I. Concepts and Procedures

1 Conceptual and Representational Issues in Melodic Comparison

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Abstract

Melodic discrimination is a fundamental requirement for many musical activities. It is essential to psychological recognition and often signifies cultural meaning. In computer applications, melodic searching and matching tasks have been extensively explored in the realm of bibliographical tools and monophonic repertories but have been relatively little used in analyses of polyphonic works.

Computer approaches to melodic comparison often produce vague or unacceptably prolific lists of false "matches." In some cases these occur because the underlying representation of the melodic material is too general. In other cases they arise from queries that are poorly adapted to the kind of repertory being examined or are inadequately articulated. Some queries assumed to be simple must operate within contexts that are conceptually complex or purposefully ambiguous.

Lessons we have learned from finding-tool projects and monophonic repertories may help to clarify and resolve issues of representation, design, and conceptualization as we approach studies of entire corpora of encoded materials and daunting quests for "melodic similarity."

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The ability to recognize melodic similarity lies at the heart of many of the questions most commonly asked about music. It is melody that enables us to distinguish one work from another. It is melody that human beings are innately able to reproduce by singing, humming, and whistling. It is melody that makes music memorable: we are likely to recall a tune long after we have forgotten its text.

It is often the subtlety of the effect that leads us to consider the possibility of engaging a computer in our research. Music bibliographers want to be able to overcome the deceptive impression of difference given by transposition or re-orchestration. They want help in resolving questions of identification and attribution. Music historians want dependable tools for locating similar tunes disguised by modular substitutions (as in the transmission of early chant), retexting (as in masses that parody motets), consolidation of parts (as in lute or keyboard transcriptions of chansons), and elaboration (as in divisions, diminutions, and variations). Folk-music researchers seeking to identify tune families depend on stress constants where rhythmic details, reflecting variations of text, may vary.

1.1 Concepts of Melody

1.1.1 Intellectual Frameworks

For two centuries or more theorists have concentrated their attention on harmony, counterpoint, and "form" in examining the fabric of music of the past. Rightly they proclaim that these aspects of music distinguish European art music from that of other cultures. In consequence, the component elements of harmony and counterpoint are rigorously and systematically described in the literature of music theory. Such terms as "I_6" and "second species" are unambiguous in meaning, at least from the perspective of observation: we would not identify a V_7 as a I_6 or fourth-species counterpoint as second. The rule-based vocabularies of harmony and counterpoint are moderately supportive of efforts at artificial composition in the styles of the sixteenth and eighteenth centuries. Schottstaedt's implementations of species counterpoint following Fux's teachings (1989) offer an apt example.

It has generally been recognized by those engaged in generative applications that even those rule-systems which we regard as extensive are far from exhaustive. Thus the task of deriving "invisible" rules of practice, never expressed formally in music-theoretical works, has attracted welcome attention. The rules accumulated through Kemal Ebcioğlu's artificial harmonizations of chorale melodies set by J. S. Bach (1986; 1992), for example, now number more than 300.

The intellectual framework for discussions of melody in European art and folk music is not yet nearly so well formed. Formal discussions of melody in German and Italian music theory of the eighteenth century are engaging but few, particularly in comparison with the copious literature on harmony, counterpoint, and form of the past three centuries, and even, vis-a-vis recent literature, with expositions of reductionist techniques of musical analysis or principles of music perception and cognition. This is partly the result of the idea, current in earlier eras, that the construction of melody allowed for inspiration and experimentation, for permutation and transformation. The "invention" of a melody was considered to be concept-based, but it was not rule-driven in the same way that harmonizations and realizations of form were. Folk melodies were considered to have arisen "unconsciously."

There is little automatic agreement on definitions for various manifestations of melody. We may all believe we have a common focus in mind when we discuss our notions of a theme, a phrase, a motive, or a fugal subject. When it comes to the design of computer applications, however, we may disagree about thematic hierarchies, about phrase boundaries, about motivic overlaps, or about the termination point of a fugal subject. These conceptual lapses are quite paralytic, because computers cannot make intuitive judgments for themselves and there is too little consensus for them to make "scientific" judgments founded on our beliefs.

The degree to which melody is a dominant part of the musical fabric is another conceptual variable. It goes without saying that folksongs in the Western tradition frequently offer a 1:1 ratio of melodic content to overall length, but the ratio is almost always diminished in art music. The extent to which it is diminished is highly variable. The point of departure for many recent discussions of melodic and structural processes has been the opening theme of Mozart's Piano Sonata K. 331 (Figure 1).

Figure 1. The opening theme of Mozart's Piano Sonata K. 331.

We must remember, however, that Mozart is extremely cogent in his musical thinking and precise in his definition of thematic material, and rarely more so than here. It is not so easy to identify motives and phrases in the rambling prose of, let us say, Glinka, or in the whimsy of seventeenth-century toccatas. These and a host of other less tractable repertories are little discussed in recent analytical literature, much less in computer applications.

The degree to which the definition of a melody may be determined by cultural convention is another issue that warrants respect. As long as we work within the European/American art-music tradition we may be able to ignore the possible confounds that divergent cultural views may bring to estimates of melodic similarity, but their influence should nonetheless be acknowledged. Ethnomusicologists, beginning with Frances Densmore's 1918 study of Teton Sioux music, seem to have the longest-lived interest in methods of melodic comparison. This is all the more commendable because these scholars work against an enormous obstacle as they change venues. George List's revealing article about Hopi concepts of melody relates that the Hopi "conceives of melody as a series of contours that are differentiated by their combination of rising and falling pitch lines. For two performances of a contour to be considered the same, only a general relationship must be maintained" (1985: 152). Where precise definitions of a melody are intended, it is well known that lapses occur in oral transmission. Conversely, however, Spitzer (1994) noted that in a situation in which variation and improvisation were acceptable (American minstrel shows), written variants of "Oh! Susanna" nonetheless tended towards regularization of accent and simplification of tonal structure.

Differences within academic subcultures also flavor our findings. Approaches to melodic comparison issuing from computer science and other statistically oriented fields value "degrees" of similarity in comparative studies, but researchers nurtured in the humanities and the performing arts tend to seek decisive answers, or at least persuasive interpretations. They want to know whether one work is or is not a paraphrase of another. If a continuum between quantitative and qualitative evaluations could be constructed, its use might be appropriate in the field of melodic comparison: some results that are "decisive" are nonetheless incorrect while, within the framework of results rated by degrees of confidence, statistical findings may occasionally oppose psychological verities.

Writing on composition at the end of the eighteenth century, the theorist Heinrich Christoph Koch attempted to provide a series of "mechanical rules" for the creation of melodies (1782-93, partial translation 1983; see also Baker 1988). He considered only *genius* to be capable of endowing a melody with beauty and only *taste* to facilitate the perception of this beauty. These obviously are human qualities that lie outside the music itself. Koch's citation of them reminds us that our concepts are ultimately an amalgamation of what is within the music and what is within our minds. Computers can only address the first.

1.1.2 Interdisciplinary Contexts

Interest in melodic studies has risen significantly in recent years. An important part of this interest is separate from, but secondarily related to, the rise of computer use. This secondary relationship often comes about through a sympathy for some other discipline which itself has been heavily influenced by computer use. For example, Eugene Narmour's books on the *Analysis and Cognition of Basic Melodic Structures* (1990) and the *Analysis and Cognition of Melodic Complexity* (1992), which provide exhaustive description of one specific melodic process—the "realization" of melodic "implication"—show the influences (via Leonard Meyer) of Gestalt psychology, artificial intelligence, and cognitive psychology.

The work of Mario Baroni and his colleagues on the establishment of rule-based grammars (1978, 1983, 1984, 1990, 1992), which illustrates a long-sustained attempt to bring systematics to the study of melody, is indebted to computational linguistics and the Chomskian idea of the existence of universal principles of grammar. Theories of grammar, in combination with techniques of artificial intelligence, also play a role in the artificial-composition experiments of David Cope (1991A, 1991B, 1992A, 1992B, 1996). Cope's composition software identifies patterns unique to individual composers and repertories and stores them in a lexicon. It selects them at random but in conformance with a grammatical classification scheme, which governs the generation of new compositions in the style of the designated composer and genre.

The exploration of the fundamental role that implicit knowledge plays in many human activities was stimulated by unforeseen difficulties that arose in artificial intelligence. Machines could not be programmed to simulate human perception beyond the limits of current understanding. The line between perceptual studies, in which the focus is on human performance or understanding (i.e., on "subjects"), and music-theoretical studies, in which the focus is on the music itself (i.e., "objects"), is often more delicate than we might suppose. In order to recognize antecedent and consequent phrases, for example, we must be (1) cognitively familiar with the concept, (2) perceptually astute in listening, and (3) neurologically able to match precept and example. Yet we cannot identify these components of a melody in music that does not contain them. Similarly, in many other tasks related to musical analysis, both subjective and objective conditions must be satisfied.

Cognitive studies may lead us towards philosophical questions that seem quite distant from practical applications. In studying melody, we must acknowledge, as Koch suggested, the role of fluctuating aesthetic values. The beauty (or "genius") of some musical effects is borne by clarity, of others by subtlety. "Taste" may be an instance of perception conditioned by cultural expectation. As musicians, we will always value the distinction between clarity and subtlety. As researchers using computers, we are challenged to provide the same degree of reliability in pursuing the one as the other. As the following considerations reveal, this is a goal which may always be somewhat elusive.

1.1.3 Content Variables: Prototypical, Disguised, and Implied Melodies

The vacuum of theoretical work underpinning studies of melody obliges us to agree on some basic terms and concepts. These terms and concepts fall into four areas—actual and ideal melodies, locations of melodies within the work, elements of melodies, and contextual aspects of melody.

Between an actual melody and the encoding of it there is often an intermediate conceptual entity, the *prototypical* melody. The prototype is a kind of generalization to which elements of information represented in the actual melody, such as rhythm, may seem irrelevant, or indeed to which unwritten information, such as stress, may seem relevant. It is this prototype, rather than the actual music, that has the greatest influence on the way in which melody is remembered—and later sought.

Although, if the music is simple enough, there may be no difference between an actual melody and its prototype, much of the literature of music theory and of music perception and cognition over the past two decades has been absorbed in questions of ambiguity—rhythmic, harmonic, and melodic. Composers have often gone to considerable lengths to hide, or to pretend to hide, the melody—to bury the treasure, as it were, so that we can enjoy the hunt.

For the purposes of computer searching, works in which the melody is isolated in a consistent way are far easier to handle than those in which it is instead interwoven with other material. Some commonly encountered kinds of disguised melodies are the following:

(1) *Compound* melodies, in which there is really only one melody but its principal notes, many fewer in number than the surface level of activity suggests, are not automatically indistinguishable from the passage in which they are embedded. These occur particularly in unaccompanied string music [Figure 2a].

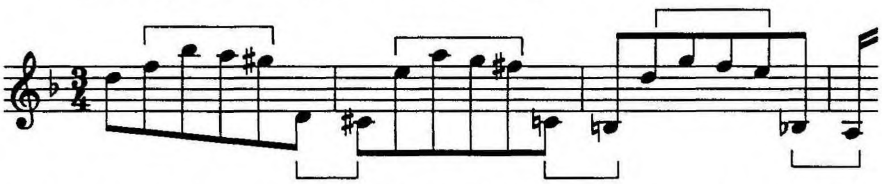


Figure 2a. A compound melody: Bach's Chaconne for unaccompanied violin. Two melodies are collapsed into one line.

(2) *Self-accompanying* melodies, in which some pitches pertain both to thematic idea and to the harmonic (or rhythmic) support [Figure 2b].

