Chapter 7: Evolutionary Morphing for Music Composition

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7.1 Introduction

From one view of composition—let us call it the inspired or "Mozartian" view—musical compositions arrive fully formed in the mind of the composer and simply require transcription. In reality, however, it seems that very few people are so inspired, and composition is often more akin to a gradual clarification and refinement of partially formed ideas on the musical landscape. Particular landmarks in the compositional landscape tend to become clear before others, such that the incomplete piece is a patchwork of disconnected musical islands. An interactive evolutionary morphing system may provide some assistance for composers, to help build bridges between musical islands by generating hybrid musical transitions.

One aim of our research was to develop artificial-life (a-life) musical techniques that morph from one musical state to the next using genetic algorithms (GA). The algorithms start with a source musical configuration and then modify and evolve it using a fitness function derived from the target musical configuration. The focus of this research is on note-sequence morphing, that is, an event-based representation of music such as found in common-practice notation or the MIDI specification. A sophisticated process of recombination and modification aims to ensure that the generated material remains coherent and that the transition resolves effectively, regardless of the duration of the morph.

Musical processes based on GA are inspired by neo-Darwinian evolution, in which a new generation of musical material is derived from existing material. The evolutionary metaphor is often extended to include selection and culling, according to a set of desirable musical attributes. Many a-life-based music systems share the basic concept of generating and selecting musical material; however, there are a wide variety of approaches to both the creation and the application of evolved material for compositional purposes. Considerations regarding the process of evolving music include how music is represented for computational evolution, what kinds of combinations and transformations of the material are used, and how fitness is measured for selection. Considerations for musical application of these techniques include how (or if) generated material is combined with other composed material and whether material from different generations is heard sequentially, in parallel, or arranged in some other structure. In this chapter we will outline an approach to using a-life—based generative algorithms to create bridging material between precomposed musical segments, a process we call evolutionary morphing. This chapter describes the design of an interactive interface for an evolutionary morphing system that assists in the visualization of the process. It addresses the ways in which we have designed our generative processes and how the resulting material is applied to composition.

7.2 Evolutionary Composition

The application of evolutionary processes to music composition has been approached from a number of different perspectives, including those of the generation of melodic material (Miranda 1993; Wiggins, Papadopoulos, Phon-Amnuaisuk, and Tuson 1998; Towsey, Brown, Diederich, and Wright 2000), the development of precomposed musical segments (Waschka 2007), and the evolution of generative musical structures (Dahlstedt 2004). Numerous other musical applications of evolutionary processes for improvisation, performance, interactive installations, sound synthesis, and musicology are beyond the scope of this chapter; many of them are more fully discussed in this book and elsewhere (Burton and Vladimirova 1999; Miranda and Biles 2007).

Of more direct relevance to this research is the use of GA for generating thematic bridging material by Horner and Goldberg (1991). They used an initial configuration of musical attributes as the raw material for the evolution and a target configuration as a fitness benchmark, and also checked that the duration of the generated material matched the start and end configurations. They also used a combination of standard random mutation and crossover with some limited musical modifications when generating new material.

A review of compositional bridges, medleys, and quodlibets, which have long been produced by composers, is well beyond the scope of this chapter. However, a particularly pertinent example of these kinds of works, the compositional process described by Byron (2003) as musical metamorphosis, is very similar in intent to the morphing process we have developed. Byron represents his metamorphic process as having the formal structure A–ABA–AB–BAB–B, where the music between sections A and B is a gradually varying weighted combination of elements from A and B. According to Bryan, "The resolution of this method will logically be the fusion of both thematic germs to create a single new theme containing related parts from both originals." Byron's methods are handcrafted, rather than computationally defined, and therefore the aesthetic selection process is built into the generation process.

