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Generative Rules for Music Performance: A Formal Description of a Rule System

This is a detailed technical presentation of performance rules resulting from a project in which music performance has been analyzed by means of an analysis-by-synthesis procedure (Sundberg et al. 1983). The rules have been developed in cooperation with Johan Sundberg and Lars Frydén. Lars Frydén is the musical expert, Johan Sundberg has contributed mostly to the cognitive aspects and, in an early stage of the project, to programming, and the author has been responsible for the organization and formulation of the final programming. The project has been extensively described and discussed in previous articles (see References).

The purpose of the rules is to convert the written score, complemented with chord symbols and phrase markers, to a musically–acceptable performance. They are currently implemented in the programming language Lisp on a Macintosh computer (Friberg and Sundberg 1986) and the software is available on request.

The rules operate on the parameters listed in Table 1. Two different tone articulation models are used. The first model uses only off-time duration (DRO), as defined in Fig. 1. The second model is more complete and uses a four-point envelope (T_1–T_4 and L_1–L_4) to shape each tone individually (see Fig. 16).

Whenever possible, the resulting deviations from the rules are additive. This means that each tone may be processed by several rules, and the deviations made from each rule will be added successively to the parameters of that tone. The order in which the rules are applied is in general not critical except for the synchronization rules and the amplitude envelope rules which have to be applied last. The mixed intonation rule must also be applied after all other intonation rules.

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The sound parameters that are manipulated by the rules are listed in Table 1. For technical reasons, the rules will be presented in this article in an order based on the resulting parameter changes. There are five groups of rules: (1) single parameter rules, (2) multiple parameter rules, (3) intonation rules, (4) amplitude envelope rules, and (5) synchronization rules. In Table 2, the rules have been sorted after their apparent musical purpose (Sundberg et al. 1991). Table 2 also lists the rule names.

Most of the rules include the quantity parameter k. This parameter is used to alter the quantity of the manipulation induced by the rule; it should always have one and the same value within each rule. The default value is $k = 1$. This value is appropriate when all rules are applied. When a rule is used in isolation, slightly higher settings of k can be necessary to produce audible changes. In some cases the best result for a piece of music is obtained when k for each rule is adjusted individually. Different settings of k can also be used to generate different performances for the same melody.

Single Parameter Rules

Rule DPC 1B. High Loud

The sound level of tones is raised by 3 dB/octave:

$$\Delta L = \frac{N - 60}{4} \cdot k \qquad [\mathrm{dB}]$$

N is the semitone number with $N = 60$ for note C_4.

Rule DDC 2B. Double Duration

A tone of duration shorter than 1 sec and half as long as the preceding tone is increased by 12 per-

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Table 1. Sound parameters that are altered by the rules and symbols used in the text

DR	Total duration of one tone, see Fig. 1.
DRO	Off-time duration, see Fig. 1.
ΔDR	Deviation of the duration from the no rule case, can be in msec or percent.
L	Level in dB.
ΔL	Relative level deviation from *L*, in dB.
VA	Vibrato amplitude in percent.
ΔVA	Relative vibrato amplitude deviation from *VA*, in percent.
VF	Vibrato frequency in Hz.
ΔF	Relative frequency deviation in cents.
$T_1 - T_4$	Time breakpoints in the level envelope
$L_1 - L_4$	Level breakpoints in the level envelope

Symbols

k A general constant that is used to alter the quantity of each rule. The normal case is for $k = 1$.

$n, n-1, n+1$ Index to the current, preceding, and following tone relatively to the current position of the rule

Table 2. Music excerpts selected for the listening experiment

P. Boulez: First eight measures of *Piano Sonata.*
A. Webern: *Third piano variation op. 27*
I. Xenakis: Excerpt from *Herma.*

Random 1: White noise frequency variation with nonquantized durations.
Random 2: Pink noise frequency variation with nonquantized durations.
Random 3: White noise frequency variation with quantized durations.
Random 4: Pink noise frequency variation with quantized durations.

cent, if the following tone is longer. The preceding tone is shortened by the same amount of msec.

$$\text{Let } \Delta DR = 0.12 \cdot DR_n \cdot k \qquad [\text{msec}]$$

$$\Delta DR_n = \Delta DR \qquad [\text{msec}]$$

$$\Delta DR_{n-1} = -\Delta DR \qquad [\text{msec}]$$

where the index n refers to the short tone and the index $n - 1$ to the preceding one of double duration.

Figure 2 shows how the rule affects the durations of a simple Swedish folk tune melody.

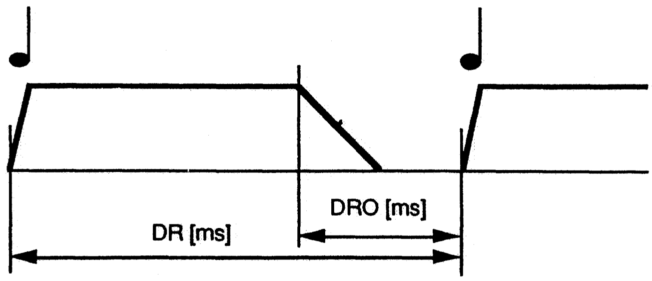

Fig. 1. Illustration of the definition of the duration parameter DR *and the micropause parameter* DRO *for a tone.*

Rule GMI 1A′. Leap Articulation

According to this rule, which is an alternative to rule GMI 1A, a micropause is inserted between the two tones in a leap. The duration of the micropause is proportional to the leap distance and the duration of the first tone. The rule is not applied over phrase or subphrase borders, nor if $DR_n > 100$ msec. Further, there are certain limitations as to the proportionality between the micropause duration and the width of the leap.

Let the first tone of the leap have the index n. Let ΔN be the absolute value of the leap interval in semitones. The upper and lower limits are given by:

$$\text{For } \Delta N > 9$$
$$N = \Delta N = 9$$

For the tone initiating the leap the following applies:

$$DRO = 8 \cdot \Delta N \left(0.3\, \frac{DR_n - 100}{600} + 0.3\right) \cdot k \quad [\text{msec}]$$

Figure 3 illustrates the effects of this rule on a music example.

