PRESS RELEASE

A new approach to extreme events such as epileptic seizures and climate change

Bonn researchers develop method for describing and predicting critical transitions in networked systems

Comm. Chairman of the Board
Prof. Dr. Bernd Weber
Tel: +49 228 287-10900
Fax: +49 228 287-9010900
bernd.weber@ukbonn.de

Communication and media

Viola Röser
Management

Tel: +49 228 287-10469
viola.roeser@ukbonn.de

Bonn University Hospital
Communication and media
Venusberg Campus 1
Build 02
53127 Bonn

Bonn, May 06 – The global climate is in an imbalance. Potential "tipping elements " include the Greenland ice sheet, coral reefs, and the Amazon rainforest. Together they form a network that can collapse if just one individual component tips. Researchers from Bonn University Hospital (UKB) and the University of Bonn have now shed light on seemingly sudden and rare, often irreversible changes within a system, such as those that can be observed in the climate, the economy, social networks or even the human brain. They took a closer look at extreme events such as epileptic seizures. Their aim was to better understand the mechanisms underlying such changes in order to ultimately make predictions. The results of their work have now been published in the journal "Physical Review Research".

Unexpected and often irreversible changes in the state or dynamics of a complex system often lead to extreme events with likely catastrophic effects on the system and its environment. "Understanding and possibly predicting such critical transitions is therefore of paramount importance. The rather modest findings achieved so far may be due to the fact that previous research approaches rarely take into account the complicated, time-dependent interactions between the subsystems that can significantly determine the behavior underlying the critical transitions," says corresponding author Prof. Klaus Lehnertz, head of the neurophysics working group at the UKB's Department of Epileptology, who also conducts research at the Interdisciplinary Center for Complex Systems at the University of Bonn.

Interactions in temporally evolving tipping subnetworks

In contrast to previous approaches , which focus on either individual system elements or the system as a whole, the Bonn researchers therefore concentrated on an intermediate level in their work - and identified a structurally and temporally coherent substructure in a network, the so-called "tipping subnetwork". This is a subnetwork within a larger, temporally changing network in which the elements can collectively reach a tipping point. Although individual nodes and links can be stable, their interconnectedness with other elements means that even a small external perturbation or a gradual change can cause several nodes and links to tip at the same time. This is because the elements in a "tipping subnetwork" are connected to each other via feedback loops. A "tipping node" or a "tipping link " can therefore increase the pressure on others, which leads to the "tipping" of the entire subnetwork. "The tipping subnetwork shows a particular temporal rigidity and isolation compared to the overall network - properties that apparently make the system particularly susceptible to extreme changes in state," says first author Timo Bröhl, a doctoral student at the University of Bonn and research assistant in Prof. Lehnertz's working group at the UKB.

The researchers from Bonn were able to identify such subnetworks for the first time both in simulation models as well as in brain activity of people with epilepsy prior to epileptic seizures. They investigated the change in the integration of network components into the functional network using local network measures based on the concept of centrality. Centrality measures aim to capture the importance of network components from different perspectives in order to allow a holistic classification of their integration into the network. "These systems can repeatedly undergo critical transitions that lead to extreme events. Our results show that tipping subnetworks capture key properties of mechanisms involved in critical transitions," says Bröhl. Changes in this involvement in the functional network can provide important information about impending extreme events.

Bridge between theory and practice

"Our work builds a bridge between theoretical physics and clinical application and also makes an important contribution to basic research in the field of complex systems and their dynamics, especially in the investigation of extreme events and critical transitions," says Bröhl and Prof. Lehnertz adds: "Our methodology opens up new possibilities for the development of mathematical and physical models and methods for the early detection of critical transitions - with potential applications in medicine, climate research and beyond."

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Scientific contact:
Prof. Dr. Klaus Lehnertz
Head of working group "Neurophysics"
Department of Epileptology, University Hospital Bonn
Interdisciplinary Center for Complex Systems, University of Bonn
Phone: (+49) 228 287-15864
E-Mail: Klaus.Lehnertz@ukbonn.de

Timo Bröhl
“Neurophysics" working group
Department of Epileptology, University Hospital Bonn
Phone: (+49) 228 287- 19353
E-mail: timo.broehl@uni-bonn.de

Press contact:
Dr. Inka Väth
Deputy Press Officer at the University Hospital Bonn (UKB)
Communications and Media Office at Bonn University Hospital
Phone: (+49) 228 287-10596
E-mail: inka.vaeth@ukbonn.de

About Bonn University Hospital: The UKB treats around 500,000 patients per year, employs around 9,500 staff and has total assets of 1.8 billion euros. In addition to the 3,500 medical and dental students, 550 people are trained in numerous healthcare professions each year. The UKB is ranked first among university hospitals (UK) in NRW in the Focus Clinic List, had over 100 million third-party funds in research in 2023 and has the second highest case mix index (case severity) in Germany. The F.A.Z. Institute awarded the UKB first place among university hospitals in the category "Germany's Training Champions 2024".