How organisms convert 2D patterns into 3D

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ABSTRACT:

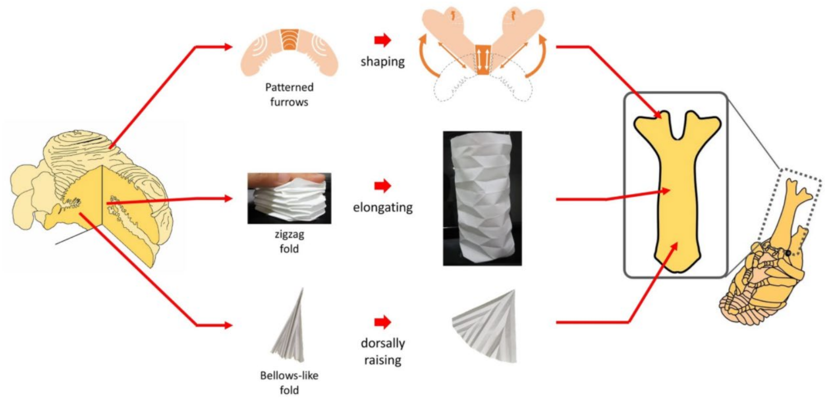
The question, "How are organisms formed?" is one of the central questions in developmental biology. In the past 30 years, embryological experiments and mathematical modeling studies have revealed the mechanisms by which individual genes are expressed in specific regions, the so-called principles of pattern formation. However, those principles deal, for the most part, only with the division of fixed fields into regions. In actual morphogenetic phenomena, pattern formation and the expansion and deformation of the field proceed simultaneously. As such, it is extremely difficult to model such a situation, because the two different elements affect each other.

To circumvent these difficulties, it is useful to study phenomena in which cellular changes and field deformation occur at different times. We believe that the deformations associated with molting in exoskeletal organisms serve this purpose.
Late morphogenesis in exoskeletons occurs through molting. During molting, (1) grooves are formed in the intracellular layer in advance, and (2) large-scale deformation occurs by expanding these grooves. The process (2) is a purely physical process because it occurs in a short time. By measuring the number, depth, and direction of the grooves, the final 3D structure can be calculated from the groove pattern.
On the other hand, process (1) is a biological process, in which the position and angle of the wrinkles are determined in a two-dimensional cell sheet, which is a kind of pattern formation.
We first examined the beetle horn primordium. Beetle pupae have huge horns, but in larvae the horn primordia are compactly folded in the head. Reproducing the folding of the primordium from serial sections and extending it with physical calculations, the structure of the pupal horn emerged. This indicates that the three-dimensional morphology of the horns is already completed by the folding pattern of the primordium. Furthermore, by examining the wrinkle patterns corresponding to the various parts of the horns, part of the logic behind the creation of the three-dimensional form was revealed.
We are currently studying the folding patterns of the helmets of treehoppers, which have more complex and diverse three-dimensional structures, through which we expect to elucidate how the complex structures of insects are designed.

Sequential photos of Japanese beetle pupation. Giant horns emerge in just 100 minutes. Because of the extremely short time, this deformation is thought to be due to the physical unfolding of the folded cell sheet.

Scientific Reports volume 11, Article number: 1017 (2021)

Relationship between wrinkle patterns in cell sheets of horn precursors and 3D morphology after unfolding.



Zoological Letters volume 6, Article number: 3 (2020)
Scientific Reports volume 7(1), Article number13939 (2017)