**Acknowledgements 特別致謝**

**Print Advising 印刷諮詢**
**HKUST Media Technology and Publishing Center**
**香港科技大學媒體科技及出版中心**








# Science Focus 科言


Issue 032, 2026


**Survival of the Sightless: Why Did Cavefish Go Blind?**
睹者生存：洞穴魚為何失去視力？

**Dimension Between Integers: Can We Measure the Length of a Coastline?**
整數之間的維度：我們能測量海岸線的長度嗎？

**Does Life Evolve Like a Great Branching Tree?**
演化樹真的是樹狀嗎？

**Q&A with HKUST Chemistry Majors**
讀化學的人：與科大學子對談

School of Science 理學院

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

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## Message from the Editor-in-Chief 主編的話

Dear Readers,

For your Easter holiday, we present to you a new issue of *Science Focus*.

For those of you who are interested in evolution, we have two articles that may expand your views. In one, we consider the unexpected outcomes of evolution in cavefish, as they adapt to a habitat without sunlight. The second article describes the transfer of genetic material between different species, beyond the usual example of how antibiotics resistance spread among bacteria. For mathematics enthusiasts, we consider why a coastline cannot be measured accurately. Finally, three generations of chemists share their stories about studying as undergraduates in HKUST.

The School of Science has organized a variety of on-campus STEAM activities in the coming weeks, including workshops and information sessions. I hope that some of you will have the opportunity to visit us at these events.

Yours faithfully,
Prof. Ho Yi Mak
*Editor-in-Chief*

親愛的讀者：

為著這個復活節假期，我們向大家呈獻最新一期《科言》。

對進化有興趣的讀者，我們準備了兩篇或許可以使您拓闊視野的文章。其中一篇探討洞穴魚在適應黑暗環境時意外演化出的不尋常特徵；第二篇討論除了抗生素抗性在細菌間傳遞的典型例子外，遺傳物質如何在物種間傳遞。此外，數學愛好者可以閱讀為何海岸線不能被準確地量度一文。最後，三個於不同年代在科大就讀的化學家將向大家分享他們就讀本科時的經歷。

理學院將於未來數週在科大校園舉辦不同的 STEAM 活動，包括工作坊和簡介會等。希望屆時有機會與大家碰面！

主編 麥晧怡教授
敬上



# What's Happening in Hong Kong? 香港科技活動

## Fun in Spring Science Activities 春日科學好節目

**Any plans for this spring? Check out the following events!**

**計劃好這個春天的課餘節目了嗎？不妨考慮以下活動！**

## Building a Dream Palace 築夢天宮

This Sky Show takes audiences on a captivating journey through time, intertwining ancient Chinese myths — like Pan Gu's creation of the world and Chang'e's lunar voyage — with the contemporary marvel of the Tiangong Space Station. Viewers will witness the impressive construction of this orbital home, featuring advanced technology such as flexible solar wings and robotic arms designed for precision tasks. The show also envisions a future where space stations serve as launching points for human exploration into the cosmos, from the Moon to Mars.

**Show Period:** Now – May 14, 2026
**Time:** 3:30 PM and 8:00 PM (Mon, Wed to Fri); 2:00 PM and 6:30 PM (Sat, Sun and public holiday)
**Venue:** Space Theatre, Hong Kong Science Museum
**Admission fee:** Standard admission: $40 (stalls), $30 (front stalls); Concession admission: $20 (stalls), $15 (front stalls)

這個天象節目帶領觀眾展開迷人的時光之旅，由盤古開天和嫦娥奔月等中國古老神話，追蹤到天宮太空站這個現代科技奇蹟。觀眾將見證這個太空家園的驚人建設，當中展示包括柔性太陽翼和為精密任務設計的機械臂等先進技術。節目亦會展望將來，預示太空站將成為人類探索宇宙的港口，允許人類展開前往月球及火星的新旅程。

**放映展期：** 現在至 2026 年 5 月 14 日
**時間：** 下午三時半及八時正（一、三至五）；下午二時正及六時半（六、日及公眾假期）
**地點：** 香港太空館天象廳
**入場費：** 標準票：40 元（後座）；30 元（前座）；優惠票：20 元（後座）；15 元（前座）

## Desert Elephants: The Adventures of Little Foot 沙漠小象走天涯

This Dome Show transports audiences to the ancient Namib Desert, the oldest desert on Earth, where African elephants strive for survival. Following a young elephant named "Little Foot," barely a month old, the show reveals her struggles for survival alongside her family as they navigate harsh wilderness, face relentless sandstorms, and fend off predators. Through their incredible endurance and deep familial bonds, these desert elephants showcase a legacy of wisdom and resilience in one of nature's most challenging environments.

**Show period:** Now – September 14, 2026
**Time:** 5:00 PM (Mon, Wed to Fri); 11:00 AM, 3:30 PM and 8:00 PM (Sat, Sun and public holiday)
**Venue:** Space Theatre, Hong Kong Space Museum
**Admission fee:** Standard admission: $40 (stalls), $30 (front stalls); Concession admission: $20 (stalls), $15 (front stalls)

這部球幕電影將觀眾帶往地球上最古老的沙漠 — 納米布沙漠，亦是非洲象掙扎求存的地方。故事圍繞一隻剛滿月，名叫「小腳板」的年幼小象。她與家族一起穿過嚴酷的荒野，面對無情的沙塵暴，並迴避捕食者的威脅。透過驚人的耐力和深厚的親情，非洲象展現了在極端環境傳承下來的智慧和韌性。

**放映日期：** 現在至 2026 年 9 月 14 日
**時間：** 下午五時正（一、三至五）；上午十一時正、下午三時半及八時正（六、日及公眾假期）
**地點：** 香港太空館天象廳
**入場費：** 標準票：40 元（後座）；30 元（前座）；優惠票：20 元（後座）；15 元（前座）

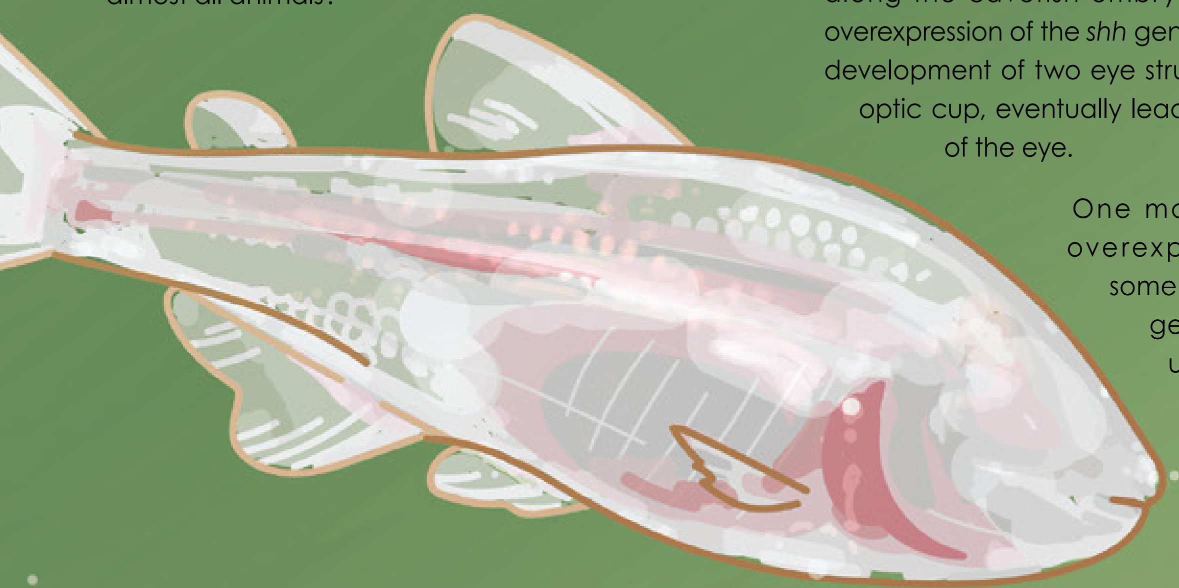
# Survival of the Sightless: Why Did Cavefish Go Blind?
# 瞎者生存：洞穴魚為何失去視力？

By Roshni Printer

## Adaptation by Losing an Ability

One of the most fascinating aspects of evolution is how population growth is linked to the inheritance of favorable traits. One famous example involves the domestication of animals, increased availability of milk, and the selective advantage to adults who can digest lactose in milk [1]. However, in some cases, evolution also manifests as the loss of traits or functions. An example is the Mexican tetra, *Astyanax mexicanus*, a freshwater fish species found in caves and streams in Central America.

