Perceiving temporal regularity in music

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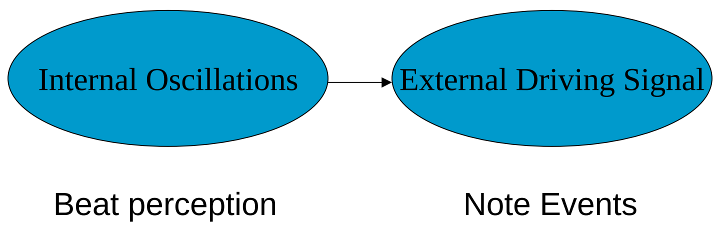
Introduction

- People have effortless ability to perceive temporal regularity in musical sequences.
- Listeners perceive temporal fluctuations or deviations as related to performers' musical intentions. (duration-lengthening)

Introduction

- The approach in this paper:
- 1.Model



Introduction

- The approach in this paper:
- 2. Experiments
  - a.Evaluate the model's ability to track different temporal periodicities
  - b.Test the model's ability to detect temporal irregularities

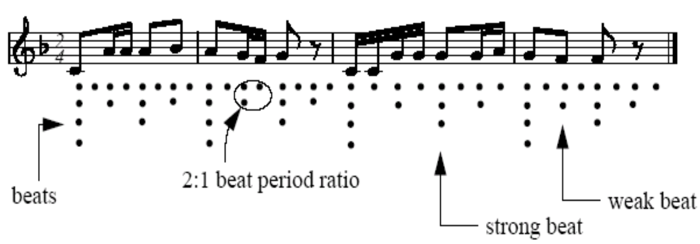
Some basic concepts

- **Rhythm**: the general sense of movement in time, including phrasing, harmony and meter.
- *Temporal patterning of event durations in a sequence*

- **Beat**: pulses marking equally spaced points in time
- *Once it is established, it may continue in mind*

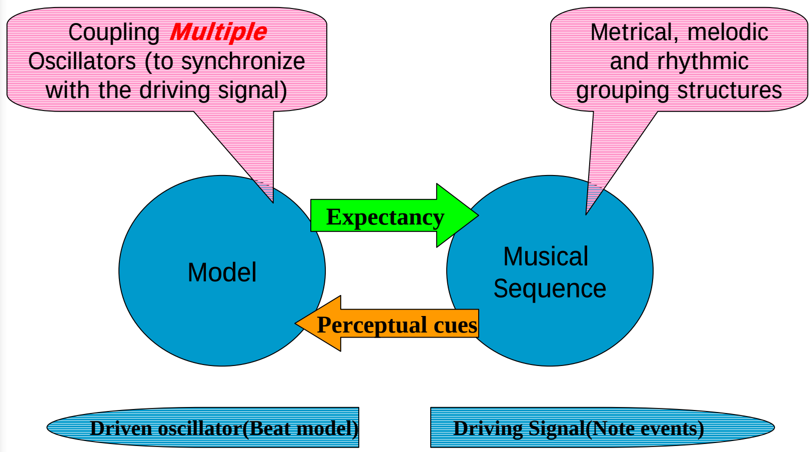
- **Metrical Structure**: alternation of strong and weak beats over time

Strong beats and weak beats



- Strong beats:points at which many beats are coincide
- Weak beats:points at which few beats are coincide
- The first position in the measure is a strong beat
- Inter-onset intervals (IOIs)

Meter perception model (Sketch) next

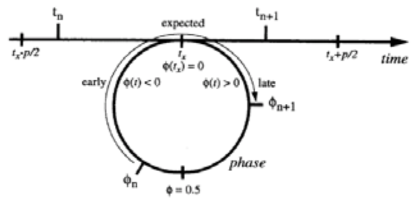


Model of single oscillator (prerequisite)

- **Oscillations** are period events (T_0)
- **Phase** at any time t: $\phi = \frac{t}{T_0}$ (between 0 and 1)
- **Synchronized**: two oscillations regularly come into phase or begin their cycles together.
- **Entrainment**: a process by which two or more oscillators achieve synchronization
- Entrainment occurs because a **coupling** between two or more oscillations causes them to synchronize
- **Coupling** allows one oscillator to perturb another by altering its **phase**, its **intrinsic period**, or both
- Meter perception model (Sketch)

Model of single oscillator (prerequisite)

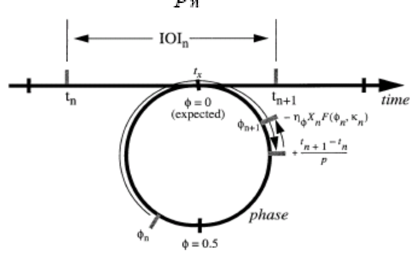
$$\phi_{n+1} = \phi_n + \frac{t_{n+1} - t_n}{p}$$



- Phase of driving oscillator at which the driven oscillator fires on iteration i
- p is the period of driven oscillator
- Φ >0, event occurred late;
- Φ =0; corresponds to time of the expected beat;
- Φ <0; event occurred early;

