Etna - a New Advanced Graphical Tree Representation of Music

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Abstract This paper presents Etna, a new advanced graphical tree representation of music seen from a composer´s point of view of music as a process of elaboration. It emphasizes and encloses a proper formal foundation and a one-to-one relation to a practical linear symbolic notation. Etna is inspired by the Generative Theory of Tonal Music (GTTM), but abstract enough to match other transformational music theories. First applied in *AVA*, a semi-automated two-phase composition system, Etna demonstrated a high degree of practicability and straight-forward implementability. Etna is predestined to be reused beyond *AVA*, for instance in computer-assisted music analysis and/or synthesis.

1 Why yet another representation?

Etna[1] delivers a representation with features that I found lacking in other reduction/elaboration-orientated music representations:

1. **Represent "music as a result of elaboration":** The representation should show the music it represents from a composer´s view. It should clearly display the various parts as they are elaborated into more refined sub parts which in turn are elaborated further. Such a "constructive" view seems best suited to express the organic character of a composition, making its offals available for inspection, analysis or/and further (re-)composition.

2. **Provide a solid formal foundation:** The representation should support scientific methodology. A formalization is needed to obtain precision, clarity and unambiguity.

3. **Include a linear notation for the graphical representation:** The representation should be easily transferrable into a notation (and vice-versa) that allows algorithmic processing which is otherwise difficult if only a graphical representation is available.

4. **Stress the visualization of elaboration/reduction and of different elaboration levels:** The representation should clearly denote the pairs of music connected by a relation of elaboration/reduction i.e. it should always be clearly visible which part is an elaboration of another part. Moreover, its topology should show all elements ordered according to their degree of elaboration.

5. **Allow superposition:** The representation should harmonize with a superposed representation to point out certain elaborations while keeping representation clarity. This is achieved by any tie-like notation (e.g. the ties in CMN[2]) such as the

[1] Elaboration-orientated Tree Notation for *AVA*

[2] Conventional Music Notation

representation of so-called *groundlines* [Chico-Töpfer; 1998, Chico-Töpfer; 2001]. They illustrate how visually clear superposing can be as a consequence of carefully designing a representation to accomodate a superposition. For space reasons, this is not further detailed in this paper.

Consequently, the approach is to properly define a number of required terms which is done mathematically (point 1). This results in the formulation of a notation as required in point 2. Finally, it is transformed into a graphical counterpart that complies with points 3-5.

2 What needs to be defined?

First of all we need some basic conventions (for a complete discussion see [Hoos; 1994]):

- let $TONE$ be the set of tone description terms i.e. of all notes *and* pauses[3]
- let a tone $t \in TONE$ be a 4-tuple $t = (\pi_t, \delta_t, \iota_t, \gamma_t)$ where π_t is the pitch, δ_t the duration, ι_t the intensity and γ_t the applied instrument; they may be extracted by $pitch(t) := \pi_t, dur(t) := \delta_t, intens(t) := \iota_t, instr(t) := \gamma_t$

The above definitions are needed to define what pitch events and sequences are:

Definition 2.1 (Pitch Event and Sequence) *A pitch event is a term $P \in POLY$. The set $POLY$ is recursively defined as follows:*

1. $\forall p \in TONE : p \in POLY$
2. $p_1, p_2 \in POLY \Longrightarrow poly(p_1, p_2) \in POLY$

A sequence is a term $S \in SEQ$. SEQ is recursively defined:

1. $\forall p \in POLY : p \in SEQ$
2. $p_1, p_2 \in SEQ \Longrightarrow seq(p_1, p_2) \in SEQ$

The function *poly* yields a "vertical tone layer" i.e. music exlusively made up of tones that start to sound at the same time; *seq* yields a sequence i.e. music exclusively made up of tones or vertical tone layers that sound one after the other. Both functions may be formally defined [Hoos; 1994]. Further conventions and short definition extensions are convenient to work comfortably with a pitch event $p = poly(t_1, poly(t_2, .., poly(t_{n-1}, t_n)..))$ and a sequence $s = seq(p_1, seq(p_2, .., seq(p_{n-1}, p_n)..))$:

- we need to work with the duration of p and s: $dur(p) := max\{dur(t_1), .., dur(t_n)\}$ and $dur(s) := dur(p_1) + dur(p_2) + .. + dur(p_n)$
- we need to refer to the pitches, intensities and instruments of p and s:

$$\begin{aligned} \Pi(p) &:= \{pitch(t_1), pitch(t_2), .., pitch(t_n)\}, & \hat{\Pi}(s) &:= \Pi(p_1) \cup \Pi(p_2) \ldots \cup \Pi(p_n) \\ I(p) &:= \{intens(t_1), intens(t_2), .., intens(t_n)\}, & \hat{I}(s) &:= I(p_1) \cup I(p_2) \ldots \cup I(p_n) \\ \Gamma(p) &:= \{instr(t_1), instr(t_2), .., instr(t_n)\}, & \hat{\Gamma}(s) &:= \Gamma(p_1) \cup \Gamma(p_2) \ldots \cup \Gamma(p_n) \end{aligned}$$

[3]a tone may be a pause, just like a number may be zero

Now we can properly define a reduction:

Definition 2.2 (Reduction) *Let $P := \{p_1, .., p_n\} \subset POLY$ be the set of pitch events of a music piece m[4]. A reduction is a term $R \in RED$; RED is recursively defined:*

1. $\forall p \in P : p \in RED$
2. $x \in RED \Longrightarrow red(x) \in RED$; $x_1, x_2 \in RED \Longrightarrow seq(x_1, x_2) \in RED$

Note that RED is very flexible as it is practically independent of any particular music theory: One of the few assumptions is the implicit notion that a reduction is a reduced version of a sequence or a pitch event x (the elaboration). Musically speaking, a drawback may seem that a number of terms in RED do not really represent reductions. However, RED is the first non-trivial term set to specify closer what a reduction is i.e. we have a term set that clearly describes the structure of a reduction. Only one term in RED is expected to be a musical reduction according to a rsp. music theory. Observe also that RED includes sequences which may seem strange since seq has an extending effect. There are two reasons for this: First, there are cases where no true reduction seems possible or advisable. Typically, this may occur when cadences are reduced, see *cadential retention* [Jackendoff, Lerdahl; 1983, pp.155-158]. Secondly, seq is needed when an elaboration is generated from a sequence as a whole.

To keep above mentioned flexibility we define red partially by deferring theory-sensitive and context-sensitive criteria to a function $\psi_m : 2^{POLY} \rightarrow POLY$ that decides which reduction to prefer (the context m is the music piece see Def.2.2):

$$red(x) := \begin{cases} x & : \; x \in POLY \\ \psi_m(\Theta_x) & : \; x = seq(x_1, x_2), x_1, x_2 \in SEQ \wedge \Theta_x := \{p \mid p \in POLY \wedge \\ & \quad \Pi(p) \subset \hat{\Pi}(x) \wedge I(p) \subset \hat{I}(x) \wedge \Gamma(p) \subset \hat{\Gamma}(x) \wedge \Pi(p) \cap \hat{\Pi}(x_1) \neq \\ & \quad \emptyset \wedge dur(p) \in \{dur(x), dur(x_1)\}\} \end{cases}$$

Note that a definition of ψ_m could be an outcome of a full formalization of the GTTM or another music theory; this is beyond the scope of this paper. Yet we have clearly defined a set of reductions Θ_x for a sequence x. It is a result of observations that characterize our reduction:

- red **yields a pitch event:** the reduction always yields a pitch event as a result i.e. it is always truly reductive because it does not extend anything, which is conceptually clean
- red **is based on the importance of pitch events:** $red(seq(x_1, x_2))$ implies x_1 to be more important than x_2 which allows to determine pivotal elements of the reduction in x_1, thus at least one tone pitch must come from x_1; red works according to the notion that the musical surface contains elaborated versions of elements that make up the reductions
- red **either keeps the same duration or that of the important part:** Normally, the duration remains unchanged; however, because there are exceptions such as upbeats which durationally disappear in a reduction, it may also be that the rsp. reduction has only a duration of $dur(x_1)$ (preferring the duration of x_1 to that of the less important x_2)

[4]note: m is not defined since only its elements need to be defined

- **semper idem sed non eodem modo:** all tone pitches, instruments and intensities come from x, the reduction does not add anything new; it selects elements from x and transforms a given elaboration to its former state

We are ready now to develop our linear notation in two steps:

1. **simplify Def.2.2:** instead of 2.2.2 we could write $x_1, x_2 \in RED \Longrightarrow seq(x_1, x_2), red(seq(x_1, x_2)) \in RED$. Because for $x \in POLY$ we have $red(x) = x$, this second version is equivalent (trivial proof)
2. **derive an infix notated equivalent:** we replace above second version, this time by its infix[5] version $x_1, x_2 \in RED \Longrightarrow x_1 - x_2, x_1 \rightarrow x_2$ (trivial equivalence proof)

Still we need an adequate linear notation for pitch events themselves. Let us use a GUIDO[6]-like notation i.e. simplified so-called *complex segments* [Chico-Töpfer; 1998] since they are straight-forward and clear enough. For instance, $\{f/4\ a\ c\}$ stands for the F major chord with a quarter duration. Indications of intensity and instrumentation are omitted for simplicity.