7.3 Note-Sequence Morphing

A number of approaches to note-sequence morphing have been attempted, notably by Mathews and Rosler (1968), Polansky (1992), Oppenheim (1995), Edlund (2004), and Wooller and Brown (2005). In summary, the techniques used include:

<*> Rendering the note sequences as continuous parameter envelopes and interpolating <*> Permuting the sequences according to particular metric spaces: pairing individual notes from the source to individual notes in the target, interpolating their values <*> Interweaving discrete units from the source and target alternately, based on probabilities derived from the morph index <*> Morphing harmonic data according to key modulation techniques and applying dissimilarity measures to influence probabilistic generation

The evolutionary morphing strategy discussed here uses aspects of these approaches as applicable to various musical circumstances but adds an overarching mutation and selection framework that, according to qualitative testing (Wooller 2007), provides

continuity and interest to the music at the sacrifice of more global coherence. Although lack of coherence would be detrimental to a *composer agent*, we have found this morphing process to be quite useful as a *composer assistant*.

We have developed an evolutionary morphing algorithm, which we refer to as the Transform Select, or TraSe, algorithm. The rationale behind the TraSe algorithm is that effective morphing can result from a series of carefully chosen compositional transformations applied to a given source music. TraSe allows greater control over stylistic elements of the music than previous morphing algorithms through user-defined weighting of various compositional transformations. The morphed music consists of a series of musical frames, one from each generation in the evolutionary process. The evolutionary approach is one of trial and error, involving mutations and fitness functions that ensure the transformed source eventually converges on the target. The TraSe algorithm has been designed to produce morphed material with the following characteristics:

- <*> Continuous morphs are afforded by the fact that any one frame is more closely related to its neighbors than to any other frame <*> Morphs that are coherent for a particular style of music are afforded through the ability to include transformations indicative of that style
- <*> The stylistic outcome is derived from manipulation and analysis of the source and target music

7.4 Compositional Structure as a Musical Topology

The representation of musical structure as a topology is a widely used metaphor, one most comprehensively explored by Mazzola (2002). In this conception musical elements of varying levels of granularity, from note, through phrase, to entire section or movement, are considered nodes in a graph. The relationships between nodes are often temporal but may also describe other parameters, such as harmonic similarity, frequency of occurrence in a work, and so on. The evolutionary morphing approach to composition continues this tradition by considering precomposed musical segments as nodes and generated musical material as links between those nodes. The structure of the resulting composition can be visualized as a graph of the compositional macrostructure.

Automatic morphing allows a composer to focus a compositional macrostructure on the basis of particular states. The morphing software works out the details in between. Its focus is to provide continuity from A to B, such that the music generated by holding the morph index at any particular point appears more closely related to the music generated by holding the morph index at the adjacent points than at any other value of the morph index. This property of continuity facilitates control of the morph by a composer but does not necessarily ensure a coherent result. It is up to the composer to navigate the morphology to produce discrete structural variations if required—for example, breakdowns, build-ups, or direct cuts. The macrostructure of a composition—that is, its overall form—can be understood as a series of sequential sections. These sections, often labeled A, B C, and so on, can be depicted as nodes in a graph, and the bridges between them as lines linking these nodes.

Owing to the emphasis on transitioning between sections, music morphing is related to DJ style mixing. However, unlike cross-fading, which relies upon the art of track selection, morphing is applicable to material that is divergent in all musical dimensions: rhythm, key, pitch-class set, tempo, and so on. This changes the nature of macrostructural practice: rather than searching for tracks which share common elements, the composer designs tracks to have maximal difference, challenging the algorithm to generate a viable result. We noticed that greater divergence in source and target produces greater diversity of material throughout the morph. This diversity of material is more clearly observed on slower time scales or by holding the morph index at particular points. In this case, the morph acts less as a transition and more as a new hybrid section.

7.5 Interactive Evolutionary Morphing

The metaphor of graph topologies to describe compositional structure forms the basis of our visual interface with the evolutionary morphing system. This interface is an effective way of introducing the evolutionary morphing compositional technique before studying the details of how musical material is represented, generated, and selected.

