SCIENCE FOCUS 科言

Issue 022, 2022

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AND TECHNOLOGY

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Message from the Editor-in-Chief 主編的話

Dear Readers,

Welcome to a new issue of *Science Focus*. I hope you have overcome the inevitable disruption to your life and study due the latest wave of COVID infections. As always, our goal is to transport you to the wonderful world of scientific discoveries, as an alternative to traveling abroad.

How many of you struggle to stay alert for school lessons, especially after lunch? We consider what goes on in the brain during a food coma and why such phenomenon may be advantageous to our ancestors. Speaking of lunch, how often do you have a plate of calamari with ketchup? Next time you do, please spare a thought on the rather intelligent squid. In some countries, experiments on cephalopods are highly regulated because of their well-developed nervous system that enables them to process and remember painful experiences. In another article, you may also learn why the physical and chemical properties of ketchup conspire against a smooth pour. For those of you who are interested in astronomy, have you heard of the name Jocelyn Bell Burnell? Her brilliant discovery of pulsars led not only to belated fame. She has used her professional influence and prize money to promote equality in science. A truly inspirational story.

Finally, I wish all of you a healthy and happy summer. I hope to meet some of you in outreach activities, organized by the School of Science, online or in person. Before then, let's stay connected via our *Science Focus* social media pages.

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

親愛的讀者：

歡迎閱讀最新一期《科言》。希望最近一波疫情在生活和學習上沒有為大家帶來太大的不便。一如既往，我們會跨越時間地域帶大家進入有趣的科學世界，暫且忘卻未能旅遊多時之苦。

除了在早上，你們試過在午飯後幾經掙扎才能提起精神上課嗎？我們會探討在飯氣攻心時腦部發生的事情，以及飯氣攻心這個現象為甚麼可能對我們的祖先帶來優勢。說到「食」，到訪西餐廳時你們會叫炸魷魚圈配茄汁嗎？下次吃魷魚圈時，不妨花數秒想想那聰穎的魷魚；由於頭足類動物的神經系統非常發達，使牠們能產生和記住疼痛感，因此與頭足類動物相關的實驗在某些國家是受到嚴格規管的。在另一篇文章中，你會學到為甚麼茄汁的物理和化學性質使我們永遠不能輕易倒出它。對天文學有興趣的你聽過 Jocelyn Bell Burnell 的名字嗎？發現脈衝星不僅為她帶來遲來的名聲，透過個人影響力和巨額獎金，她還深耕細作致力促進科學上的平等，最終促成一個鼓舞人心的故事。

最後，我希望大家在夏日裡也能保持健康和心境愉快。希望能在理學院舉辦的一些外展活動裡在線上或親身見到大家，但在這之前，讓我們透過《科言》的社交平台保持聯繫吧！

主編 麥晧怡教授
敬上

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What's Happening in Hong Kong? 香港科技活動

Fun in Summer Science Activities 夏日科學好節目

Any plans for this summer? Check out these activities!

計劃好這個夏天的好去處了嗎？不妨考慮以下活動！

HAYABUSA2~REBORN 隼鳥2號 — 星源再覓

Following the success of the space probe Hayabusa in 2010, its successor Hayabusa2 was launched in 2014 to collect soil samples from the asteroid Ryugu to study the birth of our solar system, which may hold the secret of the origin of life. It was also speculated that the samples might contain substances that are essential to life: water and organic matter.

But things did not go as planned. What happened in its lone journey of 3.2 billion kilometers? Could Hayabusa2 eventually land smoothly on the unexpectedly rough terrain that it was not designed for? Visit the Space Museum and watch the show!

Show period: Now – September 30, 2022

Time: 5:00 PM on Monday, Wednesday, Thursday and Friday (except public holiday)
11:00 AM, 3:30 PM and 8:00 PM on Saturday, Sunday and public holiday

Venue: Space Theatre, Hong Kong Space Museum

Admission fee: Standard admission:
$32 (stalls), $24 (front stalls)
Concession admission:
$16 (stalls), $12 (front stalls)

Remark: Please refer to the museum's website for more details.

隨著太空探測器隼鳥號在 2010 年任務成功，它的繼任者隼鳥 2 號亦於 2014 年發射升空，前往小行星龍宮採集土壤樣本，幫助我們解開可能蘊藏生命起源奧秘的太陽系誕生之謎。據當時估計，樣本可能會含有孕育生命必需的物質：水和有機物。

但事情發展卻不如預期。究竟隼鳥 2 號在 32 億公里的孤獨旅程中出現了甚麼狀況？最後又可以在超出其設計所容許的嶙峋地形上順利降落嗎？快到太空館觀賞這套電影吧！

映期：即日至 2022 年 9 月 30 日

時間：星期一、三、四及五（公眾假期除外）
下午五時正
星期六、日及公眾假期上午十一時正、
下午三時三十分及八時正

地點：香港太空館天象廳

入場費： 標準票：32 元（後座）；24 元（前座）
優惠票：16 元（後座）；12 元（前座）

備註：更多詳情請參閱太空館網頁。

Parade of the Five Planets June 18-28, 2022
五星連珠 2022年6月18至28日

Mercury, Venus, Mars, Jupiter and Saturn are five bright planets that are visible to the naked eye. It is uncommon for them to appear at once but here comes the chance – graced by the Moon, the five planets will do just that, from June 18 (Mon) to June 28, 2022 (Thu).

While the planets seem to form a straight line in the sky, they don't really align neatly to form a radius if we consider the top view of the solar system. The planets just coincidently cluster on the same side of the Sun that is visible on Earth – so it's rather a trick of perspective. And don't overthink – the world isn't going to end in June and the next issue of *Science Focus* will be published as scheduled!

水星、金星、火星、木星和土星是肉眼能看到的五顆行星，但五顆同時出現卻不是常見的現象。現在機會來了！ — 在月亮相伴下，五顆行星會在 2022 年 6 月 18 日(一)至 28 日(四)連成一線，上演「五星伴月」的戲碼。

雖然五顆行星會看似連成一直線，但並不會一如我們所想的在太陽系軌道的鳥瞰圖中排列成同心圓的半徑；它們只是湊巧地同時聚集在太陽的同一邊，而又位於地球上能看見的角度，因而在地球的天空上投影成一直線而已。不要想多！ — 世界不會在六月終結，而下期《科言》將會如常出版！

Search

ARTICLE

這個隨機播放清單……不太隨機！

Shuffle Playlist. Shuffle Playlist. Shuffle Playlist...

By Peace Foo 胡適之

PAUSE ⋯

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	TITLE	ARTIST	ALBUM	📅
♡	Someone Like You	Adele	21	2011-09-30
♡	FAKE LOVE	BTS	Love Yourself 轉 'Tear'	2018-05-18
♡	Incredible (with Ne-Yo)	Céline Dion, Ne-Yo	Loved Me Back To Life	2014-06-25

A coin comes up heads five times in a row. Two accidents happen on the same train line in one day. Or a shuffled playlist plays you the same artist three times running. Sometimes it seems like something other than coincidence is at work, but true randomness may not always feel that way to us.

Statistically Independent Events: The Coin Doesn't Remember!

Let's start with the coins. Many people expect a fair coin to alternate between heads and tails and will be surprised if the coin keeps coming up heads. When you first thought about it, you might have expected heads to come up half the time and tails half the time, so if heads have come up over half the time the coin should start landing on tails more often to compensate. This isn't true, of course, because the coin can't remember this! If you have a fair coin which has just landed on heads 99 times in a row, you can't say that it's more likely to land on tails next time because it's a fair coin [1]. Since each toss has no effect on the next, we say that they are statistically independent events.

If we toss a coin twice, and each toss has an equal chance of heads (H) or tails (T), there are four possible outcomes: HH, HT, TH, TT. Each outcome has the same chance (1/4) of happening, but the chances of one head and one tail in either order are 2/4 instead of 1/4. Three times, and we have eight possible outcomes: HHH, HHT, HTH, HTT, THH, TTH, THT, and TTT, each with 1/8 probability. In a series of ten tosses, the results HTHTHTHTHT and HHTHTTTTHT and TTTTTTTTTT all have the same chance of occurring – one in 2^{10}, or 1/1024 – but you'll probably remember the last one and not the others [2]. We read too much into patterns in a random sample, and we're willing to jump to conclusions based on those patterns [3].

Shuffling in Real World: Fisher – Yates Shuffle vs. Naïve Method

Take the Fisher–Yates shuffle [2], which shuffles a sequence randomly based on the input of other random numbers. Let's say there is an existing sequence of the numbers 1 to 10. First pick a random number from 1 to 10, called *n*, and remove the *n*th number in the existing sequence to begin a new sequence. For the next numbers, repeat this with any *n* from 1 to 9, from 1 to 8, and so on, until there are no numbers left in the existing sequence (see Figure 1).

This sequence is totally random if the choices of *n* are also random, and in a moment, we'll look at why this is true. We can think about the algorithm in terms of a deck of cards, removing random cards one at a time and stacking up the discarded cards in order to form a new deck.

Comparing this with other ways to shuffle cards makes it obvious why Fisher–Yates is truly random. A "naïve" method is to take each card in sequence one at a time and swap it with another randomly chosen card, repeating for every card in the deck [4]. In other words, if we shuffle three cards (marked #1, #2, and #3) using our naïve method, we first swap the first card in the sequence with either the first (unchanged), second or third card. Then we shuffle the second card with either one of the three cards, and repeat the process until we go through every position in the sequence.

The random choice at every stage is between three cards, so shuffling three times gives 3 x 3 x 3 = 3^3 = 27

n	Existing sequence	New sequence
3	1 2 ~~3~~ 4 5 6 7 8 9 10	3
8	1 2 4 5 6 7 8 ~~9~~ 10	3 9
5	1 2 4 5 ~~6~~ 7 8 10	3 9 6
2	1 ~~2~~ 4 5 7 8 10	3 9 6 2
3	1 4 ~~5~~ 7 8 10	3 9 6 2 5
5	1 4 7 8 ~~10~~	3 9 6 2 5 10
2	1 ~~4~~ 7 8	3 9 6 2 5 10 4
1	~~1~~ 7 8	3 9 6 2 5 10 4 1
2	7 ~~8~~	3 9 6 2 5 10 4 1 8
1	~~7~~	3 9 6 2 5 10 4 1 8 7

Figure 1 An example of Fisher–Yates shuffle.

permutations. But as you may know, there are only 3 x 2 x 1 = 6 possible ways to mix up the order of those three cards: 123, 132, 213, 231, 312, 321. If you list all possible permutations resulting from the naïve method, you will find that the combinations 132, 213 and 231 come up five times, while 123, 312 and 321 come up only four times. Obviously, the result is biased. If you think intuitively, since 27 is not divisible by 6 (and n^n or $n > 2$ is not divisible by $n!$ in general), some of the possible permutations must happen more often than others (if all of them are equally likely to occur, the number of shuffles will be a multiple of 6). The chances are not equal, so the naïve method is not random.

This is similar to the usual way to shuffle cards: In simple terms, we take an entire bunch of cards and swap it with another bunch of cards in the sequence. But these methods do not result in a random outcome, because the shuffled cards continue to circulate within the system.

Contrast this with Fisher–Yates. Since a card is removed from consideration after each shuffle (and gets put into a new deck), the pool to be shuffled at each stage gets smaller, and for our three-card deck there will be 3 x 2 x 1 = 6 permutations after three shuffles. Note that these permutations are calculated the same way as the possible ways of mixing up three cards: they both use the factorial function $n! = n \times (n - 1) \ldots \times 3 \times 2 \times 1$, or $3! = 3 \times 2 \times 1$ in this case which is equivalent to $3P3$. They are essentially the same algorithm in the sense that they are counted the exact same way. So the randomness behind the original selections of *n* is preserved throughout the permutations, and this is why we can guarantee Fisher–Yates is a fully random sequence provided *n* is chosen randomly.