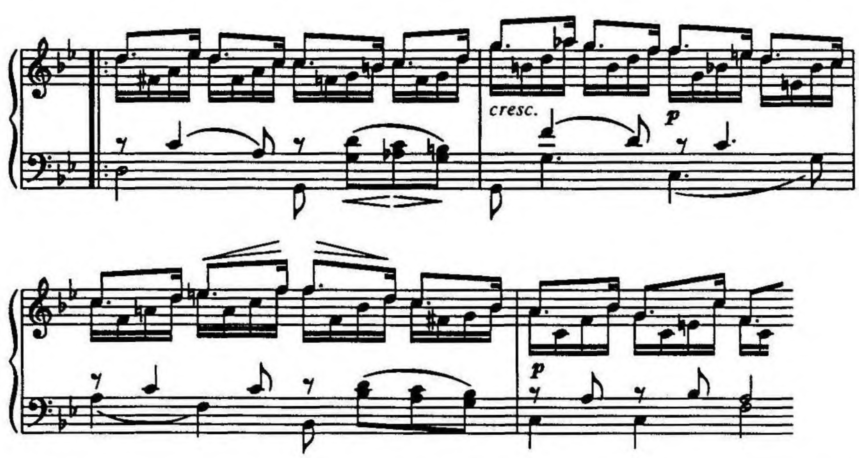


Figure 2b. A self-accompanying melody: Schubert's Impromptu, Op. 142, No. 3, Variation 1. Some pitches jointly belong to the melody and the accompaniment.

(3) *Submerged* melodies consigned to inner voices, while decorative outer voices leave different residues in the listener's mind. These are likely to occur in keyboard music [Figure 2c].

Figure 2c. A *submerged* melody: Brahms's Ballade Op. 10, No. 4. Brahms's instruction calls attention to the wish that the theme, found in an intermediate voice, should be played "with the most intimate sentiment but without too much marking of the melody." The essential content is given in the top staff as a "rhetorical reduction" by Leonard Ratner.

(4) *Roving* melodies, in which the theme migrates from part to part [Figure 2d].

Figure 2d. A *roving* melody: Haydn's keyboard variations "Gott erhalte." The melody (System 1) passes between the bass and tenor voices in Variation 2 (System 2) and between the alto and soprano in Variation 3 (System 3).

The "track" problem is particularly acute in Variation 3 (third system), where the parts might more accurately be considered to be two altos and two sopranos or bass, tenor, and two sopranos. Throughout the first half of the movement, the two "sopranos" have a syncopated canon at the unison.

(5) *Distributed* melodies, in which the defining notes are divided between parts and the prototype cannot be isolated in a single part. These occur mainly in orchestral repertory [Figure 2e].

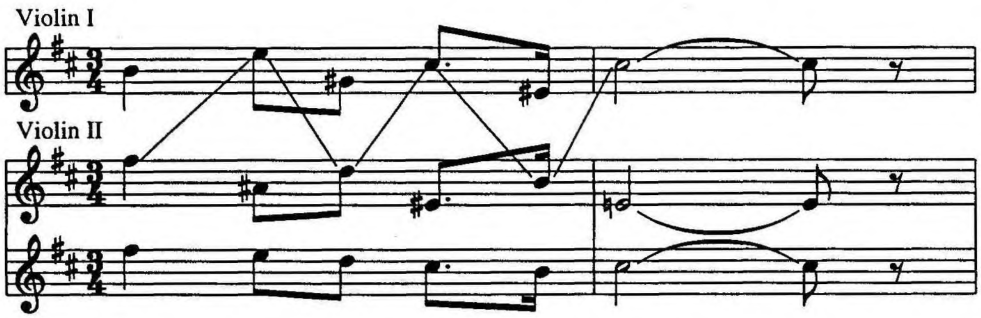


Figure 2e. A *distributed* melody: The opening of the *Adagio lamentoso* movement of Tchaikovsky's Sixth Symphony. The notes defining the principal theme are introduced alternately between the first and second violins. A composite representation is given on the third staff.

The problem with disguised melodies in computer applications is that either the encoding or the query must be structured in such a way as to make the simple strand retrievable. In keyboard music, this requires the differentiation of the material into multiple tracks or threads. Notes with two stems (2b, 2c) must appear in both tracks. To find roving melodies (2d), a query must be able to thread its way through different parts and to traverse the same material over and over. Even then, a program would only be able to compile a complete melody by having a carefully constructed model to attempt to match.

The only hope for ferreting out the prototypical melodies in compound and distributed melodies (2a, 2e) would be to separate the pitches by register into two tracks (2a) or, conversely, to collapse the tracks into one (2e) and then extract the notes that are highest in each time-slice. Unless one has reason to suspect that such phenomena occur, one would be unlikely to provide the extra apparatus necessary to find such themes.

Some similarly deceptive examples demonstrating other strategies for elusiveness are given by Crawford et al. in Chapter 3.

The most prevalent kind of lapse between precept and example may occur in Mozartean melodies where every statement of the same "thematic" material is presented slightly differently, where no single statement contains a completely unornamented "model," and yet where there may be general consensus that a common melody is implied. Agreement about the exact components of this implied, but undisclosed, model (or prototype) may be difficult to achieve.

Consider, by way of a tangible example, the various iterations of the "theme" of the Andante of Mozart's Piano Sonata K. 311 (Figure 3).

Figures 3a–e. Five iterations of the "theme" of Mozart's Piano Sonata K. 311.

None of these permutations gives a clear statement of the prototypical melody that is implied, which is arguably what is shown in Figure 3f.

Figure 3f. A prototypical melody related to the iterations shown in Figures 3a–e.

Some algorithmic approaches to the resolution of this problem will be discussed in Section 5.

1.1.4 Position Variables: Incipits and Themes

Bibliographical (or finding) tools tend to concentrate not on complete melodies but on samples of them. These samples may be taken either from the start of a movement or work, in which case they are called incipits, or from a random portion of the work that enjoys the greatest melodic importance. In the latter case the melodic material is called a theme. Most experience with computer-assisted studies of melody is based on the use of incipits or themes. Incipits form the basis of most so-called "thematic" catalogues. Some finding tools (e.g., RISM's index of music manuscripts, Lincoln's madrigal and motet indexes, LaRue's symphony catalogue) also concentrate on incipits, while others (e.g., the Barlow and Morgenstern [1948] and Parsons [1975] dictionaries) concentrate on "themes."

Incipits serve well for early and folksong repertories, in which "themes" may be coincident with incipits. Within the domain of incipit representation and searching there are significant traps. In polyphonic repertories the characteristics of incipits vary markedly between voice parts. The most important melodic information may be in the tenor in late medieval repertories; it is likely to be in the highest vocal or instrumental part in homophonic repertories of later centuries. One is more likely to find rough equivalence of melodic importance in the various part-incipits of imitative works than in homophonic ones, although in works involving elaborate counterpoint, double subjects and other complications may be present.

The development of classical instrumental music in the eighteenth and nineteenth centuries brought with it an ever greater tendency toward a concentration of interest on themes and a disintegration of the notion of continuous melody. Some passages are melodically more significant than others. The value of the melodic information in an incipit gradually decreases over this period. Opening bars less and less frequently contain important thematic information, although they might, as in the case of Wagner, contain potent harmonic indicators of what was later to evolve. "Theme" catalogues are usually concerned entirely with the melodic material that is most memorable and most essential to the description of larger musical structures (symphonies, concertos, etc.).

Programs that can automatically select "themes" from within long streams of melodic information are unlikely to appear soon, because rubrics for selection are poorly defined. At present, "themes" that are not coincident with incipits must be preselected and hand-fed or tagged in existing data. However, the data encoded for bibliographical projects (whether books of themes or books of incipits) provide a valuable laboratory for evaluating the relative success of different approaches to representation and sorting strategies, with or without algorithms for thematic indentification.

Increasingly [see the articles by Howard, Bainbridge, and Kornstädt in this issue], these underlying databanks are being made accessible via the World-Wide Web. Thus, issues that until recently may have seemed remote from common user experience suddenly assume importance. The hard scrutiny that comes with frequent use can be expected to follow as a natural consequence of improved access.

1.2 Searchable Representations of Pitch

The level and nature of the detail captured in a musical encoding exerts considerable influence on the kinds of searches that can be undertaken. The directly *representable components* of melody are pitch and duration. *Derivable components* include intervallic motion and accent. *Non-derivable components* include articulation and dynamics indications. More general aspects of the music that may be of relevance to analytical tasks include the number of voices and the work's instrumentation, genre, texture, and other general features. Two pertinent questions about the encoding of such data are these:

(1) What is the minimum set of parameters required to define a melody?

(2) What is the minimum level of specificity required of any given parameter to support multiple uses of the encoded material?

Most algorithms for melodic searching currently in use treat pitch in a relatively general way and ignore rhythmic information entirely. The equivalents in text searching might be to encode only consonants and to ignore punctuation: the results are often too inclusive and, when reference is made to the original compositions, are seen not to represent some of the most distinctive characteristics of the music. To explain why such results may occur, we first consider levels of pitch representation and then review methods for comparing pitch profiles.

1.2.1 Levels of Pitch Representation

The octave may be subdivided in many different ways. Leaving aside discussions of tuning systems, which can engage hundreds of ways for subdividing the octave, and concentrating on methods most closely associated with common experience, the most prevalent representations of pitch are the base-7, or diatonic representation (Figure 4a),

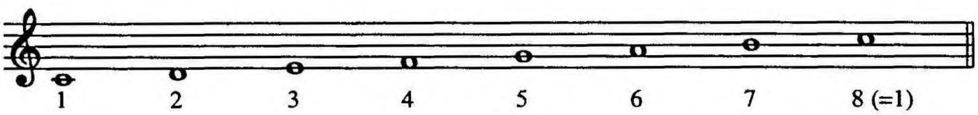


Figure 4a. Numerical values in a base-7 system of pitch representation.

which allocates one slot for each white key of the piano and/or each name-class (A..G) of common nomenclature, and the base-12 representation (Figure 4b),

Figure 4b. Numerical values in a base-12 system of pitch representation.

which allocates one slot for each black and white key and/or each equal-tempered pitch-class. The base-7 system thus is correlated with physical entities and notational concepts, while the base-12 system is correlated with physical entities and theoretical concepts. Base-7 systems have been used in many finding tools, and base-12 systems are ubiquitous in both pitch-set theory and in MIDI applications.

Both systems have limitations which can be crippling for particular kinds of melodic applications, and for this reason, many more articulate systems of pitch representation have been devised and implemented in computer applications. Sometimes these are used only as metacodes for internal processing to improve the accuracy of processing. They are not necessarily apparent to the user. Two that are representative are the base-21 system (Figure 4c),

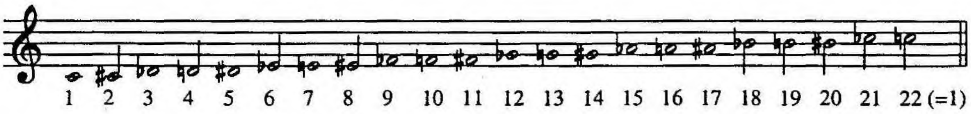


Figure 4c. Numerical values in a base-21 system of pitch representation.

and the base-40 system (Figure 4d):

Figure 4d. Numerical values in a base-40 system of pitch representation.

The base-21 system provides a sufficient number of numerals to differentiate each enharmonic tone within the range of single sharps and flats. While it does allocate a slot for all the name- and inflection-classes of common music notation, its scheme of representation does not directly correspond to physical entities or theoretical concepts.

Hewlett (1992) discovered in the mid-Eighties that two problems could be solved at once by allocating a slot to each of the "phantom" spaces that happen to correspond to black notes on the piano. This resulted in the base-40 system, which is one of a class of "solutions" to increasingly more abstract representations of tonal pitch-space. The two problems solved were *interval invariance* and *discrete accommodation of enharmonic pitches* through all double sharps and flats. There are larger numbers that also secure interval invariance and can accommodate greater degrees of inflection (e.g., triple sharps, etc.), but 40 is the lowest common denominator for tonal music through the nineteenth century.