<!Insert Figure 7.1 about here!>

Figure 7.1 depicts the visual interface of the evolutionary morphing

system. Each of the rectangles represents a precomposed musical segment, here labeled Normally in a musical segment the nodes contain all (or most) of the musical material, and the links show relationships or connections between those musical segments. With the addition of generated material provided by the morph, the ratio between precomposed sections and generated material can vary significantly using the interactive morphing approach. It becomes possible with the interactive evolutionary morphing system to extend this ratio such that the vast majority of the music is generated as variations and hybrids of the precomposed music in the nodes. The compositional topology can still be represented as a graph; however, the relative size of the nodes and connections can become a compositional choice

A, B, and C. The segments are positioned on a time line running left to right, and the distance between them determines the duration of the morph. Between the precomposed music segments are curves depicting the trajectory of the morphing index, with index value 0 at the bottom of the rectangle and index value 1 at the top. In Figure 7.1, a linear morphing transition is shown by a straight diagonal line between music segment A and music segment B. Between music segment B and music segment C the morph index stays low (mostly influenced by music segment B) until late in the transition, where it rapidly accelerates up (toward music segment C). The flat curve after music segment C indicates that the morph continues as an extension, rather than a transition, by using music segment C as both source and target for that period. Finally, the circle indicates the current position during music playback; it can also be dragged along the graph to select a new playback position. This facilitates the auditioning of any section to hear the effect of changes in parameter or position.

The evolutionary morphing system can accommodate one or more musical segments in a

composition, as shown in Figure 7.2a. Musical segments can consist of multiple parts; the structure of these segments is summarized below. Segments can theoretically be of any size, but the computational complexity of morphing multipart sequences of more than around forty notes is currently prohibitive. For this reason, normally the morphing algorithm utilizes the few measures that directly precede the morph, at the end of the precomposed segment, rather than material from the entire segment. To accommodate these two considerations, the system allows the user to specify a portion of the precomposed musical segment for use in the evolutionary process. This is shown in Figure 7.2b, where the gray section of segment A is played as part of the performed music but is not included as data for any morph involving that segment. Different sections of a segment can be specified for inclusion in morphs to and from that segment, as shown in Figure 7.2c, where a short section is specified for morphs before the segment and a larger section for use in morphs following that segment.

<!Insert Figure 7.2a, b, and c about here!>

Morphing curves are anchored at each end. They are straight (linear) by default but can have other functions added to them to provide curves such as an exponential increase. It is quite common for different rates of morphing to be required for different aspects of the music. For example, harmonic changes are stepped, while dynamic (loudness) changes can be smooth. There are methods of specifying the morphing trajectories of individual morphing parameters in the detailed editing stages outlined below. The function that controls the primary morph index is mapped onto each parameter's trajectory in such a way that a linear function for the primary morph index leaves parameter trajectories unchanged, while a change to the primary function affects all trajectories but maintains their relative differentials. Morphing curves maintain their shape when stretched or shrunk by the repositioning of music segments.

The interface (see again Figure 7.1) provides an overview of the evolutionary music morphing system and how it can be controlled at the level of whole segments, as well as the morphing curves between them. Music segments and morphing parameters can be edited to accommodate a wide variety of musical circumstances; however, the design has been somewhat biased toward the needs of mainstream (pop) electronic music, in particular the use of loop-based structures, which was the style used as a case study for developing the morphing algorithm.

7.6 The Generative Engine

The scheme implicit in the biological metaphor of evolution is that the organism is represented as a genotype (i.e., a DNA strand) for the purposes of reproduction, by means of which the genotype develops into a phenotype (i.e., a life form) for the purposes of selection. There are some a-life—based musical systems, such as those investigated by Laine and Kuuskankare (1994), that hold to this metaphor by using an algorithm or function (genotype) that is becomes a musical work (phenoype), with the function of being reproducible and capable of mutation and the fitness of the rendered musical work determining the participation of each function in the next generation. Most a-life—based music systems tend to directly represent the musical work (phenotype) for both the

generative and the selective stages of the evolutionary process. This usually means that the music is represented as a note sequence or tree structure that is subject to mutation of a parameter (e.g., pitch) and/or recombination by means of crossover.

