

# Analyzing Afro-Cuban Rhythm using Rotation-Aware Clave Template Matching with Dynamic Programming

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## Introduction

- Majority of MIR research focuses on Western pop or classical
- Effective tools for music research can benefit from domain-specific knowledge
- This paper:
  - Presented at ISMIR 2008
  - Demonstrate an effective method of tempo-tracking in Afro-Cuban music
  - Show that it is superior to generic beat tracking software

## What is Afro-Cuban Music?

- Two main categories
  - Religious – used in rituals derived from African traditions
  - Profane – *Rumba*, *son* and *comparsa* (carnival music)
- Characterized by clave rhythm
  - *Son* rhythm
  - *Rumba* rhythm



Source: Wikipedia

## Clave Rhythm



**Figure 1.** Son (left) and rumba (right) clave

- Sequence of five beats usually between 95 – 170 bpm
- Differ by a delay of sixteenth in the second beat

## Audio Examples:

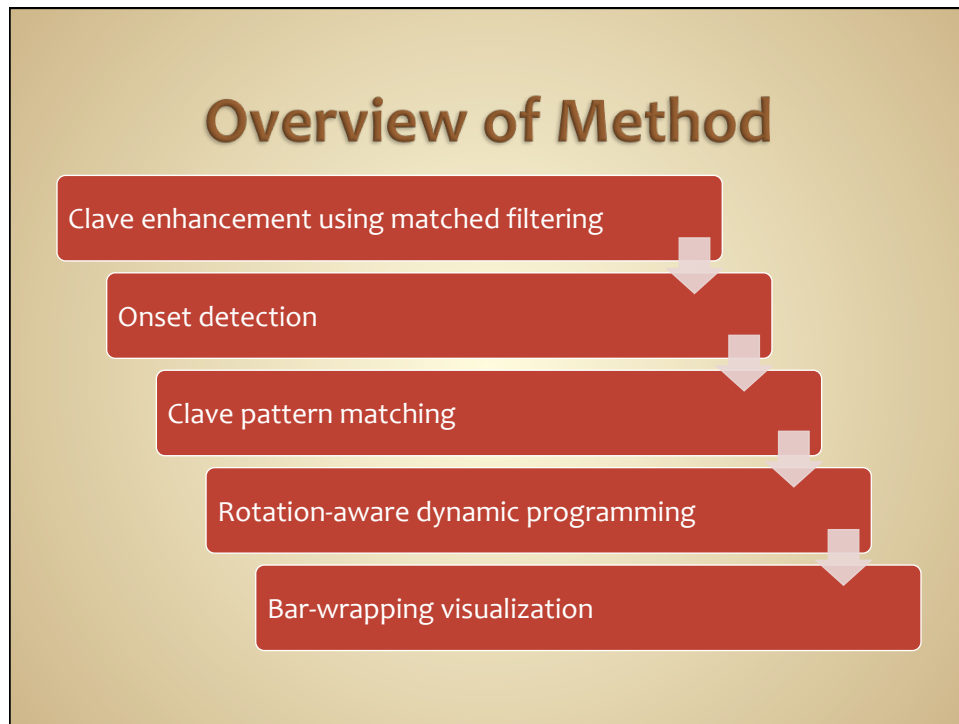
Rumba Clave: Cantar Bueno by Yoruba Andabo

Son Clave: Havana Lounge by Afro Cuban Allstars



## Why Tempo Tracking in Afro-Cuban Music

- Existing beat-tracking poor for two reasons
  - Cannot provide beat locations
  - Cannot handle complexity because of inapplicable assumptions
- Clave rhythm is syncopated
  - It provides the essential periodicity in Cuban music
- MIR research needs to expand beyond Western music



## Clave Enhancement

- Use a matched filter to enhance clave sounds
- Matched filter:
  - Find *a priori* known signal within unknown signal
  - Impulse response is time-reversed copy of known signal
- Clave is ideal:
  - Low timbral variety
  - Played consistently throughout entire song
  - Easy to extract; available unmixed at beginning of song

## Onset Detection

- Spectral flux
  - Half-wave rectified power difference in Hamming window
- Onset selected if:
  - Larger than adjacent local maxima
  - Larger than local mean
- Smoothing
  - Reduces false positives
- Filtered both directions
  - Cancel phase distortion

$$SF(n) = \sum_{k=0}^{N/2} HWR(|X(n, k)| - |X(n-1, k)|) \quad (1)$$

$$1. SF(n) \geq SF(k) \quad \forall k : n-w \leq k \leq n+w$$

$$2. SF(n) > \frac{\sum_{k=n-w}^{n+w} SF(k)}{m \cdot w + w + 1} \times thres + \delta$$

$$H(z) = \frac{0.1173 + 0.2347z^{-1} + 0.1174z^{-2}}{1 - 0.8252z^{-1} + 0.2946z^{-2}} \quad (2)$$

