one sequence with the start of the next. These rules are certainly not stochastic in any way, but rather derive from a judgment of taste that a *Scambi* composition should smoothly transition across its component parts.

Scambi is therefore an open form process piece (Dack 2009), but it is neither aleatoric nor does it permit improvisation. Insofar as its rules allow it to be assembled in a combinatorially very large number of ways, each *Scambi* composition is potentially unique, providing no other player of the *Scambi* game has chanced upon exactly the same combination. A *Scambi* composition therefore has the authorial stamp of its creator, but that creativity is constrained by Pousseur's set of rules, meaning ultimately by Pousseur's compositional aesthetic, and the musical details of each component sequence have the authorial stamp of Pousseur, derived in turn from his selective improvisations with white noise. In Nyman's (1974) taxonomy of process music, *Scambi* is a *people process*, in that the composer may choose, within limits, how to assemble Pousseur's provided materials. It also a *contextual process*, in that the choices available at any point in the piece depend on what has already been composed. In Christensen's newer (2004) taxonomy, *Scambi* is a *rule-determined process*. However, it appears to satisfy neither of Christensen's two sub-categories of rule-determined process – the *generative* and the *transformative* – as the basic material is neither created nor changed by the rules.

Pousseur's recording of one of his own realizations of *Scambi* is available on YouTube[3] and is frequently included in anthologies of early electronic music. Pousseur's second, shorter, recorded version survives but is not publicly available, a situation which also pertains to a version by Luciano Berio. Marc Wilkinson's version may have been lost (Wilkinson 1958). All these were produced in 1957. More recently, realizations of *Scambi* have been created by Andre Castro and Rudy Ceccato, as

[2] Reported by Dave Brubeck, quoted in Storb, I. (2000). Jazz Meets the World-the World Meets Jazz, LIT Verlag. p.204

[3] https://www.youtube.com/watch?v=E6vlOFApLnQ

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well as a jointly composed version by Robin Fencott and Simon Harris. These are available from the website of the AHRC-funded *Scambi* project[4].

Here, a *Scambi* realization is described which illustrates *Scambi*'s ability to represent visual structures. *Scambi* is applied to an image – the banded expression pattern of the gene *fushi tarazu* in the *Drosophila* (fruit fly) early embryo - designated as a graphic score (Figure 1). *Fushi tarazu* means "shuffle" in Japanese, and is used in genetics to name one of the pair-rule genes activated in fruit fly development. Its stripy pattern is the first sign in the fly embryo of the segmentation that will be a feature of the later larva and adult fly. The use of this graphic score is motivated simply by a desire to introduce materials from biology into the compositional process, in order to create a work situated within the current movement for Bio-Art. The realization of *Scambi* described here is therefore a work within the sub-genre of Bio-Art that might be described as Bio-Music. The use of a graphic score in the assembly of a *Scambi* realization, adds an additional layer of process to the composition. Two sets of rules therefore apply: Pousseur's standard set and the architectural rules required by the striped pattern in the graphic score.

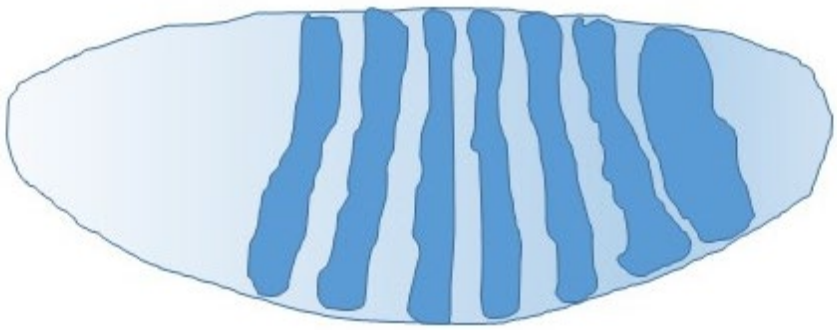

Figure 1. Sketch of typical *fushi tarazu* expression pattern. Intensity of gene expression corresponds to intensity of blue colour. For a real photograph of a *fushi tarazu* expression pattern please see: https://dev.biologists.org/content/131/10/2419.figures-only (panel K). There are many images of *fushi tarazu* available on the internet, most of which are better than this sketch, but none appear to have open source licenses, so cannot be included here.