In the TraSe algorithm the musical representation for all musical segments includes loop length, note onsets, durations, dynamics, scale degrees/passing tones, scale, and key; see, for example, the DEgree PAssing tone, or DEPA, scheme described below. It is important to bear in mind that there are two separate TraSe algorithms that operate in parallel: one for key and scale, and another for note-level data (note onset, duration, dynamic, and scale degree/passing tone). The former is referred to as a tonal morph and the latter as a *note morph*. Most of the TraSe processes described here are for the note morph. The tonal morph is essentially a more restricted version of the note morph. Both the note-morph and the tonal-morph TraSe algorithms can produce a different number of discrete sequential frames (the process of generating the frames is described below). During playback the relevant data from the current tonal-morph frame is combined with the current note-morph frame to produce an output with the representation in standard notation of pitch, duration, onset, and dynamic. Enabling the tonal morph proceed in parallel to the note morph in this way allows more specific control over the musical elements of the morph and enables note-morphing processes to be more effective at dealing with pitches that are defined relative to their tonic rather than in an atonal pitch space.

A new pitch representation scheme was developed as part of this research, the DEPA (DEgree PAssing tone) scheme, which enables accurate representation of passing tones and thus allows easy differentiation between scale and nonscale tones (Wooller 2007). In simple terms, DEPA pitch representation is similar to using the scale degree in conjunction with scales to represent the pitch. The primary difference is that twice as many scale-degree slots are allowed, so that passing tones and potential passing tones can be represented. For example, instead of seven possible scale-degree slots, there are fourteen. This permits greater flexibility when dealing with passing tones and changes of scale; for example, decisions can be made on whether to preserve the atonal quality of the passing tone in the new scale (useful for chord-oriented or vertically oriented music), fit the pitch contour (useful for melody), or maintain true pitch.

TraSe takes two musical sequences, the source and target, and produces morphed material—that is, a hybrid transition between the two. In the case of the TraSe morph, the material is a list of loops or frames, the first and last of which are the source and target respectively. The frames of the middle constitute a sequential progression of music within the morph. During playback, the morph index is used to determine which frame in the series is currently playing. Tracking the evolution of the morphing music through a series of musical sections like this affords continuity, especially if each frame is more similar to its neighbors than to the others.

The TraSe algorithm sequentially fills each frame by passing the previous frame through a chain of compositional transformation functions. The total number of frames is initially unknown because TraSe stops creating new frames only when it generates a frame that is

the same as the target. The final sequence of morphed frames is selected from the total list by quantizing frame selection to achieve the required length. With some intervening frames being skipped, the sense of a logical progression of compositional transformations leading from source to target may be lost. One way to avoid this is to use compositional transformations that afford rapid convergence with the target so that not too many excess frames are computed. Another approach is to use an add/remove transformation at the end of the compositional transformation chain that directly incorporates material from the target (see below).

The transformations that have been implemented perform a fixed number of large-scale transformations affecting the whole musical segment, except for add/remove, which deals with individual notes. There is no transposition function, because this is handled as part of the morphing of key/scale, which is a parallel application of TraSe. Each of these transformations has a set of parameter configurations, each of which are applied to transform the input, thus generating a pool of potential outputs with different mutations. The final output is determined by assessing the dissimilarity of each transformed sequence with the target note sequence. Each parameter configuration has a user-defined weighting, which can alter the dissimilarity-to-target measurement for the product of that parameter configuration. This enables greater control over stylistic biases within the transformations. The transformations also have individual dissimilarity measures that are relevant to each:

