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THE MUSICAL CONTROL OF SOUND COLOR*

A. Wayne Slawson

In a recent article (see Slawson 1981), I hazarded a set of claims that may be considered a theory of an aspect of musical timbre called *sound color*. In the present paper I shall summarize those claims briefly, develop them a bit further, and than attempt to show how one could apply some of them by discussing how my composition *Colors* was structured.

Invariance of Sound Color

Musical sounds nearly all have such well-known properties as duration, pitch, and loudness. In addition, as we analyze what we hear a bit more closely, we realize that many of them have more arcane "attributes" having to do with such things as the temporal course of a sound's intensity envelope, the regularity versus the randomness of its spectrum, its "grain" or "flutter," etc. In addition to all these features, according to the theory I am advocating, a sound has a *color* that can be independently controlled and manipulated by a composer.

Like pitch, loudness, etc., sound color (or simply color) is both a psychological attribute and a musical "element." The term color has been used to refer to mixtures of instrumental sounds, but I mean by it something more abstract and more specific — something that is not tied to the sounds of musical instruments. I have discussed the relationship of sound color to the sounds of musical instruments earlier (see *ibid.*) and will not dwell on it here. Suffice it to say that my use of the term is not inconsistent

*I am grateful to Robert Morris for his many provocative discussions while I was working on the theory and to Donald Beikman whose comments on drafts of this paper improved it considerably. The initial work on the theory was supported in part by a grant from the American Council of Learned Societies and by the University of Pittsburgh, for which I am also grateful.

with at least certain ways that the sounds of different instruments have been discussed (e.g., see Cogan & Escot 1976). The theory is probably most directly concerned with electronic music, but it is stated in general terms and may have considerably broader applicability.

Now for the theory itself. Sound color is associated, not with the spectrum of a sound, but with its *spectrum envelope*. The first, simplest, and empirically best-established of the theory's claims is the rule:

> Rule 1: to hold the color of a sound invariant, hold its spectrum envelope invariant.

Now the concept of a spectrum envelope depends on a kind of dual process model of the production of sound. In this model, a sound is the result of a *source* modified by a *filter*. Figure 1 illustrates how a particular kind of regular (harmonic) source is modified by a filter that has two prominent "pass bands," resonances, or "formants" — two "hills" that reinforce the source frequencies falling within them. The surrounding "valleys" mute the components of the source in their frequency regions.

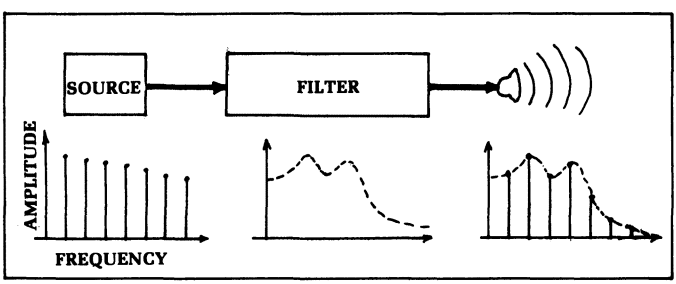

Figure 1

The Source/Filter Model of Sound Production; the filter modifies energy reaching it from the source according to the filter's spectrum envelope

For all its importance in our knowledge of, for example, the acoustics of speech production (the modern "classic" in this field is Fant 1960), the spectrum envelope may seem a bit ephemeral. It can be said to "belong to" a resonant object or cavity, but like that object or cavity, it can make no sound on its own (for an enlightening discussion see Huggins 1952). Some mechanical or acoustical

energy must excite the object or cavity and only then does its spectrum envelope become detectable in the resulting sound. Rule 1 of the theory is equivalent to saying: keep the physical properties of a sounding object or the shape of a cavity constant and the sounds you make by exciting the object or cavity will have constant sound color.

