

Examples of Cognitive Musicology: Modelling Perception of Musical Rhythm & Expectation

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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.

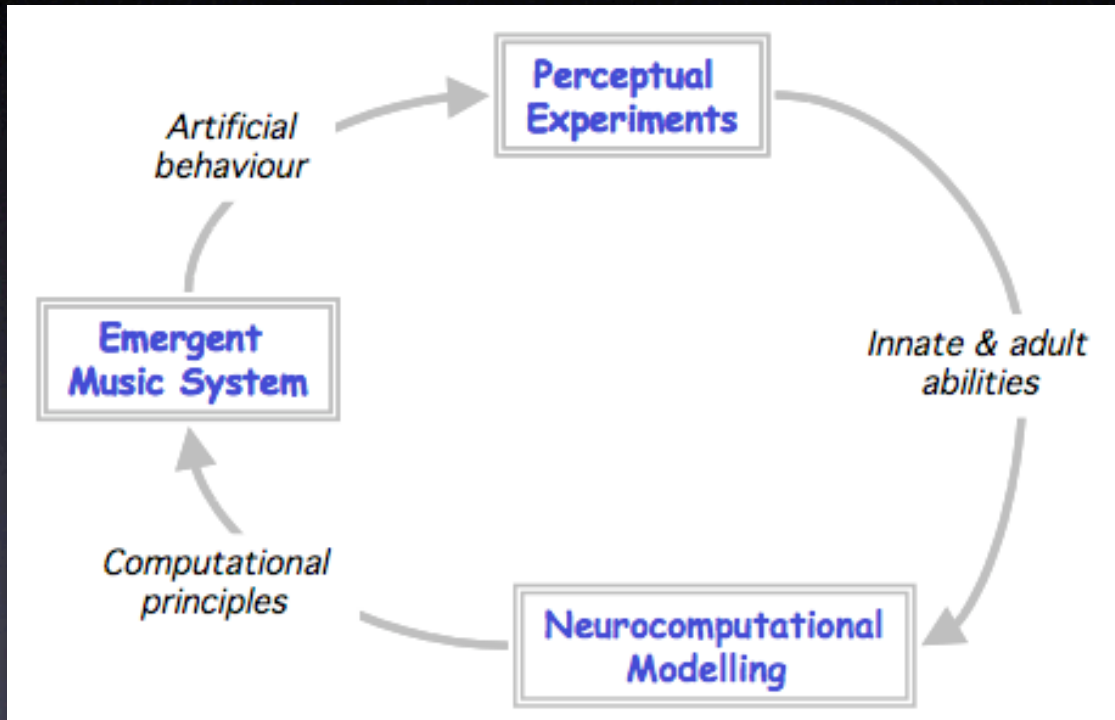
- Neuroimaging innate vs. learned auditory functions.
- Perception of musical form.
- Prefrontal cortical function controlling attention and STM.
- Spectrotemporal response fields in the thalamocortical system.
- Perception and categorisation of rhythmic patterns.
- Active perception, relative pitch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



<http://www.musiccognition.nl/EmCAP>

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Rhythmic Expectation

- Question:

- What contribution to expectation arises from the temporal structure of the rhythm?

or

- How much information is actually within the rhythmic signal?



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...some theories of musical rhythm...



Rhythm



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- **Accent sources include: dynamics, melody, harmony, articulation, timbre, onset asynchrony etc.**



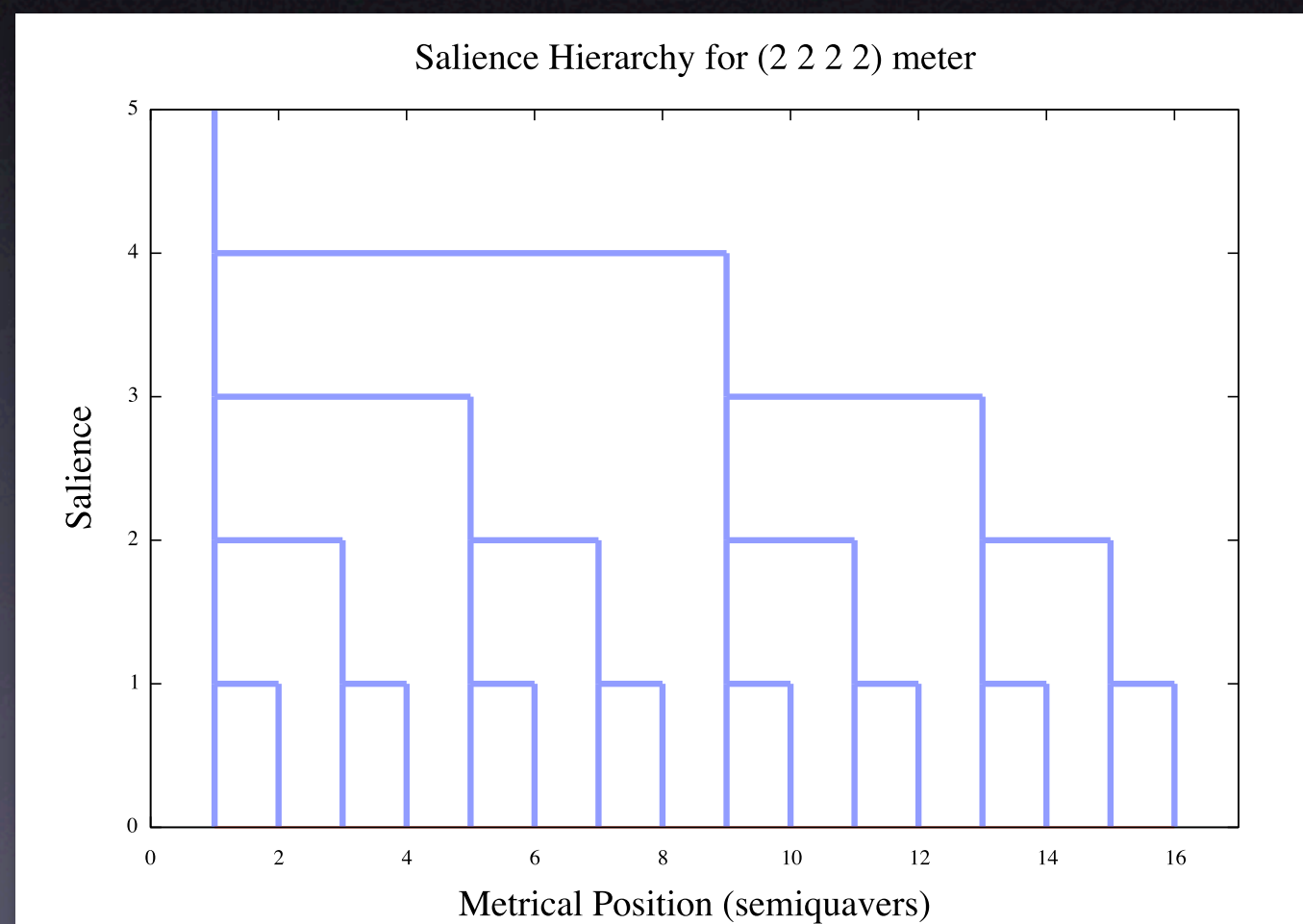
Rhythm

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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.

Meter

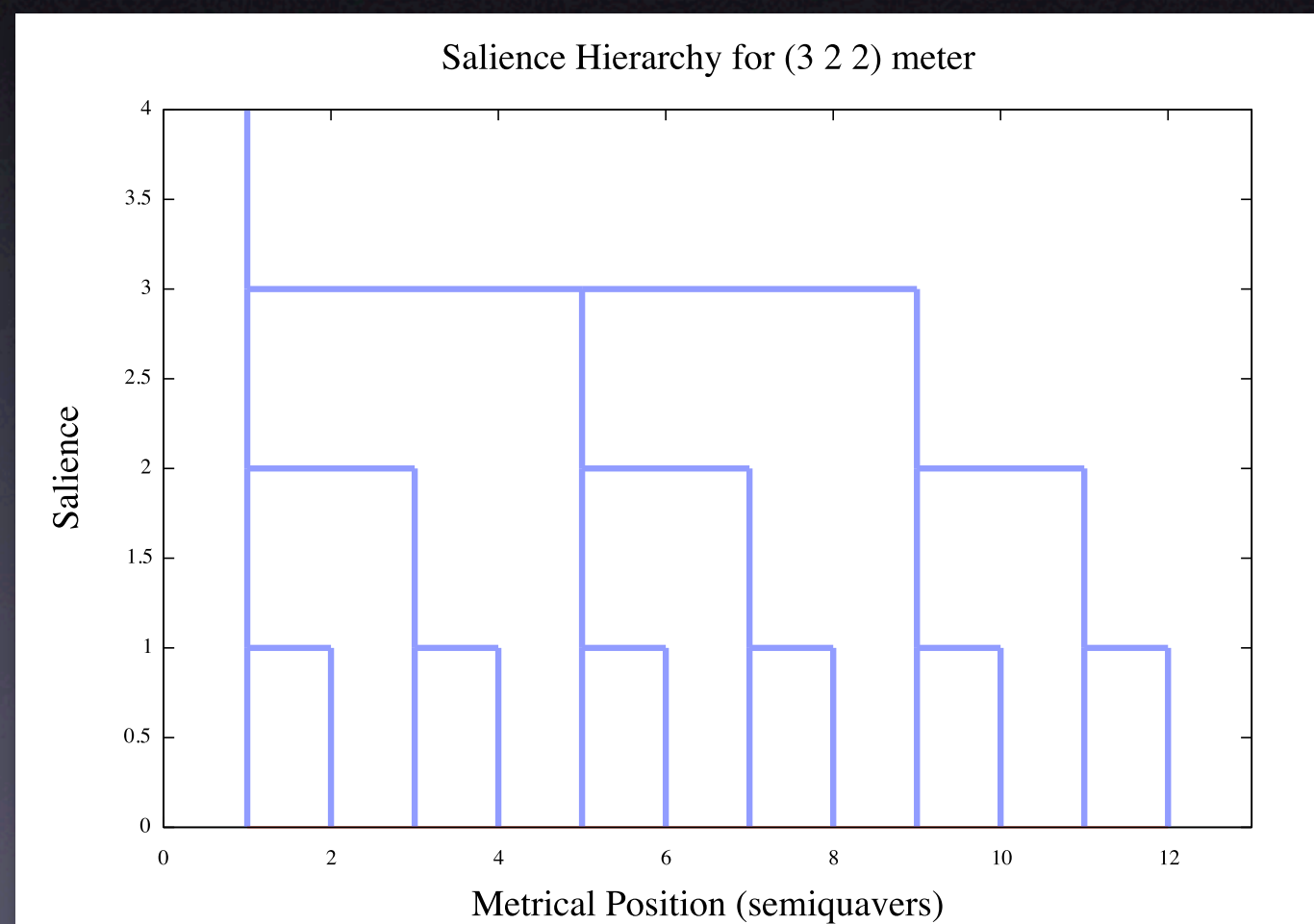
- Meter is expressed in Western music as time-signatures (4/4, 3/4 etc).

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



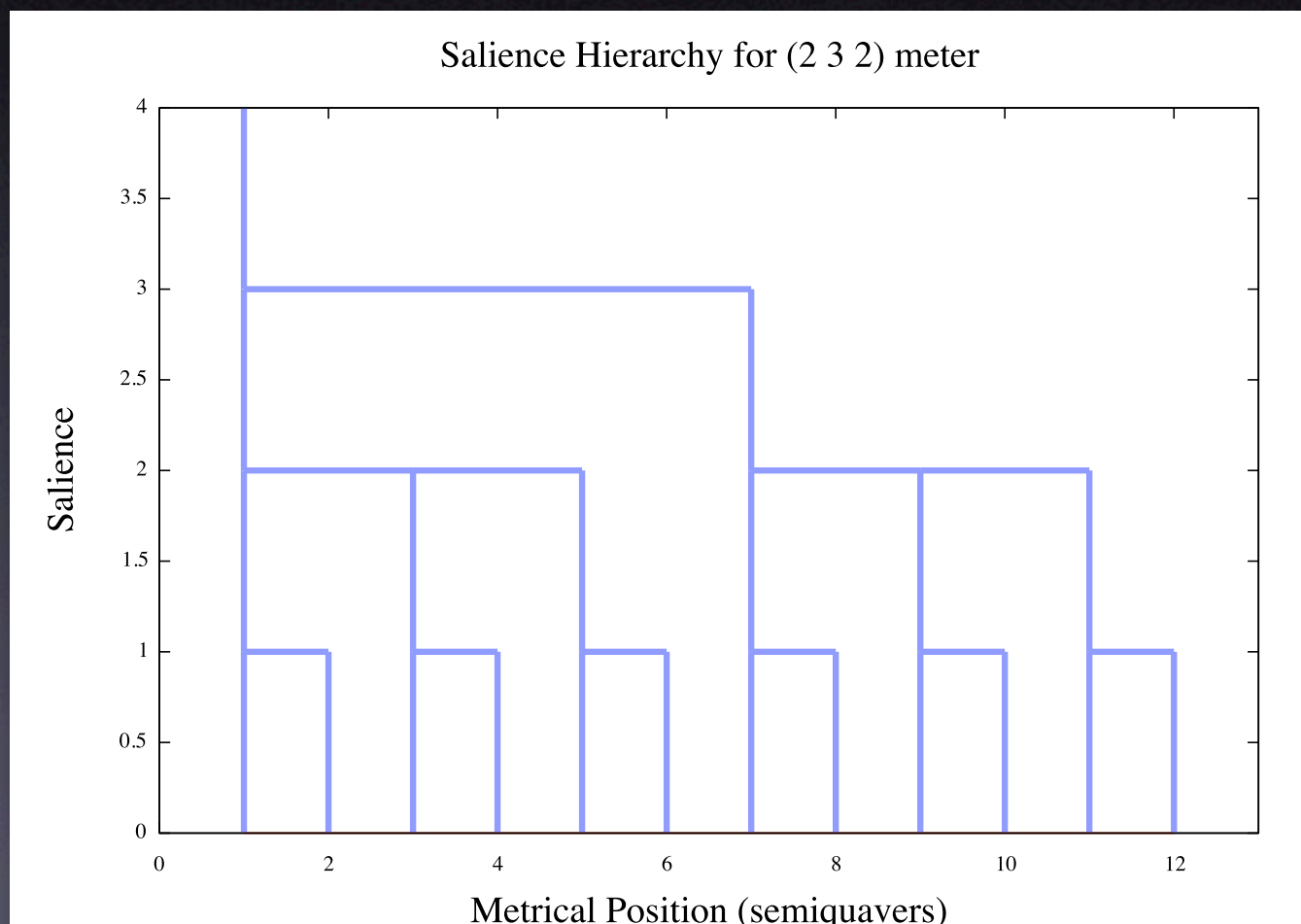
Meter

- Subdivision of 3/4 (3 beats to the bar):