Interval invariance guarantees that there is always consistency between an interval and its numerical mapping. All of the systems mentioned have some degree of invertibility, but none guarantees complementarity for all conceivable interval combinations. All systems accommodate perfect-interval combinations, provided that the tones involved regularly occur in the scale and are not altered. The *base-7 system* cannot discriminate between major and minor intervals; it can therefore accommodate thirds but not major or minor thirds. Thus it cannot be used to determine whether a chord is major or minor, since it cannot evaluate the quality of the component thirds. It would be useful for examples in a melodic minor scale (with different ascending and descending versions), since it is unable to represent inflections.

The *base-12 system* supports complementarity in terms of measuring the number of semitones correctly, but it operates outside the conventions of written tonality. For example, it would assign a difference of 4 (semitones) to both the augmented fourth C$^\sharp$–F and the major third D$^\flat$–F. This is an asset in evaluations of atonal music.

The *base-21 system* appears to be better suited to discrimination of written tones, since C$^\sharp$ and D$^\flat$ have separate numerals. When these numerals are combined to compute intervallic sizes, however, the results are not always consistent. The minor third C–E$^\flat$ has a score of 5 (6–1), while the minor third E$^\flat$–G$^\flat$ has a score of 6 (12–6).

The *base-40 system* produces consistent results for such measurements. The minor third C–E$^\flat$ (14–3) has a measure of 11; the minor third D$^\flat$–F$^\flat$ (18–7) has a measure of 11. The minor third G$^\sharp$–B (38–27) has a measure of 11. Similarly, all major sixths, irrespective of their notation, have a score of 29.

The results of computation with different bases become more unstable when the intervals involved include chromatic tones. Thus in the base 12-system the augmented fourth (e.g., C–F$^\sharp$) has a score of 6, but so does the diminished fifth (C–G$^\flat$; F$^\sharp$–C). In the base-21 system, one augmented fourth, C–F$^\sharp$ (11–1), has a score of 10, while another, F–B$^\natural$ (19–10), has a score of 9. The diminished seventh C$^\sharp$–B$^\flat$ (18–2) has a score of 16, while the diminished seventh D$^\sharp$–C (22–5) has a score of 17.

In the base-40 system, all augmented fourths (e.g., C–F$^\sharp$ or 21–3) have a score of 18, while all diminished fifths (e.g., F$^\sharp$–C or 43–21) have a score of 22. Similarly, all diminished sevenths (e.g., C$^\sharp$–B$^\flat$ or (37–4) have a score of 33, and all augmented seconds (e.g., C–D$^\sharp$ or 10–3) have a score of 7. Thus the complimentarity used in ordinary music theory exercises is preserved, with such intervals in combination always producing a sum of 40. This system for mapping enharmonic tones has been used with success in diverse applications in teaching (e.g., *MacGamut*) and analysis (e.g., *MuseData* analysis routines by Walter B. Hewlett, Essen software conversions by Lincoln Myers and *Humdrum* tools by Craig Sapp). The base-40 scheme works well as an intermediate representation, invisible to the user, provided that the original data provides the level of detail required to make it operative.

1.2.2 Pitch-based Comparisons

Methods of pitch representation merely set the stage for methods of pitch comparison. It is obvious that one cannot match models at levels of detail that have not been represented in the data being searched. For practical reasons, it is often the data that have been collected most copiously that are represented with the least detail.

Four common approaches to "melodic" comparison rely solely on pitch data. These respectively compare

(1) profiles of pitch direction,

(2) pitch contours,

(3) pitch-event strings, or

(4) intervallic contours.

Rigorous questions about levels of detail in pitch representation seem almost irrelevant to the first two but play a central role in the second two. One additional approach is to combine different levels of pitch representation (e.g., intervals and contour); it is little tested in melodic-search applications.

The most general method (1) for the comparison of two or more melodies in current use evaluates sequences of *pitch-direction* codes using the parameters up (U), down (D), and repeat (R). It was a favorite device of finding tools created in the middle decades of the twentieth century. Using a simple base-7 system of pitch representation, an "up-down" incipit might "match" such strings as `132, 142, 143, 154, 153, 152` . . . and also `243, 354, 465, 576` . . . and even `451, 581, 786`, and so forth.

The general procedure is illustrated in McAll's *Melodic Index to the Works of Johann Sebastian Bach* (1962), a finding tool organized in three parts. The first gives a general classification of directional relationships between the first four notes of each item. This is followed by a list of chromatically notated instantiations (assuming transposition to C Major or A Minor) of each contour. These are grouped according to the scale degree on which they begin. Thus for the UUU contour, there are 44 instantiations beginning on the first degree (I), two on the second (II), 11 on the third (III), one on the fourth (IV), 25 on the fifth (V), and two on the seventh (VII). (No examples begin on the sixth degree.) Extracts are shown in Figure 5a.

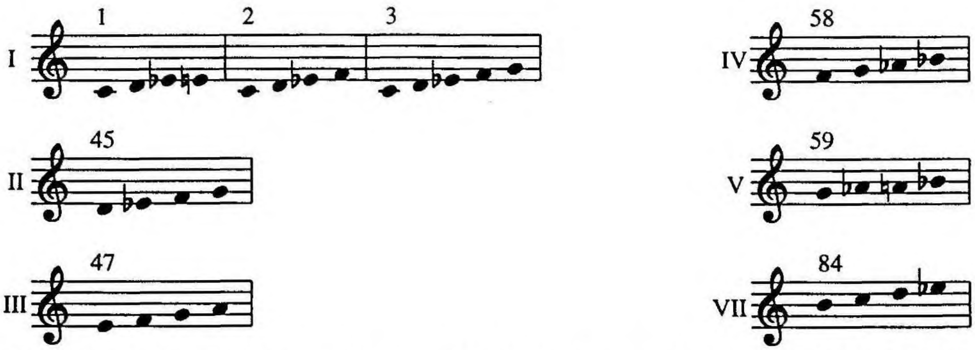


Figure 5a. Selected instantiations of the UUU sequence in McAll's *Melodic Index to the Work of J. S. Bach.* Roman numerals represent scale degrees.

In McAll's work, the profile serves merely as a mnemonic device: the actual fully notated incipits for all "matched" sources are given in the second section of the book. The five matches of the first instantiation of the UUU contour anchored to the first degree are shown in Figure 5b.

Figure 5b. The five "matches" of the first instantiation (I:1 in Figure 5a) of the UUU contour, represented by individual incipits.

When directional profiles are used without such collateral magnification of the underlying detail, the results may be of diminished value. For example, in Pont's article on "Geography and Human Song" (1990), citing a universal tendency of incipits beginning UU to predominate, only the two melodic intervals created by the first three notes are considered in the output, whereas in the underlying data, assembled by Parsons for his *Dictionary of Tunes* (1975), which covers roughly 10,000 classical themes and 4,000 popular tunes, longer streams of intervals were collected. The more general the system of representation, the longer the string will need to be to produce meaningful discriminations. Conversely, the richer the data, the shorter the string can be. In this case the combination of highly general data with very short strings leads to a superficial view, but one that is provocative when regarded as a model in need of improvement.

Pont added to data from Parsons' working tapes corresponding information for five monophonic repertories—chants from ancient Greece, chants from the *Liber Usualis*, Gaelic melodies, Peyote Indian songs, and Aboriginal songs. The three kinds of directional motion tracked produce nine logical combinations. The results of their comparison were reported by the percentage of occurrence of each of the nine intervallic-direction patterns. The results are simplified in the rank-order lists given in Figure 6.

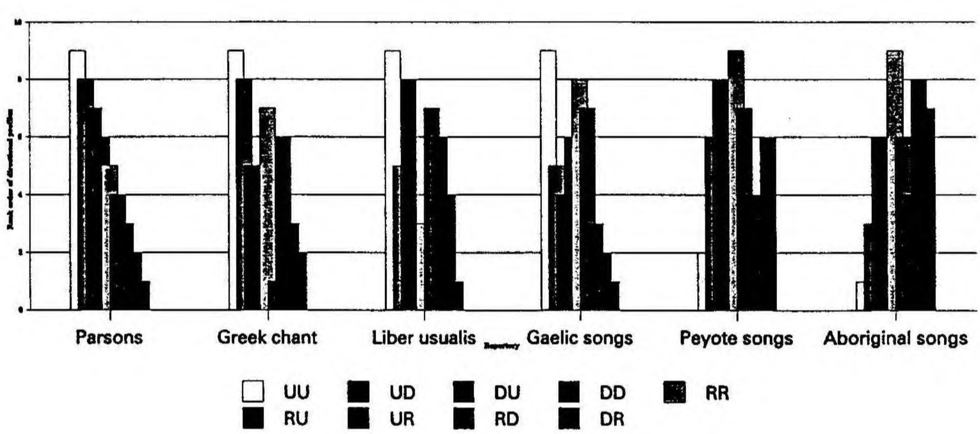


Figure 6. Comparative rankings on directional profiles in six repertories. 9 = the greatest number of occurrences.

These results raise issues that must frequently be considered in the comparison of more fully represented melodies. For comparison, the same tests have been run on other data near to hand. In Figure 7 we see comparisons with four collections in the Essen database—*Lieder* from the sixteenth century, songs from Central Europe, songs from Southeastern Europe, and children's songs. These form four different profiles, none of them consistent with any of the profiles in Figure 6.

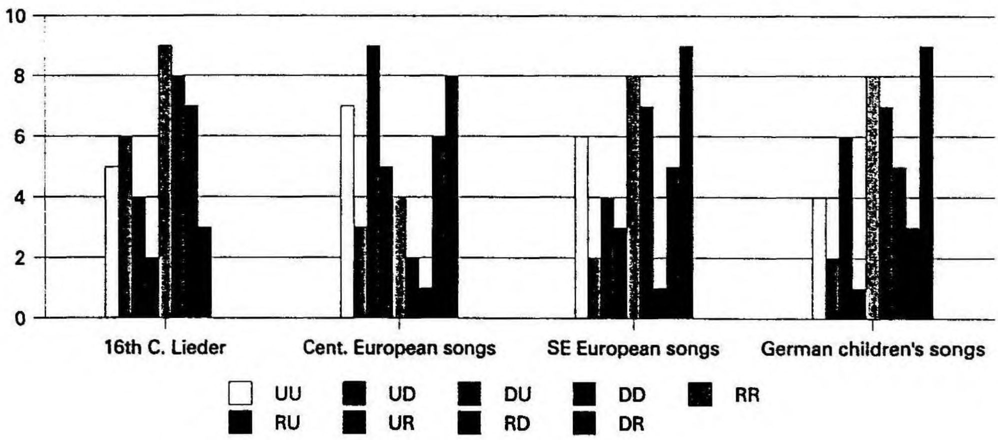


Figure 7. Directional profiles for four collections of European song.

Two problems with directional profiles become apparent. First, there is no way to determine from such a limited set of information the relationship of the third note to the first. Second, as we saw from the first level of McAll's work, each directional category conceals a great range of contours and notated pitch-strings. Third, Pont's quantities of data were small compared with those used by Parsons and those available in finding tools and source databases, such as the Essen collection and the *Musedata* corpora encoded and archived at the Center for Computer Assisted Research in the Humanities.

To more fully explore the proposition that there are universal preferences for direction, we assembled comparable information from such sets and determined that the evidence for universal preferences is weak (Figure 8). Among eighteenth-century repertories, for example, the profiles for two Italian composers (B. and A. Marcello) show poor conformance to the general profile of Italian composers in a sample of RISM data. A greater degree of similarity exists between early cantatas (Nos. 1–20) by Bach and Telemann. Handel's *Messiah* does not exhibit strong preferences for initial direction at all.