Rule GMI 1B. Leap Tone Duration

The leap tone duration rule modifies the duration of tones in singular leaps. Thus, it is applied only if the leap is preceded and followed by either a repetition or by stepwise movement along the scale.

Let ΔN be the absolute value of the leap interval in semitones. Let the first tone of the leap have the index n and the target tone index $n + 1$.

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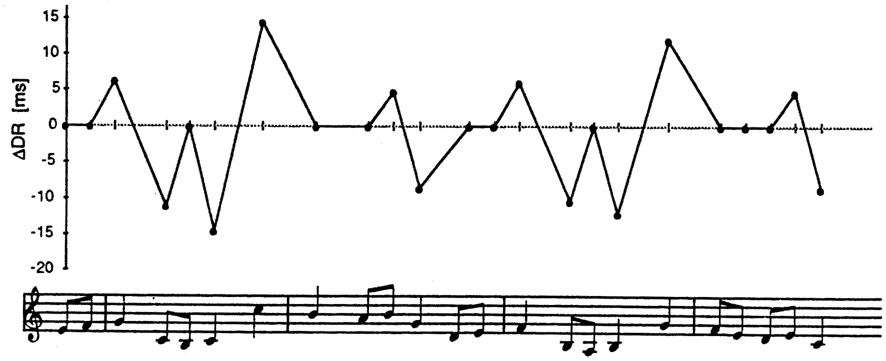
*Fig. 2. Durational deviations from nominal values resulting from rule DDC 2B (double duration) on a Swedish folktune (*Sorgeliga saker hända, *"Sad things happen").*

Fig. 3. Micropauses in terms of the DRO *parameter values induced by rule GMI 1A (leap articulation) in J. S. Bach:* Bourreé *from* Suite C major for 'cello solo, *BWV 1009.*

Fig. 4. Example of the durational deviations resulting from rule GMI 1B (leap tone duration) in J S. Bach: Bourreé *from* Suite C major for 'cello solo, *BWV 1009.*



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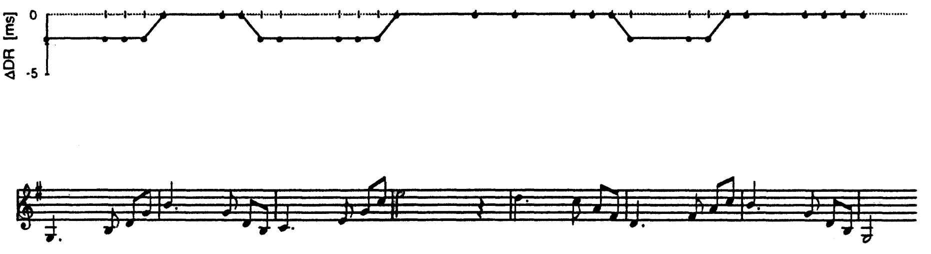

Fig. 5. Example of the durational deviations resulting from rule GMI 1C (faster uphill) in K. Jularbo: Livet i Finnskoga.

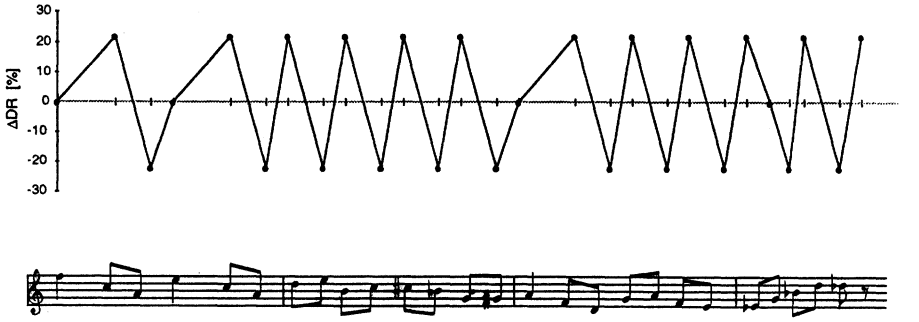

Fig. 6. Example of the durational deviations resulting from rule GMI 3 (inégalles) in C. Parker: Blues for Alice.

1. Singular ascending leap:

$$\Delta DR_n = 4.2 \cdot \sqrt{\Delta N} \cdot k \qquad [\text{msec}]$$

$$\Delta DR_{n+1} = -4.2 \cdot \sqrt{\Delta N} \cdot k \qquad [\text{msec}]$$

2. Singular descending leap:

$$\Delta DR_n = 4.2 \cdot \sqrt{\Delta N} \cdot k \qquad [\text{msec}]$$

$$\Delta DR_{n+1} = -2.4 \cdot \sqrt{\Delta N} \cdot k \qquad [\text{msec}]$$

Figure 4 illustrates how the rule affects the duration of the various tones in a music example.

Rule GMI 1C. Faster Uphill

Duration of tone is shortened by $2 \cdot k$ msec if preceding tone is lower and following tone is higher. This shortening is also applied on the first tone in an unbroken series of ascending intervals.

Figure 5 illustrates the effects of this rule on the durations of the various tones in a music excerpt.

Rule GMI 3. Inegalles

This rule is optional. In sequences of paired tones of equal duration, the duration of the tones appearing in metrically stressed positions may be lengthened by 22 percent of their duration, and the following tone is shortened by the same amount. Similarly, the first tone in the sequence is shortened, provided it appears in a metrically unstressed position.

The effects of this rule on the tone durations in a jazz example can be seen in Fig. 6.