Materials and Methods

The *Scambi* sequences, their classification and the basic rules

[4] http://scambi.mdx.ac.uk/

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Pousseur's original magnetic tape sequences have been kindly provided by Dr John Dack (Middlesex University) in aiff format. All subsequent manipulations described here were performed in Audacity[5].

When playing the *Scambi* game, there are two general strategies:

1) Ignore the rules. This is what Luciano Berio apparently did in his realization.
2) Stick to the rules.
    a. Make aesthetic choices about what to do within the rule framework.
    b. Devise meta-rules to delay the necessity to make aesthetic choices for as long as possible.

In order to maintain the ethos of process composition as far as possible, my preferred approach is 2b. Indeed, Berio's realization is a negation of process and reorientation towards the more traditional notion of composer as *auteur*. Incidentally, Pousseur still liked Berio's version.

Following Pousseur (quoted in Dack 2004), I also intend to allow the component sequences of *Scambi* to be lengthened where two sequences need to be played simultaneously with a co-ordinated start and finish. Pousseur's intention seems to have been that one sequence can simply be slowed down and, on a 1950s tape machine, that would reduce the pitch correspondingly. Although the Audacity software used for assembling *Scambi fushi tarazu* has an option for slowing without affecting pitch, I have opted to simulate the conditions of the 1950s and require the pitch to drop as the sequence is slowed down.

I also expand the *Scambi* sequence set by creating a reversed version for each. This decision was only reached after attempting a *fushi tarazu*-inspired realization with the original materials and finding that it was impossible to do so. Retrograding is, of course, a standard serialist manipulation, so I feel that reversion is an acceptable sleight of hand, in keeping with the spirit of the 1950s when total serialism was in vogue and when *Scambi* was first created. Some of the sequences could be genuinely retrograded rather than reversed, i.e. the component sounds are separated by sufficient space that they could be regarded as individual notes in a note-row. Examples of this are sequences 7 and 8 among others. On the other hand, some sequences offer so much continuous sound – for example sequence 4 – that doing so would be incredibly laborious even if feasible. I therefore settle for reversal in lieu of real retrograde. That slight sucking noise, annoying to some, produced when any highly

[5] https://www.audacityteam.org/

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attacked note is played in reverse, and widely familiar from early *musique concrète* to electronic pop music, is fortunately not too prevalent.

I found that it is easier to represent a *Scambi* architecture if the binary strings, used to represent the musical characteristics of the starts and ends of sequences, are converted to denary numbers, as shown in Table 1. Pousseur's start and end binary digit codes refer to the musical characteristics of the first and second half of each sequence. From left to right: pitch (low '0' to high '1'), tempo (slow '0' to fast '1'), sound quality (dry '0' to reverberated '1') and continuity (inclusion of pauses '0' to continuous sound '1'). So, in Table 1, sequence family A starts 0110 – low, fast, reverberated and with pauses – and ends 1100 – high, fast, dry and with pauses.

		Binary		Denary	
Family	sequence	start	end	start	end
A	1,2	0110	1100	6	12
B	3,4	0101	1111	5	15
C	5,6	1100	0101	12	5
D	7,8	1111	0110	15	6
E	9,10	1111	1000	15	8
F	11,12	1100	1011	12	11
G	13,14	1000	1100	8	12
H	15,16	1011	1111	11	15
I	17,18	0010	0101	2	5
J	19,20	0001	0110	1	6
K	21,22	0101	0001	5	1
L	23,24	0110	0010	6	2
M	25,26	1011	0001	11	1
N	27,28	1000	0010	8	2
O	29,30	0001	1000	1	8
P	31,32	0010	1011	2	11

Table 1: Binary to denary conversion of the binary string classifications of the standard *Scambi* sequence set, modifying Decroupet's table in Dack (2004).

