Multiresolution Representations of Musical Rhythm & Expectation

Leigh M. Smith

Universiteit van Amsterdam
ILLC / Music Cognition Group

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EU Project: *Emergent Cognition through Active Perception (EmCAP)*

(European Commission FP6-IST, contract 013123)

- The study of how cognitive behaviour in artificial systems can emerge through interacting with a musical environment.

- Neuroimaging innate vs. learned auditory functions.
- Perception of musical form.
- Prefrontal cortical function controlling attention and STM.
- Spectrotemporal response fields in the thalamocortical system.
- Perception and categorisation of rhythmic patterns.
- Active perception, relative pitch and emergence of tonality.
- Interactive music system: *The Music Projector*.

http://www.musiccognition.nl/EmCAP

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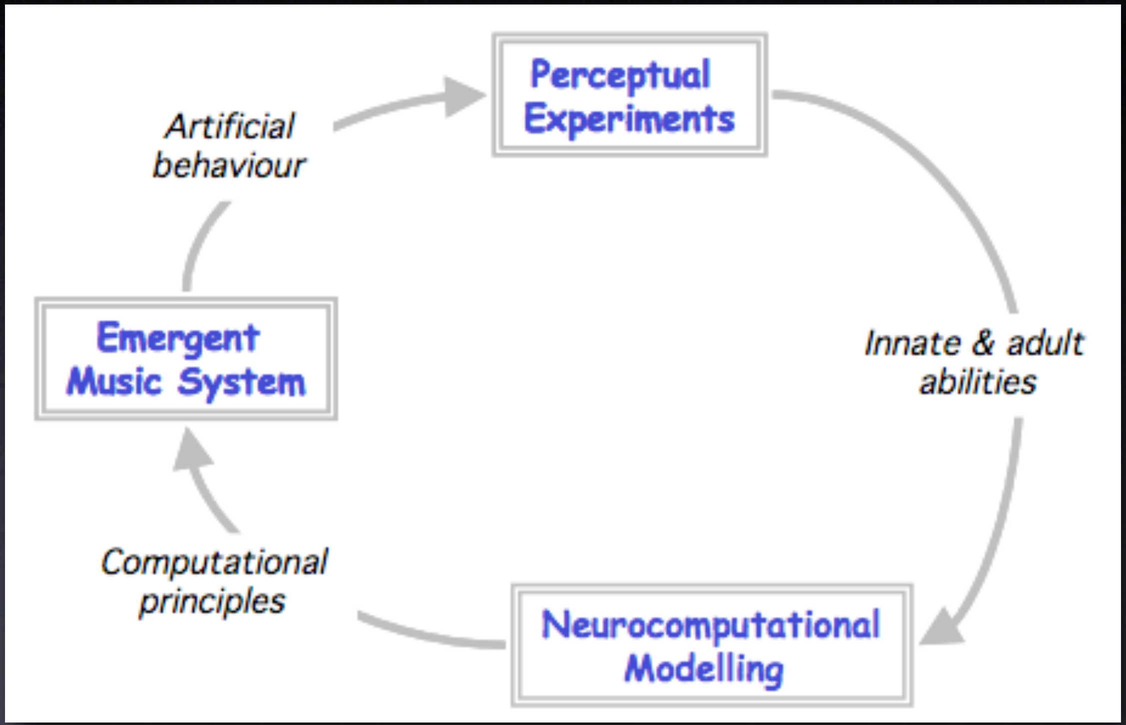

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Rhythmic Expectation

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...some theories of musical rhythm...

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  - (Not always periodic patterns)
- Accent sources include: dynamics, melody, harmony, articulation, timbre, onset asynchrony etc.
- Consists of *hierarchical* and *figural* (proximal) temporal structures.

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Meter

- Meter is expressed in Western music as time-signatures (4/4, 3/4 etc).

Subdivision of 4/4 (4 beats to the bar):

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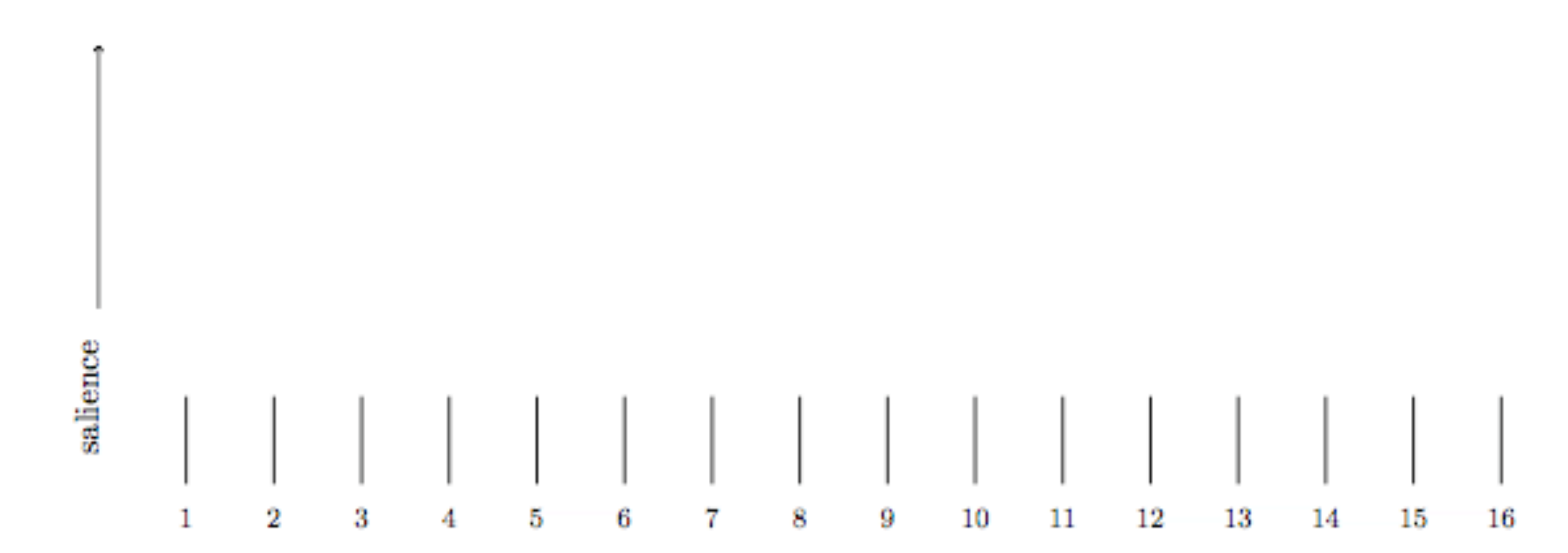
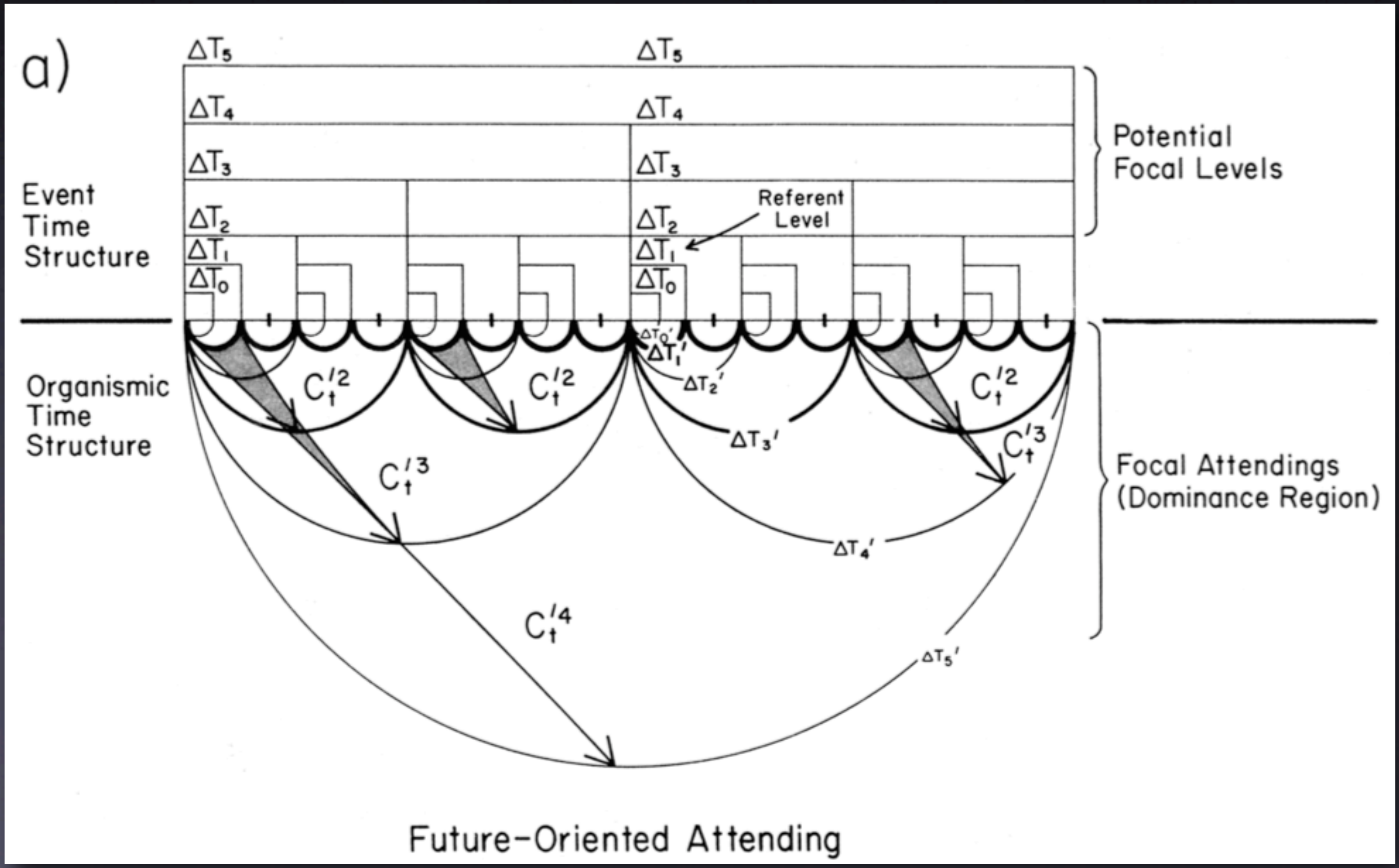


(Courtesy Olivia Ladinig)

Rhythmic Strata

- Musical rhythm can be considered as composed of a hierarchy of temporal levels or *strata* (Yeston 1976, Lerdahl & Jackendoff 1983, Clarke 1987, Jones & Boltz 1989).



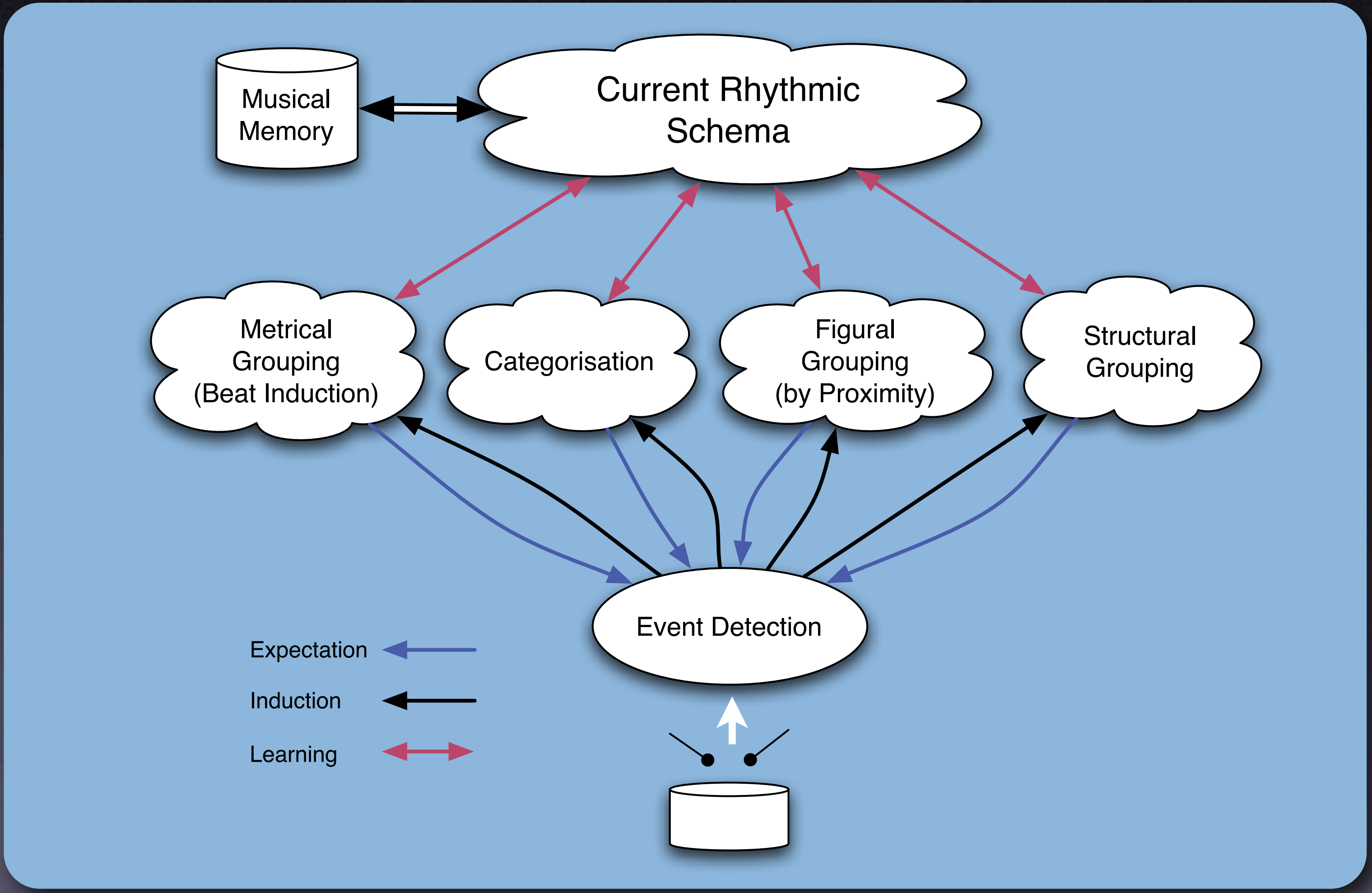
From Jones & Boltz '89

Hierarchical Grouping: Meter

- Meters are argued to arise from the interaction between temporal levels (Yeston 1976).
- Therefore a meter implies two frequencies: the pulse rate and the measure (“bar”) rate.
- The *tactus* is considered as the most salient hierarchical level, consistent with the notated meter, or the foot tapping rate (Desain & Honing 1994).