Creating a Less Random Playlist That Feels More "Random"

Now let's return to our random sequence 3-9-6-2-5-10-4-1-8-7 in Figure 1. We can call it a shuffled playlist of ten songs and say that songs 1, 4, 7, and 10 are by Adele (artist A), songs 2, 5, and 8 are by BTS (artist B), and songs 3, 6, and 9 are by Celine Dion (artist C). It looks like this:

Celine Dion > Celine Dion > Celine Dion > BTS > BTS > Adele > Adele > Adele > BTS > Adele

Which doesn't look random at all! That's because we focus on the unusual patterns of three Celine Dion and three Adele songs in a row. If you were like Spotify users between 2012 and 2014, you'd have rushed to complain [5] about all the times the shuffle algorithm played non-K-pop music over and over (assuming you also listened to K-pop before 2014). There were so many complaints, in fact, that Spotify retired the Fisher–Yates algorithm – yes, they originally used Fisher–Yates to shuffle playlists [6] – and introduced a new shuffling algorithm. Now, when you shuffle a playlist, different songs by the same artist and in the same genre are distributed roughly evenly across the list [7].

The Spotify engineers made the shuffle less random to convince you that it became more random.

一枚硬幣連續擲出五次正面，同一條路線的列車在同一天發生了兩宗意外，或是隨機播放清單連續給你三首由相同歌手演唱的歌曲。這似乎並不是巧合，但真正的隨機也許未如我們想像中的那樣。

統計上獨立的事件：硬幣並沒有記性！

讓我們先從硬幣說起。擲一枚公平的硬幣(fair coin)時，很多人會預期正面和反面朝上的結果會交替出現，連續擲出正面大概會使我們目瞪口呆。在沒有細想之下，你可能也會估計正面和反面出現的次數會各佔一半，所以如果正面出現的比例多於一半時，反面應該就將會出現得更頻密來補償之前不均的結果 — 當然，這個想法是錯誤的，因為硬幣並不會記得先前的結果！如果你有一枚公平的硬幣，它連續擲出了 99 次正面朝上的結果，你不能說下次會有較大機會擲出反面，因為它畢竟是一枚公平的硬幣 [1]。由於每次拋擲對下次結果都沒有影響，我們稱這些為統計上獨立的事件。

如果我們擲兩次硬幣，每次正面或反面朝上的機會均等，以下是四個可能的結果：正正、正反、反正和反反。每個結果發生的機會都相同（1/4），但以任何次序出現一正一反的機率為 2/4 而不是 1/4。擲三次的話會有八種可能：正正正、正正反、正反正、正反反、反正正、反反正、反正反和反反反，每種可能的機率均為 1/8。一連擲十次的話，正反正反正反正反正反、正正反正反反反正反和反反反反反反反反反三者的機率都一樣，均為 $1/2^{10}$ 或 1/1024，可是會令你留下深刻印象的肯定是最後一個組合而不是其他 [2]。我們太著迷於從隨機產生的結果中找規律，並會就此輕率地下結論 [3]。

現實上的洗牌演算法：Fisher－Yates 洗牌法與天真法

讓我們先介紹 Fisher–Yates 洗牌法 [2]，它根據另一組隨機數字把序列隨機地打亂。假設現在有一組由數字 1 至 10 組成的序列。首先從 1 至 10 選一個隨機號碼叫 n，然後移除上述序列中第 n 個數字放到一組新序列裡。之後對序列中餘下的數字重覆以上步驟，從 1 至 9、1 至 8 中選 n，如此類推，直至序列中的所有數字都被移除（見圖一）。

如果 n 的選擇是隨機的，那新序列也會是完全隨機的。讓我們來看看為甚麼這個關係會成立。我們可以以一副卡牌作比喻來理解這個演算法：每次隨機移除一張卡牌，並把移除的卡牌疊起來組成一副新的卡組。

把這個演算法與其他洗牌方法作比較可以突顯為甚麼 Fisher–Yates 法是真正隨機。有一個「天真（naïve）」的方法是每次在卡組中取出一張卡牌，然後與另一張隨機選擇的卡牌交換位置，再對卡組中的每張卡重覆以上步驟 [4]。換言之，如果我們用天真法洗一副有三張卡的卡組（卡牌上標記了 #1、#2 和 #3），第一步我們會把卡組中的第一張卡與第一（不變）、第二或第三張卡的其中一張交換位置。然後到第二張卡，我們又使它與三張卡的其中一張對換位置；重覆以上過程直至卡組中的每一張卡都洗過一遍。

每一步我們都隨機從三張卡裡面選擇一張，因此三回合一共可以帶來 3 x 3 x 3 = 3^3 = 27 個排列（permutations）結果。思路清晰的你大概已經意識到我們只有 3 x 2 x 1 = 6 種方式來排列三張卡牌：123, 132, 213, 231, 312 和 321。如果你把從天真法每一步產生的可能排列逐一列出，你會發現 132, 213 和 231 出現了五次，而 123, 312 和 321 只出現四次，結果顯然是偏倚的。憑直覺也能得知因為 27 並不能被 6 整除（基本上 n^n 或 $n > 2$ 都不能被 $n!$ 整除），所以某些排列一定會比其他出現得更多（如果每個排列出現的機會均等，排列結果的數目應是 6 的倍數）。由於機會不均等，因此天真法並不隨機。

這與我們平時洗撲克牌的方式相似：簡單來說就是將卡組中的一疊卡牌與另一疊互換位置；可是這些方法都不會產生隨機的結果，因為洗過的卡牌都繼續在系統裡流轉。

跟 Fisher–Yates 法對比一下，由於每個回合都有一張卡被移除（並調到新的卡組中），所以被考慮的卡牌會越來越少，而在我們一副三張卡的例子裡，三回合只會帶來 3 x 2 x 1 = 6 個排列結果。計算這種排列結果數目的方法與計算三張卡牌有多少個排列可能性的方法一樣：兩者都用到階乘函數 $n! = n \times (n-1) \ldots \times 3 \times 2 \times 1$；在我們的例子中是 $3! = 3 \times 2 \times 1$，亦等同 $3P3$。兩者背後的計算思路基本上相同，相同之處在於列出所有可能排列的方式。因此，n 本身的隨機性在洗牌中被得以保留；這也是為甚麼只要能確保 n 是隨機選出的，就能保證 Fisher–Yates 法能提供一個完全隨機的序列。

創造不太隨機但感覺隨機的播放清單

現在回到我們在圖一的隨機序列：3-9-6-2-5-10-4-1-8-7。它是我們共有十首歌的隨機播放清單：曲目一、四、七、十是 Adele（藝人甲）的歌，曲目二、五、八是 BTS 防彈少年團（藝人乙）的歌，而曲目三、六、九是 Celine Dion（藝人丙）的歌。播放清單看來是這樣的：

Celine Dion > Celine Dion > Celine Dion > BTS 防彈少年團 > BTS 防彈少年團 > Adele > Adele > Adele > BTS 防彈少年團 > Adele

這樣的播放清單看起來一點兒也不隨機！這是因為我們不經意地聚焦在連續三首 Celine Dion 和 Adele 的歌這個不尋常的規律裡。假如你是 2012 至 2014 年的 Spotify 用家，你也許已經急不及待去投訴 [5] 這個不給你聽 K-pop 的該死隨機播放清單（假設你在 2014 年前已經在聽 K-pop）。那年 Spotify 實在收到太多投訴，使他們放棄原來使用的 Fisher–Yates 演算法而引入新的演算法(對！他們原本是用 Fisher–Yates 法來產生隨機播放清單 [6]）。現在選擇隨機播放時，演算法會確保由同一歌手演唱或屬於同一種類的歌曲大致平均地分佈在播放清單中 [7]。

正是 Spotify 工程師把播放清單弄得不再隨機，來令你相信它變得更加隨機。

n	原來序列	新序列
3	1 2 ~~3~~ 4 5 6 7 8 9 10	3
8	1 2 4 5 6 7 8 ~~9~~ 10	3 9
5	1 2 4 5 ~~6~~ 7 8 10	3 9 6
2	1 ~~2~~ 4 5 7 8 10	3 9 6 2
3	1 4 ~~5~~ 7 8 10	3 9 6 2 5
5	1 4 7 8 ~~10~~	3 9 6 2 5 10
2	1 ~~4~~ 7 8	3 9 6 2 5 10 4
1	~~1~~ 7 8	3 9 6 2 5 10 4 1
2	7 ~~8~~	3 9 6 2 5 10 4 1 8
1	~~7~~	3 9 6 2 5 10 4 1 8 7

圖一　Fisher–Yates 洗牌法的一例

References　參考資料：

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Lost Lessons –

Succumbing to the Inescapable Food Coma

飯氣攻心 –

害我們上課睡著的惡作劇把戲？

By Dana Kim 金娥凜

Yawn

Oh no, your teacher stares at you. You rub your eyes, trying to focus on the differentiation problem your teacher asked you to solve.

You start to think, is it the bowl of noodles I had for lunch? Why is it that a food coma hits us so hard every time after lunch?

Common Misconception About Food Coma

Traditionally, it is believed that sleepiness after a meal is due to the redistribution of blood flow. We think that blood rushes through the stomach and intestines to facilitate digestion, resulting in a reduction in blood and oxygen supplies to our brain and hence the induction of post-meal sleepiness, medically known as postprandial somnolence [1].

However, this is not the case. Blood redistribution theory fails because cerebral blood flow and brain oxygenation are known to be preferentially maintained under a wide range of physiological conditions [2]. They are strictly maintained even during exercise when much of the blood is diverted to muscles; and in fact, a study revealed that there was no measurable change in the blood flow to the brain in carotids after feeding [2]. Therefore, the intake of food will probably not affect brain oxygenation and cerebral blood flow [2].

Post-Meal Hormonal Change and Food Coma

So, what could be the possible reasons behind food coma? With the postprandial increase in insulin level as an example, feeding can promote or inhibit the secretion of a lot of hormones to maintain homeostasis. Such hormonal changes can also reduce the desire for food intake by introducing a feeling of satiety. It has been suggested that the hormones involved may simultaneously affect the sleeping centers in the brain and contribute to food coma (footnote 1) [1, 2]. We will examine two (of the many) examples – melatonin and orexin.

In addition to its role in regulating gastrointestinal motility [3], melatonin is commonly known as a hormone that regulates sleep-wake cycle – high levels of melatonin induce sleep. This has been shown by administrating melatonin to animals and humans in previous studies [2]. In fact, the gut increases the synthesis of melatonin considerably after meal consumption, so such increase is considered to be a contributing factor to food coma [2].

For orexin, it is known to be a hormone which promotes hunger, along with wakefulness, presumably through increasing the firing rate of neurons in an arousal center in the hypothalamus [2], which was hypothesized to work by inhibiting the sleep centers [1]. Therefore, the reduction of orexin after a meal may contribute to the sleep-inducing effect by leaving off the inhibition of the sleep centers [2].

Consider the Bigger Picture: Interactions Between Brain Centers

While some scientists incline to attribute the cause of food coma to the action of certain hormones, some take a further step back [1]. On top of the idea that the hunger-satiety axis modulates the sleep-wake axis, this view emphasizes the interaction between brain centers in the hypothalamus, and hormones are considered as just messengers that facilitate communication between organs.

As illustrated by the example of orexin above, there are four major centers in the hypothalamus that affect satiety and drowsiness. They can be simplified as the hunger, satiety, arousal and sleep centers. Hunger often comes with wakefulness; the hunger center is hypothesized to stimulate the arousal center and inhibit the sleep center. The arousal center itself works by inhibiting the sleep center, too. However, in the state of satiety, the satiety center inhibits the hunger center so everything in the pathway becomes the opposite and drowsiness occurs. The interactions are summarized in Figure 1.