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Binary to denary conversion makes it slightly easier (to my eye) to notice what is missing from Table 1. For instance, there is no sequence beginning with 0001 that ends with 0010, in denary notation there is no sequence that is 1..2. For sequence of denary type 1..*n*. we only have 1..6 (family J) and 1..8 (family O). Also, some denary numbers do not occur at all, either at the start or end of sequences – 3, 4, 7, 9, 10, 13, 14, 16. So there are only eight possible ways a sequence can start or finish and therefore 64 possible combinations, out of which only 16 exist in the *Scambi* universe. With retrograding allowed, we cannot create new numbers, or indeed new combinations, but we can create more start/end flexibility in the existing combinations, as shown in Table 2.

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		Binary		Denary	
Family	sequence	start	end	start	end
A	1,2	0110	1100	6	12
Ar	1r,2r	1100	0110	12	6
B	3,4	0101	1111	5	15
Br	3r,4r	1111	0101	15	5
C	5,6	1100	0101	12	5
Cr	5r,6r	0101	1100	5	12
D	7,8	1111	0110	15	6
Dr	7r,8r	0110	1111	6	15
E	9,10	1111	1000	15	8
Er	9r,10r	1000	1111	8	15
F	11,12	1100	1011	12	11
Fr	11r,12r	1011	1100	11	12
G	13,14	1000	1100	8	12
Gr	13r,14r	1100	1000	12	8
H	15,16	1011	1111	11	15
Hr	15r,16r	1111	1011	15	11
I	17,18	0010	0101	2	5
Ir	17r,18r	0101	0010	5	2
J	19,20	0001	0110	1	6
Jr	19r,20r	0110	0001	6	1
K	21,22	0101	0001	5	1
Kr	21r,22r	0001	0101	1	5
L	23,24	0110	0010	6	2
Lr	23r,24r	0010	0110	2	6
M	25,26	1011	0001	11	1
Mr	25r,26r	0001	1011	1	11
N	27,28	1000	0010	8	2
Nr	27r,28r	0010	1000	2	8
O	29,30	0001	1000	1	8
Or	29r,30r	1000	0001	8	1
P	31,32	0010	1011	2	11
Pr	31r,32r	1011	0010	11	2

Table 2: Expansion of Table 1 with “retrogrades” (in fact reversions)

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So, after addition of retrogrades, there is still no 1..2, but we now have both a 1..8 and an 8..1 (O and Or, respectively), for instance.

Interpretation of the graphic score, and the meta-rules

Fushi tarazu's stripy pattern immediately suggests assembling the *Scambi* sequences in alternating bands of spare and dense textures. This is quite in keeping with Pousseur's original notion of *Scambi* sequences being arranged in "waves". Following the graphic score (Figure 1), the overall architecture of *Scambi fushi tarazu* is:

Head – stripe 1 – gap 1 – stripe 2 …….. stripe *n* – tail

n is as large a number as can be forced under the rules of *Scambi* and the meta-rules, without running out of sequences. A "perfect" set of meta-rules would remove all necessity for aesthetic decisions and render *Scambi fushi tarazu* a pure process composition. The meta-rules adopted are as follows:

1) Where an option exists, always choose a *Scambi* sequence beginning with a low denary "start" value, in preference to a higher valued one (see Table 2).
2) Don't repeat a pattern (meaning a start..end pair *x*..*y*; see Table 2) unless compelled to do so.
3) Only use each sequence once, so a pattern *x*..*y* can only be used a maximum of twice (see Table 2).
4) If sequences that need to start and stop together are of different lengths, only lengthen – never shorten.

I hope that greater clarity in these meta-rules will become apparent as I step through the construction process. They proved not to be "perfect" and some aesthetic decisions did have to be made.

Composition

The head is the extreme left end of the embryo. Meta-rule 1 requires the lowest number to be selected, and this would be a sequence of denary pattern 1..5 (since there are no 1..4 or lower fragments; see Table 2). This pattern is found in the retrogrades of sequence family K, in other words sequences 21r and 22r. At this point the first aesthetic choice is required, to use one or the other, according to taste.