Active Rhythm Perception

- Viewed as a resonance between top down and bottom-up processes (see e.g Desain & Honing 1999):



Model Requirements

- Accounts for multiple, overlapping, temporal contexts.
- Multiple beat hypotheses.
- Identification of tactus.
- Expressive timing (*tempo rubato*).

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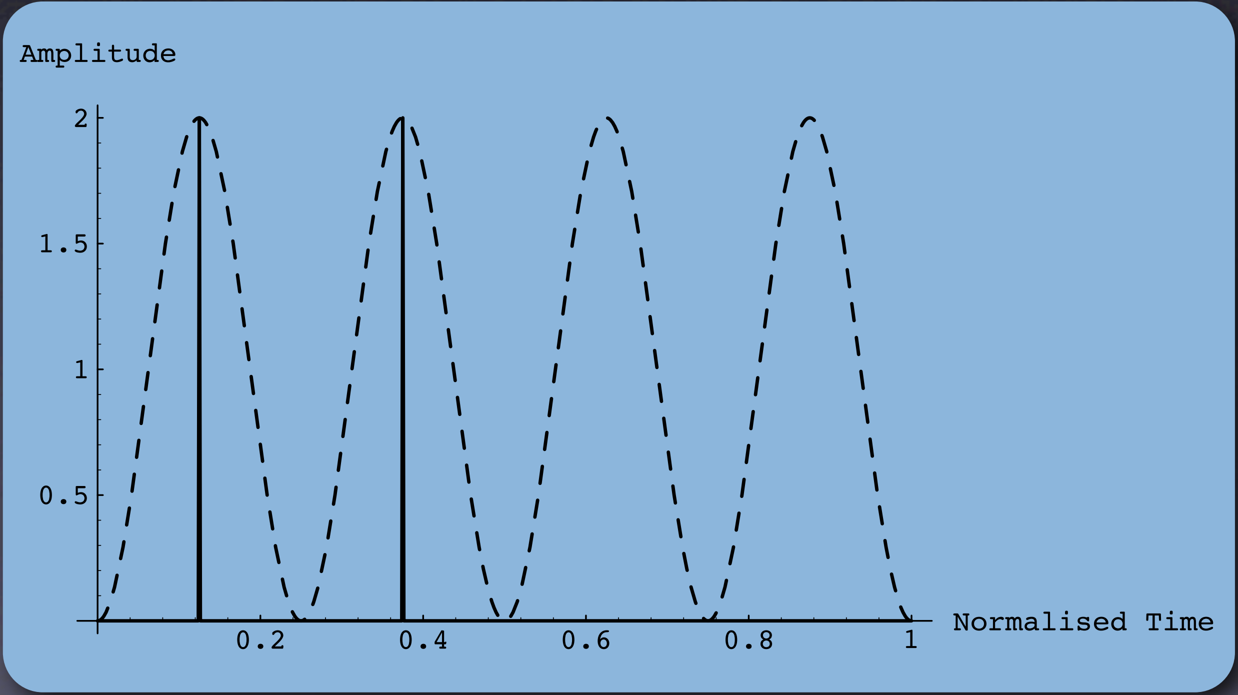
Existing Rhythmic Models

- Parsing metrical grammars (Longuet-Higgins and Lee 1982).
- Forward projection of likelihood (Desain 1992).
- Autocorrelation (Desain & Vos 1990, Brown 1993).
- Oscillator bank entrainment (Toiviainen 1998, Large 1994, Ohya 1994, Miller, Scarborough & Jones 1989).
- Auditory-Motor "Primal Sketch" (Todd 1994, Todd, O'Boyle & Lee 1999) from Sombrero filter banks.

Rhythm as a signal

- **Rhythm models have often implicitly dealt with rhythm as composed of periodic components:**
  - Consider each beat as a *critical sample* of the amplitude envelope, weighted by the peak amplitude.
  - The rhythm analysed is therefore a train of impulses, sampling the rectification of the auditory signal.



Spectrogram (STFT)

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...the
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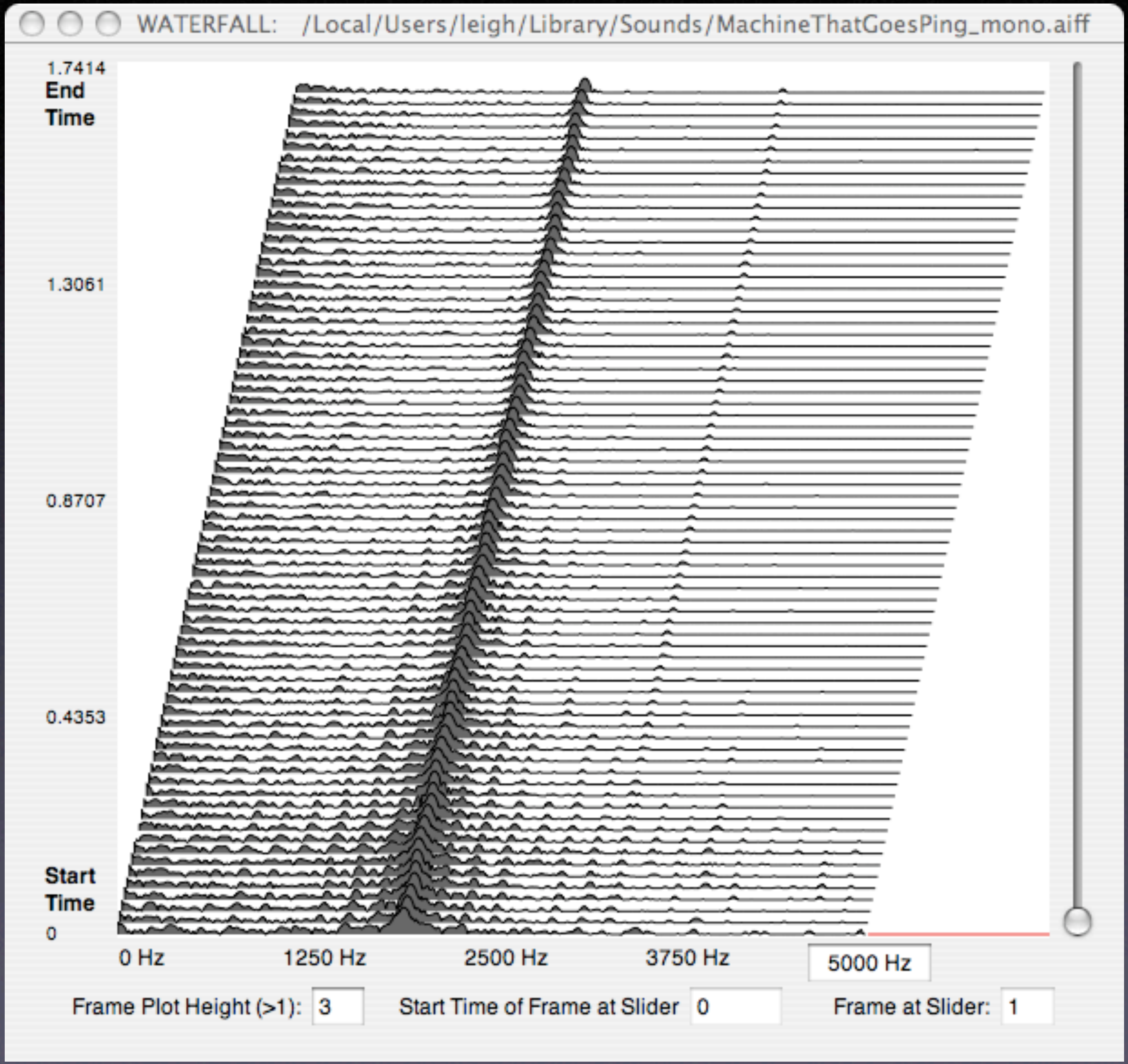
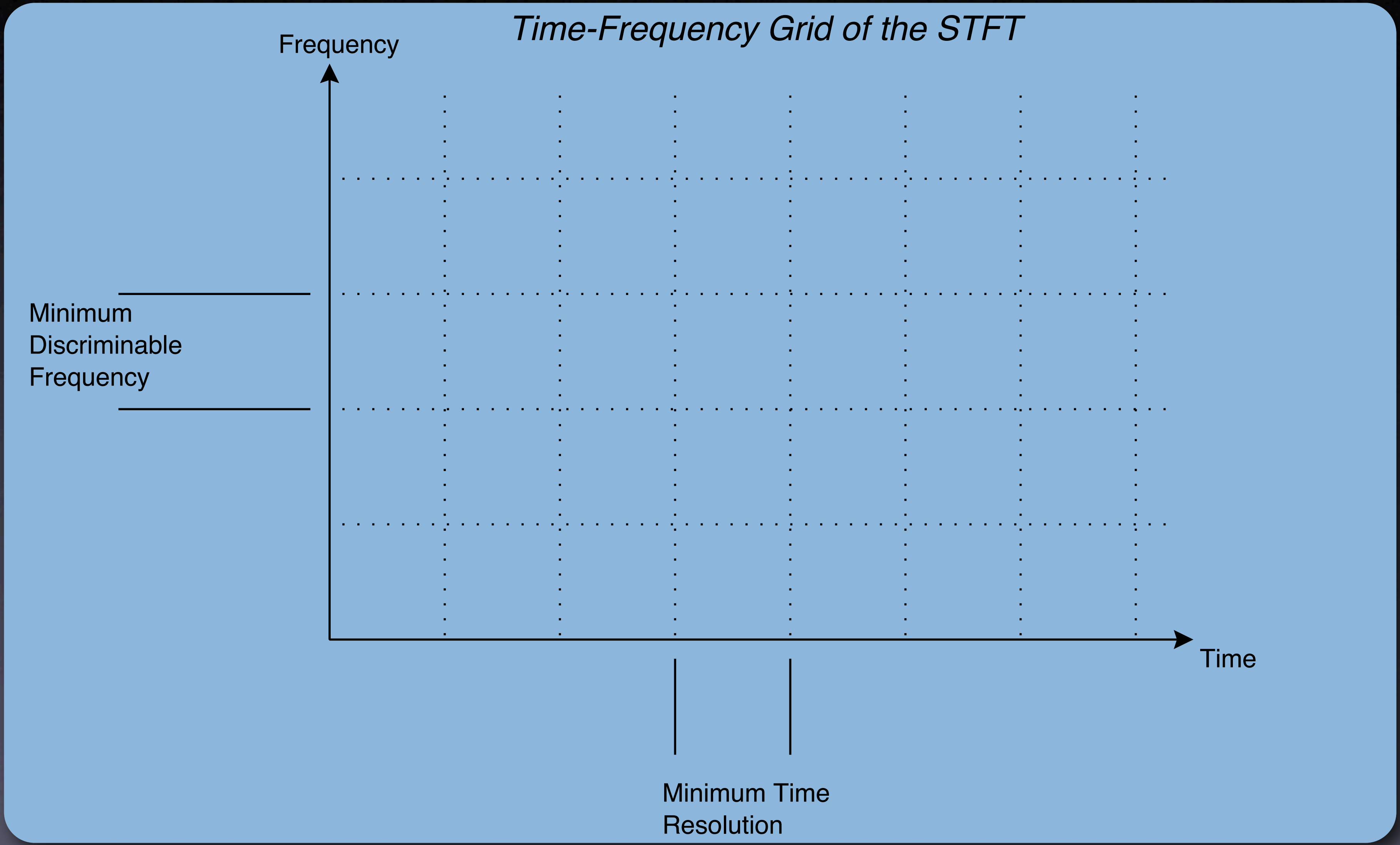


Short Term Fourier Transform



Wavelet time-frequency analysis

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$$g(t) = e^{-t^2/2} \cdot e^{i\omega_0 t}$$

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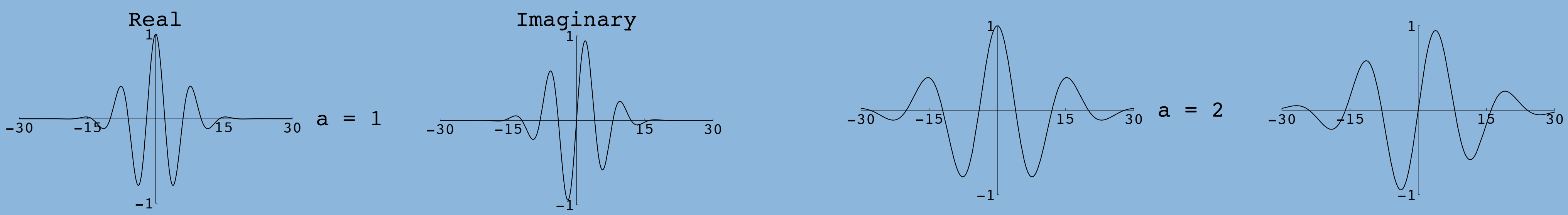

Implementation

- Implemented as a set of complex value bandpass filters in Fourier domain.
- Scaling produces a “zooming” time window for each frequency “scale”.
- Creates simultaneous time and frequency localisation close to the Heisenberg inequality.