Mexican tetra exists as surface form and cave-dwelling form. Unlike the former which lives near the water surface and have well-developed eyes, the latter lives in caves and have lost their eyes during evolution [2]. Early eye development begins as usual but is disrupted prematurely in the cavefish embryo, and then their eyes degenerate within a few days [2, 3]. The striking difference between the two morphs of the species raises an important question: Why did they lose their sight, which is a fundamental survival function for almost all animals?



Although it seems counterintuitive to lose a function, the answer may lie in energy conservation. In the dark environment of underwater caves where the food supply is scarce, maintaining eyesight poses an unnecessary energy demand to the fish [4]. The metabolic cost of this complex function on the neural tissue to process visual information simply inflicts a heavy burden. Studies found that the cost of vision in young surface-dwelling Mexican tetra can reach up to 15% of their resting energy expenditure, a cost that can be avoided by its cave-dwelling counterpart [4].

## How Do Cavefish Lose Their Eyes?

Therefore, one can expect the loss of eyes to be a trait favored by natural selection in dark environments. Then, how can embryonic eye degeneration be achieved at the genetic and molecular levels? Sonic hedgehog (Shh; footnote 1) protein is a morphogen that plays a role in the differentiation of embryonic cells into the brain and spinal cord, eyes, and many other parts of the body [5]. Scientists observed that the Shh protein is expressed in an expanded region along the cavefish embryonic midline [2, 6]. The overexpression of the *shh* gene was found to inhibit the development of two eye structures, namely lens and optic cup, eventually leading to the degeneration of the eye.

One may speculate that the overexpression is caused by some mutation in the two *shh* genes of the cavefish, but unfortunately no mutation was found in *shh* [6]. There is a possibility that the mutations are in other genes which in turn influence the expression of *shh* [6]. Interestingly, it was reported that the overexpression of *shh* simultaneously increases the number of taste buds and jaw size in cavefish, enhancing their ability to taste and smell. This is terminologically known as "pleiotropy," in which a single gene influences multiple seemingly unrelated traits [7]. Considering the loss of eyes as a tradeoff, some scientists even hypothesized that it is the trait of enhanced oral and taste bud development that is favored by natural selection [6].

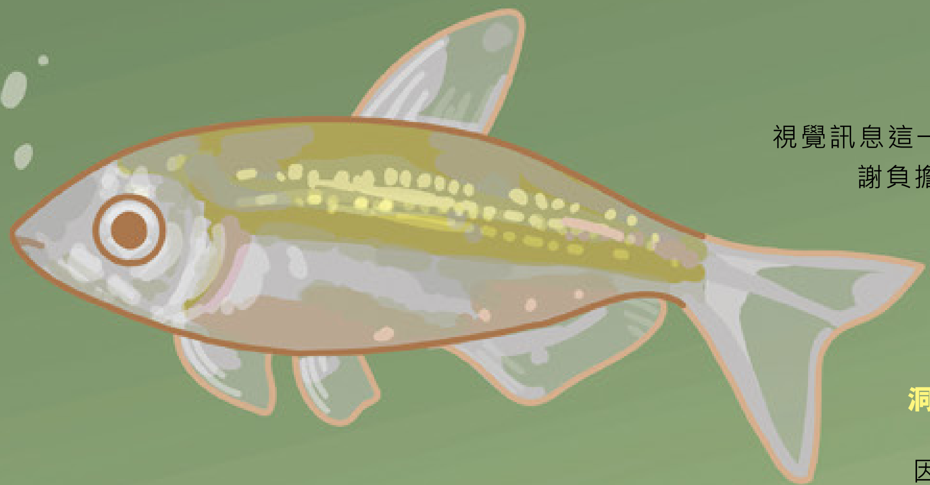
Nevertheless, regardless of the different guesses regarding the "true meaning" of the trait, a more recent study on the cavefish originated from Pachón cave in Mexico suggested that the loss-of-eyes phenotype could be a result of epigenetic gene silencing, meaning that the phenotype may not be caused by DNA mutations (alternations in DNA sequence) but other mechanisms that turn off the eye development genes [8]. The research team attributed the phenotype to the DNA methylation of those genes, in which methyl groups (–$CH_3$) are added to DNA to inhibit transcription. The expression of the modified genes is therefore stopped, so as their functions to support normal eye development. It is also worth mentioning that many of those inactivated genes are also found in humans and associated with human eye diseases. Thus, further investigation could potentially deepen our understanding of those diseases in human.

## Adaptive Strategy Beyond the Loss of Eyes

Cavefish also compensate for the lack of vision through other heightened senses, such as vibration attraction behavior (VAB) [9]. VAB is the ability of some cavefish populations to locate prey by sensing water disturbance. This shift from visual to non-visual methods of survival shows the reallocation of resources that happens because of the environment. Cavefish have also shown evolution in traits such as losses of melanin pigmentation and circadian rhythms, increases in fat stores and body weight, and as mentioned before, the enhanced gustatory and olfactory systems [2, 9].

## Different Roads Lead to Rome

While different populations of cavefish develop similar adaptive traits, termed "convergent evolution," the underlying genetic events or mechanisms are not necessarily the same [10]. The surface fish ancestors which presumably got trapped in different caves and formed different populations have probably developed those traits independently [2, 3, 10]. An example is the albinism in the Molino population and the Pachón population [10]. *oca2* is a pigmentation gene required to maintain normal pigmentation of Mexican tetra. In those populations, a deletion can be found in *oca2* gene, which causes the production of nonfunctional Oca2 protein. Notably, the deleted sequence within the gene is different in the two populations, meaning that the mutations occurred independently after the ancestors had settled in their caves. Therefore, evolution does not always follow a single path; parallel and convergent evolution of the same species can take place. This makes the *Astyanax mexicanus* an interesting model to study



evolution by allowing researchers to understand how geographically separated populations evolved independently to adapt to similar environments.

### The Lesson Learned

The cavefish is smart – they don't pay the price for vision when there is nothing to see! By studying them, scientists have gained important insights into development, genetics, evolution and human diseases.

1. This protein from the hedgehog family was named after the video game character, Sonic the Hedgehog [11], by Robert Riddle and his research advisor Cliff Tabin. It is a vertebrate homolog of hedgehog, a protein originally discovered in the fruit fly, *Drosophila*. The other vertebrate homologs are named Desert hedgehog and Indian hedgehog. Each hedgehog protein is known to play important roles in the development of specific body parts.

### 透過失去能力適應環境

在進化這個課題上，其中一個最引人入勝的地方是研究種群增長與遺傳有利特徵之間的關係，當中著名的例子是畜牧使牛奶產量增加，為能消化牛奶中乳糖的成年人帶來生存優勢一例 [1]。然而，進化有時也會體現於特徵或功能的喪失。墨西哥麗脂鯉（*Astyanax mexicanus*）是其中一例，牠是居於中美洲洞穴和溪流的淡水魚。

墨西哥麗脂鯉存在兩種形態：表面形態和洞穴形態。前者棲息於水面附近，擁有發達的眼睛；後者居於洞穴，在演化過程中失去了眼睛 [2]。洞穴魚胚胎的早期眼部發育會如常展開，但不久便會中斷，且眼睛會在數天內退化 [2, 3]。兩種形態之間的顯著差異引發一個重要問題：為何牠們會喪失視力？視力幾乎是所有動物的基本生存功能。

儘管以失去功能的形式進化似乎有違常理，但答案可能在於節省能量。在食物供應稀少的黑暗水底洞穴裡，維持視力為墨西哥麗脂鯉帶來不必要的能量需求 [4]，處理視覺訊息這一複雜功能無疑對神經組織造成沉重的代謝負擔。研究發現，以棲息於水面的年幼墨西哥麗脂鯉為例，維持視覺所需的能量可達其休息能量消耗的 15%，相反居於洞穴的夥伴則能避免這個不必要的成本 [4]。

### 洞穴魚如何失去眼睛？

因此，不難想到喪失眼睛在黑暗環境中會是一種受自然選擇青睞的特徵。那麼，胚胎眼部退化是如何在遺傳和分子層面上實現的呢？音速刺蝟蛋白（sonic hedgehog，簡稱 Shh；見註一）是一種形態決定因子，參與胚胎細胞分化成大腦及脊髓、眼睛，以及身體其他部分的過程 [5]。科學家觀察到音速刺蝟蛋白在洞穴魚胚胎的表達位置超越胚胎中線 [2, 6]，該基因的過度表達已知會抑制晶體和視杯這兩個眼部結構的發展，最終導致眼睛退化。