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The first stripe is next. For this I select all sequences that can follow 1..5. So the head and the beginnings of the first stripe area are as follows (Table 3):

		5	1
		5	2
1	5		
		5	12
		5	15

Table 3: Commencement of the compositional architecture in the head and first stripe.

Just as an aesthetic choice was made for which 1..5 to choose, so again any of the pairs of 5..1, 5..2 etc can be chosen. Since these are to be played simultaneously, the composer's taste may dictate what combines best. There are 16 possible combinations, so one can either take considerable time over it, or adopt some aleatoric technique, in the manner of John Cage. Meta-rule 4 is applicable at this point – all sequences in the first stripe need to be the same length, so the shorter ones are slowed down to ensure a flush ending.

The sequences are now all heading out in different directions in terms of their "end" values, so the stripe has to now be brought round again to a single value. Meta-rule 1 is applied again: if possible we should aim to land on a low number – can we get them to converge on *x*..2? The answer is no, because there is no 1..2 to follow 5..1. The lowest is 1..5. However, meta-rule 2 is now applied – 1..5 has already been used, so 1..6 is next. This means that all the others must also converge on 6. This can be done without breaking any of the meta-rules. The complete first stripe is therefore (Table 4):

		5	1	1	6
		5	2	2	6
1	5				
		5	12	12	6
		5	15	15	6

Table 4: Completion of the compositional architecture of the head and first stripe.

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I hope it is now obvious where this is going. The first gap is next and it has to be the lowest sequence beginning with 6, so we have (Table 5):

		5	1	1	6		
		5	2	2	6		
1	5					6	1
		5	12	12	6		
		5	15	15	6		

Table 5: Completion of the compositional architecture of the head, first stripe and first gap.

And then the second stripe and second gap follow naturally (Table 6):

		5	1	1	6		1	5	5	1	
		5	2	2	6		1	6	6	1	
1	5					6	1				1 8
		5	12	12	6		1	8	8	1	
		5	15	15	6		1	11	11	1	

Table 6: Completion of the compositional architecture of the head, and the first two stripes and gaps. Patterns that have been used twice are coloured.

Notice that 1..5 and 1..6 become the first patterns to occur for a second time. At this point the unused member of the pair (either sequences 21r or 22r for 1..5 and either 19 or 20 for 1..6; see Table 2) should be used. This is a forced repeat usage of 1..6 and 1..5. Meta-rule 2 says no repetitions unless compelled, but here we are compelled.

For the second gap, since 1..5 and 1..6 have already been used twice and are now out of action completely, the second gap has to be 1..8, itself forced for the second time. 5..1 is also required to be used for a second time in the second stripe. We continue (Table 7).

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		5	1	1	6		1	5	5	1		8	1	1	11		2	5	5	2								
		5	2	2	6		1	6	6	1		8	2	2	11		2	6	6	2								
1	5					6	1				1	8				11	2				2	5							
		5	12	12	6		1	8	8	1		8	12	12	11		2	8	8	2		5	12	12	8				
		5	15	15	6		1	11	11	1		8	15	15	11		2	11	11	2		5	15	15	8				

Table 7: Complete compositional architecture of *Scambi fushi tarazu* to the point where options are exhausted within the rules of the process. Patterns that have been used twice are coloured.

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11..1 has already been used, so the third gap must be 11..2. By this point, we start to run out of options. Once we find ourselves back at 2..5 (Table 7, fourth gap), it is impossible to fill the upper part of the next (fifth) stripe. Therefore the *Scambi fushi tarazu* process is declared over at gap 2..5, which is now redesignated as a concluding tail.

So we now have in Table 7 a blueprint in terms of the patterns to use for a *fushi tarazu* realization of 4 stripes, 3 gaps, a head and a tail. The head, tail and gaps can be placed at the centre of the stereo axis and the 4 layers of each stripe component arranged 100% left, 50% left, 50% right and 100% right.

