



# 電腦與大腦

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林秀豪@NTHU



你能讀懂這些文字嗎？

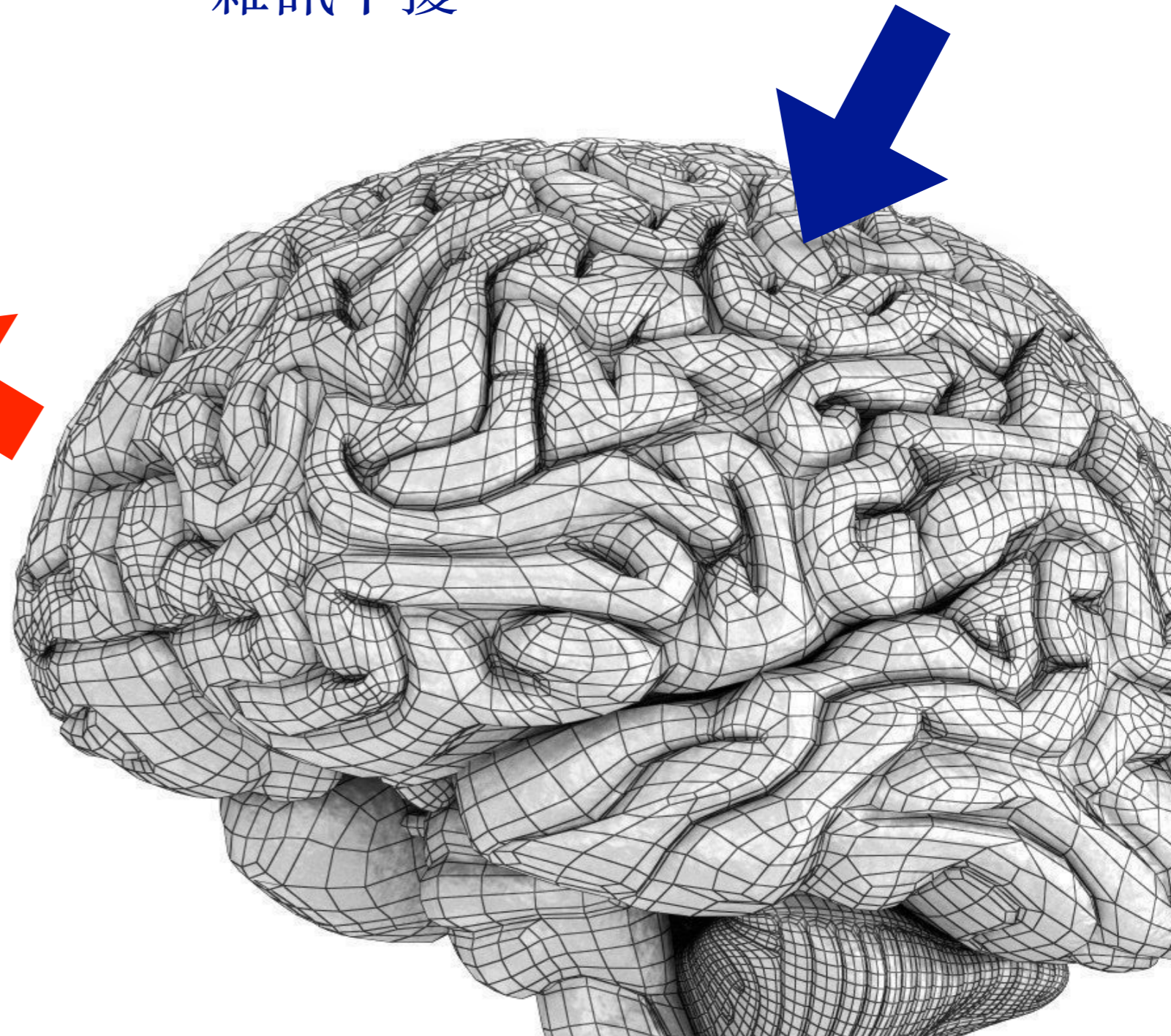
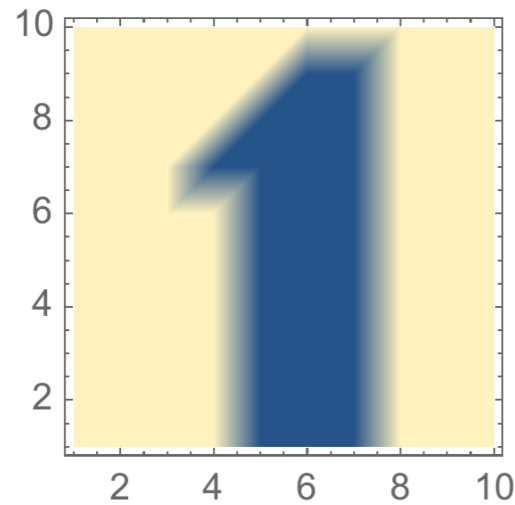
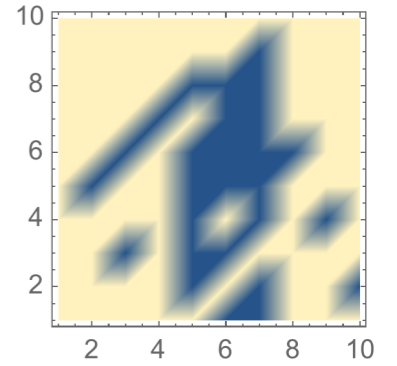
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I find it rea\*l\* amazin\* t\*at  
y\*u ar\* abl\* to re\*d t\*is te\*t.  
You\* brai\* i\* abl\* t\* fill in  
missi\*g info\*matio\*.