我們可以藉此推測，過度表達是由於洞穴魚的兩個音速刺蝟蛋白基因發生了某種突變，然而科學家並未在該基因找到突變 [6]。可能的情況還有其他基因發生突變，輾轉影響音速刺蝟蛋白基因的表達 [6]。有趣的是，有研究指出音速刺蝟蛋白的過度表達同時增加了洞穴魚的味蕾數目和下頜大小，強化了牠們的味覺和嗅覺。在生物學術語上，這被稱為「基因多效性」，即是單一基因影響多個看似無關的特徵 [7]。考慮到喪失眼睛可能只是取捨之下的代價，一些科學家甚至假設強化口腔和味蕾才是在自然選擇中受到眷顧的特徵 [6]。

儘管科學家對失去眼睛的「真實意義」有著不同猜測，最近一項研究墨西哥 Pachón 洞穴裡洞穴魚種群的研究表明，失去眼睛的表現型可能是由表觀遺傳基因靜默（epigenetic gene silencing）所致，意味著該表現型可能不是由 DNA 突變（DNA 序列的改變）造成，而是透過其他機制關掉眼部發育基因 [8]。研究團隊將其歸因於基因的 DNA 甲基化，即是甲基基團（$-CH_3$）被添加到這些基因的 DNA 中，導致轉錄過程受到抑制，亦使基因表達及其支持正常眼部發育的功能停止。值得一提的是，人類體內包含許多這些被抑制的基因，它們正正與人類眼睛疾病相關，可見進一步研究可能有助增加我們對這些疾病的認識。

### 失去視力之外的適應策略

洞穴魚亦會透過增強其他感官來補償視力缺失，例如「振動吸引行為」等 [9]。振動吸引行為是某些洞穴魚種群能透過感知水流擾動來得知獵物位置的能力。這種從視覺到非視覺的生存策略轉換說明了資源會根據環境改變而重新調動。洞穴魚還進化出其他特徵，譬如失去黑色素和生理時鐘、增加脂肪儲備和體重，以及之前提到受強化的味覺和嗅覺系統等 [2, 9]。

### 條條大路通羅馬

儘管不同洞穴魚種群不約而同地發展出相似的適應特徵，學術上稱為「趨同進化」，但背後在基因層面上的原由或機制卻未必相同 [10]。科學家相信棲息於水面的墨西哥麗脂鯉祖先是因為被困於不同洞穴而衍生不同種群，繼而獨立發展出相似的適應特徵 [2, 3, 10]。其中一例是 Molino 種群和 Pachón 種群的白化現象 [10]。*oca2* 是維持墨西哥麗脂鯉身體顏色所需的色素基因，在白化群體中，*oca2* 基因均含有一些缺失，導致產生的 Oca2 蛋白失去功能。值得留意的是，在這兩個群體中缺失的基因序列並不相同，意味著突變是在祖先定居於不同洞穴後才獨立發生。因此，進化並非總是單線發展，同一物種可以平行地進行趨同演化。這也使墨西哥麗脂鯉成為一個研究演化的有趣模型，因為研究人員可以藉此了解在地理隔離下群體是如何獨立演化以適應相類似的環境。

### 得到的啟示

洞穴魚是聰明的物種，牠們在沒有東西看的環境下不會為視力付出代價。透過研究牠們，科學家能獲得對發育、遺傳、演化和人類疾病的重要見解。

1. 這個屬於刺蝟蛋白家族的蛋白質由 Robert Riddle 及其研究導師 Cliff Tabin 以電玩角色「超音鼠」（Sonic the Hedgehog）命名 [11]。科學家原本從果蠅發現中刺蝟蛋白，而音速刺蝟蛋白則是從脊椎動物裡發現的同系物（homolog）。其他從脊椎動物裡發現的同系物分別名為沙漠刺蝟和印度刺蝟；每種刺蝟蛋白已知在特定身體部分的發育中扮演重要角色。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# Dimension Between Integers: Can We Measure the Length of a Coastline?

# 整數之間的維度：我們能測量海岸線的長度嗎？

By Devandhira Wijaya Wangsa

## Measuring Coastlines

How long is the coastline of Hong Kong? Here are the different answers from different organizations:

- ***Central Intelligence Agency of USA: 733 km [1]***
- ***World Resources Institute: 955 km [2]***
- ***Hong Kong Environmental Protection Department: 1,178 km [3]***

What causes these inconsistencies in the data? Lewis Fry Richardson (1881–1953), an English mathematician who studied the possible correlation between the length of shared borders and the chance of a war outbreak, was also puzzled by the same kind of inconsistency [4]. He found that Portugal reported its border with Spain as 1,214 km, while Spain claimed 987 km [5]. This discrepancy led to the discovery of the "coastline paradox."

Why do measurements of the same coastline differ? Let's first understand how the measurement of complex shapes can be carried out systematically. For smooth curves (e.g. no corners) defined by mathematical functions, their exact length can be calculated using calculus. However, for jagged, irregular shapes like coastlines that exist in the real world, no simple formula works. Their complexity requires a systematic approach, such as using fixed-length segments to approximate their length consistently and accurately.

Imagine a curve that is smooth but seemingly random (figure 1a). Intuitively, we could use a string resembling its shape. Although this is an accurate method, this approach is practically not feasible when implemented in a computer. This is also not systematic because the string's shape depends on how it's placed, making results inconsistent and hard to replicate, especially if we were to apply the method to intricate shapes like coastlines. Instead, we can lay out straight line segments of equal lengths — let's call them "sticks" — to approximate the curve, as shown by the sticks of different lengths in figures 1b and 1c. We then add up the total length of the sticks to get an approximation of the curve's length. We can expect the approximation to get more accurate as we choose shorter and shorter sticks. Ideally, when the length of each stick is sufficiently short, we get a very good estimate of the length of the curve.

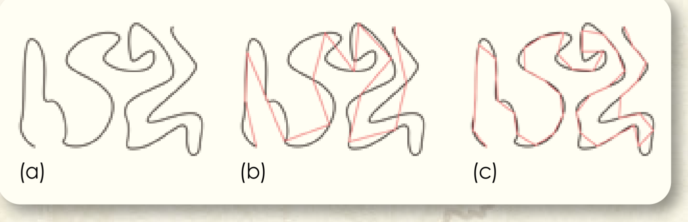



**Figure 1** (a) A curve that is smooth but seemingly random. (b, c) Straight line segments of equal lengths are used to approximate the curve's length.

However, when people use this method to measure the coastline of Great Britain, the result is counterintuitive. Using smaller sticks increases the measured length dramatically; using one-meter sticks will result in a total length over 15,000 km [6], which is even longer than Earth's diameter (12,756 km) [7]! This defies our expectation that finer measurements yield more accurate results, so obviously, coastlines are not something trivial.

## Fractals

Figure 2a shows the Koch snowflake, an example that can help us understand what's going on with the paradox. As illustrated in figure 2b, here's how it's constructed:

1. ***Start from a straight-line segment of length 1.***
2. ***Divide it into three line segments of equal length (so each line segment has length 1/3), then replace the middle segment with an equilateral triangle's two sides.***
3. ***For each existing line segment, perform step two.***
4. ***By repeating this process infinitely, you'll construct the upper section of the Koch snowflake! To obtain the full shape, simply make three copies of your constructed piece and attach them together in a triangular formation.***

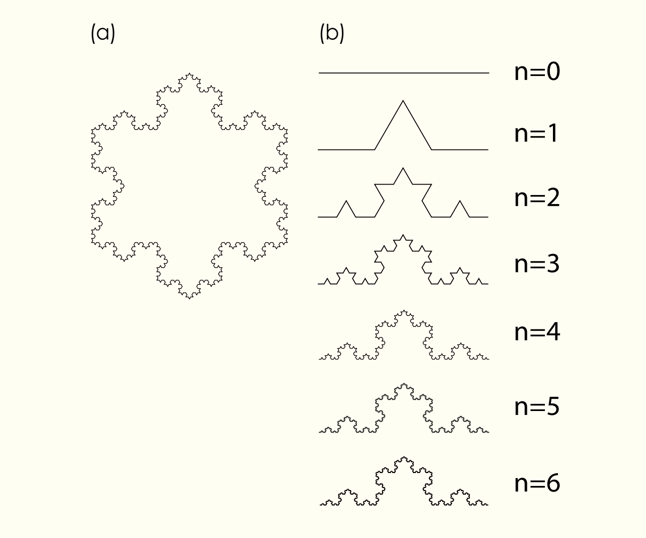



**Figure 2** (a) Koch snowflake and (b) how it is constructed through a series of iterations.

Unlike a smooth curve, which simplifies when zoomed in, the Koch snowflake remains complex at every scale (figure 3). More details will be revealed when you zoom in more, while the pattern shows similarity at every level, making it a "fractal." To calculate the length of one of its three sides:

- ***Recall that we started with a line of length 1.***
- ***The next iteration gives four line segments of length 1/3, making a total of 4/3.***
- ***The third step further divides each line segment into four, giving 16 lines of length 1/9, making a total of 16/9...***

Inductively, the total length after each iteration creates a geometric sequence with a ratio of 4/3. Since the ratio is greater than one, the length will go infinitely large. Therefore, the Koch snowflake has infinite perimeter.