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Rule GMI 4′. Articulation of Repetition

The off-time duration of the first tone in a repetition is:

$$DRO = 35 \cdot k \qquad \text{[msec]}$$

Rule GMA 3. Final Ritard

This rule is optional. Let T_n be the running time from the beginning of the ritard to the current tone, indexed n, and let T_{tot} be the total length of the ritard. The time T_n is taken at the middle of each tone, i.e., at $DR_n/2$. Then, the change in duration for the notes in the ritard will be:

$$\Delta DR_n = \frac{100}{\sqrt{1.1 - \frac{T_n}{T_{tot}}}} \qquad \text{[percent]}$$

(Maximum 330 percent at the last tone)

Multiple Parameter Rules

Rule DDC 1. Durational Contrast

Notes with duration between 30 and 600 msecs are shortened and decreased in amplitude depending on their durations according to two breakpoint functions with the following values:

DR:	30	200	400	600
DR [msec]:	0	−16.5	−10.5	0
L [dB]:	0	−0.825	−0.525	0

Figure 7 illustrates these modifications graphically, and Fig. 8 shows how the durations in a music excerpt are affected.

Rule DPC 2A. Melodic Charge

Given the harmony over which a tone appears, the melodic charge if this tone can be seen as a measure of its "remarkableness."

The melodic charge for the various scale tones in a C major or minor context are:

Tone:	C	G	D	A	E	B	F♯	D♭	A♭	E♭	B♭	F
C_{mel}:	0	1	2	3	4	5	6	6.5	5.5	4.5	3.5	2.5

1. Amplitude and duration are added in proportion to the tone's melodic charge C_{mel} relative to the root of the prevailing chord.

$$\Delta L = 0.2 \cdot C_{mel} \cdot k \quad \text{[dB]}$$

(Maximum 1.3 dB for $k = 1$)

$$\Delta DR = \frac{2}{3} \cdot C_{mel}\, k \quad \text{[percent]}$$

(Maximum 4.3 percent for $k = 1$)

2. Unevennesses in ΔL caused by (1) above are smoothed. Let the index n denote the current tone, the index $n + 1$ the following tone and $n - 1$ the preceding tone. If tone $n - 1$ initiates a major or minor second, if its duration is equal to that of tone n and shorter than 500 msec, and if $\Delta L_{n-1} < 0.5 \cdot \Delta L_n$, then a $\Delta L_{n-1} = 0.75 \cdot \Delta L_n$ is given to that tone. If the third tone in this sequence has a $\Delta L_{n+1} < 0.5 \cdot \Delta L_n$, it receives a $\Delta L_{n+1} = 0.55 \cdot \Delta L_n$.

3 Extra vibrato amplitude ΔVA is added in proportion to the ΔL resulting from (1) and (2) above.

$$\Delta VA = \frac{0.3}{2} \cdot \Delta L \quad \text{[percent]}$$

(Maximum 0.2 percent for $k = 1$)

Figure 9 shows the sound level, duration and vibrato effects of the rule on a music example.

Rule GMA 1. Phrase

Phrases consist of subphrases. Signs for both these structural elements are edited into the input notation by hand. The rule converts these markers according to the following:

1. For the last tone of phrase:

$$\Delta DR = 40 \cdot k \qquad \text{[msec]}$$

$$DRO = 80 \cdot k \qquad \text{[msec]}$$

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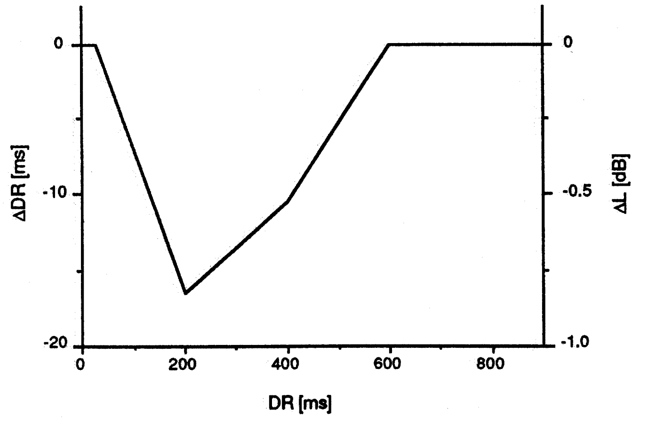
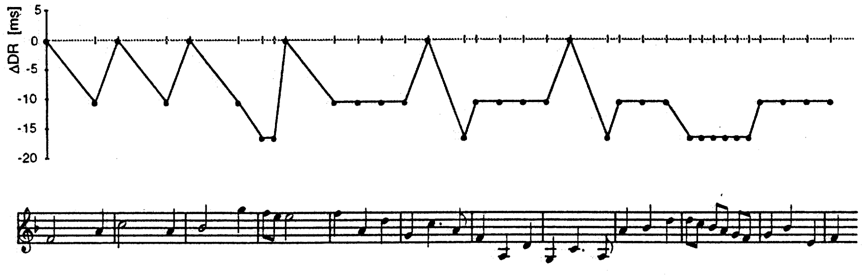
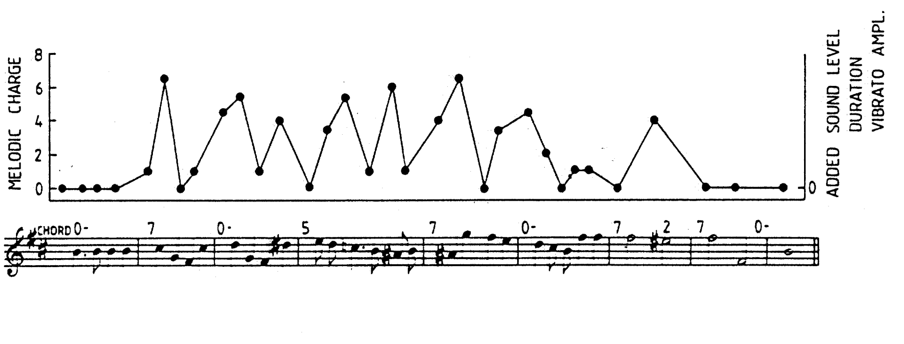
Fig. 7. Duration and amplitude changes depending on the original duration according to rule DDC 1 (durational contrast).

Fig. 8. Example of the durational deviations resulting of rule DDC 1 (durational contrast) in W. A. Mozart: Klaviersonate in F major.