# 資訊動態重組！

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即便輸入的圖案受到  
雜訊干擾……



大腦還是可以藉由神經元連結，**動態組合**記憶中的資訊，呈現較為完整的圖案。

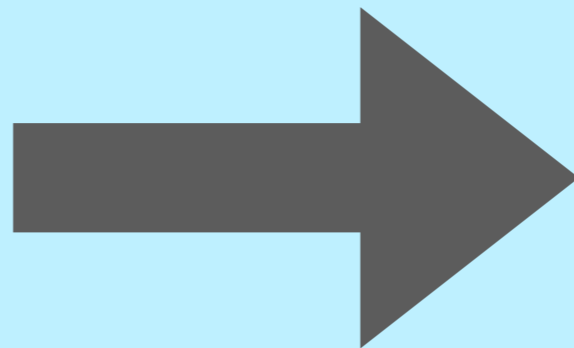
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# 自旋流 與 磁性記憶體

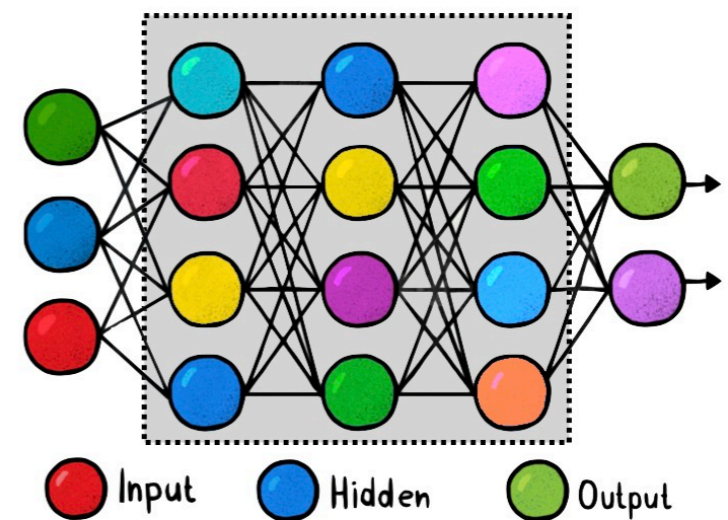
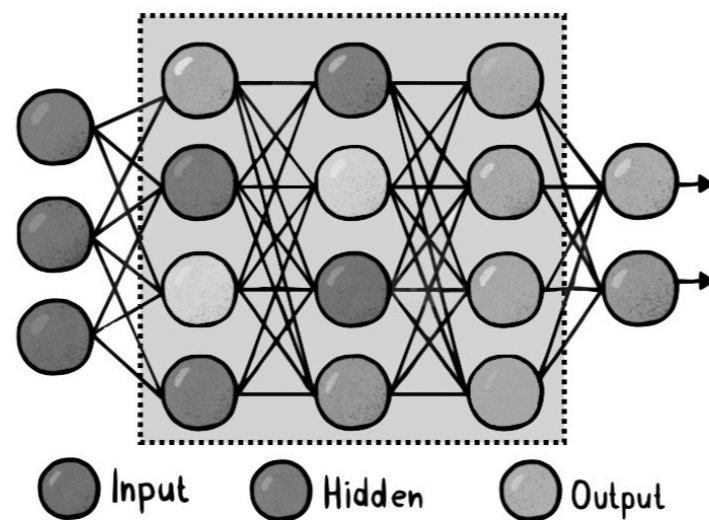
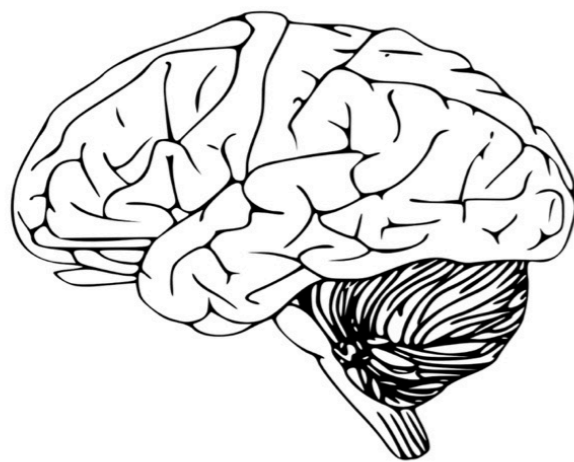
Should a scientist work on something *he is good at*?

Or, should a scientist work on something *he is excited about*?