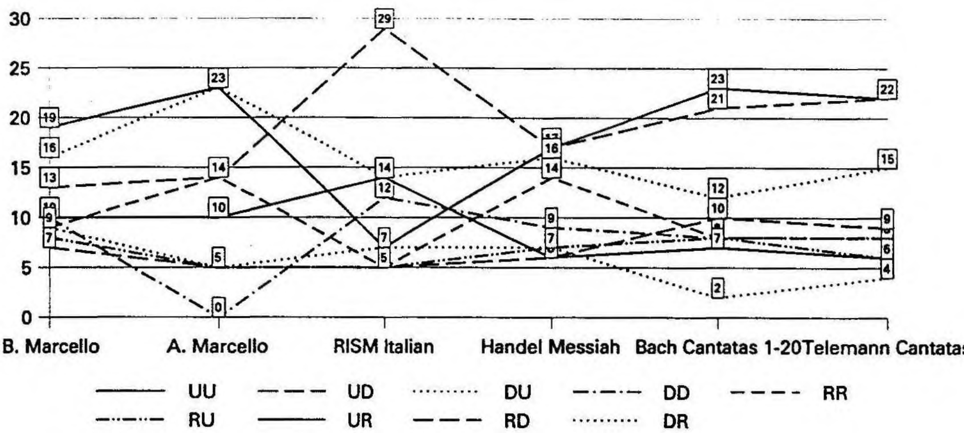


Figure 8. Directional profiles for various encoded repertories of Baroque vocal music.

In Figure 9, we present similar profiles for eighteenth-century instrumental music, with data for twentieth-century bebop (compiled by Williams 1985) included for further comparison. The contrast between the even-handedness of Beethoven and the clear preferences of bebop is possibly more striking than the indicated consistency within the Bach and Telemann repertories when both instrumental and vocal music are considered (see again Figure 8). We would expect differences between vocal and instrumental music, but these differences do not seem to be as significant as those between particular composers and even, in results not shown, between the early and late styles of individual composers.

The problems associated with unknown relationships between non-contiguous intervals in directional profiles (which pertain to all the material shown in Figures 6–9) have been well recognized in ethnomusicology. Although Seeger (1960) claimed that an up/down/repeat typology was adequate for distinguishing contours, Adams (1976) refined this approach to distinguish three *primary* features, which were

(1) slope (degree of),

(2) deviation (from current direction), and

(3) reciprocal (the relationship of the current pitch to the initial pitch),

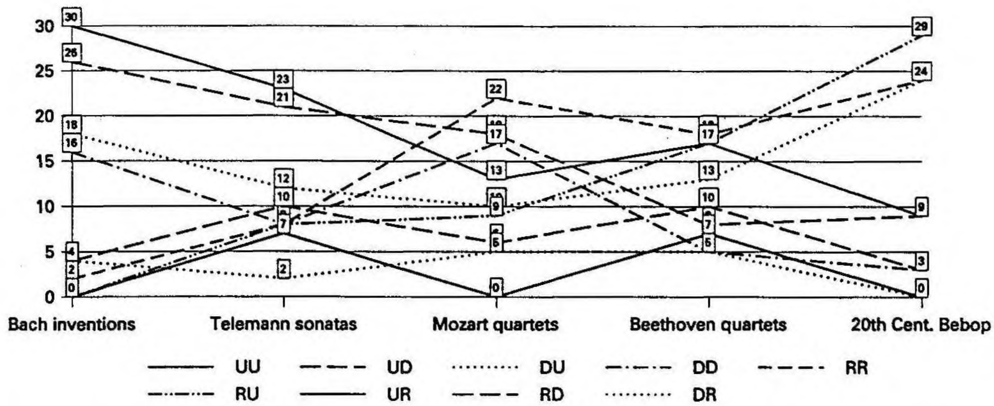


Figure 9. Directional profiles for various encoded repertories of eighteenth- and twentieth-century instrumental music.

from three possible *secondary* features,

(1) repetition (of the pitch),

(2) recurrence (of the same pitch after intervening pitches), and

(3) accommodation of "conjunct" and "disjunct" segments of melody.

Adams noted that there was wide latitude in the use of term "contour" in ethnomusicological studies from Densmore forward.

Pitch contours (2) (frequently called "melodic" contours) give more definite information than directional profiles while retaining the kind of generality that may be required for studies based on performance or general features of melodic content. Sonographic data from audio input may be used to show undulating lines that illustrate the shapes of melodies (see, for example, Lubej 1995-96).

Another type of contour is that which considers the overall relationship of average pitches within a succession of phrases, in short a phrase contour. Relationships between successive starting or ending points are more clearly conveyed than in a directional profile, since such a procedure requires a numerical representation of pitch at the outset. In his study of melodic arches, for example, Huron (1995-96) noted the tendency for folksongs with six phrases to exhibit the "McDonald's effect"—a concave arch nested in the convex arch formed by the outer phrases (Figure 10).

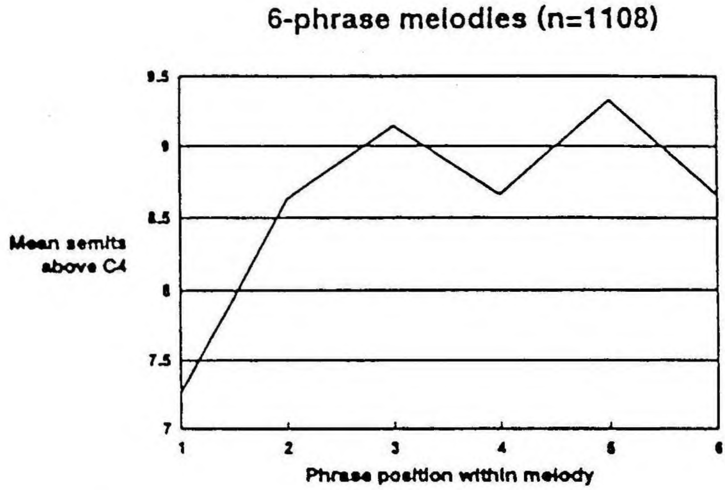


Figure 10. Phrase contour: the "McDonald's" effect in six-phrase melodies (after Huron's analysis of the Essen database).

Like directional profiles, graphic contours are useful for demonstrating highly generalized results. However, they lack the specificity to support direct comparison of works.

Greater levels of detail in pitch representation play a defining role in two more explicit approaches to melodic comparison:

(1) sequential profiles of pitch strings (diatonic, chromatic, or enharmonic) and

(2) sequential profiles of melodic intervals.

Pitch-event strings (3) may employ the base-7, -12, -21, -40 or any other workable system of pitch representation. In addition, they may or may not indicate the register (or octave) in which each pitch occurs. Indications may be relative to the most prevalent octave (as in *EsAC* code or Braille musical notation) or absolute (as in MIDI key numbers).

In *moveable-register* representations, an arbitrary range of limited extent is set as a default. Pitch may be defined in relation to the vertical position of written notes on a clef. Some early computer systems of representation, such as *IML-MIR* and *DARMS*, both encoded pitch according to graphic placement. In Princeton's *IML-MIR* system, pitches were identified by letter name, but no absolute octave or register information was provided. *DARMS* (extensively described in Selfridge-Field 1997) assigns the numbers 1..7 to the same seven-note span addressed by letter-names in *IML-MIR*, and like *IML-MIR*, *DARMS* is clef-dependent. If one takes account of both clef and pitch name, *IML-MIR* may be said to be absolute in its transcription of pitches. *DARMS*, in contrast, is always relative, for "pitches" do not have names; they only have "vertical heights." *DARMS* is relative over a very long number line, however, for negative and positive numbers of arbitrary extent can be tolerated.

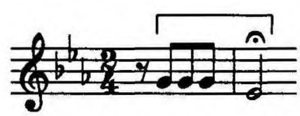
Moveable-register systems were actually in use in the last century, particularly among those following Curwen's "tonic sol-fa" system (1875) for singing. Later employed both as a simplified way to distribute popular songs and as the foundation for a method to collate hymn tunes (see, for example, Love 1891), Curwen's method explicitly represented scale degree, relative octave, duration, barlines, slurs, grace notes, and other features of music. See Figure 11.

The most successful equivalent of the "tonic sol-fa" approach is found in the diatonically encoded material of the Essen Database of folksongs originated by Helmut Schaffrath (1992A, 1992B, 1993; also Selfridge-Field 1997). The associated *EsAC* code (described in Selfridge-Field 1997) makes a relative provision for octave encoding: each work has a principal octave and can refer, through the use of plus and minus signs, to the immediately adjacent octaves.

Figure 11. A moveable-register ("tonic sol-fa") representation of the "New St. Ann" tune (from Love, p. 258). Moveable *do* (d) here = B^b in the octave above Middle C.

Does reliance on registral switches handicap melodic searches? Missing registral cues in the Princeton data would have created mistaken impressions of melodic contour had the data been used extensively for analysis. *DARMS* data has been more extensively used for analytical tasks involving melody (e.g., Lincoln 1988, 1993) of various kinds. That its system of representation is not biased towards any particular key or mode is a blessing for atonal applications (*DARMS* has found its most sustained following among set-theorists) and sometimes a curse (data verification is difficult). The lack of explicit registral information may incline *DARMS* towards slightly cumbersome meta-representations, such as Brinkman's binomial approach (1986A) to pitch representation. Combinatory schemes have the disadvantage (vis-à-vis the base-7, -12, -21, and -40 systems reviewed earlier) that two numbers (with different numerical bases) must be manipulated in analytical endeavors, as in nested English measures such as pounds/shillings/pence or feet/yards/miles computations.

What is more problematic in melodic searches is the complete absence of either registral or directional information. For example, the seven-letter code (plus chromatic symbols) used by Barlow and Morgenstern (1948), in strings of six to ten pitch names, enables low-level sorting but, given short strings as queries, can produce some absurd "matches" (Figure 12a–b). Matches for the opening of Beethoven's Fifth Symphony,



(GGGEb) as given by Barlow and Morgenstern, include the following:

Figure 12a. Handel's Organ Concerto Op. 7, No. 1.

Figure 12b. Dvořák's Slavonic Dance Op. 72, No. 6.

Similarly, the thematic-identifier volume of Jan La Rue's eighteenth-century symphony catalogue (1988) provides only schematic information about pitch; for registral information we must await the publication of the music volume. The principal themes from the opening movement of Haydn's "Military" Symphony appear as shown in Figure 13. In the related incipits of Figure 13, a parameter for register or octave would enable us to know that the contours are similar.

```
14646   G:DGDCBA//DEGDEDCBA H411 HAYDN
```

Figure 13. LaRue's listing for the opening movement of Haydn's "Military" Symphony and the music represented.

Pitch-string comparisons are defensible in the study of monophonic medieval repertories, because in many cases there is no firm knowledge of durational values. Even here, though, another parameter may be essential to infer contours. In Andrew Hughes's database of *Late Medieval Liturgical Offices* (1994), for example, a mode indicator makes a base-7 pitch-code interpretable. Medievalists have been making enviable progress in studies of chant centonization by coordinating syllabic information from text underlay with pitch information (Figure 14; see Haas 1991 and 1992), or details about the physical appearance of neumes with pitch information (Binford-Walsh 1990, 1991, et al.).

