Adaptivity in Oscillator-based Pulse and Metre Perception

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EST 1894

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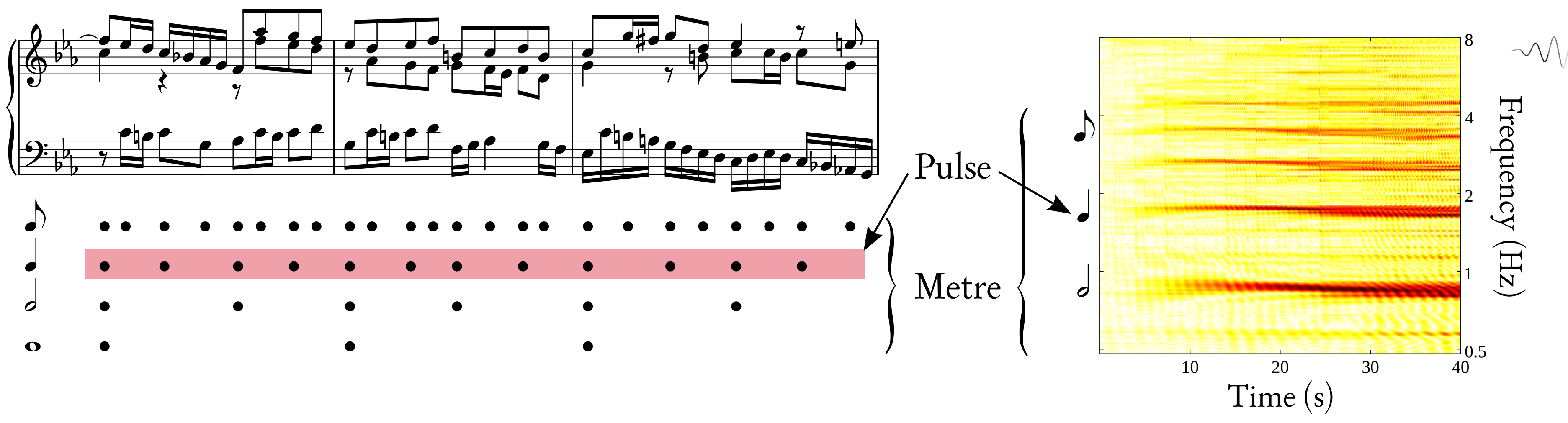
Beat Induction

A perceptual and cognitive process by which a steady **pulse** is perceived when listening to a rhythm.

Metre

The multi-layered divisions of time present in music, of which the referent layer is the **pulse**. Other layers in music **divide** the pulse into the smallest subdivisions of time, and **extend** it towards larger measures, phrases, periods, and even higher order forms.



Nonlinear Resonance

A model of the way our entire nervous system resonates to rhythms. A population of neurons is represented as a canonical **nonlinear oscillator**.

Expressive Timing

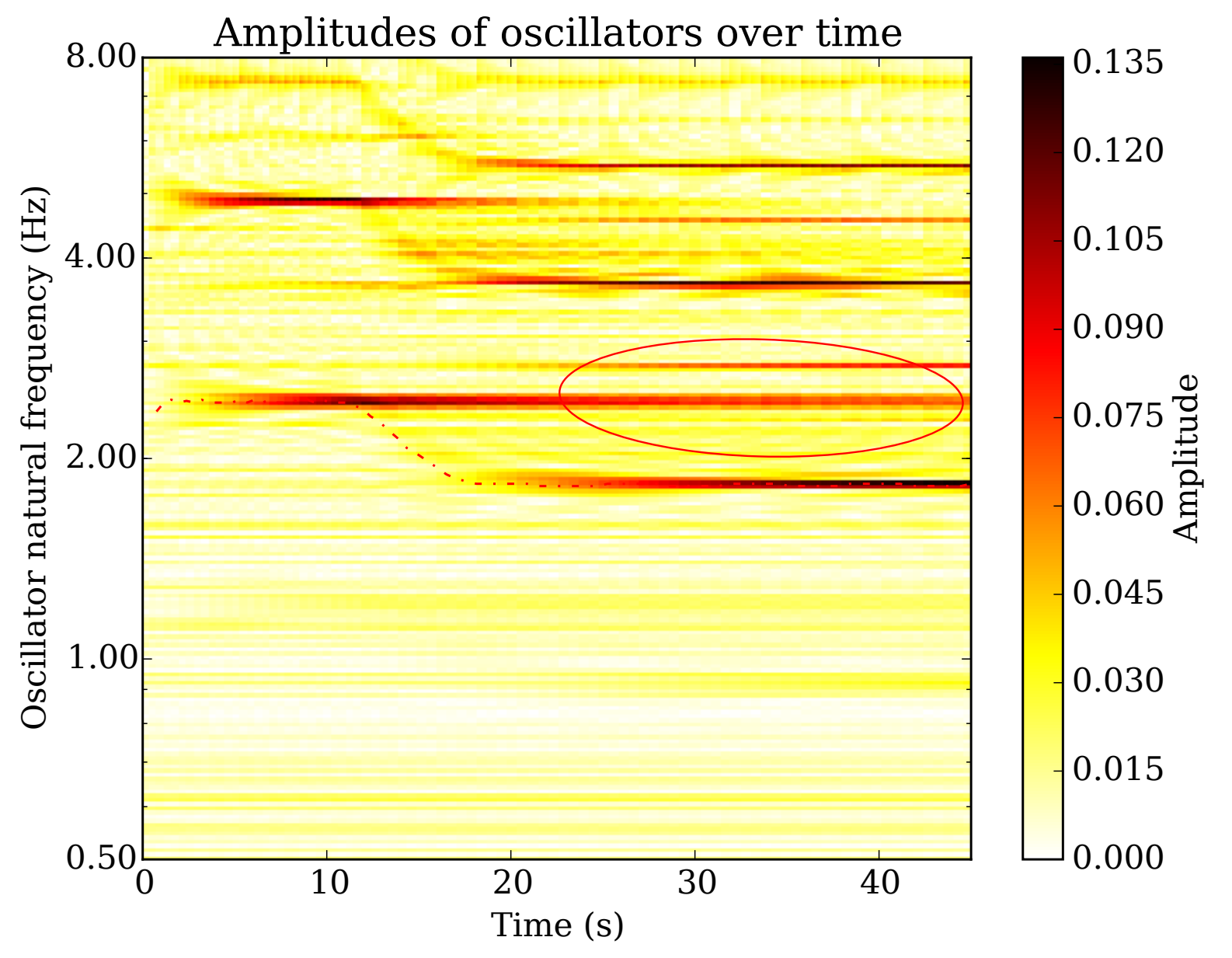
Expressive shaping of the music including **tempo change**, rubato, and groove that affects the perception of the **pulse** and **metre**.