2009



2019



# Wissenschaftler der NTHU versehen MRAM der nächsten Generation mit einem „Spin“

17  
APR  
2019

Twittern

0

Gefällt mir

0

Weiterempfehlen

HSINCHU, Taiwan

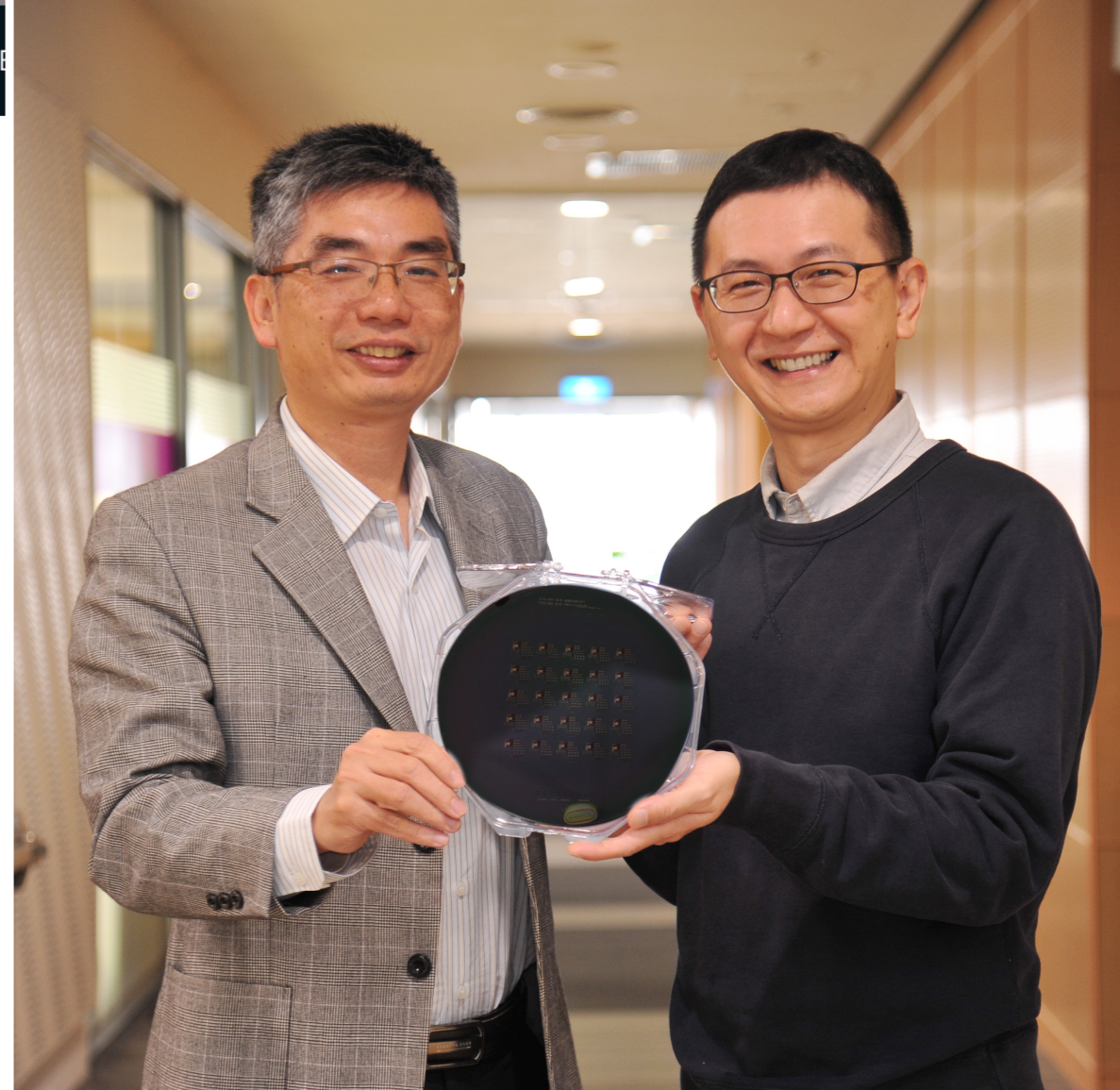
Der Speicher Magnetoresistive Random Access Memory (MRAM) wird künftig die Grundlage der digitalen Technologie der nächsten Generation bilden. Die effiziente und effektive Manipulation des MRAM stellt jedoch eine Herausforderung dar. Einem interdisziplinären Forschungsteam der National Tsing Hua University (NTHU) in Taiwan unter der Leitung von Prof. Chih-Huang Lai und Prof. Hsiu-Hau Lin gelang kürzlich ein revolutionärer Durchbruch. Mithilfe einer nur wenige Nanometer dicken Platinschicht wird *Spinstrom* erzeugt, um die gepinnten magnetischen Momente nach Belieben zu schalten - diese Aufgabe wurde bislang noch nie gelöst.

Diese Pressemitteilung enthält multimediale Inhalte. Die vollständige Mitteilung hier ansehen: <https://www.businesswire.com/news/home/20190417005058/de/>



Professor Lai Chih-huang (left) and Lin Hsiu-hau of NTHU using hand gestures to represent the 0-1 concept in digital memory. (Photo: National Tsing Hua University)

Angefangen bei Mobiltelefonen über Computer, tragbare Geräte, das Internet der Dinge bis hin zu intelligenten Stadtbetrieben ist die Verarbeitung und Speicherung von Daten äußerst wichtig. In Bezug auf ein schnelleres Lesen und Schreiben, einen geringeren Stromverbrauch und den Erhalt von Daten bei einem Stromausfall hebt sich der MRAM in einem starken Konkurrenzumfeld ab. Der jüngst in *Nature Materials* veröffentlichte Durchbruch von Lai und Lin beflügelt die MRAM-Technologie und findet in Industrie und Wissenschaft Beachtung.

