PRESS RELEASE

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Nash Equilibria: The Hidden Math Behind Predator–Prey Behaviors

Using game theory, researchers show how attack and defense strategies emerge as stable behavioral dynamics

Animal survival depends on effective attack and defense strategies, yet how these behaviors arise remains unclear. Addressing this question, a recent study shows that predator and prey behaviors emerge naturally as stable patterns shaped by simple sensory abilities and motor rules. These patterns correspond to Nash equilibria—states in which neither predator nor prey can improve its outcome by unilaterally changing behavior—providing a theoretical framework for understanding predator–prey interactions.

Nature is filled with remarkable diversity and complex interactions. However, its complexity is not random; it is shaped by systematic rules that determine how organisms behave. Attack and defense behaviors are among the most fundamental actions animals perform to survive. While predators use strategies such as chasing or ambushing to capture their prey, defense tactics, such as fleeing or freezing, are usually used by the prey to avoid being caught. Although these behaviors are widely observed in many species, an important question persists: On what basis do these behaviors arise, and why do they stay stable in different conditions?

Addressing this issue, a research team from the University of Toyama, led by Professor Hiroyuki Ichijo and Associate Professor Tomoya Nakamura from the Department of Anatomy, Faculty of Medicine, along with medical student Yuichiro Kawamura from the School of Medicine, used a computational approach to understand the strategic predator–prey behaviors. The researchers combined game theory with individual-based behavioral models and demonstrated that the seemingly complex attack and defense behaviors could be simply derived as Nash equilibrium strategies (a mathematically stable balance of behaviors). Their study was published in *PLOS Computational Biology* on November 21, 2025.

"*Nash equilibria can explain stable predator–prey behaviors where neither predator nor prey benefits from changing its strategy unilaterally,*" says Prof. Ichijo. "*Remarkably, these stable behaviors arise from simple sensory and motor, without requiring complex assumptions*."

In the simulation model, the predator and prey "agents" were assigned only basic functions such as the ability to detect an opponent within a certain distance and the capacity to increase or decrease movement speed in response. When the researchers mathematically analyzed the predator–prey behavior using game theory, they found that specific combinations of detection ability and movement strategy consistently produced distinct and stable behavioral outcomes. Notably, even under these simplified conditions, the models reproduced well-known natural behaviors, such as chasing, ambushing, escaping, and freezing. For example, if a prey can detect predators from farther away, escaping becomes the best and most stable strategy, whereas certain sensing conditions for predators favored ambushing or chasing strategies.

"*Interestingly, these behaviors emerged without assuming any complex cognitive processes or requiring fine-grained sensing abilities. Instead, they came simply from the basic rules of interaction, showing that complex behavior can grow out of simple mechanisms,*" remarks Prof. Ichijo.

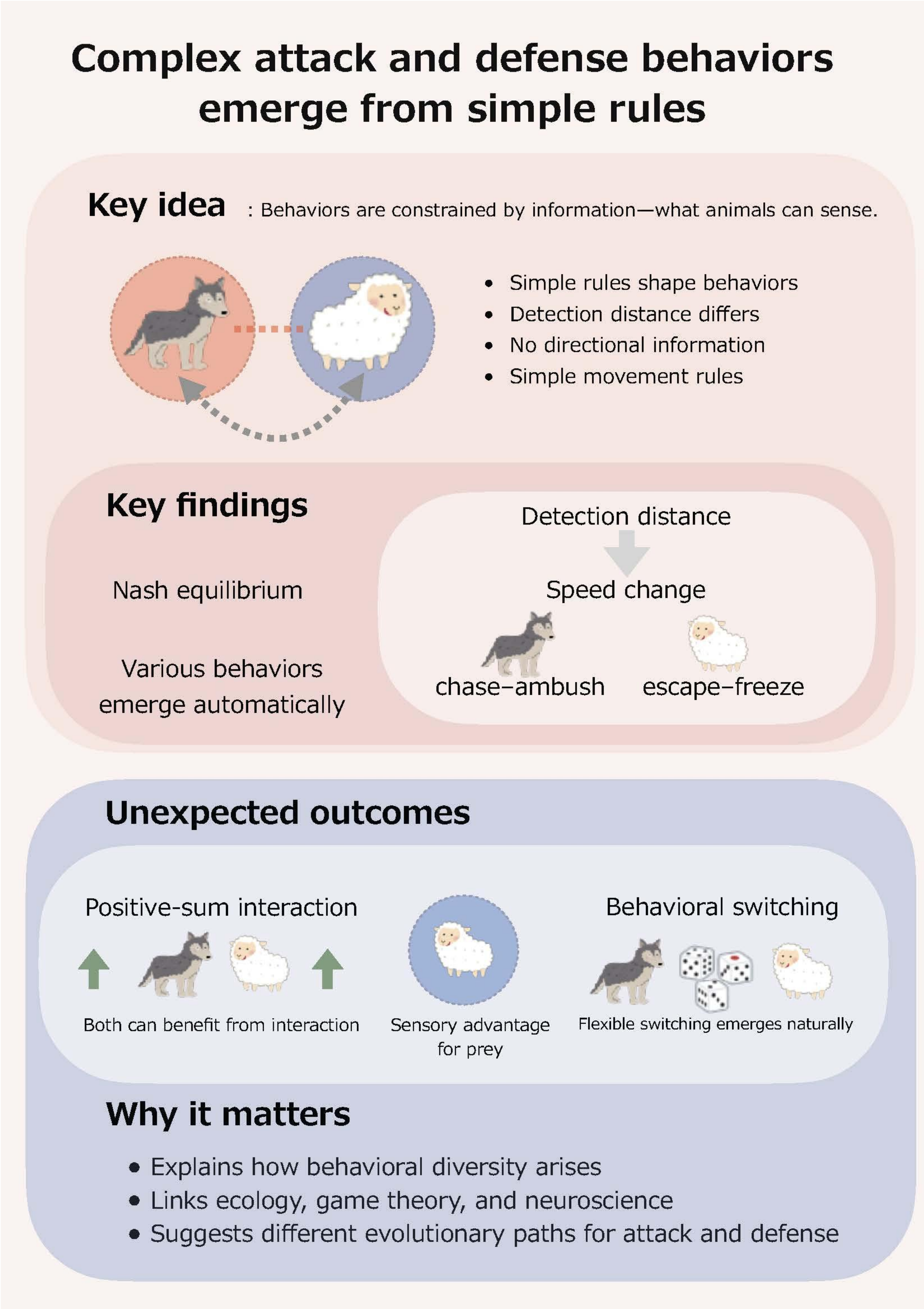
One key finding was that the predator–prey interactions were not always strictly competitive; in many simulated conditions, both predators and prey benefited simultaneously, challenging the traditional "winner-versus-loser" assumption. For instance, when predators could detect prey from farther away, they also competed more with each other, which in some situations helped prey populations survive better, even while predators were still successfully attacking.

