CHAPTER IV

Computer-Aided Composition and *Bamboula Squared*

Bamboula Squared for orchestra and quadraphonic tape was composed in 1984. Conducted by the composer, the American Composer's Orchestra premiered the piece on June 4, 1984 in Avery Fisher Hall in New York City during the *Horizons '84* contemporary music festival.

Bamboula Squared lasts 16½ minutes and employs a standard orchestra including piano and two percussionists playing marimba, vibraphone, xylophone and bass drum. [24] The four-channel tape consists of ten sections of computer-composed and synthesized music ranging in duration from 5 to 110 seconds. In performance, the tape is started and stopped by an operator who follows a score. [25] Though the computer synthesized sounds were recorded over 4 channels, they are played back over two speakers on either side of the stage in a stereo panorama spanning the orchestra.

The computer music of *Bamboula Squared* was created by applying random signals with a 1/f power spectrum to the selection of pitch/time values for notes. The significance of the choice of this particular spectral density will be discussed below. It should be noted here however that notes generated by the simple use of various probabilistic functions will almost certainly not have any particular musical structure or sense, any more than monkeys pounding at typewriters are likely to produce intelligible language, let alone literature. But grammatical constraints can be placed on the raw energy of randomness by filtering the output of the note-generation program with musical rules for note successions and simultaneities. Such rules, by definition, represent complete notions of musicality, notions which may either reflect a composer's current practice or a new one. (This must be the case since only completely articulated and rules can be coded into successfully operating computer programs.)

[24] Charles Wuorinen, *Bamboula Squared,* New York: C. F. Peters, 1984. Peters provides performance copies of the tape part.

[25] This writer was the tape operator at the premiere. Having the best knowledge of the elements of each section this writer was able to adjust playback level and overall equalization to provide the best blend of the taped music with the orchestral in each instance. Support for this writer's participation was provided by Meet the Composer in New York and the Center for Music Experiment.

As one example, the values of a random sequence may be taken to specify frequency values for events in many different ways. They may be interpreted directly as cycles per second, e.g. 0.073 Hz, 453 Hz or 90.926 kHz, by mapping the values of the sequence into the positive real numbers and concatenating the "Hz" unit of measure. Note however that in the example above the first and third frequencies would specify two "tones" which are inaudible at any loudness while the second frequency would be out-of-tune with most current Western instruments and orchestras, falling as it does midway between A and Bb in the octave above middle C. Alternatively, the values of the sequence can be converted into equal-tempered note names by filling a table with such note names and mapping the random values into the positive integers which are then used as indices to the contents of the table. For *Bamboula Squared* this was accomplished by using the macro pre-processer of the UNIX C compiler as shown here:

```
#define SEMITONE(number) (BASE * (2"(number/12)))Hz");
```

The latter course is the one this writer chose. It was appropriate since the music produced was to be featured in a performance by a conventional orchestra of conventionally notated equal-tempered music.

In fact because the output of the compositional algorithm was used without any modifications and because of the loudness and bright timbres of the computer music, a concerto with nature resulted in which the random-controlled music and the orchestral music sound together on equal terms. As Wuorinen wrote in his program note for the world premiere, "The tape part for *Bamboula Squared* is made [so that] a `music of nature' emerges from the mingling of traditional compositional values and approaches with numerical models of certain processes in the natural world." [26]

Information about Wuorinen's ideas of form and structure will provide some background for understanding the compositional practice in *Bamboula Squared.*

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[26] Program for the New York Philharmonic 1983-84 season, Horizons '84, Program VI, "Orchestral Music with Computers"

CHAPTER V

A Description of Wuorinen's Concept of Form

A detailed and indexed guide to the practicum which embodies Wuorinen's concept of form may be found in his *Simple Composition,* a manual of rules, suggestions, and observations about composing. He reveals explicitly in his introductory discussion of "Form and Composition" (chapter eleven) that he understands much music - Western and non-Western alike - to be cast more or less in a single narrative shape in which "a work seems to be perceived largely in terms of its development toward a focal or high point, or climax..." [27]

It is important to note that he uses the word "development" here in a different sense than he does when speaking of "Schoenberg [who] follows developmental gestural-shape processes taken over from the Germanic tradition..." [28] It is in contrast to Schoenberg that he mentions a specifically twentieth-century formal pattern, namely Stravinsky's "juxtaposition of dissimilar entities whose constant recombination and simultaneous individual transformation completes ...the sense of having moved from somewhere to somewhere else, and (sometimes) back again as well..." [29] So here "development" means a pattern of statement, transformation, and restatement which creates a sense of musical movement.