- <*> The *divide/merge* transformation affects the number of notes in the input note sequence without dramatically altering the musical intentions. It has five parameter configurations: merge forward, merge backward, split-quarter, split-half, and split-three-quarters
- <*> The *rate* transformation focuses on a change in speed, preserving the pitch contour but dramatically altering notes' start time. Rate simply multiplies the start time of each note in the input by a certain ratio, cutting out notes if they exceed the loop length or looping the pattern as many times as needed to fill the loop length when required
 *> The phase transformation shifts the start time of each note within the pattern by a
- <*> The *phase* transformation shifts the start time of each note within the pattern by a certain amount, for example half a beat, either ahead or behind. Where the new onsets exceed the loop boundary, they are wrapped around
- <*> The *harmonize* transformation is aimed at incorporating a simple harmonic dimension to the music. It works by either adding or removing parallel harmony at each of the tonal intervals, from the third through to the octave. Although not all of these intervals are particularly common, they are included to provide flexibility; stylistic preferences for each interval can be adjusted using the weights
- <*> The *scale pitch* transformation is designed to expand or reduce pitch range in the musical pattern while maintaining the contour. The approach applies a simple scaling technique to the pitch of each note, relative to the tonic closest to the pitch centroid. The scale factor is quantized to twelve possible configurations
- <*> The *inversion* transformation is designed to invert the harmony of the input pattern. This is similar to chord inversion but can be applied to any number of pitches
- <*> The *octave* transformation simply shifts the whole pattern by the number of octaves specified with an input parameter

<*> The add/remove transformation either adds or removes a single note. It is designed to guarantee that the output will be closer to the target than the input. It achieves this because each note in the input is considered for removal and each note in the target is considered for addition. Add/remove differs from the other transformations in that it directly incorporates material from the target. Also, the number of parameter configurations for the add/remove transformation is dynamic rather than fixed; each configuration is related to an individual note from source or target, which may vary.

There is also the *key/scale* morph, which is a special transform-select process that deals with key and mode data, rather than sequences of notes, and operates in parallel to the note-based transformations described above. Each of the frames generated by the key/scale morph contains a key, from C to B, and a scale, including the church modes. Every possible combination of key and scale is considered for each frame, and the dissimilarity-to-target measure is a weighted combination of proximity in the circle-of-fifths and the circle-of-chroma metric spaces (Shepard 1982). A user-defined parameter controls the rate of change in a target level of dissimilarity-to-target (rather than aiming for a total match, which would allow convergence in the first frame), effectively enabling the number of frames to be controlled.

Allowing specific compositional transformations to be designed and plugged into the algorithm enables elements of compositional style to be specified; for example, the harmonize transformation creates or removes harmonies at particular intervals, while the rate transformation speeds up or slows down the music by certain commonly used ratios. The transformations are evolutionary in the sense that they produce a range of different patterns, from which only one is selected for output.

A variety of fitness methods and approaches have been used in generative music systems: comparison with some target music (Horner and Goldberg 1991), random selection (Waschka 2007), adherence to heuristic rules (Towsey, Brown, Diederich, and Wright 2000), subjective or aesthetic evaluation by human reviewers (Dahlstedt 2004), and assessment by a trained connectionist network (Gibson and Byrne 1991). Like that of approach relies on a comparison of the mutated note sequences to the target, but unlike in their work, the length of the mutated note sequence is not a fitness requirement, because the musical transformations we use ensure that the length of the mutation is fixed.

We introduce additional layers of refinement that allow for more control over continuity and stylistic features of the morph. In TraSe, the fitness of the candidates generated by each of the transformations mentioned above is determined by how closely the candidates match a precalculated level of dissimilarity with the target note sequence.

7.6.1 Fitness Function and Selection

A variety of fitness methods and approaches have been used in generative music systems: comparison with some target music (Horner and Goldberg 1991), random selection (Waschka 2007), adherence to heuristic rules (Towsey, Brown, Diederich, and Wright 2000), subjective or aesthetic evaluation by human reviewers (Dahlstedt 2004), and assessment by a trained connectionist network (Gibson and Byrne 1991). Like that of

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We introduce additional layers of refinement that allow for more control over continuity and stylistic features of the morph. In TraSe, the fitness of the candidates generated by each of the transformations mentioned above is determined by how closely the candidates match a precalculated level of dissimilarity with the target note sequence. It is important to note that the fitness requirement is not necessarily an exact match with the target. The goal is to have a certain amount of dissimilarity with the target note sequence. During the start of the process, a high level of dissimilarity-to-target is required, but as each frame is generated, the required level of dissimilarity-to-target drops. By the end, the required level of dissimilarity should be zero—that is, a perfect match. This feature is intended to ensure that a direct match does not occur prematurely; it allows the "scenic route" to be taken, exposing the musicality of the various transformations by generating a series of frames.