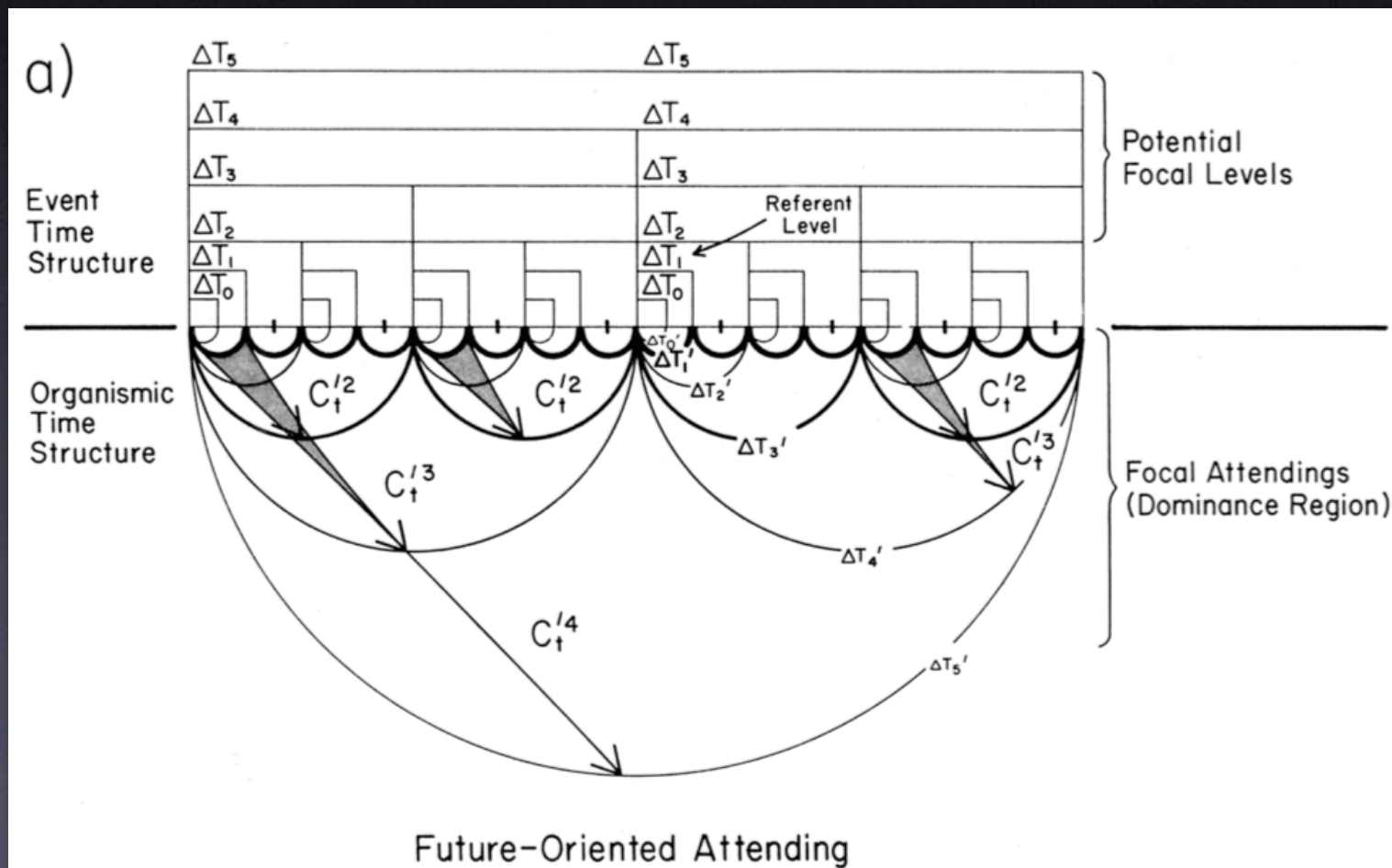
Meter

- Subdivision of 6/8:



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

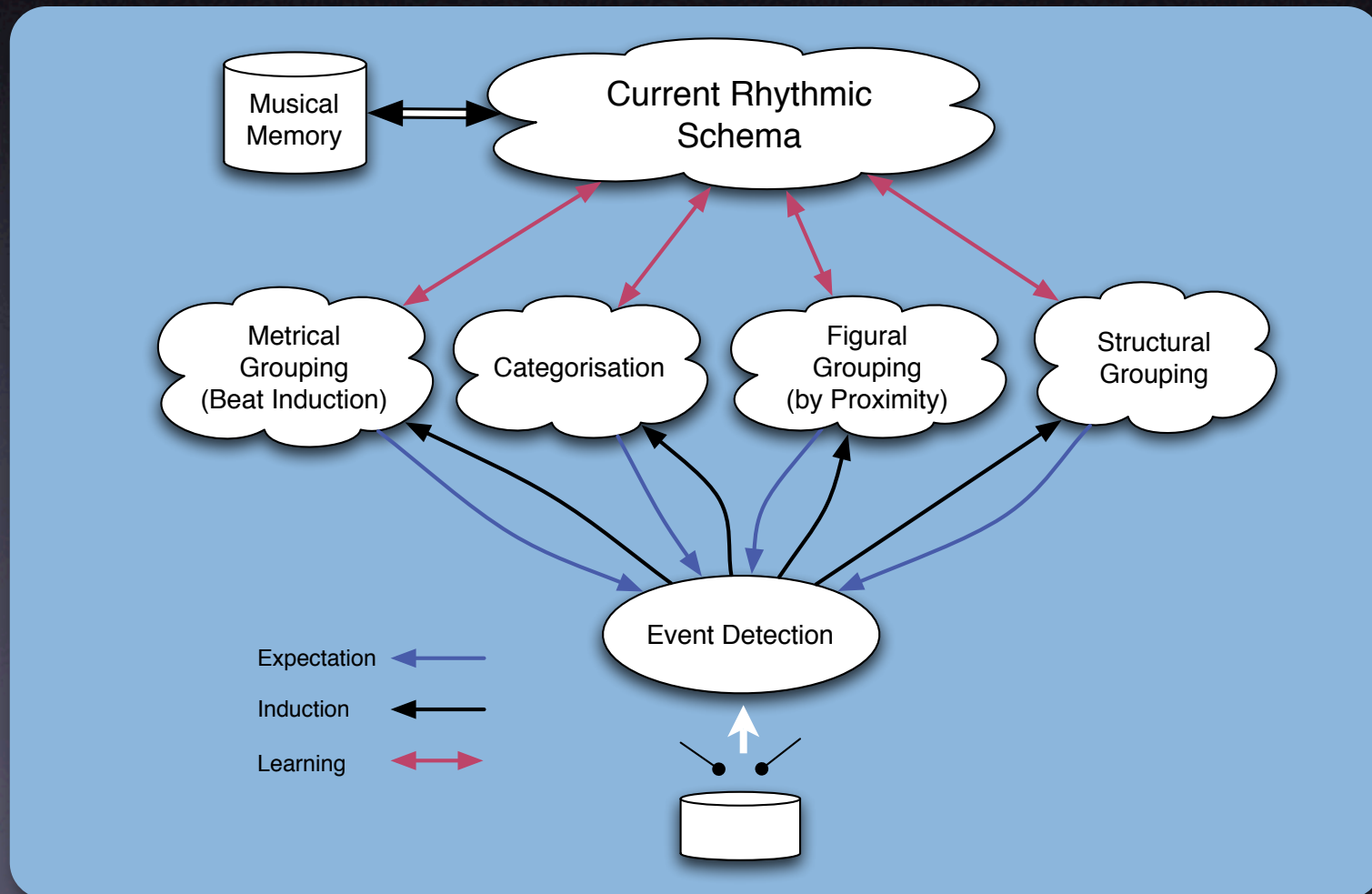


Hierarchical Grouping: Meter

- 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*).

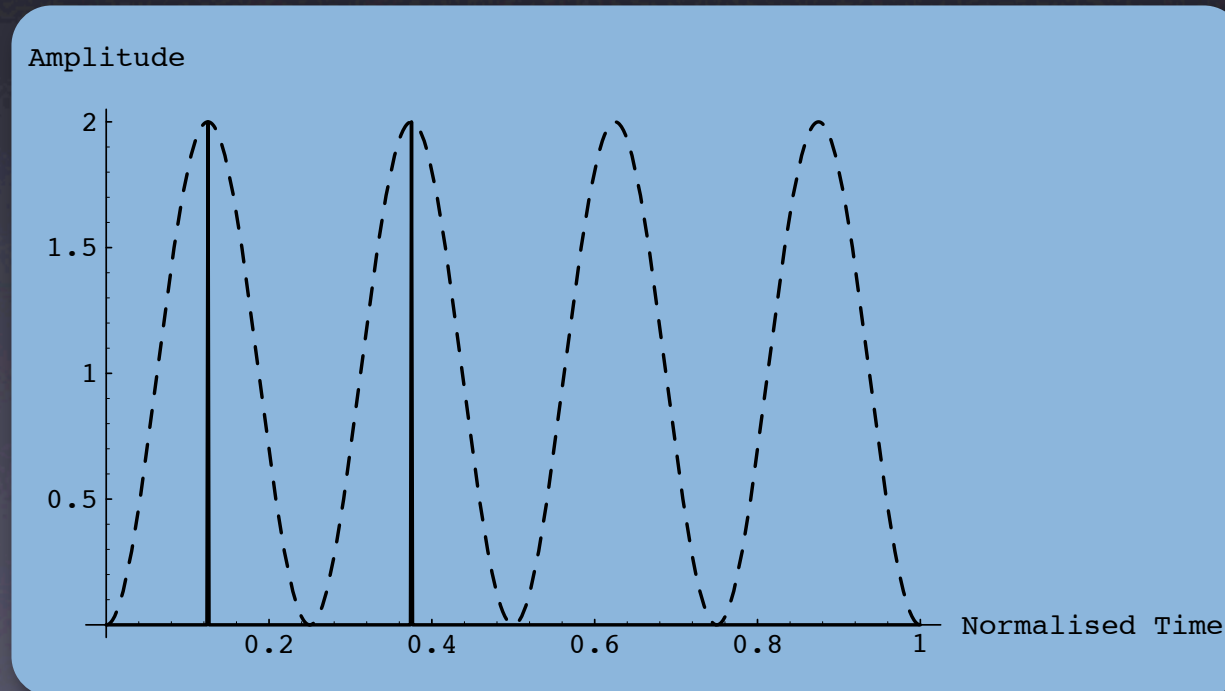


Existing Rhythmic Models

- 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)

- The Short Term Fourier Transform has been traditionally used for analysis of time varying signals.
 - Example: Audio analysis...



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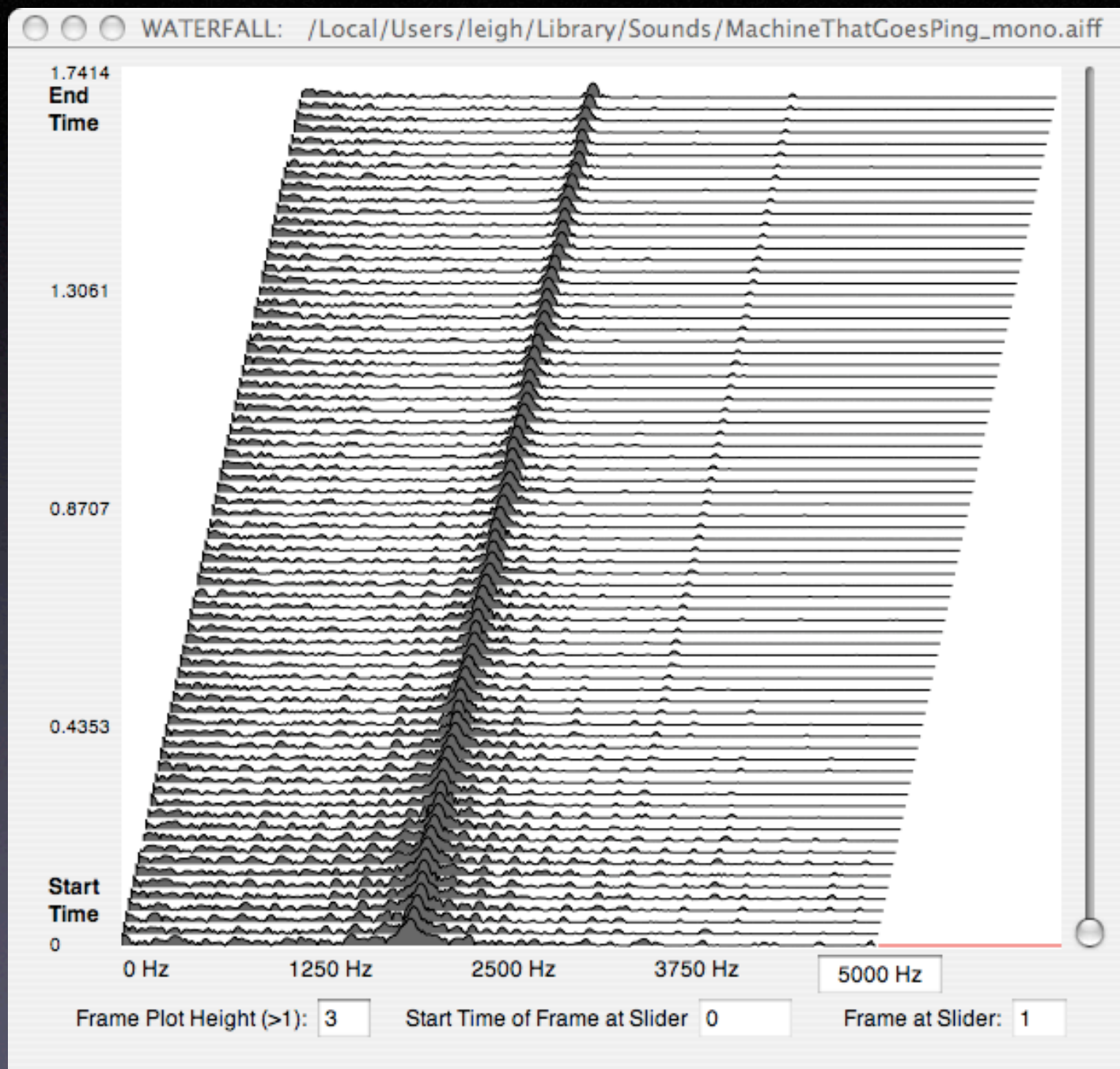
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 - Example: Audio analysis...

...the
machine that
goes ping...

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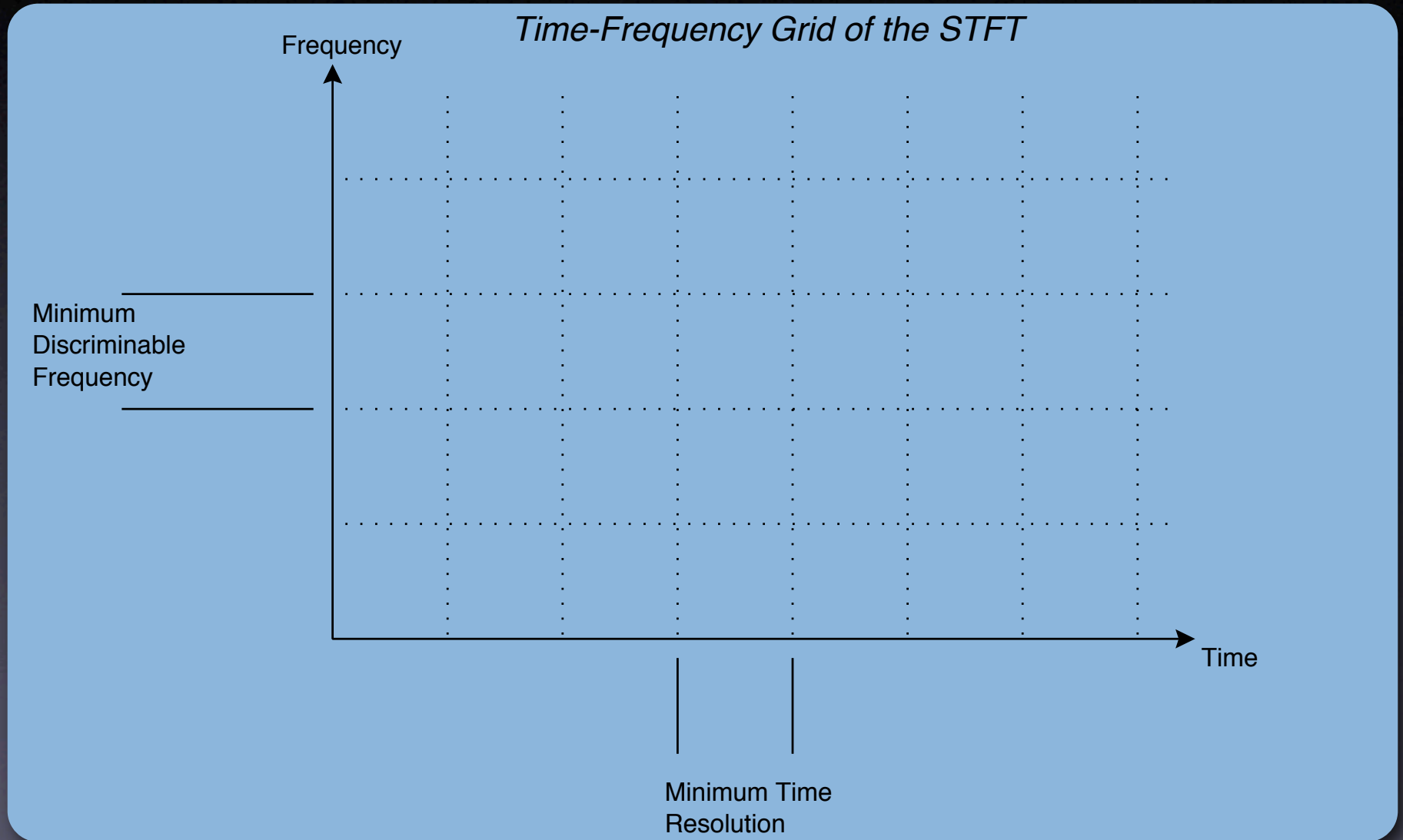


Spectrogram (STFT)





Short Term Fourier Transform





Wavelet time-frequency analysis

Continuous wavelet transform (CWT) decomposes (**invertibly**) a signal onto scaled and translated instances of a *finite* time “mother function” or “basis”.