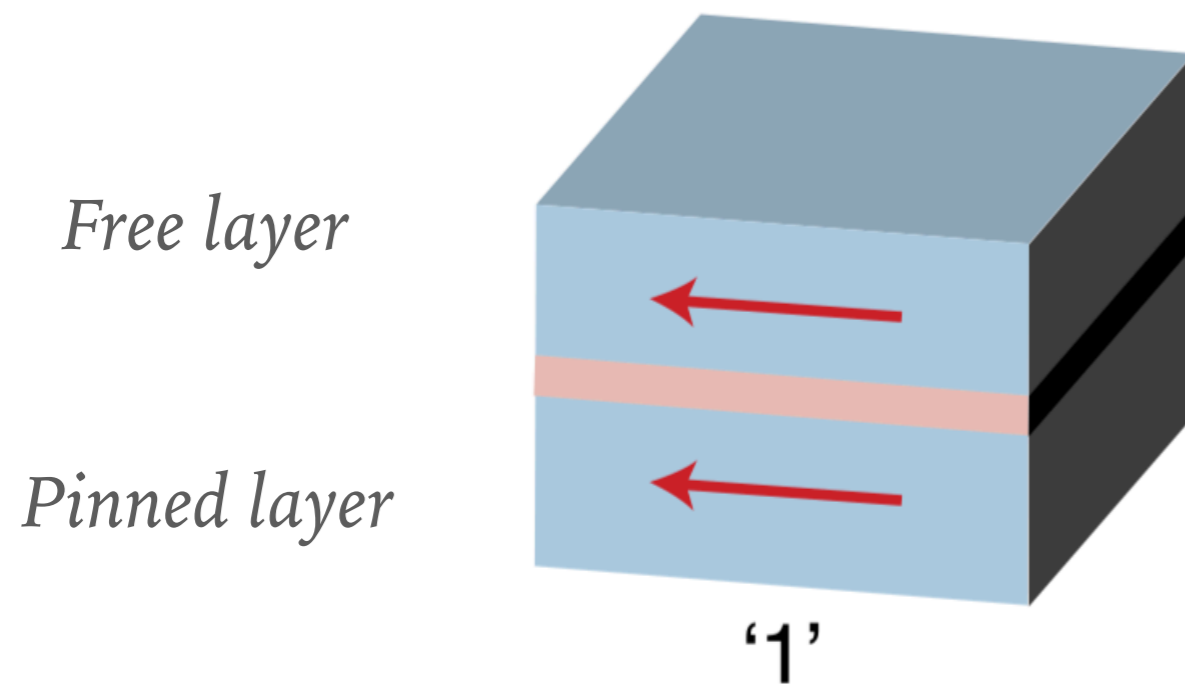


## 用自旋流操控 磁性記憶體

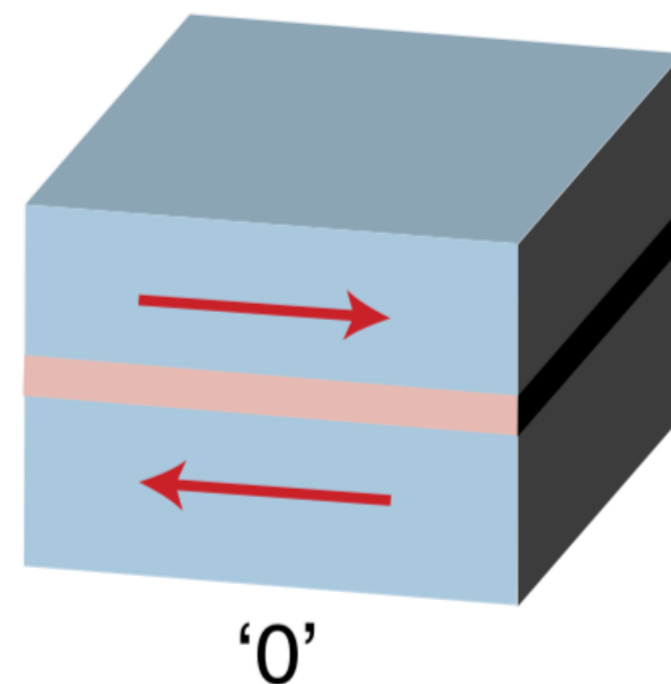
材料與物理跨領域  
合作，突破 MRAM  
過往60年技術瓶頸

# 磁性記憶體 (MRAM)

*Nature Physics 14, 220 (2018)*



磁矩方向**相同**時，電子容易穿過 — **低電阻態**

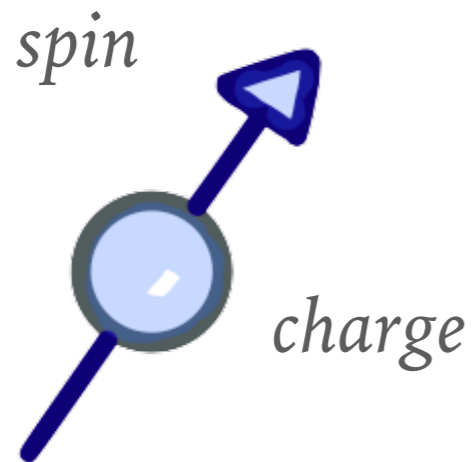


磁矩方向**相反**時，電子不易穿過 — **高電阻態**

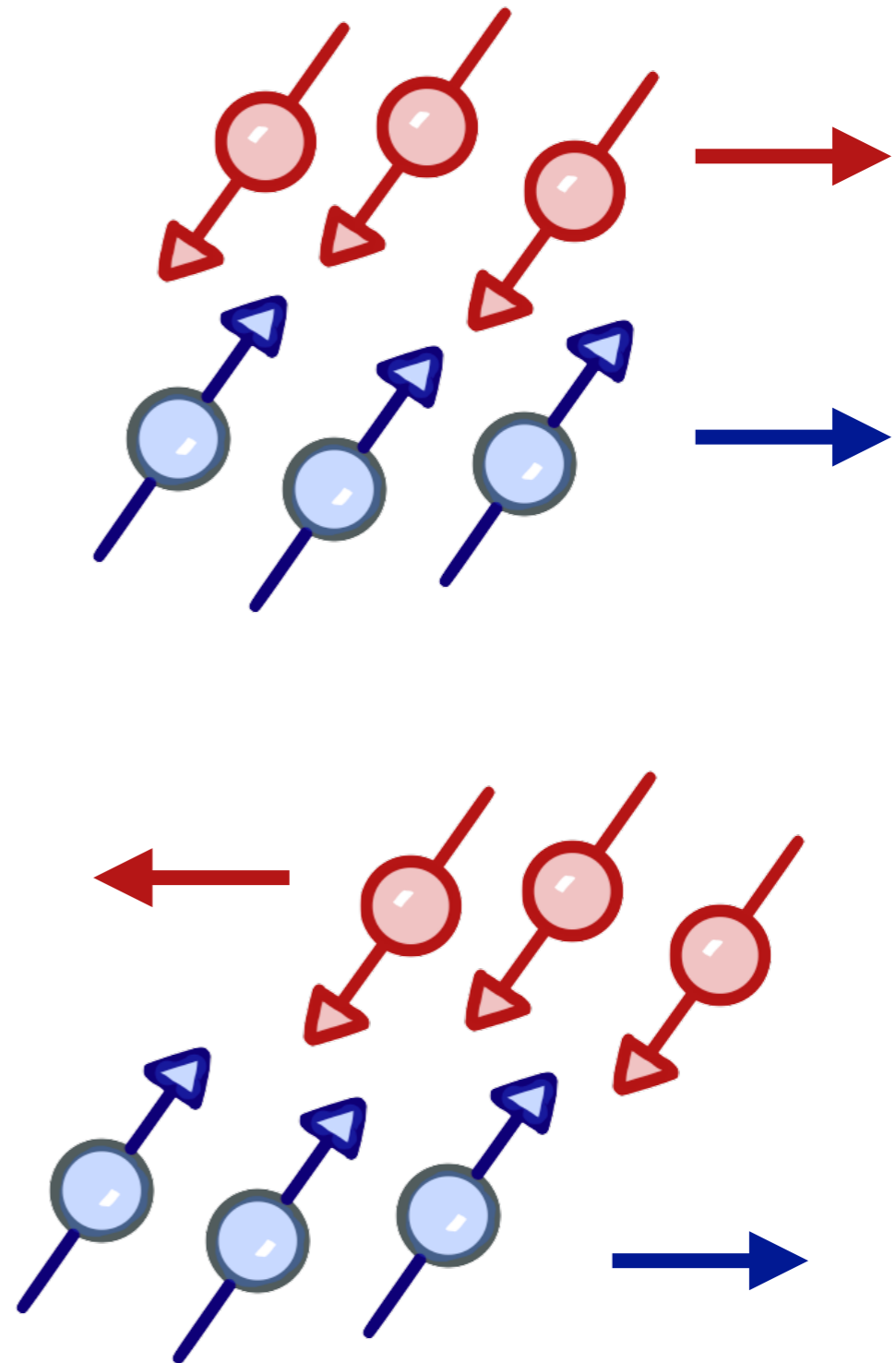