Example: Sinusoidal Signal

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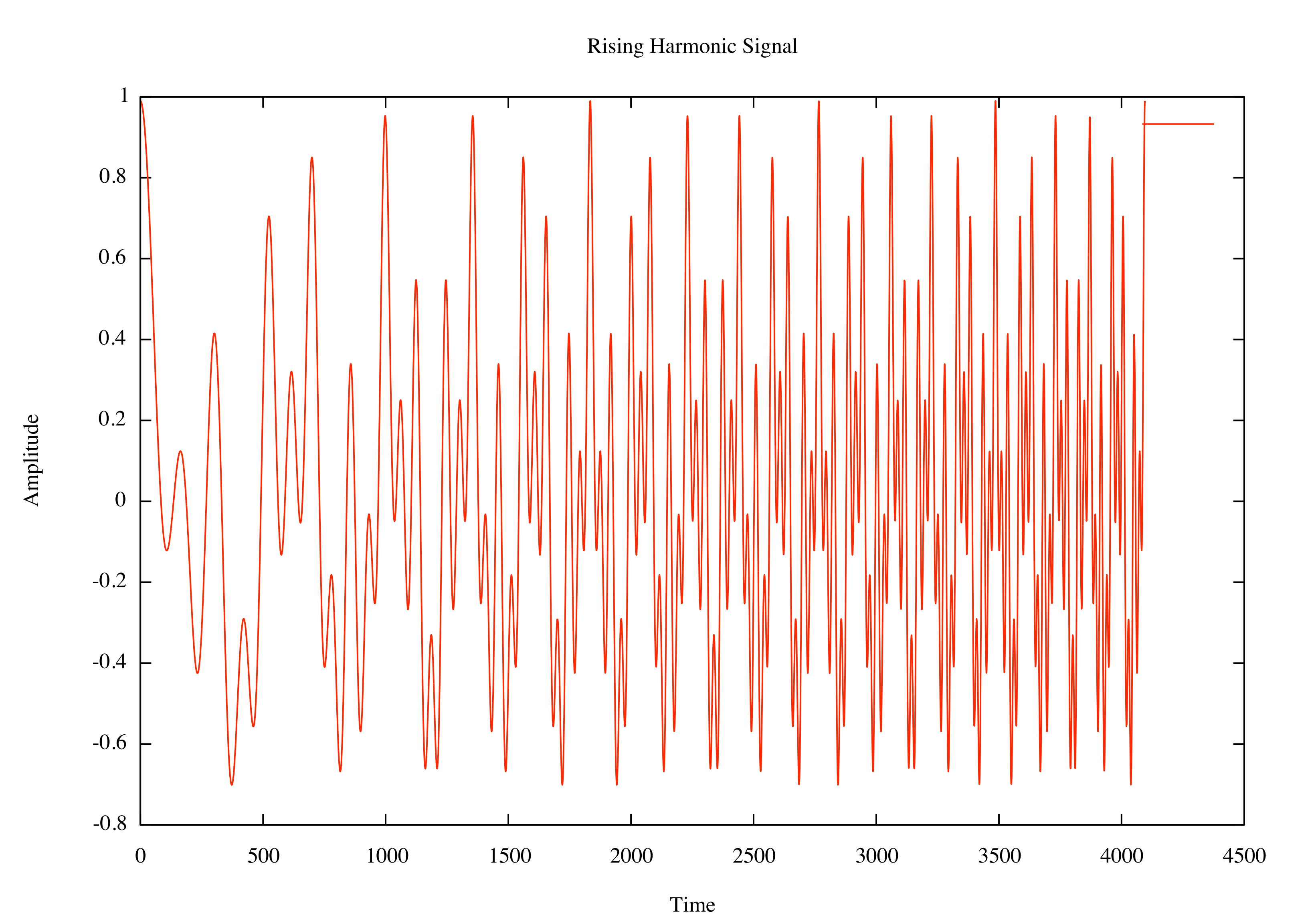

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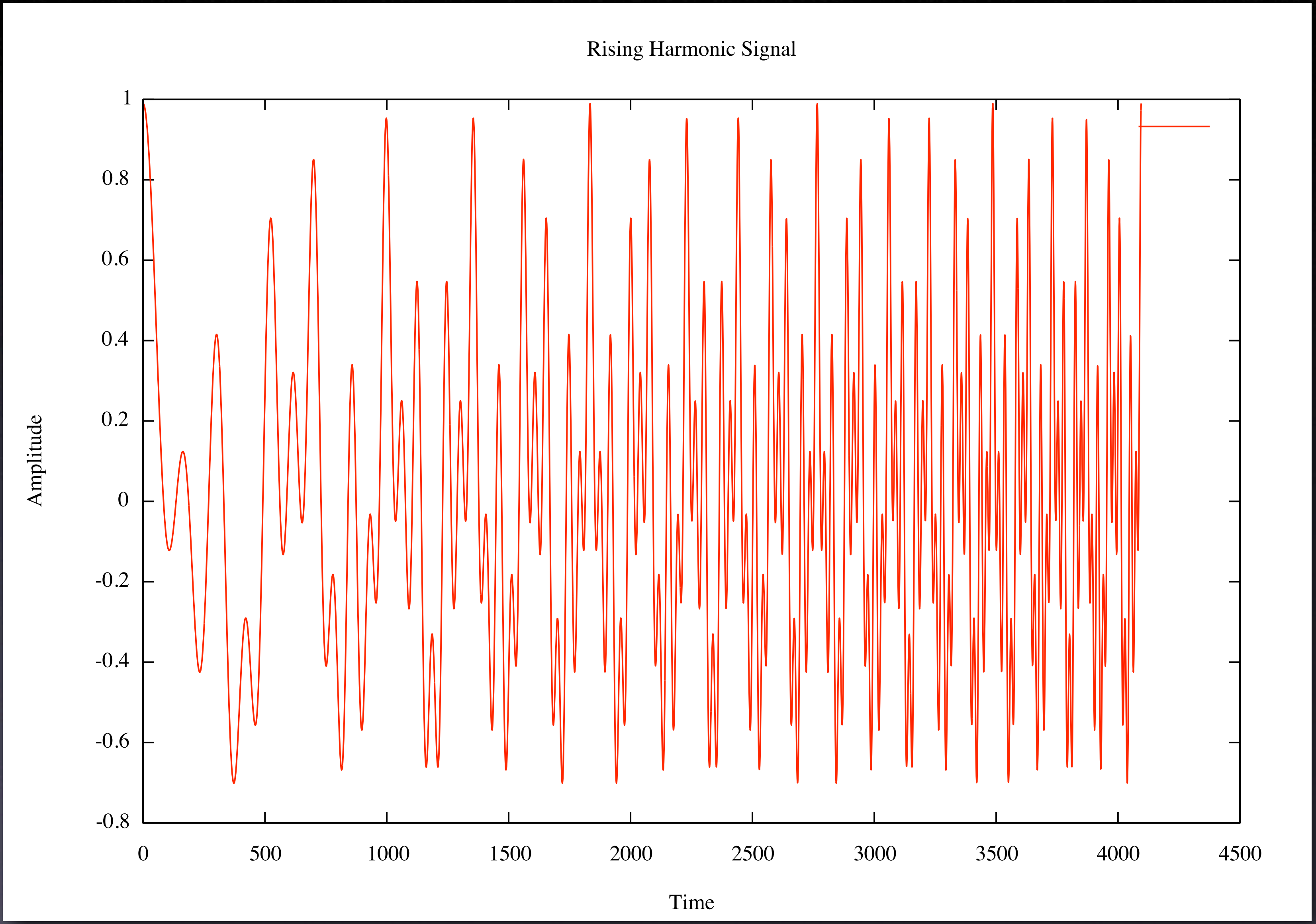

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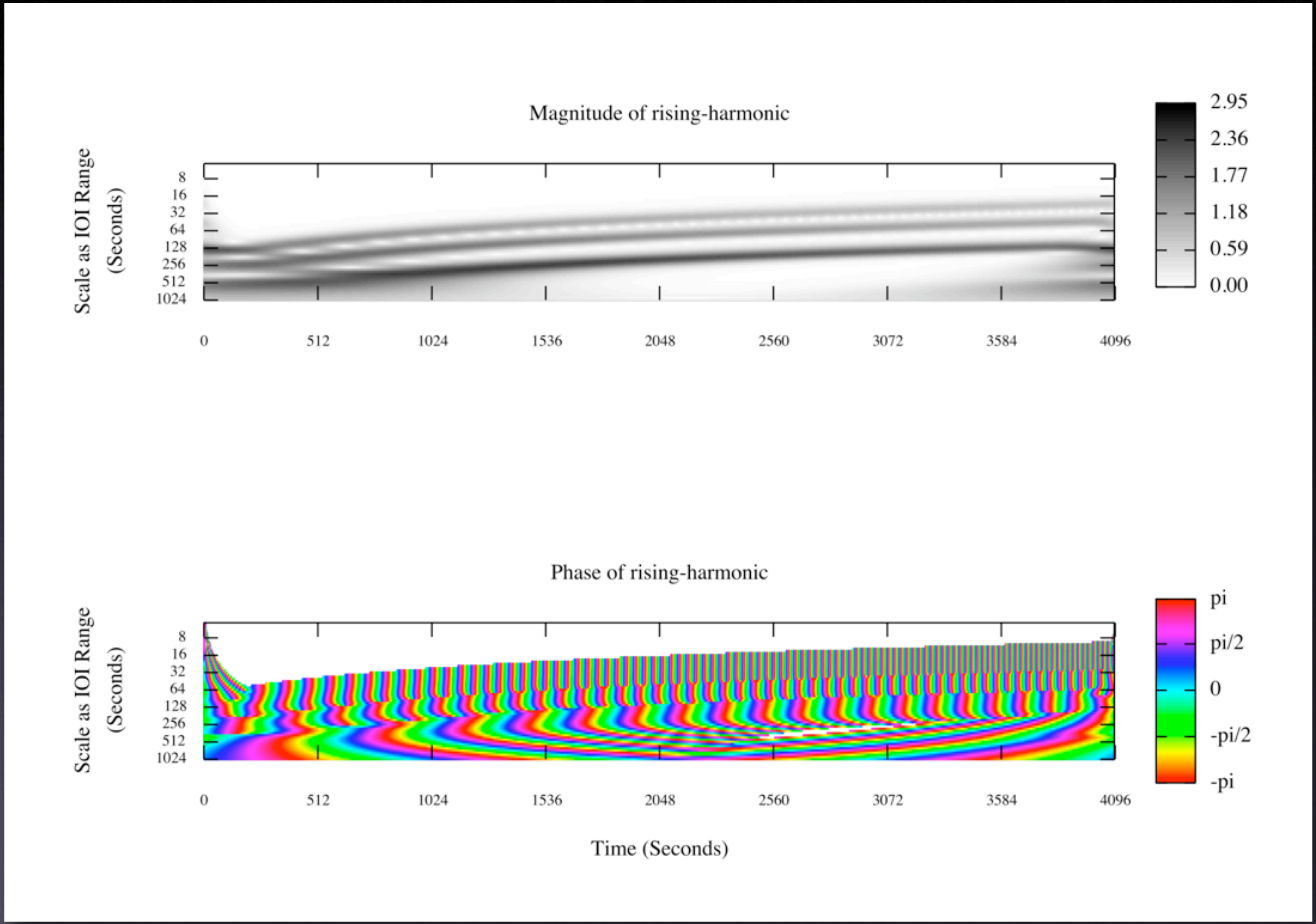