The most common everyday "use" of sound color is in vowel sounds. A man, a women, or a child speaking, shouting, or whispering the "same" vowel sound is exploiting the invariance of sound color that is claimed by Rule 1 of the theory. Filters are used in nearly all electronic music. A particularly striking way in which Rule 1 is applied in that music involves the use of invariant filters to link, by means of the resulting invariant sound color, sections of a work having contrasting sound sources.

Many electronic pieces feature a great many different sound colors drawn from a rich and varied musical "space." My second claim represents an attempt to postulate a theoretical structure for that space.

The Dimensions of Sound Color

Rule 1 tells us how to keep a particular sound color constant, but it does not tell us how different sound colors relate to each other. Borrowing freely from a well-known phonetic theory (see Chomsky & Halle 1968), I have proposed a series of dimensions that appear to govern certain kinds of invariances among different sound colors. There are a number of these dimensions in the full-blown version of the theory, but the main ones are ACUTENESS, OPENNESS, SMALLNESS, and LAXNESS. Before discussing the dimensions in detail, let me clarify what I mean by "relating" sound colors and "certain kinds of invariances" in sound color by stating Rule 2 of the theory:

> Rule 2: To change a color while holding it invariant with respect to one of the dimensions, arrange to move through the color space along *contours of equal value* associated with that dimension.

The key to Rule 2 is of course the actual location of those "contours of equal value." I have plotted some of them in Figure 2.

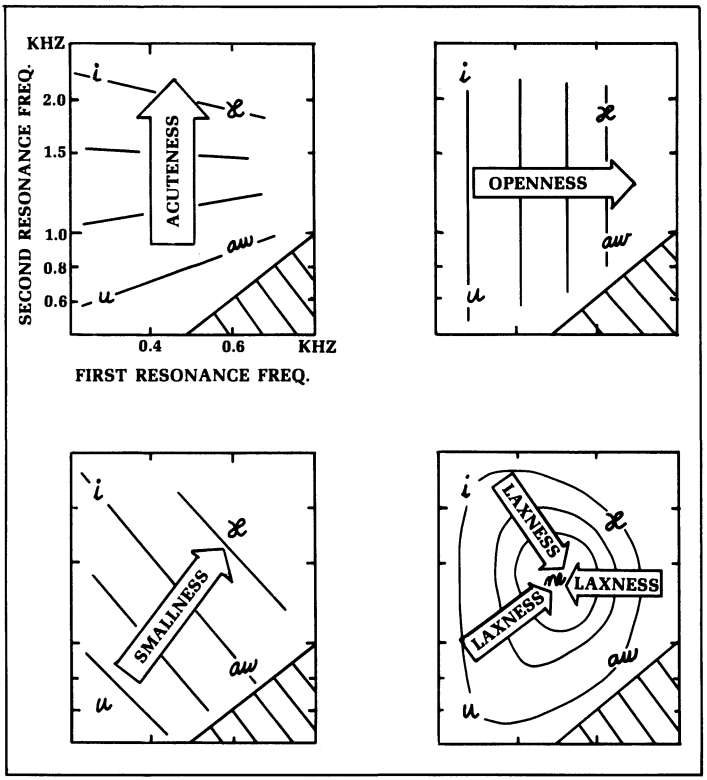

Figure 2

Equal-Value Contours of Sound Color Dimensions; the arrows indicate the direction of increasing value for each dimension; the lighter lines are examples of equal-value contours

The axes in this figure are, respectively, the center frequencies of the first and second resonances — the peaks on the hills of Figure 1. The few representative vowels in the figures provide a rough orientation to the space. Narrowing down for the moment on just the dimensions of ACUTENESS and OPENNESS, we can observe that the [u]-like color is low in ACUTENESS and OPENNESS whereas [ae] (as in "had") is highly ACUTE and highly OPEN. The [i]-like color is highly ACUTE and non-OPEN, in contrast to [aw] (as in "fog"), which is non-ACUTE and highly OPEN.