# 電流 V.S. 自旋流

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電子帶有電荷，移動就會產生**電流**。



由於相對論效應，電子也帶有自旋，那是否能創造出**自旋流**呢？

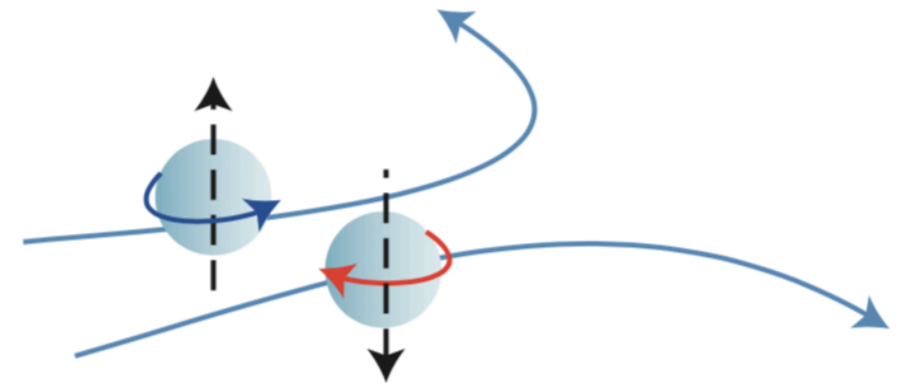


# 自旋-軌道 交互作用

*Nature Physics 10, 340 (2014)*

由於相對論性效應，電子在電場中運動會感受到「磁場」

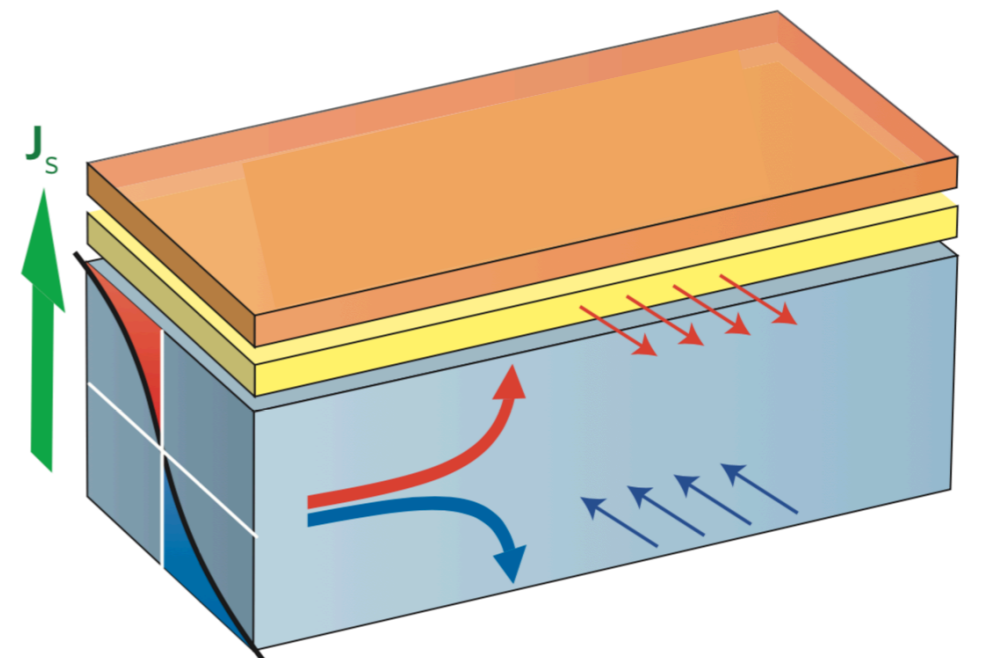
*spin-dependent scattering*



$$H_{\text{SO}} = g \left( \frac{\vec{v}}{c} \times \nabla V \right) \cdot \vec{S}$$