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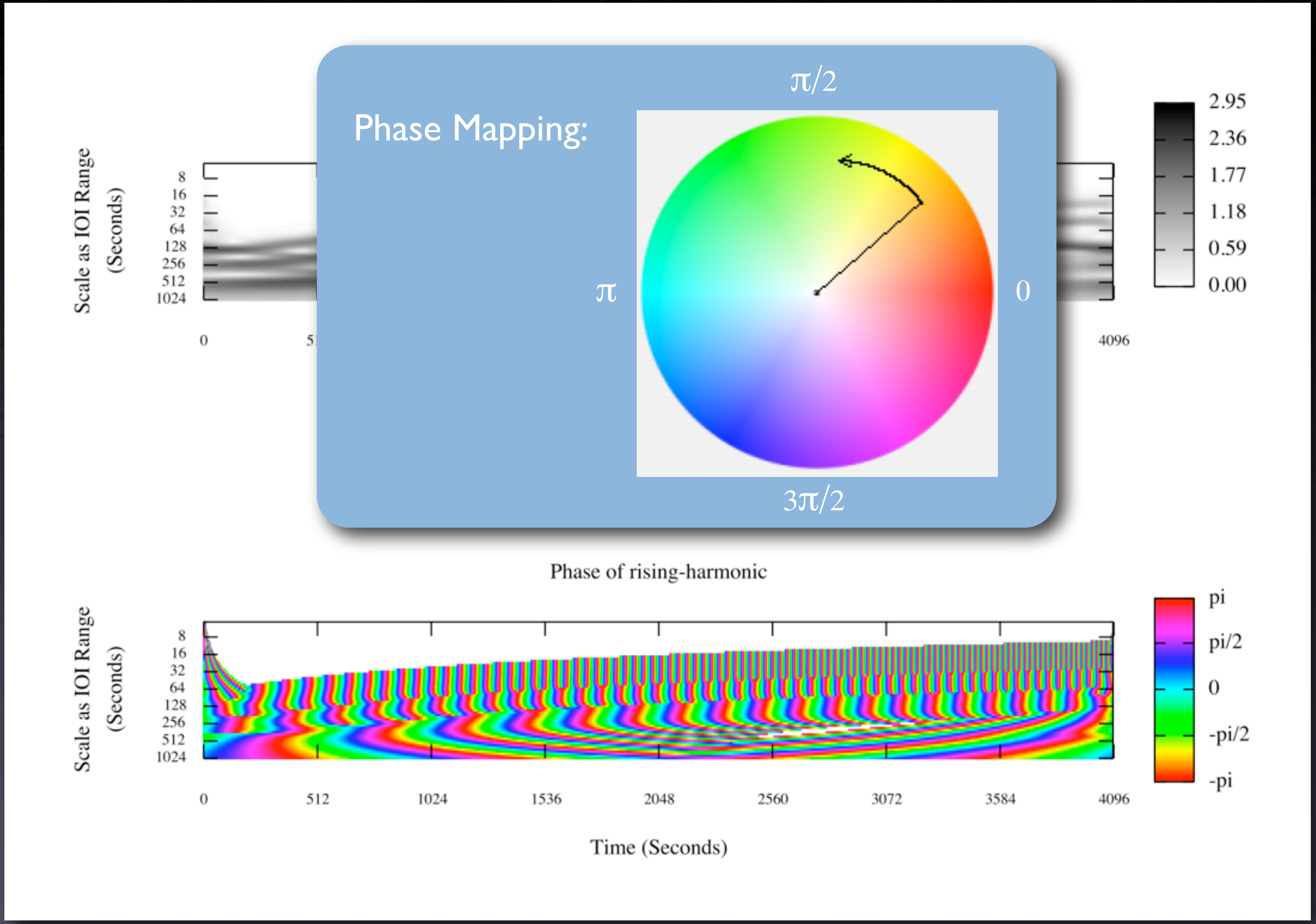
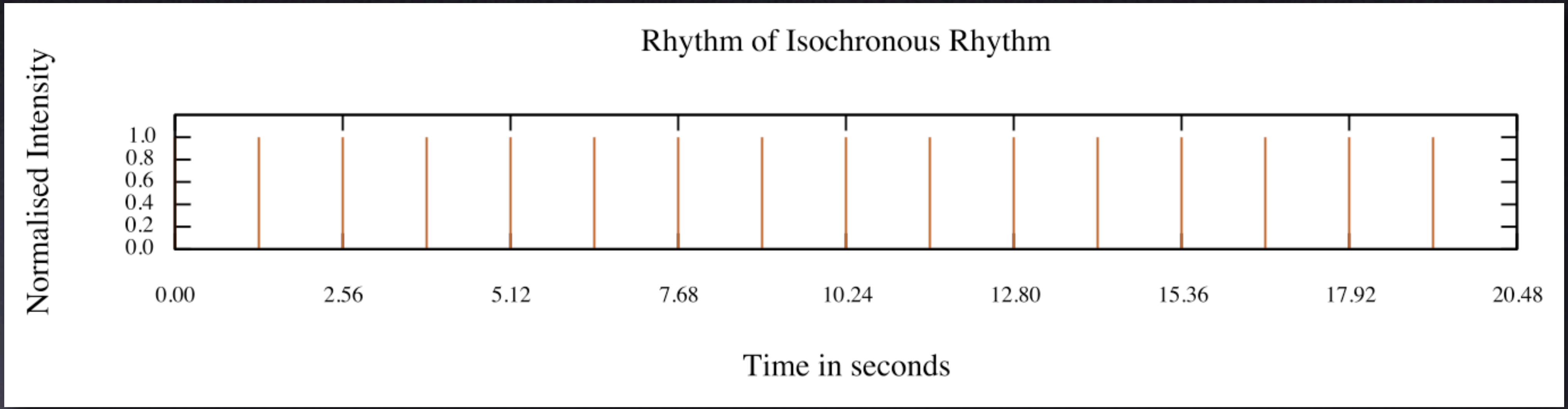


Example: Simple Rhythm

An isochronous pulse rhythmic signal:



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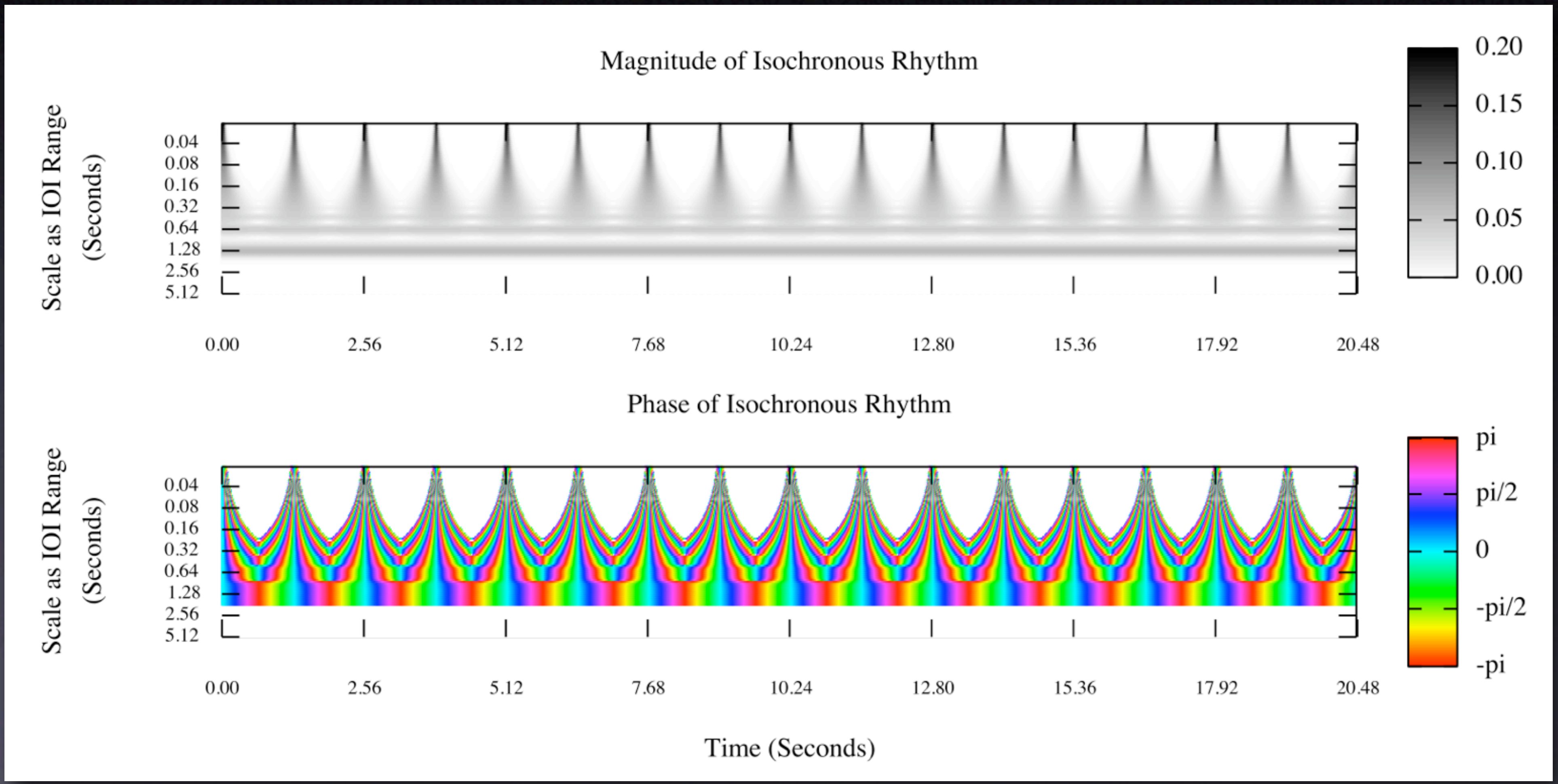

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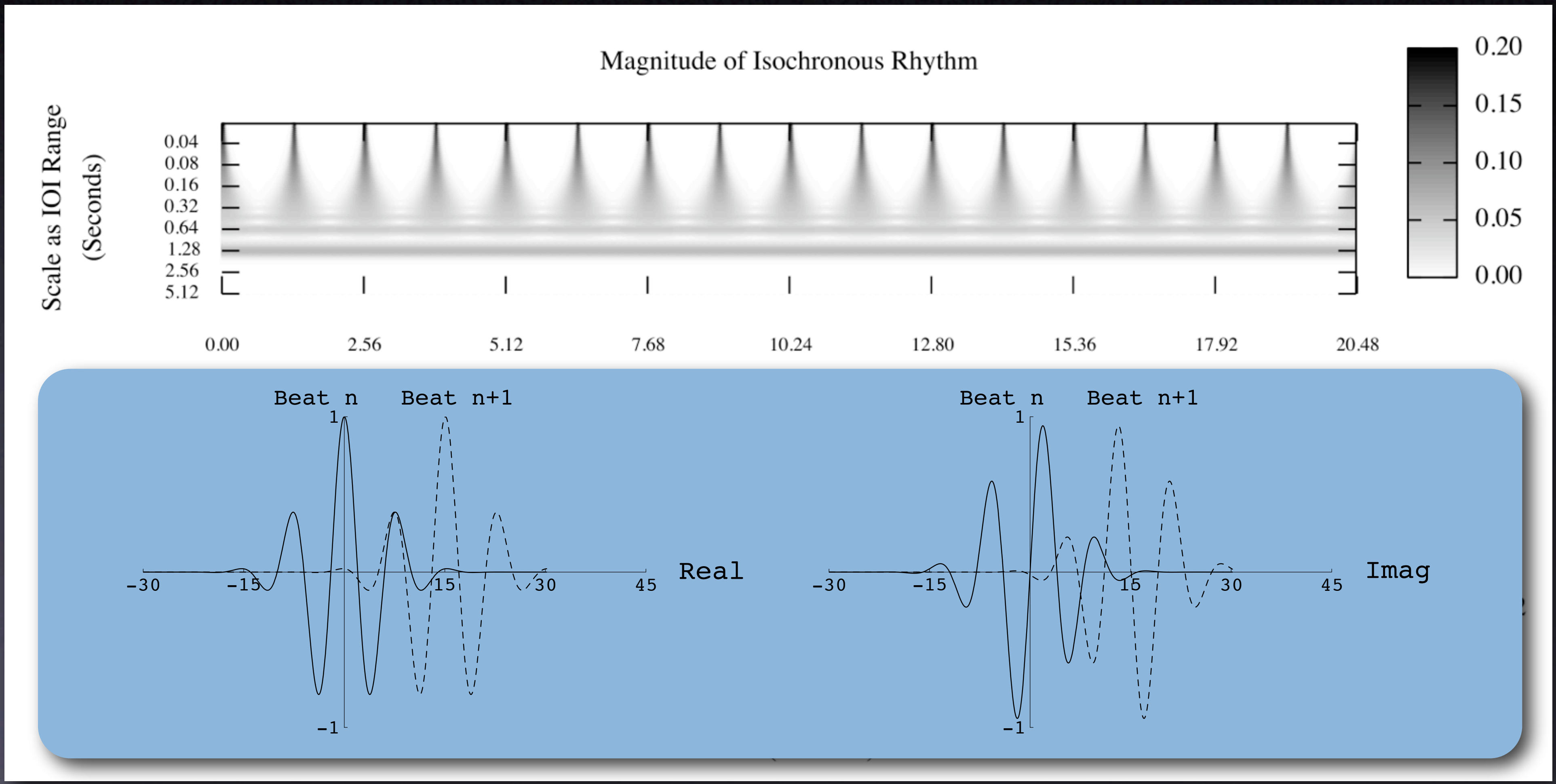

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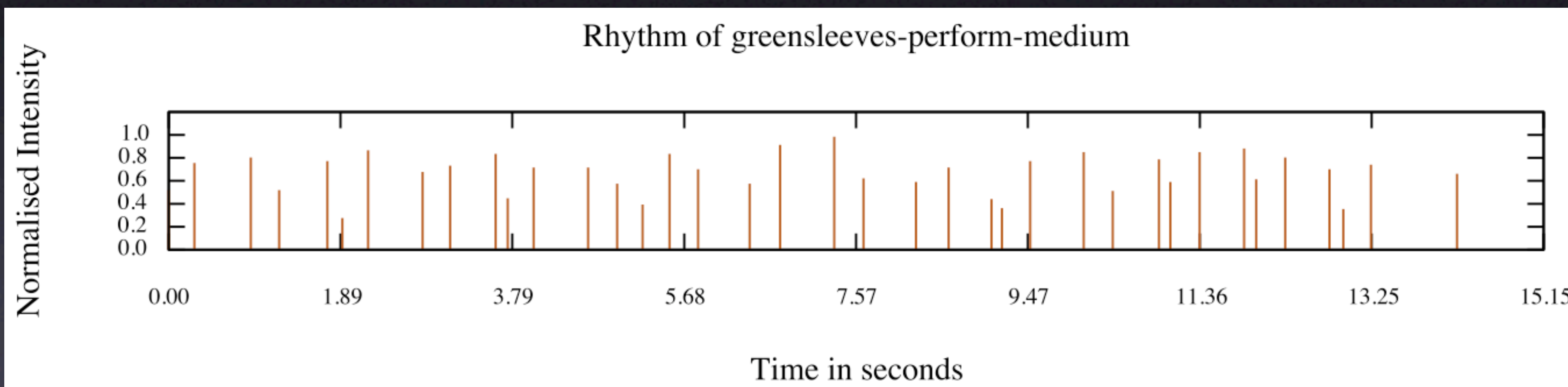
- The CWT enables representation of temporal structure in terms of time varying rhythmic frequencies.
- Produces magnitude and phase measures which reveal time-frequency *ridges* indicating the frequencies present in the input rhythm signal (collectively a *skeleton,* Tchamitchian & Torrésani '92).