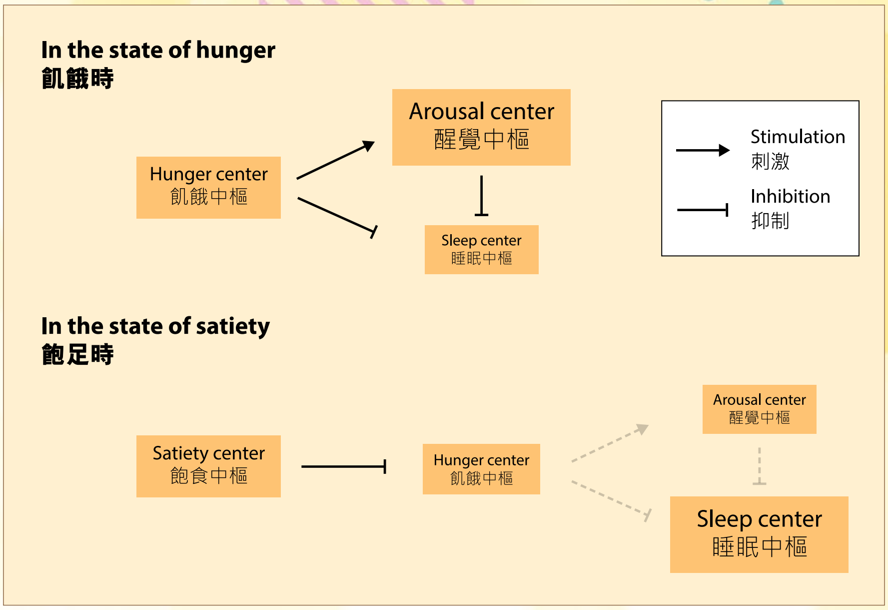

Figure 1 The interactions between the four brain centers before and after a meal.
圖一 與餐後嗜睡相關的四個大腦中樞在進食前後的相互作用

So, it is useful to understand what would lead to the feeling of satiety, which intertwines with the occurrence of post-meal sleepiness. In fact, our body judges whether we should feel full by our energy level and by the physical conditions of the stomach [1].

To know whether we are replenished with energy after a meal, arcuate nucleus (ARC; footnote 2) in the hypothalamus detects the increase in the level of a blood-borne metabolite, malonyl-CoA, whose level correlates with that of ATP ("energy"). Having combined other metabolic signals, ARC can stimulate the satiety center and inhibit the hunger center through hormonal regulation. This contributes to the feelings of satiety and drowsiness.

Meanwhile, our stomach should be stuffed with food for quite a while after eating. Vagus nerve branches can sense the gastric distension and delayed gastric emptying, which in turn lead to the release of some other gut hormones that stimulate the satiety center by their own actions and through vagal stimulation. This eventually yields the same feelings of being full and sleepy. Furthermore, this can account for the reason why solid food could induce greater drowsiness than liquid food, which is because solid food can cause greater gastric distension and further delay gastric emptying.

Food Coma in the Light of Evolution

So now, you may all be wondering – is it necessary for the satiety response to link to drowsiness? All it does it gets us into trouble for dozing off during class, right? True, but evolutionary biology suggests that there might be a reason behind post-meal sleepiness.

To understand, we need to view this phenomenon in the Darwinian context – any suboptimal effort allocation can result in a selection disadvantage [4]. For a species to survive in natural selection, they must spend their limited energy and effort wisely.

Speaking of these, some researchers speculated that digestion is a demanding metabolic process that requires focused effort and energy expenditure [2]. In response to that, our body may choose to temporarily lower its sensitivity to external stimuli to let our body “concentrate” on digestion by reducing energy and effort demands [2]. This could be the reason why we suddenly lose the vigor to hunt for extra calories.

Another plausible reason is that post-meal sleepiness may help consolidate what we learned from the circumstances that led to energy acquisition [2]. The brain is known to be plastic, or flexible, as neurons can rewire themselves to enable more effective communication. This serves as the basis of learning and memory. It has been proposed that neuronal connections can be remodeled and strengthened during sleep [5], so sleep is long suspected to be a process that facilitates learning. With this concept in mind, post-meal sleep was suggested to subconsciously reinforce what you learn from the energy-acquiring experience before the meal – say, hunting. It prepares you for future opportunities to acquire energy [2].

So, food coma could actually give us an edge in natural selection!

Unraveling the Mystery Between Feeding Biology and Sleep

Research studies on physiology and neuroscience have unveiled layers of mysteries of food coma by deciphering the functions of different hormones and brain parts. However, to this day, we are still unable to confirm why or how we get food coma confidently. Similar to many other scientific topics, like why we sleep, there are still many unanswered questions regarding the potential link between feeding biology and sleep.

* 呵欠 *

不得了，老師盯著你還未趕及合起的嘴。你擦了擦眼睛，竭力把專注力放回老師叫你解的那道微分題目上。

你開始想：是不是中午吃的那碗麵在作祟？為甚麼每次午餐後都必然飯氣攻心？

對於飯氣攻心的常見誤解

傳統上，人們相信餐後嗜睡是由於血流重新分配所致，血液被認為會流向胃部及腸道以幫助消化，因此分薄了供應至腦部的血液和氧，引發餐後嗜睡的現象 [1]。

然而這是錯誤的。血流改變理論不成立的原因是因為身體已知會在大部分生理狀況下優先維持通往大腦的血流和供氧量 [2]，即使是運動期間當大部分血液都被送至肌肉時，大腦的血流和供氧仍然會被嚴密地保持在適當水平；而事實上，有研究指出在攝食後經頸動脈通往腦部的血流並沒有錄得可量度的變化 [2]，因此攝食並不太可能會影響腦部供氧和大腦血流 [2]。

飯後的激素改變與飯氣攻心

那麼，我們又可以怎樣解釋飯氣攻心呢？以餐後胰島素水平增加為例，進食可以增加或抑制體內一系列激素的分泌，以維持體內平衡。這些激素水平的改變也可以透過帶來飽足的感覺，減低我們對食物的慾望。有研究指出當中涉及的激素可能同時影響腦部的睡眠中樞，導致飯氣攻心的情況（註一）[1, 2]。以下我們會檢視（許多激素當中的）兩個例子：褪黑激素（melatonin）和食慾素（orexin）。

除了參與腸胃蠕動外 [3]，褪黑激素亦眾所周知是一種調節睡眠清醒周期（sleep-wake cycle）的激素，對動物和人類施以褪黑激素的多項研究中已證明高褪黑激素水平能引發睡意 [2]。事實上，餐後腸道會增加褪黑激素的合成，這被認為是餐後嗜睡的成因之一 [2]。

至於食慾素，它是一種能同時引發飢餓感和令人保持清醒的激素。據科學家推測，食慾素能增加下丘腦醒覺中樞裡神經元的放電頻率 [2]，使醒覺中樞能有效地抑制睡眠中樞而令我們保持清醒 [1]。因此，餐後食慾素減少可能會使睡眠中樞失去原來的抑制而引發睡意 [2]。

從宏觀角度看腦部中樞間的相互作用

有些科學家傾向把飯氣攻心的成因歸咎於某些激素的作用，但亦有科學家退後一步從宏觀的角度看待這個問題 [1]。在飢餓—飽足軸（hunger-satiety axis）能調節睡眠—清醒軸（sleep-wake axis）的概念之上，這種觀點強調下丘腦裡面不同中樞間的相互作用，而激素的角色僅被看成器官之間的訊息傳遞者而已。

正如上面食慾素的例子提及過，下丘腦裡面有四個影響飽足感和睡意的主要中樞，簡單來說它們可以分為飢餓、飽食、醒覺和睡眠中樞。飢餓通常伴隨著清醒；科學家推測飢餓中樞能刺激醒覺中樞和抑制睡眠中樞，而醒覺中樞本身亦能抑制睡眠中樞。可是當飽足時，飽食中樞會抑制飢餓中樞，令機制內的相互作用都呈現相反效果而引發睡意。圖一總結了以上提及的相互作用。

因此，了解甚麼會引起飽足感非常重要，因為它與餐後嗜睡息息相關。事實上，我們身體會透過偵測我們的能量水平和胃部的物理狀況來判斷我們是否應該感到飽足 [1]。

要知道我們在進食後能量是否得到補充，下丘腦內的弓狀核（註二）會探測血液中代謝物丙二酰輔酶 A（malonyl-CoA）濃度的增加，而丙二酰輔酶 A 的水平正正與 ATP（即「能量」）的水平相關。在同時考慮其他代謝訊號後，弓狀核便能透過激素調節的方式刺激飽食中樞及抑制飢餓中樞，給予我們飽足和睏倦的感覺。

與此同時，我們的胃部在飯後好一段時間都會被食物填滿。迷走神經的分支能感覺到胃膨脹（gastric distension）和比平時所需時間較長的胃排空（gastric emptying），這會令身體分泌其他胃腸激素以直接或透過迷走神經刺激的方式刺激飽食中樞，最終也會帶來飽足和睏倦的感覺。除此之外，這也能解釋為甚麼固體食物比流質食物更能引發睡意，這是因為固體食物能令胃部膨脹得更大和逗留在胃部更久。

餐後嗜睡在進化上的意義

現在，你們也許在想：真的有必要把飽腹感連繫到睡意

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1 Editor’s note: Recall that one hormone can target multiple organs in hormonal coordination (cf. nervous coordination), so it is common for a hormone to perform multiple functions in different organs.

2 Nucleus: In the central nervous system, the word “nucleus” is used to describe a group of neurons that are located in a defined anatomical position.

上嗎？那只是害我們在課堂上睡著的惡作劇把戲吧？或許是的，但演化生物學告訴我們餐後嗜睡背後可能真的有其重要性。

要明白箇中原因，我們要從達爾文主義分析餐後嗜睡這個現象：要知道物種在分配有限的精力時，稍有差池都可能導致物種在自然選擇中失利 [4]。換言之，如果一個物種要在自然選擇中生存過來，就必須要明智地分配其有限的能量和精力。

說到這些，有科學家猜測消化是耗費精力和能量的代謝作用，所以身體可能選擇暫時降低對外界刺激的靈敏度，減少對能量和精力的需求以專注於消化上 [2]，這可能就是為甚麼我們在餐後突然對尋找額外熱量意興闌珊的原因。

另一個可能的原因是餐後嗜睡有助鞏固我們在獲取能量的活動中學到的東西 [2]。我們的腦部是可塑的，神經元之間可以透過改變它們的接駁方式令溝通更為有效，這正是學習和記憶背後的根據。科學家曾經提出神經元間的連接可以在睡眠中被改變和鞏固 [5]，因此睡眠一直被猜測是有助學習的過程。有了這個概念，科學家提出飯後睡眠有助我們在不自覺的情況下，鞏固我們在餐前獲取能量的活動（例如打獵）中學到的東西，令我們有更充分的準備去面對下次能夠獲取能量的機會 [2]。所以，餐後嗜睡其實能在自然選擇中為我們帶來優勢。

解開攝食生物學與睡眠之間的謎

生理學和神經科學上的研究已透過闡釋不同激素和大腦部分的功能揭示了飯氣攻心的重重謎團，但直至今天，我們仍不能完全肯定飯氣攻心背後的原因和原理。跟其他許多科學問題，像是為甚麼我們需要睡覺一樣，攝食生物學和睡眠之間的可能關係確實有著很多尚待解答的問題。

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1 編按：神經和激素協調的異同是課堂上老師會一再提及的重點：激素可以影響多於一個器官。因此一種激素能在不同器官發揮不同功能其實也不太令人意外。

2 神經核：「核」在這裡是形容在中樞神經系統中，處於解剖結構上同一位置的一組神經元。

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MYTHBUSTERS : The Golden

By Aastha Shreeharsh

The world we live in is a big place – a vast expanse of land and sea, in an even bigger cosmic web known as the universe, much of which remains a mystery to us. Making sense of our place in the universe has always been a comfort to humanity in the face of the unknown. The most significant way we do this is by seeking patterns. One such example is the golden ratio.