Curves like the Koch snowflake that have an infinite length are known as "non-rectifiable curve." The name comes from the fact that those curves cannot be "rectified," or "straightened out" like a piece of string and then measured.

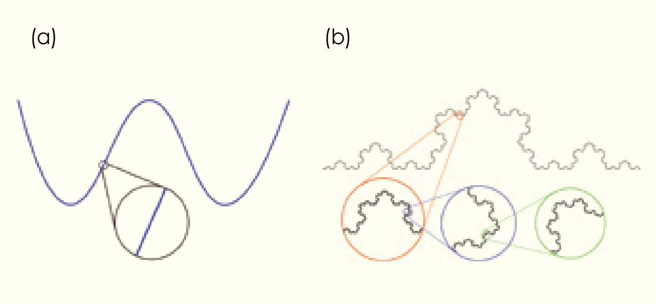



**Figure 3** Illustrations showing that (a) a smooth curve simplifies to almost a straight line when zoomed in, while (b) the Koch snowflake remains complex at every scale.

Notably, many well-known examples of fractals show "self-similarity" meaning that they look similar at different scales, such as the Mandelbrot set, Julia set, Sierpinski triangle (Sierpinski gasket), and Sierpinski carpet.

## Fractal Dimension

Let's think of this intuitively: Our experience with shapes tells us that any bounded one-dimensional object like line segments have a non-zero yet finite length, but zero area. Meanwhile, bounded two-dimensional objects like surfaces (e.g. a piece of paper), have infinite "length," as they can be thought of as shapes that consist of infinitely many lines, yet a non-zero finite area. Then where does the Koch snowflake fit? Considering the snowflake as a hollow shape, its infinite perimeter but zero area suggests a dimension between one and two.

This intuitive idea naturally leads us to the concept of non-integer dimension — the fractal dimension, which describes how "complex" a geometric object is.

For example, to find out the fractal dimension of the Koch snowflake, let's recap how dimension works: Think about a two-dimensional square of length 1, we know that by lengthening its sides by two means that we obtain $4 = 2^2$ copies of the original square, and by three obtains $9 = 3^2$ copies. This is exactly because the square is two-dimensional. In general, scaling, for example, a shape of dimension $d$ by a scale factor of $c$ will give $c^d$ times its original copy (try this out yourself with a line or cube).

Let's take the upper part of the Koch snowflake now. By how the snowflake is constructed, scaling the snowflake by three gives four of the original copies. Therefore, if we need to assign a dimension $d$, then by the reasoning above we should require $4 = 3^d$, in other words $d = \log 4 / \log 3$.

How about coastlines? Strictly speaking, coastlines are not fractals because fractals are abstract theoretical shapes, but coastlines are fractal-like (that is, having fractal features) to the point where people would approximate their fractal dimension. For instance, the coastline of South Africa, a smooth one in the atlas, has a fractal dimension of 1.02, while those for the border between Spain and Portugal and the west coast of Great Britain are 1.14 and 1.25, respectively [8], meaning that they are more complicated.

## Conclusion

After all, can we measure the length of a coastline? The essence of the coastline paradox is the fact that coastlines are non-rectifiable curves since nowhere in real world is perfectly smooth, and when you zoom in on a map, there are always more jagged parts (usually rocks) which lengthen the coastline.

In addition, the length also depends on which standard was taken. As you can imagine, lengths measured at different tide levels can differ significantly because land can become submerged and invisible during high tide. If there is a river, whether and how to include the estuary and its tributaries poses a challenging question. Therefore, a simple answer is: No coastline can be measured objectively.

### Math Challenge

**Let's find the area of a Koch snowflake! Let $s$ be the side length of the initial triangle before any "iteration." Find the area of the Koch snowflake in the first few iterations in terms of $s$. What happens when we take the iteration to infinity?**

**(Hint: Infinite geometric series)**

**Answer:**

## 測量海岸線

香港的海岸線有多長？以下是來自不同組織的答案：

- ***美國中央情報局：733 公里 [1]***
- ***世界資源研究所：955 公里 [2]***
- ***香港環境保護署：1,178 公里 [3]***

甚麼導致這些數據之間的差異？英國數學家 Lewis Fry Richardson（1881–1953）曾經研究邊境長度與爆發戰爭之間的關聯，但他亦對文獻中不一致的邊境長度感到無所適從 [4]。他發現葡萄牙一方的資料報告其與西班牙的邊境長度為 1,214 公里，而西班牙一方則聲稱長度為 987 公里 [5]。這個差異及後延伸出「海岸線悖論」的發現。

為甚麼對同一海岸線作的測量結果會有所不同？讓我們先了解如何有系統地量度複雜形狀的長度。對於由數學函數定義的光滑曲線（例如沒有角的曲線），我們可以用微積分來計算其確實長度。然而，對於像海岸線那些現實世界中參差不齊的非規則形狀，並沒有一條簡單公式行得通。它們的複雜性需要有系統的方法來對付，例如使用多條固定長度的線段來準確地估計長度，確保每次量度都能得出一致的結果。

試想像一條光滑但看似隨意的曲線（圖一甲）。憑直覺思考，我們似乎可以用一根線來模仿其形狀。儘管這是一個準確的方法，但實際在電腦上並不能這樣操作。這也不是有系統的方法，因為繩子的形狀取決於它的放置方式，使每次量度結果不一致且難以重複，尤其當我們將此方法應用於複雜如海岸線的形狀時。換個方法，我們可以使用長度相等的直線段 — 姑且稱之為「小棒」 — 來估計曲線長度，正如圖一乙和圖一丙就使用了不同長度的小棒。我們將小棒的長度相加，以獲得曲線長度的近似值。隨著我們選用更短的小棒，就可以期望近似值將變得越發準確。在理想情況下，當每根小棒的長度足夠短時，我們就可以對曲線長度作出非常精準的估計。

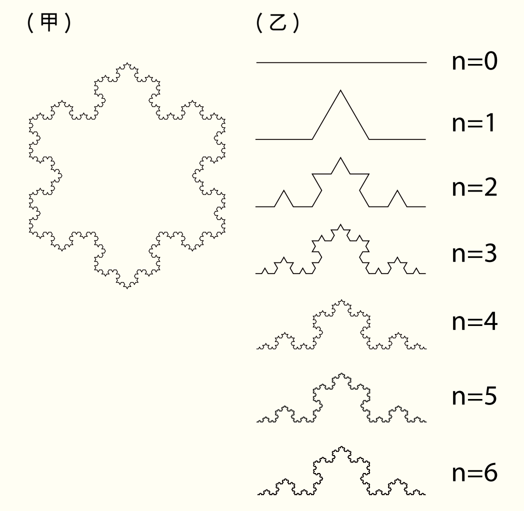

**圖一** （甲）一條光滑但看似隨意的曲線。（乙及丙）分別使用兩款長度相等的直線段來估計曲線長度。

可是，當人們用這個方法測量大不列顛島的海岸線時，結果卻出人意表。使用較短的小棒會得出驚人的長度：使用一米小棒時海岸線將超過 15,000 公里 [6]，這比地球直徑（12,756 公里）還要長 [7]！結果違反我們對「更精細量度能帶來更準確結果」的預期，因此顯然地，海岸線並不是一個尋常的形狀。