Musical Example

- The rhythm of "Greensleeves"...



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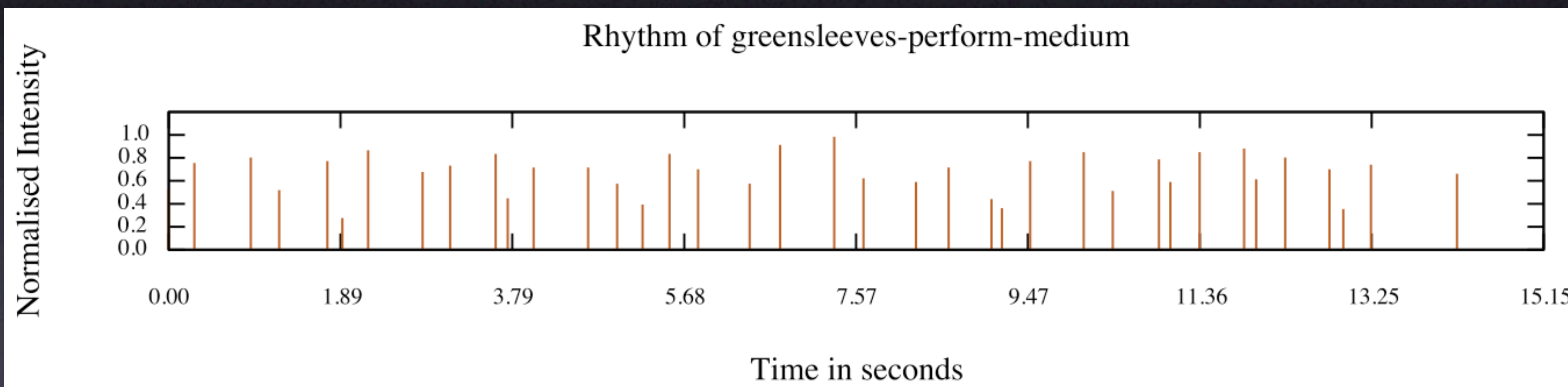

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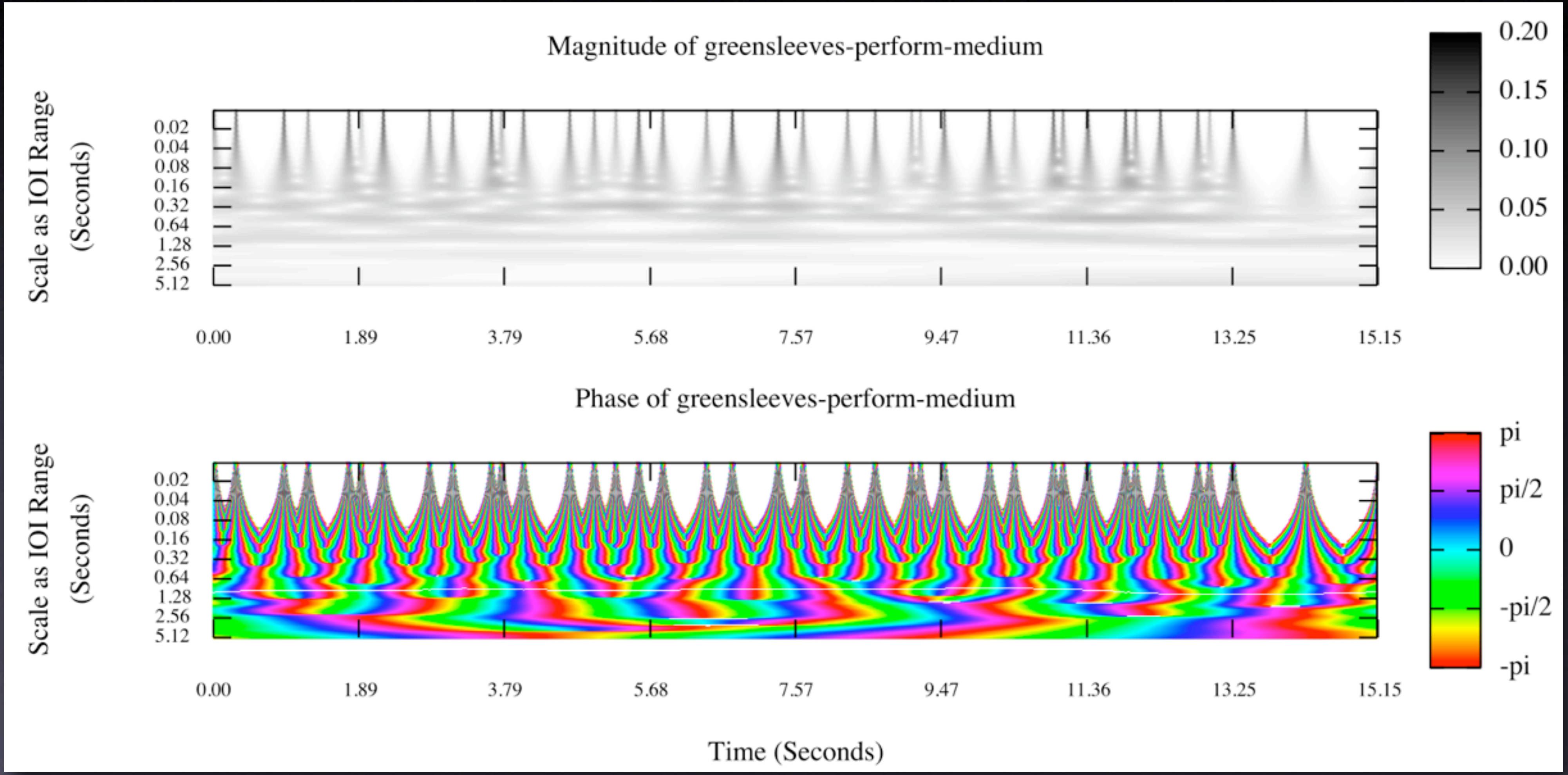
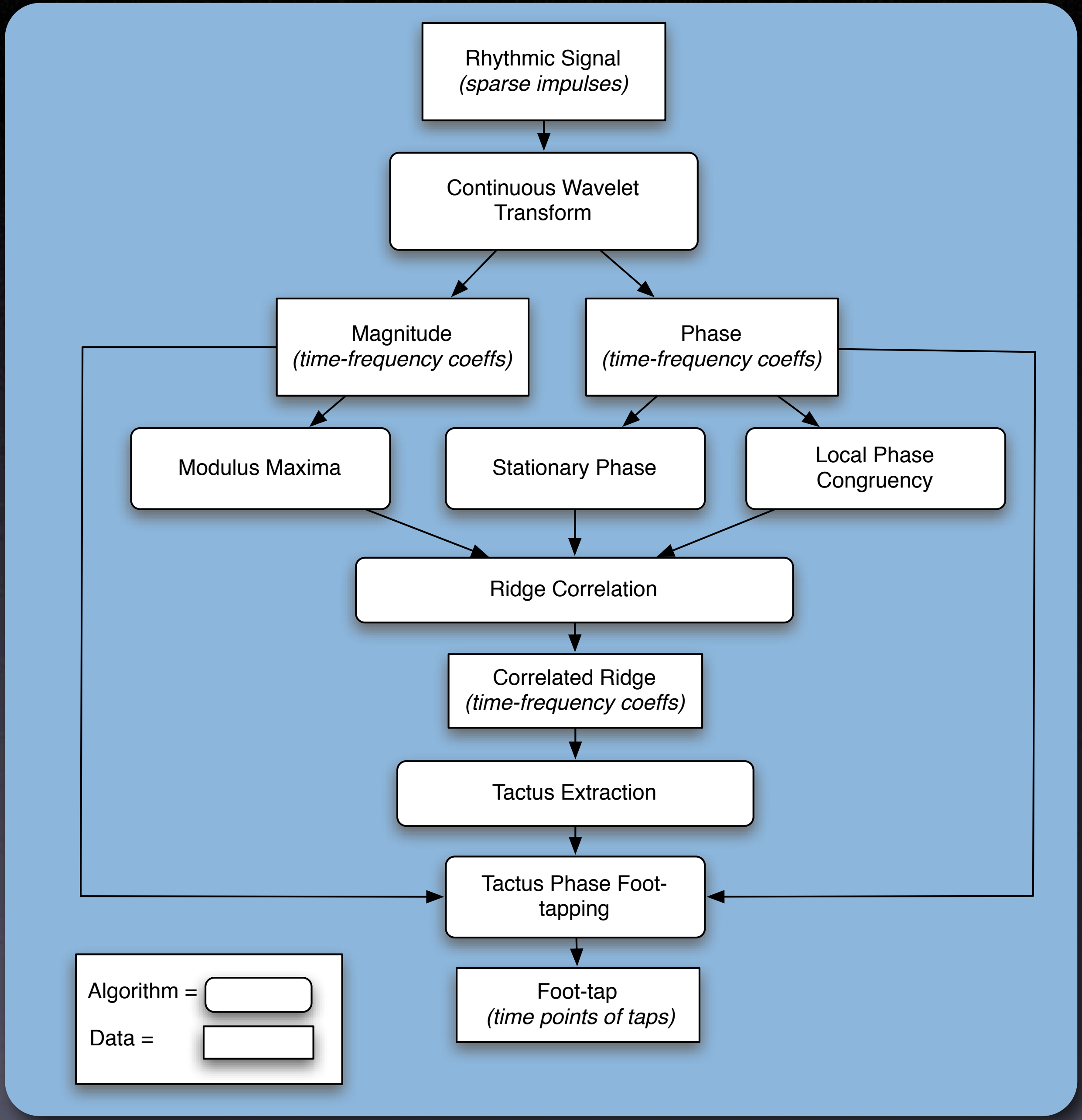


System Overview



Application:
Foot-tapping by reconstruction

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- Suppress all but the magnitude coefficients of the extracted tactus ridge.
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- Produces a sinusoidal AM signal with an intact phase, and a period matching the foot-tap interval.
- Nominating a starting beat and noting its phase, all other foot-taps are generated for the same phase value.

Tapping to Greensleeves

- The rhythm of "Greensleeves" with computed foot-tap...

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Interpretation

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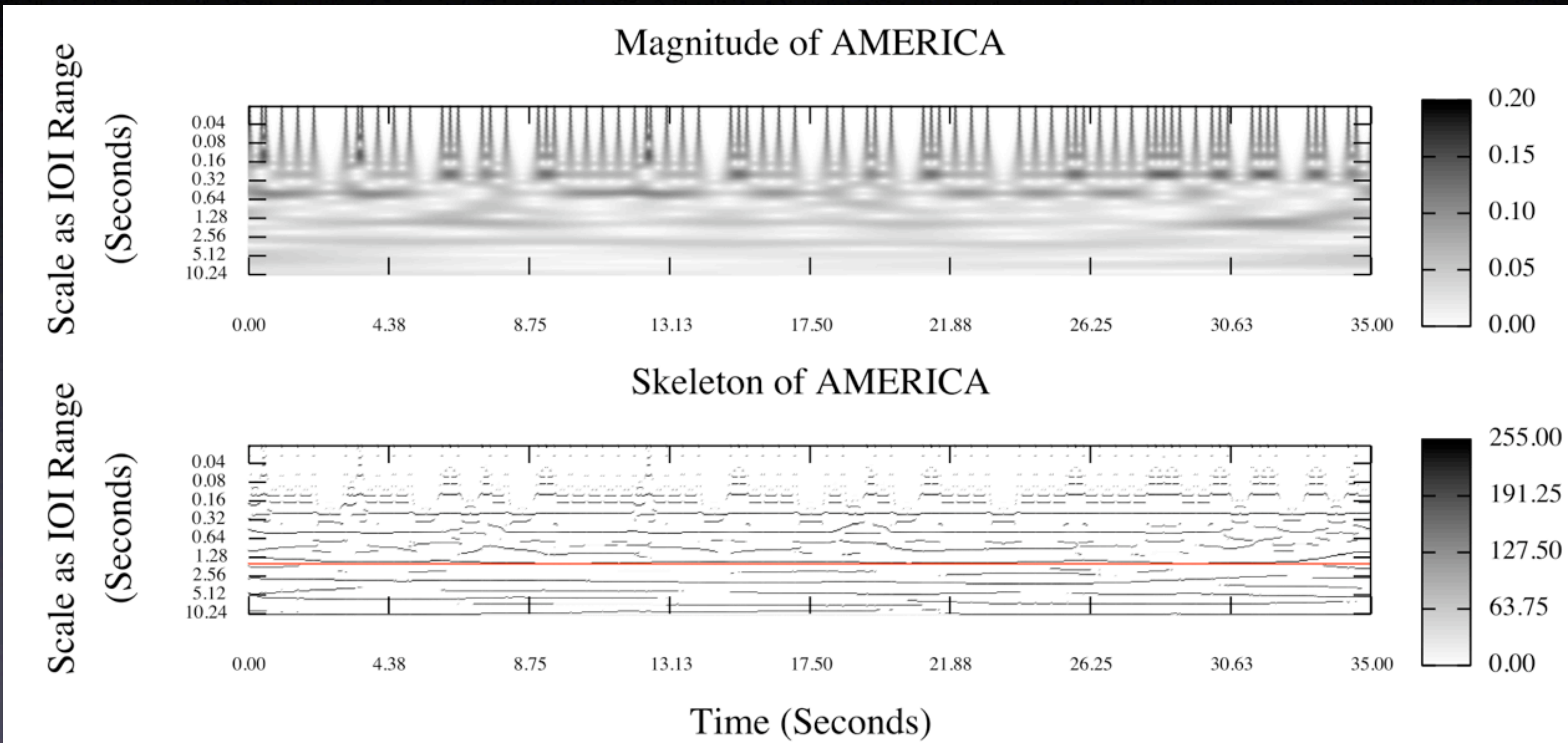
  - Indicates how much structure is in the rhythmic signal.
- Metrical durations from CWT suggests that rhythmic strata (ridges) may act as (bottom-up) cues to a metrical interpretation.
- Establishes a distinction between top-down expectation and bottom-up categorisation processes.