Gradient Frequency Neural Network (GFNN)

A network of canonical **oscillators** distributed across a frequency gradient. Rhythm-harmonic frequency information is added to the signal, which can be interpreted as a perception of **metre** (Large et al., 2010).

Interference

We have found that, GFNNs **perform poorly** when dealing with tempo change. A memory of the original tempo can persist, causing interference in the output.



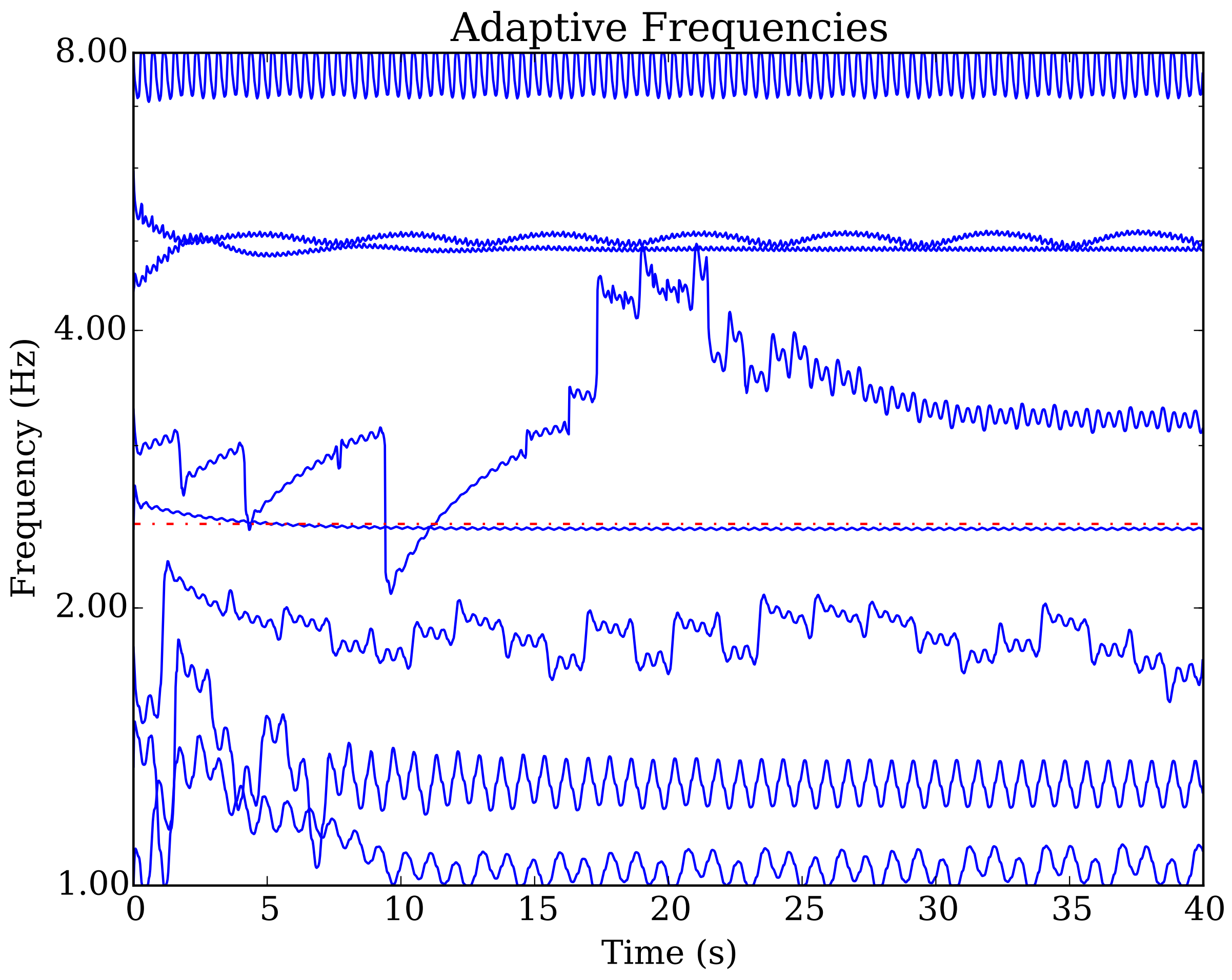
Adaptive Frequency Neural Network (AFNN)