This insight critically changes how scientists view predator-prey relationships. Instead of being a purely hostile battle, these interactions create situations where both sides independently benefit by engaging in the attack or defense behavior. Furthermore, the study also highlights the importance of sensory abilities for survival. Even subtle changes in the sensing or detection ability of an animal can completely alter its behavior, such as whether it chooses to run or freeze or decides to chase or wait in ambush. This effectively explains why sensory evolution is so strongly tied to behavioral adaptation in nature.

"*Rather than focusing on the development of a specific technology, our research provides a general framework for understanding animal behavior in natural settings*," notes Prof. Ichijo. "*This framework offers a theoretical basis for explaining why certain strategies emerge and remain stable in nature, and it may also inform future applications in robotics and AI.*"

Overall, this study deepens our understanding of animal survival by showing that stable attack and defense strategies emerge naturally from behavioral patterns grounded in sensory capability and motor control. By mathematically identifying the Nash equilibria governing these interactions, the research bridges individual behavioral mechanisms with system-level stability, providing a robust theoretical model for understanding how survival is organized in nature.

Image



Title: How Simple Sensing and Movement Rules Generate Diverse and Stable Predator–Prey Behaviors

Caption: Researchers used computational simulations to demonstrate how simple sensing and movement rules—such as detection of distance and speed changes—constrain predator–prey interactions.
In a simplified model, detection alone (without directional information) triggers movement responses, producing chasing, ambush, escape, or freezing behaviors. Varying sensory ranges and movement rules lead to predictable, stable attack and defense strategies consistent with Nash equilibrium, while also allowing flexible behavioral switching and sensory advantages to emerge naturally.
Credit: Professor Hiroyuki Ichijo from the University of Toyama, Japan
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Reference

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About University of Toyama, Japan

University of Toyama is a leading national university located in Toyama Prefecture, Japan, with campuses in Toyama City and Takaoka City. Formed in 2005 through the integration of three former national institutions, the university brings together a broad spectrum of disciplines across its 9 undergraduate schools, 8 graduate schools, and a range of specialized institutes. With more than 9,000 students, including a growing international cohort, the university is dedicated to high-quality education, cutting-edge research, and meaningful social contribution. Guided by the mission to cultivate individuals with creativity, ethical awareness, and a strong sense of purpose, the University of Toyama fosters learning that integrates the humanities, social sciences, natural sciences, and life sciences. The university emphasizes a global standard of education while remaining deeply engaged with the local community.

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About Professor Hiroyuki Ichijo from the University of Toyama, Japan

Hiroyuki Ichijo is a Professor in the Department of Anatomy at the University of Toyama in Japan. He earned his M.D. and Ph.D. from Kyoto Prefectural University of Medicine after graduating from Sapporo Medical University. He has held research and teaching positions at the Max Planck Institute for Developmental Biology and the University of Tsukuba. He pursues a wide range of interests and is known for challenging questions that are rarely addressed by others, with a focus on neuroscience and developmental neurobiology, particularly in the study of neural circuitry, axon guidance, and the relationships between brain structure and function.

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