Now we are ready to see how Rule 2 is applied. Suppose we wanted to hold OPENNESS constant and high. Following Rule 2, we could move vertically along the rightmost equal-OPENNESS contour changing color between the ACUTE [ae] and the non-ACUTE

[aw] without changing OPENNESS. We would be holding one aspect of sound color — OPENNESS — constant while changing other aspects.

The SMALLNESS dimension has equal-value contours parallel to the northwest to southeast diagonal. The SMALLest color is that associated with [ae]; the least SMALL, with [u]. Since [i], the neutral color, and [aw] all fall on the same equal-SMALLNESS contour, they all have the same — in this case, medium — SMALLNESS value.

The LAXNESS dimension is an interesting one, whose equal-value contours are quite unlike those of the other dimensions. They cut through a whole raft of quite different colors. What is captured by LAXNESS is analogous to the relations between long vowels, their short versions, and finally the so-called "neutral" vowel. Starting with the least LAX contour, we might traverse the colors corresponding to the vowels in "beet," "bat," "ought," and "who'd." A similar trip around the contour of medium LAXNESS would take us through colors like those in the words "bit," "bet," "hut," and "hood." Finally the point of maximal LAXNESS — the innermost "contour" — reduces all colors to the same bland, neutral color toward which vowels tend when they are in unstressed syllables.

There is some empirical evidence that we perceive sound according to the dimensions of ACUTENESS and OPENNESS and some rather indirect support on rational grounds for SMALLNESS (see Slawson 1981 for a discussion of this evidence). There is precious little independent support for LAXNESS, but influenced by some informal experiments with synthesized patterns of colors of differing LAXNESS, I have been led to believe that LAXNESS has both psychological reality and musical potential.*

A good deal of empirical study is needed to establish the psychoacoustic status of the dimensions and, most importantly, to locate the equal value contours with some precision. It appears, in the meantime, that the dimensions — with all their present imprecision of definition — may be of considerable use to composers, particularly of electronic music. In some sense one can argue that they already have been. To cite only a single, striking example, consider the opening of Milton Babbitt's *Ensembles for Synthesizer*. The static sounds that frame the introduction of this work fit very nicely into the two-dimensional subspace of color

*Three examples of these experimental tapes were played at the Symposium.

consisting of ACUTENESS and OPENNESS and, at the same time, they seem to include both LAX and non-LAX sounds.

Operations on Sound Color

The final claim, or set of claims, of the theory has to do with ways of controlling changes in sound colors. The idea is to define operations on sets of sound colors that transform them while preserving certain relations among the members of the sets. The operations on sound color are analogous to those we use to transform pitch classes. A color can be *transposed* and it can be *inverted*. In sound color space, however, these operations are performed *with respect to a dimension*. It follows that there are a good many more such operations on sound color than there are on pitch classes.

Transposition

Rule 3a defines transposition of sound color:

> Rule 3a: To *transpose* a color with respect to a dimension, shift the color in the direction of the dimension (perpendicular to its equal value contours). When the boundary of the space is reached, "wrap-around" to the opposite boundary and continue shifting in the same direction.

This rather messy rule represents a situation that is quite analogous to transposition of pitch. With pitch we move in the direction of a (single) dimension until we reach the (octave) boundary and then we "wrap-around" and start at the opposite boundary (the next octave). The perceptually strong equivalence of the "same" pitches in different octaves make transposition of pitch a musical operation of great value. The boundaries are not nearly as clear in the case of sound color and there is no such thing as octave equivalence in the color realm. In fact transposition of a sequence of sound colors can be rather costly in terms of lost relationships among members of the sequence.

Figure 3 illustrates transposition of a sequence of colors (represented by their nearest vowel-like equivalents) in which the "wrap-around" feature does not need to be invoked and the invariant relations among the colors are rather well preserved.