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$$W_s(b, a) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} s(\tau) \cdot \bar{g}\left(\frac{\tau - b}{a}\right) d\tau, \quad a > 0$$

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



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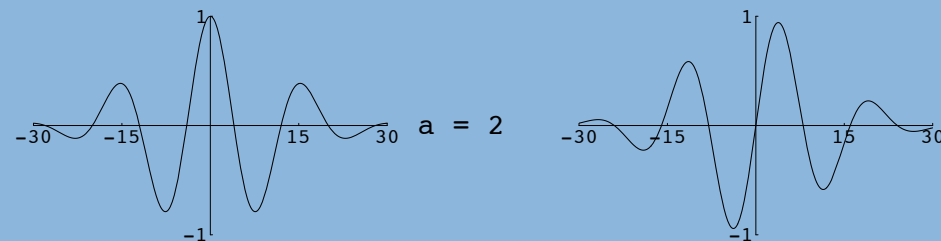
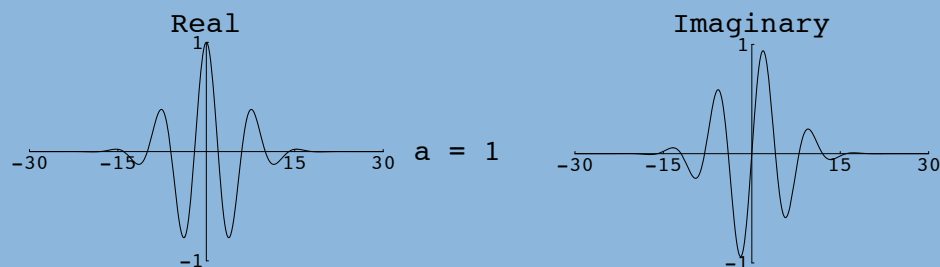
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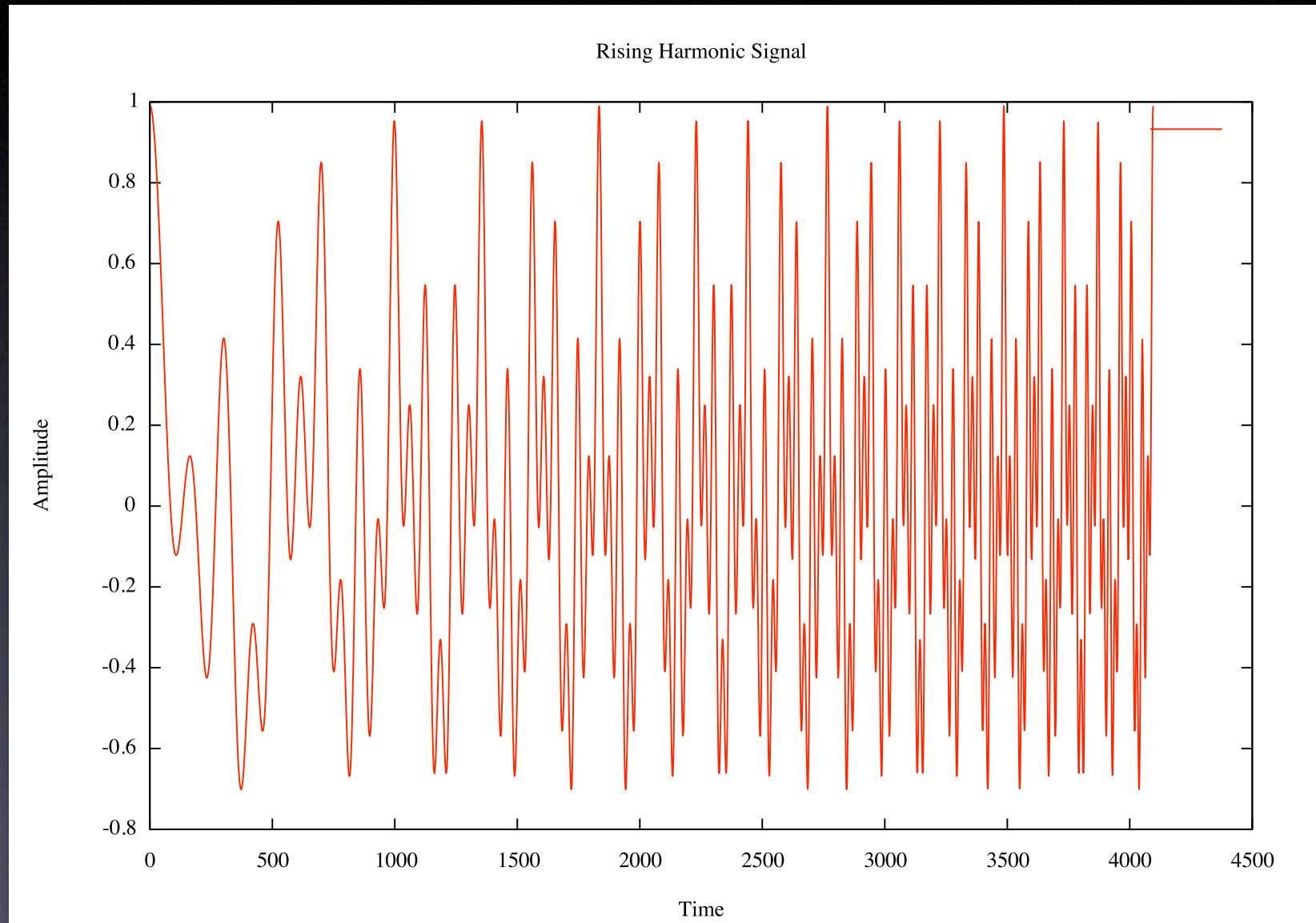
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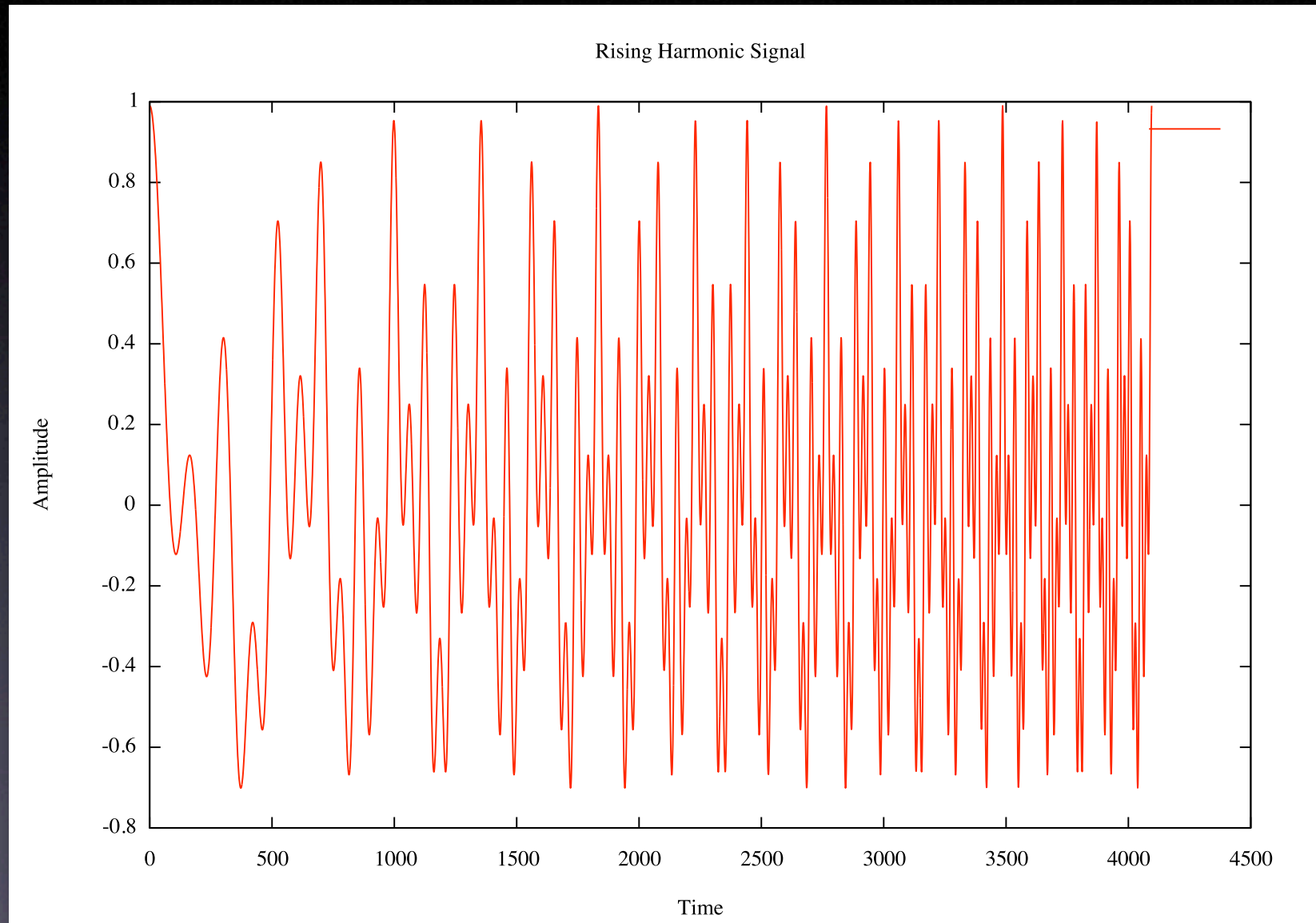




