A GENERIC NONLINEAR MODEL FOR AUDITORY PERCEPTION

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This paper proposes a novel model for central auditory processing, a network of nonlinear oscillators. The properties of such networks are common to a family of physiological models that includes active cochlear models and oscillatory neural networks. Auditory perception can be modeled based on the generic properties of such physiological mechanisms, providing a bridge between physiology and psychoacoustics.

1 Introduction

Recent evidence has led to the proposal that active amplification, in the form of Andronov-Hopf type nonlinearities, is the basic mechanism of the mammalian cochlear response (Choe *et al.*, 1998). The cochlea may perform a sort of nonlinear (active) frequency transformation, using a network of locally coupled outer-hair cell oscillators. Nonlinear frequency transformation has also been observed at the neural level. Neurons that respond selectively to temporal and spectral features of communication sounds have been discovered in the central auditory systems of a variety of animal species (e.g. Crawford, 1997). Interval selective cells in the midbrain of the fish *Pollimyrus*, for example, have been succesfully modeled as nonlinear neural resonators based on anatomical and physiological data (Large & Crawford, 2002). Moreover, nonlinear resonance is a plausible candidate as a neural mechanism for pitch perception in humans (Cartwright *et al.*, 1999). This leads to the hypothesis that the mammalian auditory system performs nonlinear frequency transformation of incoming auditory stimuli at the periphery and also in the central auditory nervous system. After an initial analysis by the cochlea, networks of neural resonators further transform the stimulus.

2 Model and Discussion

A neural resonator can be modeled as a simple network of two neurons, one excitatory and one inhibitory (Wilson & Cowan, 1973). A nonlinear frequency transform can be computed using a network of coupled neural oscillators, each tuned to a distinct eigenfrequency, and driven by an external stimulus. Normal form analysis of such a network reveals a number of generic properties of nonlinear frequency transformation. These properties include extreme sensitivity to weak stimuli, sharp frequency tuning, amplitude compression, frequency detuning, nonlinear distortions, and natural phase differences. These properties predict many significant psychoacoustic phenomena, including hearing thresholds, frequency discrimination, loudness scaling, Stevens' rule, combination tones, pitch shift and dichotic pitch. Some of these phenomena can be explained by cochlear nonlinearities, however others appear to require (at least) a second nonlinear transformation operating on the output of the first. For example, cochlear frequency tuning worsens as stimulus intensity increases, yet frequency discrimination improves. Figure 1 illustrates a model that can explain this perceptual phenomenon.

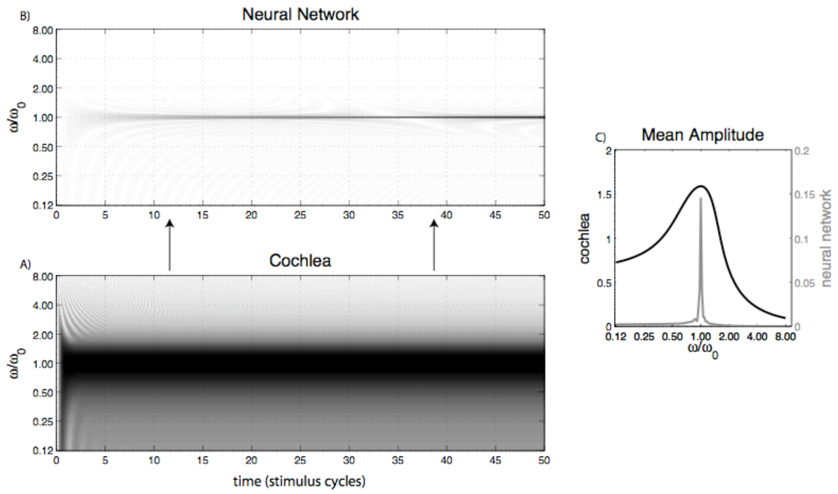

Figure 1. (A) Andronov-Hopf cochlea driven by a high intensity sinusoid (radian frequency ω_0). The cochlear model has poor frequency tuning at this intensity, but provides input to (B) a network of neural Andronov-Hopf resonators (radian frequency ω). The network of neural resonators displays sharp frequency tuning. Time and frequency (relative to the stimulus) are shown on the horizontal and vertical respectively; gray level indicates response amplitude. (C) Comparison of response amplitude and tuning.

Acknowledgments

This research was supported by NSF grant BCS-0094229.

References

Cartwright, J. H. E., Gonzålez, D. L., & Piro, O. (1999). Nonlinear dynamics of the perceived pitch of complex sounds. *Physical Review Letters, 82*(26), 5389-5392.

Choe, Y., Magnasco, M. O., & Hudspeth, A. J. (1998). A model for amplification of hair-bundle motion by cyclical binding of ca2+ to mechanoelectrical-transduction channels. *Proceedings of the National Academy of Sciences, 95*, 15321-15336.

Crawford, J. D. (1997). Feature detection by auditory neurons in the brain of a sound-producing fish. *Journal of Comparative Physiology A, 180*, 439-450.

Large, E. W., & Crawford, J. D. (2002). Auditory temporal computation: Interval selectivity based on post-inhibitory rebound. *Journal of Computational Neuroscience, 13*, 125-142.

Wilson, H. R., & Cowan, J. D. (1973). A mathematical theory of the functional dynamics of cortical and thalamic nervous tissue. *Kybernetik, 13*, 55-80.