The sense of "development" he uses in his remark about form supposes that the act of creating (or perceiving) form in music occurs in the listener. Relationships among entities, that is, notes and their epiphenomena, which are necessarily explicit and immanent, are the province of the composer, in which he exercises his craft. But the perception of form is a listener's perception of "large gestural shapes or unfoldings, and the exploitation of these..." [30] Here is an insight into Stravinsky's oft-repeated remark that his music could express nothing except itself. It can be seen that this is not the trivial news that a piece is only its notes; rather its notes are themselves only a fixed statement of an underlying form which could conceivably admit of other statements, be shown by other notes. Wuorinen asserts that "a sense of the work...can all be encompassed instantaneously—you do not have to `listen' to it in your mind's ear to know what it contains." [31] That a work can be transformed from *sound,* a domain in which time is one-dimensional and

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27 Wuorinen, Charles, *Simple Composition* (New York: Longman, 1979), p. 145
28 Wuorinen, *Simple Composition, p.* 146
29 Wuorinen, *Simple Composition,* p. 146
30 Wuorinen, *Simple Composition,* p. 145
31 Wuorinen, *Simple Composition,* p. 148

can only move forward, into *sense,* a domain in which sound-in-time may gain depth and weight through memory and may or may not move only forward suggests, demands that other correspondences of "notes" to "form" can be made. The composer, by dint of knowledge and craft, may have shown the most delightful path to apprehension of a form; common sense compels us to realize that there must be other, less excellent or, perhaps, only different paths.

Wuorinen neatly curtails the extent of the idea of form - it is a story, one of a very few. Thus it is necessarily *a familiar* story, the telling of which is the composer's and the listener's chief delight. The means of form-revealing, the myriad details which will demonstrate the chosen form, are that which may be structured - selected, combined, shuffled.

CHAPTER VI

Some of the Origins of Wuorinen's Concept of Structure

Wuorinen's structuring methods are perhaps most fruitfully seen as dynamic with an almost biological manner of change and becoming. The composer creates an adequately rich pre-compositional environment. He has learned from his own music and other music he admires what is appropriate to his needs. Then he introduces a seed, a germ of an idea - a form - and, as that form begins to precipitate elements from its environment, he will prune and augment as his conception of a possible final shape dictates. He has designed the seed and the environment to interact in certain ways which exemplify his ideas about structure. [32] This was very much the character of our collaboration. Where he provided an overall musical vision, this writer created the means for achieving the audible result. Our work paralleled that of the composer and performer except that we were working entirely within the realm of CAC.

One of the strongest (certainly it is ubiquitous) structuring principles to be seen in Wuorinen's work is that of *parsimony*. In general, the area of application for this principle is in the precompositional descriptions of the material to be used. Another important principle, one which underlies much of the tape part of *Bamboula Squared, is* that of *naturalness.* Its area of application is in the specification of actual notes from available or virtual material. First, a look at parsimony.

In *Simple Composition* Wuorinen subsumes under the heading "structure" all that can be forthrightly determined in a systematic way. Pitch, characterized by interval, and, less independently, rhythm, characterized by attack point, are grouped into ordered collections, or sets. Wuorinen employs the familiar language of twelve-tone music, with a few of his own practical additions, to describe these sets in their canonical forms as well as after transformation. He then discusses means for extending the range of available material by derivation, partitioning, and

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[32] One might wonder what necessity there is for a model of structure which may be like the one described above and which supplants those preexisting models which have served many composers until the latter half of the twentieth century. Historically, Wuorinen sees the composer grappling with contemporary issues as existentially free: he is compelled to do nothing and free to do anything. There is no supporting framework of common practice and conventional syntax on which any new music may be registered and measured. There are instead individual strong and weak principles which guide the writing out of a work and, insofar as it is designed to be intelligible, the understanding of it. Importantly, this description of structuring follows his own practice; it did not precede it.

combinatoriality. 33

The fundamental transformations of series are those familiar from classic twelve-tone theory — transposition, retrogression, and inversion. Other operations - multiplication and rotation - are the simplest interval-changing and interval order changing operations respectively and occupy his attention for at least as many pages as the previous ones. Finally, "...these operations and their results form a closed system of transformations"[34] though of course rotation may generate a larger such closed system. These operations are intended to make as much as possible of as little - in the way of basic material - as possible. The desire for a unified expression in the work determines that the work's structure be drawn wholly from a small set of elements and operations.