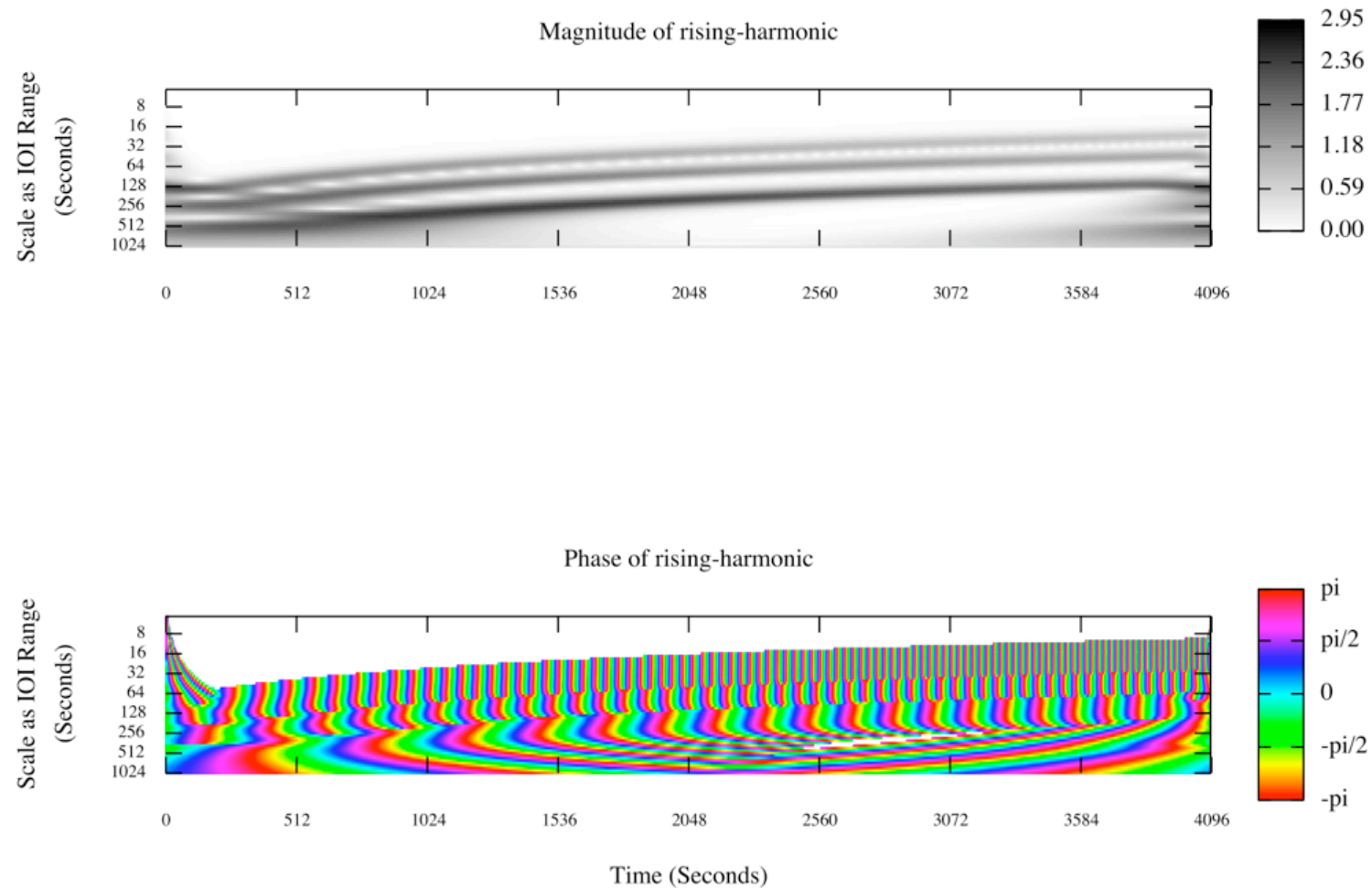
Example: Sinusoidal Signal



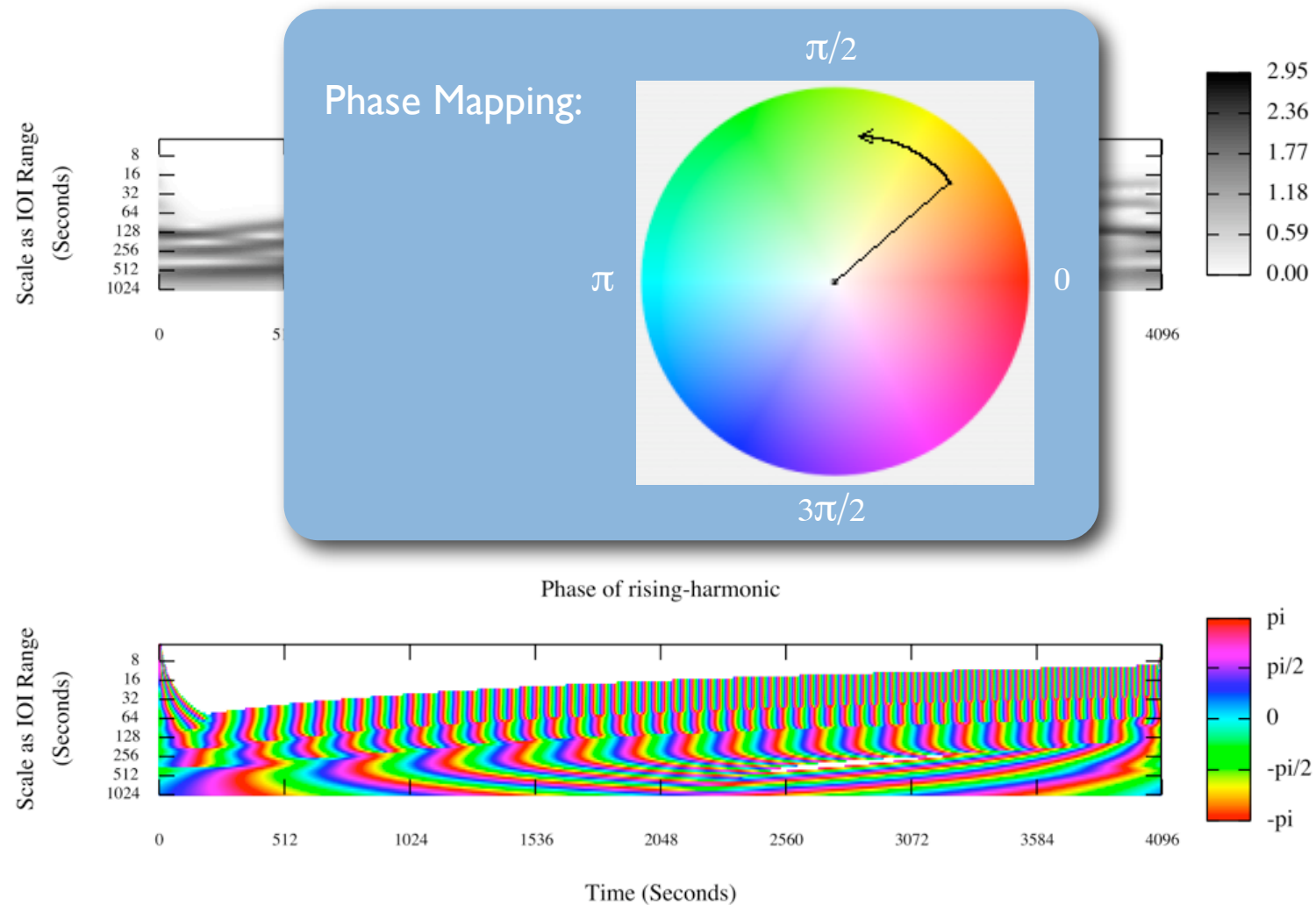
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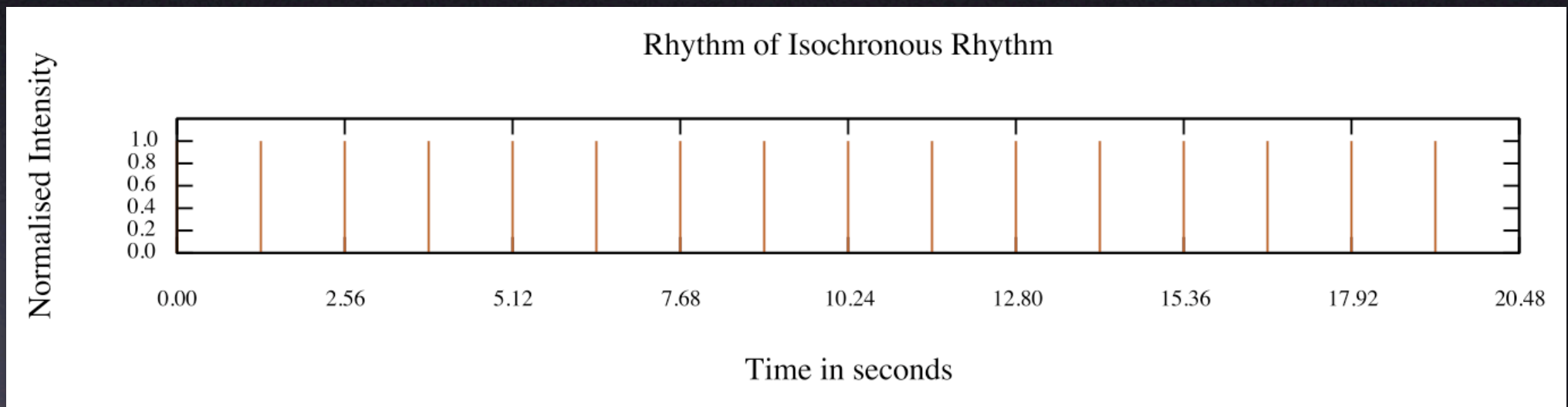
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Example: Simple Rhythm

An isochronous pulse rhythmic signal:



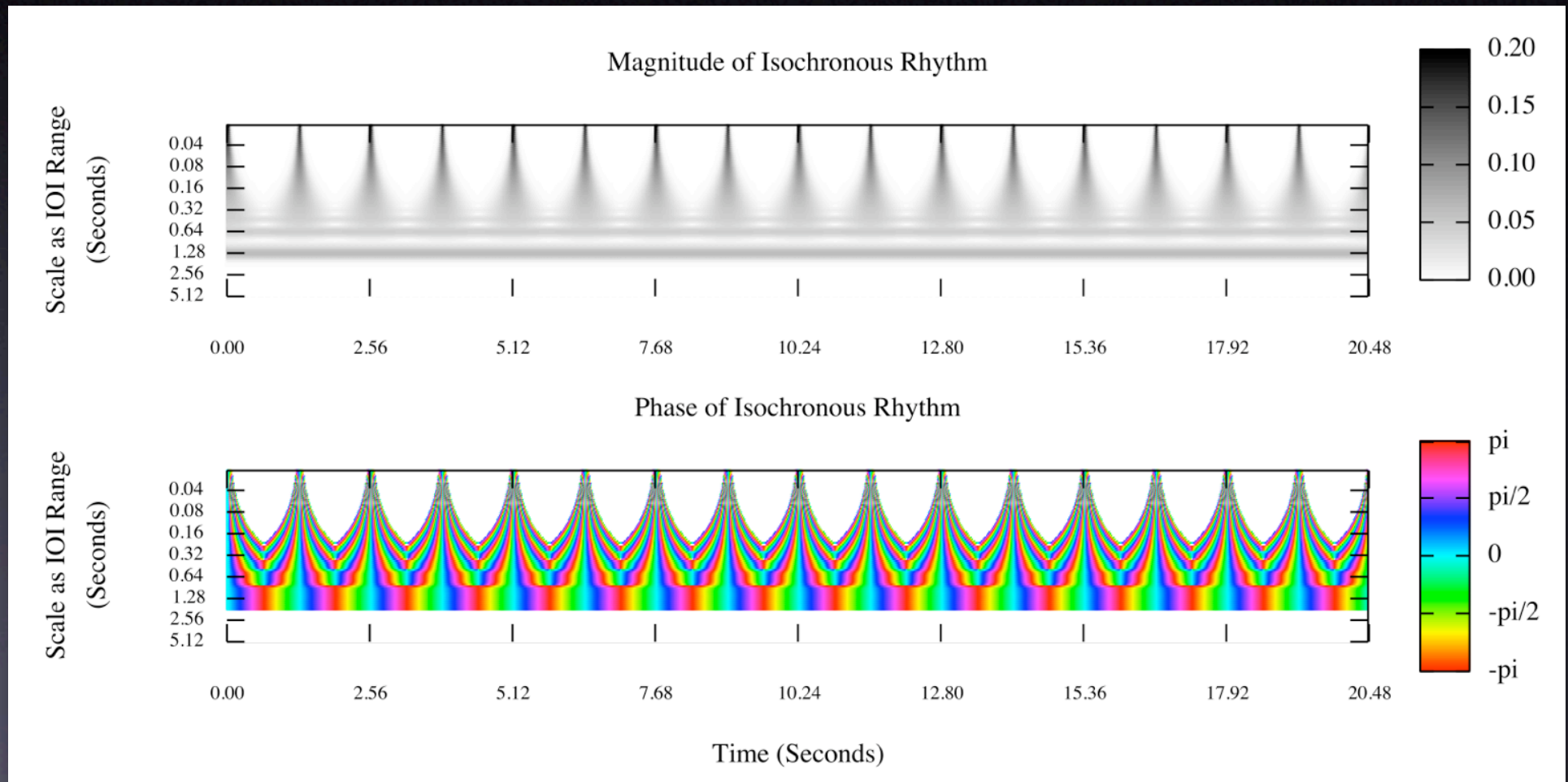


Example: Simple Rhythm

Scalogram and Phasogram of an isochronous pulse rhythmic signal:

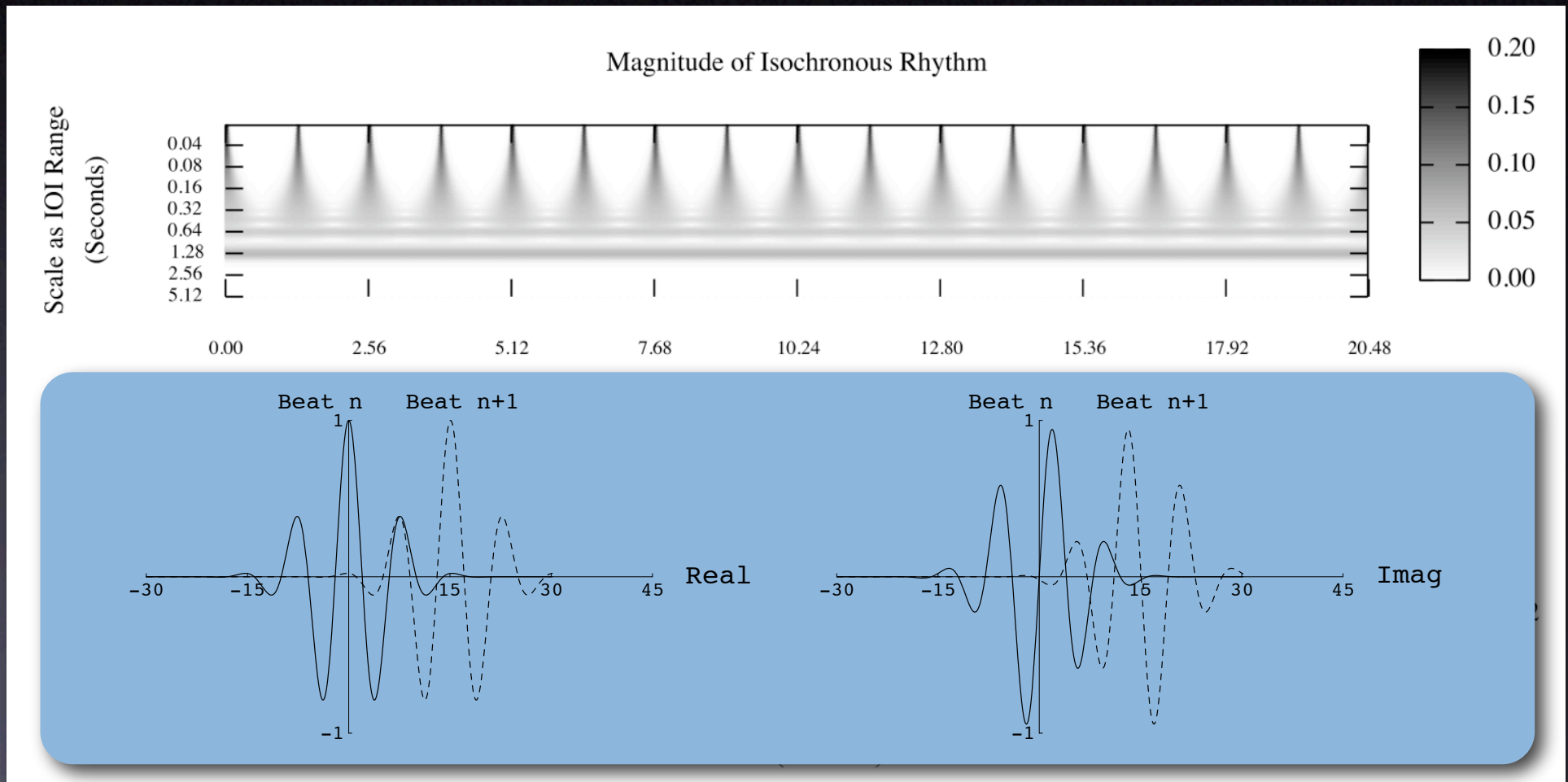
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Wavelets for Rhythm

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Wavelets for Rhythm

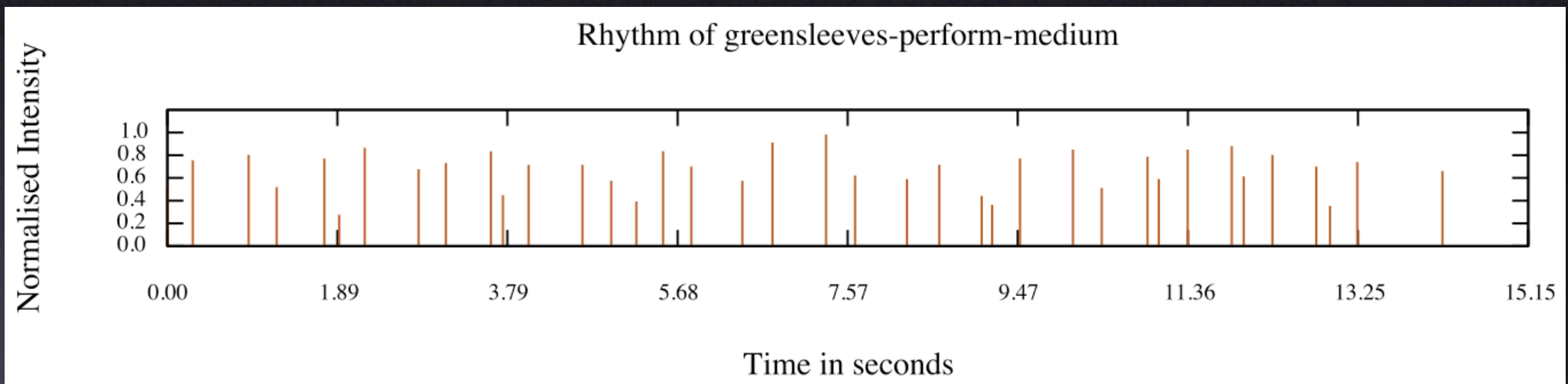
(Smith & Honing in press: Journal of Mathematics & Music 2008)

- 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 & Torr sani '92).