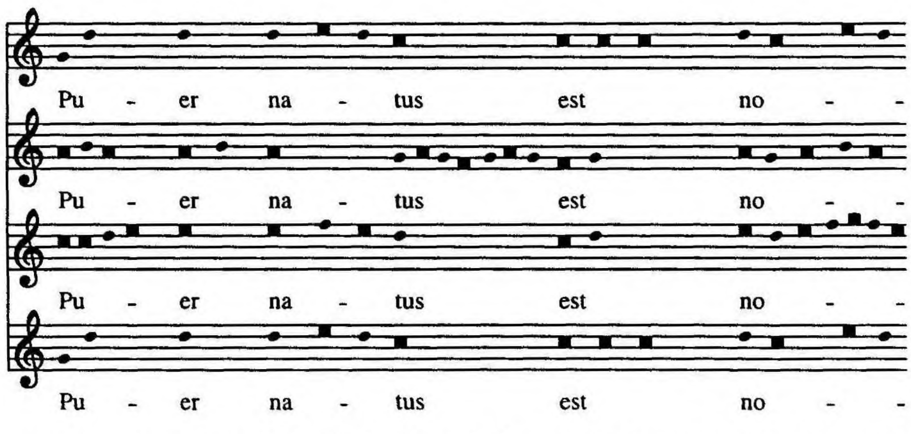


Figure 14. A comparison of chant melodies, based on coordination of text syllables, produced by Max Haas's *Chatull Gadol* program.

The *SCRIBE* database of fourteenth-century music explicitly encodes neume types and pitches (Stinson 1992; Selfridge-Field, 1990: 25). Associated software supports color separation of mensural notation, which expresses durational relationships through the use of black, red, and "white" (unfilled) notes. Yet in studies of search strategies, *SCRIBE*'s manager, John Stinson, has discovered that when notational information is ignored and pitch sequence alone is considered, concordances with chants of the tenth century are more likely to be found. This result demonstrates the apparently immutable truth of computer applications that attributes that are absolutely essential in one application may simply hinder the efficiency of another.

While precise note names are often desired for analytical tasks in music history, theory, and bibliography, more generalized representations tend to be preferred in psychological studies. *Intervallic profiles* (4) provide this generalization. They may either be encoded as such or derived from note-specific data. Direct encoding of intervals inhibits data verification, however.

Recent literature on studies of melodic perception is sometimes vague on the subject of data representation. Rosner and Meyer (1986) used "recordings." Vos and Troost (1989) say their material was played on the organ. Edworthy (1985) and Dowling (1986) used pitch strings (in the latter case a base-12 one), while letter names were used in the reporting phase of Monaghan and Carterette (1985) and Bartlett and Dowling (1988). In one study posing a particularly abstract question (How able are listeners to recognize similar contours with non-similar intervallic sequences?), results are reported in terms of pure-tone frequencies (Carterette, Kohl, and Pitt 1986). Would a different approach yield a different psychological profile, or a more uniform presentation of data lead to more consistent results? Studies in this field remain too rare to predict the answer to this question. In general psychologists focus intense scrutiny on small quantities of musical data, while music scholars may be inclined to survey larger quantities of data more loosely.

Halperin, after directly encoding intervals in a study of troubadour music (1978), developed a simple but foresighted procedure for intervallic comparison in a later study of Ambrosian chant (1986: 32). He first encoded the music on a continuous number-line of semitones representing the gamut (G–c"). The F below *gamma-ut* (the first G of the index) was encoded as a zero, the G as 2, the A above it as 4, and so forth. Then he converted his data to an arbitrary intervallic code suited to sorting: a prime was 0, a minor second was 1, a major second 2, and so forth. Because his original encoding used a number-line, he was able to specify whether each of these intervals was rising or falling. Thus his searches (which ultimately showed different kinds of modal use in diverse elements of the liturgy) preserved directional and intervallic information while his meta-data stayed within the range of signed single-digit integers.

1.2.3 Confounds: Rests, Repeated Notes, and Grace Notes

Three elements of notation can confound both contour and intervallic-profile comparisons. These are rests, repeated notes, and grace notes. Researchers focussed on contours often argue that all three disrupt the "flow" of the line. Contour, after all, conceptually requires a continuous line, but this line is a representation of the melody. In the music itself the disruption may be an intended means of punctuation (rests), accentuation (grace notes), or energy-building (repeated notes).

When pitch is encoded without any reference to duration, rests will normally be absent because effectively they are durations without pitch content.

Repeated notes are more problematical, because the numbers in which they can occur are so variable and because without durational information their importance cannot be evaluated. Thus they are treated in highly diverse ways. LaRue gives 64 as the greatest number of times a single note was repeated consecutively in the symphonic material he listed in the thematic-identifier volume of his catalogue of eighteenth-century symphonies (1988). If we were working with short incipits, the inclusion of such repeats would squeeze out the information that we really want—that which is closest to the prototypical melody. Bryant and Chapman, in creating a melodic index to Haydn's works (1982), give the first four repetitions of a note as separate ciphers but use summary numerical indicators for five and more repetitions (e.g., `C6DEF`).

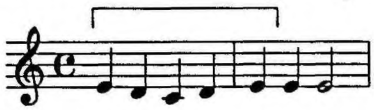
Repeated notes are ignored in Lincoln's meta-data (1988; 1993), which is sorted by intervallic size and direction based on the first nine discrete pitches. Durations, although undoubtedly included in the original *DARMS* code and although obviously necessary for printing, were excluded from the indexes in his two important finding aids (each based on several tens of thousands of incipits). When the intervallic index of the madrigal volumes was used to seek matches to unattributed works, the absence of repeated notes proved to have an insidious effect (Selfridge-Field, 1990).

Grace notes are infinitely problematical, since their interpretation has varied over time while their notation has remained fixed. The grace notes in Figure 12b (above) might legitimately be considered extraneous to the "theme" but the one in Figure 13 is essential to the melody. Bryant and Chapman represent incipits containing grace notes twice, in order not to guess which way a user will search for it, whereas La Rue gives grace notes full weight. A listener remembering a theme is unlikely to know whether any of the notes might have been notated as grace notes, and thus would expect to find the pitch included in a finding tool. When grace notes were included in RISM experiments in searching [see Howard], fewer events were required to produce discrete sorts, suggesting that although we may consider them parenthetical in Figure 12b, grace notes are an essential part of the melody. There may be a historical confound here, however, since RISM concentrates on works composed between roughly 1600 and 1825 (better typified in Figure 13); Dvořák's Slavonic Dances, in which the grace notes contribute to accentuation more than to melodic substance, are from 1878.

1.3 Searchable Representations of Duration and Accent

That few of the studies thus far cited take any durational or accentual information into account results partly from practical considerations. Several databases that are now large were designed two or three decades ago. When computer memory was scarce, optimal design favored concise representations. Also, multi-dimensional searches are necessarily more complex than one-dimensional ones, so programming and debugging time are significantly greater. Yet a tendency to dismiss durational information as being "not strictly necessary" for melodic enquiries seems often to stem from the belief that melody can be defined entirely by pitch-events or by other information that can be extrapolated from pitch information. Apparently we are more conscious of pitch change than of duration or accentual features of melodies in performance. Certainly pitch control requires more conscious effort by vocalists and instrumentalists than does the control of rhythm or stress.

Dorothy Gross (1975) was among the first computer researchers to observe that a pitch-string is not the equivalent of a melody. Recent studies in musical perception suggest that durational values may outweigh pitch values in facilitating melodic recognition. No one would maintain that the three themes shown in Figure 15, with pitch-content matching the (transposed) pitch-string EDCDE, as in the children's song "Mary Had a Little Lamb,"



are qualitatively the same.

Figures 15a–c. "Themes" from (a) Bruckner's Symphony No. 7, Movement 3; (b) Mozart's String Quartet in D, K. 575, Movement 3; and (c) Schubert's Overture to *Rosamunde.*

General theories of rhythm have attracted some interest in recent years, but given their long history (stretching back to antiquity), it may be a fair summary to say that rhythmic patterns have been far more stable in Western culture than have pitch patterns. Therefore there may be less need to develop theories of rhythm. No general theory of rhythm has been rigorously tested in analytical applications. Tangian's proposal for a binary classification of rhythmic patterns (1992) is indicative of approaches that may be testable. Craig Sapp (1998, unpublished research) has recently implemented some elements of Swain's theory of harmonic rhythm (1998), which is eminently well suited to computer implementation, as *Humdrum* tools.

One highly systematic approach to the concurrent representation of rhythmic and accentual patterns is the one appearing in Moritz Hauptmann's study of harmony and meter (1853; reprinted 1991). Note the binomial method for specifying rhythmic patterns in Figure 16.

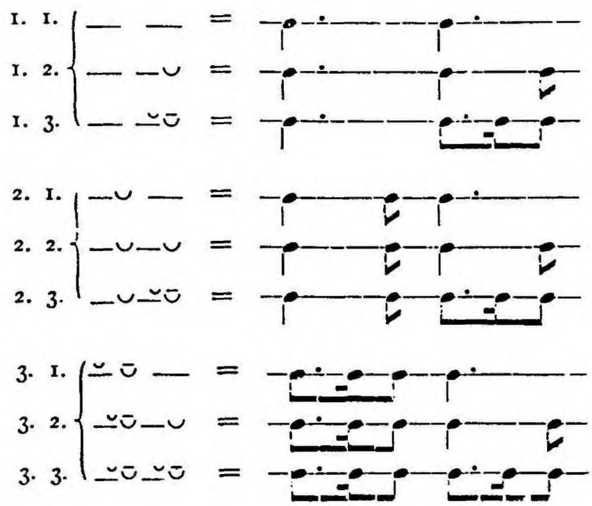


Figure 16. Excerpt from Moritz Hauptmann's system [1853] for distinguishing rhythmic patterns in 6/8 meter.

For practical purposes, the provisions of such comprehensive encoding schemes as *DARMS, SCORE, Kern* (for the *Humdrum Toolkit*), *MuseData,* and *Plaine and Easie Code* (used by RISM) are fully functional. Among these, *SCORE* is noteworthy for sequestering all durational information in a separate string. *Humdrum* is notable for accepting encodings that may consist only of durational information; syntax checkers for other systems will ordinarily object to the lack of concurrent pitch information.

Accentuation is especially pertinent to the study of folk repertories, and in general ethnomusicologists seem to have devoted more thought to the matter of comparing stress patterns than have musicologists. In studies of American folk-tune repertories, for example, Bevil (1988, 1992A, 1992B) encoded indicators for stress together with those for pitch and duration (in what appear to be separate digits of a single integer). This facilitated searches for particular combinations of pitch and duration, pitch and stress, and duration and stress. From these measures multiple viewpoints on the same thematic material could be obtained. His software also overlaid images of closely related variants (Figure 17, showing Bevil 1988: 119).

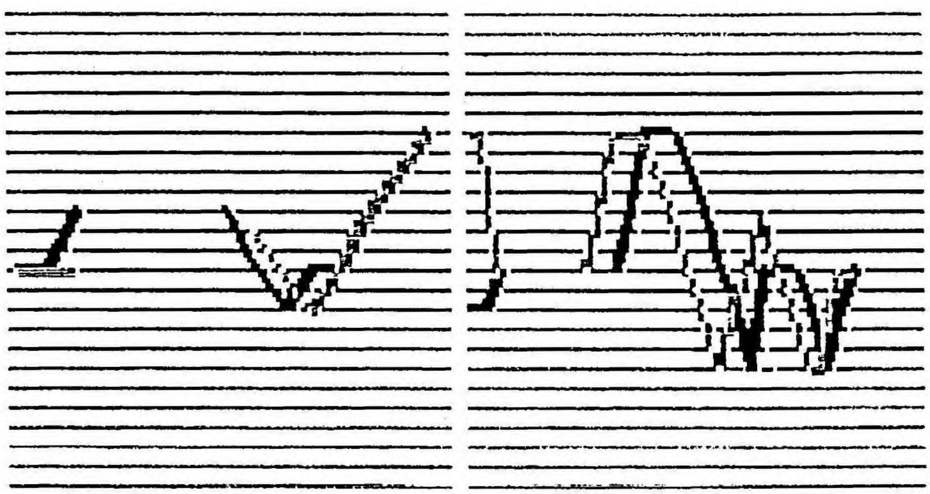


Figure 17. J. Marshall Bevil's computer overlay of melodic variants of an Appalachian folksong.