## 碎形

圖二甲展示了科赫雪花（Koch snowflake），一個可以幫助我們理解上述悖論的圖形。圖二乙說明了解圖形的構建方法：

1. ***首先畫一條長度為 1 的直線段。***
2. ***將其分為三條等長的線段（因此每條線段的長度為 1/3），然後用等邊三角形的兩條邊替換中間的線段。***
3. ***對現有的每條線段執行第二步。***
4. ***透過無限次重複這個過程，您將能構建出科赫雪花的頂部。要獲得完整形狀，只需要複製出三個副本並將它們按三角形方式排列。***



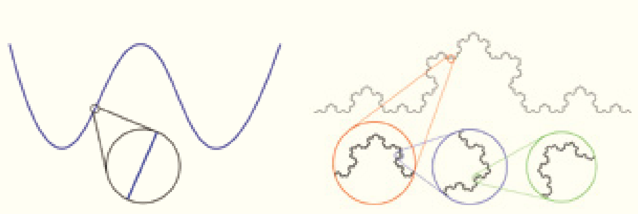

**圖二** （甲）科赫雪花及（乙）如何透過一系列重複的步驟構建科赫雪花。

光滑曲線被放大時形狀會變得簡單，但科赫雪花與光滑曲線不同，它在每個比例下形狀始終保持複雜（圖三）。進一步放大會顯現更多細節，而每個層次上的圖案都展示出相似性，使其成為「碎形」。要計算其三條邊之中其中一條的長度：

- ***記得我們最初由一條長度為 1 的線段開始。***
- ***下一回合產生出四條長度為 1/3 的線段，使總長度為 4/3。***
- ***第三回合將每條線段再變為四分，得出 16 條長度為 1/9 的線，使總長度為 16/9……***

如此類推，每回合的總長度構成了一個公比為 4/3 的等比數列。由於公比大於一，長度將無限增大，因此科赫雪花有無限長的周界。

像科赫雪花這樣具無限長度的曲線被稱為「不可求長曲線」，它們無法像一條繩子般被「拉直」然後量度長度。




**圖三** 上圖展示（甲）光滑曲線被放大時幾乎簡化成一條直線，而（乙）科赫雪花在每個比例下形狀始終保持複雜。

值得注意的是，許多著名的碎形均展示出「自相似性」，意味著它們在不同縮放比例下看起來都相似，比如曼德布洛特集合（Mandelbrot set）、朱利亞集合（Julia set）、謝爾賓斯基三角形（Sierpinski triangle 或 Sierpinski gasket）及謝爾賓斯基地毯（Sierpinski carpet）。

## 碎形維度

讓我們以直覺思考：我們對形狀的經驗告訴我們，任何有界的一維物體（如線段）都有非零但有限的長度，且其面積為零；有界的二維物體（如表面，例如一張紙）則因為可以被視為由無數條線構成，所以具有無限「長度」，而同時擁有非零但有限的面積。這樣的話，科赫雪花又應該如何定位呢？如果我們把科赫雪花視為中空的形狀，那麼它同時擁有無限周長但零面積這一點，就反映了其維度介乎一和二之間。

這個直觀的想法讓我們萌生非整數維度的概念 — 碎形維度，它能描述幾何形狀的「複雜性」。

例如在找出科赫雪花的碎形維度之前，讓我們回顧維度的定義：試想像一個邊長為 1 的二維正方形，我們知道將其邊長乘二，會獲得 $4 = 2^2$ 個原來的正方形；乘三就會獲得 $9 = 3^2$ 個原來的正方形，這正因為該正方形是二維的。簡單來說，放大或縮小一個維度為 $d$ 的形狀時，若縮放因子為 $c$，結果將會得出 $c^d$ 個原來形狀的副本（你可以嘗試用一條線或立方體來驗證這一點）。

現在讓我們檢視科赫雪花的頂部。根據雪花的構建方法，將雪花放大為原來的三倍將得出四個原來形狀的副本。因此，如果我們需要決定科赫雪花的維度 $d$，那麼根據上述推理，公式將變成 $4 = 3^d$，換言之 $d = \log 4 / \log 3$。

那麼海岸線呢？嚴格來說，海岸線並不是碎形，因為碎形是抽象的理論圖形，但海岸線具有碎形的部分特徵，與碎形相似得人們會嘗試計算其碎形維度，譬如在地圖上看起來光滑的南非海岸線擁有 1.02 的碎形維度，而西班牙與葡萄牙的邊界，以及英國西海岸的碎形維度分別為 1.14 和 1.25 [8]，意味著它們的形狀較為複雜。

## 結論

討論了這麼久，到底我們能測量海岸線的長度嗎？海岸線悖論的關鍵在於海岸線屬於不可求長曲線，因為現實世界中不存在完全光滑的邊界；當您在地圖上放大海岸線時，總是出現更多彎曲的部分（通常是岩石），使海岸線的長度增加。

此外，長度還取決於所採用的標準。不難想像，不同漲退水位下測量的海岸線長度會顯著不同，因為高潮時陸地可能會被淹沒而變得不可見。如果海岸線上有一條河流，是否以及如何將河口及其支流納入海岸線長度將會是一個具挑戰性的問題。因此，簡單的答案是：沒有海岸線可以被客觀地量度。

### 數學挑戰站

**讓我們來計算科赫雪花的面積！設最初未進行任何重複步驟前的三角形邊長為 *s*，試以 *s* 表示科赫雪花在最初數次重複過程後的面積。求重複過程次數趨向無限時的面積。**

**（提示：等比數列的無限項之和）**

**答案：**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# Does Life Evolve Like a Great Branching Tree?

# 演化樹真的是樹狀嗎？

By Helen Wong 王思齊

> **"There is grandeur in this view of life ... from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."**
>
> Charles Darwin
> the Origin of Species [1]

Darwin's theory of evolution by natural selection explains how life evolves through inherited changes passed from one generation to the next. When it comes to inheritance, we often think of genes being passed down vertically from parents to offspring. This pattern, known as "vertical gene transfer," has long been considered the main way genetic information moves through populations. However, it is not the only way: Genes can also move horizontally between unrelated organisms in a process called "horizontal gene transfer" (HGT). Once thought to be rare, HGT is now known to occur across nearly all branches of life and plays a key role in how life adapts in fast and sometimes surprising ways [2–3].

## HGT in Prokaryotes

While the term HGT might be new to you, chances are you have already heard of one of its consequences: antibiotic resistance in pathogenic bacteria. This is one of the most famous examples in action.

Bacteria (and possibly archaea) can acquire "foreign" antibiotic resistance genes and other genetic materials through three main processes: transformation, transduction, and conjugation (figure 1). In transformation, bacteria take up naked DNA from their surroundings, often in the form of plasmids. Transduction involves the transfer of genes between bacterial hosts by bacteriophages, which are viruses that infect bacteria. DNA can also be transferred from one bacterium to another through conjugation, during which bacteria mate by forming a cell-to-cell connection. HGT is so widespread among bacteria that researchers estimate that around one-third of all gene transfers in bacterial evolution happen this way [4].

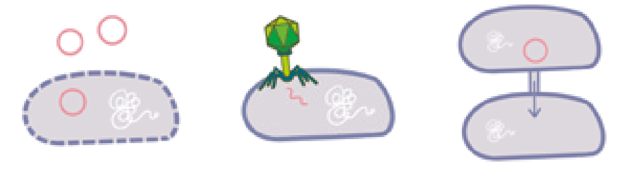



**Figure 1** Illustration of the three major mechanisms of horizontal gene transfer in prokaryotes: transformation, transduction, and conjugation.

## HGT in Eukaryotes

However, things are different for eukaryotes, such as animals, plants, and fungi. For most eukaryotes, germ cells are kept separate from somatic cells [2–3]. This means that if a foreign gene ends up in a somatic cell, it won't be passed down to the next generation; only genes that incorporate into sperms and eggs, or their progenitor cells (cells that will divide into sperms and eggs), can be inherited. Therefore, for HGT to have lasting effects in eukaryotes, it often has to happen in a germ cell.

Still, HGT can occur in eukaryotes, and certain conditions seem to increase its likelihood. These include processes like phagocytosis, where cells engulf other cells or particles, and symbiosis, where two different organisms live in close association. HGT may also happen more frequently during early developmental stages when the organism only consists of one or a few unspecialized cells, such as when it is a spore, zygote, or embryo.