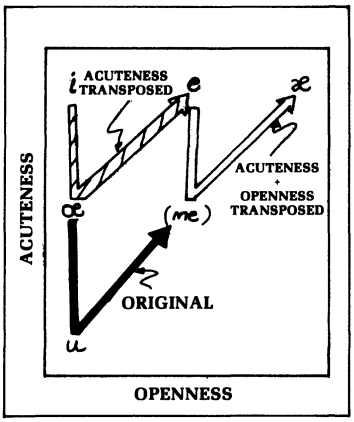

Figure 3
Transposition with Respect to ACUTENESS and OPENNESS

Inversion

Inversion of sound color is carried out, in each dimension, with reference to the neutral, maximally LAX color. For each dimension (except LAXNESS itself, where inversion is undefined), the equal-value contour that passes through the neutral color is defined as the axis of inversion with respect to that dimension. Taking these axes as the locii of "zero" value for each dimension, we can assign positive and negative values to the equal-value contours on opposite sides of the "zero" contour. Given this implied metric in the sound color space, we can define inversion rather simply:

> Rule 3b: To invert a sound color with respect to a dimension, complement its value on that dimension.

Once more, let me illustrate with an example. Suppose we have the sequence of colors corresponding to the vowels [u, i, aw, ae] that we wish to invert with respect to ACUTENESS, keeping the OPENNESS of each of the sounds the same. Notice that the [u] and [aw] have strongly negative values of ACUTENESS (they are far "below" the axis of inversion), and that [i] and [ae] have strongly positive values. Complementing these ACUTENESS values results in the ACUTENESS-inverted sequence [i, u, ae, aw]. To take another example, suppose we wish to invert the original sequence with respect to SMALLNESS. The result is [ae, i, aw, u], Since [i]

and [aw] are on the "zero" SMALLNESS contour, they invert into themselves.

Although evident only in arrays larger than the four-color sets, inversion retains to a greater degree "intervallic" relationships than does transposition. In contrast to the case of the analogous pitch operations, the inversion of sound color seems to be a somewhat more "natural" transformation than is sound color transposition.

I hope this brief summary has given at least some flavor of the sound color theory I am developing. For the rest of this paper I would like to concentrate on ways that I discovered I could use the color operations in a musical composition.

Musical Operations on a Nine-Color Set

I based the work, *Colors*, on a series of nine sound colors corresponding roughly to the vowels [oh ("boat"), ee ("mate"), uu, aw, ii, ae, oe (Geman o-umlaut), aa ("pot"), and ne (neutral)]. This set of nine colors, in its unordered form, is one of only a small number that can be thought of as *normal*.

What I mean by a normal set is one for which the operations (except for transpositions in LAXNESS) transform members of the set into members of the same set. Figure 4 shows this nine-color set in terms of the nearest vowel equivalents.

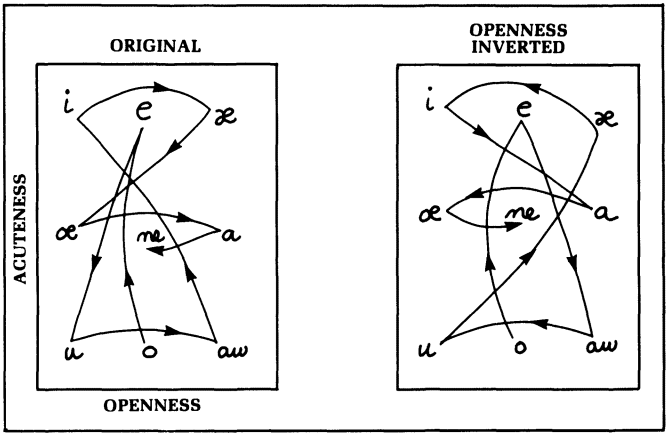

Figure 4

The Color Series from Colors *and an Inversion; the order of the nine-color series is specified by the directed lines connecting the vowel equivalents in the plot on the left; the plot on the right is the* OPENNESS *inversion of the original series; the ordinate is the (perceived)* ACUTENESS *dimension; the abscissa, the* OPENNESS *dimension*

It is fairly easy to verify normality for this set and for any other square array of colors. While in principle there are many such arrays, only the first few squares result in color sets whose members would be perceptually distinguishable. A few other symmetrical arrangements of colors are normal — including at least one twelve-color set — but an investigation of them is beyond the scope of this paper.