There are several fairly simple ways of including brief information about duration, accentuation, or phrase structure in databases consisting principally of pitch information. Gustafson's thematic locator for the works of Lully (1989) uses a blank space to represent a barline in a base-7 representation of pitches. The incipits are separated by mode (major or minor), and each one includes a field for meter and key. The number of items within the bar gives some idea of the kinds of durations included. Some examples in the minor mode are shown in Figure 18.

```
1 13 2377167                    3    g
1 132 1765 4325                 2    g
1 1321 17123421722 511          2    e
```

Figure 18. Use of a blank space to separate measures in Gustafson's thematic locator for the works of Lully.

A similar use of barline divisions is employed in Temperley's *Hymn Tune Index* (see *hti.music.uiuc.edu/introduction.htm*).

The Essen databases not only use a blank space to encode barlines but also give a visual representation of duration with underline characters and mark phrase endings with a hard return (Figures 19a–b). Here too a base-7 octave is used to represent pitch.

```
-5 1_.231 -5_.-3-4-5 -6_.-71-6 -5_-4_ [Hard Return]
-3_ -4_-6_-5-4 -3-51_3_ 321_-7_ 1__ [Hard Return]
```

Figure 19. (a) Beginning of an *EsAC* encoding of the German folksong "Der Mai tritt ein mit Freuden" and (b) the corresponding music.

The Essen analysis tools, designed by Barbara Jesser (1991) with contributions by other Schaffrath pupils, used data in this format to derive profiles of pitches on the first beat of each measure (i.e., the most heavily accented notes), of rhythmic features, and of song structure. Although in the initial output, the accented notes were extracted with their original values, in later processing they were regularized (Figure 20a) to facilitate the printing of a melodic spine (Figure 20b).

(a) `1_.-5_.-6_.-5_.-4_.-3_.3_.1_.`

(b)

Figure 20. (a) Extracted melodic-spine information for the music shown in Figure 19 and (b) its musical realization.

Although, apart from the Essen databases, it is unusual to encode phrase information, its presence can be critical for certain kinds of "melodic" searches. In Brinkman's study of the reuse of chorale tunes in Bach's *Orgelbüchlein* (1986; thesis submitted in 1978), it was postulated that from any given sequence of pitches constituting a phrase in a chorale, a series of "patterns" of progressively fewer pitches could be culled. Great care was taken not to store patterns that crossed phrase boundaries in the look-up lexicon of pitch-strings, but the search algorithm (as judged from the output) seemed to be indifferent to phrase boundaries when producing "matches" (Selfridge-Field, 1993).

1.4 Strategies for Multi-Dimensional Data Comparison

We have already seen several prototypes for two-dimensional searches, but so far they have not concentrated on a parallel traversal of information representing pitch and duration. Many strategies for doing this have been tried, but none have been generally adopted.

1.4.1 The Kernel-Filling Model

Concurrent representations of pitch and duration data may pair diverse levels of generality and specificity in an asymmetric way. In studies aimed at discovering unwritten rules of melodic construction in detail sufficient to generate new melodies of the same kinds, Mario Baroni and his collaborators have concentrated on "melodic symmetries [which] take into account pitch contours [and] metrical patterns" (1990: 211). The repertories they have explored include German chorale tunes, eighteenth-century French chansons, and seventeenth-century Italian cantatas.

In Baroni's work, the melody is seen to evolve from a *kernel* that consists of the outer notes of a phrase. The intervening notes, which give the melody its contour and character, are seen to "fill" a space created by these poles. The apparent resemblance of this approach to Leonard Meyer's theory of gap-fill (1956) is superficial, since Meyer enlists elements of harmony and rhythm in his argument and gives much greater emphasis to contour. By its nature, Baroni's approach tolerates approximation in the representation of pitch. The study of chanson melodies (1990) determined that "there are no cases of phrases having the same melodic [=pitch] contour but a different metrical structure." Would a more precise system of pitch representation (from which a larger roster of "contours" could be derived) produce different results? At present there is no evidence one way or the other.

To create new melodies in the style of the model thus derived, Baroni first generates a rhythmic profile. Pitches are then poured into this profile. Some resulting chorale melodies (from Baroni and Jacoboni 1978: 146f.) are shown in Figure 21. The "kernel" in 21a is a descending third, while that of 21b is an ascending fourth. (In this base-7 system any clef could display the results.)

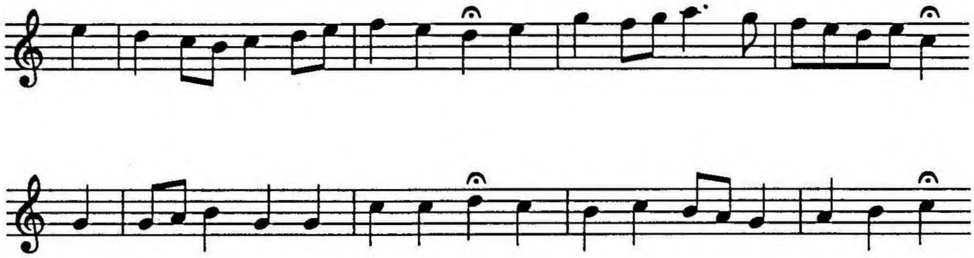


Figure 21a–b. Two chorale melodies generated by Baroni and Jacoboni.

1.4.2 Accented-Note Models

In an effort to create meta-information commensurate with that of melodic intervals, the Russian mathematician Zarhipov (1965) proposed the use of profiles of stress change as one of three tiers of information available for melodic analysis (see Bakhmutova 1989). Zarhipov's four-tier scheme of melodic representation is illustrated in Figure 22. The tiers are:

(1) ordinal numbers representing successive events,

(2) melodic intervals, indicated diatonically at the intermediate positions,

(3) ordinal numbers representing the positions within the bar at which these tones are struck, and

(4) rhythmic transitions, coincident with (2), represented by a plus sign (+) when moving from a stronger to a weaker position and by a minus sign (−) in the opposite case.


```
(a)  1   2   3   4   5   6   7   8   9   10
(b)    1   1   2-  2   0   1-  1-  1   4-
(c)  1   4   1   4   1   2   3   4   1   3
(d)    +   -   +   -   +   -   +   -   +
```

Figure 22. Zarhipov's four-tier system for representing (a) event numbers, (b) intervallic change, (c) beats on which events occur, and (d) durational change.

Abstractions (2) and (4) can be collapsed into a single line in which the first operator following a numeral indicates melodic direction and the second indicates stress change, e.g., `1++1+-2-+2+-0++1--1-+1+-4-+`. Zarhipov's system is noteworthy for its combination of explicit and implicit information, for its effort to coordinate several strings of data at the same time, and for its model of collapsing multiple variables into a single string for easier processing.

Another approach to the coordination of elements representing both the pitch and duration domains is offered by the music psychologist Mari Riess Jones (1993). She differentiates between two kinds of pitch accents, *melodic-contour accents* and *melodic-interval accents,* and also between two kinds of implications of duration, which correspond to the literary concepts (traceable to antiquity) of qualitative and quantitative accents. She calls these *strong-beat accents* and *elongational accents.* From these she contemplates the possibility of investigating *joint-accent* structure and *temporal phrasing*. Joint-accent structure codes give a composite view of the amount of activity collected from earlier profiles, giving one stroke each for a "filled" beat, a "melodic" (i.e., pitch) accent, and a temporal accent (Figure 23). Jones's collective structures are conceptually similar to Lerdahl and Jackendoff's representation of metrical structure (1983: Chapter 4) in "time-span reductions."

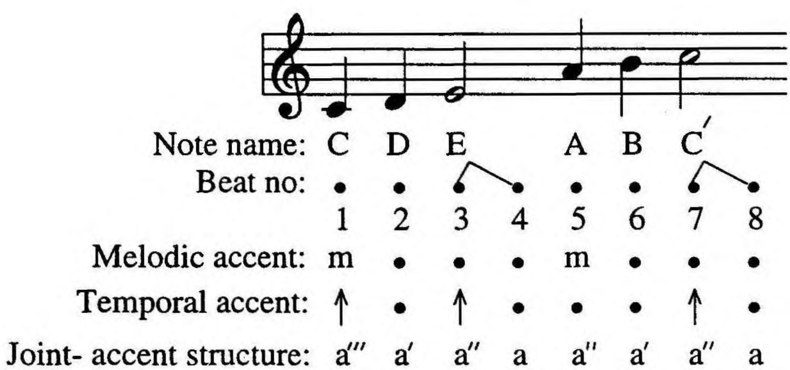


Figure 23. Jones's concepts of melodic accent (derived from pitch contour), temporal accent (derived from beat structure), and joint-accent structure (cumulative).

Where the notion of a "pattern" includes information thus derived, she proposes to investigate both *dynamic-pattern similarity* and *dynamic-pattern simplicity*. Although Jones gives only a few examples and modest statistics, her notions may be of potential value in music-theoretic endeavors involving computer processing.

1.4.3 Coupling Procedures

Because of the possibility that two-dimensional searches can process both absolute (e.g., pitch) and relative (e.g., intervallic) information concurrently, there is some potential for a warping effect to occur in the combination. This is particularly the case if one of the data variables represents elapsed time, as it does in the work of Suk Won Yi on similarity. Because data describing intervals (relative information) is combined with data describing duration (absolute information) in a composite measure, it is unclear whether the assumed coordinates are vertically aligned in the most advantageous way.

The "warp" comes about in the following way. In a sounding melody, pitch lingers for the duration of the event. When the music is to be represented for processing, the pitch can be determined at the onset of the event, while the duration must be computed at its termination. A melodic interval cannot be computed until the next pitch is sounded, and so there is a continual zigzag in the data-collection path (see Figure 24).

1.4.4 Synthetic Data-Models

Another approach to coordinated comparisons of pitch and duration data is to synthesize elements from each domain in modules of "complete" melodic information. This reduces the number of symbols that must be manipulated, thereby simplifying (but also in some cases restricting) the search. Arthur Wenk designed such a system for his work on Debussy (1988): recurrent rhythmic patterns assumed a single code which was linked with a series of pitch names suited to the pattern. Balaban has written extensively about synthetic schemes of representation and manipulation, but usually from the standpoint of investigating structural issues (for a list of her writings, see Balaban 1992).

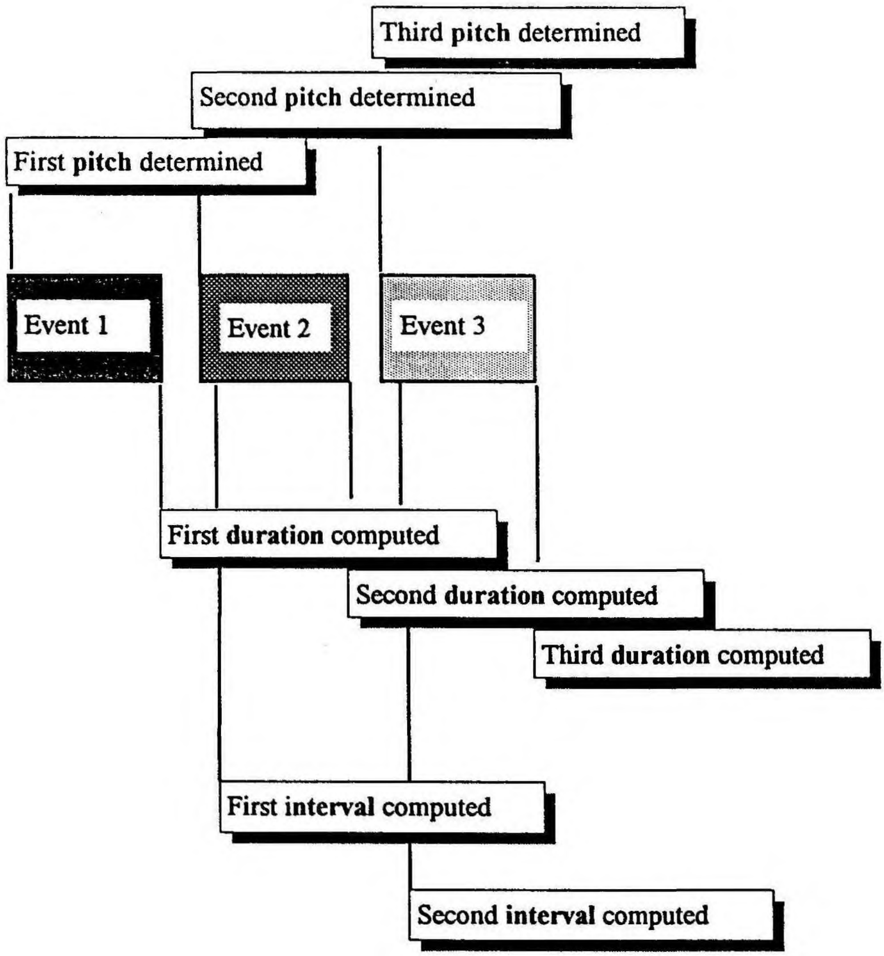


Figure 24. A time-ordered schematic view of the collection points for pitch, duration, and intervallic data.

