生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	微結構產生顏色 (Microstructures create color)
生物系統 LIVING SYSTEM	壁蜂、木蜂 *Osmia, Xylocopa* (Mason Bees, Carpenter Bees)
功能類別 FUNCTIONS	#改變光線/顏色 #Modify light/color
作用機制標題	細小的微結構透過光散射而不是使用傳統的色素來產生顏色 (Tiny microstructures create color through light scattering, instead of with traditional pigments.)
生物系統/作用機制示意圖	

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

動物獲得自身的色彩主要是透過兩種方式。動物可以直接使用色素產生自身的色彩，或者可以利用細小的微結構或奈米結構來將光線散射 (scatter) 成不同的波長，以產生結構色。色素色通常看來都一樣，但結構色往往能呈現虹光色彩 (iridescent colour)，隨著你觀看視角的不同度而改變色調 (hue)。加入能使結構瓦解的化合物，例如水或酒精，會使這些動物的顏色失去光澤，但當化合物被移除後又會逆轉。在國家地理 (National Geographic) 的一部影片，對本觀念提供了很好的解釋。

許多壁蜂屬 (*Osmia*) 的蜜蜂有著艷麗的藍色閃爍虹光。馬來西亞木蜂 (Malaysian carpenter bees) 的翅膀有著鮮艷的紫色及綠色，而集蜂 (sweat bees) 則呈現閃耀的藍色。所有這些顏色都不是由身體中的色素形成，而是由於結構所導致的光線散射。馬來西亞木蜂的翅膀有三層分明的薄層，每層都有獨特的結構樣式。翅膀中閃耀著紫色及藍色的部分有著明顯不同的結構，但這些結構的功能仍是未知。

鮮艷的色彩可以做為一種求偶訊號，在有著強烈雌雄異形 (sexual dimorphism) 的物種中經常出現。研究亦建議鮮艷、閃耀的訊號有著虹光色彩可能迷惑掠食者。色彩能干擾辨識形狀的能力，這可能會妨害掠食者區分獵物作為食物的能力。

這些資訊亦可在卡爾加里大學 (University of Calgary) 的無脊椎動物收藏 (Invertebrate collection) 中獲得，該處曾進行以蜜蜂為靈感設計的部分研究。

There are two main ways an animal can get its colouration. An animal can produce its colour directly using pigments, or it can use tiny microstructures or nanostructures to scatter light into different wavelengths and produce structural colour. Pigment colour will always look the same, but structural colour often manifests as an iridescent colour that changes hue as you look at it from different angles. Adding compounds that disrupt the structures, like water or alcohol, will cause the animal's colour to lose its sheen, but the effect is reversed when the compound is removed. This concept is well explained in a video from National Geographic.

Many bees from the *Osmia* genus have a brilliant iridescent blue shine. The wings of Malaysian carpenter bees have a brilliant purple and green colour, while sweat bees can also exhibit a blue sheen. All of these colours are caused not by pigments in the body, but by structures that cause light scattering. The wings of the Malaysian carpenter bee have three distinct layers, each with unique structures patterning them. Parts of the wing that shine purple and blue have distinctly different structures, but the functions of these structures are still unknown.

Bright colours could be used as a mating signal and are often in species with strong sexual dimorphism. Studies also suggest that bright, flashy signals with iridescent colours may confuse predators. Colour interferes with the ability to recognize shapes, which may impair a predators ability to distinguish its prey as food.

This information is also available from the University of Calgary Invertebrate collection, where it was curated as part of a study on design inspired by bees.

文獻引用 (REFERENCES)

「對於木蜂翅膀中色彩產生結構更進一步的探討，需要討論所看到的結構帶來的多重功能。蜜蜂翅膀中的奈米結構提供了不同的功能（例如自我修復、產生顏色、防水性、自潔作用）。得到色彩產生的深層原理，會幫助未來生產這些色彩的人造產品。由於結構色並不會褪去，以及在生產過程中不會牽涉到染料，有望在不同的技術中被應用，例如在衣服製造（例如蠟染）及感應工具的智能色彩、防偽標籤（例如識別偽造鈔票），或是生產動態及鮮艷的顏料及塗層。」(Matin et al., 2010: 13)

「以類似的方式，虹光創造出可變化的顏色和強烈的邊界 (intensity boundary)，因此能干擾一般用於辨識物體的穩定邊界特徵 (stable edge features)：虹光的閃亮能使物體變得更引人注目，但變化的色彩及邊界亦可以欺騙或迷惑潛在的掠食者。這種效果可能在那些缺乏靈長類視覺皮質 (primate visual cortex) 所具有之廣泛上游處理特性 (extensive upstream processing characteristic) 的動物中會尤其嚴重。」 (Kjernsmo et al. 2018)

「自然中的色彩有三個主要來源：色素、結構色及生物發光。結構色是特別的，其顏色由微米 (micro-) 或奈米 (nano-) 結構所產生，並且鮮艷而閃耀。結構色中最普遍的機制是薄膜干涉 (film interference)、繞射光柵 (diffraction grating)、光散射 (scattering) 及光子晶體 (photonic crystals)。生物性色彩主要衍生自薄膜干涉，包括了薄膜及多重薄膜干涉。」 (Sun et al., 2013: 14862)

"Further investigation concerning the colour-generating structures in the carpenter bee wing will have to deal with the multi-functionality of the structures seen. The nanostructures in the bee wing serve various functions (such as for example self-repair, colour generation, water resistivity, self-cleaning). Extracting the deep principles concerning the colour generation will assist future man-made production of such colours. Since structural colours do not bleach, and no dyes are involved in the production process, various technological applications, e.g., in clothing production (such as batik) and smart colours for sensing applications, security labelling (such as spotting fake bank notes, [25]) or the manufacture of dynamic and vivid paints and coatings can be envisaged [32]." (Matin et al., 2010: 13)

"In a similar way, iridescence creates changing colour and intensity boundaries, thereby disrupting the stable edge features normally used in object recognition: the brightness of iridescence may make (varying) parts of objects more conspicuous, but the changing colour patterns and boundaries could also deceive and confuse potential predators. This effect might be particularly acute in animals that lack the extensive upstream processing characteristic of the primate visual cortex." (Kjernsmo et al. 2018)

"Nature's color has three main sources: pigments, structural colors and bioluminescence. Structural color is a special one, which is the color produced by micro- or nano-structures, and is bright and dazzling. The most common mechanisms of structural colors are film interference, diffraction grating, scattering and photonic crystals. Biological colors are mainly derived from film interference, which includes thin-film and multi-film interference." (Sun et al., 2013: 14862)

參考文獻清單與連結 (REFERENCE LIST)

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Kjernsmo, K., J. R. Hall, C. Doyle, N. Khuzayim, I. C. Cuthill, N. E. Scott-Samuel, and H. M. Whitney. (2018). Iridescence impairs object recognition in bumblebees. *Scientific Reports* 8: 8095. (https://www.nature.com/articles/s41598-018-26571-6)

Sun, J., B. Bhushan, and J. Tong. (2013). Structural coloration in nature. *RSC Advances* 3. (https://www.researchgate.net/publication/255772388_Structural_coloration_in_nature)

延伸閱讀

https://www.youtube.com/watch?v=KN7krvnm2uM

生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)

https://en.wikipedia.org/wiki/osmia
https://www.onezoom.org/life/@osmia
https://eol.org/pages/2753366

撰寫/翻譯/編修者與日期

譚國鎏翻譯 (2021/03/22); 許秋容編修 (2021/04/22)

AskNature 原文連結

https://asknature.org/strategy/microstructures-create-color/