Musical Example

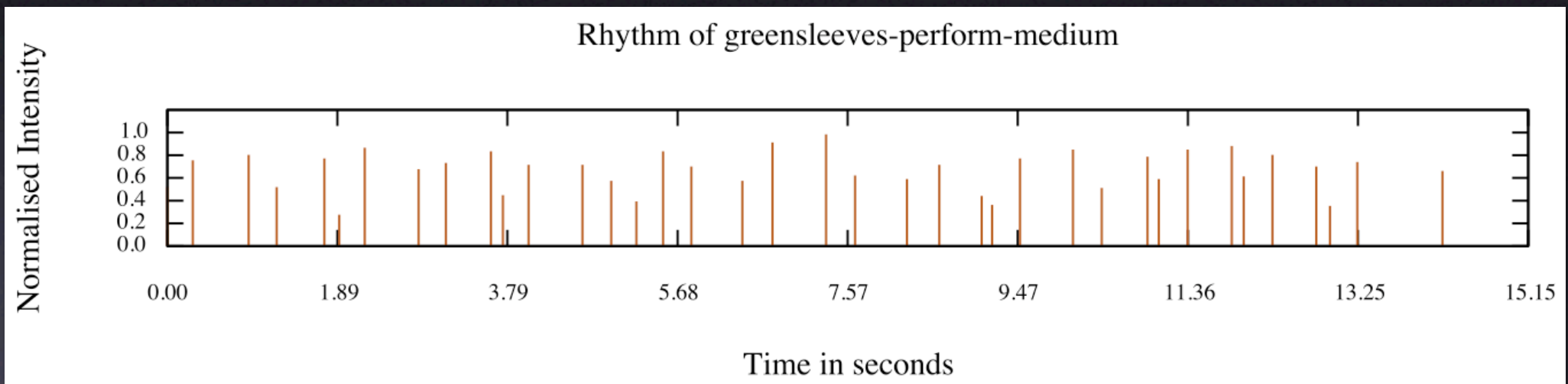
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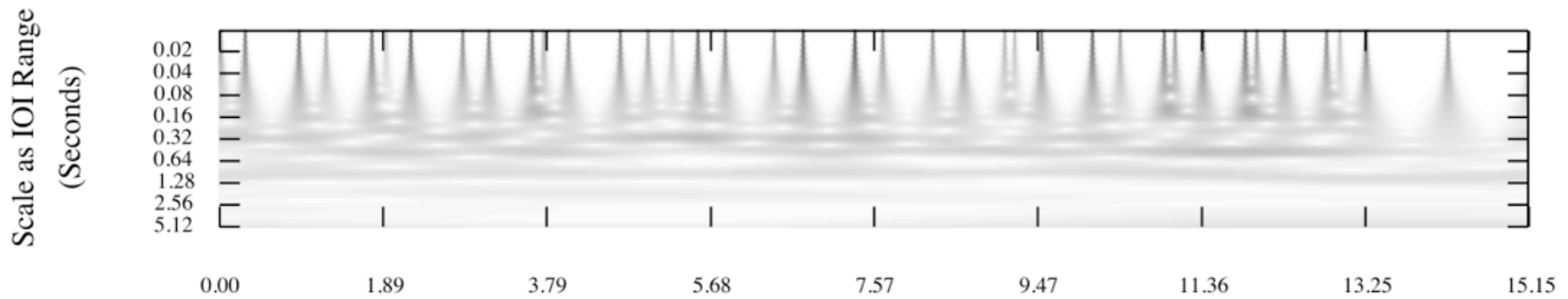
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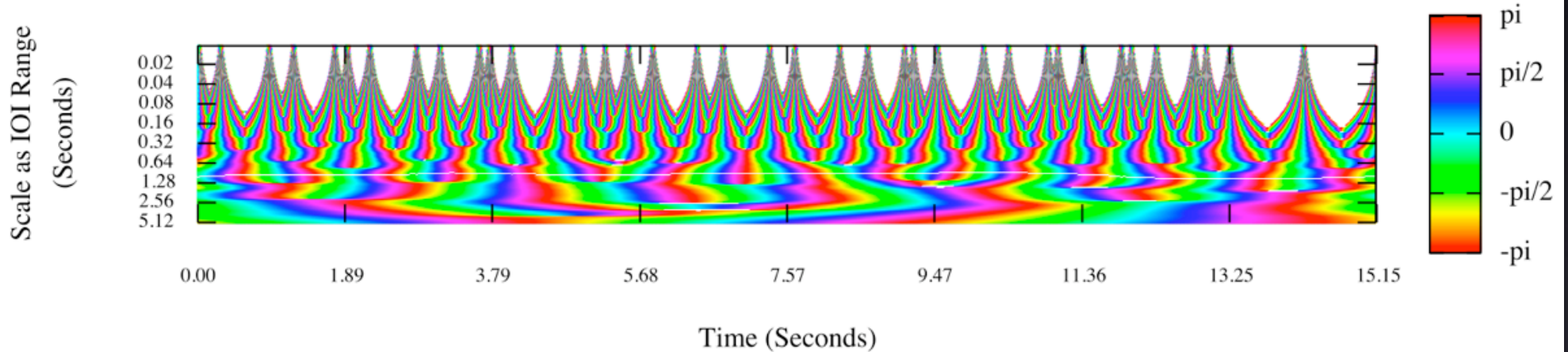


Greensleeves

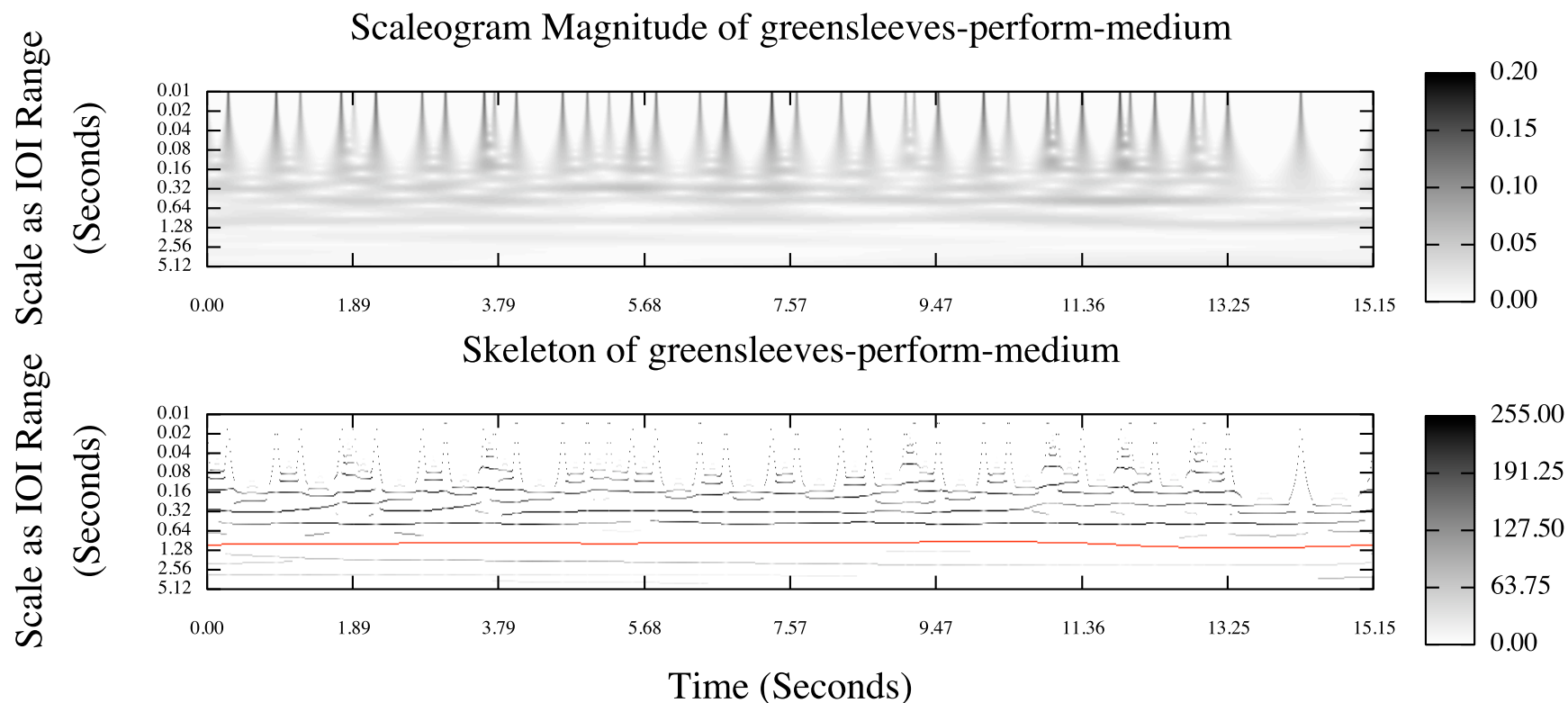
Magnitude of greensleeves-perform-medium



Phase of greensleeves-perform-medium



Skeleton of Greensleeves





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Application:

Foot-tapping by reconstruction

- Suppress all but the magnitude coefficients of the extracted tactus ridge.
- Invert the reduced magnitude and original phase planes back to the time domain.
- 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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- 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.



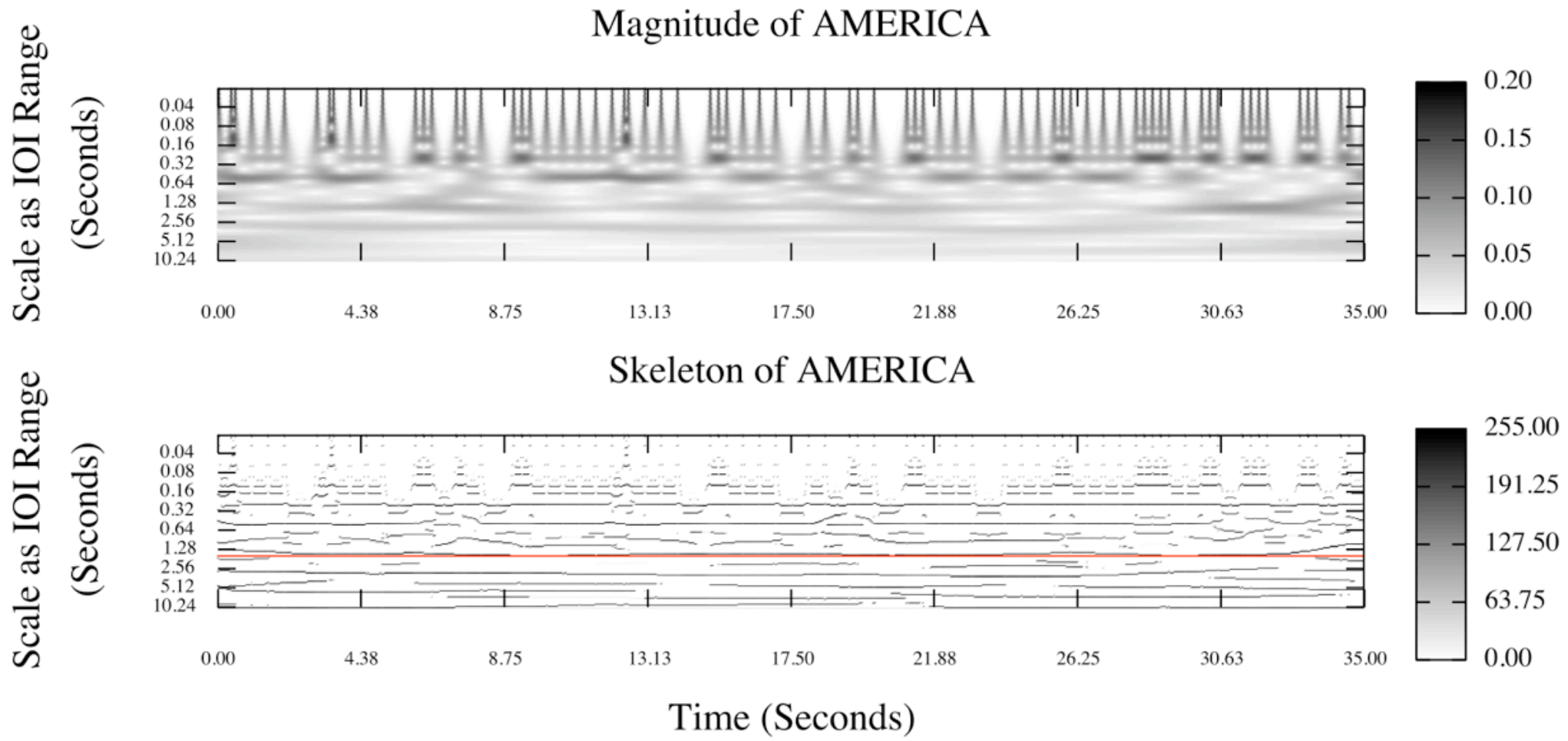
Evaluation Data: Anthems

(Smith & Honing: ICoMCS 2007)

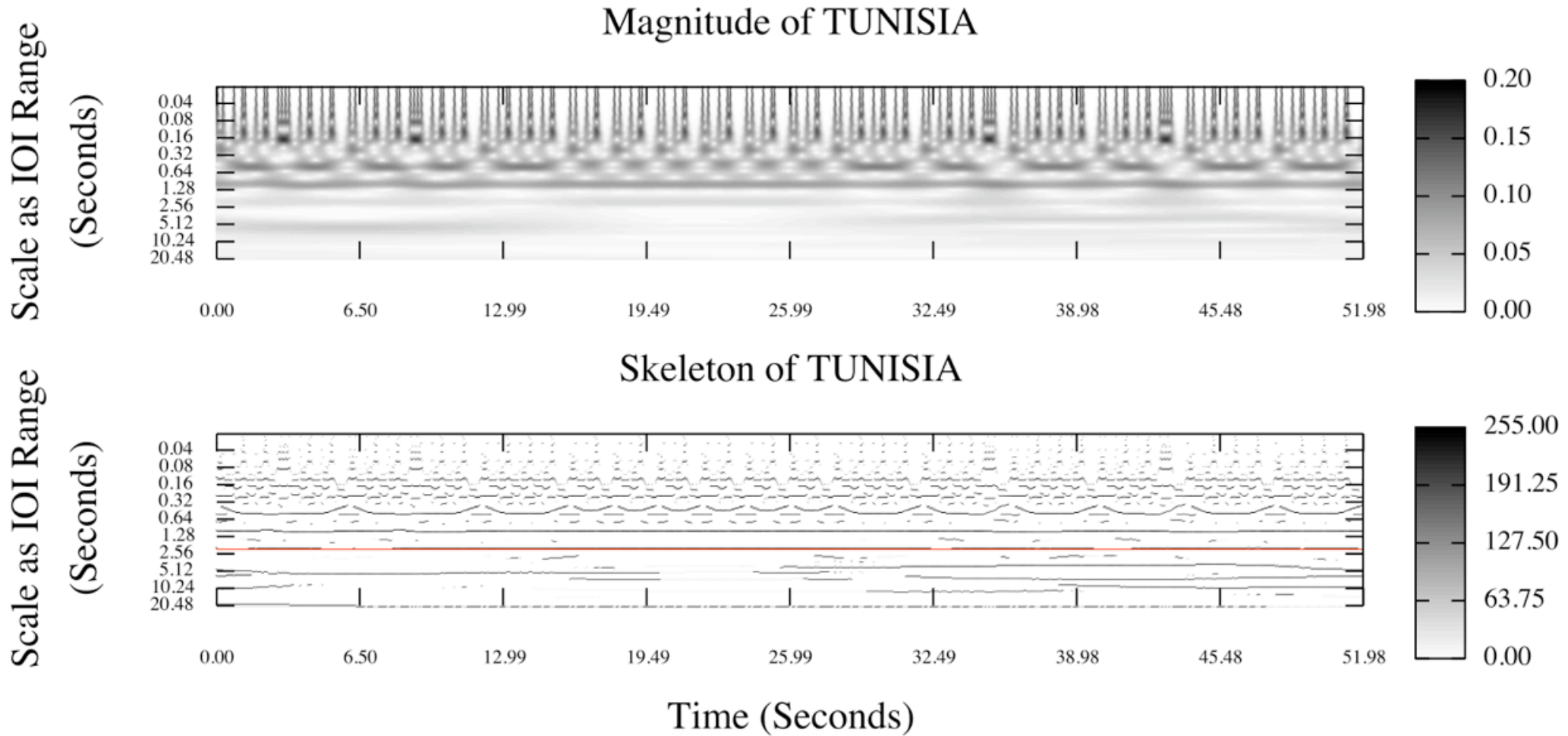
- 105 National Anthems (Shaw & Coleman 1960).
- Rhythms transcribed into interonset intervals (IOI), quarter-note & bar duration, anacrusis.
- No melodic, intensity or expression accents.
- Also used in analysis of rule-based systems of Longuet-Higgins & Lee (1982, 1985, 1991) (Desain & Honing 1999).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