電子運動軌跡與自旋方向有關

電流通過**重金屬薄膜**時，由於自旋-軌道交互作用，自旋方向相反的電子，也往相反方向運動，可有效產生**自旋流**



“

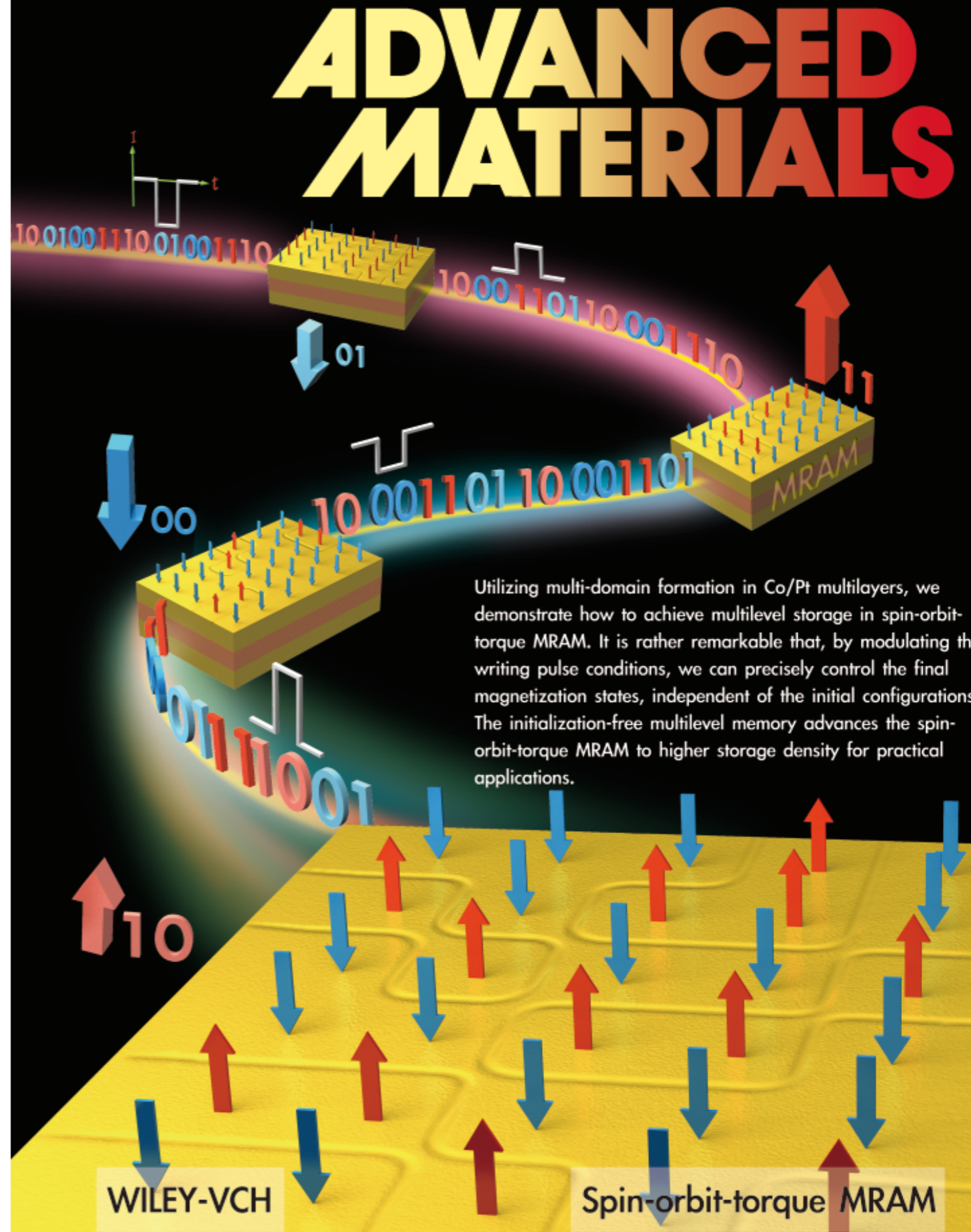
兩個突破

# 多組態記憶體

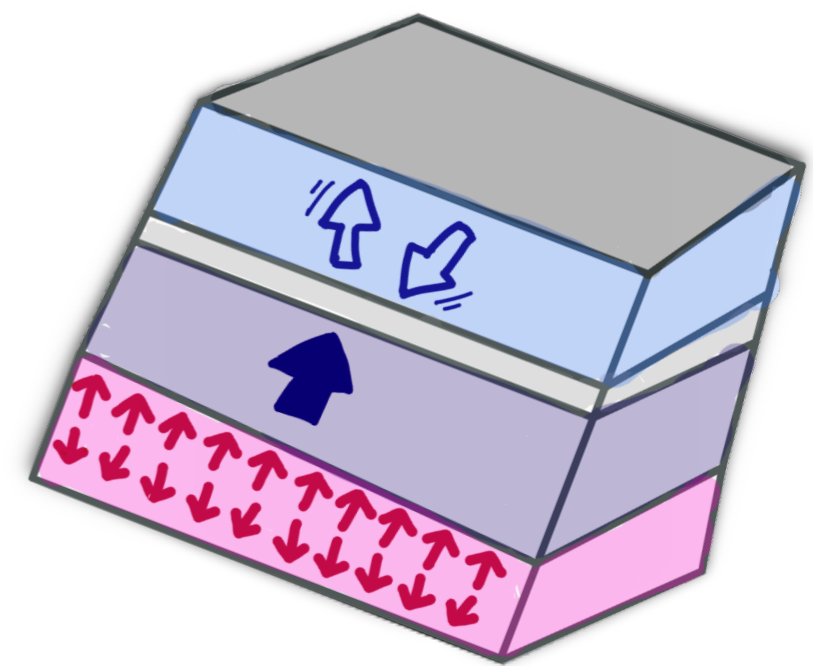
過往多組態記憶體操作時，都必須回到「起始態」，因此讀寫不便。

