Cell sizes, clumping explain how animals form sharp patterns

While scientists knew diffusion played a role in animals creating different patterns on their skin, they couldn't determine how exactly an imperfect pattern took shape; a new model has come very close by adding diffusiophoresis to the mix

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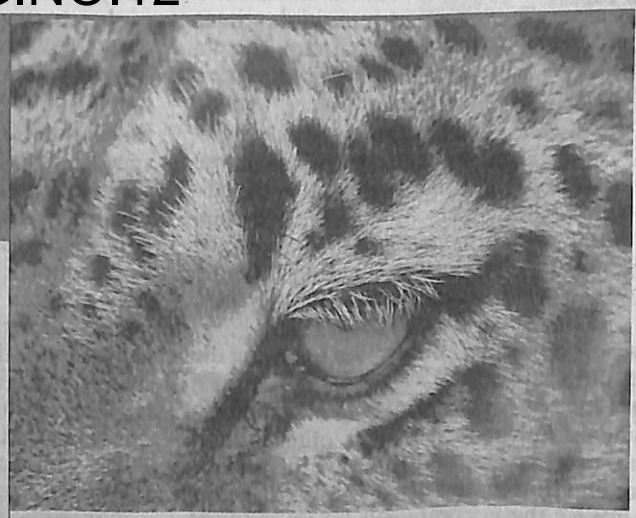
Islands of colour

Researchers have found a simple model that recreates animals' coat patterns

- Classic Turing models explain diffusion-driven pigment patterns but often yield blurry and poorly bounded motifs
- Researchers recently found diffusiophoresis, where particles can attract or repel, producing sharper simulated patterns than before
- Early simulations yielded patterns that were too perfect compared to the irregular animal coat patterns observed in nature
- By assigning cells different sizes in a simulation, the researchers were able to reproduce imperfect yet realistic patterns seen on animals
- The cells' sizes governed their ability to pack together to create tight pigmented regions separated by sparser gaps
- While the model is itself imperfect, researchers expect it could pave the way for better camouflage and textile designs



Simple physics can give rise to natural wonders. AMANDA SWANEPOEL

For many decades now, scientists and biologists have been trying to understand how the mesmerising patterns in animal coats emerge from a group of underdeveloped cells.

The British mathematician Alan Turing proposed in the early 1950s that as cells and tissue develop, they produce certain molecules or chemical agents that diffuse into their surroundings, react with each other, and eventually enable the process of producing pigments for the patterns. Simultaneously, other interactions could inhibit their diffusion, creating non-pigmented spaces between patterns and confining them to particular areas. This model is why the resulting patterns are today called Turing patterns.

However, when scientists simulated this model on computers, the patterns didn't develop the kind of sharp outlines seen on zebras, leopards, and snakes. Instead, it yielded blurry patterns, as if the diffusion wasn't confined.

A new study from the University of Colorado-Boulder, published in Matter on October 27, has reportedly figured out how animal coat patterns with sharp edges take shape.

In 2023, a team led by Ankur Gupta, the new study's coauthor and assistant professor at the chemical and biological engineering department, identified a phenomenon called diffusiophoresis: where colloidal particles suspended in a fluid or dispersion medium could attract other particles like a magnet, clumping them together.

When they ran simulations, they found diffusiophoresis could result in sharper patterns than the Turing model created. However, these patterns were symmetrical, whereas in nature they have little imperfections.

In the new study, Dr. Gupta and his colleague Siamak Mirfendereski improved their own model by assigning specific sizes to different cells, then simulated the movement of these cells through tissues. And there they were: the imperfect Turing patterns much like those in the wild. Say a molecule is moving through a liquid medium. Because it's so small, it will be affected by small temperature changes happening around it. Seen from afar, the molecule will seem to be jittering around in random directions, and its journey through the medium in this way is called diffusion. It's what happens, for example, when some ink is dropped into a glass of water: the ink molecules diffuse over time to spread out evenly.

The team found that when it used the Turing model, the patterns appeared blurry without proper boundaries, meaning the pigments were only allowed to diffuse. But if they were allowed to clump together, the team found that little clumps would form in the medium, with particles aggregating together. This phenomenon is called diffusiophoresis.

When the researchers modeled the entire system with diffusiophoresis, they observed that patterns did occur and that they were much sharper than the classical Turing model. But because the cells all had the same size, the patterns were too perfect.

In the aforementioned example, the updated model is akin to some particles in the water being attracted to the ink molecules while others are repelled.

The cells' size matters in this scenario because it controls how well the cells can be packed around each other when they clump.

In the model, when the cells were small compared to the pattern thickness, they could move freely and fit neatly into new patterns and the clumps they formed were smooth and well-organised. But as the cell got bigger, approaching the width of the chemical pattern, they started to bump into each other more and couldn't fit perfectly into the pattern's 'ideal' spots, leading to imperfections. Some areas could be packed tightly while others were sparse or fragmented.

Since larger cells also have more surface area, they could form broader patterns than those formed by smaller cells. But when they were even larger, the cells couldn't form complete patterns at all. The clumps become irregular and coarse, like the uneven spots seen in real biological tissue.

"When we simply modeled the cells with various sizes, our ... patterns suddenly became much more realistic," Dr. Gupta said. "The imperfections in patterns are present and tightened, and something like the idea of discreteness is observed in this framework, and these patterns resemble more closely what we find in nature."

The study isn't without limitations. The new model doesn't account for biological forces within a tissue or cell (e.g. adhesion) and it also simulated cells as hard spheres rather than as the permeable and squishy blobs they really are – both issues the researchers said could be resolved in future studies. For now, the new findings do come close to explaining natural patterns found in various animals, and could pave the way for better camouflage and textile design.

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