Example: America



Example: Tunisia





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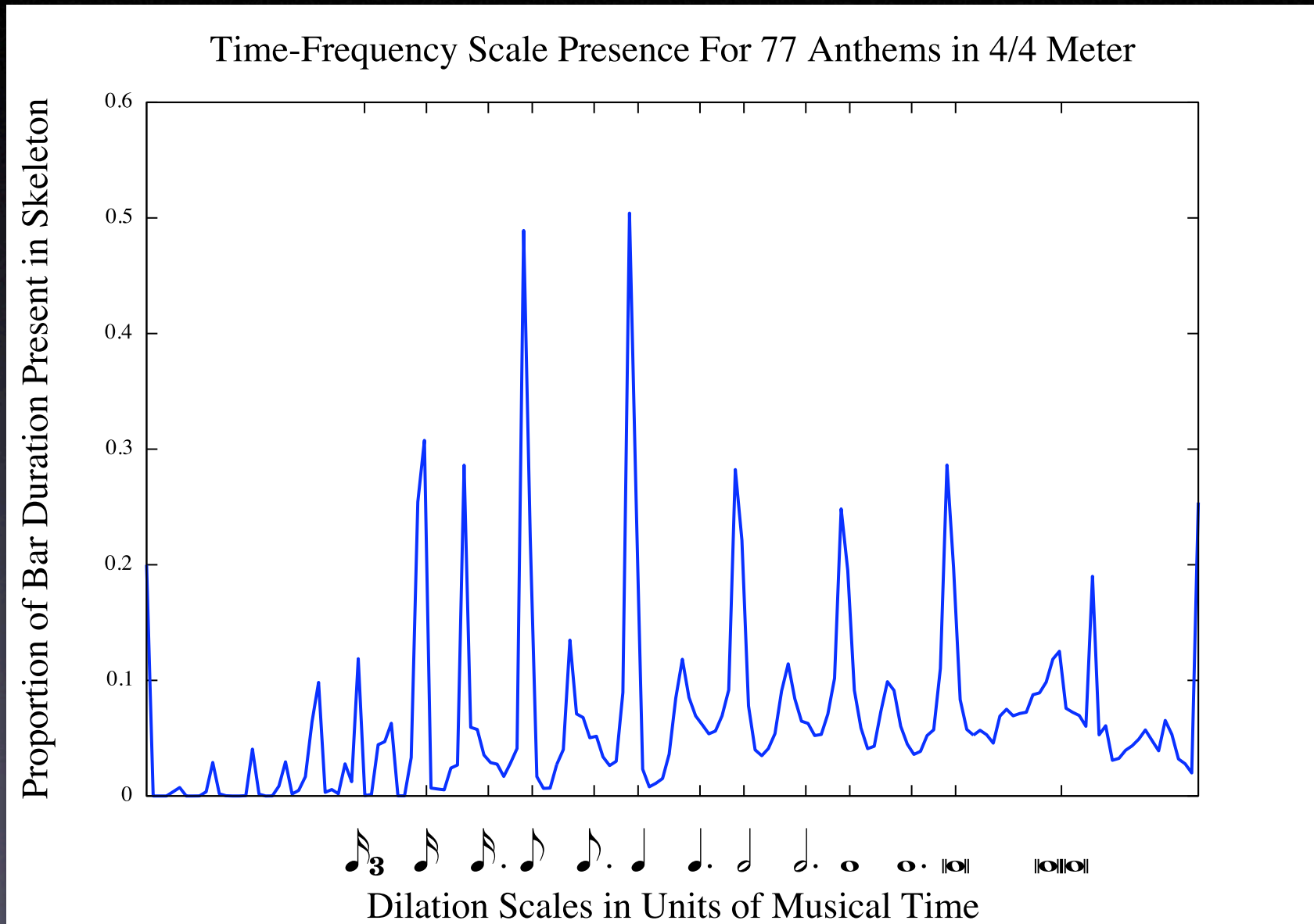
- Ridge Presence: relative occurrence of a ridge (r) at each dilation scale (a), over the duration (B) of each rhythm.

$$P_a = \sum_{b=0}^{B-1} \frac{r(W_{b,a})}{B}$$

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

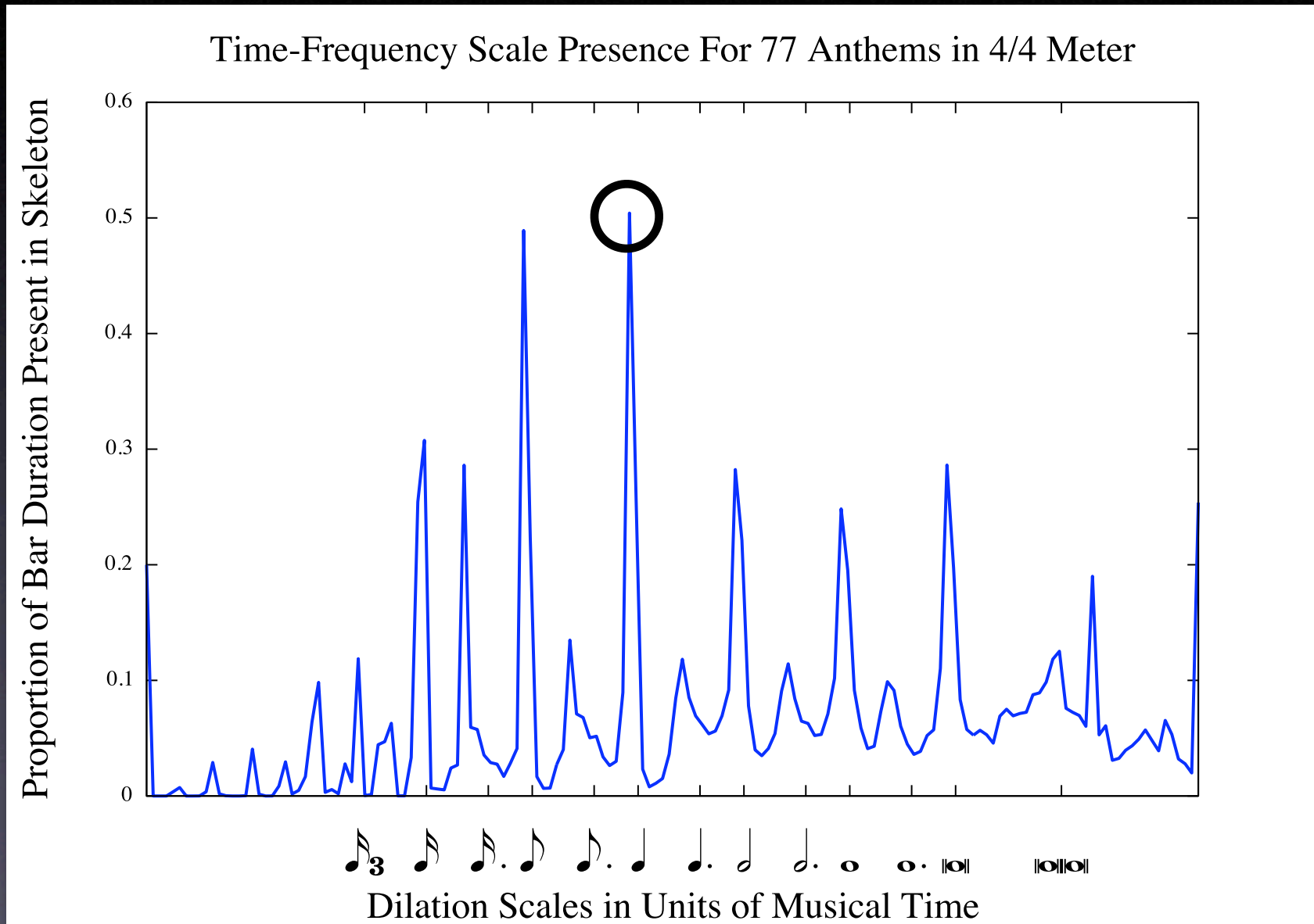


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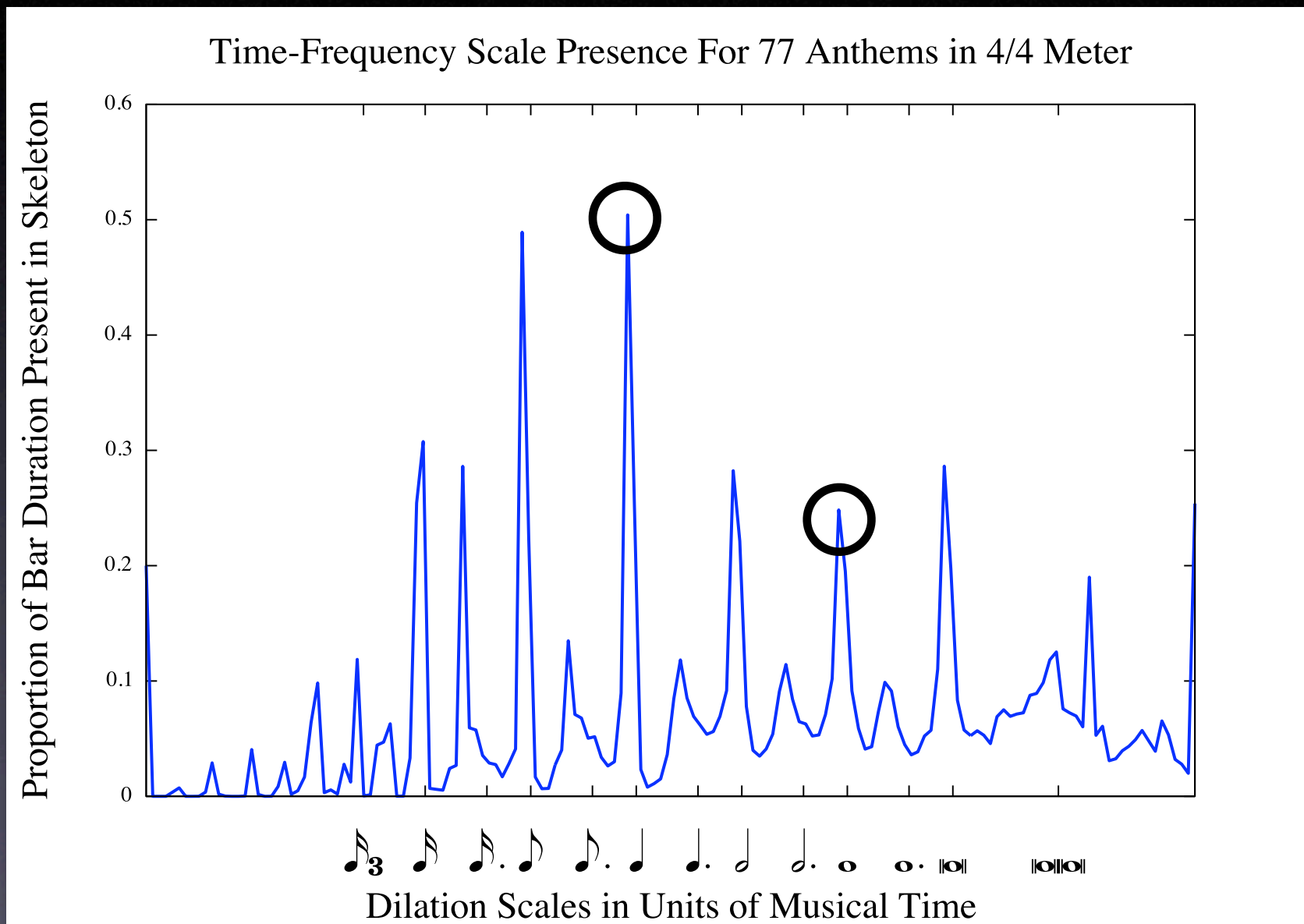




