Study investigates collapse of natural or social systems

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A tipping point is a critical threshold at which a dynamical system undergoes an irreversible transformation, typically owing to a small change in inputs or parameters. This concept is very broad and can refer to the extinction of an animal or a plant species, the depletion of a water source, or the financial collapse of an institution, among many other natural and social phenomena.

Numerical simulations of tipping points by Everton Santos Medeiros, a researcher at the University of São Paulo's Physics Institute (IF-USP) in Brazil, provide a better understanding of the characteristics of this point of no return and what happens to a system after its occurrence. The study has been published in *Scientific Reports*.

"Oceanic, atmospheric, ecological, economic and other systems can undergo transitions of this kind," Medeiros told Agência FAPESP. "The system's parameters change gradually until a limit is reached at which one small change causes an abrupt and irreversible transition. The concept of a tipping point is well known in the literature. Our study set out to investigate what happens shortly after this critical transition."

Medeiros designed a generic cyclical dynamical system to model this type of transition. He chose a cyclical system because most natural phenomena are cyclical in response to periodic forcings, such as differences in sunlight associated with the seasons of the year.

"Hence our preference for a generic cyclical dynamical system that could be described by a simple differential equation," Medeiros explained. "Our numerical simulations varied the parameters of the equation until they reached a tipping point defined by elimination of the behavior they described."

Professor Iberê Luiz Caldas, co-author of the article, made an important distinction: "Our study focuses not on complex dynamical systems, but on simple dynamical systems that can display complex behavior, i.e., dynamical systems described by non-linear differential equations that have complex solutions." These systems were studied by the great French physicist, mathematician and philosopher Henri Poincaré (1854-1912).

Hysteresis is a key feature of the transitions that are classified as tipping points: Once the critical threshold is reached and the dynamical regime is abruptly destroyed, the regime cannot be restored by simply reversing the trend that caused the collapse. The extinction of an animal species, the depletion of a water reservoir and the thawing of a glacier all follow this type of hysteretic pattern in which irreversible damage is done when the tipping point is reached.

"But what our study showed, and this is its main contribution, is that for certain cyclical phenomena, the dynamics of the system last for a certain time after the tipping point, and this persistence may mask the transition itself," Medeiros said. "Take an endangered species, for example. It may have passed the point of no return and become irreversibly doomed. Nevertheless, individual members of the species continue to exist and reproduce in the wild. This transient effect conceals the fact that in the long run, the species is already extinct. In our study, through numerical simulation, we succeeded in observing this transient effect following the singularity that configures a tipping point."

Thus, the fundamentals of a phenomenon change irreversibly at the tipping point, but owing to a kind of "residual effect" the process appears to retain its original characteristics for a time, masking the transformation that has occurred.

"Because of the transient effect, hysteretic change is mistaken for gradual change that can easily be corrected. The transition may appear smooth but may actually be critical. In this case, eliminating the cause isn't sufficient to reverse the system's collapse," Medeiros said.

"It's hard to know in real-life situations whether a tipping point has been reached or not," Caldas said. "For example, can the Atlantic Rainforest between São Paulo and Santos be rehabilitated, or is it irremediably lost? There's still a lot of vegetation in the area, so people get the impression that it can be restored by initiatives capable of remedying the damage done. But is that the case? Isn't the remaining vegetation just a transient effect, so that the collapse of the forest in that region can't be reversed? One lesson to be drawn from our study is that a great deal of care has to be taken when symptoms of deterioration appear. Not every deterioration can be reversed."

More information: Everton S. Medeiros et al. Trapping Phenomenon Attenuates the Consequences of Tipping Points for Limit Cycles, *Scientific Reports* (2017). DOI: 10.1038/srep42351

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