

## The dynamics of dynamics: A model of musical expression

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### About the author

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- temporal coding in auditory cortical processing
- Sensorimotor processing
- Acoustic sensitivity of vestibular system



### Basic Terms

- Tempo:

$$v_x = \frac{\Delta x}{\Delta t_x} = \frac{x_2 - x_1}{t_{x_2} - t_{x_1}}$$

- Dynamic/Intensity

$$I = \frac{1}{T}$$

$$I = \sum_{i=1}^n \frac{1}{nT_i}$$

- X: metrical distance
- t: onset time
- T: hammer flight time
- n: number of the notes in a group

### Tempo and Dynamics: some observations

- Musical phrasing has its origin in the kinematic and dynamic variations involved in single motor actions (Stetson, Sachs)
- Phrase is often marked by an accelerando /ritardando shape (Seashore, Todd, Shaffer...)
- Some empirical supports
- A tendency of tonal power to rise to a peak and then fall away (Seashore)

### Gabrielsson's research

### Gabrielsson's research

- crescendo/decrescendo marks a phrase
- The degree of crescendo at the beginning of the phrase is often a function of the structural importance of the phrase

### Shaffer's research

- A high degree of reproducibility
- A high correlation
- The faster the louder, the slower the softer
- No direct relationship between dynamic marking and actual performance
- The more important the boundary, the greater the decrescendo/ritardando.

### Propositions

- A group is phrased by a crescendo/decrescendo shape
- The particular shape is a function of structural importance
- Musical dynamics is coupled to tempo

### Model- Framework and assumptions

- AES Abstract Expression System
- AES  $\leftrightarrow$  musical expression

vs

- machine  $\leftrightarrow$  formal language

- AES provides a language with which to describe the objects encountered in musical expression

### Components of a model for musical expression

- Representation of structure
- Structure variables
- Performance procedure
- Independent variable (x or t)
- Encoding function
- Style parameters

### Representation of Structure (LISP)

```

(setq tree '(A B))
(setq A '(a a))
(setq B '(b b))
(setq a '(g4 g4))
(setq b '(g4 g4))
(setq g4 '(1 1 1 1)).
    
```

### Structure variables

$(L,S)_i = (16,0), (16,1),$   
 $(L,S)_{j_2} = (8,0), (8,1), (8,0), (8,1),$   
 $(L,S)_{j_4} = (4,0), (4,1), (4,0), (4,1), (4,0), (4,1), (4,0), (4,1).$

### Performance Procedure

- Neil Todd, A computational model of rubato, Contemporary Music Review, 1989, Vol. 3, pp 69-88
- A heuristic and recursive algorithm
- Mapping from representation to performance
- Look ahead and plan the phrasing of a group at a given level then move down to the next sub-group, look ahead and plan, and so on

back

### Encoding Function -- Linear Tempo

$$a(t) = a,$$

$$v(t) = u + at,$$

$$x(t) = ut + 1/2at^2,$$

$$a(x) = a,$$

$$v(x) = (u^2 + 2ax)^{1/2},$$

$$t(x) = (1/a)[(u^2 + 2ax)^{1/2} - u],$$

### Encoding Function -- Linear Tempo

- Giving a reasonable approximation (Kronman and Sundberg)
- Tempo should be linear in time within a single accelerando or ritardando (Longuet Higgins and Lisle)
- Equations of elementary mechanics can be used to model an expressive change of tempo

### Encoding Function --Energy, Tempo and Intensity

- Particle with mass m
- V-shaped potential well
- Metrical distance is normalized with length,  $X_j = \frac{x}{L_j}$

### Encoding Function --Energy, Tempo and Intensity

$E = T + V$   
 $T = \frac{1}{2}mv^2$   
 $V_{+,j}(x) = U \frac{X_j}{\Delta_j} \cdot 0 \leq X_j \leq \Delta_j$   
 $V_{\square,j}(x) = U \frac{1 - X_j}{1 - \Delta_j} \cdot \Delta_j \leq X_j \leq 1$   
 $v_{+,j}(x) = \sqrt{\frac{2}{m}(E - V_{+,j})}$   
 $I_x = K v_x^2$   
 $I_{+,j} = (2K/m)(E - V_{+,j})$

### Coupling with structure variable S

$\delta_j = \delta_0 + c_\delta S_j$   
 $U_j = U_0 + c_U S_j$   
 $X_j = X_{0j} + c_X S_j$   
 $X_{0j} = \frac{x}{L_j}$

(a)  $c_\delta = c_U = c_X = 0$ , no coupling;  
 (b)  $c_\delta = c_X = 0$ , potential depth shift;  
 (c)  $c_U = c_X = 0$ , offset shift;  
 (d)  $c_\delta = c_U = 0$ , coordinate shift.