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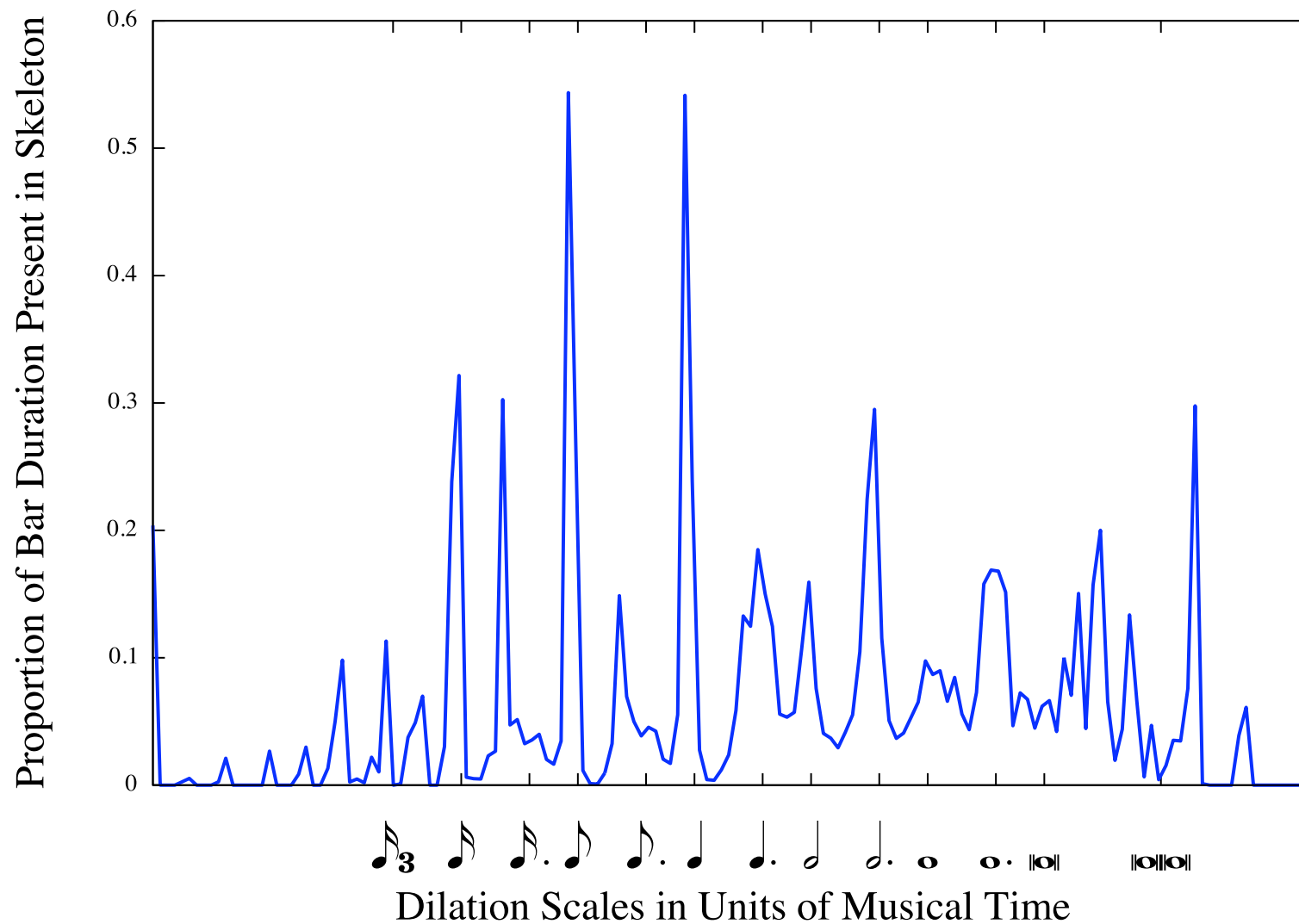
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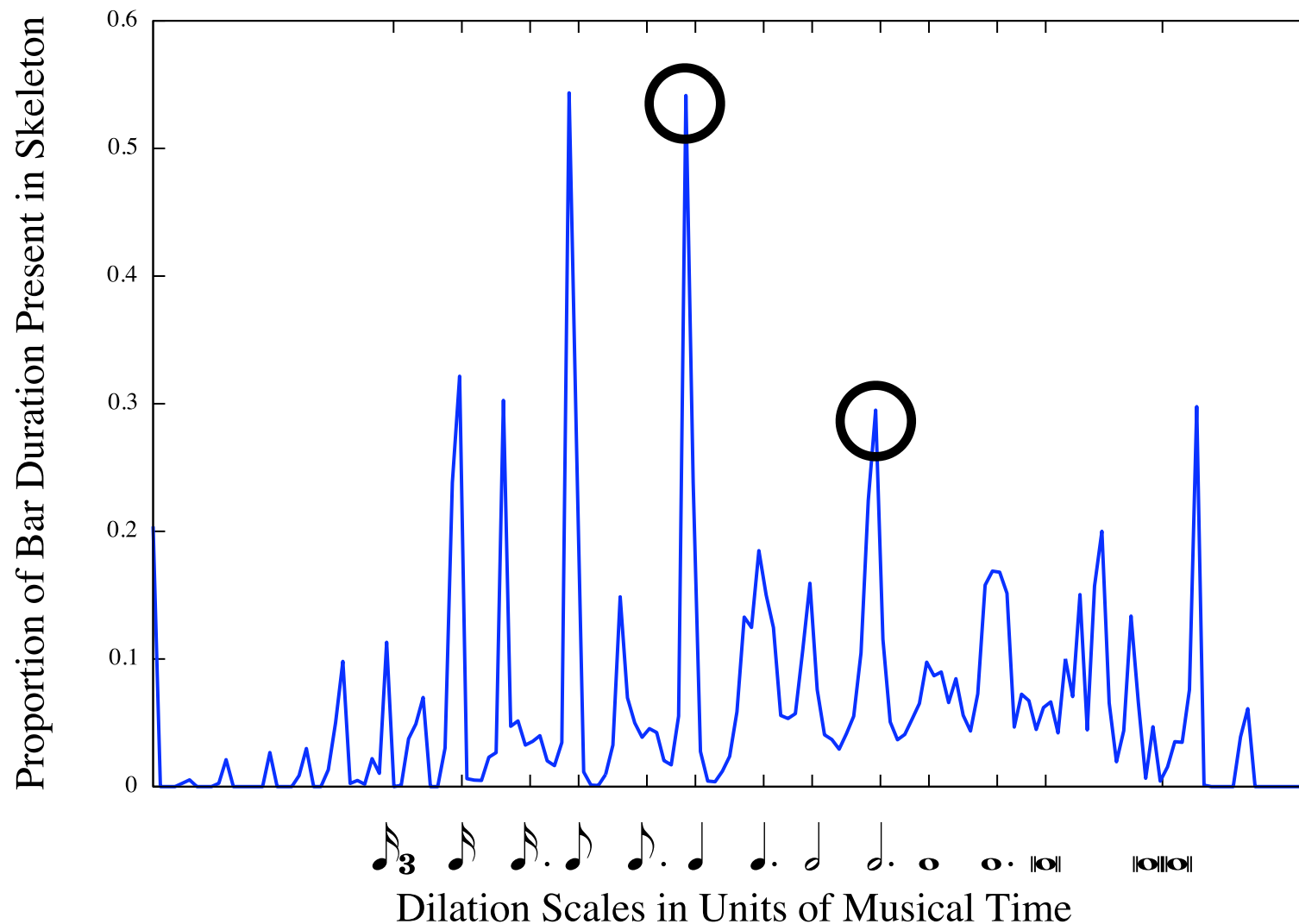
Triple Meter

Time-Frequency Scale Presence For 10 Anthems in 3/4 Meter



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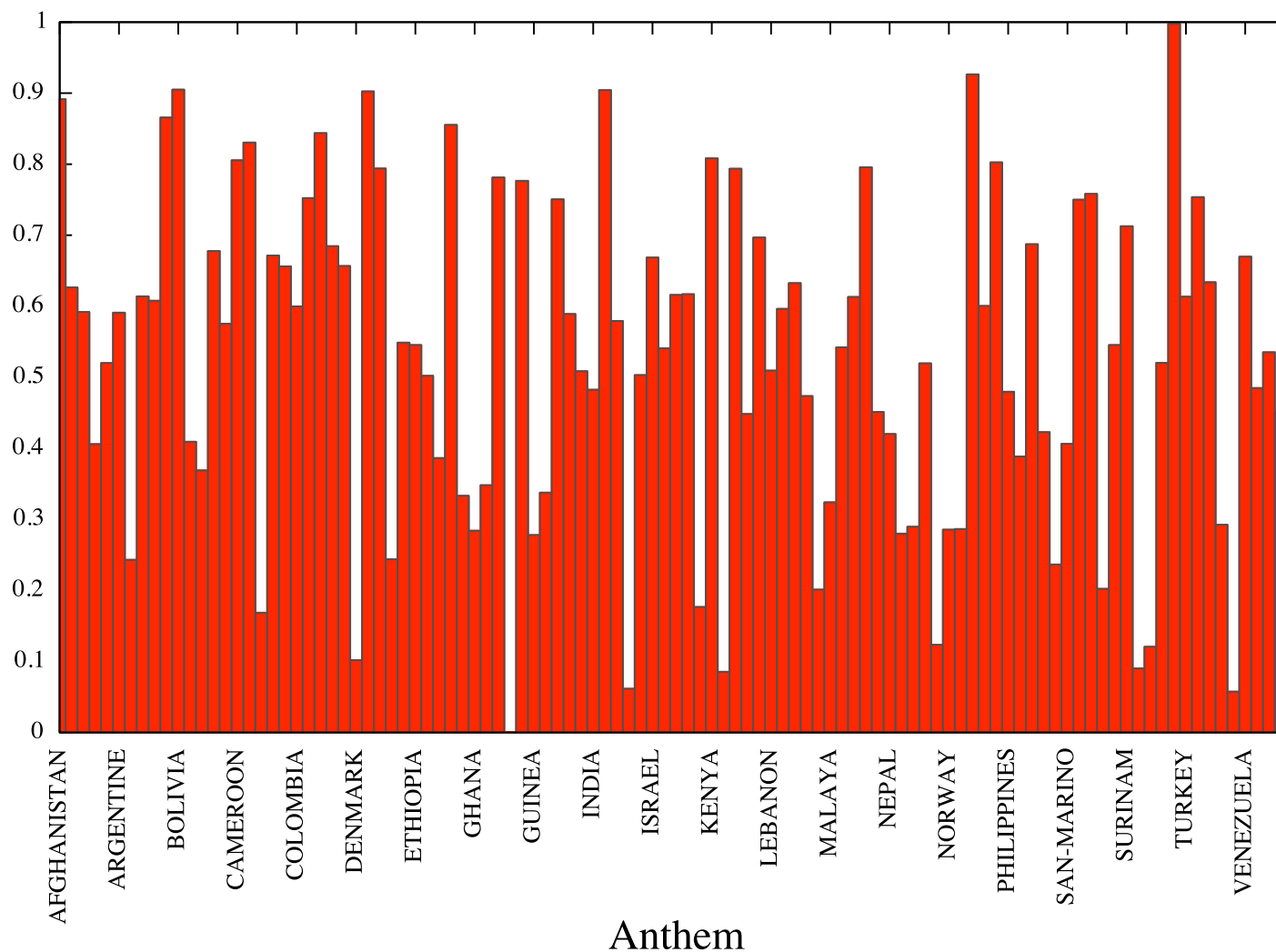
Time-Frequency Scale Presence For 10 Anthems in 3/4 Meter



Presence of Bar Ridges

Proportion of Bar Duration Present in Skeleton

Bar presence of /Users/leigh/Data/Anthems





Evaluation



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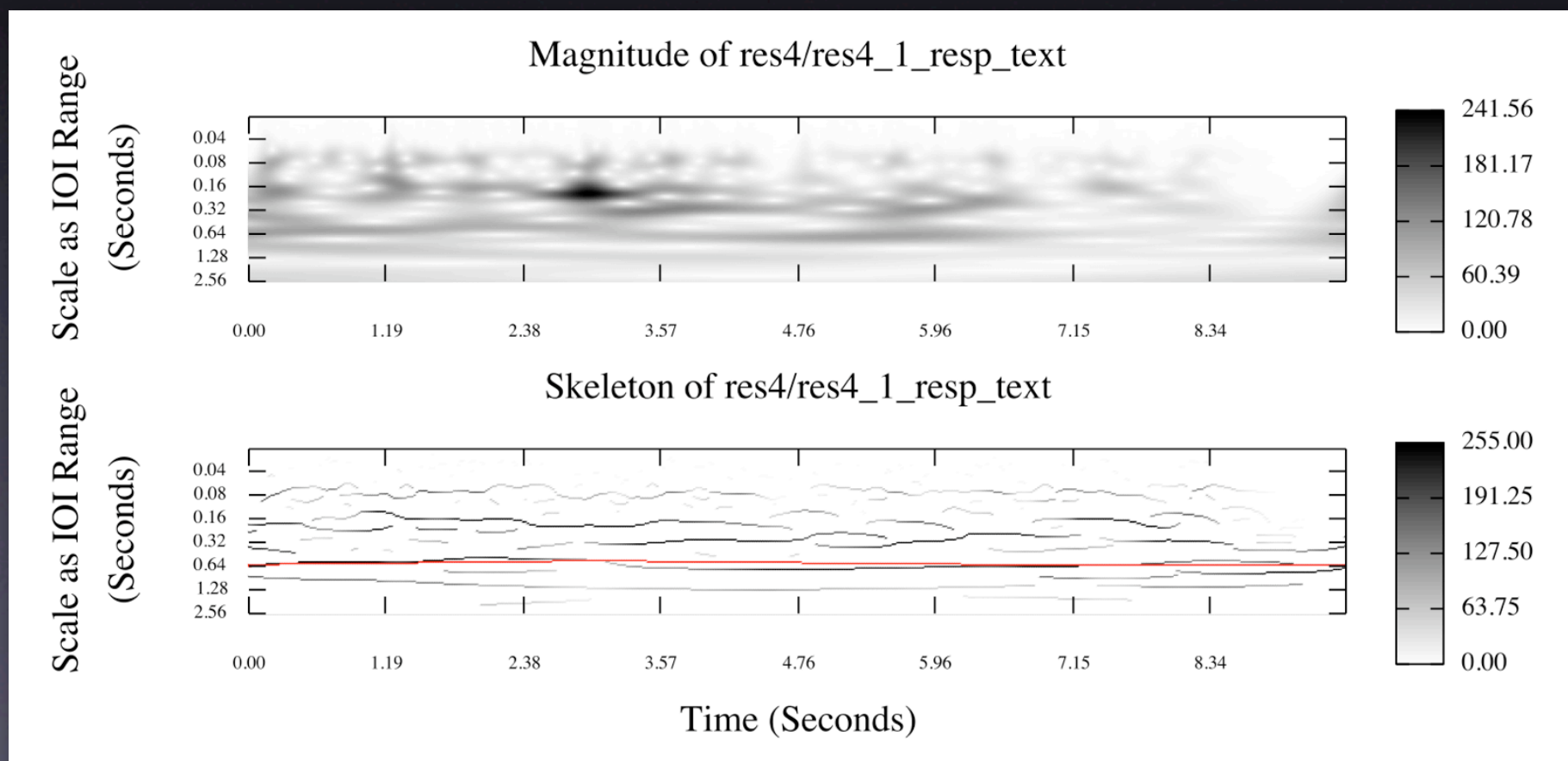


Evaluation

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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