Unlike bacteria, the main way foreign DNA becomes part of a eukaryotic genome is through a process called "non-homologous end joining." This is a natural DNA repair mechanism that fixes breaks by directly connecting the broken ends of DNA. When foreign DNA is present during this repair process, it can sometimes be inserted into the genome.

Although biologists haven't reached a consensus on how common HGT is in eukaryotes, some fascinating examples have been documented. One involves an aphid ancestor acquiring carotenoid genes from fungi [5]. This was the first time a group of carotenoid genes was found in an animal genome. These pigment-producing genes allow aphids to produce red, green, and yellow colors. In nature, red and green aphids are both common because predators and parasites tend to prefer one color over the other, thus retaining the color variation.

A more recent example of HGT in eukaryotes involves a newly discovered system similar to CRISPR-Cas systems [6–7]. CRISPR is a naturally occurring DNA sequence found in prokaryotic genomes, derived from fragments of past invading viral DNA [8]. During subsequent infections, a family of DNA-cutting enzymes (or more technically "endonucleases") called Cas uses complementary RNA transcribed from CRISPR sequences as a guide to recognize the invader's DNA, and then destroy matching viral DNA to protect themselves. While researchers wondered whether such RNA-guided systems only exist in prokaryotes, they found the eukaryotic counterpart in fungi. At its core is an RNA-guided endonuclease called Fanzor. Interestingly, scientists discovered that the Fanzor genes may have originated from prokaryotic *tnpB* genes, which were likely transferred to eukaryotes through HGT.

## Detecting HGT Events

So, how do scientists actually find these examples of HGT? The key lies in looking closely at the gene that was horizontally transferred. Since it originally came from another species, it should still look similar to the version in the original donor species in terms of the amino acid sequence encoded.

This idea is the basis for a common method called "phylogenetic conflict [2–3]." In simple terms, scientists compare two kinds of "family trees": one for the species themselves, and one for the gene in question. If a gene was transferred from one species to another, the gene tree might show two species as closely related, even if the species tree says otherwise. For example, in figure 2, if gene X was transferred from species C to species D, the gene X tree would wrongly suggest that C and D are close relatives as they share a more similar gene X.

But a tree mismatch isn't always enough to prove that HGT happened. There could be other reasons for the odd pattern, such as contamination during DNA sequencing [3]. To be more certain, scientists would check where gene X is located in the genome of species D. If gene X is found right next to other genes that are already known to belong to species D, that's a good sign it's truly a part of D's genome, rather than just a stray piece of DNA from somewhere else. It also helps to see if gene X has common features of a real gene, like introns (non-coding sequences commonly found in eukaryotic genes). On top of that, RNA sequencing data can show if the gene is actually expressed and used by the cell.

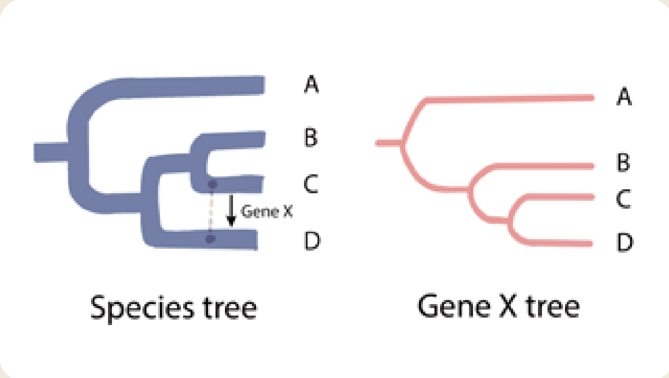



**Figure 2** Phylogenetic conflict arising from a mismatch between a species tree and a gene tree. If gene X was horizontally transferred from species C to species D, the gene X tree would wrongly suggest that C and D are close relatives as they share a more similar gene X.

## HGT and the Tree of Life

The phylogenetic conflicts introduced by HGT have led some biologists to question whether Darwin's tree of life model still fully captures the complexity of evolutionary relationships, especially among prokaryotes [9]. In Darwin's metaphor, life evolves like a great branching tree, with species diverging from common ancestors over time. HGT adds a new dimension to this picture: It causes some branches to reach sideways, connecting distant twigs in unexpected ways. This lateral exchange creates a more web-like structure, leading some to propose a network model of evolution rather than a strictly branching tree. Yet whether life is ultimately represented as a tree, a network, or a mix of both, one thing remains clear: HGT has played a profound role in shaping the evolution of the "endless forms most beautiful and most wonderful."

**「這種看待生命的觀點蘊含偉大意義……**
**從如此簡單的起點，**
**演化出無數最美麗且最奇妙的生命形式，**
**過程至今仍在進行。」**

**查理斯・達爾文**
《物種起源》[1]

達爾文提出以天擇為機制的演化理論，解釋了生命如何透過世代相傳的遺傳特徵演化。談到遺傳，我們通常想到基因從親代「垂直」傳遞給後代。這種被稱為「垂直基因轉移」(vertical gene transfer) 的模式長久以來被認為是遺傳訊息在種群中流動的主要方式。然而，這並不是唯一途徑：基因也可以在沒有親緣關係的物種之間「水平」移動，這種現象稱為「水平基因轉移」(horizontal gene transfer)。過去水平基因轉移被認為非常罕見，但現在已知它曾經發生於幾乎所有生命分支中，有助物種快速適應環境 [2–3] 。

## 原核生物的水平基因轉移

雖然水平基因轉移這個名詞可能很陌生，但你大概早已聽過它帶來的後果之一：致病細菌的抗生素抗性，這是最廣為人知的例子之一。

細菌 (甚或可能是古細菌) 可以透過三種主要機制獲取「外來」的抗生素抗性基因及其他遺傳物質：轉化、轉導和接合 (圖一)。在轉化過程中，細菌會從周遭環境直接獲取以質粒為主的裸 DNA。轉導則是指透過噬菌體 (一種感染細菌的病毒) 在細菌宿主之間轉移基因。DNA 也可以透過接合從一顆細菌轉移到另一顆細菌，過程中細菌會直接與另一顆細菌連接以進行交配。水平基因轉移在細菌中非常普遍，有研究估算在細菌演化過程中大約三分之一的基因轉移都透過這種方式發生 [4]。

## 真核生物的水平基因轉移

然而，對於動物、植物和真菌等真核生物來說，情況有所不同。由於大部分真核生物的生殖細胞與體細胞都被隔開 [2–3]，意味著若外來基因進入體細胞，它將無法被傳遞給下一代，而只有被整合到精子或卵子，或其祖細胞 (將會分裂成精子或卵子的細胞) 的基因才會得以遺傳。因此，水平基因轉移通常要發生在生殖細胞，才能對真核生物產生長久的影響。


**圖一** 原核生物中水平基因轉移的三大機制示意圖：轉化、轉導與接合。

儘管如此，水平基因轉移仍然可以在真核生物中發生，而某些條件似乎會增加其發生的可能性。這些條件包括吞噬作用，即細胞吞噬其他細胞或顆粒；以及共生，即兩種不同生物緊密共存。此外，水平基因轉移也可能更頻繁地發生在個體僅由一個或數個未分化細胞組成的早期發育階段，例如孢子、合子和胚胎等。

與細菌不同的是，外來 DNA 主要透過「非同源性末端接合」進入真核生物的基因組，這種天然的 DNA 修復機制直接連接斷裂的 DNA 末端，但當修復過程中有外來 DNA 時，這些 DNA 有時便會被意外地插入到基因組中。

雖然生物學家尚未就真核生物中水平基因轉移有多普遍達成共識，但他們已經記錄到一些引人入勝的例子，例如蚜蟲祖先從真菌獲取類胡蘿蔔素基因 [5]。這是科學家首次在動物基因組發現類胡蘿蔔素基因，這些色素基因使蚜蟲身體產生紅色、綠色或黃色色素。在自然界中，紅色和綠色蚜蟲都比較常見，因為掠食者與寄生者往往只偏好其中一種顏色，從而保留了蚜蟲顏色的多樣性。