This architecture could, as mentioned above be achieved in various ways, as the meta-rules prove to be incapable of removing the necessity for aesthetic decisions. The *Scambi fushi tarazu* realization created here uses the sequences shown in Table 8:

	22	19		22r	21		30r	25r		17	17r	
	18r	23r		20	20r		27	32		24r	23	
21r			19r			29			32r			18
	6r	2r		30	29r		14	11		27r	28	
	3	7		26r	26		10r	16r		31	31r	

Table 8: *Scambi* sequences (Table 2) satisfying the architecture displayed in Table 7.

This realization uses 18 sequences in forward orientation and 19 in reverse, i.e. 37 of the 64 sequences in Table 2. Where aesthetic choices had to be made, I usually opted for the sparser of the alternatives, in order to prevent the stripes from becoming too dense in texture. Since the stripes consist of four sequences played simultaneously, mixing and rendering to a quadrophonic realization would be ideal. A stereo version of the final composition described here is on YouTube[6] and its appearance in Audacity is shown in Figure 2. The Audacity file is provided within the Supplementary Materials.

[6] https://www.youtube.com/watch?v=X6qDwhmZ01k

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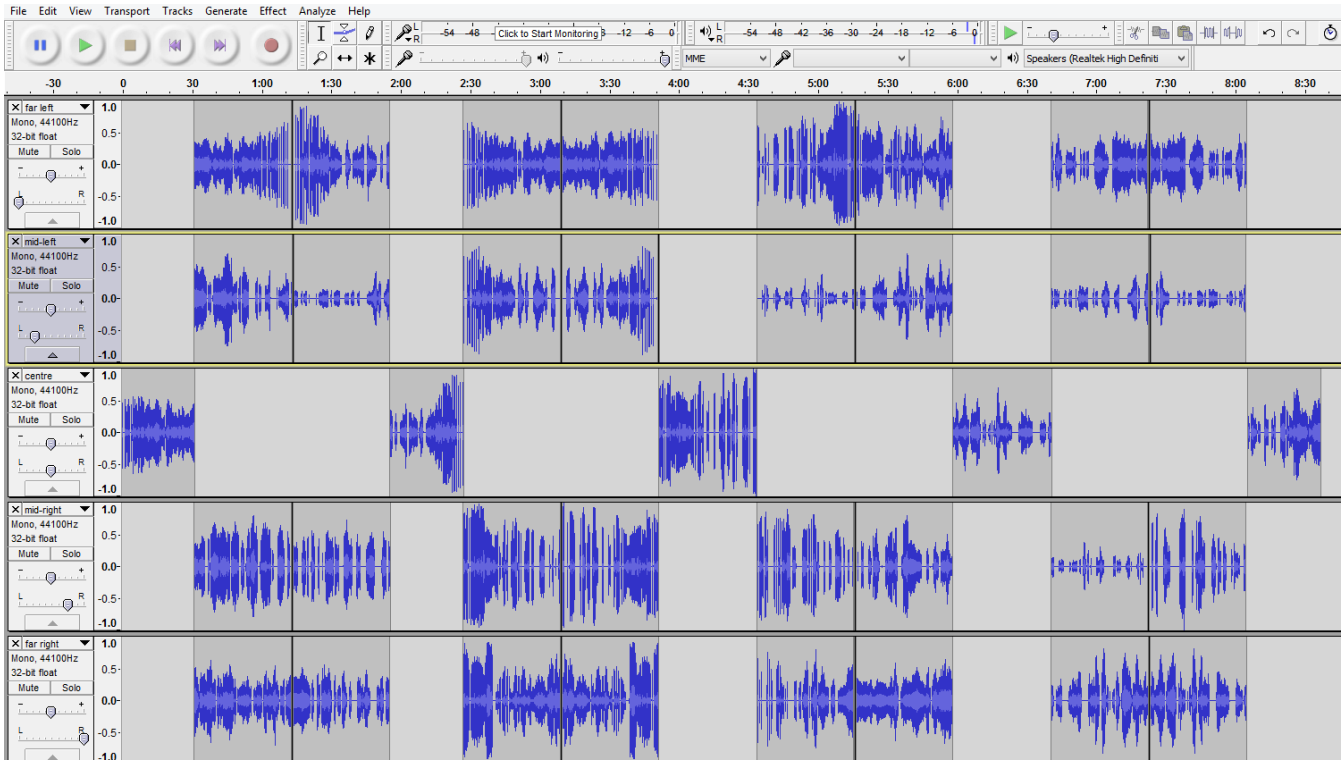