- 用**電流**產生**自旋流**
- 用**自旋**控制**電流**

藉由自旋的自組裝動力學，任何組態間的轉變，可由電流脈衝直接操控。

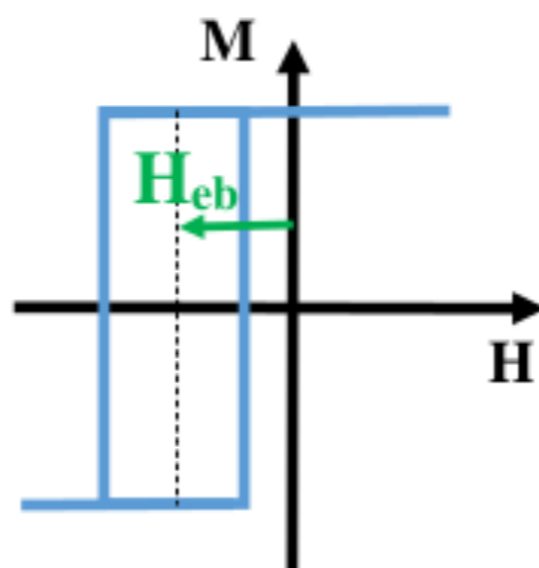
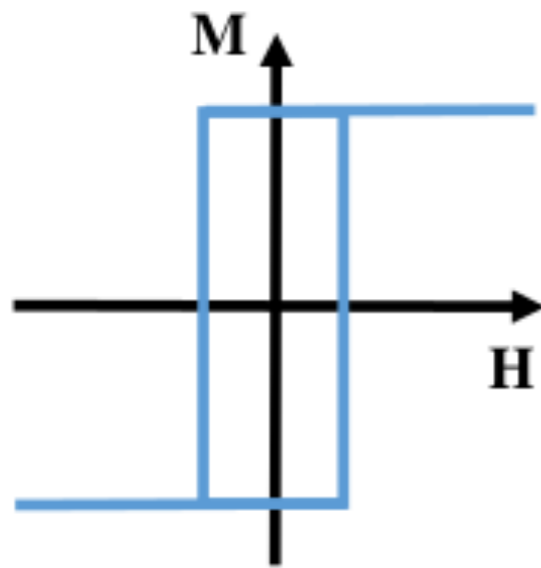
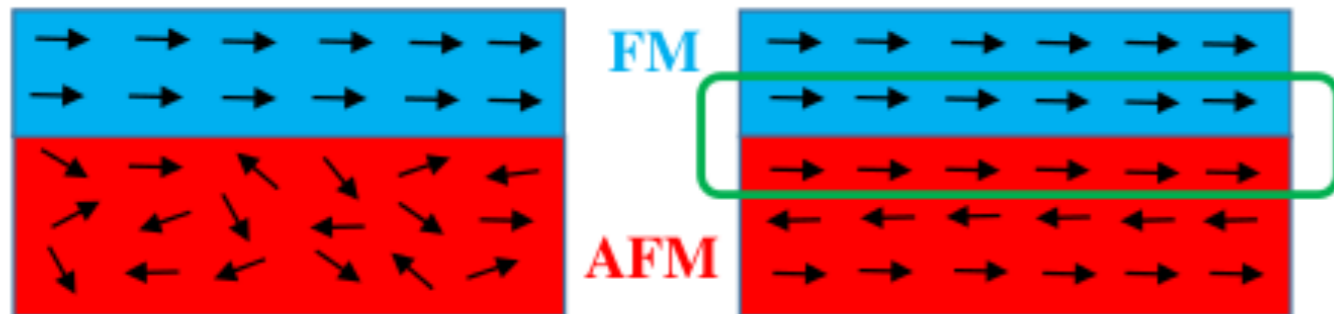