Denoted by the Greek letter phi (ϕ), the golden ratio is an irrational number – an unending number with infinite digits that cannot be expressed as a ratio of two integers, just like π – that has caught the attention of mathematicians, biologists, artists, and architects across the world throughout history [1]. You may be wondering exactly what the golden ratio is and what makes it so special. In order to understand it, let's assume a variable x, which represents the length of a line segment. The line segment is then divided into two parts, one longer than the other. The length of the longer part is normalized to one and that of the remaining part becomes x – 1, as illustrated in Figure 1.

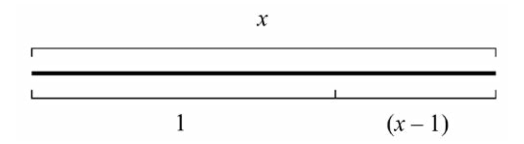

Figure 1 *Division of a line segment of length x into two parts.*

So, what would the ratio between x and the longer part be, such that it is equal to that between the longer and shorter parts?

$$\frac{x}{1} = \frac{1}{x-1}$$

To find the value of such a "divine proportion" x, we can create a quadratic equation from the relationship above:

$$x^2 - x - 1 = 0$$

By solving the equation and rejecting the negative solution, we can get x equals to $\frac{1+\sqrt{5}}{2}$, approximately 1.618 – this value is the golden ratio. Another famous mathematical concept you may have heard of, the Fibonacci numbers (F_n) forming the Fibonacci sequence, is also closely related to this ratio. Each number in this sequence is the sum of its two predecessors: 0, 1, 1, 2, 3, 5 and so on. The limit of the ratio between each number and its predecessor is, as you can probably tell, the golden ratio, ϕ. In other words, the higher the Fibonacci numbers, the closer the ratio is to ϕ.

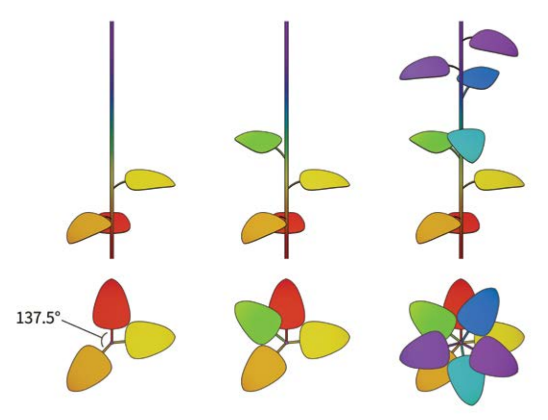

Figure 2 *Spiral phyllotaxis. (Leaves at consecutive vertical levels are pseudo-colored differently from red to purple.)*

Often linked to the "beauty of proportion" [2], ϕ appears in various areas of nature and was said to have inspired artists and architects for centuries. For instance, phyllotaxis (arrangement of leaves around the stem) of certain plants was discovered to be related to the golden ratio. While the angle between successive leaves or leaf pairs can be 90 degrees (decussate pattern) or 180 degrees (distichous pattern), spiral phyllotaxis with an angle close to the golden angle, approximately 137.5 degrees (footnote 1; figure 2), is also prevalent in plants [3]. It is not hard to imagine that such recurrent encounters with this ratio in nature have probably intrigued and awed ancient Greeks and us, as we can identify the incorporation of the ratio into the Parthenon and da Vinci's *The Last Supper* [1]. The frequent appearance of the golden ratio in artwork begs the question: Is the golden

Ratio Around Us

流言終結者：黃金比例真是無處不在嗎？

ratio really a solution to our pursuit of beauty?

Much to our surprise, this might just be our wishful thinking. It may be overthinking that has led us to identify its seemingly overwhelming presence in nature. The human brain loves seeking patterns, so much that perhaps it "favors" the emergence of ϕ in many of these instances, even when there is no concrete evidence to support the notion [1]. The most compelling case of this myth is the look of nautilus shells.

Nautilus is a sea creature from the same animal class, Cephalopoda, as squids and octopi. Unlike other cephalopods, its home is a beautiful, chambered shell with a spiral. These spirals are known as logarithmic spirals or growth spirals – spirals that keep growing further apart from the innermost curves as illustrated in Figure 3.

Nautilus shells are said to be the prime example of the appearance of ϕ in the natural world, with their logarithmic spirals suggested to have an aspect ratio equivalent to the golden ratio – a deeply held belief that is so popular in no small part due to literature such as Dan Brown's *Da Vinci Code*, renowned scientists and academic institutions like the Smithsonian (footnote 2) perpetuating this "fact" [2].

Yet, if you were to ever inspect a nautilus shell for yourself in real life, you may find the aspect ratio actually closer to 4:3 (1.333) than ϕ (1.618). When this myth of every nautilus shell having the golden ratio is thought about more deeply, isn't it kind of odd to think that every single nautilus shell in existence would have the same ratio? It would be more believable if this ratio is varied, even by a few decimal numbers, in different specimens, right?

Figure 3 *Logarithmic spiral of nautilus.*

That's precisely the same thought a certain researcher by the name of Christopher Bartlett had. He went so far as to surmise that even the 4:3 ratio is not an accurate aspect ratio for most nautilus shells. When 80 shells were examined from the Smithsonian collections, the average ratio came out to be 1.310. All shells had varying ratios with slightly different number; making it absolutely wrong to state that all these spirals somehow have the same measurement, say, 1.6 – a value much closer to the actual value of ϕ than 1.310 [2].

Why did so many scientists and educators believe this myth then? Well, as covered in this article before, the way humans survive and interpret the world is through seeking out patterns. Sometimes we do this subconsciously against our better judgement, which leads to flawed speculations such as the fantasy of the golden ratio being all around us; however, another great thing about humanity is our insatiable curiosity, which helps us not only create these myths but debunk them just as well.

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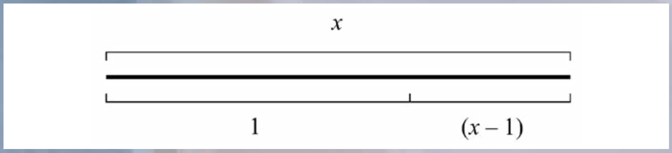
1 The golden angle: Imagine that we want to divide a circle into two sectors in the golden ratio. After setting up a quadratic equation with the smaller and larger central angles as x degrees and (360 – x) degrees respectively, you will be able to get the golden angle x, which is approximately 137.5 degrees.

2 The Smithsonian Institution: A large museum, education and research complex in Washington, D.C. in the US.

MYTHBUSTERS : The Golden

我們居住的世界浩瀚無垠 — 遼闊的陸地和海洋，亦只是宇宙的一小部分。透過嘗試理解我們所身處的世界，對人類而言是一種在未知中的慰藉。我們透過從事物中找出規律來認識世界，黃金比例就是其中一個例子。

在數學上，黃金比例以希臘字母 φ 表示。它是一個無理數，與 π 一樣有著無限個小數位，並且不能被表達成兩個整數之比。在歷史長河中，黃金比例這個無理數吸引了世界上不少數學家、生物學家、藝術家和建築師的目光 [1]。你或許現在就想知道黃金比例究竟是甚麼，以及它為何如此獨特；在搞清楚這一切之前，讓我們先設 x 為一線段的長度，然後把這線段一分為二，當中一段比另一段長。如圖一所示，設較長一段的長度為 1，而餘下部分為 $x - 1$。



圖一 *把長度為 x 的線段分成兩部分*

那麼，如果 x 與較長一段之比和較長一段與較短一段之比相同，前者之比需為甚麼？

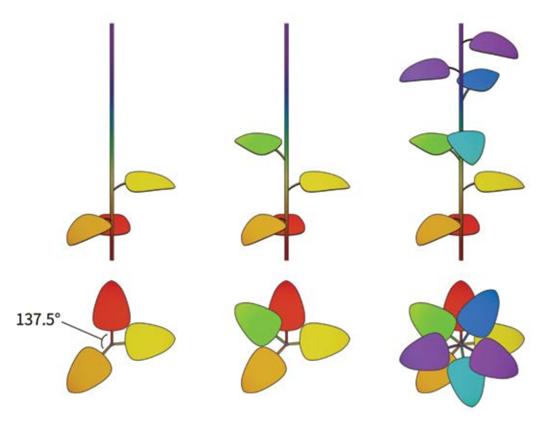
$$\frac{x}{1} = \frac{1}{x-1}$$

要找出這個「神聖比例」x 的值，我們可以藉上述關係推導出一條二元方程。

$$x^2 - x - 1 = 0$$

透過解方程並捨去負數解後，我們可以得出 x 等於 $\frac{1+\sqrt{5}}{2}$，大約是 1.618 – 這就是黃金比例的值。你可能聽過另一個與黃金比例相關的著名數學概念 – 斐波那契數（Fibonacci numbers (F_n)），數列中的每個數均為其前兩者之和：0, 1, 1, 2, 3, 5……聰明的你也許已經察覺到，每個斐波那契數與數列中前一個數之比的極限（limit）正是黃金比例 φ。換言之，隨著數列中的數字越來越大，前後兩者之比會越接近 φ。

人們經常把 φ 與美學扯上關係，稱之為「比例之美」[2]。φ 出現在大自然的不同領域中，還據說在過去數千年啟發了不少藝術家和建築師。譬如說某些植物的葉序（葉片圍繞莖部生長的排列形態）與黃金分割相關，在相鄰葉片或葉片對之間的角度可以呈 90 度（稱為十字或交互形態）或 180 度（二列形態）的同時，螺旋葉序也是在植物中非常普遍的，當中相鄰葉片或葉片對的角度是與黃金角度接近的 137.5 度（註一；圖二）[3]。不難想像我們在大自然中一次又一次地與這個比例的相遇，大概已經勾起古希臘人和我們對它的興趣和敬畏之情，這從巴特農神殿的建築融合了黃金比例和達文西的〈最後的晚餐〉中就能看到端倪 [1]。黃金比例接二連三出地現在不同作品中，使人不禁問道：在人類追求美感的探索中，黃金比例真的是構成美的其中一個的因素嗎？



圖二 *螺旋葉序（低至高的葉片依次以紅至紫的「假色（pseudo color）」表示。）*

令人意外的是，這也許只是我們一廂情願，是過分猜想令我們認為它在大自然中無所不在。人類腦袋天生喜愛尋找規律，喜愛得即使沒有實質證據支持也寧願相信 φ 出現不同情境中 [1]。關於這個誤會最具說服力的例子是鸚鵡螺外殼的外觀。

鸚鵡螺是一種海洋生物，與魷魚和八爪魚都屬於頭足綱的動物。與其他頭足綱動物不同，鸚鵡螺居住在分成多個腔室的漂亮螺旋外殼中。牠們外殼的螺旋曲線被稱為對數螺線或成長螺線，就是如圖三所示不斷從最內層曲線向外成長的螺旋。

鸚鵡螺外殼對數螺線的長闊比被認為與黃金比例相符，因此亦被公認是自然界中出現 φ 的著名例子。人們之所以會有這個根深蒂固的概念，要多得包括 Dan Brown 的《達文西密碼》等文學作品及史密森尼學會（The Smithsonian Institution；註二）等學術機構和其他知名科學家錯誤地宣揚這件「事實」[2]。