The articulation of the surface of the deeper structure follows the specification of background possibilities. But he emphasizes that immediate musical needs dictate its actual nature. Those needs, at least in *Bamboula Squared*, were that the tape part play in conjunction with conventional orchestral instruments without suggesting an unwarranted dichotomy between the two. There are as many ways in which such a dichotomy could have occurred as there are meaningful dimensions of variation in the music itself. Filling the requirement that the tape music "fit" with the orchestral music demanded my attention in a variety of ways which only became obvious after the music began to be heard. Once composed and realized, the CAC-music had to be integrated temporally into the actual performance. Therefore this writer organized it into successive "cues" loaded onto a reel of analog tape. The tape was constructed so that the sections of music were separated by blank paper leader. In order to insure synchrony of playback for each section, each section of tape was silently brought to its beginning and then, at the proper moment, sounded by activating the "play" mode of the tape machine. Thus each "cue" can be viewed as a single, though complex, event which is prompted by a cue found in the score and given by the conductor and precipitated by a single gesture. As performance then, this method of playing the CAC-music differs in length and complexity but not in kind from a percussionist's performance.

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33 He insures that materials, the potential composition, must be handled very differently from notes, the actual piece. This is done using a number notation which compels thoroughgoing abstraction. Series and matrices are expressed as numbers rather than notes, for the focus is on relationships, not identities. This in contradistinction to the section, Surface of Compositions, which precedes Structure (in the book) and which uses conventional notation, including note heads, beams, staves, and meters, exclusively.

34 Wuorinen, *Composition*, p. 95

The other guiding principle of structuring was, as mentioned above, naturalness. More specifically, two aspects of naturalness are cultivated. Here, "nature " is represented by a randomly fluctuating signal which can take on various values over time, One requisite aspect of the signal is that it display self-similarity or self-affinity. The other is that its power spectrum be of the kind identified as "1/f". 1/f noise is noise in which the magnitude of a given frequency's presence in the noise signal is inversely proportional to the frequency itself. Lower frequencies are favored relative to higher ones and equal power is present in every octave of noise rather than for every frequency. With 1/f noise, in general, smaller changes are more likely than large ones. Large ones are not impossible, but the larger they are the less likely they are to occur. For events which follow one another in time this can give a semblance of smooth change of the sort found in music composed in other ways (whether formalized or not).

1/f - or any characteristic spectral contour - can be easily thought of graphically. Good graphs picture information in some revealing and incisive way. Of course, they achieve their directness at the expense of completeness - the information represented is in some way simplified. Graphs display values and can be useful in the consideration and analysis of even such complex entities as pieces of music. The magnitude of variations of any one-dimensional variable can be represented by a graph called the line spectrum. This graph is somewhat like a histogram which tallies the number of times any given individual magnitude values occur within a certain time span. Any aspect of music which can be represented as variation along a single continuum can be graphed as a line spectrum. There is no representation of the succession of time in such a graph however; each value is compared only to others of its kind, irrespective of when they might have occurred.

Self-similarity is defined in a rigorous way and also illustrated in *The Fractal Nature of Geometry* by Benoit Mandelbrot. Self-affinity describes a type of hierarchy in which the pans recursively repeat the structure of the whole. [35] Examination of the elements of the hierarchy, on any scale, reflect shapes found on other scales. While this admits of a precise description in geometric terms, several intervening steps must be taken to produce a music (let alone a musical) result in accord with this principle. Some of these steps will be detailed in the discussion of the tape part of *Bamboula Squared* which follows.