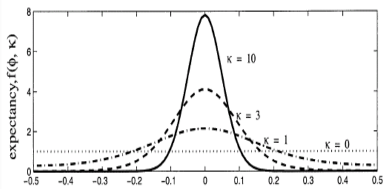
Model of single oscillator

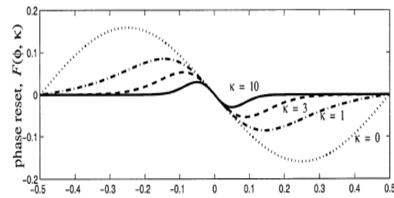
$$\phi_{n+1} = \phi_n + \frac{t_{n+1} - t_n}{p_n} - \eta_\phi X_n F(\phi_n, \kappa_n) \qquad (mod_{-0.5,0.5}1)$$



- F(Φ,k) is the non-linear coupling function;
- Xn is the amplitude of the nth onset (=1)
- η is the coupling strength
- k is a focus or concentration parameter that determines the extent of an expectancy function

Expectancy function and Phase resetting function





$$f(\phi, \kappa) = \frac{1}{I_0(\kappa)} \exp \kappa \cos 2\pi\phi \qquad F(\phi, \kappa) = \frac{1}{2\pi \exp \kappa} [\exp \kappa \cos 2\pi\phi] \sin 2\pi\phi$$

- Period coupling:

$$p_{n+1} = p_n(1 + \eta_p X_n F(\phi_n, \kappa_n))$$

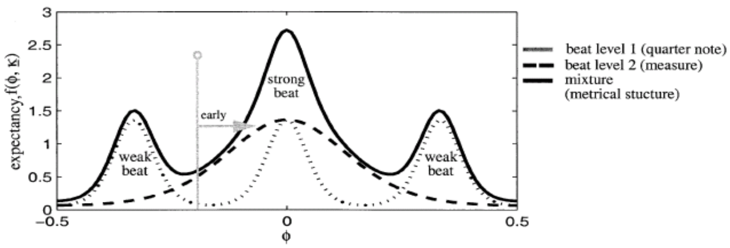
$$\phi_{n+1} = \phi_n + \frac{t_{n+1} - t_n}{p_n} - \eta_\phi X_n F(\phi_n, \kappa_n) \qquad (mod_{-0.5,0.5} 1)$$

Modeling hierarchical metrical structures (inter-coupling)

- Musical rhythms typically contain multiple periodicities
- The internal oscillators are coupled to one another so as to preserve certain phase and period relationships
- Phase coupling strength α_Φ
- Period coupling strength $\alpha_{\mathbf{p}}$
- Mixture of von Mises distributions

$$f_j(\phi) = \frac{1}{I_0(\kappa_j)} \exp \kappa_j \cos 2\pi j\phi \qquad f(\phi, \underline{\kappa}) = \sum_j w_j f_j(\phi)$$

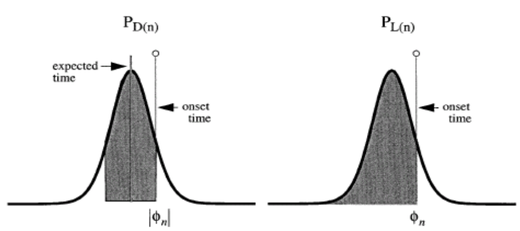
Sensitivity to temporal fluctuations: 1.Categorizing note onsets



- To find the associated level for ever note event
- Calculation: $f_j(\phi) = \frac{1}{I_0(\kappa_j)} \exp \kappa_j \cos 2\pi j\phi$

$$f(\phi, \underline{\kappa}) = \sum_j w_j f_j(\phi) \qquad \tau_j = \frac{w_j f_j(\phi)}{f(\phi, \underline{\kappa})}$$

Sensitivity to temporal fluctuations: 2.Detecting Phrase-final lengthening



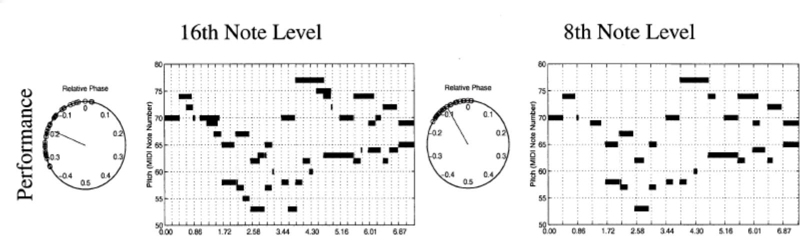
- $P_{D(n)}$: Probability that the event was heard as deviating from its expected time.
- $P_{L(n)}$: Probability that the event was heard as occurring late in the cycle.

$$P_{D(n)} = 2\int_{x=0}^{|\phi_n|} f(x, \kappa)\, dx \qquad P_{L(n)} = \int_{x=-0.5}^{\phi_n} f(x, \kappa)\, dx \qquad P_{P(n)} = P_{D(n)} P_{L(n)}$$

Experiment (horizontal temporal fluctuations)

