Emergence of linguistic laws in human voice

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Linguistic laws constitute one of the quantitative cornerstones of modern cognitive sciences and have been routinely investigated in written corpora, or in the equivalent transcription of oral corpora. This means that inferences of statistical patterns of language in acoustics are biased by the arbitrary, language-dependent segmentation of the signal, and virtually precludes the possibility of making comparative studies between human voice and other animal communication systems. Here we bridge this gap by proposing a method that allows to measure such patterns in acoustic signals of arbitrary origin, without needs to have access to the language corpus underneath.

We have explored the equivalent of linguistic laws directly in acoustic signals, founding that human voice -which actually complies to SOC dynamics with critical exponents compatible with those found in another critical fenomena as rainfall- manifests the analog of classical linguistic laws found in written texts (Zipfs law, Heaps law and the brevity law or law of abbreviation). These laws are invariant under variation of the energy threshold θ, and can be collapsed under universal functions accordingly. As θ is the only free parameter of the method, this invariance determines that the results are not afflicted by ambiguities associated to arbitrarily defining unit boundaries.

This current study focus and scans voice properties at intraphonemic timescales, where the statistical laws of language emerge directly from the physical magnitudes that govern acoustic communication. One could thus speculate that the emergence of these complex patterns is just a consequence of the presence of SOC, what in turn would support the physical origin of linguistic laws

The method has been applied to sixteen different human languages, recovering successfully some well-known laws of human communication at timescales even below the phoneme and finding yet another link between complexity and criticality in a biological system. These methods further pave the way for new comparative studies in animal communication or the analysis of signals of unknown code.

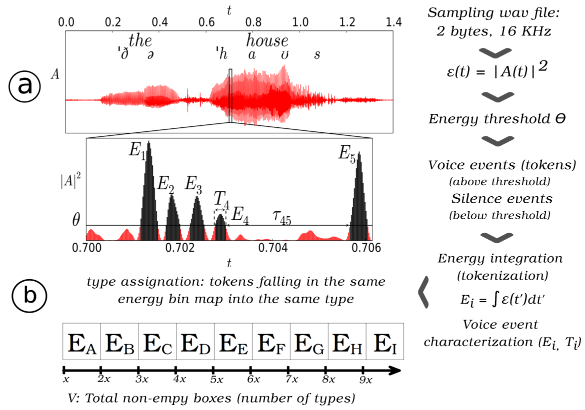

Figure 1: This figure illustrates the methodology to extract a sequence of types from an acoustic signal. Waveform series $A(t)$ are sampled at 16Khz from the system. In (a) we plot the instantaneous energy per unit time $\epsilon(t) = |A|^2$ from an excerpt of the top panel. The energy threshold θ, defined as the instantaneous energy level for which a fixed percentage of the entire data remains above-threshold, helps us to unambiguously define a token or voice event (a subsequence of time stamps for which $\epsilon(t) >$) from silence events of duration τ. The energy released E in a voice event is computed from the integration of the instantaneous energy over the duration of that event (dark area in the figure denotes the energy released in a given voice event). By performing a linear binning tokens are classified into several bins that we call types. The vocabulary V agglutinates those types that appear at least once

Journal of Statistical Mechanics: Theory and Experiment, 2010(11):P11030

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