Extends a GFNN with Righetti et al.'s (2006) Hebbian learning rule. Hebbian learning is a correlation-based learning observed in neural networks, and is therefore **biologically plausible**. The oscillator frequencies adapt to the stimulus through an **attraction** to local areas of resonance.

$$\frac{d\omega_i}{dt} = \frac{-\epsilon_f}{r} x(t)\sin(\phi_i) - \frac{\epsilon_h}{r}\left(\frac{\omega_i - \omega_{i0}}{\omega_{i0}}\right)$$

A secondary **elasticity** rule is also added, which attracts the frequencies back to their original value.

This allows for a great reduction in **network density**, reducing interference and increasing efficiency.



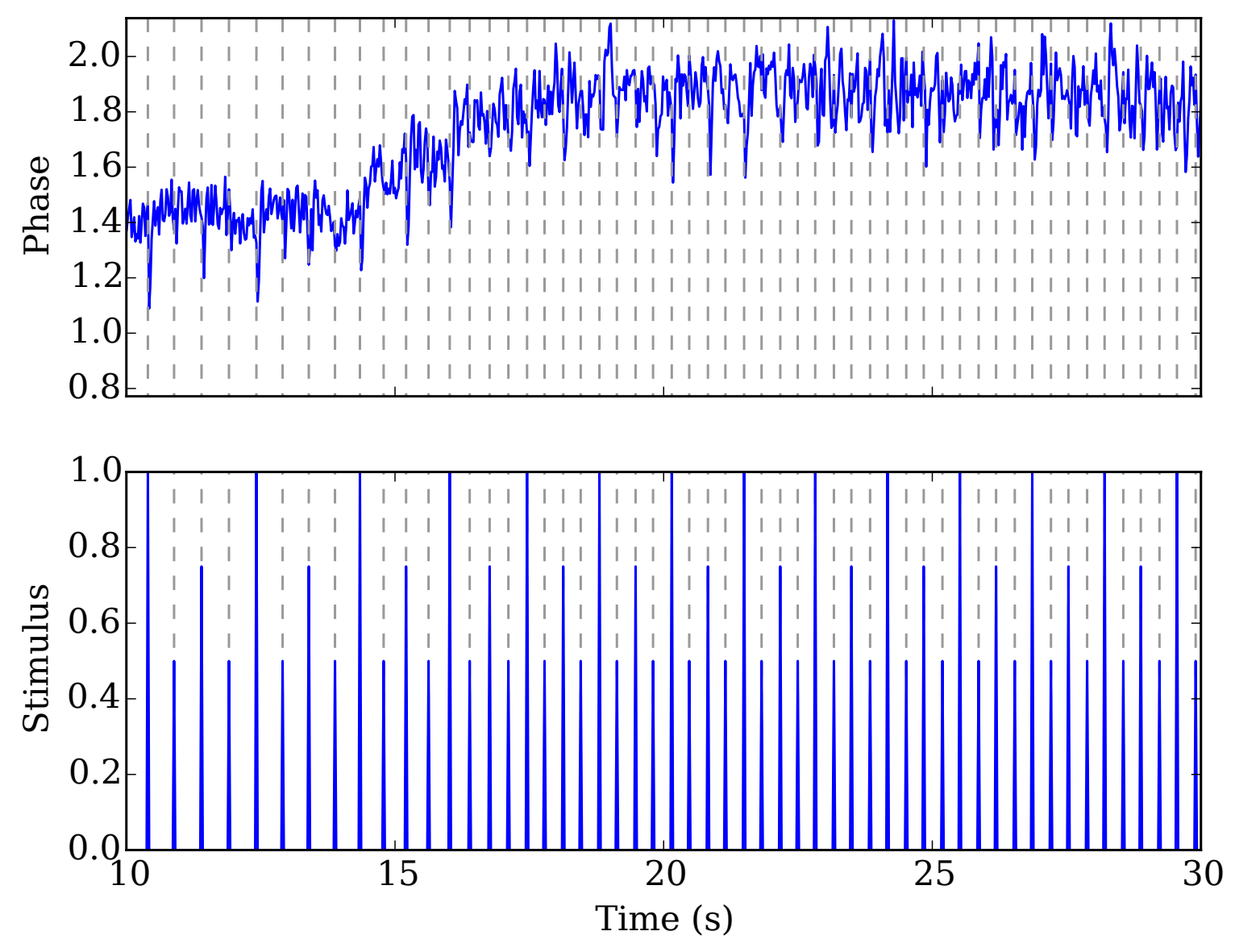
Evaluation

+ Compare **weighted phase output** (WPO) with a **ground truth phase** signal.
+ WPO is shown in (1) where *r* is the magnitude (|*z*|) and φ is the angle (*arg(z)*) of the oscillators.

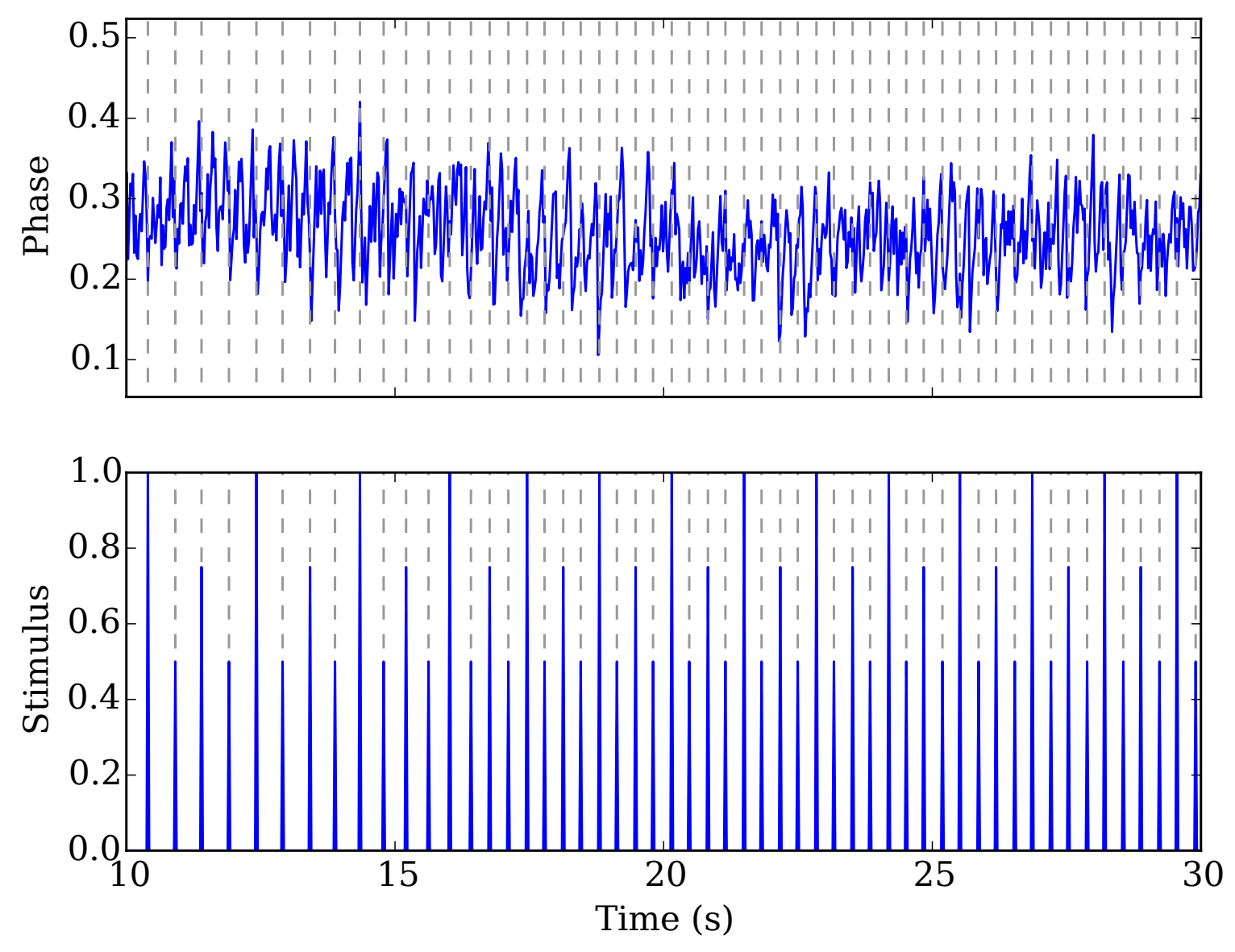
$$\Phi = \sum_{i=0}^{N} r_i \varphi_i \qquad (1)$$

+ Ground truth signal resembles an **inverted beat-pointer** model and represents phase growing from 0 to 2π in an oscillation.
+ Quantitative comparison via Pearson product-moment correlation coefficient (PCC)

AFNNs and GFNNs operate on more than one metrical level, so **small positive correlations** indicate good frequency and phase response.