Evaluation Data: Anthems

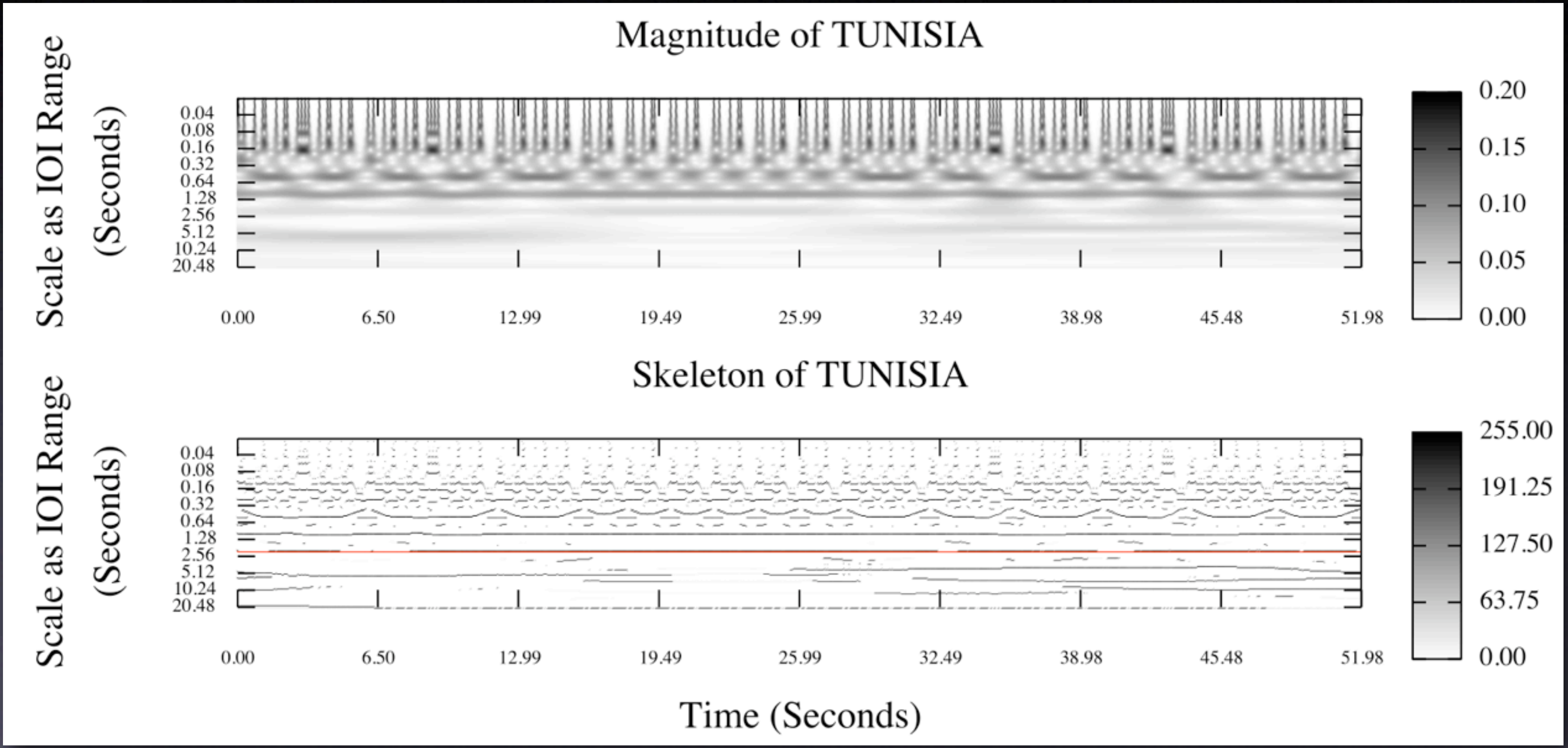
(Smith & Honing: ICoMCS 2007)

- 105 National Anthems (Shaw & Coleman 1960).
- Rhythms transcribed into interonset intervals (IOI), quarter-note & bar duration, anacrusis.
- No melodic, intensity or expression accents.
- Also used in analysis of rule-based systems of Longuet-Higgins & Lee (1982, 1985, 1991) (Desain & Honing 1999).
- Limited to a maximum length of 82 seconds each.

Example: America



Example: Tunisia



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Ridge Presence

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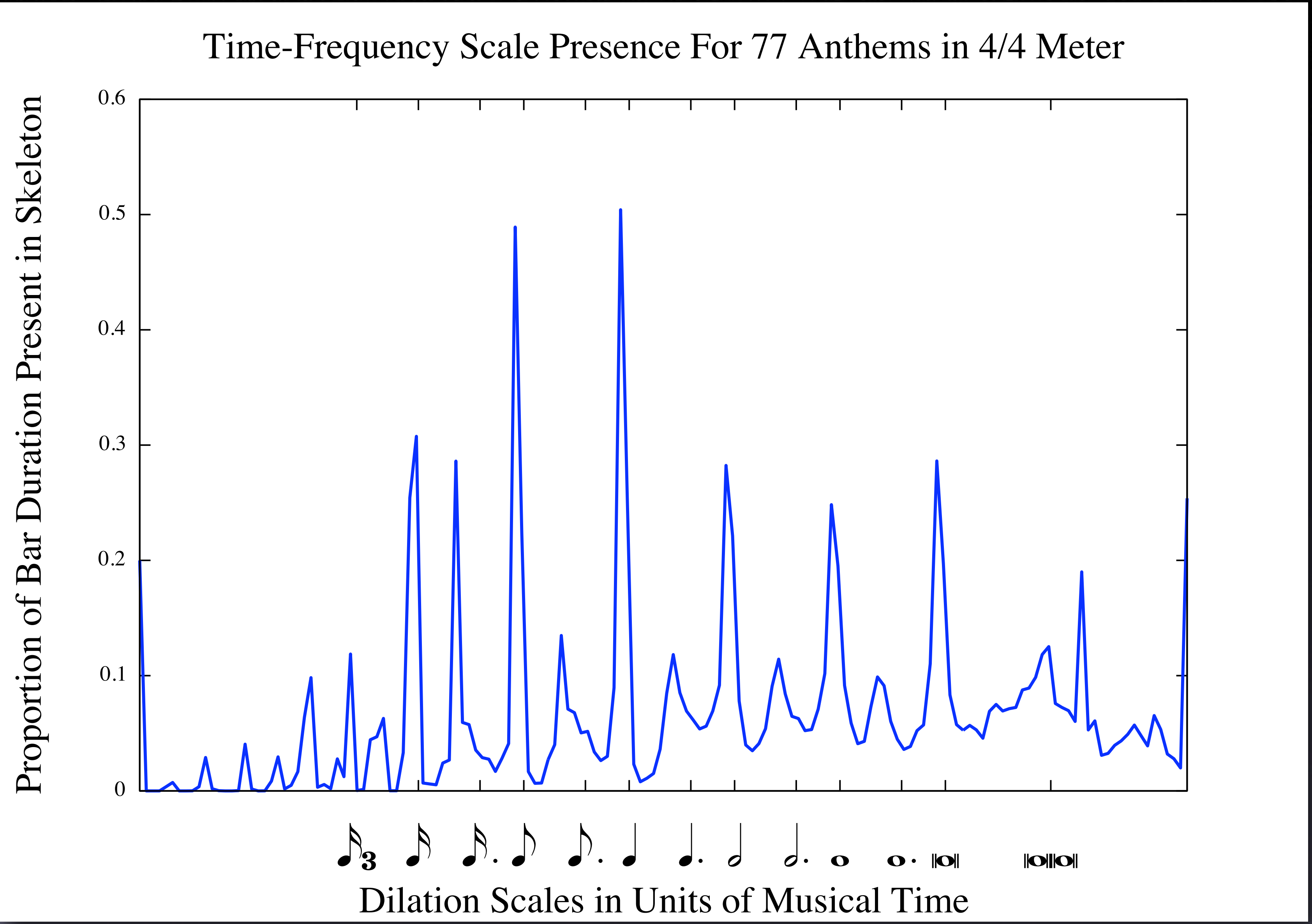
- Average Ridge Presence: relative frequency of occurrence of each ridge averaged across *all* rhythms of a given meter.

Average Ridge Presence



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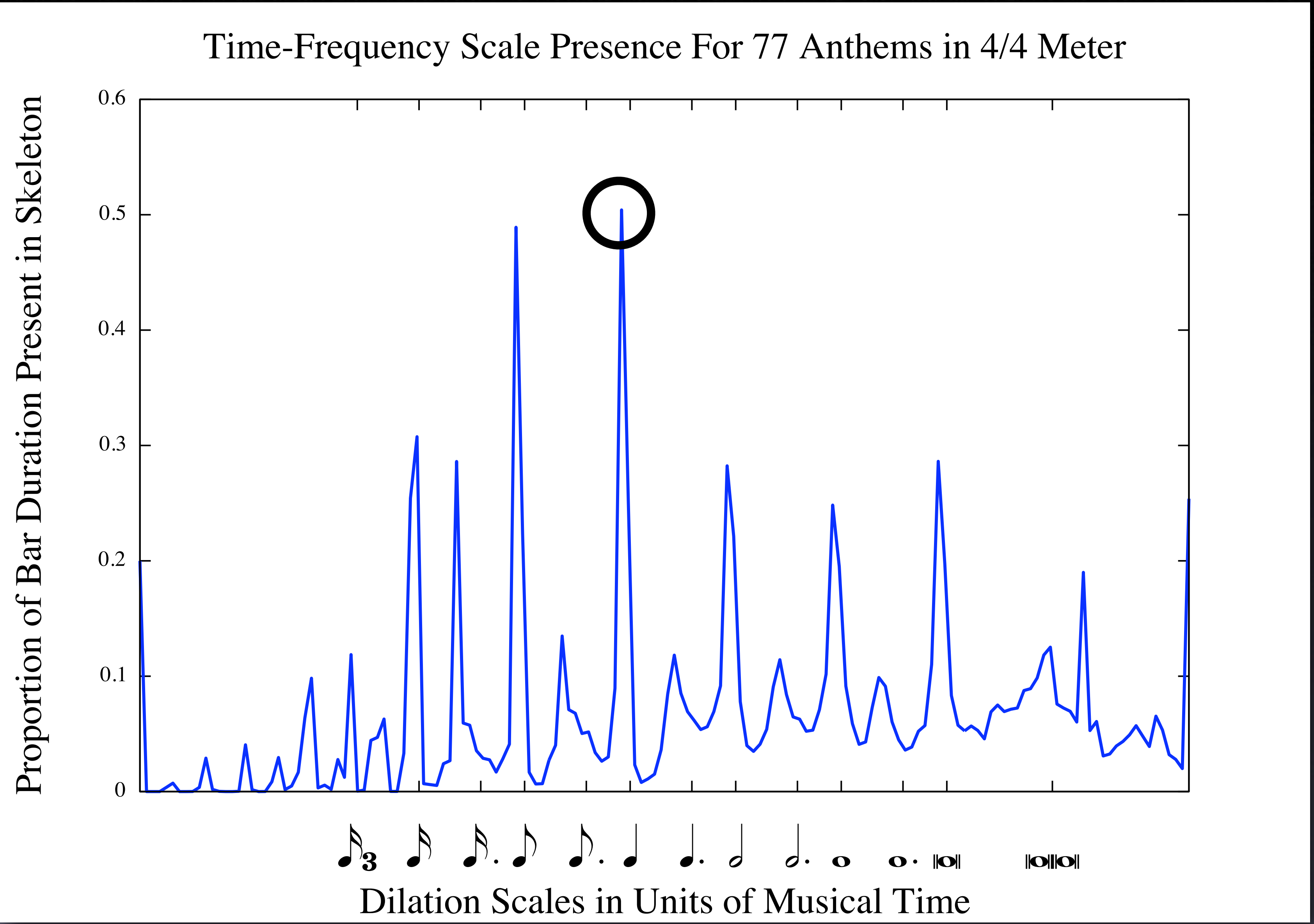