The second aspect of naturalness, the 1/f spectrum, is a measure of the spectral density of changes in such fluctuating quantities as voltages found in vacuum tubes and nerve

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[35] Tommaso Bolognesi, "Automatic Composition: Experiments with Self-Similar Music" *Computer Music Journal, v. 7,* n. 1 (spring 1983) :p. 26.

membranes, sunspot activity, the flood levels of the river Nile, and recorded music. [36] "The power spectcum...of [these] many fluctuating physical variables...is '1/f-like'..." [37] *1/f* variations which, when plotted as frequency versus time, are a random signal, a type of noise and are representative of the behavior over time of many systems in nature; this intrigues Wuorinen. That such variation is typical of music as different as Bach and rock excited his interest in using such variations in his own automatic and computer-aided compositional activities. [38] The work of Voss and Clark provides a valuable insight into Wuorinen's and others' heuristic notion that most kinds of noise are not sufficiently musical to be used to control sound in a parametric way. (For an introductory discussion see [39].)

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[36] Richard F. Voss and John Clark, "' *1/f* noise' in music: Music from *1/f* noise," *Journal of the Acoustical Society of America, v.* 63, n. 1 (January 1978) :pp. 258-263.

[37] Richard F. Voss and John Clark, "` *1/f* noise' in music and speech," *Nature, v.* 258 (November 27, 1975) :pp. 317-318.

[38] This work was first done at Bell Labs by Wuorinen and Mark Liberman in the late 1960's and early '70's. Private communication with Charles Wuorinen.

[39] Martin Gardner, "Mathematical Games - White and brown music, fractal curves and one-over-f fluctuations," *Scientific American,* (March 1979) :pp. 16-31.

CHAPTER VII

Production

The most general facility for sound production at CARL is the *cmusic* software synthesis program.[40] Using such a facility demands that every aspect of the sound to be produced be completely specified in advance of its actual computation. The sound signals, once computed, are then available via digital-to-analog converters for auditioning or recording. Because of the completely explicit nature of *cmusic* synthesis input specifications — "scores" — one may examine a very clear record of the composer's instructions. Though this program may also be used to produce digital *rrucsique concrete,* only completely synthesized sounds were used *in Bamboula Squared.*

The first requirement in undertaking the compositional effort was to have a completely specific list of what was to be done. In this case, that meant either knowing or being able to find out exactly what the notes of each of the blocks were to be. Accordingly, the next step in the production effort was to state and code the algorithm for the generation of new notes to be derived from the pre-existing (orchestral) pitch lists and pitch trend lines. After discussion with the production staff at CARL, an initial statement of the algorithm was proposed.

- Obtain **some random number of random numbers.**

These random numbers were to come from a 1/f noise signal of suitable length and whose values were suitably scaled. For this application the noise was scaled to be integers between 1 and 96, the number of semitones in the pitch range to be occupied in the blocks. The first value obtained would be used as the upper limit on the number of successive random numbers to be obtained. The lower limit would always be 0. Here is the code for the assignment of the random number of numbers to the variable denoting the number of breakpoints that were to occur in the strand.

```
num_of_breakpoints = scalenfrand(0, breakpointlimit);
```

- **Use the numbers to** instantiate, as interpolated notes, divisions of the operant ranges of pitch and time.

After having been sorted, the largest number would be used as the denominator of ratios, the

40 For a complete discussion of this program see the *CARL Start-up Kit* and related on-line documentation at CARL. Also see, F. Richard Moore, "The Computer Audio Research Laboratory at UCSD", *Computer Music Journal, v.6,* n. 1, 1982.

numerators of which would be the other numbers. The ratios thus obtained would be used to specify attack points along the available time axis which would be of a given duration. If that duration was six seconds for example, a ratio of 3/67 would be interpreted to specify a note's begin-time at 0.268657 seconds after the beginning of a section; a ratio of 33/67 an attack at 2.955224 seconds; and so forth.