Figure 2. *Scambi fushi tarazu* in Table 8, assembled in Audacity.

Figure 2 shows that the process produces the occasional appearance of "mirror images" – a sequence followed by its retrograde, e.g. 26r then 26 in stripe 2 lowest track, 31 then 31r in stripe 4 lowest track. The stripes are louder than the intervening solo sequences, simply because more sound is being played simultaneously, but this is appropriate for creating the intended stripy effect. Volumes were also adjusted to avoid distortion in the louder moments and slightly at the joins to make them less audible – although the sudden transitions from stereo arms to centre are also part of the stripy effect and any slight jolting effects as this happens are left in. Pousseur's available recorded version of *Scambi* does appear to have some volume adjustments for some of the sequences, presumably added on purely aesthetic grounds.

Biologists reading this may by now have spotted an obvious discrepancy between Figure 1 and Figure 2. In the real world, *fushi tarazu* has 7 stripes, not 4. In order to produce a more biologically accurate realization, meta-rule 3 would need to be scrapped to allow some x..y patterns to be used for a third time, or potentially more. Any realization of *Scambi* where repetition of sequences is permitted without a ceiling, could potentially be endless, and for this reason there are theoretically an infinite number of *Scambis* awaiting realization, one of which would be a true 7-stripe *fushi*

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tarazu. The present realization has a duration of just over 8'30'', so a 7-stripe version would be around 6' longer.

Since 4 sequences are being played simultaneously in the stripes, this could potentially make for a very dense texture. However, Pousseur engineered a lightness to the component sounds of *Scambi* that means that sonic clarity is rarely a problem.

Future Possibilities

What other biological objects could be used as graphic scores to inspire other Scambi compositions? The *fushi tarazu* stripe pattern was chosen here for its simplicity and the fact that it is well known to developmental biologists and geneticists. Its ubiquity in undergraduate teaching possibly means that it is known to most biologists who have graduated since the 1990s. Other iconic biological shapes are the obvious next option, of which the most famous is probably the DNA double helix. One might, for instance be able to design a single concatenation of *Scambi* components to represent one strand, and then another to represent its complement – perhaps the retrogrades of the "top strand". Alternatively, one might seek to define a correspondence table between DNA bases and *Scambi* encodings. This is more challenging – see Table 2. If a top/complementary two-channel duet can be created, it would still be two-dimensional. To create the effect of a double-helix, some form of sound design would be required to give the illusion of the sound coiling in space.

Two single-channel *Scambi* concatenations that are developed independently, could also be aligned, for instance using the Smith-Waterman algorithm, provided that a distance matrix could be derived to relate some form of sonic distance between individual *Scambi* components. As in an alignment of DNA or proteins sequences, gaps could be inserted to maximise the alignment score. *Scambi* contrapuntal duet compositions could thus be created to express the principles of the alignment algorithm. This project is in preparation.

Acknowledgments

Dr John Dack (Middlesex University) kindly provided the component *Scambi* sequences, as well as much encouragement and personal reminiscences of Henri Pousseur. I am also grateful to Dr Alan Marsden (Lancaster Institute for the Contemporary Arts) and Dr Linda O Keeffe (Edinburgh College of Art) for their much valued time and advice.

Supplementary Materials

Pousseur's *Scambi* components, along with the Audacity file and associated directories for the version reported here, are available from: https://doi.org/10.17635/lancaster/researchdata/334

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