I. PERIODICITY FROM NATURAL DYNAMICS

Periodic signals abound in nature; from planetary orbits and rotations down to mechanical vibrations. When extracting information from a complex environment, the most salient properties to be extracted are periodicities relating to data too regular to be of accidental nature. In the auditory world, these signals arrive in terms of pressure waves that in their basic variants are wellunderstood in terms of mostly linear physics [6]; the further information processing steps by humans then require nonlinear physics principles [7–9]. Clearly, all over in physics we are confronted with harmonic oscillators that naturally entrain wave equations; partly, because Hooke's law is a good approximation to many physical systems.

It seems, however, justified to ask where the origin of this *abundance* of periodic signals generated in the animal world may be? Here we put forward that observed periodicity may often emerge even from a less specialized source: from an underlying chaotic process. In the animal world, the dynamical processes are generally much more complicated and usually nonlinear. A classical example are pattern generators taken in a very general sense. If we take the animal gaits as the illustrative example, we may ignore in this context that their generating frequencies are somewhat low, seen from an auditory angle. As a tendency young animals make strange - as we will interpret it: chaotic - movements. Chaos provides

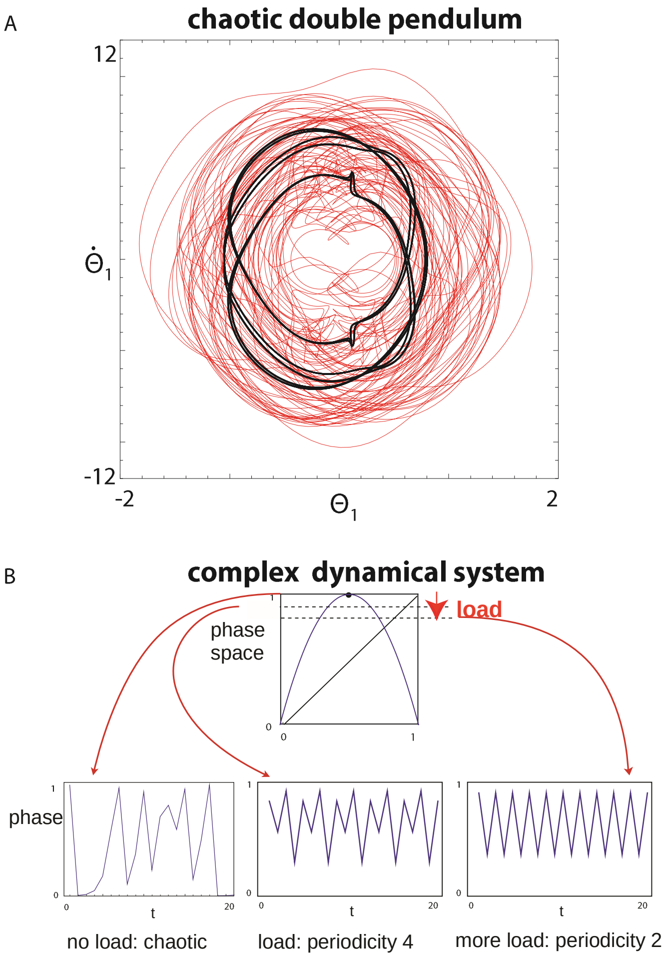

FIG. 1: A. Free (red) vs. soft limiter-controlled (black) orbit of a chaotic double pendulum model of a double-joint limb. Limiter by a spring that becomes active whenever in one of the joints, an angle exceeds a threshold. B. Explanatory example: Fully chaotic iterated parabola with limiters at different heights (dashed), leading to periodic motion.

the basic basin from which partial motions are selected, offering a great richness of choices to the system [10, 11]. Influence of living conditions or conditions arising from the survival paradigm then constrains the selection in an easy to grasp manner to simpler, less costly behavior, by acting as limiting conditions that change chaotic into periodic behaviors, a paradigm known under the name of limiter control [12–15]. It can moreover be inferred that the energy spent in a limiter-controlled periodic state is minimal [16]. For animals, load, weight or speed may act as such limiters; seen for instance in the transition from walk (period 4) to trot (period 2) 'gaits' in quadrupeds under the constraint of increasing speed or by the weight paradigm illustrated in a more abstract way in Fig. 1. As a result, periodic signals are not restricted to simple physical oscillators, they are also the most basic sound signatures of more complex systems from the animal world. Here, we illustrate this by taking, similarly to Ref. [12], two joints that would move chaotically, if not limited by elastic forces active as soon as one has crossed a certain threshold. Without loss of generality, we may restrict the control to the upper joint, where we introduce a springtype energy $V = \frac{1}{2}k[\theta_1 - \mathrm{sign}(\theta_1)\theta_0]^2$ that only becomes active for $|\theta_1| > |\theta_0|$. The addition to Hamilton's equations $\propto k\,[\theta_1 - \mathrm{sign}(\theta_1)\theta_0]$, for $|\theta_1| > |\theta_0|$ offers, by a choice of θ_0 to force the system onto a desired periodic orbit.