The interpolated note's pitch would be determined by the following scheme: there would be parallel to the time axis a pitch axis whose extent would be from one given pitch to some other given pitch. Just as each ratio would represent a determinate location along the time axis so it would along the pitch axis. A simple example would be a pitch axis extending from middle C to the Eb three semitones above. A point at 33/67 along such an axis (assuming it represented a linear pitch transition) would resolve, after rounding to the nearest integer, to C#, one semitone above middle C. [41]

```
trans(startpitch_as_float,transition_as_float,endpitch_as_float,
num_of_values,pitchval);
```

This nominal pitch would then have added to it some positive or negative random number of semitones.

```
pitch_dev = (int)scalenfrand(-pitchdev, pitchdev);
```

The pitch axis pitch and the deviation together would then determine the pitch of the new interpolated note.

```
outpitch_end = pitchval[0] + pitch_dev;
```

To understand how this process actually was used to create the music for *Bamboula* requires more explanation but the algorithm itself is really very simple. Information was drawn from pre-existing orchestral music and recorded as a list of vectors in a pitch/time space. Each section was notated so as to define the beginning and end points of a strand or portion of the block on the time and pitch axes. For example a line reading

```
0.0 11.052632 55 13
```

defines a strand the first notes of which would begin to sound at time 0 and have a pitch of "55" or the "e" at the top of the treble staff, counting up from the 27.5 Hz "a" as "0". The strand

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[41] It happened that any arbitrary transition between given semitones could be specified; this was not really central to the working of the algorithm.

would have as its last specified pitch "13" which would begin 11.052 seconds after the beginning. (See Appendix 5 for graphic representations of these in pitch/time space.) The input notefiles consisted of any number of such strands. A program then read these notefiles - there was one per block - and generated new strings of interpolated notes using the algorithm detailed above. (See Appendix 6 for graphic representations of these notes.) These new strings were written out by the program in two ways: as a score file suitable for passing to *cmusic* for actual computation or as a new input notefile suitable for use in a subsequent iteration of the note-generation program. A few other decisions were required to enable *cmusic* synthesis: the creation of excitation functions to model various kinds of plucks, the definition of macros for the specification of pitch, and a scheme for allocation of music to virtual output channel. These were relatively minor.

Recursive iterations of the new-note-generation process were used for only two blocks, 5 and 9. In the case of 5 there were three levels of recursion; in 9, seven. In all cases, but especially these two, the musical outcome was markedly sensitive to the selection of controlling values such as the seed for the 1/f random number generator and the nature of the pitch transition. These values, along with the possible number of breakpoints in the strands of a block and the amount of pitch deviation, were selected by trial-and-error. Further research will be required to determine the nature and intensity of this sensitivity.

The sonic realization of the notes produced by the composing programs was the only step which remained to be done before the music was completed.

CHAPTER VIII

A Brief Description of the Plucked-String Algorithm

At the beginning of the project too definite a statement of the timbral features of the synthesized sounds which were ultimately to be used for the work was avoided. This was consistent with a "top-down" approach. Precise specification of features of a given hierarchical level of the composition were postponed until the part of the level directly above was more or less completely worked out. Some things were certain however:

I) that the loudness contour should, in general, feature a sharp attack and exponential decay;
2) that the spectrum should evolve over time from bright to mellow; and
3) that there would be a glissando integrated into each note.
However, the actual glissando portion of the note should be quite obviously inflectional and decorative rather than fundamentally structural.

As the structure of the computer music portion of *Bamboula Squared* was completed, listening tests were begun. They revealed that the Karplus-Strong "plucked string" synthesis algorithm as extended into general musical utility by Jaffe and Smith would be suitable for the actual sonic realization of the music. [42] The cited articles are the definitive introductions to this technique and the interested reader is referred to them for more details. As its name suggests, sounds generated with this algorithm resemble sounds of plucked or struck strings. Briefly, the Karplus-Strong algorithm consists of a delay line which recirculates its contents with various filters inserted into the feedback loop. It is a fortuitous computational analog of some aspects of the behavior of a vibrating string. These aspects dovetailed neatly with the desiderata listed above.

Jaffe and Smith write, "The simulator provides a high degree of flexibility that begins to approach that of a skilled player performing on a real musical instrument." And further, "[The algorithm] was found to be...suffrciently idiosyncratic to maintain a characteristic identity." [43]

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[42] Kevin Karplus and Alex Strong "Digital Synthesis of Plucked-String and Drum Timbres," *Computer Music Journal, v.* 7, n. 2 (summer 1983) :pp. 43 - 55 and
David A. Jaffe and Julius O. Smith, "Extensions of the Karplus-Strong Plucked-String Algoritlun," *Computer Music Journal, v.* 7, n. 2 (summer 1983) :pp. 56 - 69.

