Rhythm Detection Framework
A Study of the Characterization of Clave in Latin American Music

Mehmet Vurkaç
Statistical Signal Processing

Outline
• Goal
• Significance
  – Commercial Uses
  – Scientific/Artistic Inquiry
• Definitions and Assumptions
  – Terminology
  – Deterministic vs. Stochastic
  – Stationary, Ergodic?
• Data
• Methods
  – Autocorrelation (Deterministic and Stochastic)
  – PSD Estimate (Filterbank Analogy)
• Results
• Conclusion

Goal
• To characterize the rhythmic structure of West African-based Latin American music in absolute mathematical terms.

Significance
• Commercial Uses
  – Digital Studio Workstations
    • User-Friendly Editing
    • Intelligent Arranging
  – Content-Searchable Internet Databases
  – Algorithmic Composition
• Scientific /Artistic Inquiry
  – Scientific Curiosity
    • Arbitrary cultural phenomenon or a mathematical characteristic?
  – Teaching Insight
    • Analytical or intuitive study?

Definitions
• Clave
  – Form
    • Binary Structure
    • Son, Rumba, Bossa, and derivatives
  – Direction
    • “3-2”
    • “2-3”
  – Significance
    • Framework For Composition and Improvisation
• Music Technology Terminology
  – Sequencing, Sampling
  – MIDI, Quantization

Assumptions
• Quantized sequenced music is deterministic.
• Quantized rhythm is periodic. (cut and paste)
• Live music is at best quasi-periodic; often a sum of harmonic stochastic processes and quasi-periodic deterministic processes.
• Improvisation and melody are not independent of, but are uncorrelated with the quasi-periodic rhythm.
Assumptions

- The population consists of all realizations of clave-based music at a tempo of 120 BPM.
- The clave and its derivative rhythms are deterministic, with a period of 4 quarter notes.
- Live music involves interactions between musicians based on psychological and environmental factors that cannot be modeled in a deterministic fashion.
- Over all realizations, all pitches (frequencies) and timbres (harmonic spectra) are equally likely. All rhythms are not.

Assumptions

- Thus, melodic content over the ensemble is truly random, while rhythmic content is considered deterministic.
- Since musical pieces all have a start and an end, true stationarity is not valid.
- Taking time zero to be the start of each piece, local stationarity can be assumed because all pitches and timbres are equally likely.
- The process is asymptotically ergodic in the mean because the ensemble mean at any point in time will equal the time average over infinite time.

Methods

- Autocorrelation
  - The autocorrelation of the clave form is used to model the expected rhythmic structure of a clave-based piece.
  - Autocorrelation of the piece under study is then compared to the model to deduce stylistic attributes.

- PSD Estimate
  - The 50%-overlap Welch-Bartlett PSD estimate is used.
  - Filterbank Interpretation of the periodogram
  - Improved variance and MSE performance over the periodogram with little increase in bias

- "In some practical applications, correlation is used to identify periodicities in an observed physical signal which may be corrupted by random interference."
  - The deterministic autocorrelation sequence and the biased estimate of autocorrelation for stochastic processes are equivalent to within a constant.

Data Set

<table>
<thead>
<tr>
<th></th>
<th>Pure</th>
<th>1/8 White Noise</th>
<th>w/ Music</th>
<th>M</th>
<th>w/ Music</th>
</tr>
</thead>
<tbody>
<tr>
<td>Son Clave</td>
<td>pS</td>
<td>xS</td>
<td>MS</td>
<td>KS</td>
<td></td>
</tr>
<tr>
<td>Rumba Clave</td>
<td>pR</td>
<td>xR</td>
<td>MR</td>
<td>KR</td>
<td></td>
</tr>
<tr>
<td>Rumba Cascara</td>
<td>pC</td>
<td>xC</td>
<td>MC</td>
<td>KC</td>
<td></td>
</tr>
</tbody>
</table>
Data: Rumba Clave

Results: Autocorrelation

Results: PSD Estimate

Results: PSD Estimate
Conclusion

- Autocorrelation can give specific information about periodic and quasi-periodic content in a music signal that can be treated as a combination of random and deterministic elements.
- Interpretation of the information from autocorrelation requires genre-specific knowledge.
- Extraction of such information becomes challenging as the signals under analysis become more and more complex.
- A rigorous method of comparing the model and the signal under consideration needs to be developed.
- Narrowband filters tuned to expected frequencies of rhythmic instruments may be utilized with envelope extraction to carry out the extraction of rhythmic structure from autocorrelation.