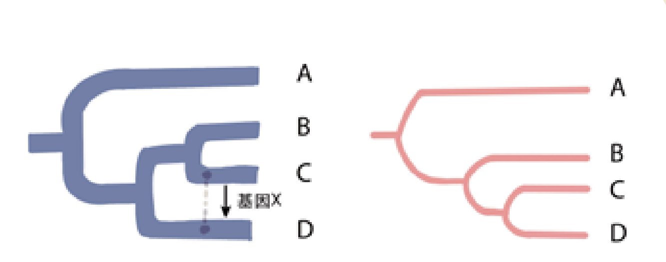
水平基因轉移另一個較近期的例子則涉及一種類似 CRISPR-Cas 系統的新機制 [6–7]。CRISPR 是一種天然存在於原核生物基因組的 DNA 序列，源自過往入侵原核生物的病毒 DNA 片段 [8]。在隨後的感染中，一類稱為 Cas 的 DNA 切割酶 (更專業的說法是「核酸內切酶」) 能利用從 CRISPR 序列轉錄而來的互補 RNA 作為「嚮導」，識別並摧毀匹配的病毒 DNA 以保護自身。研究人員曾猜想這種 RNA 引導系統是否只存在於原核生物，結

果卻在真菌發現在真核生物中類似的系統，其核心是一種稱為 Fanzor 的 RNA 引導核酸內切酶。有趣的是，科學家發現 Fanzor 基因可能源於原核生物的 *tnpB* 基因，而 *tnpB* 基因很可能是透過水平基因轉移移植到真核生物中。

### 如何偵測水平基因轉移

話說回來，科學家究竟是如何發現這些水平基因轉移的例子呢？箇中關鍵就在於將著眼點放於水平轉移的基因本身。由於這些基因源自其他物種，因此編碼著的氨基酸序列應該仍與原來物種的版本有著一定程度上的相似。

這個概念構成了一種名為「譜系衝突」（phylogenetic conflict）的常用方法 [2–3]。簡而言之，科學家會比較兩種「演化樹」：一種是物種本身的演化樹，另一種是目標基因的演化樹。如果某個基因從一個物種轉移到另一個物種，即使物種本身的演化樹顯示兩個物種之間並沒有親緣關係，該基因的演化樹也可能會顯示兩個物種為密切相關。例如在圖二中，如果基因 X 從物種 C 轉移到物種 D，那麼基因 X 的演化樹就會錯誤地顯示 C 和 D 為近親，因為它們擁有非常相似的基因 X。




**圖二** 由於物種樹與基因樹不一致而產生的譜系衝突。如果基因 X 是從物種 C 水平轉移到物種 D，則基因 X 的演化樹會錯誤地顯示 C 和 D 為近親，因為它們擁有非常相似的基因 X。

然而，僅僅依賴演化樹的不匹配並不足以證明水平基因轉移確實發生過，因為這個不尋常的現象也可能由其他原因引起，例如 DNA 測序過程受到污染等 [3]。為了更有把握，科學家會檢查基因 X 在物種 D 基因組中的位置，如果基因 X 位於已知屬於物種 D 的其他基因旁邊，這是一個正面跡象顯示它確實成為了物種 D 基因組的一部分，而不是來歷不明的游離 DNA 片段。我們還可以觀察基因 X 是否具備真實基因的特徵，例如擁有內含子（真核生物基因中常見的非編碼序列）等。此外，RNA 測序數據還可以確定該基因是否真的在細胞中被表達和使用。

### 水平基因轉移與生命之樹

水平基因轉移帶來的譜系衝突令一些生物學家開始質疑達爾文的生命樹模型是否還能完整描述演化關係的複雜性，尤其是在原核生物間錯綜複雜的親緣關係 [9]。在達爾文的比喻中，生命演化如同一棵龐大的二叉分支樹，物種隨著時間的推移從共同祖先分化出來。水平基因轉移則為這個景象增添了新的維度：它使一些分支側向延伸，將遙遠的枝條以出人意表的方式連結。這種橫向連結創造出更像網狀的結構，使有些學者提出以網絡模型取代以二分形式擴展的樹狀結構。然而，無論生命最終以一棵樹、一個網絡，還是兩者兼而有之的形態展現，有一點始終不變：水平基因轉移深深影響了演化過程，塑造出「無數最美麗且最奇妙的生命形式」。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# Q&A with HKUST Chemistry Majors

## 讀化學的人：與科大學子對談


By Daria Zaitseva


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Undergraduate Year 3 student majoring in Chemistry
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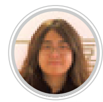
理學士（化學）（2012）

### What inspired you to major in chemistry?
### 甚麼啟發你選擇主修化學？



**Samuel**

My choice was chemistry because I want to work in the pharmaceutical industry, especially in the drug discovery field. I grew up in an ordinary family, so when we are hit with medical bills, insurance does not always cover everything. We have to look for funding and see who is merciful enough to grant us money to buy those expensive drugs. After learning that drugs can be made by synthesis, I thought there should be a way for companies to find a cheaper route to produce drugs. So that's what I want to do in my career.

我選擇主修化學是因為我想在製藥行業工作，尤其在藥物研發方面。我在一個普通家庭長大，當我們面臨醫療帳單時，保險並不總是能涵蓋所有費用，因此我們必須尋找資助，看看哪個有心人能資助我們購買昂貴的藥物。在得知可以透過合成方法製造藥物後，我猜世上應該存在一些合成路徑可以讓藥廠利用更便宜的方法製藥，這就是我未來想從事的職業。

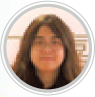
**Abigail**

I'm not familiar with business or engineering because I didn't take those classes back in high school, so I went with science. In the first year of university, we took all kinds of classes. I don't recall having a strong preference, but math and physics were slightly too hard for me. There are lots of unfamiliar English terms in life science because I studied biology in Chinese back in high school. Therefore, chemistry was the least challenging subject for me. I found it OK to learn chemistry, so I chose chemistry. It was a very practical choice.

我對商學或工程並不熟悉，因為我在高中時沒有選修相關科目，所以大學選修了理學。在大學的第一年，我們上了各種各樣的課程。我記得自己沒有強烈的偏好，但數學和物理對我來說略為困難。生命科學中也有很多陌生的英文語彙，因為我在高中時用中文學習生物。因此，化學對我來說是當中挑戰性最低的科目，而我對學習化學感覺還好，所以就選擇了化學。這是一個非常實際的選擇。

## What is your plan at this stage of your career? How has your perspective on chemistry evolved during your time at HKUST and beyond?

## 在職業生涯這個階段你的計劃是甚麼？在科大讀書和畢業後，你對化學的看法有著怎樣的改變？



### Samuel

Back in secondary school my view was naiver. I just thought that I would come here to study, go into the research field, discover some new stuff, and make use of the power of chemistry to solve the problem of high drug prices. But as it turned out – as with basically everything in life – it's not that simple.

Pharmaceutical companies do have their concerns. They are responsible for their shareholders, so they may have no choice but to pursue profit maximization. That means my vision may not come true in the end. But that doesn't mean that I should give up, right? I shall persist because I might one day encounter a company which shares my wish and vision. Even though it might be difficult to control the market price, the goal should still be to lower the cost of diagnostic tests and drugs, so that they can be readily available to the public.

我讀中學的時候我的想法比較天真：我只想來這裡讀書，然後從事研究，發現一些新東西，利用化學的力量解決藥價高昂的問題。但就像生活中所有事情一樣，事情並不會那麼簡單。

藥廠也有它們的顧慮，他們需要對股東負責，因此可能別無他選，只能追求利潤最大化。這意味我的願景最終可能無法實現，但這並不代表我應該放棄，對吧？我應該堅持下去，因為可能有一天我會遇到一家與我懷著相同願景的公司。儘管可能沒有辦法下調市場價格，但我仍希望降低診斷測試和藥物的成本，讓市民大眾能觸手可及。

### Ho Nam

After earning my PhD degree, my lab mate and I founded a startup that develops medical devices for *in vitro* fertilization (IVF) clinics. It has been eight years now, and we have raised about four rounds of investment and funding. We have also won the HKUST-Sino One Million Dollar Entrepreneurship Competition back in 2019. Currently we are doing clinical trials in hospitals in the Chinese Mainland.

When I was still an undergrad, I joined Professor Hongkai Wu's lab. We used technology like nanofabrication to make microfluidic chips, a kind of chip that manipulates and analyses tiny amounts of fluids. We got to do 3D printing and modeling, electronics, and different kinds of things that is more like analytical chemistry.

When people think of chemistry, they tend not to think about instruments at first. But indeed, most of the chemical discoveries were enabled by the invention of new instruments. When you have techniques like infra-red (IR) spectroscopy and nuclear magnetic resonance (NMR) spectroscopy, you will be able to detect and analyze chemicals. That's how our understanding of chemistry can evolve. I didn't know this side of chemistry when I was in high school.