然而，如果你有機會親身檢視鸚鵡螺外殼，你會發現它的長闊比與其說是接近 φ (1.618)，其實更接近 4:3 (1.333)。如果再一次認真思考「每個鸚鵡螺外殼都符合黃

金比例」這個流言的話，你不覺得世間上所有鸚鵡螺外殼都擁有一模一樣比例的想法有點奇怪嗎？相反，如果每個樣本之間都有著些微差異，即使是小數點後數個位也好，這不是會更為合理嗎？

這正是一位名叫 Christopher Bartlett 的研究員所抱持的想法，他甚至推測 4:3 也不能準確地描述大多數鸚鵡螺外殼的比例。在檢查史密森尼學會館藏的 80 個外殼後，他最終發現平均比例是 1.310。另外，全部外殼的比例都有著些微差異，因此所有外殼均擁有 1.6 之類相同比例的說法顯然是錯的，而 1.310 本身也比 1.6 離 φ 的準確值更遠 [2]。

那為甚麼有這麼多科學家和教育工作者相信這個流言呢？嗯，像前面提到的一樣，人類的生存之道以及對自然萬物之理的詮釋一向有賴觀察規律，有時潛意識對尋找規律的固執會勝過我們的理性判斷，以致出現黃金比例無處不在等的美麗錯覺；然而，人性的另一個優點是我們有著無窮的好奇心，使我們不但能創造流言，亦能破解流言。

圖三 *鸚鵡螺的對數螺線*

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[1] 黃金角度：假設我們要把一個圓形以黃金比例分成兩個扇形，在設大小扇形的圓心角分別為 x 和 $(360-x)$ 度後，便可以設一道二元方程。解方程後會得出黃金角度 x 約為 137.5 度。

[2] 史密森尼學會：集博物館、教育及研究機構於一身，位處美國華盛頓特區的大型綜合學術組織。

The Science of
From
茄汁的科學：從物理

Ketchup can be a struggle to work with. You may have seen the following when a ketchup bottle is taken out of the fridge. Try and fail to tip the ketchup out. Smack the bottle hard, many times, and wait even longer, and suddenly all the ketchup splashes out at once and you end up with much more than you need. Ketchup is a very versatile condiment – it goes well with all kinds of food – so everyone who uses it may have similar experience repeatedly. But why does this keep happening? And why does it happen with ketchup specifically?

Ketchup as a Fluid with Variable Viscosity

When we want the ketchup to be runny, it comes out of the fridge frozen and cold and decidedly not runny. At this point it may be described in physics terms as viscous, or difficult to flow [1]. Rather than waiting for it to thaw, most people will hit the bottom of the ketchup bottle sharply. Based on Newton's Law of viscosity, a fluid flows at a speed in proportion to the force applied. However, ketchup has the property of thixotropy [2]. It means that the extent to which ketchup becomes less viscous, or runnier, is disproportional to the applied force. Therefore, ketchup is also referred to as a non-Newtonian fluid [3].

Why is ketchup like this? In viscous fluids, molecules are unable to move freely, due to the attractive forces between them or because larger molecules act as physical barriers [1]. In the case of ketchup, 95% of which is made of small molecules like water, vinegar (ethanoic acid) and salts [2], but ketchup is thixotropic because of the precise nature of that other 5%.

Ketchup contains several types of large sugar molecules (polysaccharides) which make up the remaining 5% of its content [1]. The most important is pectin, which is present in tomatoes (and most other fruits and vegetables) as a "sticky" polysaccharide that helps to bind the cell walls together [1]. When breaking up the skins and other tomato solids during the process of making ketchup, pectin is released to the pulp [3]. Pectin and other fiber molecules then form a matrix of large molecules held together by electrical charges between them [1]. This also means that small polar molecules, including water, can't travel as easily as before because of their intermolecular attractions to the matrix [1]. And when it's difficult for them to flow, ketchup becomes viscous.

You may see a layer of water appear when ketchup is left alone for long periods. Excess water can eventually separate out of this molecular matrix on its own; this is known as leaching [1]. What you need to do is to shake to homogenize it – to redistribute the molecules of the ketchup. But remember, the fluid is a non-Newtonian one. When you shake it or smack the bottom of the bottle, the force applied will break the molecular interactions holding this matrix together and allow the water in the fluid to flow more quickly, at a speed out of proportion to the force applied!

The Secret Behind Its Long Shelf Life

These properties are direct consequences of ketchup's historical development after the introduction of tomato to the recipe. Let's explore the secret behind the long shelf life of ketchup. From its origins as a fermented fish sauce in China and Southeast Asia (where the Hokkien Chinese word kê-tsiap gave the sauce its name [4]), and after tomatoes became the latest in a long line of ingredients used in its production, ketchup was well-known for its stability of up to a year [4, 5]. A common technique for extending its shelf life was to add acid to inhibit microbial growth, so the early ketchups without tomato were also sour [5]. Entering the era of tomato ketchup, chemical preservatives were once added to the early commercial formulas to preserve the products [4]. However, by the late 19th century several manufacturers and scientists became convinced that the widely used preservative sodium

Ketchup:
Physics to Microbiology
到微生物學

By Peace Foo 胡適之

benzoate was unsafe [4]. This motivated Henry Heinz and his company to search for a preservative-free ketchup [5, 6].

As other food scientists discovered [5], the key lay in the ripeness of the tomatoes used and the addition of more solutes. Ripe tomatoes contain more pectin and pectic acid, which are created by enzymatic reactions during the ripening process. Not only did the higher pectin content thicken the ketchup, the technique that Heinz adopted also called for the addition of more salt, sugar and vinegar [5], which did several things. The pectic acid and vinegar made ketchup more acidic. The addition of solutes like salt and sugar reduced the ability of water molecules to move, not just within ketchup, but also into microorganisms for the biological reactions necessary to support their growth [7]. Both effects inhibit microbial growth synergistically and prevent spoiling without resorting to preservatives. As a bonus, the riper tomatoes and added vinegar and sugar made ketchup both sweeter and sourer [8], giving it its distinct and much-loved flavor.

It turns out additional tricks can be applied to the bottle for holding the ketchup, in order to facilitate a "smooth pour" [9]. But that will be the topic of another story.

茄汁是一種不太友善的醬汁。以下是你把茄汁從雪櫃取出後發生的連環不幸事件：你嘗試倒出茄汁但不果，然後多次猛力拍打瓶底，但茄汁依然無動於衷，只好苦等一會後再來一次 — 啊 —！這次茄汁一下子從瓶裡射出，而你根本用不著那麼多茄汁。茄汁是用途廣泛的調味料，適合配搭不同食物，因此以上情境也許是茄汁愛好者習以為常的經驗。但為甚麼這樣的事情會一再發生呢？為甚麼只有茄汁會出現以上的情況？

作為有可變黏度流體的茄汁

我們想茄汁容易流動，但從雪櫃取出的茄汁卻是冰冷的，決不是容易流動的。這時在物理學上它可以被形容為黏滯（viscous），即不易流動 [1]。與其待它解凍，大多數人會選擇用力敲打茄汁瓶的底部。根據牛頓黏滯定律，流體的流動速度應與施加的力成正比，但茄汁有觸變性（thixotropy）的特點 [2]，意思是茄汁變稀或變得容易流動的程度與施力是不成比例的，故此茄汁又被稱為非牛頓流體 [3]。

為甚麼茄汁會有這樣的特性？由於分子間的吸引力或有大型分子充當物理障礙阻礙分子流動 [1]，黏滯流體裡的分子不能自由流動。至於茄汁，它 95% 的成分是由水和醋（乙酸）等等的小分子及鹽組成 [2]，但其觸變性正是由另外 5% 的成分所賦予的。

茄汁另外 5% 的成分是多種大型糖分子（多糖）[1]，當中影響力最大的是果膠，它是番茄（及其他很多蔬果和植物）裡具黏性的多糖，作用是把相鄰的細胞壁連接起來 [1]。製作茄汁時把番茄皮和果肉攪碎會把果膠釋放至番茄漿內 [3]，果膠和其他纖維分子會構成大型分子網絡結構，當中靠分子的電荷把分子網絡拉住 [1]。這亦意味著包括水在內的小極性分子並不能再自由流動，因為它們會被分子間作用力拉向網絡 [1]；當它們不能自由流動時，茄汁就會變得黏滯。

你可能見過茄汁在放置一段長時間後表面會浮現一層水；事實上，過多的水份最終可以離開分子網絡，這過程稱為瀝取（leaching）[1]。此時你需要搖勻茄汁，使分子再一次均勻分配而達至均勻化（homogenized）。但記著，茄汁是非牛頓流體，當你搖動茄汁瓶或猛敲瓶底時，施加的力會破壞維持分子網絡的分子間引力，令茄汁中的水份以與所施的力不相稱的速度飛快濺出！

茄汁的防腐之謎

茄汁有以上特性都是歷史上把番茄引入「茄汁」配方後的結果，現在讓我們探究一下茄汁保鮮的秘密吧。膎汁原是發祥於中國及東南亞的一種魚露，名稱來自福建話（註一）[4]，配方輾轉被改頭換面並加入番茄後才變成今天的茄汁，不過無論是最初的魚露還是現在的茄汁，都是以長達一年的保質期聞名 [4, 5]。其中一個延長保質期的常用方法是加入酸性物質來抑制微生物生長，因此早期的膎汁即使沒有番茄，味道也是酸的 [5]。進入以番茄製作茄汁的年代後，人們曾經加入化學防腐劑到早期的商業配方裡以延長保質期 [4]，但在 19 世紀後期一些生產商和科學家開始相信被廣泛使用的防腐劑苯甲酸鈉（sodium benzoate）並不安全 [4]，這驅使 Henry Heinz 及他旗下的公司尋找方法製造不含防腐劑的茄汁 [5, 6]。

食品科學家發現決定性的因素在於番茄的成熟程度和加入溶質的量 [5]。成熟的番茄含有更多果膠和果膠酸，那是在成熟過程中透過酶促使的反應所產生的。不單是高果膠含量使茄汁變得更濃稠，Heinz 所用的方法還需要加入更多的鹽、糖和醋 [5]，它們均有不同作用：果膠酸和醋能增加茄汁酸性；而加入鹽、糖之類的溶質有助降低水分子移動的能力，不僅是在茄汁內，還減少進入微生物體內的水分子，這有助切斷供其生長反應所需的水份來源 [7]。這些改動都能在不加入防腐劑下抑制微生物生長，以免茄汁變壞。使用更成熟的番茄及加入醋和糖同亦能錦上添花，使茄汁變得更甜更酸 [8]，塑造出茄汁獨特和更受人喜愛的酸甜味。

最後，人們還發現原來對茄汁瓶的設計做一些改動就能使我們每次都能輕易地倒出茄汁 [9]。不過這又是另一個故事了……

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1 膎汁：「膎」的粵音為haai4（讀：鞋）[10]，解作「以鹽醃製的魚蝦、肉類」[11]。

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INVADE AND ADAPT

GENOME EVOLUTION VIA TRANSPOSABLE ELEMENTS

融為一體的不速之客

轉位子與基因組演化

By Kit Kan 簡迎曦

In Issue 018, we introduced you to the concept of transposable elements and its discoverer, Barbara McClintock. Maybe you find it crazy that our DNA can jump around the genome, creating new insertions. Still, there are many more fascinating things about these elements. This article will take you through some of the most intriguing things about transposable elements and what they do other than jumping around.