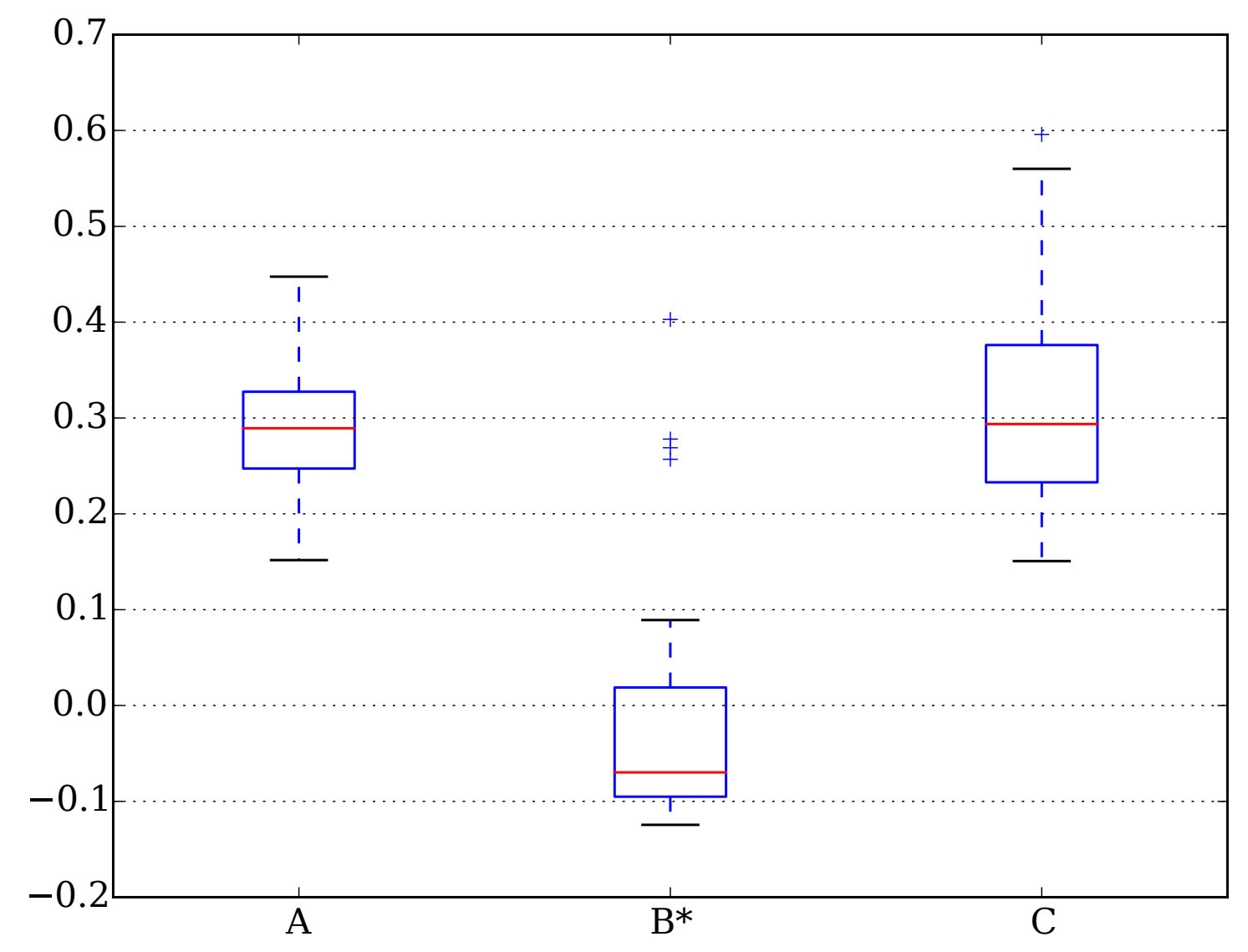


WPO over time of GFNN



WPO over time of AFNN

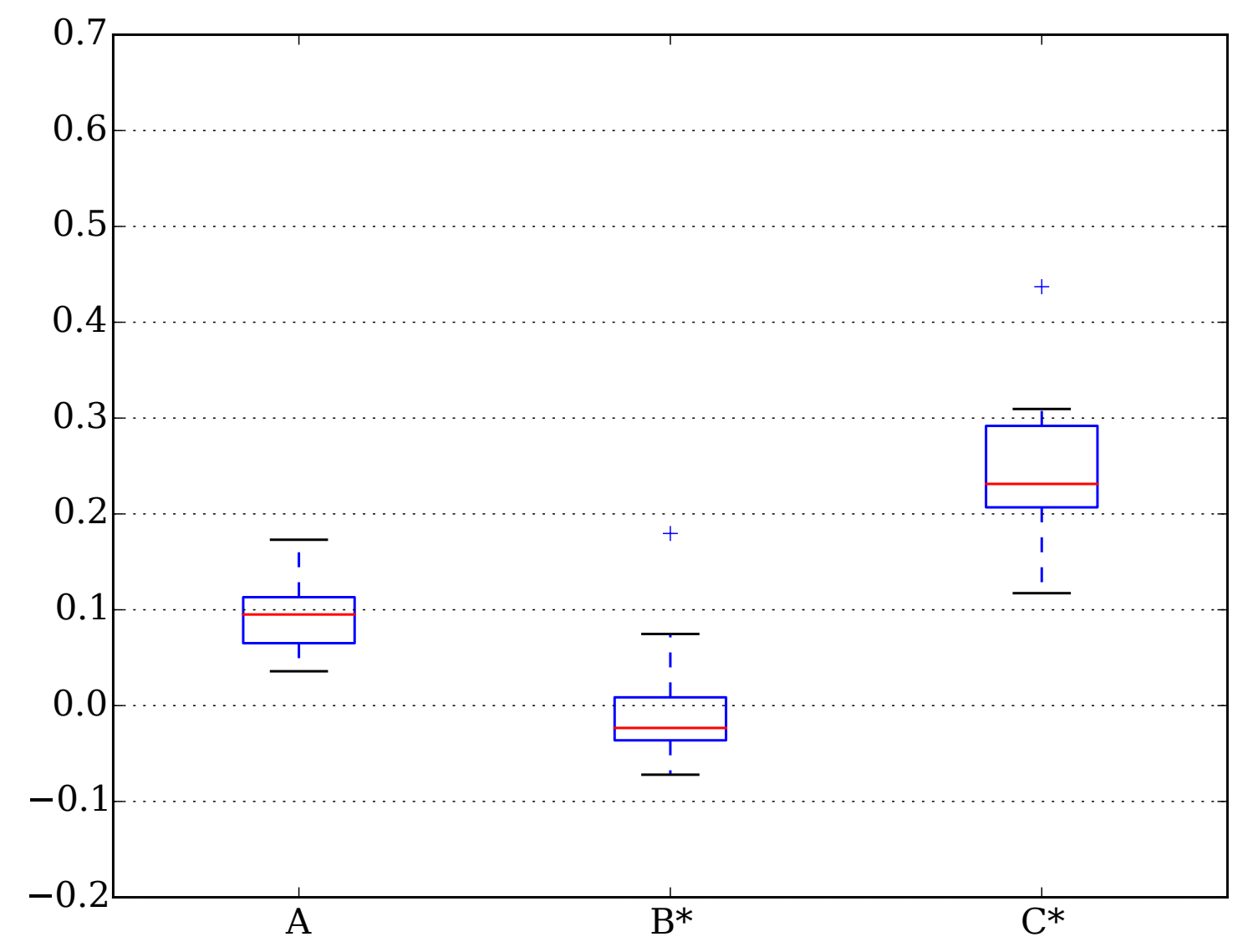
Results