Discussing the measures in terms of dissimilarity rather than similarity is an arbitrary choice, but it is useful because dissimilarity can be thought of as distance, which is a natural method of comparing two items. The dissimilarity measure is not a distance metric in the formal sense, because triangle inequality is not necessarily upheld. The dissimilarity measure for a particular transformation is designed to complement that transformation.

The divide/merge, phase, and rate transformations all use a bidirectional nearest-neighbor (NN) comparison to provide the dissimilarity-to-target measurement. This calculates the average distance between each note in the candidate note sequence with its NN in the target note sequence and, conversely, each note in the target with its NN in the candidate. It is necessary to calculate in both directions because the NN of one note is not necessarily the NN of the other. A dissimilarity measure that takes the difference in area between envelopes for pitch and onset is used for the rate and inversion transformations. For the harmonies transformation, the dissimilarity measure is a weighted combination of average harmonic interval from the tonic and the difference in the average number of polyphonic streams. For the scale pitch transformation, the dissimilarity measure is the average distance of pitches from the central tonic pitch. The octave transformation uses the difference in average pitch.

The difference of each dissimilarity-to-target measurement to the required dissimilarity-to-target level for the frame being generated can be weighted by the composer. These weightings are important because they allow various parameter configurations to be favored over others during the selection process, which means that aesthetic preferences for each compositional transformation can be controlled by the composer.

7.6.2 Controlling the Morph

One of the challenges of generating music automatically with computers is that different cultures, styles, and instruments have their own conventions and constraints. Therefore,

to get the best from the evolutionary music morphing process various parameters need to be set to control the morph to meet stylistic and aesthetic requirements. Although the system, based on its representation and modification constructs, has an influence on the musical outcome, the composer can bring about significant change by setting various morphing parameters. The kinds of changes thus generated include influence over the macroscopic structure of the work, the musical function of the morph, and the degree of continuity or variation, among other properties.

The macroscopic structure of a morph is controlled primarily via the envelope of the primary morph index for each part—various functions that influence how source and target timbres of each part are cross-faded. In order to assist continuity, the user can tweak the gradient offset and the degree of exponential curve for the function that influences the primary morph index. Moreover, the primary morph index can be quantized to control precisely how many changes will be heard. For example, much of the mainstream electronic music that was used for the study was based on length cycles of four, eight, or sixteen, and so it often makes sense to quantize the morph index to four discrete levels.

The composer is able to effect breakdowns and sequential morphing of the different parts through the gradient and offset of the timbre cross-fade functions. For example, a breakdown may be produced by reducing the gradient and shifting the offset of the volume functions so that only one part is heard during most of the morph. Alternatively, the composer can adjust the offsets and gradients of the cross-fade functions and morphindex functions such that changes in each part are introduced in turn, while the other parts remain unchanged. This often appears to produce more acceptable results than when the changes are continuous and equally constant in all parts.

Parameters that allow control over the degree of continuity and variation as well as other effects include the number of transformations per frame, or mutation limit; the target number of frames (transform speed); and the global weighting on "no change" as a transformation parameter configuration. Reducing the number of transformations per frame has the effect of spreading the transformations through a greater number of frames and increasing continuity over longer time spans. This is particularly important in the first few frames, which tend to undergo the most drastic changes if no limit is set. Variation can be increased by reducing the transform speed, which forces the algorithm to "take the scenic route." Transform speed controls how fast the required level of dissimilarity with the target approaches zero as each frame is generated. A global no-change factor factors the weighting of each no-change parameter configuration for the transformations. If this weighting is reduced, it forces the algorithm to constantly induce change, whether or not the change approaches convergence. This can be very useful if the composer wishes to explore different variations of the morph rather than simply to follow the most direct musical path between precomposed segments.