A more elaborate, in fact quite elegant mathematical procedure was devised by Wolfram Steinbeck, an early pupil of Helmut Schaffrath and an encoder of several thousand folksongs in the Essen databases, to synthesize information about stress, pitch, and duration into one integer (1982: 48–49).

With his terms translated into English, Steinbeck's formula worked as follows: Where S = score, B = beat position, P = pitch, D = duration, and N = the number of digits in the duration specification,

$$S = ((B \times 100) + P) \times 10^{N} + D$$

In his system, the code for a half note is 8 and the code for E4 is 45 (Steinbeck uses a base-19 system of pitch representation; it excludes F♭ and B♯). Where the beat position is 4 and N = 1,

$$S = ((4 \times 100) + 45) \times 10^{1} + 8$$
$$S = (445 \times 10) + 8$$
$$S = 4458$$

If the same note were on the first beat (B = 1), the composite score would be 1458. In the original example, if the pitch-code (P) were 60 (C♯3), the composite score would be 4608. This composite numeral (Figure 25) is parsable and easily comprehensible:

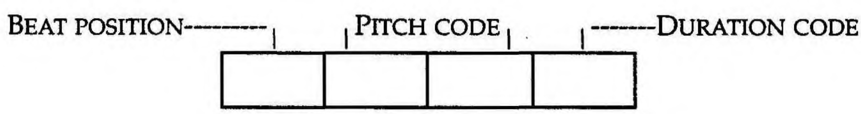


Figure 25. Wolfram Steinbeck's composite four-digit representation of beat position, pitch, and duration.

Steinbeck's intention was to simplify the task of recognizing similarity in pairs of melodies similar to those shown in the discussion of Leppig's work (below).

In his study of bebop melodies, J. Kent Williams (1985: 60) assessed the frequency of a series of pitch-direction profiles (UU, RR, etc.) in conjunction with a list of thirteen composite rhythmic figures. To produce the rhythmic-figure dimension of this array, Williams collapsed another two-dimensional array coupling four first-note/last-note accentual cases (strong-strong, strong-anticipated, anticipated-strong, or anticipated-anticipated) with specific rhythmic patterns. This first-order array is shown in Figure 26.

Figure 26. J. Kent Williams's scheme for coupling accentual relationships of first and last notes of a pattern with specific rhythmic formulae. This look-up array feeds composite results (e.g., 5SS, for Group 5, strong-strong) to a second array with directional profiles of pitch (e.g., UU, DR).

The basic approach of using streams of arrays suggests various other procedures for relating elements of information about pitch and duration. The pitch-axis of a subsequent array could contain information about direction (as it does here) or contour, about diatonic or enharmonic pitch-string categories, and so forth. The rhythm-axis could convey information about duration or stress, or about some hierarchical scale of events or combinations of events. Williams's choice was to couple fairly general information on pitch direction with more precise information about rhythmic figures. He also examined the Baroni-Jacoboni concept of the *kernel*, which he terms a *cumulative interval*.

A third approach to synthesizing information about pitch and rhythm is provided by Suk Won Yi (1990). Starting from an orientation influenced by semiotics, linguistics, and studies in perception, he creates statistical measures of "melodic activity" as an aid to comparing melodic contours in selected Schubert and Schumann *Lieder*. Eight measurements are used. The first (intervallic change), the second (duration), and last (a *coefficient of melodic activity*) for the first ten events of Mozart's G-Minor Symphony (K. 550) are represented by Yi in a vertically organized table (Figure 27), which is rotated for presentation here.

Interval	-1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	8.00	0.00
Duration	0.25	0.25	0.50	0.25	0.25	0.50	0.25	0.25	0.50	1.00
Coefficient of Melodic Activity	2.61	1.91	1.91	2.61	1.91	1.91	2.61	1.91	3.48	0.53

Figure 27. Synthesis by Yi of intervallic and durational data to produce a "coefficient of melodic activity."

Yi (1990: 52) is eager to get at the problem of a truly melodic contour as opposed to a mere contour of pitches. Being sensitive to the emphasis of perceptual studies, he has chosen to couple intervallic data with durational data. Intervals are computed from a semitone representation converted to a decimal format (as is duration) for processing. To the traditional analyst of music this may seem to be an orthogonal coupling, since the size of, let us say, the first interval of a work can only be established slightly after the second duration begins (Figure 24). The consequence of this implied diagonal coupling is that inter-domain pattern relationships may be less evident in the statistical result than in another format. In Figure 27, the coupling of pitches rather than intervals with durations would have preserved an indication of the third iteration of the three-note pattern in the ninth coefficient.

The problematic element here is the rest in Bar 3 (Figure 27), which completes the ninth "interval." After changing the last number for duration to reflect the actual note value (Yi seems to have elongated the value of the high B♭ by that of the rest [event #11, if the first two rests are ignored] in order to produce his `1.0` for the duration in the tenth cell), we find that an overlapping set of patterns has emerged. In each three-event group, repetition of a duration regularly introduces repetition of a pitch. Viewed conversely, a decrease in pitch prompts an increase in duration.

If Yi had coordinated pitch information with rhythmic information, his results for the above example would resemble those in Figure 28 and the third iteration of the pattern would be evident.

Pitch	9	8	8	9	8	8	9	8	8	16
Duration	.25	.25	.5	.25	.25	.5	.25	.25	.5	.5

Figure 28. A revision of Yi's data, substituting pitch for intervallic data in order to produce a clearer sense of overlapping patterns.

This attempt to make cognitive and perceptual principles the basis for melodic analysis inadvertently poses an array of important questions for logical approaches to melodic analysis. It points out that paradoxes inhere in our basic definitions of pitch and duration. The concept of pitch without duration is as meaningless for music as the concept of duration without pitch. We discuss these parameters as though they were entirely separable, but at some cosmological level, they are not. The idea of coupling pitch with duration also implies an orthogonal coupling; it simply has a different slant from the coupling of intervallic data with pitch data (see Figure 24).

Yi himself calls attention to another difficulty inherent in composite statistics, one that Crerar (1985) called "statistical mush": once multiple threads of information are reduced to a single measure (here of melodic activity for each "event"), it is no longer possible to know whether the identical results (here coefficients) express a high score for melody combined with a low one for duration, the reverse, or equal measures for both. Thus, measures in which pitch and durational information (or their substitutes) are synthesized in a single figure have some limitations in helping us answer musical questions about music.

1.4.5 Parallel-Processing Models

If synthetic data and composite results are not an ultimate answer, what procedures exist for managing multiple data streams in an uncoupled way? The German mathematician Manfred Leppig (1987) has proposed some simple routines for similarity searches in which perceptually correct results might be impeded by contextual differences or surface details. For example, to find parallel passages obscured by variant meters, such as those shown in Figures 29a and b,

Figures 29. (a) The French folksong "Ah, vous dirai-je, maman" and (b) the German folksong "Alle Vögel sind schon da."

Leppig's procedure involves (1) the assignment of diatonic numbers to map pitch and arbitrary integers to identify durations, (2) the comparison of pitch-strings, and (3) the computation of item-by-item differences, with the aim of establishing the total number of matching tones. A comparison of the above examples would yield the series of differences shown in Figure 29c:

1:	1	3	5	8	6	86	5	4	5	3	1	2	1
2:	1	1	5	5	6	6	5	4	4	3	3	223	1
D:	0	2	0	3	0	2	0	0	1	0	-2	0	0

Figure 29c. Pitch-strings for the melodies shown in Figures 29a and b. Numerical differences (D) are given in Row 3.

Then (4) by various sliding routines (both horizontal sliding, to offset differences in starting position, and vertical sliding, to capture ephemeral transpositions), nearly corresponding passages can be identified by the large number of zeroes their comparison generates.

In comparing durations Leppig only computes hits (*) and misses (–). See Figure 30. This procedure can also be substituted for the more articulate pitch-comparison shown in Figure 29c.

Pitch comparison:	*	–	*	–	*	–	*	*	–	*	–	*	*
Duration comparison:	–	–	*	*	*	–	*	–	–	*	*	–	*

Figure 30. Comparison of pitch and duration streams as hits (*) or misses (–).

Scores can be produced by converting hits and misses to percentages of events. What this particular result reveals is a similarity in the pitch-content of accented tones. We would not cognitively consider "Ah, vous dirai-je maman" and "Alle Vögel sind schon da" to be "similar" melodies. The purpose of the discovery here is to reveal structural similarities that defy perception. Leppig's explorations, which were based on the use of the Essen databases, show the rich potential that exists in some fairly simple approaches to comparison. At the same time, they support the goal of accountability for both pitch-data and duration-data.

1.5 Prototypes, Reductions, and Similarity Searches

Are reductions prototypes? If we look again at Figure 20b in relation to Figure 19b, we see that the spine (20b) hardly gives the flavor of the original (19b). In the reduction, the upbeat is absent and the octave leap is distracting, for despite its lowly beat position, it is somehow the a' in Bar 6 that seems to be centrally important, as it completes the triadic flourish created by the preceding eighth notes. Computers can produce simple reductions, like 20b, with the greatest of ease. Prototypes that are not monorhythmic are much more difficult to derive.

We can explore this lapse in a more elaborate context by reconsidering Mozart's Piano Sonata K. 311 (see Figures 3a–e). Reductions offer a tempting solution to fuzzy matching because they suppress the differences of surface detail. But do they suppress the most appropriate surface details? In a search for the prototypical theme (conjecturally Figure 3f), we find that no simply-implemented reductive method produces it.

Nine reductions (Figures 31a–i) are easily derived:

(1) A pitch-string representation of each example, e.g.,

```
3 4 3 2 3 4 5 4 3 2 1
```

would readily separate 3d, because of its chromatic notes, from the others. If ties were suppressed, it would recognize 1a and 1e as being the same through the first nine pitches. It would recognize 1c and 1d as identical through the first ten pitches. The length of the string on which the comparison is run would obviously influence the results of the search.

(2) A duration profile of each example would pair 3a with 3b as

```
E S. T E E / E S S E E
```

(where E = eighth, etc.) and would indicate 3c, 3d, and 3e to be different from each other.

(3) An accented-note profile capturing the pitch on each quarter-note beat would render two results—one for 3a through 3d (Figure 31a) and one for 3e (Figure 31b).

(4) An accented-note profile capturing the pitch on each eighth-note beat would differentiate four sets—3a, 3b/c, 3d, and 3e (Figures 31c–f).

(5) A more rhythmically varied profile could be created by capturing only the notes that are emphasized by harmonic change in the full context. Three harmonic-reinforcement profiles (Figures 31g–i) could thus be created. These would represent the sets 3a, 3b–d, and 3e.

Figures 31a–i. Nine reductions of the melodic material in Figures 3a–3.