取得博士學位後，我和實驗室裡的夥伴創立了一家初創公司，開發用於人工受孕診所的醫療設備。到現在已經八年了，而我們早於 2019 年已在「科大 – 信和百萬獎金創業大賽」中取得冠軍，也籌集了大約四輪資金。目前我們正在內地的醫院進行臨床試驗。

當我還是本科生的時候，我加入了吳洪開教授的實驗室。我們用納米組裝等技術製作微流控芯片，那是一種能操控和分析微量液體的芯片。我們會進行三維列印和建立模型，以及從事關於電子學和其他更像是分析化學的工作。

當人們想到化學，通常不會首先想起儀器。但事實上，大多數化學發現都是由新發明的儀器所促成的。當你擁有紅外光譜法和核磁共振光譜法等技術時，就能檢測和分析化學物質，這樣能推動化學的發展，然而我在高中並不了解化學的這一面。

## Beyond technical knowledge, what personal qualities or characteristics do you believe are essential to excel and make an impact as a chemist?

## 除了學術知識外，你認為甚麼個人特質能使化學家成功及發揮影響力？

### Abigail

I feel like you need a lot of patience, because for a lot of experiments you won't have an answer at first. You will likely fail many, many, many times. It is normal even if you don't have any results for a month. Another thing is to pay attention to detail. If you miss them, it's common that you won't have any results that make sense because you didn't notice the problems at first. A lot of very good research came from an accident, too, so whether you can spot the details can make a difference.

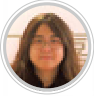
我認為需要很多耐性，因為對於很多實驗，你不會一開始就有預設答案。你可能會失敗很多很多次，即使一個月沒有任何結果也不足為奇。另一樣是要關注細節，如果你忽略細節，就很難歸納出有意義的結果，因為你一開始就沒有注意到問題所在。另外許多優秀研究也是意外下的結果，關鍵就在於你是否能夠注意到箇中細節。

### Ho Nam

The most important things are passion and curiosity. Passion is important because as an entrepreneur there are lots of people reporting to me and I need to make a lot of decisions every day. You need to spend a lot of time thinking about the situation, the goal of your company and how to achieve it. Facing so many problems and challenges, passion will keep you away from suffering burnout. Plus, when you really like what you are doing, as a researcher or an entrepreneur, you will be willing to spend more time than others. This will result in a higher chance, although not guaranteed, to succeed.

最重要是熱情和好奇心。熱情很重要，因為作為一名創業者，我每天需要與很多下屬交流，並做出許多決定，因此需要花很多時間思考當前情況、公司的目標，以及如何實現它們。面對如此多的問題和挑戰，熱情可以避免你因耗盡心力而感到倦怠。此外，當你真正喜歡自己所做的事情時，無論從事研究或創業也好，你就會願意比別人花更多時間。這能提高成功的機會，雖然沒有人能保證成功。

## What are some stereotypes surrounding chemistry that you would like to dispel?
## 想為一些關於化學的誤解澄清嗎？



### Samuel

I do organic chemistry and it really pains me when I hear people misuse the term "organic." Some food labels might say, "Oh, we're from an organic farm, very healthy. We don't use fertilizers." The term is almost always coupled with the statement that "We don't have chemicals in it," which is purely insane. The word "organic" in organic chemistry doesn't mean that you use natural things but stands for the chemistry surrounding the element carbon. There can't be a lack of chemicals in anything because a lack of chemicals would mean a lack of, basically, existence. So, that's a common misuse of the word.

我從事有機化學，因此聽到人們亂用「有機」一詞會令我感到痛心。有些食物標籤會說：「您知道嗎？我們來自有機農場，非常健康。我們不使用化學肥料。」這個詞語幾乎代表「我們不含化學物質」— 完全荒謬的一句話。有機化學中「有機」並不代表使用天然物質，而是指圍繞碳元素的化學。任何東西都不能缺乏化學物質，因為缺乏化學物質基本上就代表不存在。這是一個常見的誤用。

### Abigail

There's a stereotype about chemistry majors being somewhat "nerdy." I did meet a high percentage of people being very smart and hardworking. They could concentrate on one thing and really loved it enough that they wanted to do it 24 hours. I'm the kind of person who cares much about work-life balance, so I once feel like maybe people like me won't be a good candidate for doing research, or for working in science. But later I found that it's not true; all kinds of people can do research.

其中一個刻板印象是認為讀化學的人有點「書呆子」。我確實遇過很多非常聰明和努力的人，他們能專注於一件事，並熱愛到可以從事24小時不止息的程度。然而我是那種非常重視工作和生活平衡的人，所以懷疑過像自己這樣的人是否不適合做研究，或從事與科學相關的工作，但後來我發現並不是這樣的，各種各樣的人也可以從事研究。

### Ho Nam

People often think chemistry is only about organic synthesis or making drugs. They watch TV series like *Breaking Bad* and ask if we can actually "cook" like that in an RV. The reality is very different. The necessary precursors are government-restricted, and the solvents involved are incredibly toxic. We perform organic synthesis inside high-tech fume hoods for a reason. It is dangerous and should never be attempted at home.

Meanwhile, chemists also make instruments and materials. When you learn more, you will also find that chemistry is actually intertwined with physics and biology. They are all inseparable.

人們常常認為化學只是關於有機合成或製藥，他們看完《絕命毒師》(*Breaking Bad*)等電視劇後會問我們是否真的能在露營車裡製毒，但現實卻大相徑庭：製毒所需的原材料受政府嚴密監管，所涉及的溶劑也毒性無比。我們在設計精密的通風櫃裡進行有機合成是有原因的，因此那很危險，絕對不應在家嘗試。

與此同時，化學家還製造儀器和材料。當你對化學了解更深，你還會發現它實際上與物理和生物密不可分。

## Do you have any advice for high school students thinking of studying chemistry?
## 你有甚麼建議給予考慮修讀化學的高中生？

### Abigail

If you are really focused and love chemistry like you just want to do it for your whole life, you can choose as many chemistry classes as you want to find your interest within that. I also suggest exploring as much as possible in university, especially for people who are not sure about what they're interested in or good at. I took a lot of music courses because I like music a lot. I also took humanities classes like literature. I never regret and still remember what I learned. Funny for like certain chemistry classes, I don't like organic chemistry at all, so I don't remember anything because I never touched it after I graduated.

Besides, exchange programs are really good. I went to Denmark for a summer exchange, and then Switzerland for semester exchange. It was some special time in life that after graduation you won't have the same experience like that, even if you have vacations there.

如果你目標非常明確，熱愛化學得只想終身沉浸於這個領域，那你可以儘可能修讀最多的化學課來找到自己在化學裡的興趣。我也建議在大學期間儘量探索不同事物，特別是不確定自己興趣或專長的同學。我選了很多音樂課，因為我非常喜歡音樂；我也選過一些人文課，譬如文學，但我從不後悔，並仍然記得從中學到的東西。有趣的是，對於某些化學課 — 例如我完全不喜歡有機化學 — 我反而會記不住任何東西，因為畢業後我再沒有接觸過它。

此外，交換留學真的很棒：我去丹麥進行了夏季交換，然後去瑞士進行了學期交換。那是人生中的特別時光，因為畢業後即使你到那裡度假，你將不會有同樣的感受。

### Ho Nam

When I was a high school student, I never thought I would be an entrepreneur. I don't think you can plan so many years ahead. As a high school student, we can only plan one or two years ahead. Just follow what you like most – if you like chemistry, then join the chemistry department. When you study in university, you will explore and experience much more than you would imagine now. You will see different research groups, different research topics, and other things not related to chemistry at all. When you find something you really like, just go for it. You will spend time on it and gain passion. Eventually, you will have a great chance to succeed.

當我還是高中生的時候，我從未想過自己會創業，因此我不認為你能計劃多年後的未來。作為高中生，我們只能計劃未來一至兩年。追隨自己最喜歡的：如果你喜歡化學，那就進入化學系吧。在大學裡，你會探索和體驗很多現在未曾想過的事情；你會遇到不同的研究團隊、不同的研究主題，以及其他與化學完全無關的東西。當你找到自己真正喜歡的東西時，就去追隨它吧。你會花時間投身其中並予以熱情，最終將有很大機會成功。

Visit the following webpage to read the **Complete interview!**
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