Figure 4 also illustrates one of the operations that is well-defined in this nine-color set: inversion with respect to OPENNESS. Notice how the succession of "opposite" colors in consecutive pairs in the original sequence is transformed into similarly opposite colors in the inversion. The ACUTENESS inversion also preserves that relationship. It can be verified that SMALLNESS inversion and transposition with respect to all the dimensions except for LAXNESS are well-defined in this set.

The Composition of *Colors*

The test of all this theorizing about sound color is of course in the composing. My own compositional work has included a number of studies and experiments and, as of January 1981, one extended piece. *Colors* is a quadraphonic tape piece that was realized in the Computer and Electronic Music Studio at the University of Pittsburgh. It is in the form of a set of eleven variations on a single rather involved bipartite structure of seven contrapuntal strands of sound colors. The second half of that basic structure — the "theme" — is the retrograde of the first. Without attempting a complete description of the structure, let me indicate a few details that will illustrate my approach, in this piece at least, to composition with sound color.

Combinatoriality and Color Aggregates

I have been attracted to certain techniques of twelve-tone music in my music for instruments, so it was natural for me to attempt to apply similar techniques in the realm of sound color. In particular, I sought an analogy to the method of combining different versions of a pitch-class series known as *combinatoriality* (see Starr & Morris 1977).

In this method, invented by Schoenberg, two or more versions of a twelve-tone row are lined up more or less like separate contrapuntal voices in such a way that all twelve tones are present in the *vertical* structure before any tone is repeated. In

the extension of the method first used by Babbitt and extended and formalized by Starr and Morris, these vertical "aggregates" can be formed quite freely from any of the contemporaneous rows. For example, in a five-row structure the first aggregate might be made up of five pitch classes from the first row, two from the second, none at all from the third and fourth, and four from the fifth row. A great deal of contrapuntal flexibility is provided by such an arrangement, while preserving the kind of integration of pitch materials that makes the twelve-tone method attractive in the first place.

The basic idea of combinatoriality can be translated quite directly into the structuring of sound color, provided that a set of discrete colors is to be used. Suppose, for example, that we attempt to combine the original set as displayed in Figure 4 with its OPENNESS inversion. We find that the combination is impossible because, in this particular set, the OPENNESS inversion results in a simple permutation of pairs, leaving colors in nearly the same order in both series. By the same token, the original can be combined easily with the retrograde of the OPENNESS inversion. The first four colors of the original series and the first five colors of the retrograde OPENNESS inversion form the first of two aggregates of nine colors with the remaining colors from each of the series forming the second. This "combinatorial matrix" is illustrated in Table I:

	Aggreg. 1	Aggreg. 2
Original series :	o e u aw :	i ae oe a ne :
Retro. Inv. O. :	ne oe a i ae :	u aw e o :

Table 1

A Two-Series, Two-Aggregate Combinatorial Matrix

The swapping operation described by Starr and Morris can be applied to this matrix to produce another with quite different contrapuntal possibilities (Table II):

	Aggreg. 1	Aggreg. 2
Original series :	o e :	u aw i ae oe a ne :
Retro. Inv. O. :	ne oe a i ae u aw :	e o :

Table II

Another Combinatorial Matrix

These combinations of the two versions of the basic series are interesting because of the possibilities that are presented for relating pairs across aggregate boundaries. For example, in the first matrix, the [i ae] in the first aggregate can be associated with the same pair in the second aggregate or, similarly, the pairs [u aw] in both aggregates can be related.