Fig. 9. Example of the amplitude deviations induced by rule DPC 2A (melodic charge) in J. S. Bach: Kyrie I *from* B minor mass. *The chords are given in terms of the interval, in steps, between the root and the root of the tonic. A minus sign represents a minor triad.*







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2. For the last tone of subphrase:

$$DRO = 80 \cdot k \qquad [\text{msec}]$$

3. For the last tone of piece:

$$\Delta DR = 80 \cdot k \qquad [\text{msec}]$$

Figure 10 shows the effects in terms of micropauses and lengthenings effects of the rule on a music example.

Rule GMA 2A. Harmonic Charge

Given the harmonic context, the "remarkableness" of a chord is measured in terms of its harmonic charge. It is computed from the melodic charge of the chord tones as related to the root of the tonic:

$$C_{harm} = 2 \cdot \left(\frac{C_{mel,\mathrm{I}}}{2} + \frac{C_{mel,\mathrm{III}}}{3} + \frac{C_{mel,\mathrm{V}}}{6} \right) - 3$$

where I, III, and V denote the chord's root, third, and fifth. Figure 11 shows the harmonic charge values for the scale tones assuming the harmonic context of a C major chord.

1. Crescendi and diminuendi reflecting changes in harmonic charge are produced by increasing the sound level gradually toward the occurrence of a chord with greater harmonic charge than the previous chord, and vice versa. The level increase ΔL at the chord change notes:

   $$\Delta L = 1.5 \cdot \sqrt{C_{harm}} \cdot k \qquad [\text{dB}]$$

   Intermediate notes are given intermediate sound levels. The level increase starts no earlier than 1.9 sec ahead of the chord change. The level starts to decrease immediately after the chord change and ends at the next chord change. If the crescendo time is short, only a portion of the L should be added so as to avoid too fast crescendos.
2. Rallentandi and accelerandi accompany the crescendi and diminuendi. The duration DR is increased in proportion to the level ΔL added in the crescendos due to chord changes.

   $$DR = DR \cdot \sqrt{1 + 0.018\Delta L} \qquad [\text{msec}]$$

3. The vibrato frequency is proportional to ΔL above. (This rule is preliminary.)

   $$VF = 5 + 0.81 \cdot \Delta L \qquad [\text{Hz}]$$

4. The tempo is slowed according to the harmonic charge. To all tones appearing over a given chord an extra duration ΔDR is added. It is proportional to the harmonic charge.

   $$\Delta DR = 2 \cdot \sqrt{C_{harm}} \cdot k \qquad [\text{msec}]$$

5. An extra duration of ΔDR is given to the first tone appearing over the new chord:

   $$\Delta DR = 8 \cdot \sqrt{C_{harm}} \cdot k \qquad [\text{msec}]$$

Figure 12 illustrates how the rule affects the sound levels, durations, and vibrato amplitude values of the tones of a music example.

Rule GMA 2B. Chromatic Charge

This rule replaces rule DPC 2A and GMA 2A for atonal music (Friberg et al. 1991). Chromatic charge is defined as:

$$C_{chrom} = [(32 - \Delta N) \bmod 12] - 6$$

where ΔN is the absolute value of the interval in semitones to the next tone, disregarding rests. C_{chrom} is smoothed by averaging over five tones. The resulting mean, $C_{chrom,\,mean}$, is assigned to the middle tone of the five. Amplitude and duration are then added in proportion to $C_{chrom,mean}$:

$$\Delta L = 1.35 \cdot C_{chrom,mean} \cdot k \qquad [\text{dB}]$$

$$\Delta DR = 0.009 \cdot C_{chrom,mean} \cdot k \qquad [\text{percent}]$$

Figure 13 illustrates the effects of the rule on a music example.

Intonation Rules

Rule DPC 1A. High Sharp

In one-voice music, pitch is sharpened by 4 cents/octave relative to equal temperament.

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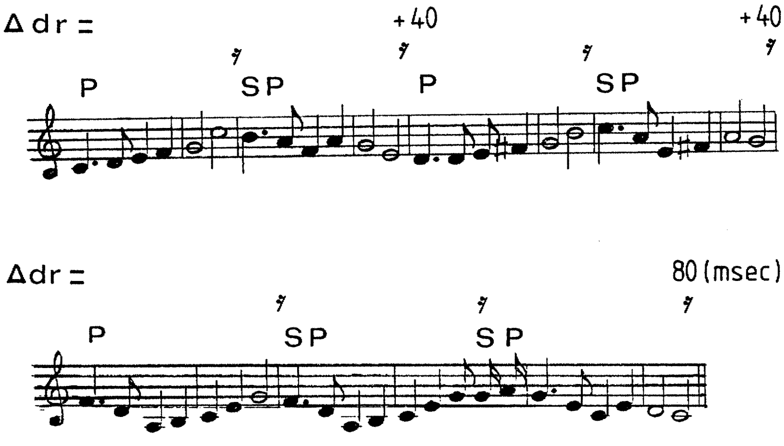
Fig. 10. Phrase and subphrase markers induced by rule GMA 1 (phrase) in A. Tegnér's nursery tune Ekorn satt i granen *("The squirrel sat in the fur tree").*

Fig. 11. Harmonic charge of all major and minor (m) chords in the key of C.