Classification and Origin

Transposable elements (TEs) can be classified into two types based on their mechanism of insertion. Class 1 TEs are called retrotransposons. These elements jump around the genome by a copy-and-paste mechanism. The retrotransposons are first transcribed into an RNA intermediate, then reverse transcribed into DNA. This process creates a DNA segment identical to the original retrotransposon. The DNA copy is then integrated into the genome to create a new insertion. Class 2 TEs are DNA transposons that can be cut and pasted without amplification. A DNA transposon is excised from the original position and re-integrated into another part of the genome with the help of an enzyme called transposase. All TEs together make up around 50% of the human genome [1], although, throughout evolutionary, most have lost their ability to jump around.

If you are familiar with the mechanism of viral infection, you may see some resemblance between these mechanisms. Indeed, retrotransposons and a particular type of virus, retrovirus, share many similarities, such as the ability to insert their DNA, synthesized from reverse transcription, into the host genome. In fact, endogenous retrovirus (ERV; not retrovirus but viral DNA in our genome) are a type of retrotransposon, which are the remnants of viral germ-line infections millions of years ago. The viral genome was integrated into our ancestors' genome and passed on to future generations. ERVs make up around 7-8% of the human genome [2]. In short, we are part human and part virus. (Note that not all retrotransposons can be directly traced to a viral origin.)

Regulation and Adaptation

While having viral DNA in our genome and DNA jumping around surely stun most people, these features could also be dangerous. If the host does not develop a mechanism to suppress transposition and transcription of viral DNA, it risks mutation and re-infection. Insertion of TEs into functional sequences in the genome or expression of viral proteins may cause harmful effects to the host. Luckily, our body has multiple repression mechanisms against TEs to keep us safe. The expression of genes depends greatly on the accessibility of the DNA. If a segment of DNA is open, machineries required for transcription, such as RNA polymerase, can bind to that segment and activate transcription to express the gene. However, when the DNA is condensed, those machineries cannot bind and that region of DNA is repressed (footnote 1). Epigenetic modifications are some of the ways in which TEs are repressed through altering DNA accessibility [1]. When these mechanisms are faulty, diseases may arise. Dysregulated TEs has been shown to cause neuronal death [3], hemophilia [4] and cancer.

Since most TEs are repressed and thought to be harmful to the host, for a very long time, they were called "junk DNA", as they appear to be non-functional and solely parasitic. However, in recent years, some TEs are found to be adapted into the host genome to perform certain functions. Some TEs serve as binding sites for transcription factors (TFs),

which are proteins that bind to specific regions of DNA to regulate the transcription of the gene nearby (footnote 2). A study on human and mouse cell lines revealed that, for the 26 TFs examined, around 20% of transcription factor binding sites are embedded in TEs [5]. The insertion of TEs into the genome may have provided a novel way for the cell to exert a finer control on gene expression.

From an unaccepted discovery to one of the most important concepts in modern genetics, transposable elements have revolutionized our understanding on genomes and evolution. We often see novel observable traits appear as the results of evolution as species adapting to the external environment, but transposable elements taught us that the evolution of genomes is also in action deep inside the cell.

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1 Editor's remark: Let us go beyond the curriculum for a while – phenotype is not only determined by genetic sequence or allele. This is a field in biology called "epigenetics", which is defined as the study of phenotypical changes without alternations in the DNA sequence.

2 Transcription factor: DNA-binding proteins, which bind to specific DNA sequences to either facilitate or repress transcription. For example, you will learn in undergraduate courses that, in eukaryotes, a class of TFs called general transcription factors (GTFs) is required to initiate transcription by helping RNA polymerases locate the start site. It sits on the DNA before RNA polymerase comes. TFs can also control where and when a gene is turned on.

在第十八期，我們向大家介紹過轉位子（transposable elements）的概念及其發現者 Barbara McClintock。也許你會認為 DNA 能在基因組內跳來跳去，並插入其他位置是一件很瘋狂的事。然而，轉位子還有更多奇特的地方。本文將告訴你一些有關轉位子最有趣的事情，以及它們除了跳躍外的實質功用。

分類及起源

轉位子可根據其插入機制分為兩種類型。I 型轉位子又名反轉錄轉位子（retrotransposons），它們通過「複製後貼上（copy-and-paste）」的機制在基因組內跳來跳去。這些反轉錄轉位子首先會被轉錄成 RNA，然後反轉錄成 DNA。過程中複製出一段與原來反轉錄轉位子相同的 DNA，新合成的 DNA 複本會插入基因組中。II 型轉位子則通過「剪下後貼上（cut-and-paste）」的機制把自己重新插入至基因組。II 型轉位子會從原來位置被切出，在轉位酶（transposase）協助下重新插入基因組另一個位置。所有轉位子加起來佔人類基因組約 50% [1]，儘管在演化過程中大多數轉位子都已經失去跳躍能力。

如果你熟悉病毒感染的機制，你可能會發現它們頗為相似。的確，反轉錄轉位子和反轉錄病毒有著許多相似之處，例如它們能將由反轉錄合成而來的 DNA 插入宿主基因組。事實上，內源性反轉錄病毒（endogenous retrovirus (ERV)；它不是一種反轉錄病毒，而是我們基因組中的病毒 DNA）是其中一種反轉錄轉位子，它是數百萬年前病毒多次感染生殖細胞後遺留下來的 DNA。病毒基因組就此進入了我們祖先的基因組內，並遺傳至後世。內源性反轉錄病毒約佔人類基因組的 7-8% [2]。總而言之，人類的基因組中充斥著病毒的 DNA。（但請注意，並不是所有反轉錄轉位子都證實來自病毒。）

調控及適應

人類基因組中存在病毒基因和 DNA 能跳來跳去這兩個事實大概會使不少人感到震驚，而這樣也可能會為我們帶來危險。如果宿主沒有發展出抑制病毒 DNA 轉位和轉錄的機制，宿主就有發生基因突變和再次感染的風險。轉位子貿然插入基因組內已知有用的序列，或病毒蛋白得以表達都可能對宿主有害。可幸的是，我們身體有多種抑制轉位子的機制，以確保我們的安全。基因表達很大程度上取決於 DNA 的開放程度（accessibility），如果一段 DNA 的是開放的，

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轉錄所需的工具，例如 RNA 聚合酶，便可以與該段 DNA 結合並開始轉錄以表達基因。可是當 DNA 凝縮時，這些工具就不能結合到 DNA 上，該處 DNA 的表達便會受到抑制（註一）。表觀遺傳修飾（epigenetic modifications）是其中一個抑制轉位子的途徑，原理是改變 DNA 的開放程度 [1]。這些機制出現故障時可能會引發疾病，轉位子失調被證實會導致神經元死亡 [3]、血友病 [4] 和癌症。

由於大多數轉位子都被抑制和被認為對宿主有害，在以往一段很長的時間裡，它們被稱為「垃圾 DNA」，因為它們似乎只是寄生在基因組而沒有任何功能。然而，近年一些轉位子被發現已適應並融入了宿主基因組，並執行著一些有用的功能。一些轉位子成為了轉錄因子（transcription factor）與 DNA 的結合位置，從而影響附近基因轉錄的效率（註二）。一項針對人類和小鼠細胞的研究發現，對於所檢視的 26 個轉錄因子，大約 20% 轉錄因子的結合位置都位於轉位子中 [5]，轉位子進入基因組因此可能為細胞提供了前所未見的新方法來更細緻地控制基因表達。

從一個未被接受的發現到現代遺傳學中最重要的概念之一，轉位子徹底改變了我們對基因組和演化的理解。隨著物種適應外在環境，我們經常觀察到它們發展出一些可見的新性狀（或特徵），但轉位子告訴我們，基因組其實也一直在細胞深處默默地演化。

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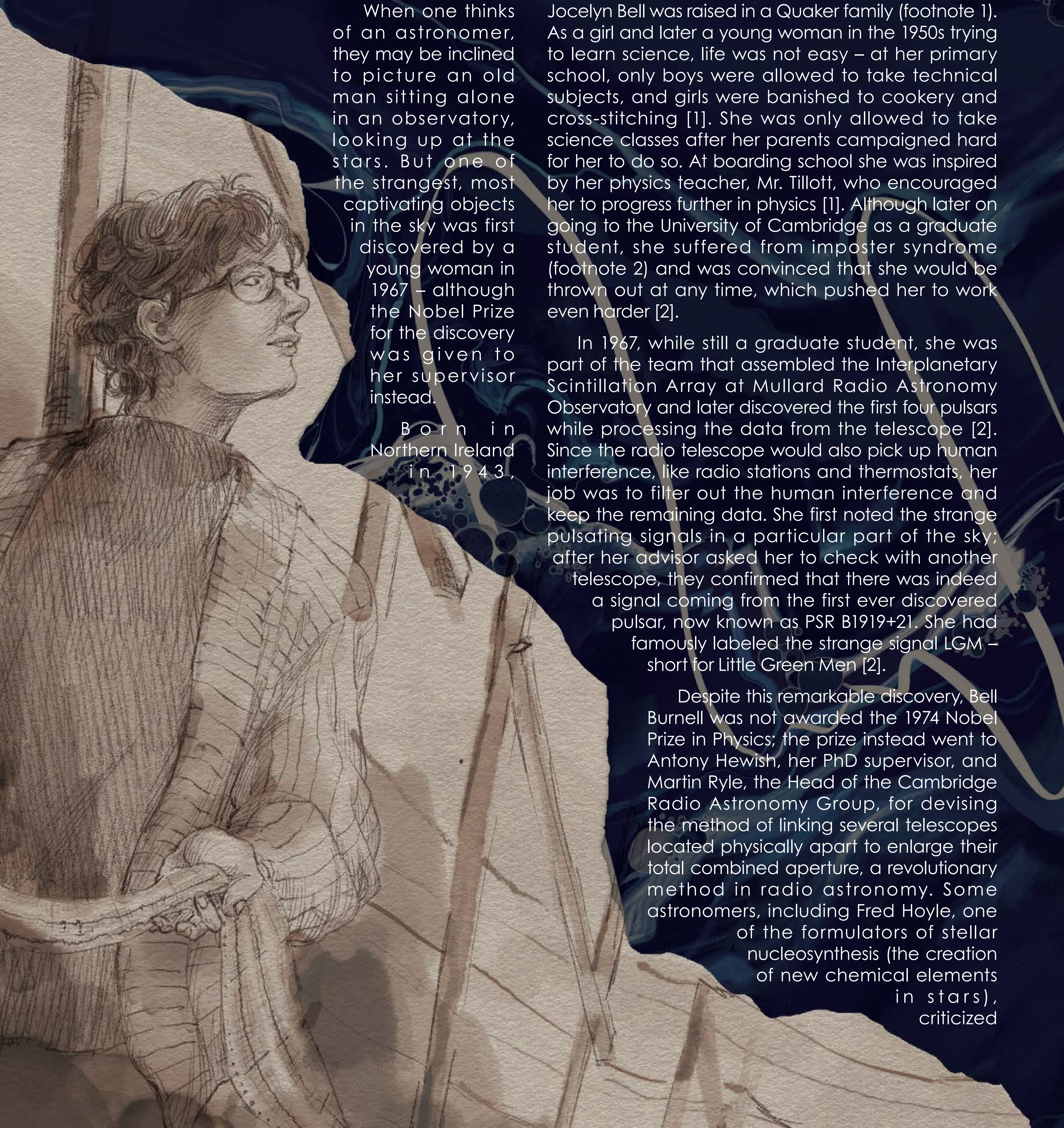
1 編按：介紹一下文憑試課程外的知識：表現型並不只是由基因序列或等位基因決定。這是生物學中的一個稱為「表觀遺傳學（epigenetics）」的領域，研究表現型如何在不改變 DNA 序列下被改變。

2 轉錄因子：它是一種與 DNA 結合的蛋白質，能與特定 DNA 序列結合以促進或抑制轉錄。例如，你將在大學本科課程中學到，真核生物需要通用轉錄因子（general transcription factors/GTFs）幫助 RNA 聚合酶找出轉錄的起點，才能開始轉錄。它需要先與 DNA 結合，然後 RNA 聚合酶才能到達。轉錄因子還能控制基因表達的位置和時機。