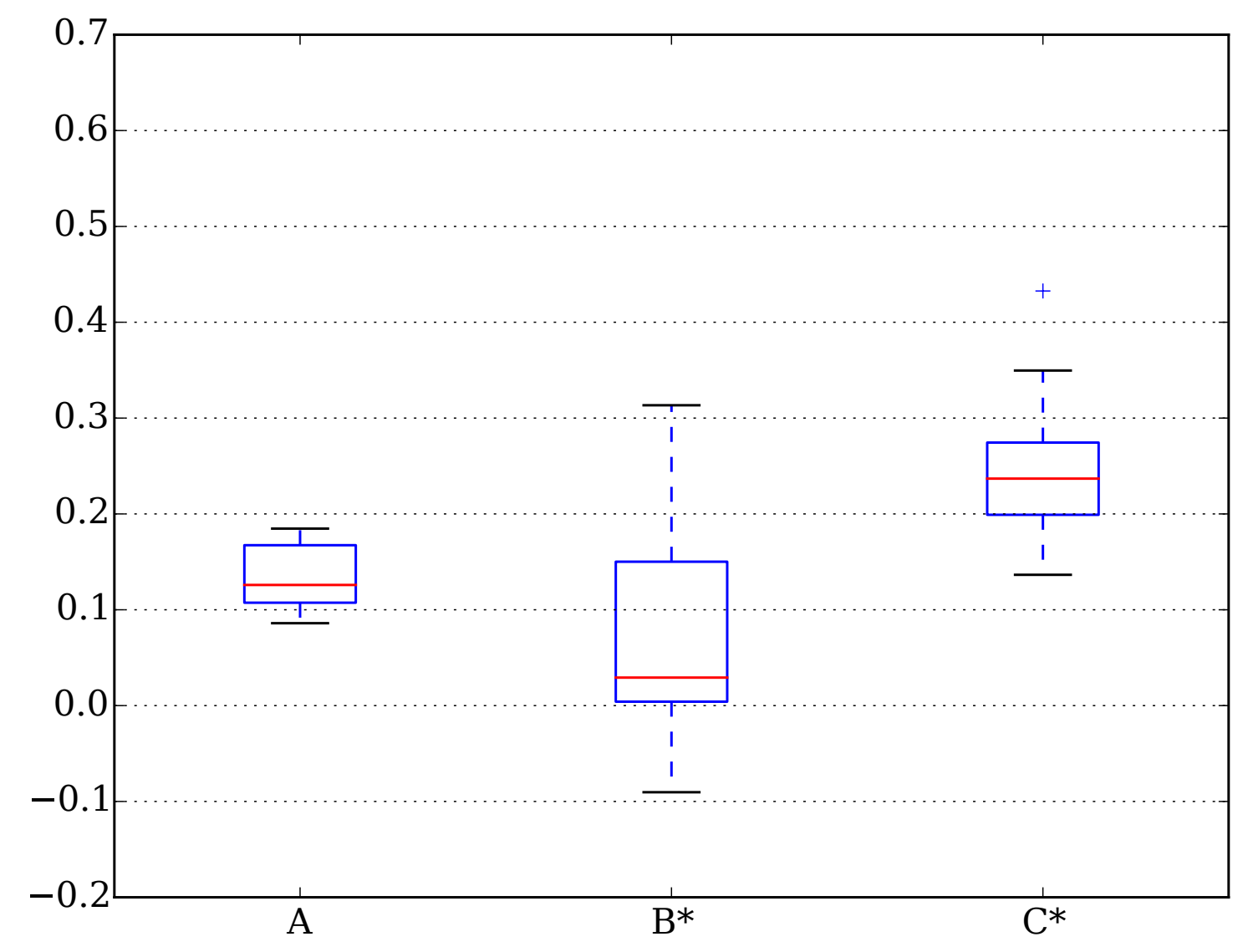
Isochronous

When compared with GFNNs, AFNNs show an **improved response** to rhythmic stimuli with both **steady** and **varying** pulse.