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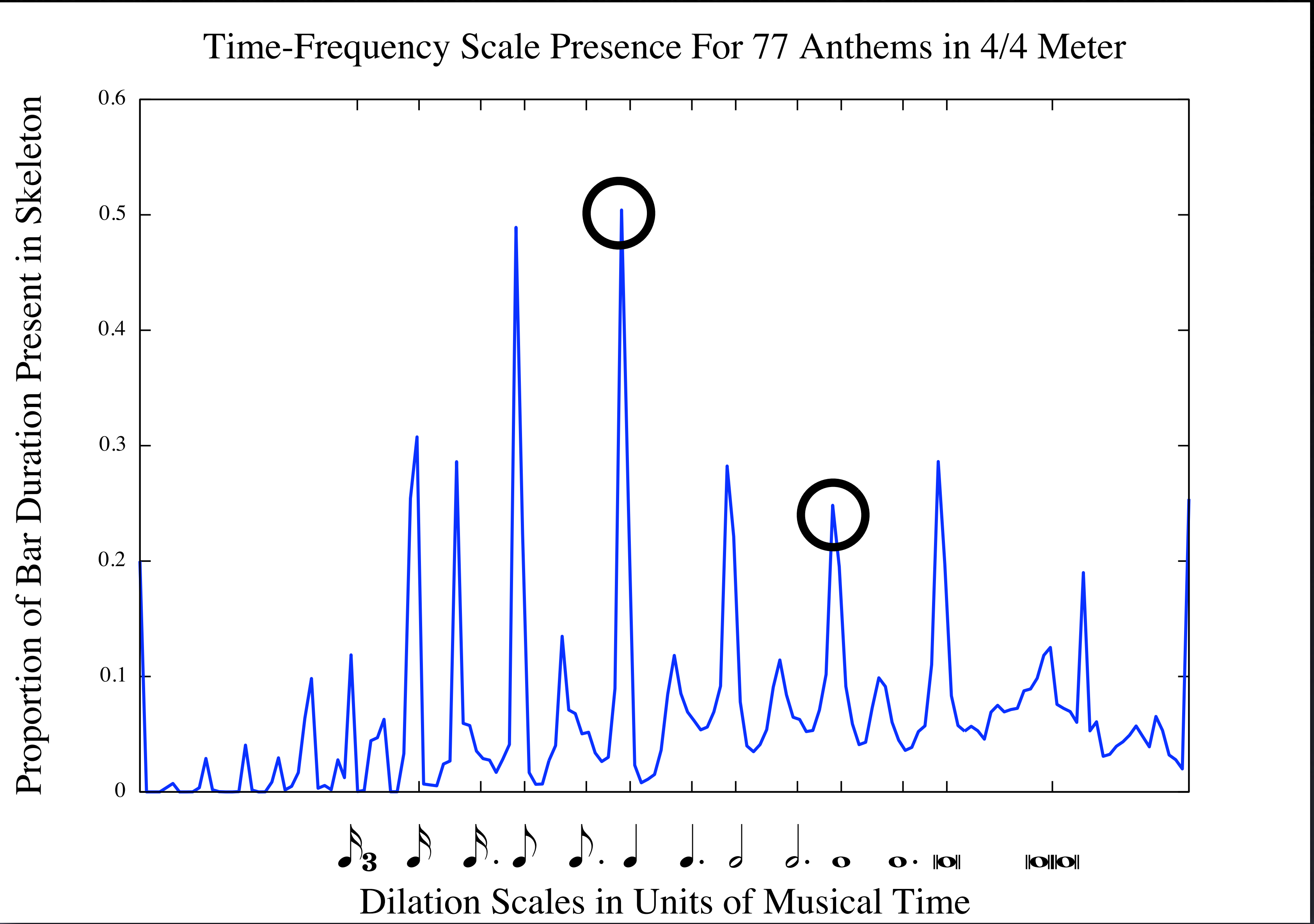
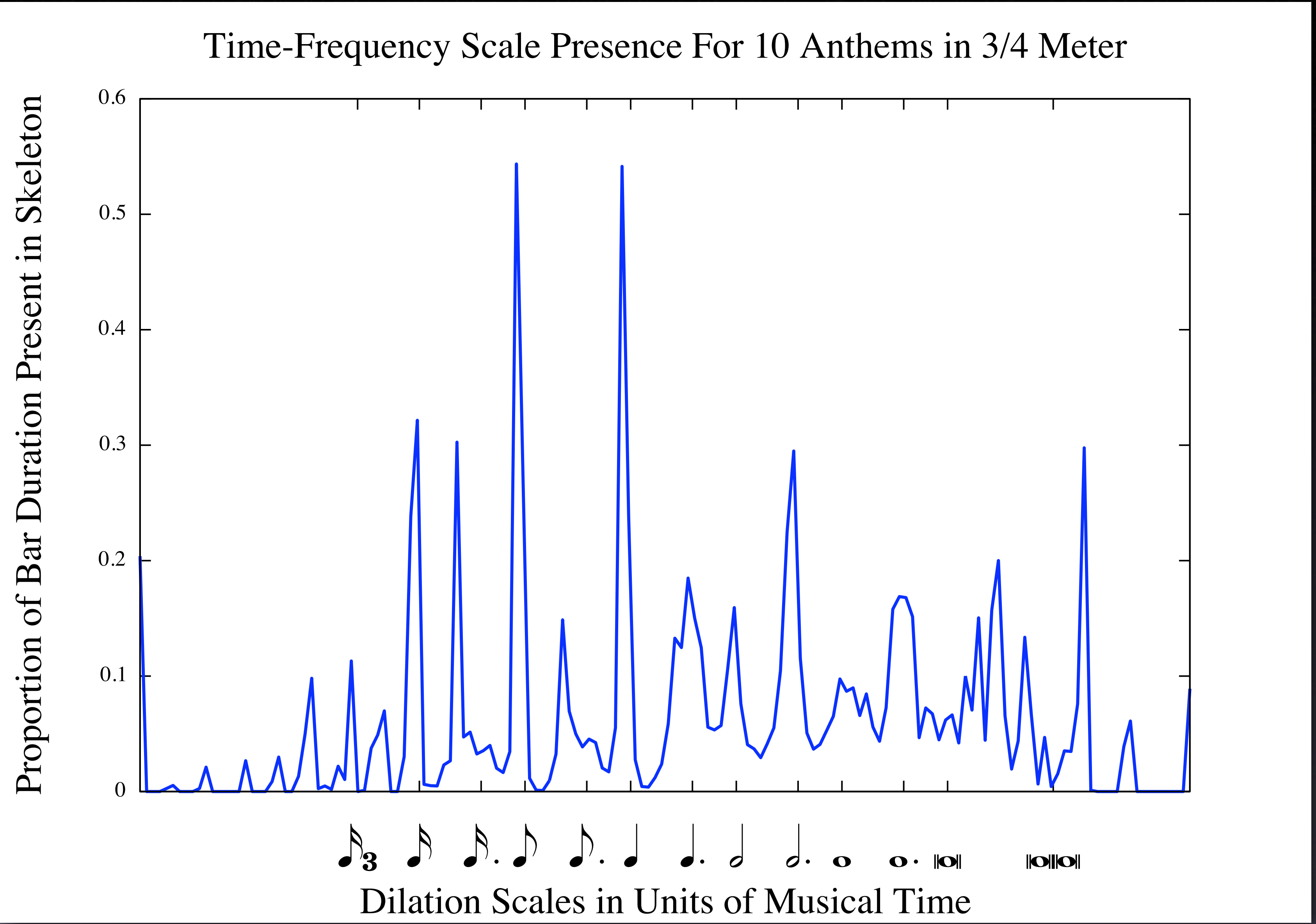


Triple Meter



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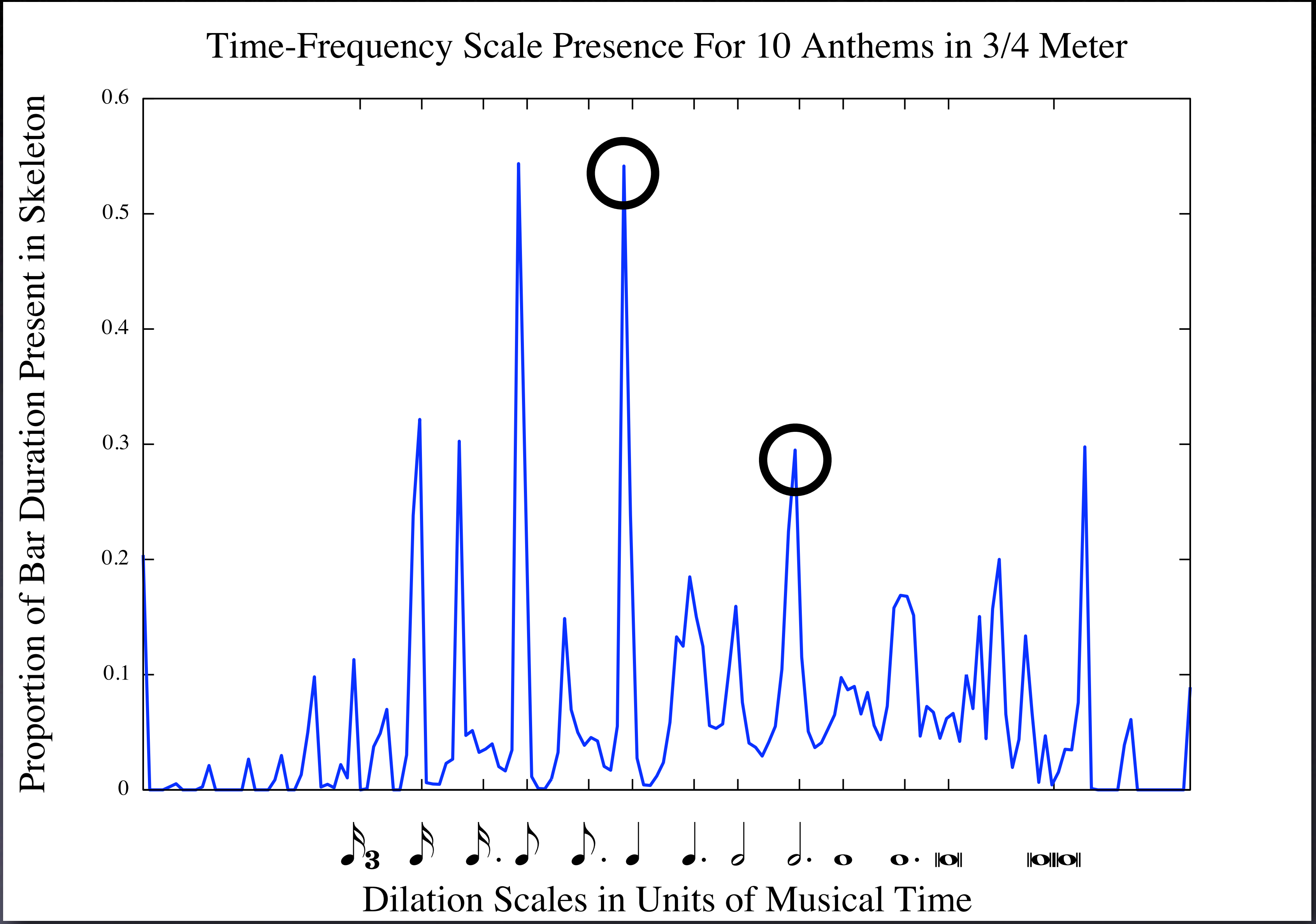
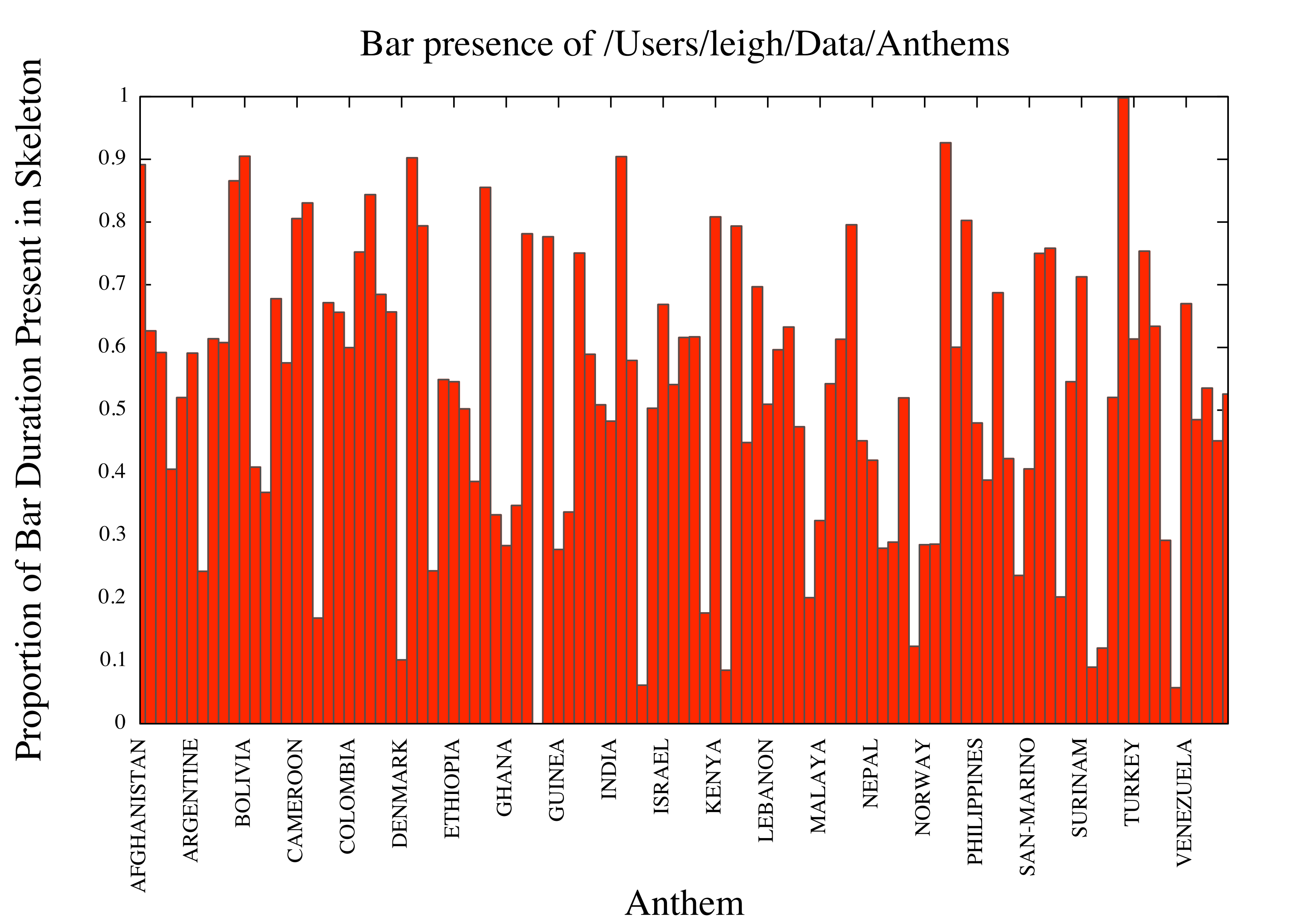