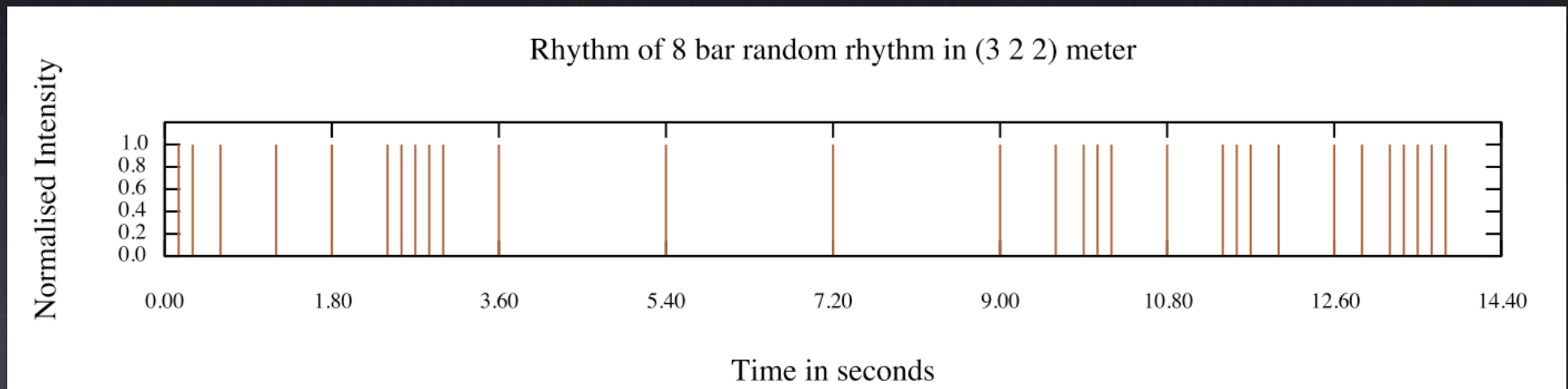
Expectation

- 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

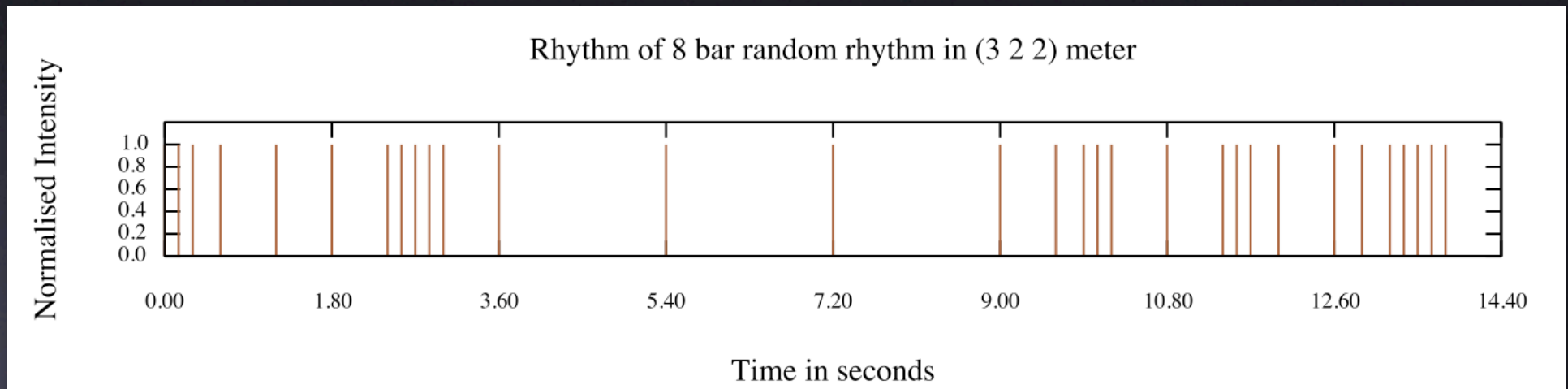
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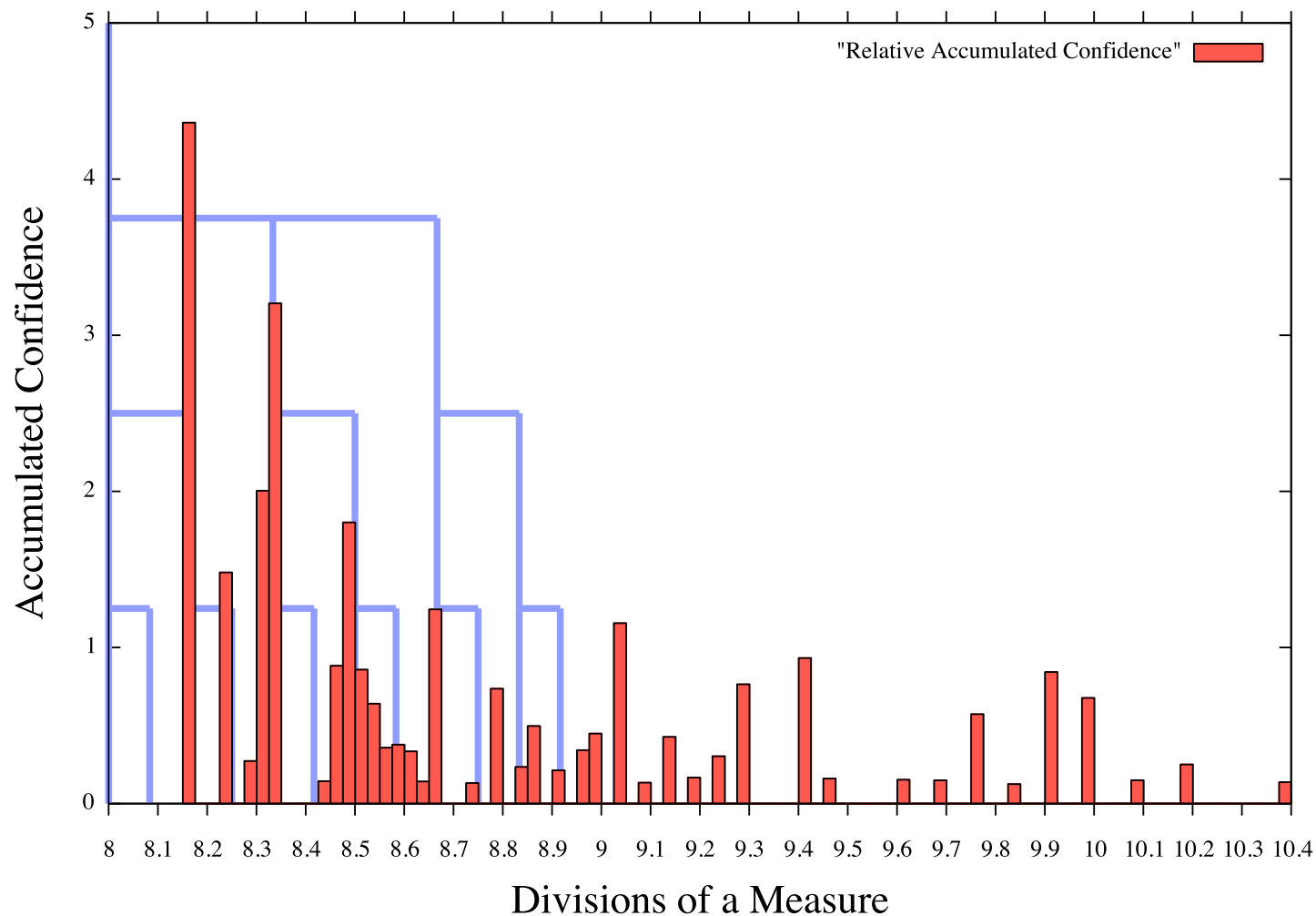
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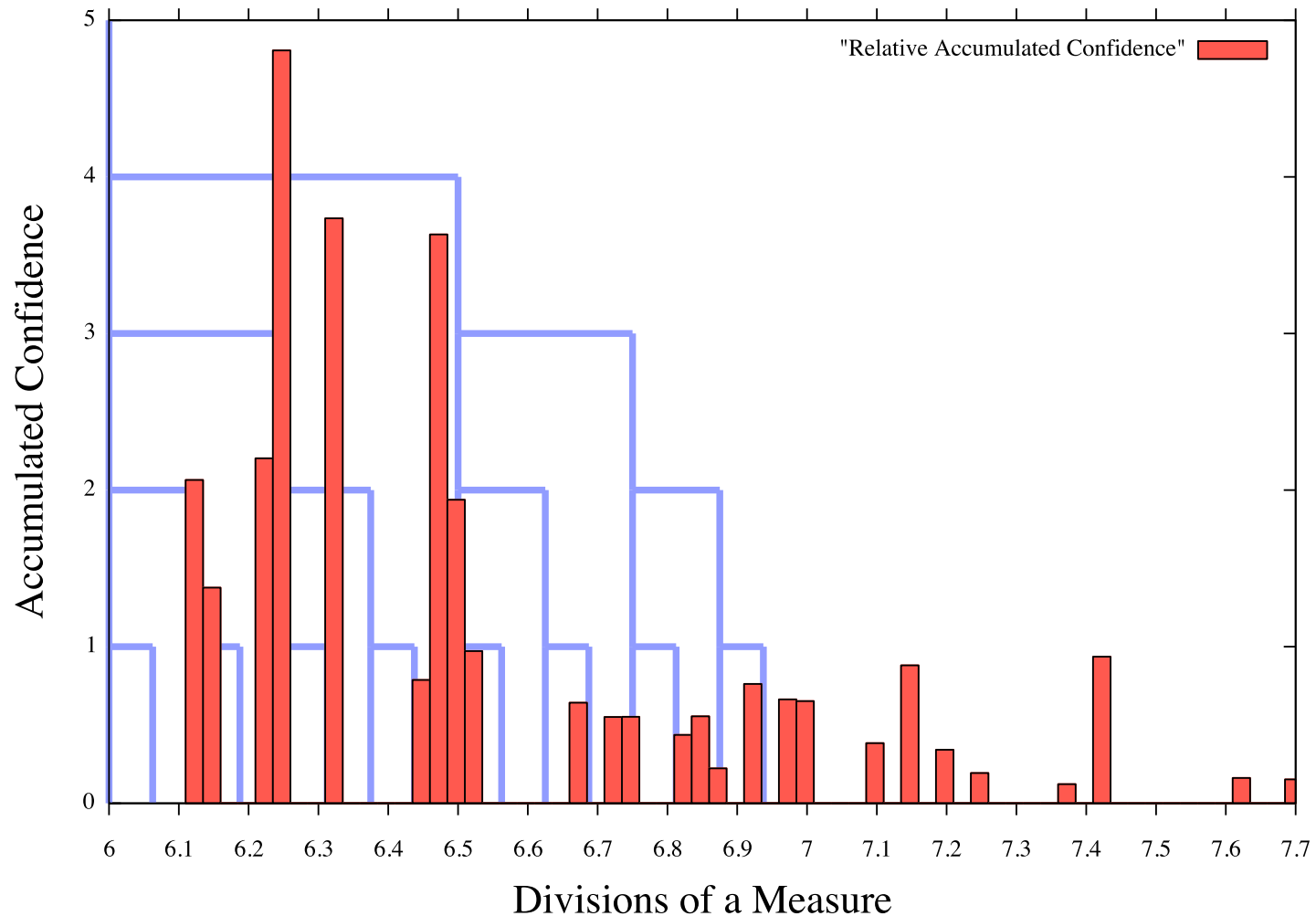
Accumulated Expectation Confidences for 20 random rhythms in 3/4 meter of 8 measures





Emerging Metrical Context

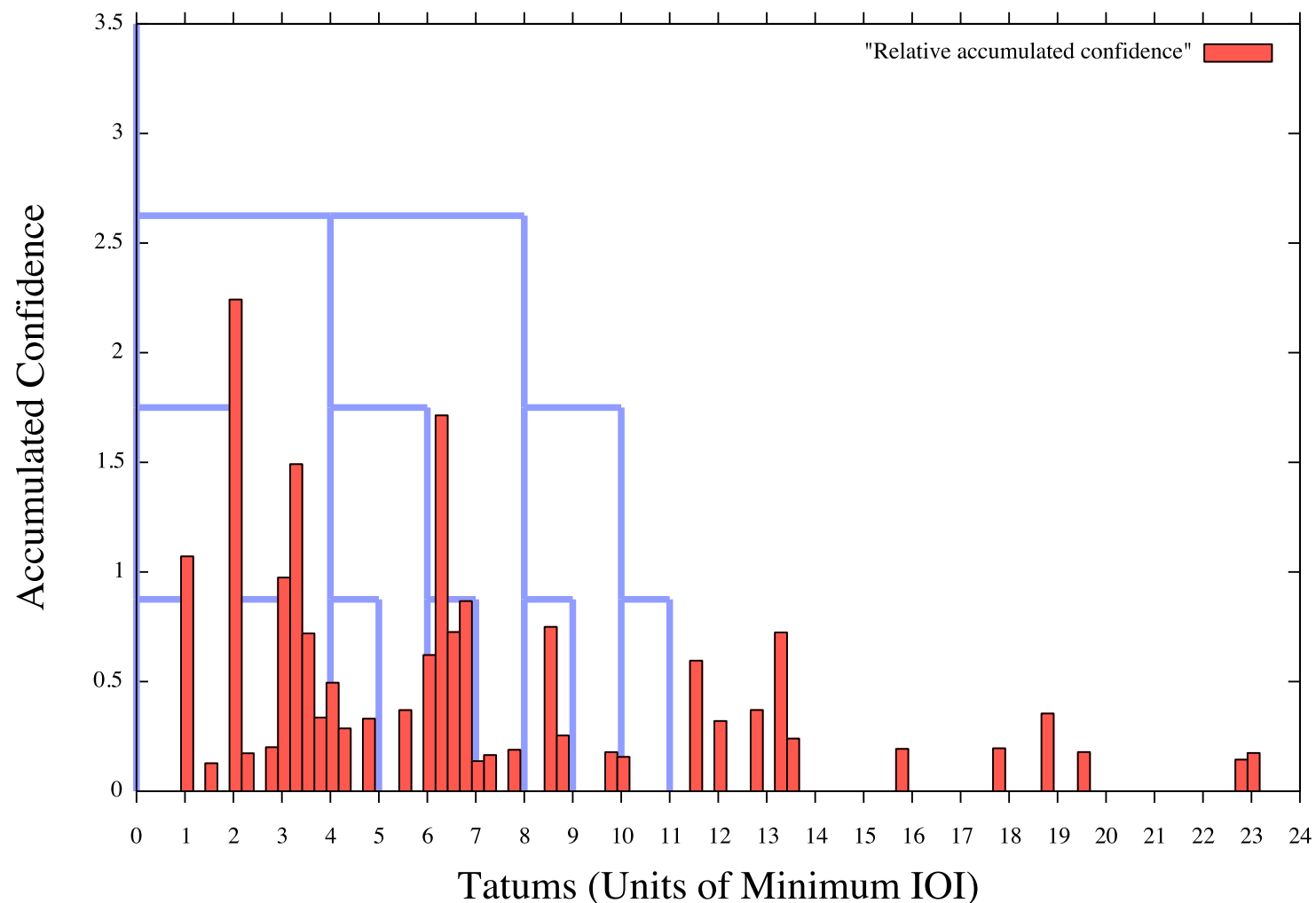
Accumulated Expectation Confidences for 20 random rhythms in 4/4 meter of 6 measures





Performed Rhythms

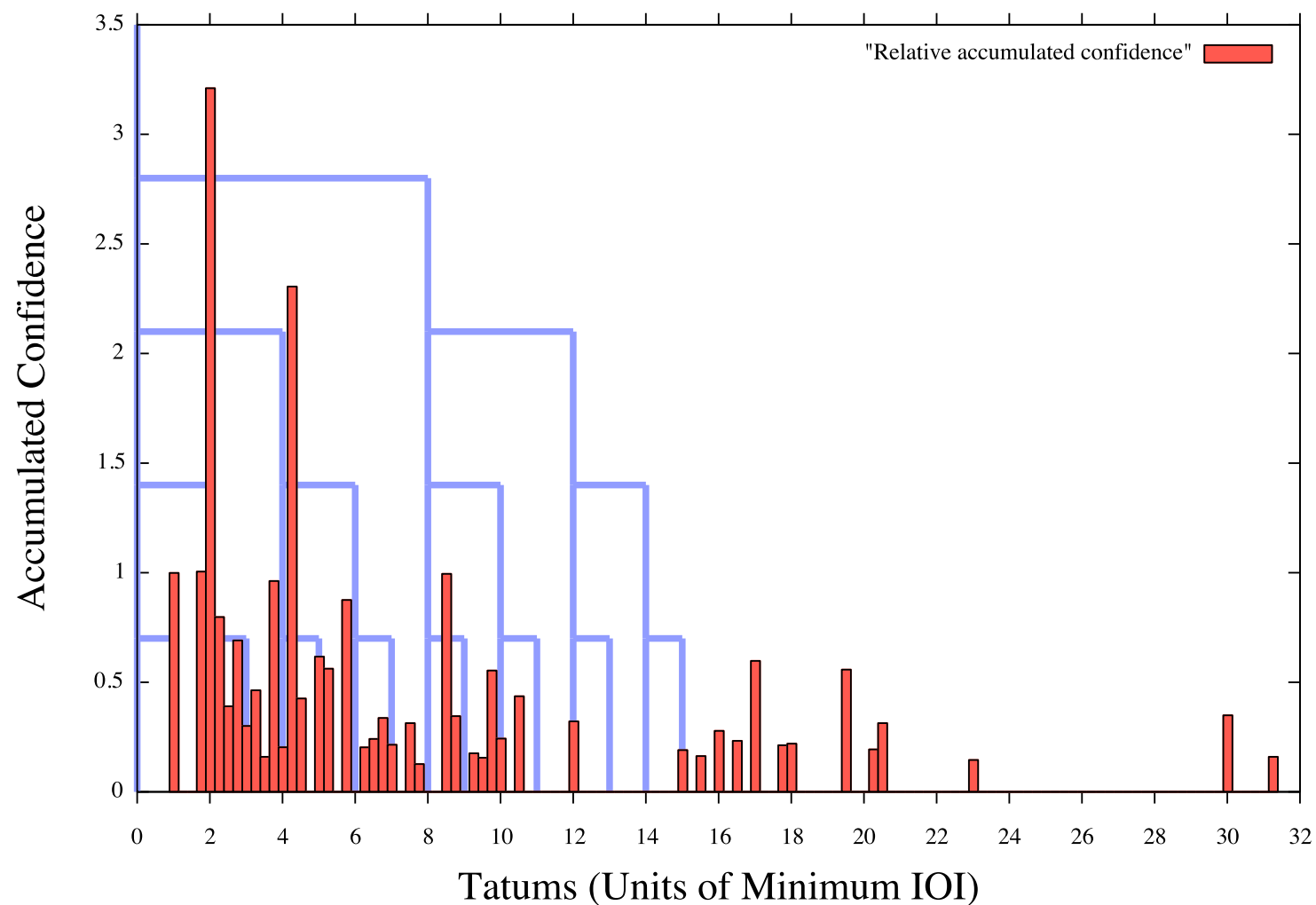
Accumulated Expectation Time-Values for 13 Performed Rhythms in 3/4 Meter





Performed Rhythms

Accumulated Expectation Time-Values for 16 Performed Rhythms in 4/4 Meter





Further Work



Further Work

- 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>