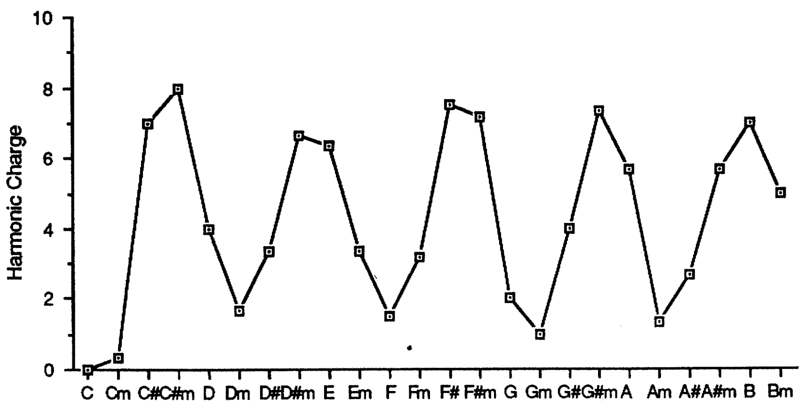


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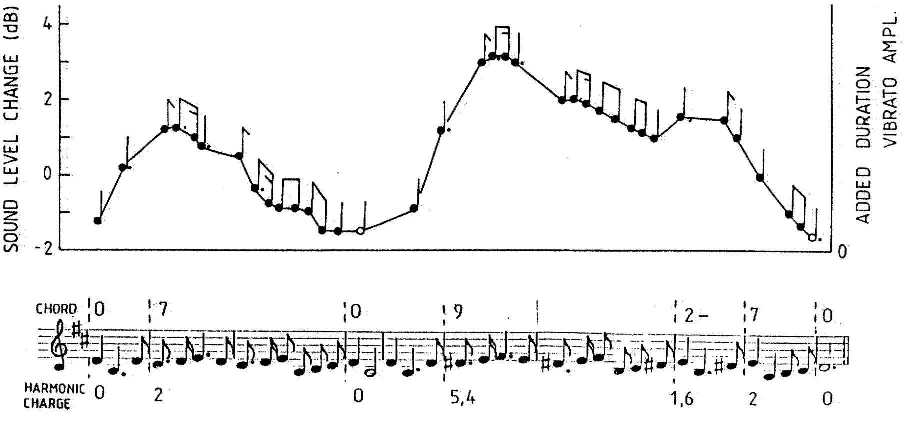
Fig. 12. Example of amplitude deviations resulting from application of rule GMA 2A (harmonic charge) in a theme from F. Schubert's Symphony in B minor, (*"*The Un-Finished*")*.

Fig. 13. Example of amplitude deviations produced by rule GMA 2B (chromatic charge) on a melody generated by a random function. Note that high values are generated in areas where the notes are close together in pitch and low values in areas of large intervals.



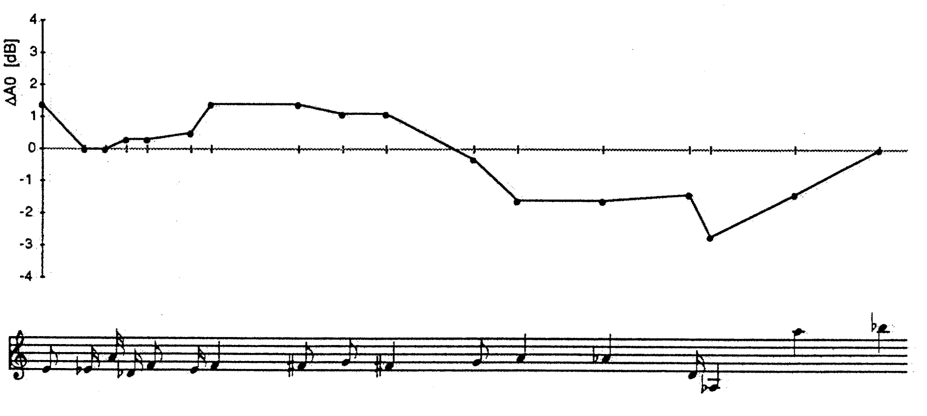


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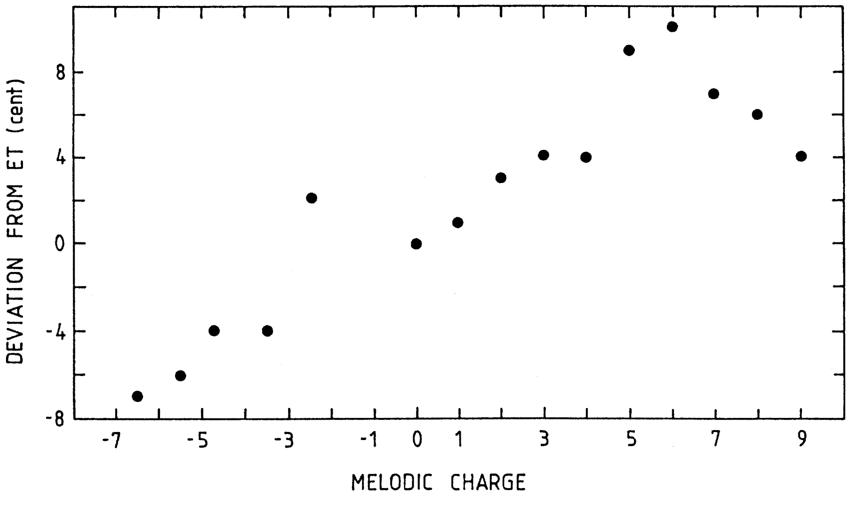
Fig. 14. Frequency deviations according to rule DPC 2B (melodic intonation) expressed as function of melodic charge as defined in rule DPC 2A.



$$\Delta F = (N - 60) \cdot \frac{4}{12} \cdot k \qquad \text{[cent]}$$

where N is the semitone number with $N = 60$ for C_4.

Rule DPC 2B. Melodic Intonation

The fine tuning of the scale tones is adjusted according to the following table:

IC:	0	1	2	3	4	5	6	7	8	9	10	11
ΔF_{mel}:	0	−7(7)	3	−4(4)	4	2	10	1	−6(6)	4	−4	9

$$\Delta F = \Delta F_{mel} \cdot k \qquad \text{[cent]}$$

IC is the number of semitones above the root of the chord and ΔF is the added deviation for that tone. The number given within parentheses is used when a tone is completing and initiating semitone intervals. This rule can be used in monophonic contexts only. These values show a relation with melodic charge, as can be seen in Fig. 14. Figure 15 shows how the rule affects the tuning in a music excerpt.