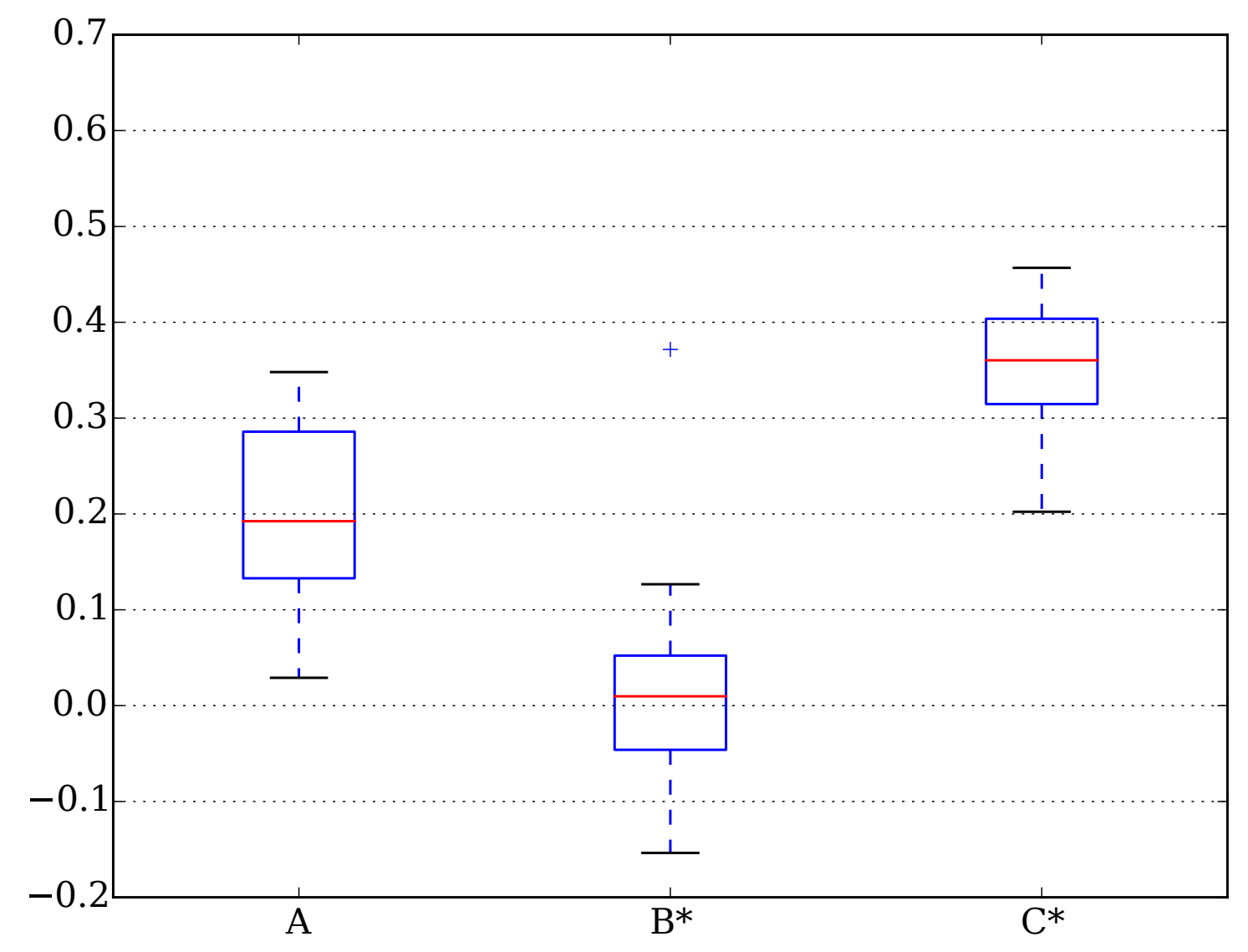
A) GFNN
B) Low density GFNN
C) AFNN
*Denotes significance in a Wilcoxon signed rank test ($p < 0.05$)