Presence of Bar Ridges



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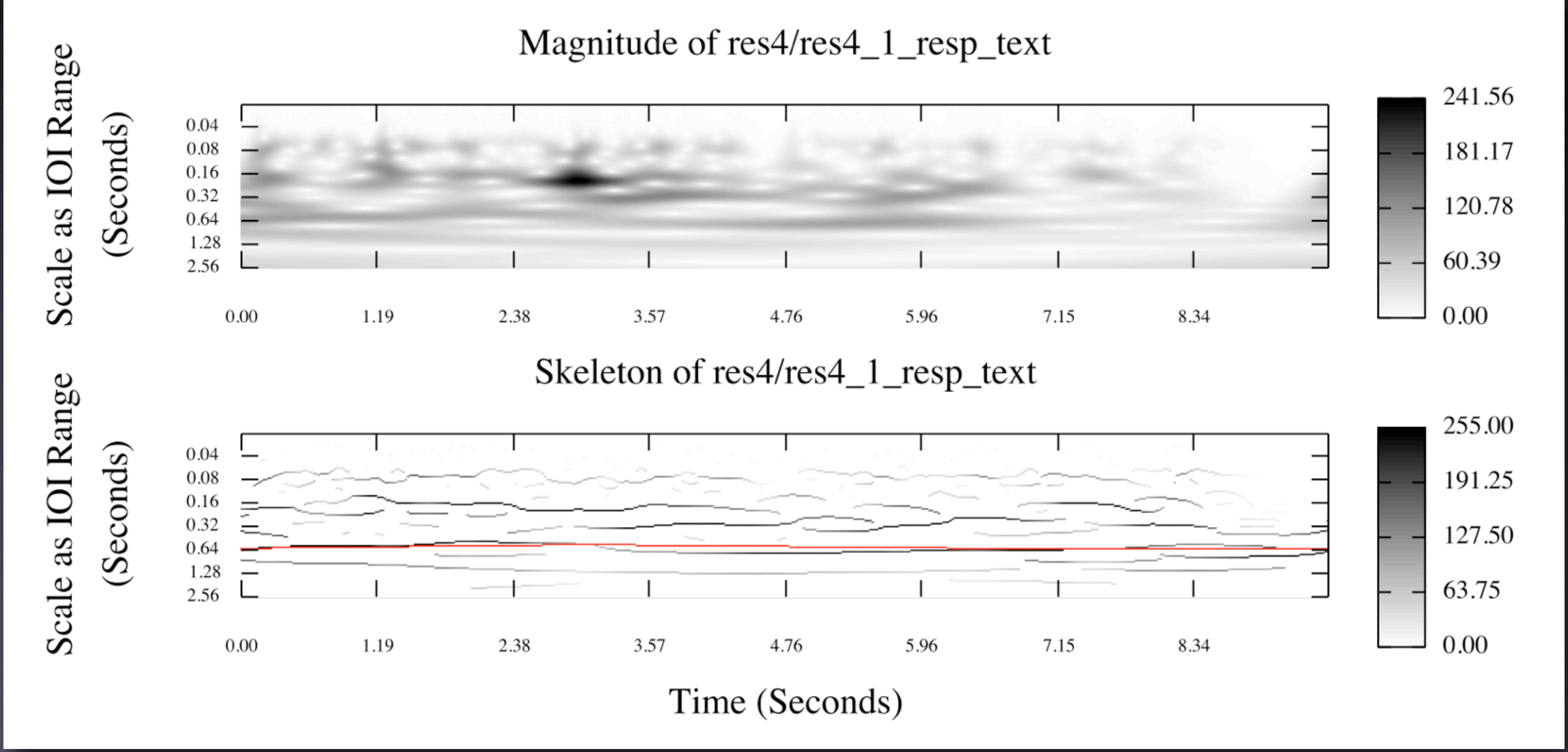
- Stable over anthem database, exceptions probably due to lack of harmonic/melodic disambiguation.
- Not simply statistical (only 33 anthems have any interonset-intervals of bar duration).

Memory Based Tactus

- Wavelet rhythm analysis is also applicable to continuous onset salience traces from auditory models (Coath et. al, to appear: Connection Science 2008).



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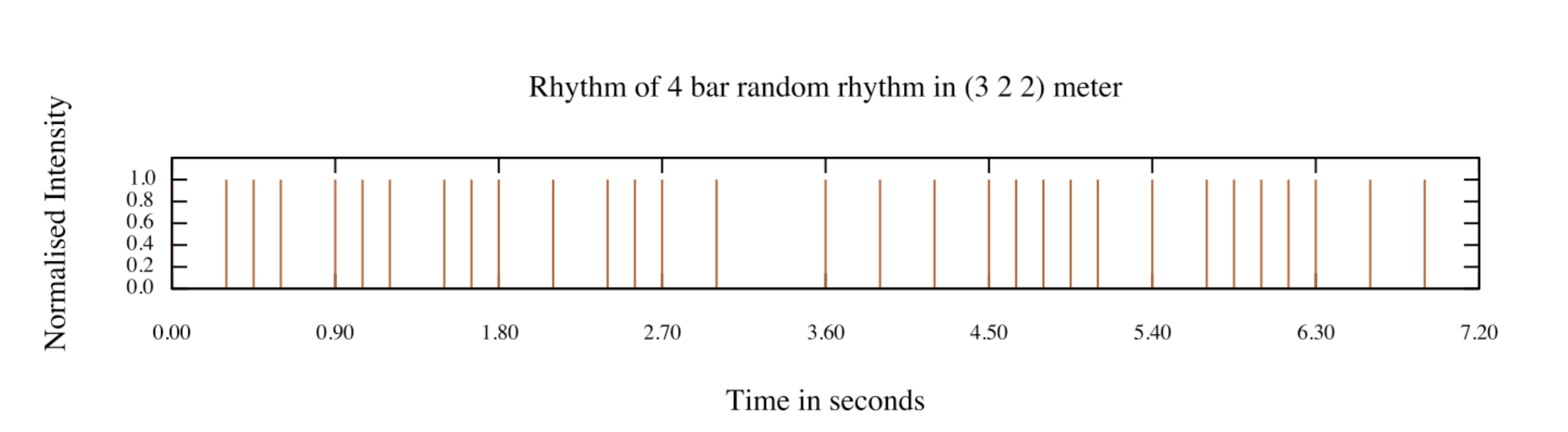
- Example 1: Original... ...Original + Accompaniment
- Example 2: ...Original + Accompaniment

Expectation

- Generates future expectation times given a performed rhythm.
- Uses lossy windowed integrator to amass likelihood of projected time periods.
- Weighted by absolute tempo constraints.
- Uses CWT phase measures to correct the projected periods for phase at the edge of the time window.

Emerging Metrical Context

- Example 3/4 rhythm (no accents)



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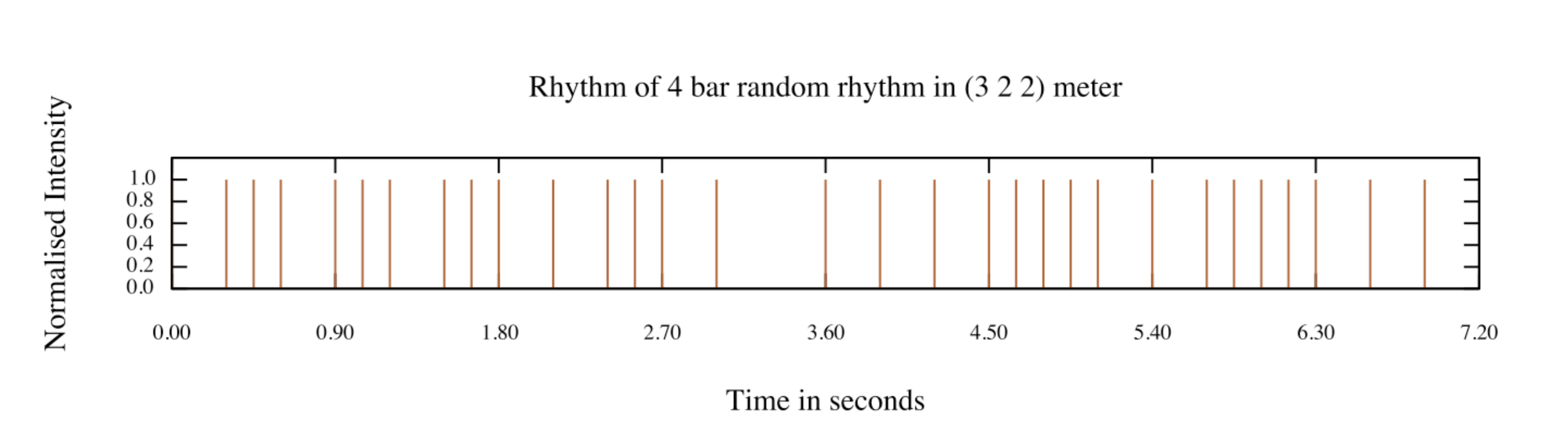

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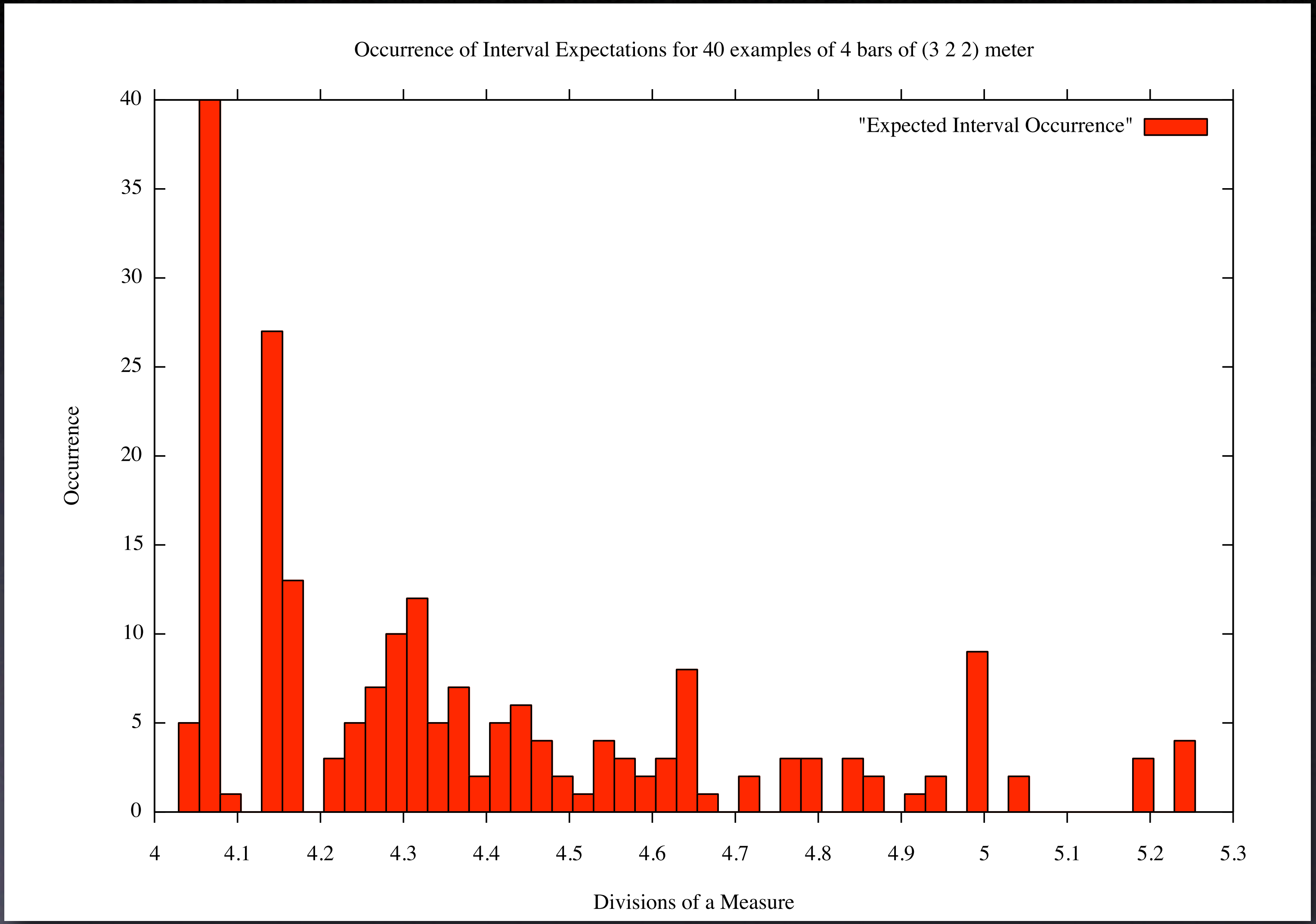

Further Work

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- Use of rhythmic phase that is available from the CWT to identify an anacrusis (upbeat).
- Compare performance against larger datasets (e.g MIREX).
- Derivation of causal multiresolution model combined with memory store for retrospection.

http://www.hum.uva.nl/mmm

http://www.science.uva.nl/~lsmith