Rule ENS 1. Mixed Intonation for Ensemble Music

This rule attempts to solve the dilemma that long sustained chords sound rough when played according to the equally tempered scale, harmonically acceptable but melodically unacceptable when played according to just intonation, and melodically acceptable but harmonically unacceptable when played in accordance with Rule DPC 2B (melodic intonation).

As long as any simultaneously sounding tone is shorter than 400 msec, the tones in each voice

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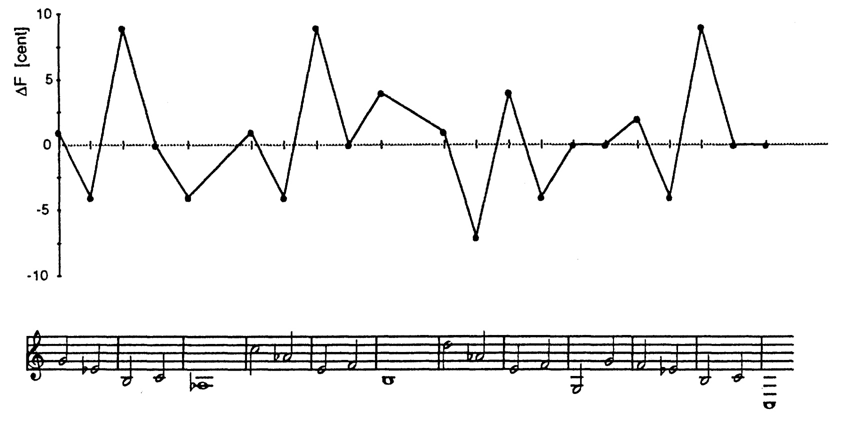
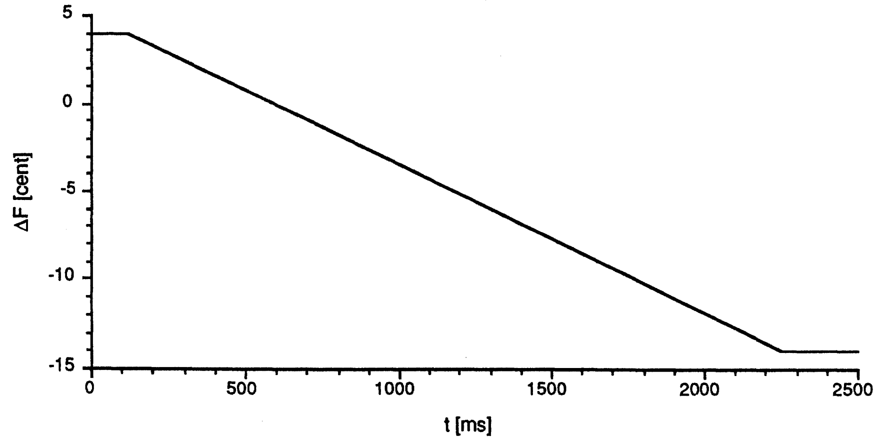
Fig. 15. Example of frequency deviations from equal-tempered tuning of rule DPC 2B (melodic intonation) in a theme from the Sarabande *in J. S. Bach's* Suite, c minor, for cello solo, *BWV 452.*

Fig. 16. Example of the time function for the adjustment of tuning according to rule ENS 1 (mixed intonation). The graph shows how the tuning, in cents relative to equal-tempered tuning, is changed for the major third of a current chord. Note that, since the rate of change is constant, the target deviation will never be fully reached for notes shorter than 2.2 sec in this case.





adhere to the melodic intonation in accordance with Rule DPC 2B. When all simultaneous notes at any given time are longer than 400 msec, each tone will start with the melodic intonation for the first 120 msec of the duration. Then, the fundamental frequency will approach just intonation (beatfree) at a constant rate of 4.7 cent/sec, as illustrated in Fig. 16 for the case of a major third. Just intonation, as defined in the table below, is designed to produce negligible beating against the root of the current

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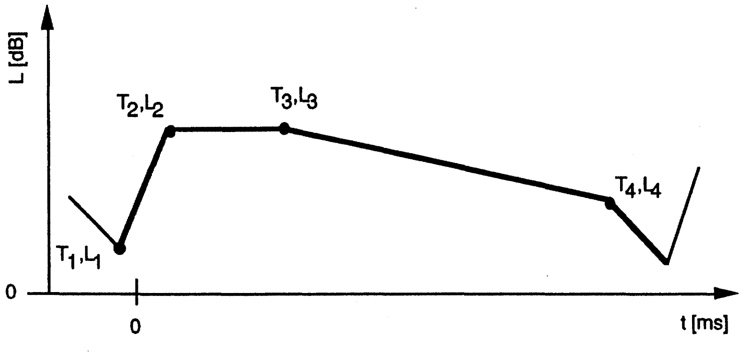
Fig. 17. Envelope parameters for a tone; t = 0 is assumed to correspond, roughly, to the perceived onset of the tone. According to the rules this perceptual onset is independent of changes in risetime. Accents are produced by raising the second and third level values L_2 *and* L_3.



chord. If a new tone arrives during a long tone, the intonation of the long tone starts over again from the beginning with the value corresponding to melodic intonation. This rule can also be applied to a one-voice music.

IC:	0	1	2	3	4	5	6	7	8	9	10	11
ΔF_{harm}:	0	5	4	16	−14	−2	−10	2	14	−16	18	−12

IC is the number of semitones above the root of the chord and ΔF_{harm} is the target deviation in cents for that tone.

Amplitude Envelope Rules

Rule DDC 2A. Accents (Tentative Formulation)

Accents are distributed to notes involved in durational contrast. Accents are distributed in three cases: (a) notes surrounded by longer notes; (b) first of several equally short notes followed by a longer tone; and (c) the first long tone following a tone provided with an accent according to cases (a) or (b).

The sound–level envelope of each tone is defined by interpolation between four points specified by time and level values; this is illustrated in Fig. 17. For the computation of the starting level of accented notes, the total duration of the tone *DR*, the total sound level *L*, the accent weight *W*, and the dip value *D* are used.