The Basic Structure in Colors

The structure of *Colors* is considerably more complicated. As mentioned above, the basic structure is made up of seven linear strands. Each half of the basic structure is a single combinatorial matrix with a maximum of two linear versions of the series in each strand. Table III shows that combinatorial matrix:

	Aggr. 1:Dura. 4/4.5	A2:5/2.5	A3:3/7	A4:6/2
S1	[o e u aw i ae oe	a ne]		[o e u
S2		[i u e ae	o aw	ne a
S3			[e i ae oe	aw i
S4	[ne	o oe	a u	
S5				
S6				[ae
S7	[a	aw	ne	oe

	A5:7/1	A6:1/5	A7:2/3	A8:4.5/6	A9:3.5/4	
S1		aw) i ae	oe a ne]			
S2	oe]	[o	u aw i ae	oe a	e ne]	
S3	a u(aw	ne	o]			
S4	ae	e]				
S5	[ne	a		o e aw ae	u i o e]	
S6	i e	oe		ne u	o a aw]	
S7	o	u	e	i	a e]	

Table III
The Color Combinatorial Matrix of *Colors*:
the durations of each aggregate are relative,
the first number applying to the first half of
the basic structure, the second to the second half
(when the matrix is presented in retrograde);
the actual durations change from variation to variation;
brackets enclose linear versions of the basic series

The first aggregate is distinctive in that seven colors of the basic series are presented consecutively in a single strand. Since this matrix is used in reverse order for the second half of

the basic structure, the retrograde of that same sequence ends the basic structure — once more in a single voice. The beginnings and endings of each variation are similar and distinctive as a result of this "color melody" derived from the structure of the first aggregate.

Another consequence of the overall form of the basic structure is the juxtaposition of aggregate 9 and its retrograde at the middle of the structure. In many of the variations the [ae] color in the seventh strand punctuates the exact center of the structure — the single, prominent, usually low-pitched "note" serving both the direct and retrograded aggregates.

A pair of features of the structure that serve as landmarks are aggregate 6 in the direct half of the structure and aggregate 5 in the retrograded half. Here the single exception to strictness of the retrograde is a swapping of the [aw] between aggregates 5 and 6 in the second half (indicated by the parentheses in Table III). These two aggregates are the "thickest" and most active of all because they are the only ones that have at least one representative from each of the strands and, at the same time, they are the briefest in duration in both halves of the structure.

Of course, color is only one of the musical elements controlled in the work. But in general the pitches and the "character" of the sound — whether for example it is noise, frequency-modulated, pulsed, etc. — serve to emphasize the basic color structure and to expose it in different ways. Throughout most of the work, the details, the fastest moving events, the "foreground," have to do with sound color, not with pitch or some other aspects of sound.

I want to emphasize that the techniques I have used to compose *Colors* are by no means the only way of applying the theory of sound color. In particular, there is nothing to prevent a composer from using more "intuitive" methods while still exploiting the dimensional structure of the sound color space and the operations of color transposition and inversion.

Conclusions and Perspectives

I realize that as many questions as answers are raised by this theory of sound color. Among those that I find most interesting at the moment are such matters as how to extend the sound color space outside of the general frequency region of the vowels, how to use transposition in LAXNESS in a musically and theoretically

satisfying way, and how to relate color with pitch. Of course a great many psychoacoustic questions are posed by the theory. I invite any and all who may be so inclined to join me in attempting to answer some of them.

By no means am I the first to recognize the spectrum envelope as an important musical element (e.g., see Cogan & Escot 1976). It has been exploited by many composers, particularly of electronic music. I hope my theoretical work can contribute a little order and suggest some ways of controlling color musically. I find this world of sound color a fascinating one, which I seem only to have sampled; I would be delighted if others are drawn to try their hands at it from their own perspectives.

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