A morph is a hybridization of source and target, but also a transition between source and target. If the composer wishes to focus on hybridity, it would be typical to set the morph index constant at a particular point, iteratively sample the results, and tweak parameters.

To focus on the morph as a transition, it would be typical to adjust morph-index quantization, offset, gradient, and exponent, as well as the cross-fade functions, as mentioned above. The process can also be induced to perform variations on material by morphing the source to itself and reducing the global no-change factor to zero. The morph can also be controlled through the weightings of specific parameter configurations for each transformation. For example, if the density of the morph seems too high, the "merge" settings of the divide/merge transformation can be favored. The composer may reduce the pitch range of an overly expressive part by favorably weighting the smaller ratios of the scale pitch transformation.

7.7 Demonstration

For the following demonstration we used two simple tunes, one for the source and one for the target. The source is playful, with short, staccato notes played at 1.5 beat intervals which, against the 4/4 drums, creates a three-against-four polyrhythm with a single-measure macro-cycle. It contains the pitches C, D, F, and B, and the tonal movement is I–IV. In contrast, the target is an ambiguous, rising tonal wash with long notes that are mostly syncopated, a greater pitch range, and a mostly upward contour. Two pitches, E and G, are absent from the source and F is excluded from the target. The tonal movement could be interpreted as ii–I, VII–I, V–I, or possibly other combinations. Both source and target have six notes; they can be seen in the first and last measures of Figure 7.3.

An initial musical problem with TraSe is that mutation tends to be greater during the beginning of the morph, where multiple transformations are applied within a single frame, compared to the end of the morph, where the add/remove transformation performs slight adjustments. In response to this, TraSe caps the number of transformations that may occur in each frame. The effect is smoother changes during the beginning; however, more frames are generated, as the following eight-frame example demonstrates. Pianoroll notation has been used, not only because it is endemic to the electronic music styles with which the morphing software is used, but also to reflect more clearly the durations of layered notes that are in the target.

<!Insert Figure 7.3—TOP + BOTTOM (they go on top of each other)—about here!>

In frame 1 (Figure 7.3, m. 2), a pitch-shrink and upward inversion was applied; the mutation limit of two transformations per frame obstructed any other transformations.

In frame 2 (Figure 7.3, m. 3), the scale pitch transformation shifted every pitch down by a tonal step, except for the E6 at 3.75, which was shifted down to B5. An add/remove transformation added the D5 at 1.5 and the C6 at 3.5.

In frame 3 (Figure 7.3, m. 4) a dramatic scale pitch transformation occurred, shifting the E5s at 1.0 and 2.5 to G5, the D5 at 1.5 to E5, the G5 at 1.75 up to D6, the F5s on 3.0 and 4.0 up to B5, the C6 at 3.5 up to C7, and the B5 at 3.75 up to A6. An octave transformation then shifted the whole pattern down one octave.

In frame 4 (Figure 7.3, m. 5), the only transformation applied was add/remove, which

added the B5 at 4.25 and replaced the G4 at 2.5 with G5.

In frame 5 (Figure 7.3, m. 6), a divide/merge transformation applied a forward merge, consolidating the D5 at 1.75 into the E4 at 1.5, the B4 flat at 3.0 into the G5 at 2.5, the B5 at 3.75 into the C6 at 3.5, and the B4 at 4.5 into the B5 at 4.25. A scale pitch transformation then applied a pitch-shrink, shifting the G4 at 1.0 up to A4, the E4 at 1.5 up to G4, the G5 at 2.5 down to F5, the C6 at 3.5 down to A5, and the B5 at 4.25 down to G5.

In frame 6 (Figure 7.3, m. 7), add/remove was the only transformation applied, which added the E5 at 3.25 and replaced the G4 at 1.5 with D5.