(A) Short tone surrounded by longer ones

Let the short tone have the index n and the previous tone $n - 1$. Then,

$$W = \frac{14.25}{\sqrt{DR_n}}$$

$$D = L_{n-1} + (0.0003DR_n + 0.5)(L_{n-1} - L_n) - \frac{304}{DR_n}$$

The level envelope of the short tone is given by:

For $DR_n \geqslant 300$ msec

$$T_1 = -(40W/3 + 5) \qquad L_1 = 0.8D$$
$$T_2 = 30/W \qquad L_2 = L_n + W$$
$$T_3 = 30/W + 30 \qquad L_3 = L_n + W$$

For $DR_n < 300$ msec

$$T_1 = -W/3 \qquad L_1 = D + 0.5(L_n - D)$$
$$T_2 = 0.1DR_n/3 \qquad L_2 = L_n + 2W$$
$$T_3 = 0.2DR_n/3 \qquad L_3 = L_n + 2W$$

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The preceding tone's last envelope point can be derived by:

For $DR_{n-1} \geqslant 300$ msec

For $DR_{n-1} \geqslant 400W$

$$T_4 = DR_{n-1} - 12W$$

For $DR_{n-1} < 400W$

$$T_4 = 0.7DR_{n-1}$$

For $DR_{n-1} < 300$ msec

$$T_4 = DR_{n-1} - 12W$$

(B) First of several equally short notes following a longer one

Let the first short tone have the index n and the previous tone $n - 1$.

$$W = \frac{22.5}{\sqrt{DR_n}}$$

$$D = L_{n-1} + (0.0003DR_n + 0.5)(L_{n-1} - L_n) - \frac{633}{DR_n}$$

The level envelope of the first short tone is given by:

For $DR_n \geqslant 300$ msec

$$T_1 = -10(W + 3/8) \qquad L_1 = D + 0.5(L_n - D)$$

$$T_2 = 50/W \qquad L_2 = L_n + W$$

$$T_3 = 50/W + 50 \qquad L_3 = L_n + W$$

For $DR_n < 300$ msec

$$T_1 = -(40W/3 + 5) \qquad L_1 = L_n - 0.0044DR_n \cdot (L_n - D)$$

$$T_2 = DR_n/3 \qquad L_2 = L_n + 0.8W$$

$$T_3 = 2DR_n/3 \qquad L_3 = L_2$$

The preceding tone's last envelope point can be described by:

For $DR_{n-1} \geqslant 200W$

$$T_4 = DR_{n-1} - 60W$$

For $DR_{n-1} < 200W$

$$T_4 = 0.7DR_{n-1}$$

(C) Long tone after one or more equally short notes, the first of which had an accent with the weight $W_{P,+A}$ and the duration of $DR_{P,+A}$

Let the long tone have the index n and the previous tone $n - 1$.

$$W = 0.8W_{P,+A}$$

$$D = L_{n-1} + (0.0003DR_n + 0.5)(L_n - L_{n-1}) - 12.8(W_{P,+A})2$$

The level envelope of the long tone is given by:

For $DR_n \geqslant 300$ msec

$$T_1 = -(40W/3 + 5) \qquad L_1 = D + 0.2(L_n - D)$$

$$T_2 = 50/W \qquad L_2 = L_n + W$$

$$T_3 = 50/W + 30 \qquad L_3 = L_n + W$$

The preceding tone's last envelope point:

For $DR_{n-1} \geqslant 300$ msec

For $DR_{n-1} \geqslant 400W$

$$T_4 = DR_{n-1} - 12W$$

For $DR_{n-1} < 400W$

$$T_4 = 0.7DR_{n-1}$$

For $DR_{n-1} < 300$ msec

$$T_{4}, = DR_{n-1} - 12W$$

Rule GMI 1A. Leap Articulation (Alternative, Tentative Formation)

Let the target tone of the leap have the index $n + 1$ and the first tone of the leap the index n. Define ΔN as the absolute value of the number of semitones in the leap. This rule should not be applied over phrase or subphrase borders or if previous rule DDC 2A was applied at the leap. Only for $\Delta DR_n > 300$ msec, $DR_{n+1} > 300$ msec and $\Delta N > 2$.

Upper and lower limit:

For $\Delta N > 9$

$$\Delta N = 9$$

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The dip value D is given as:

ascending leap

$$D = L_{n+1} + (0.5 + 0.0003DR_{n+1}) \cdot (L_{n+1} - L_n) - 5\Delta N/4 \text{ dB}$$

descending leap

$$D = L_{n+1} + (0.5 + 0.0003DR_{n+1}) \cdot (L_{n+1} - L_n) - 3\Delta N/4 \text{ dB}$$

The envelope for the target tone is then:

$$T_1 = -(10 + 3\Delta N) \qquad L_1 = D$$

$$T_2 = 5\Delta N \qquad L_2 = L_{n+1} + 0.5\Delta N/4$$

$$T_3 = T_2 + 30 \qquad L_3 = L_2$$

The first tone's last envelope point is:

For $DR_{n+1} > 300$ msec

For $DR_{n+1} \geqslant 300\ \Delta N$ msec

ascending leap

$$T_4 = DR_n - 9\Delta N$$

descending leap

$$T_4 = DR_n - 7\Delta N$$

For $DR_{n+1} < 300\Delta N$ msec

$$T_4 = 0.7DR_n$$

For $DR_{n+1} < 300$ msec

$$T_4 = DR_n - 3\Delta N$$

Rule GMI 2. Amplitude Smoothing

This rule eliminates steps in sound level. It is not applied across phrase or subphrase boundaries, or at repetitions.

$$L_{4,n} = L_n + T_{4,n}(L_{n+1} - L_n)/DR_n$$

Rule GMI 4. Repetition Articulation (Tentative Formulation)

Let the first tone in pairwise grouped repetitions have the index $n - 1$ and the second the index n.