超越一切殊榮：
Transcending the Prizes:

JOCELYN BELL BURNELL

By Sonia Choy 蔡蒨珩

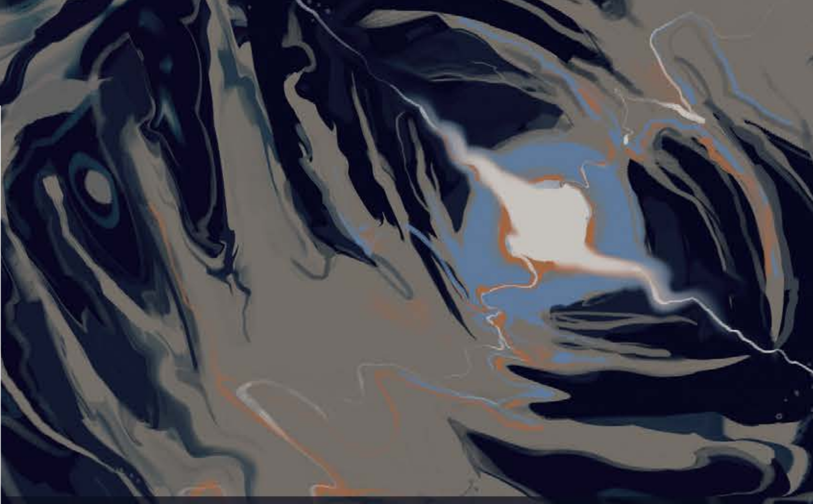


When one thinks of an astronomer, they may be inclined to picture an old man sitting alone in an observatory, looking up at the stars. But one of the strangest, most captivating objects in the sky was first discovered by a young woman in 1967 – although the Nobel Prize for the discovery was given to her supervisor instead.

Born in Northern Ireland in 1943, Jocelyn Bell was raised in a Quaker family (footnote 1). As a girl and later a young woman in the 1950s trying to learn science, life was not easy – at her primary school, only boys were allowed to take technical subjects, and girls were banished to cookery and cross-stitching [1]. She was only allowed to take science classes after her parents campaigned hard for her to do so. At boarding school she was inspired by her physics teacher, Mr. Tillott, who encouraged her to progress further in physics [1]. Although later on going to the University of Cambridge as a graduate student, she suffered from imposter syndrome (footnote 2) and was convinced that she would be thrown out at any time, which pushed her to work even harder [2].

In 1967, while still a graduate student, she was part of the team that assembled the Interplanetary Scintillation Array at Mullard Radio Astronomy Observatory and later discovered the first four pulsars while processing the data from the telescope [2]. Since the radio telescope would also pick up human interference, like radio stations and thermostats, her job was to filter out the human interference and keep the remaining data. She first noted the strange pulsating signals in a particular part of the sky; after her advisor asked her to check with another telescope, they confirmed that there was indeed a signal coming from the first ever discovered pulsar, now known as PSR B1919+21. She had famously labeled the strange signal LGM – short for Little Green Men [2].

Despite this remarkable discovery, Bell Burnell was not awarded the 1974 Nobel Prize in Physics; the prize instead went to Antony Hewish, her PhD supervisor, and Martin Ryle, the Head of the Cambridge Radio Astronomy Group, for devising the method of linking several telescopes located physically apart to enlarge their total combined aperture, a revolutionary method in radio astronomy. Some astronomers, including Fred Hoyle, one of the formulators of stellar nucleosynthesis (the creation of new chemical elements in stars), criticized



Pulsars are some of the most fascinating objects in the universe. We have since learned that they are rotating neutron stars, formed from the cores of massive stars after their collapse. Only 20 to 24 km in diameter [3], they contain around 1.4 to 2.16 times the mass of the Sun (the diameter of the Sun is around 1.4 million kilometers), and are the densest known stellar objects – any more mass, and the stellar core will collapse into a black hole instead [4].

To get a sense of how dense neutron stars are, imagine a small sugar cube that you may add into your morning coffee, weighting around two grams. However, cutting out the size of a sugar cube from a neutron star, it would weigh approximately one trillion kilograms – 5 x 10^{14} times of a normal sugar cube, and about the weight of Mount Everest [5].

Pulsars have very strong spinning magnetic fields, causing streams of charged particles (like electrons and protons) to shoot along the magnetic poles. When charged particles accelerate, radiation is emitted so these streams can produce powerful beams of light in a range of wavelengths from radio wave to gamma ray [3, 6]; as the neutron star and its magnetic field spin, the beam of light sweeps over Earth, creating the visual effect on paper that the star is blinking, or pulsating – hence its name.

this decision, and it has been a point of controversy ever since. Many more sensational articles even go as far as to portray Hewish, her advisor, as an unsympathetic figure, but he was in fact supportive of his student's work, and his development of the techniques and interpretation of the discovery also deserved to be recognized. Bell Burnell believed that a Nobel Prize should not be given to a graduate student (as she was at the time) unless in exceptional cases, but was upset by other media encounters. In a recent lecture, she described that reporters would ask Hewish about the astrophysics, and she would largely get personal questions, like how many boyfriends she had, and what color her hair was [7].

Jocelyn Bell became engaged to Martin Burnell, a local government officer, in 1968; her husband's job required him to move around the UK frequently, and so she had to move positions frequently and work part-time for 18 years, raising her son in the process. As a result, when one looks at her research output, it may not be as impressive (at first sight) when compared to her male colleagues of a similar age because of such family commitments. Nevertheless, she continued to work on astronomy for many years, studying mainly neutron stars and pulsars, and campaigned for the involvement of more women in astrophysics. Active in the scientific community, she was the first ever female president of both the Institute of Physics (2008-2010) and the Royal Society of Edinburgh (2014-2018).

Despite living in the 21st century, where there has been significant progress on many fronts of gender equality, Bell Burnell's story still highlights an interesting question. On the surface, opportunities may still be equally available to people of all genders, but many women are still held back from their work, often by choice, by traditional family roles, as they tend to take up the majority of family duties. Although many only know Bell Burnell for the discovery of pulsars and "missing out" on the Nobel Prize, this story also forces us to examine the deeper issues regarding gender equality beyond just accessibility, and one can only wonder what she could have done if she had worked full-time.

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1 Quakers: Members of the Religious Society of Friends, a historically Protestant Christian community.

2 Imposter syndrome: A feeling of inferiority among some high achievers, especially graduate students (master or PhD students), who attribute their achievements to luck instead of their competence and fear they will be found out as a fraud one day. There is a growing awareness in Western countries of this common psychological phenomenon which may lead to anxiety and depression among graduate students [8].

說起天文學家，浮現在人們腦海中的也許是一個孤獨的老人坐在觀測站裡，在黑夜中仰望繁星；但天上其中一種最奇怪、最引人入勝的星體卻是由一位年輕女性在1967年發現，然而她從未為此得到諾貝爾獎。

Jocelyn Bell 於 1943 年在北愛爾蘭出生，在信奉貴格會（Quaker）的家庭中長大（註一）。作為在上世紀五十年代生活的女孩，要學習科學一點也不容易。在她就讀的小學裡只有男生可以修讀理工科，而女孩子就只可以學習烹飪和縫紉 [1]，有幸在她父母極力爭取下，Bell 獲准上科學課。在讀寄宿學校時，她的啟蒙老師 Tillott 先生鼓勵 Bell 繼續進修物理 [1]。雖然後來成了劍橋大學的研究生，但冒名頂替症候群（imposter syndrome；註二）卻一直困擾著她：她深信自己隨時會被踢出校，這令她更加用功來嘗試證明自己 [2]。

1967 年，當時還是研究生的 Bell 是在馬拉德無線電天文台（Mullard Radio Astronomy Observatory）組裝行星際閃爍陣列（Interplanetary Scintillation Array）望遠鏡的一員，她在其後分析數據時首次發現了四顆脈衝星 [2]。由於無線電望遠鏡收集的數據包含了電台廣播和恆溫器等人類活動的干擾，因此她需要將人為干擾剔除，只留下來自外太空的電波信號。她注意到天空某個方向出現奇怪的脈衝信號，在論文導師要求下，她再用另一組望遠鏡核對數據，從而確定那是來自一顆脈衝星的信號，那顆星現在被命名為 PSR B1919+21。眾所周知當時 Bell 曾給這奇怪信號改了一個有趣的名字 — LGM，也就是 Little Green Men（小綠人，意指外星人）[2]。

雖然作出了如此重大的發現，可是 Bell Burnell 並沒有得到 1974 年的諾貝爾物理學獎；那年得獎者為她的博士論文指導老師 Antony Hewish 和劍橋無線電天文研究組主席 Martin Ryle，後者憑藉在無線電天文學上革命性的發明而獲獎。Ryle

脈衝星是宇宙中最有趣的星體之一。我們其後知道它們是轉動中的中子星，由重恆星核心塌縮而成。中子星以密度極高見稱，是我們認知內密度最高的星體：直徑只有20至24公里 [3]，重量卻是太陽的1.4到2.16倍（但太陽的直徑大約是140萬公里）。如果質量再多，恆星核心就會塌縮成黑洞而不是中子星 [4]。

中子星的密度實在高得難以想像。我們平時加進咖啡裡的一顆方糖大約是兩克，如果要從中子星切出與方糖大小相約的一部分，相應的重量就會接近一萬億（或一兆）公斤，即是一顆方糖的5x10^{14}倍，約是整個珠穆朗瑪峰的重量 [5]！

脈衝星有著非常強大的旋轉磁場，令一束束帶電粒子（譬如電子和質子）隨著磁極的方向射出。當帶電粒子加速，它們會散發輻射，因而產生波長範圍由無線電波到伽瑪射線的強大電磁波束 [3, 6]；這些電磁波會隨著中子星及其磁場的轉動而定時掃過地球，在圖表上製造出脈搏般的視覺效果，我們因此將其命名為脈衝星。

巧妙地設計出把坐落於不同地方的望遠鏡連結，從而增加望遠鏡總孔徑的方法。有些天文學家批評諾貝爾獎委員會的決定，包括提出恆星核合成（解釋恆星中創造新化學元素的理論）的 Fred Hoyle，這也引伸出各方多年的爭辯。不少報導為了吸引讀者，更將 Hewish 寫成一位冷酷無情的指導老師，但他其實也有支持學生的研究，而正是他研發的觀測技術和在分析結果時的見解促成了這次發現，所以也值得被表彰。Bell Burnell 自己則覺得在正常情況下諾貝爾獎不應該頒發給研究生（她當時的身份），但是令她更不開心的是媒體的訪問。在最近一次講座中，她憶述記者往往會將天體物理學的問題交予 Hewish 回答，而她只會被問及私人問題，譬如曾經結識多少個男朋友和頭髮原來的顏色是什麼等等 [7]。

Jocelyn Bell 在 1968 年與地方公務員 Martin Burnell 訂婚。丈夫的工作需要他們不時搬遷到英國不同城市居住，使 Bell Burnell 需要持續地轉職，當中更因照顧孩子而在 18 年間只能從事半職的研究工作。驟眼一看，她的研究成果未必及得上同期的男性同事，但當知道她的處境後便能對箇中原因略知一二。儘管如此，她仍繼續從事天文研究多年，研究不同中子星和脈衝星，也成為鼓勵更多女性投身天體物理學的領袖之一。Bell Burnell 一直活躍於科學界，更當選英國物理學會（2008-2010）和愛丁堡皇家學會（2014-2018）史上第一位女主席。

即使生活在 21 世紀，社會看似在促進男女平等的各方面已經進步了不少，Bell Burnell 的故事依然帶出一個值得深思的問題：驟眼看來，各種機會似乎的確是平等地開放給全部性別的人，但不少女性在工作上的發展依然受到掣肘，這往往是出於她們自己的決定，又或者是傳統家庭觀念對女性的期望，令不少職業女性仍然選擇扛起照顧家庭的大部分責任。雖然提起 Bell Burnell，大多數人只會想到脈衝星和她與諾貝爾獎擦身而過一事，但是這個故事也促使我們探討她後來的生活：男女平等並不應該只是門面上的開放。如果她能從事全職研究的話，又會發現什麼新事物嗎？嗯，我們永遠也不會知道。

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[1] 貴格會：又稱公誼會或教友派（Religious Society of Friends），歷史上是基督教新教的教派之一。

[2] 冒名頂替症候群：一種出現於部分高成就者（尤其是研究生，即碩士或博士生）的自卑感，他們會認為自己並沒有這樣的能力，過往只是因為幸運之類的因素而成功，生怕別人有一天會發現自己是騙子。近年西方學術界開始關注這個令不少研究生出現焦慮和抑鬱症狀的心理現象 [8]。

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地球上的「外星智慧生物」：
頭足類動物
The Amazing Cephalopods

By Sirius Lee 李揚

The Cephalopods

"Szechuan pepper. Salt. Chinese five spice. Grind. Seasoning into a bowl. Corn flour. Squid. Score. It helps to tenderize the squid. Cut. Tentacles halved and go straight into the seasoning. Now, we are ready to cook." While Mr. Gordon Ramsay was demonstrating how to prepare the delicious cuisine of crispy salt and pepper squid, did you know that cephalopods like squids have been favored by scientists not only as food, but as research objects?