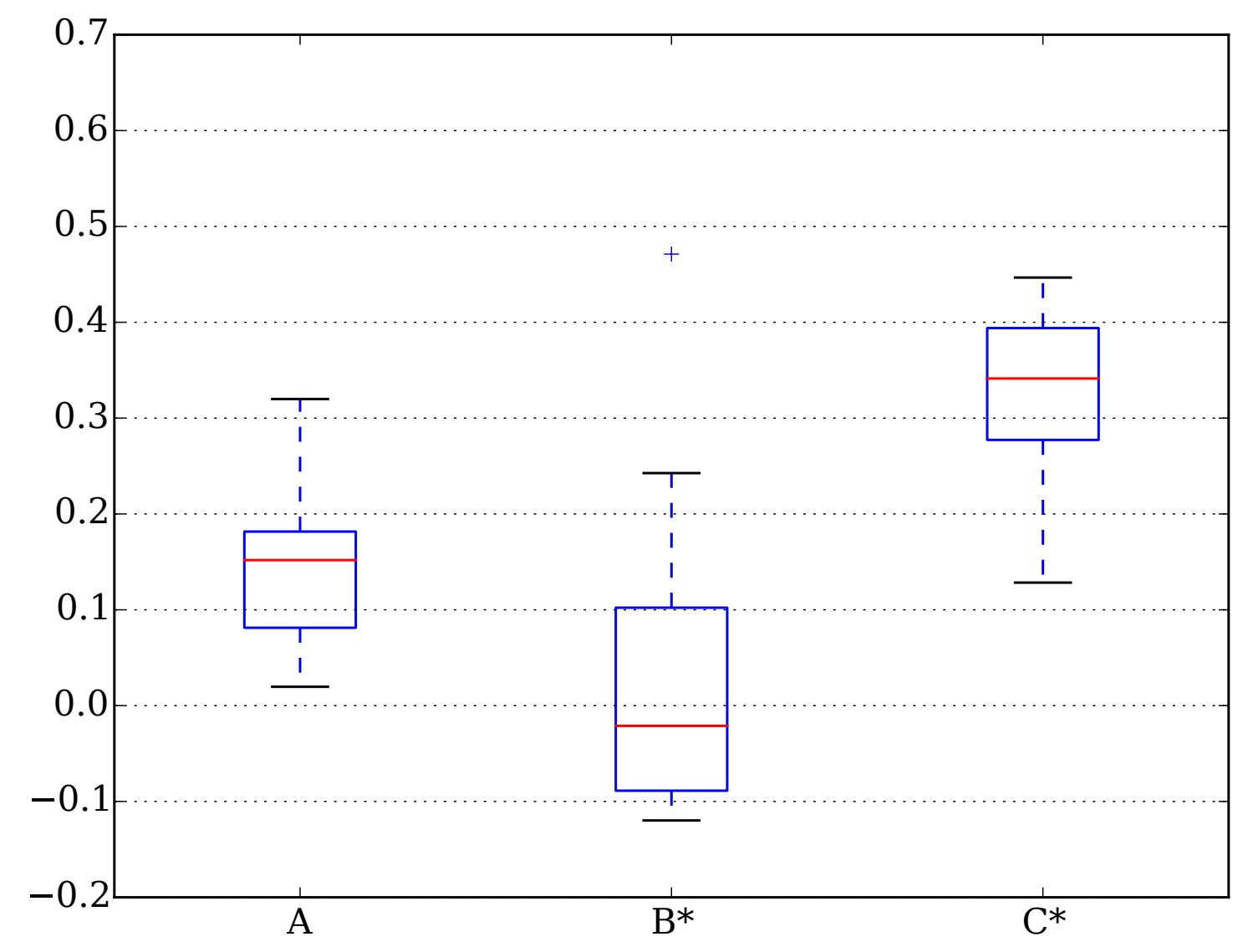
Accel.



Rit.



Doppio Mov



Doppio Piu

Edward W. Large. Neurodynamics of Music. In Mari R. Jones, Richard R. Fay, and Arthur N. Popper, editors, Music Perception, number 36 in Springer Handbook of Auditory Research, pages 201–31. Springer New York, 2010.
Ludovic Righetti, Jonas Buchli, and Auke J. Ijspeert. Dynamic hebbian learning in adaptive frequency oscillators. Physica D: Nonlinear Phenomena, 216 (2):269–81, 2006.