- Test sets: Piano performances of 2- and 3-part inventions by Bach.
- 6 players* 4phrase conditions *2 voice entrances *3 excerpts=144 performances
- The simulated oscillations tracked the 16th-note and 8th-note levels of the metrical structure
- Parameters: p_{16th}= initial IOI=1/2*p_{8th};
- Φ_0 =0; k=3; $\eta_\Phi = 1.0; \eta_p = 0.4; \eta_k = 0.2$
  $\alpha_\Phi = \alpha_p = 1/0$ (coupled/uncoupled)
- Analyzed by circular statistics

Performance timing experiment

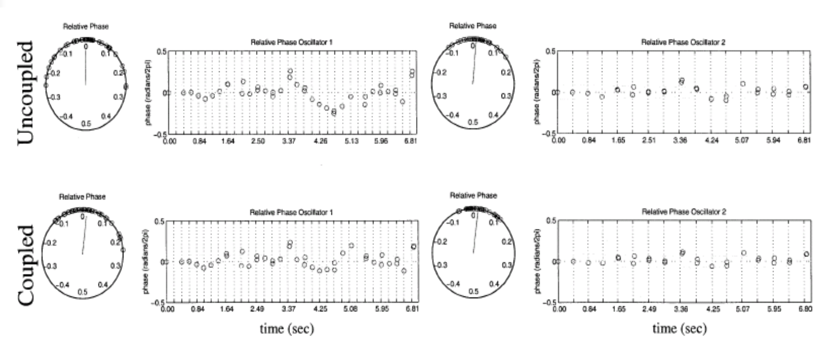


- Performance timing $\Phi = \frac{t_{onsettime} - t_{expectedtime}}{\bar{p}}$
- Dev16th>Dev8th, more expressive timing at the 16th-note level
- Events on and around the notated boundaries had larger relative phase
- Pianists significantly lengthened events at phrase boundaries

Model tracking experiment

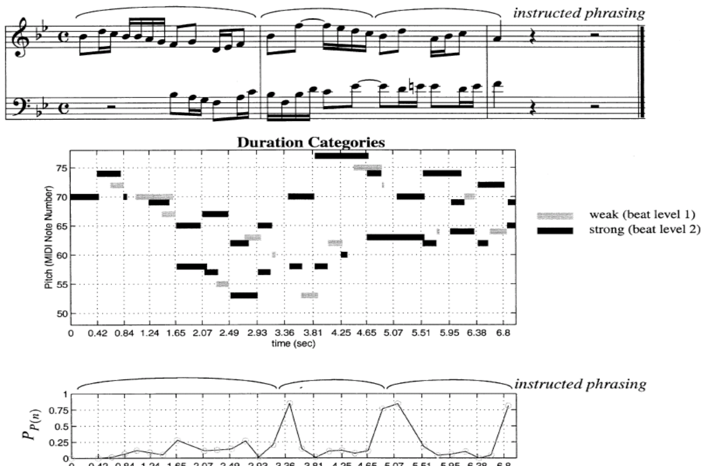
- Phase: $\phi_{n+1} = \phi_n + \frac{t_{n+1} - t_n}{p_n} - \eta_\phi X_n F(\phi_n, \kappa_n) \qquad (mod_{-0.5,0.5} 1)$
- Angular Dev=0.0801 (smaller than Angular Dev of performance timing)
- ----*The model adapted phase and period to track the ongoing sequences*
- 1. Different phrase conditions:
  - *The model tracked better in the natural phrase than in the experimental phrase conditions*
- 2. Different metrical level:
  - *The smaller level showed more variability*
- 3. Different voices:
  - *Equally well*

Model tracking experiment



- 4. Coupled and Uncoupled
  - *Tracking by coupled oscillators was better than by the uncoupled oscillators.*
  - *The coupled oscillator model consistently outperformed the uncoupled model, and more so at the smaller metrical level (16th-note)*

Experiment of detecting phrase boundaries



$$P_{D(n)} = 2\int_{x=0}^{|\phi_n|} f(x,\kappa)\,dx \qquad P_{L(n)} = \int_{x=-0.5}^{\phi_n} f(x,\kappa)\,dx \qquad P_{P(n)} = P_{D(n)}P_{L(n)}$$

Experiment of detecting phrase boundaries

Table 1
Number of events passing lengthening criterion for performance and model

Model	Performance	
	>75%	<75%
>.75	234 (64%)	120 (12%)
<.75	121 (36%)	935 (88%)

- The model probability of the event >0.75
- The IOI of the event is greater than 75% of all performed events
- Conclusion: the model was able to detect lengthening more often than chance at locations where performers used lengthening

Conclusions

- The model is good
- The first test of a multiple oscillator model tracking music performances
- The model's beat tracking variability was slightly lower than the amount of stimulus variability
- The model detected those events that contained rubato (phrase-final lengthening) well
- The coupling of oscillators improved the model's beat-tracking
- Coupling aided beat-tracking most at metrical levels that contained the most temporal variability.

References

- 1. Glass, L., & Mackey, M. C. (1988). *From clocks to chaos: the rhythms of life.*
- 2. Large, E. W., & Kolen, J. F.(1994). Resonance and the perception of musical meter. *Connection Science,* 6. 177-208
- 3. Large, E. W., & Jones, M. R. (1999). The dynamics of attending: how we track time varying events. *Psychological Review,* 106(1), 119-159