## Clave Pattern Matching

- Match whole rhythmic patterns (templates) rather than individual beats
- Consider all tempi and possible rotations of clave pattern

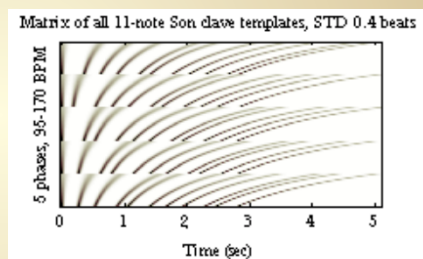
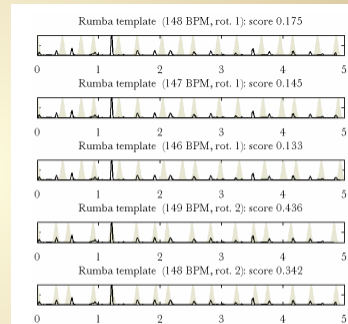


Figure 3. Clave Templates for all rotations and tempi

## Clave Pattern Matching

- Cross-correlation of templates with energy envelope to get score
- Create a score grid

$$score(i, j, k) = \sum_{t=0}^{LT_{j,k}-1} T_{j,k}(t)O(t_i + t) \quad (3)$$



**Figure 4.** Matching different templates (filled grey) to the CB recording's energy envelope (black line). The X-axis is time (seconds), with zero the time of the onset under consideration. The score for each template match represents how well that template lines up with the energy envelope.

## Dynamic Programming

### ROTATION-BLIND

- Explicitly discourage large tempo changes
- Estimate the best tempo path by means of a cost function

$$scoreRB(i, j) = \max_k(score(i, j, k)) \quad k : 1..5$$

$$PC(P) = \sum_{i=0:n-1} C_{i,P(i)} + \sum_{i=0:n-2} F(P(i), P(i+1))$$

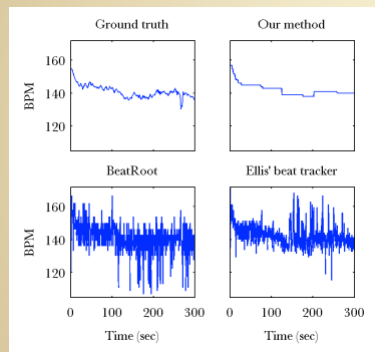
### ROTATION-AWARE

- Handles rotation in clave rhythm
- Adds a phase term to the cost function

$$\hat{\phi}_2 = \phi_1 + \Delta T((j_1 + j_2)/2)/(4 \times 60)$$

## Results

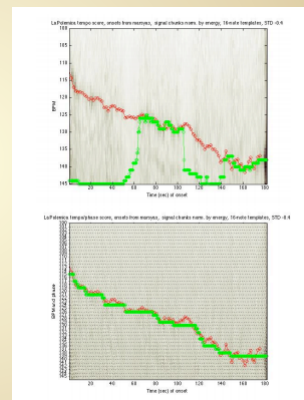
- Overall results of tempo tracking
- Comparison with BeatRoot and Ellis' dynamic programming



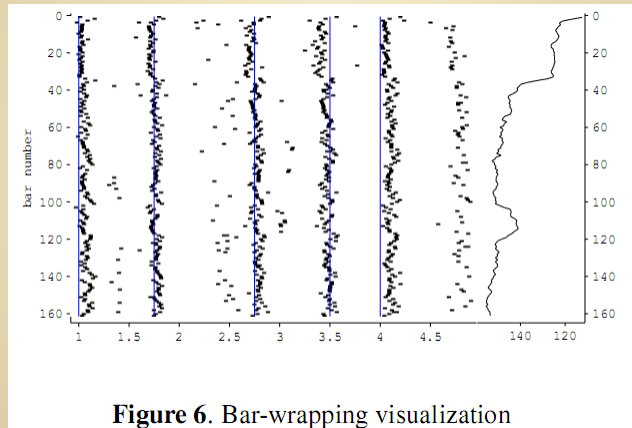
## Results

	LP	CB	CH	PD	LPWT	PDWT
RB	40	26	22.9	63.1	39.96	62.7
RA	1.75	11	1.54	3.10	2.043	57.9

Table 1. RMS (in BPM) results for tempo curve estimation



## Bar Wrapping Visualization



## Conclusion

- Beat- and tempo-tracking algorithm that works well for the Afro-Cuban genre
- Incorporates domain specific knowledge
- Importance of clave rhythm:
  - Never stops
  - Almost never changes
  - Consistent timbre for matched filtering
  - Often begin with clave alone
  - Plays one of a few predetermined templates
- Hope to further the field of computational ethnomusicology (CE)