In frame 7 (Figure 7.3, m. 8), a scale pitch transformation shifted the A5 at 3.5 up to B5 and the G5 at 4.25 up to A5. The first cycle of an add/remove transformation replaced the A4 at 1.0 with C5, and the second cycle replaced the B5 on 3.5 with C6.

In frame 8 (Figure 7.3, m. 9), a scale pitch transformation shifted the C6 at 3.5 slightly up to D6 and the A5 at 4.25 up to B5. The first cycle of an add/remove transformation reasserted the C6 at 3.5, and the second cycle replaced the F5 at 2.5 with G5.

The emergent nature of evolutionary morphing becomes apparent when one considers that transformations of any frame can have significant implications for transformations of later frames and the number of frames that are generated. This example also shows that imposing a limit on the number of transformations that occur in each frame reduces the severity of mutation, particularly in the first few frames. The limit ensured there would be only two transformations per frame, while other examples averaged three or more.

7.8 Conclusions

Evolutionary approaches to music offer new opportunities to support a variety of compositional strategies. In this chapter we discussed the use of evolutionary morphing of music as a technique that allows the composer to approach the creative task at the level of the macrostructure. Compositional form is often conceived as a topology of landmarks over time; the use of note-sequence morphing can allow the composer to create material at these landmarks and have the computer assist with generating the material in between. This affords a very interactive method of composition in which commitments to most of the musical material are provisional and the musical structure and content can easily be experimented with.

Features of the morphing algorithm have been evaluated informally (through subjective reflection), automatically (through batch generation), and formally (through an extensive qualitative online questionnaire). Although all evaluations were previously discussed in detail elsewhere (Wooller 2007), a short summary is provided below.

As well as demonstrating how a composer might use the software, informal evaluation highlighted the emergent nature of the evolutionary processes. For example, in some situations, reducing the transform speed unexpectedly led to convergence in fewer

frames. This was found, upon examination of the processes, to be due to a particular candidate of a particular transformation, which induced "side effects" that were influential on subsequent iterations of the transform chain.

Informal evaluation also highlighted how transformations need to be designed so as to balance a clear stylistic effect with the ability to evolve the pattern smoothly toward the target. Dissimilarity measures need to be designed to work well with other transformations, so that if a dramatic result is judged as being similar to the target by some specific measure, a subsequent transformation will be able to bring the pattern back on course.

With key/scale morphing, parameters have a more direct influence on the results, and informal evaluation reveals how common key modulations can be achieved by searching for the appropriate parameter combination. The key/scale morphing algorithm can also be used to find non-obvious but logical progressions from the key and scale of the source to that of the target. Automatically generated source, target, and morphing examples highlighted the difficulties that morphing presents absent appropriate manual parametric control from the user. Over-generation of frames was particularly evident. Despite this problem, the potential of compositional transformations to assist convergence in fewer frames than was achieved by purely add/remove transformation was also demonstrated.

In lengthy formal qualitative tests, nine respondents displayed a diversity of opinion about the outcomes, with positive and negative views on a particular change often being held by an even mix of participants. Perhaps different participants are listening to different parts in the music, or they may have different levels of tolerance to change or inactivity. When compared to human-composed transitions, clear trends in opinion emerged between the composition style of the morphing algorithm and that of the human composer. Continuous variation was a feature of the algorithm, while layering was favored by the human composer. When compared to human-composed morphs, the evolutionary morphs were perceived to be competent in many ways—sometimes innovative, but frequently criticized for messy pattern combinations and deficiencies in structural clarity. On the whole, both the human-composed and evolutionary morphs were judged to be applicable to real-world contexts.

Researching evolutionary approaches to compositional morphing has only just begun, and there are many possibilities for future work. They include note thinning, to avoid textual thickness and harmonic clashes; note clustering, to allow musical phrasing; new transformations, to extend the range of compositional capabilities; automated layering, to allow higher-level structural features such as breakdowns; and automatic adjustment of parameters, which would uncover less obvious—but workable—settings and reduce the time spent by the user.

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