[43] Jaffe and Smith, "Extensions..." *Computer Music Journal,* p. *68.*

The word "simulator" used here reinforces the notion that what we sought to create or invoke was a performing collaborator with some degree of identity and autonomy, a collaborator who (which?) could fill the role of soloist in a concerto convincingly.

The algorithm also has the virtue of being relatively economical to compute, thus allowing for more iterations of a "specification-synthesis-audition" process to take place in a given interval of time. The importance of being able to hear many different versions of the music one after another justifies a concern for economy, a concern which would otherwise not have an obvious relevance to an artistic endeavor. The actual sonic realization of the computer music can be thought of as a performance of the music. This performance had to combine with the performance of the orchestra to create a performance of the complete work. Since the tape was to be played back at the premiere through a high-quality professional sound reinforcement system, a modicum of control could be exercised over playback level and overall tonal balance. Such control, though necessary to the performance, would not be sufficient to change the fundamental character of the sound of the music.

With an ear toward the final integration of the two performance forces, the listening process resulted in a refinement of the *cmusic* version of the plucked-string algorithm, the unit generator *fltdelay*. [44] The capability of using arbitrary sound files as the initial contents of the delay line at the heart of the plucked-string algorithm allowed for the possibility of using specially tailored noise signals as excitations for the "string". A wide variety of such signals was employed in the various sections of computer music according to the orchestral timbral context of the piece during those times both were sounding. 1/f or pink noise, inharmonic complexes and pulse waves of varying degrees of richness were used in addition to the white noise provided for in Karplus' and Strong's original statement.

Finally, as noted above, the sounds produced by the algorithm closely resemble sounds which were already widely employed in previous music. It was anticipated that the computer-composed music would be somewhat new in manner and content. An overlay of timbral novelty might have clouded the salience of that music by compounding the uncertainties of both style and substance. Scientific experimental procedure typically requires that all aspects of the behavior of a system be held constant except for a single dimension of variation in order to unambiguously ascribe to that dimension the power of producing an observed result. Perhaps there can be a similar control in artistic experimentation in which variations of a single factor — in this case the 1/f

[44] See the *CARL Start-Up Kit* and CARL on-line documentation for details about the operation of this unit generator.

probabilistically generated music — can be observed for their special effect on the overall work.

CHAPTER IX

Conclusion

A project to do musical production using CAC at CARL was completed. Using *cmusic* and other elements of the CARL software distribution, stand-alone CAC programs written by this writer, and other facilities of the UNIX operating system such as file I/O, a major musical work, the tape part of *Bamboula Squared,* was created.

To generate the computer music portion of *Bamboula Squared* an algorithm for computer-aided composition was specified and coded to create scores for *crnusic* synthesis. In the algorithm endpoints are given - where musical strands are to start and end. The transitions between these given endpoints are articulated by breakpoints selected by the program. The musical salience of the probabilistically generated material is "guaranteed" by interpolating between endpoints which are "known" and "well-defined" by other, more conventional music compositional criteria. An hypothesis is that the interpolations differ in kind from those made by note-by-note algorithms or applications of other probability distribution functions because of the property of self-similarity which is a distinctive feature of sequences generated by 1/f means. Rather in the fashion of a hologram the distinctive contour of a sequence is present from the very first selection of interpolated breakpoints and is revealed in greater and greater detail as more and more breakpoints are chosen. This differs from note-by-note selection schemes in that they are rnore like a scheme which reveals a picture line-by-line in some simple way such as left-to-right and top-to-bottom like a television picture for example. The shape, hazy at first perhaps, becomes clearer while in the other case, the shape may only be manifest near the end of the completion of the filling-in process.

CAC can be used by the composer as one of a suite of tools. Just as the composer may surrender to the performer some degree of autonomy in the execution/realization of the composed work, so he or she may surrender to an algorithm some autonomy in the specification of the outermost level of sonic detail of a work. Then the composer is relieved of the burden of providing a complete description but can be sure that the resulting sound corresponds within some acceptable limit to his or her intentions.