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Hearing: The next level of understanding

Stoop, R.

Abstract: Despite a long history of research involving some of the greater physicists the world has known (Ohm, von Helmholte, von Bekesy), the understanding of the mammalian, in particular human, hearing is still in its infancy. The present state of teaching of how we hear and listen is still centered around the Fourier analyzer partitioning incoming sounds into its frequency components, and that is it pretty much. We will, however see that the strong nonlinearities at work in the cochlea (providing a dynamical range of the signal up to 130 DB), demand this simple view to be dramatically changed. To show this, we follow a complex sound that enters the cochlea and consider what parts of the cochlea are elicited, and what turns out in the end to be responsible for human pitch perception. We do this on the basis of our biophysically detailed model of the cochlea [1-4] (based on Andronov-Hopf small signal amplifying outer hair cells [5]) that has been shown to reproduce all - even the most intricate - measured features of mammalian hearing (eg loudness dependence of pitch, pitch-shift effects, phase properties along the cochlea and much more [4, 6-7]), the measurements originating from laser-interferometry as well as results psychoacoustic roasts (for the latter, it is essential that the signal remains essential unaltered during the signal transduction from the continuous biophysics motions of the basilar membrane to the spike patterns at the upper end of the auditory nerve (to achieve this, biology exploits the potential of stochastic resonance [8]) . We look at this neuronal system (outer hair cells can be regarded as an archetype of such cells) from the angle of criticality, a viewpoint that is presently widely taken by neuroscientists with a physics background. A critical state of a (neuronal) network is characterized by power-law statistics, as the fingerprint of existing long-range correlation within the system at this state. We find, indeed, power-law distributions of links leading from already activated sites to consecutively activated sites within the cochlea, following the nonlinear interaction paradigm of combination tone generation.

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Hearing: the Next Level of Understanding

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Despite a long history of research involving some of the greater physicists the world has known (Ohm, von Helmholtz, von Bekesy), the understanding of the mammalian, in particular human, hearing is still in its infancy. The present state of teaching of how we hear and listen is still centered around the Fourier analyzer partitioning incoming sounds into its frequency components, and that is it pretty much.

We will, however see that the strong nonlinearities at work in the cochlea (providing a dynamical range of the signal up to 130 DB), demand this simple view to be dramatically changed. To show this, we follow a complex sound that enters the cochlea and consider what parts of the cochlea are elicited, and what turns out in the end to be responsible for human pitch perception. We do this on the basis of our biophysically detailed model of the cochlea [1-4] (based on Andronov-Hopf small signal amplifying outer hair cells [5]) that has been shown to reproduce all - even the most intricate - measured features of mammalian hearing (e.g. loudness dependence of pitch, pitch-shift effects, phase properties along the cochlea and much more [4, 6-7]), the measurements originating from laser-interferometry as well as results psychoacoustic roasts (for the latter, it is essential that the signal remains essential unaltered during the signal transduction from the continuous biophysics motions of the basilar membrane to the spike patterns at the upper end of the auditory nerve (to achieve this, biology exploits the potential of stochastic resonance [8]).

We look at this neuronal system (outer hair cells can be regarded as an archetype of such cells) from the angle of criticality, a viewpoint that is presently widely taken by neuroscientists with a physics background. A critical state of a (neuronal) network is characterized by power-law statistics, as the fingerprint of existing long-range correlation within the system at this state. We find, indeed, power-law distributions of links leading from already activated sites to consecutively activated sites within the cochlea, following the nonlinear interaction paradigm of combination tone generation.

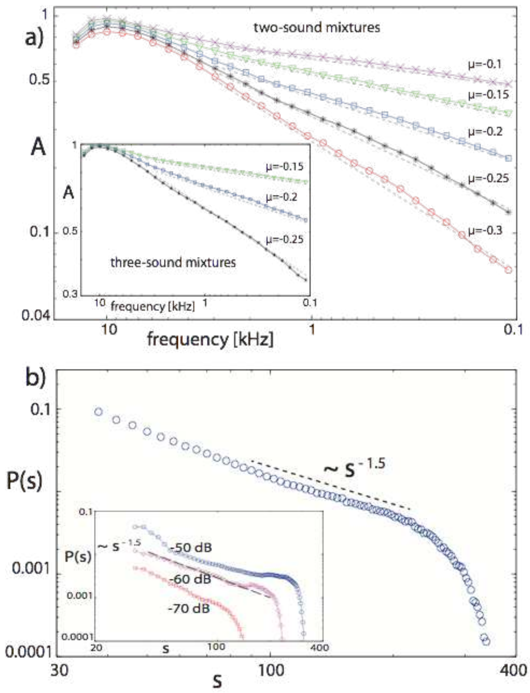

Fig. 1. a) A: number of activations i.e. above hearing threshold. Random sound levels (-80,-40) dB (rms) complex мtones.b) s: size of activation network by number of links. Two complex tones of random amplitude and frequency. Insets: Results for fixed amplitudes, indicating subcritical, critical and supercritical network states

These results suggest a critical network of the branching percolation universality class, paving more generally the way towards a novel understanding of the meaning of learning in neuronal networks. In our paradigm, learning is implemented by tuning away amplifier units that are unrelated to the desired signal. Indeed, in this way, substantial auditory scene analysis can be achieved [7].

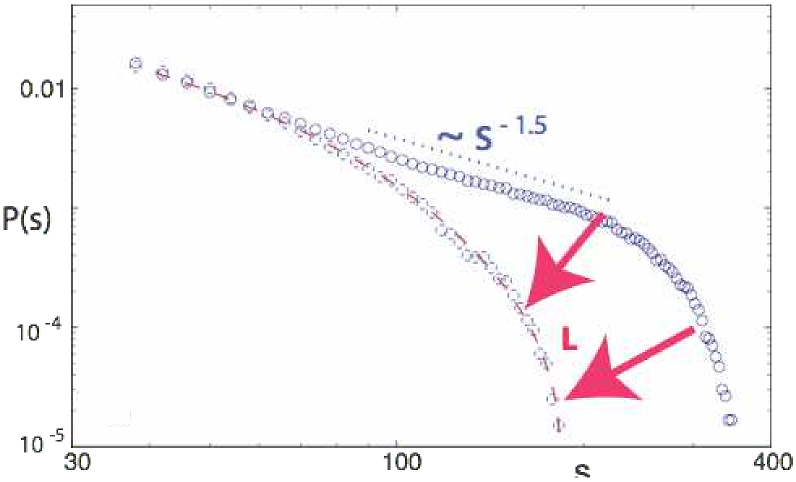

Fig. 2. Detuning of two frequency bands (nodes 15,16 and nodes 19,20,21) from μ = −0.25 to μ = −2.0: The initial s−1.5 power-law distribution changes into a strictly convex distribution shape (line L)

In the context of the theory of the thermodynamical formalism of dynamical systems, this change can be interpreted as the specification of a ground state of the network able to accommodate all potential stimulations, towards a more specific sound-targeting network.

In this way, the analysis of the hearing system contributes fundamental insight also for the brain.We hope that our approach will also lead us to a deeper understanding of the nature of otoacoustic emissions, the phenomenon of the sounds generated in many constructs of the mammalian ear.

Acknowledgements

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Analysis of the Brain Activity in Rodents Being Under Influence of General Anesthesia

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This time a great attention of researchers is devoted to the study of the brain activity [1; 2]. Such interest is connected, first of all, with the desire of the researchers to understand the fundamental principles of the brain activity as well as