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Using the structure of natural scenes and sounds to predict neural response properties in the brain

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The natural scenes and sounds we encounter in the world are highly structured. The fact that animals and humans are so efficient at processing these sensory signals compared with the latest algorithms running on the fastest modern computers suggests that our brains can exploit this structure. We have developed a sparse mathematical representation of speech that minimizes the number of active model neurons needed to represent typical speech sounds. The model learns several well-known acoustic features of speech such as harmonic stacks, formants, onsets and terminations, but we also find more exotic structures in the spectrogra representation of sound such as localized checkerboard patterns and frequency-modulated excitatory subregions flanked by suppressive sidebands. Moreover, several of these novel features resemble neuronal receptive fields reported in the Inferior Colliculus (IC), as well as auditory thalamus (MGBv) and primary auditory cortex (A1), and our model neurons exhibit the same tradeoff in spectrotemporal resolution as has been observed in IC. To our knowledge, this is the first demonstration that receptive fields of neurons in the ascending mammalian auditory pathway beyond the auditory nerve can be predicted based on coding principles and the statistical properties of recorded sounds. We have also developed a biologically-inspired neural network model of primary visual cortex (V1) that can learn a sparse representation of natural scenes using spiking neurons and strictly local plasticity rules. The representation learned by our model is in good agreement with measured receptive fields in V1, demonstrating that sparse sensory coding can be achieved in a realistic biological setting.