"Cephalo-pod," literally means "head-foot" in Greek, and these animals are characterized by the presence of tentacles attached to their head. This class includes squids, octopuses, cuttlefishes and nautiluses. They are highly regarded, given titles such as "the smartest invertebrates" and "the alien intelligence," and have been useful for understanding advanced cognitive evolution.

Their complex behavior never ceases to amaze us in the field or in the laboratory. Observation suggests that octopuses can learn spatial cues from the surroundings to help with their navigation, gaining spatial memory that prevents them from repeatedly scrounging the same areas for resources [1]. Cuttlefish can exert self-control and delay their actions in favor of immediate gratification (footnote 1), displaying a sign of decision-making [2]. Squids react to threats in a rapid manner and escape with their highly propulsive jets [3]. On top of their abilities to go on a furious fight of pushing and biting among the males in pursuit of a mate, cuttlefishes can also deploy tactics where they sneak around and mate with the hiding female without other males noticing [1].

Aside from their impressive behavior, their sophisticated skin, with color, pattern and texture changing features, is certainly one of their most extraordinary abilities. For camouflage, they first need to observe the surroundings. After analyzing the visual information, the brain will fire neural signals to millions of color-changing cells to create the camouflage pattern. Octopuses and cuttlefishes can further enhance the mimicry by morphing their skin into the 3D texture of the background, such as a sandy seafloor [1]. It takes literally the blink of an eye, about 200 milliseconds, to change their appearance [1]. This fascinating property has enabled them to survive with brilliant camouflage, crawling around without being detected.

Commonly Used Model Organisms

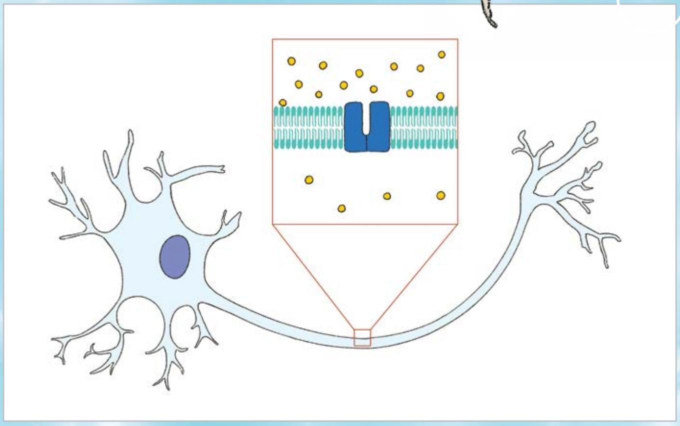
Our relationship with cephalopods is not limited to the appreciation of their external appearance and behavior. Groundbreaking discoveries have come from laboratory studies of their nervous system.

Led by Sir Alan Hodgkin, Sir Andrew Huxley and Sir Bernard Katz, squid were used in the early days of neuroscience as a system for experimenting with neuronal functions, including the nerve impulse. Certain squid neurons have remarkably long and thick (up to 1 mm in diameter) axons, the long projections that extend from neurons. These giant axons offer us a great flexibility for experiments, such as the insertion of electrodes for voltage and current measurement [4, 5]. Based on past observations that the intracellular sodium concentration inside the squid axon was lower than that of the sea water (external fluid), Hodgkin and Huxley conducted pivotal experiments and obtained results that suggest an influx of sodium ions during the transmission of electrical signals (footnote 2) [6]. This discovery

has had a profound impact on neuroscience, uncovering the fundamental basis of how information flows in the nerve, as well as kickstarting the study of the role of ion channels in the process [4, 5]. Further investigations were also conducted by administering channel blockers (inhibitors) to modify the impulse. Further investigations revealed the involvement of additional ions that contribute to signal transmission in axons. [7]. Without a shadow of a doubt, the sacrifice of cephalopods has an undeniable significance in our quest for knowledge, especially in our comprehension of the nervous system.

Marine Organisms Are More Than Seafood

In the history of scientific research, marine organisms have been extensively studied to elucidate biological phenomena and structural designs. Apart from cephalopods, sea urchins have been used to study developmental biology, revealing the roles of different proteins in cell cycle progression, while sea slugs gave us a glimpse into how memory works. If you have the chance to interact with these friends of ours, what would you do?



A diagram showing the difference in sodium ion (yellow) concentration across the membrane of an axon, the long projection that extends from a neuron, which is responsible for communication between neurons.

上圖展示軸突細胞膜兩側的鈉離子（黃）濃度差。軸突是神經元向外延展的細長結構，負責神經元之間的溝通。

頭足類動物

「花椒、鹽、五香粉。把調味料磨碎，放進碗裡。粟粉。魷魚切花，這有助嫩化肉質。切開。把觸鬚切成一半放進調味料裡。現在我們準備好烹調了。」在 Gordon Ramsay 示範如何烹調出一道令人垂涎的脆炸椒鹽鮮魷的同時，你有沒有想過魷魚等頭足類動物本身也是一個絕佳的實驗研究對象？

頭足類動物的英文「cephalopod」在希臘文上有著「頭足」（cephalo-pod）的意思，顧名思義，這類動物的特徵是觸手附在頭部。頭足綱的成員包括魷魚、章魚、墨魚和鸚鵡螺。牠們被受景仰，擁有「最聰明的無脊椎動物」及「外星智慧生物」等稱號，亦有助我們了解高階認知能力的進化。

牠們的複雜行為無論在野外還是實驗室內都總讓我們驚嘆不已。章魚可以從環境取得空間線索以協助辨認方向，避免重複地在同一區域搜尋資源 [1]。墨魚有自我約束能力，懂得克制自己的行動，面對眼前的誘惑亦能拒絕作出短視的決定（註一），展示出具決策能力的跡象 [2]。魷魚能迅速對威脅作出反應，噴出推進力強的水流敏捷地逃走 [3]。在爭奪配偶上，雄性墨魚有與競爭對手展開肉搏戰的能力，牠們會互相推撞和啃咬對方；不過善戰的墨魚有時還是會按照情況用上其他策略，例如趁其他雄性沒有留意的情況下，溜到躲在一旁的雌性身邊與其交配，智取而不力敵 [1]。

除了令人印象深刻的行為外，牠們複雜的皮膚擁有能改變顏色、圖案和質感的特性，

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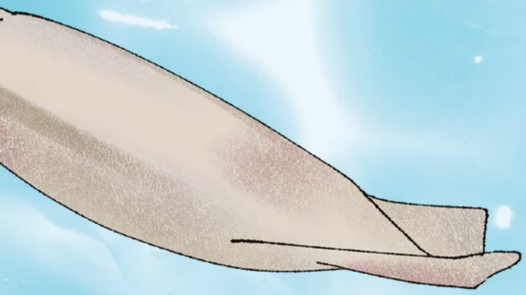
1 Delayed gratification: A subject studied extensively in psychology, defined as "the ability to either forgo immediate temptation or to persist in an undesirable activity, in order to reach a later goal [8]."

2 Editor's remark: If you are interested in how neurons fire a nerve impulse, you may search "action potential" on YouTube. The mechanism is covered in first-year biology and was once a topic in the abolished HKALE.



絕對亦是牠們其中一種非凡的能力。為了偽裝成周邊環境，牠們首先要觀察四周。在分析從視覺得來的資訊後，牠們會由大腦向身體上數百萬個變色細胞發放神經訊號，把身體「染上」保護色。章魚和墨魚更可以透過把皮膚的變形，變成跟背景一樣的立體質感來加強擬態（mimicry）的效果，例如模仿海底沙質的凹凸不平 [1]。牠們名符其實地能在「眨眼」間改變自己的外觀，過程只需 200 毫秒 [1]。這項教人讚嘆的特性使牠們能以高超的偽裝能力生存下來，到處遊走而不被察覺。

實驗中常用的模式生物

我們與頭足類動物有著更深厚的關係，並不止於單單欣賞牠們奇妙的外貌特性。很多突破性發現始於我們在實驗室裡對牠們神經系統進行的實驗。

在早期的神經學研究中，以 Alan Hodgkin 爵士、Andrew Huxley 爵士和 Bernard Katz 爵士為首的生物學家善用魷魚來研究神經元功能，包括神經脈衝。魷魚的一些神經元有著又長又厚的軸突（直徑可以長達一毫米），那是神經元向外延展的細長結構。這些巨大的軸突在實驗設計上為我們帶來很大的自由度，例如我們可以插入電極量度電壓和電流等 [4, 5]。過往研究指出魷魚軸突內的鈉濃度比海水（外部液體）低，Hodgkin 和 Huxley 因此設計了一些關鍵實驗並獲得數據表明電訊號傳遞時鈉離子會湧入細胞（註二） [6]。這個發現為神經科學界為來了深遠的影響，它揭示了信息在神經內傳遞的基礎，也推動了對離子通道在過程中扮演著什麼角色的相關研究 [4, 5]。進一步研究用到不同離子通道的阻斷劑（抑制劑）來改變神經脈衝。透過嘗試把一個個實驗觀察連結起來並作出解釋，科學家最終得知軸突內的神經傳遞過程亦涉及其他離子 [7]。毫無疑問，頭足類動物的犧牲在我們探求知識的道路上有著莫大的意義，尤其是加深了我們對神經系統的了解。

海洋生物並不只是美味的海鮮

在科學研究的歷史上，我們經常透過研究海洋生物來闡明一些生物現象和結構。在頭足綱以外，海膽也被用作研究發育生物學（developmental biology），揭示了不同蛋白質在細胞週期進展上的角色；而海蛞蝓讓我們初步認識到記憶是如何運作的。若果你有機會碰上我們這些好朋友，你又會怎樣對待牠們？

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1 延宕滿足（delay gratification）：它是在心理學中被廣泛研究的課題，定義為「克制眼前誘惑或持續令自己不快的活動，以達成未來目標的一種能力 [8]」。

2 編按：如果你對神經元如何產生神經脈衝感興趣，可以在 YouTube 搜索「動作電位（action potential）」。其運作原理被包涵在大學一年級的生物學課程中，也曾經是香港高級程度會考的課題。

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