In order to derive these profiles, a program would need to be able to determine from other voices of the work which parts are so reinforced. Thus information solely from within a melody may be insufficient to support this kind of "melodic" search. The results of procedures (1) through (5) are summarized in Figure 32.

Presentation	Reduction to quarter-note values	Reduction to eighth-note values	Reduction determined by harmonic reinforcement	Prototype common to iterations a–e
3a	31a	31c	31g	3f
3b	31a	31d	31h	3f
3c	31a	31d	31h	3f
3d	31a	31e	31h	3f
3e	31b	31f	31i	3f

Figure 32. Summary of reductionist procedures, results, and passages to which they are applicable.

Note that none of these procedures produces the melodic prototype shown in Figure 3f.

If we further examine the music in its full context, we find that there is an important melodic/harmonic implication that cannot be derived by any of the above means. This is that the C that falls on the second beat of the second bar is an appoggiatura, which causes all of the above reductions to fail to select the implied (that is, harmonically congruent) B in this position. The B is required to produce the prototypical melody

That Mozart avoids ever placing this note squarely on the beat may tell us something important about his style and about the difficulty of finding formulae to compensate for the melodic, harmonic, and rhythmic displacements caused by *appoggiature*.

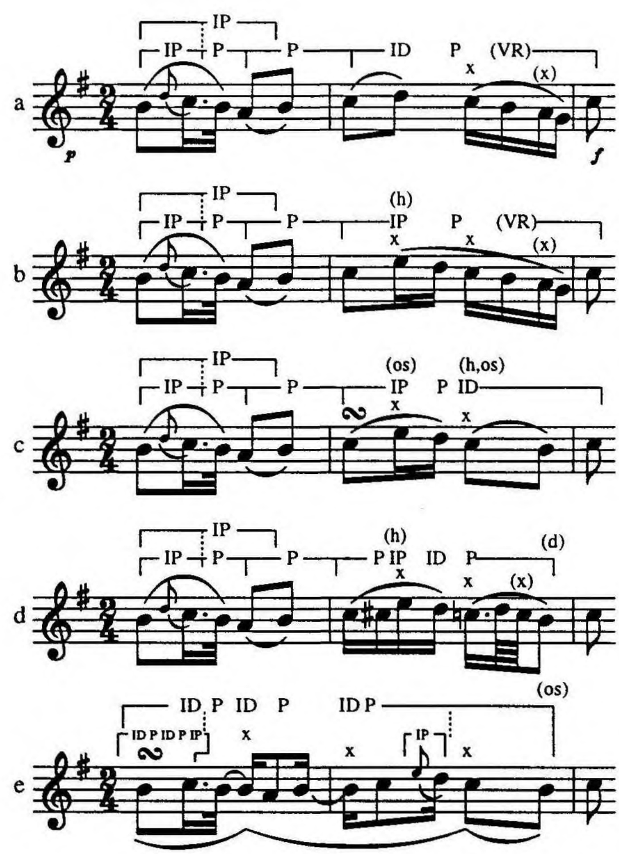
To overcome the problem posed by Figure 3 it would be necessary to design a procedure permitting not only mixed durations but also rhythmic alterations and/or pitch substitutions for the purpose of facilitating the creation of a provisionally prototypical model. The result would have a vague resemblance to an added treble in fifth-species counterpoint. Williams approached this strategy when he employed a rhythmic-regularization procedure to facilitate the analysis of jazz melodies. In his data, syncopation was "usually effected by shifting notes slightly backward with respect to the metrical grid so that they anticipate the beat," and in his analysis, "unsyncopation . . . shift[ed] the attack-point . . . ahead to make melody congruent with harmony." Williams also removed "jazz turns" [inverted mordents], which usually begin on a strong beat, to facilitate melodic comparison (1985: 45).

Since a growing proportion of recent writings on melody have been stimulated by the works of Narmour (1990, 1992), it seemed appropriate to solicit his views on this example. The first iteration (Figure 3a) is in fact included in Narmour (1992: 219), in a discussion of "missing structural tones" under the general subject of "melodic chaining." Because Narmour's response was substantial and earnest, it is useful to quote it here together with an accompanying set of examples (Figure 33).

In brief, Narmour's interest is in describing various combinations of intervals and durations in incremental three-pitch contexts. Therefore it is combinatorially more complex than other systems discussed here. The system is hierarchical, admitting harmonic information at higher levels, looks both forward and backward, observes direction, and classifies intervallic sizes in precisely defined clusters (e.g., "a fifth or greater"). In Figure 33, brackets mark melodic segments. Letters and letter combinations classify pitch sequences with regard to (a) the size and (b) the direction of the interval, as well as whether (c) the intervallic movement and (d) the directional relationship satisfy or deny principles of "implication-realization" (I-R). IP, for example, is an *intervallic process* which satisfies expectations of intervallic behavior but denies registral implications. D indicates a duplicate (i.e., a repeated note). A change of direction is a "reversal" (R). A VP (registral process) satisfies a registral implication but denies an intervallic one, and so forth.

Narmour (personal correspondence, 13 May 1992) writes of K. 311,

> The theoretical symbols [used in the implication-realization model] capture very well the similarities and differences between the variations (chiefly in their second measures). For instance, P(VR) appears in a structural chain in measure 2 in Figures 3a and 3b; an IPP begins in measure 2 of both examples 3b and 3c; PIDP appears at the end (measure 2) in both examples 3d and 3e. Note that according to the implication-realization model, in the first three versions (a, b, c) the tone B does *not*



Figures 33a–e. Eugene Narmour's reworking of Figures 3a–e in accordance with the implication-realization model.

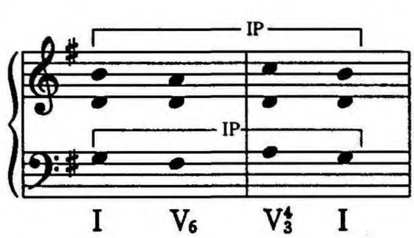


Figure 33f. Narmour's harmonic reduction of 3f.

transform to a higher level because, though a resolution of dissonance, it is metrically weak; thus I disagree that this B is a "dominating tone" in the second half of the second bar.

Observe significantly, however, that this B *does* become transformationally structural (and "dominating") in Figure 3d. This would also stylistically influence the immediate repeat of the pattern in Figure 3e. In other words, Mozart deforms the schema (or prototype) during the first three appearances of the melody, allowing it to merge fully only toward the end of the piece. Whether it is a common compositional strategy of his style needs to be investigated, as you say.

As regards the style schema on which this passage is based, I would have said the melody was a simple changing-tone one (a single `IP` in my terms), which I have shown in the schema on my manuscript sheet [Figure 33]. Thus to treat your question about whether the `I-R` model would generate your prototype (Figure 3e), the answer is no because your reduction mixes both quarter-note and eighth-note levels, which the `I-R` model generally disallows (unless chaining or combining occur).

This prompts the thought that the reductions best suited to melodic searching and comparison may not be as concise as those used by the `I-R` model, which was developed for analytical purposes. Consider some possible reductions of the well-known Bach minuet shown in Figure 34. Figure 34b is a reduction of the melody (34a) that almost aspires to reductive logic of a compound melody (cf. Figure 2a). Once we have heard 34b, however, we may well ask why the "distracting" surface detail should be retained in the odd-numbered bars. Bar 1 cannot be reduced to quarter-note values, because the changing tone (A) on beat 2, if selected as a surrogate pitch for the beat in a prototypical melody, would give a misleading sense of the harmony outlined in the bar (D minor instead of B♭ major). Thus we arrive at 34c, where the bar-by-bar accentual quality of the reduction in 34b is retained, but the details are reversed: there is more activity in the even-numbered bars. Figure 34d, analogous to a simple *Urlinie* (in the vocabulary of Heinrich Schenker), does not have nearly as much character as a "melody" as 34b or 34c, with their mixed durations.

Or consider the C♯-Major Prelude in Book I of Bach's *Well-Tempered Clavier* (Figure 35). It too is reducible to a one-note-per-measure format. An intermediate reduction with mixed durations could retain a sense of identity that is missing from the mere set of parallel tenths that could result. Yet it could not be derived simply by further reduction of the right-hand "melody,"

Figures 34a–d. (a) The Minuet I in $B^{\flat}$ Major from the First Partita and (b–d) three possible reductions of it.

since some of the tones of intermediate significance are marked accentually in the left-hand accompaniment. Here the issue hinges on the question of which notes should be repeated (for there are no novel pitches to flesh out an intermediate reduction). A regular quarter-eighth pattern captures the rhythmic sense conveyed by the left-hand part, but if one took literally only those notes repeated in the right-hand part, the result would be more erratic. Some method for admitting repeated notes is as essential here as it is in searches, even those based on "contours."

Figure 35. The opening bars of Bach's Prelude in $C^{\sharp}$ Major from Book I of the *Well-Tempered Clavier.*

How much reduction is enough? Enough, that is, to facilitate computer recognition of cognitively recognizable "matches." How much is too much? Too much, that is, for the retention of some semblance of musical coherence. The answers will vary with the goals of the query and with the repertory at hand. This necessarily complicates the prospects for the derivation of algorithms that identify melodic prototypes. Conversely, prototypes may have only a general identity not susceptible to explicit translation in every case. That is why they are potentially so valuable. Melodic prototypes are cognitive entities, while reductions are derived from the music itself. In the process of searching for melodic matches, we are frequently trying to match mind with matter.

1.6 Conclusions

There are many approaches to melodic study that have not been broached here. We have not considered Renaissance diminution techniques, Baroque *Figuren* (and their rhetorical implications) or improvisational formulae, variation techniques of the eighteenth and nineteenth centuries, modular approaches to the "musical grammar" of song repertories, nor features of self-similarity in the construction of melodies. We have not taken account of many recent analytical procedures involving grouping structures or sophisticated reduction techniques. These are all important components of the larger study of melodic process but computer applications at this juncture need to solidify their position in simpler domains before putting elaborate models into practice.

We have made an effort to look at the ways in which melody is conceived and represented in various domains of music scholarship. Differences of objective certainly dictate divergent emphases. It appears, however, that if we were to generalize across these subdisciplines, we would agree that the most successful efforts involving computer searching to date have been those that manipulate more than one variable. That is, a coordinated search of any two streams of information, however general, seems to yield a more refined result than any one parameter, however specific. Even when both parameters come from the same domain (e.g., direction and contour from the pitch domain), rather than from an equilateral pairing (pitch interval and stress interval), the results seem to be improved.

What users most seem to need is multiple options, in order to suit highly divergent goals. In this respect, our dedicatee, the late Prof. Dr. Helmut Schaffrath, together with his pupils and colleagues, set a sterling example. In their collective effort, they have permitted us to extract and compare pitches or intervals, durations, indexes of the tones actually used (in contrast to one-octave scales), cadence tones, accented tones, "form" as dictated by pitch profiles, "form" as dictated by duration profiles, and contour information. These capabilities can be used to compare two items or to analyze entire repertories. Admittedly, these capabilities all rest on an encoding system designed for monophonic music, but melodic searching is by nature a monophonic exercise and most search data currently available for analysis is monophonic.

We need to approach enquiries into melodic similarity with flexibility, with respect for the underlying complexity of the largely unconscious procedures that produce melodies, and with gratitude to those who have had the boldness to tackle the conceptual problems that inhere in the subject. This article shifts back and forth between conceptual and representational issues precisely because in computer applications the two are intertwined. Neither a naive idea implemented in a sophisticated way nor a sophisticated idea filtered through a crude implementation will get us very far. We need to examine clearly articulated concepts of melody in relation to their suitability for processing, but we almost certainly need more theoretical literature on the subject of melody as well as more interdisciplinary discussions of approaches. The computer adds one more level of complexity to an already challenging mass of substance, but it also creates common interests and new opportunities for understanding in an otherwise disparate array of pursuits.

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