3 Examples of linear and graphical ETNA representations

How are graphical ETNA representations built and related to linear ones? The example[7]

$(((c2 \rightarrow c) \rightarrow (g \rightarrow g)) \rightarrow ((a \rightarrow a) \leftarrow (g \rightarrow g))) \leftarrow$
$(((f \rightarrow f) \leftarrow (e \rightarrow e)) \leftarrow ((d \rightarrow (tr \leftarrow d2/8.)) \leftarrow (e2/16 \leftarrow c2/2)))$

shows that we need to apply the reduction arrow $\rightarrow$ in its counter direction to keep the information related to the time when a pitch event occurs. This also allows to read the term from left to right like CMN. Equivalence with Def.2.2 is kept since we can trivially extend RED to generate $x_2 \leftarrow x_1$ with $x_2 \leftarrow x_1 := x_1 \rightarrow x_2$; now we can define a graphical representation that complies with 1.3-1.5: A reduction $x_1 \rightarrow x_2$ is made into a graphical view by bending the arrow twice so that it resembles a squared bracket whose ends are directly over x_1, x_2; the same is done for a sequence $x_1 - x_2$ (without an arrow peak). Graphical ETNA representations are principally built by nesting such "squared bracket arrows" one over another w.r.t. Def.2.2 (e.g. Fig.2). So all linear ETNA representations can be expressed as graphical ones. Conversely, the latter can always be transformed into their linear versions if they are built as described.

With ETNA we can also establish a well-ordered structure orientated along piece-specific duration levels of the rsp. reductions. They can be derived from the piece´s group structure[8]. Note that this is not necessary. But it achieves clarity by displaying reductions that do not have piece-specific durations on the same level as the next higher

[5] note that $x_1 \rightarrow x_2$ stands for the infix version of $red(seq(x_1, x_2))$

[6] see [Hoos et al.; 1998]

[7] note that tr stands for *Triller* i.e. the tone is elaborated by a specific ornamentation

[8] see [Jackendoff, Lerdahl; 1983]; note that a graphical ETNA fulfills all the properties demanded there by definition (if time-dependency is respected as described). Of course, all pitch events of the piece must be considered.

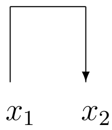

Figure 1: A reduction $x_1 \rightarrow x_2$. The arrow peak always points to the elaboration

duration level. E.g. if reduction $e/4 \rightarrow e/8$. has a duration of $1/4 + 1/8 + 1/16$, then it may be displayed on level 1/2.

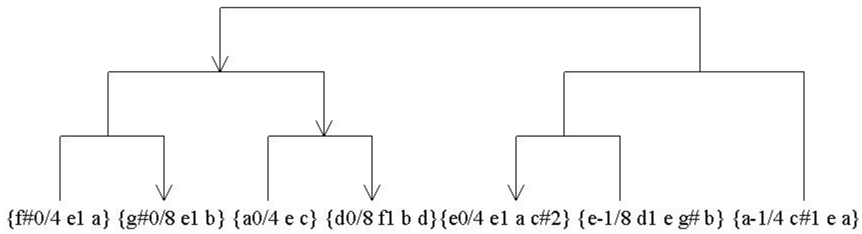

Figure 2: A graphical Etna of K.331 mm 7-8 where cadential retention yields {e-1/8 *d*1 *e* *g*♯ *b*} – {a-1/4 *c*♯1 *e* *a*}

4 Conclusion and Further Remarks

Etna, a powerful superposable tree notation to represent musical transformation, is formally founded and based on a well-defined linear notation. The Etna Builder [Chico-Töpfer; 2001] makes its visualization easy and supports their export to other formats. Etna is part of the *AVA Project* which aims at delivering an open component-orientated music system for various musician user groups. The *AVA* web site is planned to go online in the 3rd quarter of 2001.

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