Then, the following applies to the first tone in repetition:

If Rule DDC 2A (b) has not been applied:

For $DR_n < 330$ msec

$$T_4 = 0.75DR_{n-1} \qquad L_4 = L_{n-1}$$

For $DR_n \geqslant 330$ msec

$$T_4 = DR_{n-1} - 100 \qquad L_4 = L_{n-1}$$

For Rule DDC 2A (b) is applied:

$$T_4 = DR_{n-1}/2$$

The second tone in repetition:

IF Rule DDC 2A (b) has not been applied to the second tone:

For $DR_{n-1} > 330$ msec

$$D = L_{n-1} - 25 \text{ dB}$$

For $DR_{n-1} \leqslant 330$ msec

$$D = L_{n-1} - 0.075DR_{n-1} \text{ dB}$$

$$T_1 = -10 \qquad L_1 = D$$

$$T_2 = 20$$

For the case that Rule DDC 2A (b) has been applied to the second tone:

$$T_1 = -40$$

$$T_2 = 30 \qquad L_2 = L_2 + 1.5$$

$$T_3 = 70$$

Synchronization Rules

Rule ENS 2. Melody Synchronization

After application of rules affecting the tone durations, the timing of several simultaneous voices will differ. The following strategy is used for synchronizing such voices.

All nondurational rules are applied to all voices.

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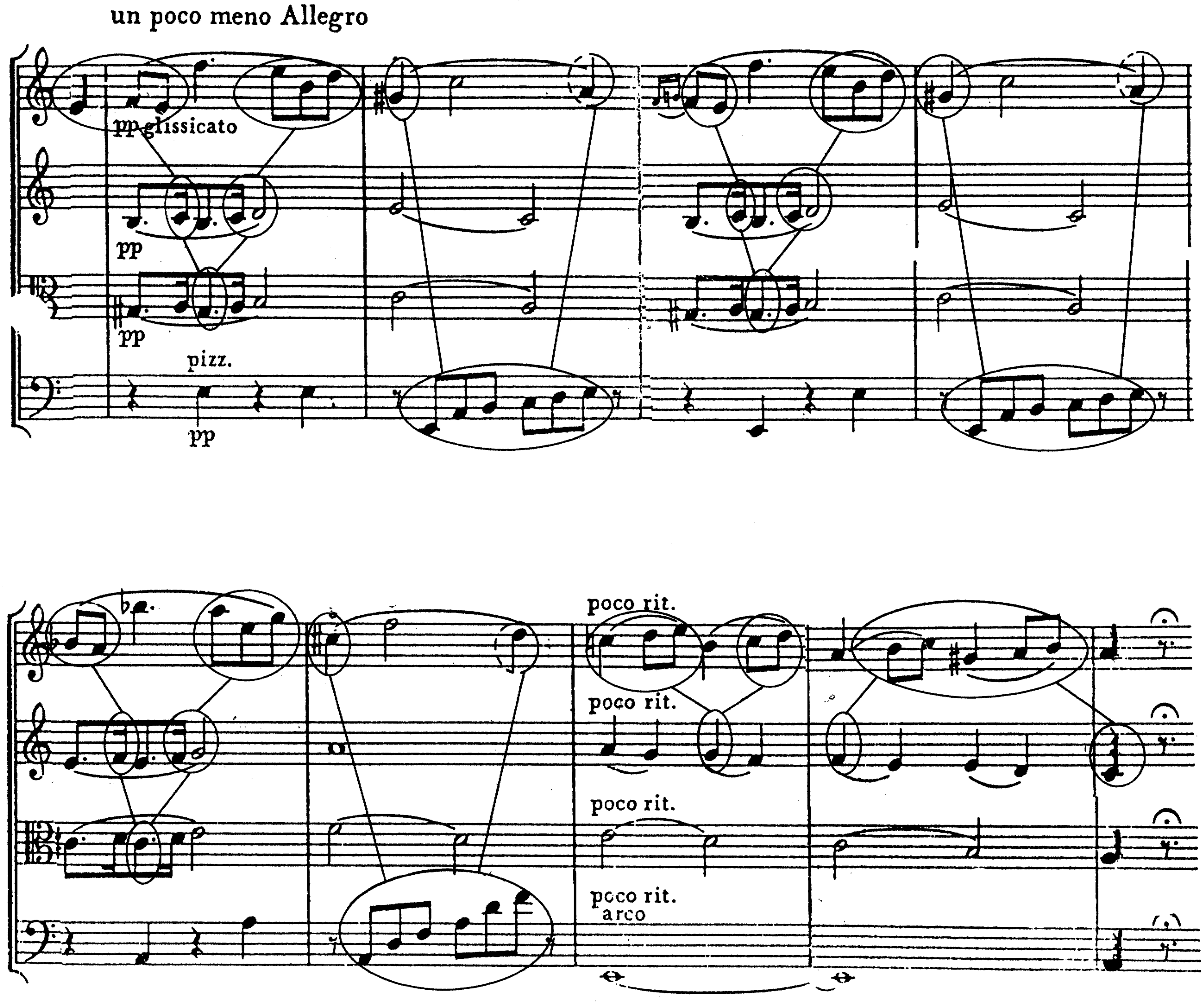
Fig. 18. Illustration of the strategy used for synchronization in ensemble music. The circled notes indicate the extracted synchronization melody, which gives the timing for all other notes in rule ENS 2 (melodic synchronization).



A new voice is constructed that consists of the shortest tone played by any of the voices at any time. If there are several equally short notes, the one with the highest melodic charge is selected, see Fig. 18.

To this new synchronization voice, all durational rules are applied.

The timing information from this synchronization voice is then used to synchronize all the original voices.

This rule particularly important in polyphonic music where the voices have approximately the same importance. On the other hand, it would not apply to the accompaniment of a solo part, where the solo is often leading slightly over the accompaniment (Palmer 1988).

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Rule ENS 3. Bar Sync (Optional)

This rule may occasionally replace ENS 2 in rhythmically very complicated bars, for example, when a septol appears together with four notes in a 4/4 bar.

For each bar: select the voice which has the greatest number of notes; and adjust the other voices proportionally so that their bar-durations will equal that of the first mentioned voice.

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