### Encoding Function with N components

$I_x = \sum_{i=1}^N (2K/m_i)(E - V_{i,j})$   
 $V_{+,j}(x) = U_{j,i} \frac{X_{j,i}}{\Delta_{j,i}} \cdot 0 \leq X_{0j,i} \leq \Delta_{j,i}$   
 $V_{\square,j}(x) = U_{j,i} \frac{1 - X_{j,i}}{1 - \Delta_{j,i}} \cdot \Delta_{j,i} \leq X_{0j,i} \leq 1$

$\delta_{j,i} = \delta_0 + c_\delta S_{j,i}$   
 $U_{j,i} = U_0 + c_U S_{j,i}$   
 $X_{j,i} = X_{0j,i} + c_X S_{j,i}$

- I refers to the structural level
- Normalization requires

$$\sum_{i=1}^N \frac{1}{m_i} = 1.$$

back

### Style parameters and results

$E = I_{\min}/2K$   
 $U_0 = (I_{\min} - I_{\max})/2K$   
 $K = I_{\max}/v_{\max}^2$

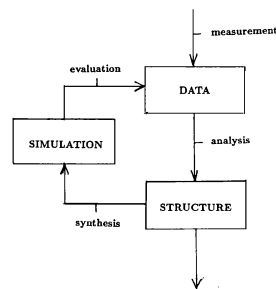
$U_{0,1} = U_{0,2} = U_{0,3} = U_0$   
 $\delta_{0,1} = \delta_{0,2} = \delta_{0,3} = \delta_0$   
 $c_{U,1} = c_{U,2} = c_{U,3} = c_U$   
 $c_{\delta,1} = c_{\delta,2} = c_{\delta,3} = c_\delta$   
 $c_{X,1} = c_{X,2} = c_{X,3} = c_X$

$I_{\min} = 0$   
 $I_{\max} = 100$   
 $v_{\max} = 1$   
 $E = 0$   
 $U_0 = 1/2$   
 $K = 100$

$\Delta_{j,0} = (0.3, 0.5, 0.7)$

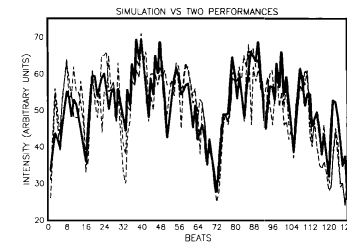
- Results are shown in the paper

## Analytic Method



- Performance data is the input
- Guess the structure (L,S)
- Estimates parameters by regressing
- Stop the recursion till the error is acceptable

## Results



```

(setq g2 '(1 1))
(setq g3 '(1 1 1))
(setq g4 '(1 1 1 1))
(setq g5 '(1 1 1 1 1))
(setq g6 '(1 1 1 1 1 1))
(setq tsr '(A B))
(setq A '((G1 G2) G3 G4 G5))
(setq B '((G6 G7 G8 G9) G10))
(setq G1 '(g5 g5 g6))
(setq G2 '(g5 g5 g3 g4))
(setq G3 '(g2 g2 g2 g4))
(setq G4 '(g2 g2 g4))
(setq G5 '(g6 g5 g2 g4 g4))
(setq G6 '(g5 g4 g3))
(setq G7 '(g5 g4))
(setq G8 '(g4 g2 g2 g4))
(setq G9 '(g5 g3 g4 g3))
(setq G10 '(g6 g2))
  
```

- Chopin Prelude
- Simulation (bold line) vs Performance data (dotted line)

## Discussion

- Assumptions:
  - Musical expression has its origins in simple motor actions
  - Perception of tempo/dynamics is based on an internal sense of motion
  - The internal sense is organized in a hierarchical manner
- Psychological / neurophysiological interpretation:
  - Organs of ear are sensitive to gravity, linear and rotational acceleration
  - Vestibular system is involved

## Conclusions

- The model needs to be tested with a large number of performances
- The simulation needs to be tested by producing synthetic performances