# Goals

Language is one of the most complicated phenomena in everyday life, and by far the most common means by which human beings interact with each other. Viewed as a dynamical system, it is fascinating that spatial (written) and temporal (spoken) patterns can couple brain states so effectively! A key capability for this process is the remarkable properties of the mammalian cochlea, the organ that transduces the mechanical vibrations of sound into neural impulses. Our goals in this project are **to understand quantitatively the function of the cochlea** in the context of language, and **to study the characteristics of the local parameter space**, with an eye toward the evolution of the cochlea's capabilities (on the "slow time-scale" of evolution[5]).

# Plan

We will begin by developing a computer simulation of the basilar membrane of the cochlea, the organ responsible for mechanical spectral analysis of incoming auditory stimulation[8, 9]. The basilar membrane can be approximated as a series of coupled mass-spring oscillators with different resonant properties [2, 7], as a cascade of filters [1], using finite element methods [10], finite difference methods [3], or a variety of other techniques. Our first task will be to evaluate each of these approaches for ease of implementation, biological accuracy, and mathematical elegance (or ease of analysis). After choosing and implementing a model, we will test the simulation by coupling the boundary conditions with recordings of actual speech. Time permitting, we will pursue some of the following extensions:

- analyze the sensitivity of cochlear functions to various tuning parameters [11] and identify bifurcations
- develop a neural model of phoneme classification [6], which will be coupled to the output of the basilar membrane model
- attempt a mechanical cochlea [2, 4]

# References

[1] E. Ambikairajah, N. D. Black, and R. Linggard. Digital filter simulation of the basilar membrane. *Computer Speech and Language*, 3(2):105–118, Apr. 1989. doi: 10.1016/0885-2308(89)90024-7.

[2] F. Chen, H. I. Cohen, T. G. Bifano, J. Castle, J. Fortin, C. Kapusta, D. C. Mountain, A. Zosuls, and A. E. Hubbard. A hydromechanical biomimetic cochlea: experiments and models. *Journal of the Acoustical Society of America*, 119(1):394–405, 2006. doi: 10.1121/1.2141296.

[3] E. Givelberg and J. Bunn. A comprehensive three-dimensional model of the cochlea. *Journal of Computational Physics*, 191(2):377–391, Nov. 2003. doi: 10.106/S0021-9991(03)00319-X.

[4] R. M. Keolian. A demonstration apparatus of the cochlea. *Journal of the Acoustical Society of America*, 101 (2):1199–1201, 1997. doi: 10.1121/1.419497.

[5] G. A. Manley. A review of some current concepts of the functional evolution of the ear in terrestrial vertebrates. *Evolution*, 26(4):608–621, Dec. 1972.

[6] N. Mesgarani, S. V. David, J. B. Fritz, and S. A. Shamma. Phoneme representation and classification in primary auditory cortex. *Journal of the Acoustical Society of America*, 123(2):899–909, Feb. 2008.

[7] D. C. Mountain and A. E. Hubbard. Analysis and synthesis of cochlear mechanical function using models. In *Auditory Computation*, volume 6, pages 62–120. Springer-Verlag, New York, 1996.

[8] K. E. Nilsen and I. J. Russell. Timing of cochlear feedback: a spatial and temporal representation of a tone across the basilar membrane. *Nature Neuroscience*, 2:642–648, 1999. doi: 10.1038/10197.

[9] M. A. Ruggero, N. C. Rich, A. Recio, S. S. Narayan, and L. Robles. Basilar membrane responses to tones at the base of the chinchilla cochlea. *Journal of the Acoustical Society of America*, 101(4):2151–2163, 1997. doi: 10.1121/1.418265.

[10] E. B. Skrodzka. Mechanical passive and active models of the human basilar membrane. *Applied Acoustics*, 66 (12):1321–1338, Dec. 2005. doi: 10.1016/j.apacoust.2005.04.006.

[11] G. K. Yates. Basilar membrane nonlinearity and its influence on auditory nerve rate-intensity functions. *Hearing Research*, 50(1):145–162, Dec. 1990.