# 交換偏移 (EXCHANGE BIAS)

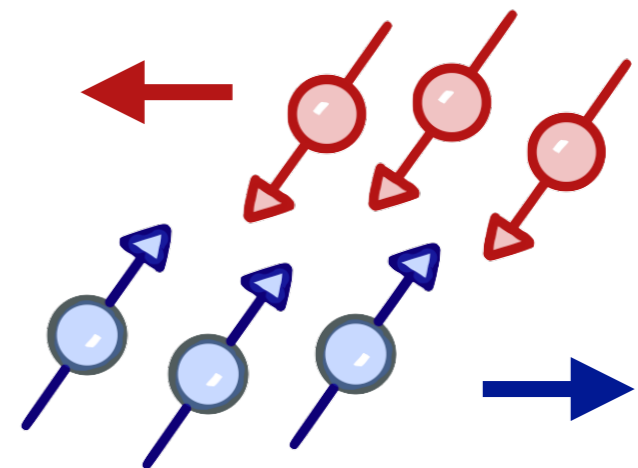


$$T > T_N$$

$$T < T_N$$



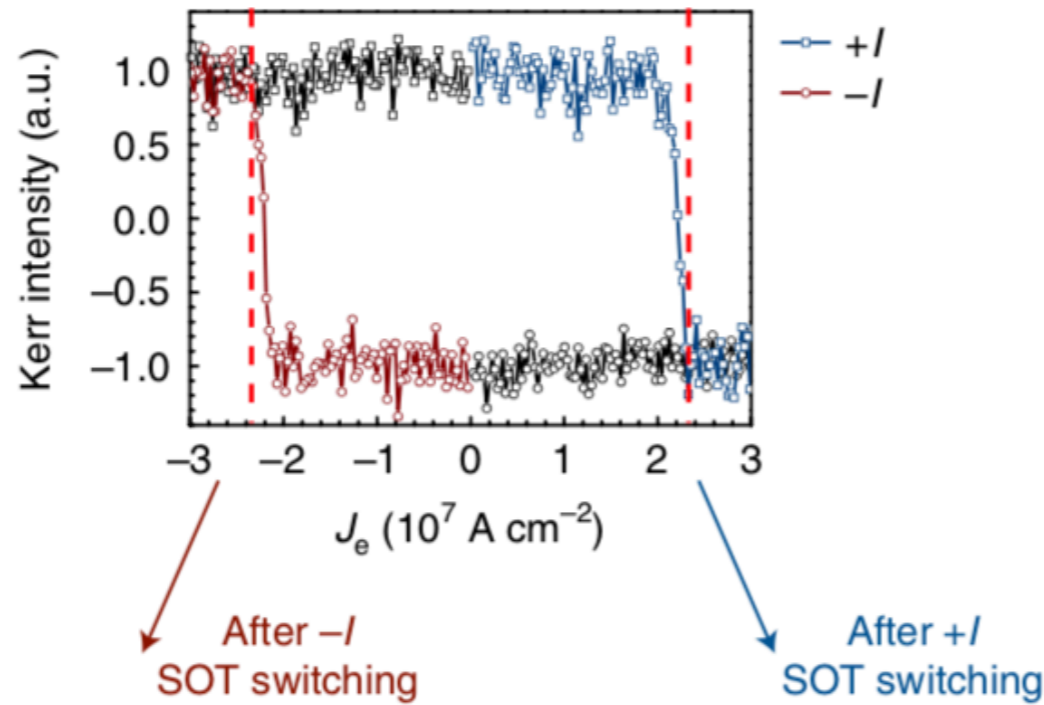
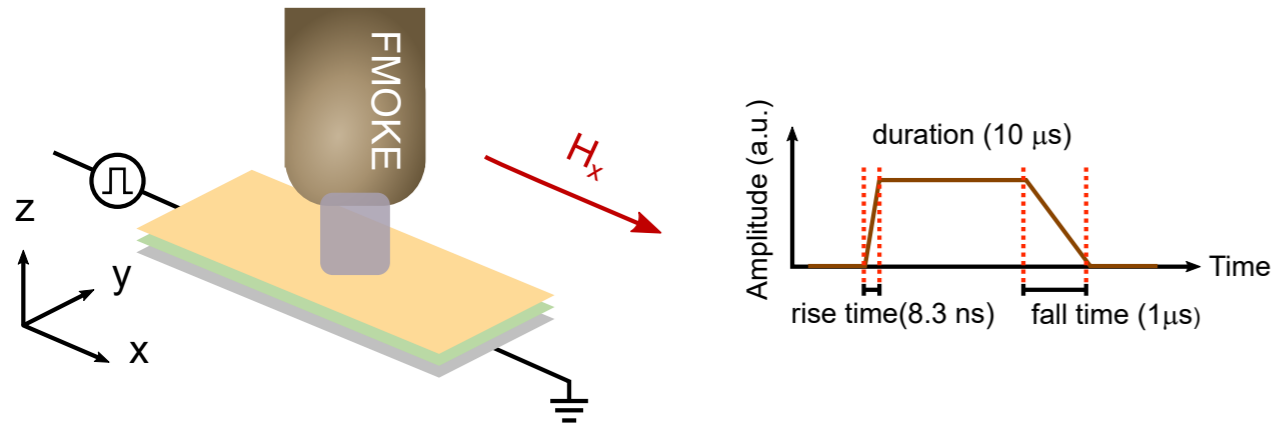
若要改變交換偏移方向：  
 (1) 升高溫度 (2) 施加外場  
 (3) 退火，但這種操控方式  
 無法與目前製程結合。



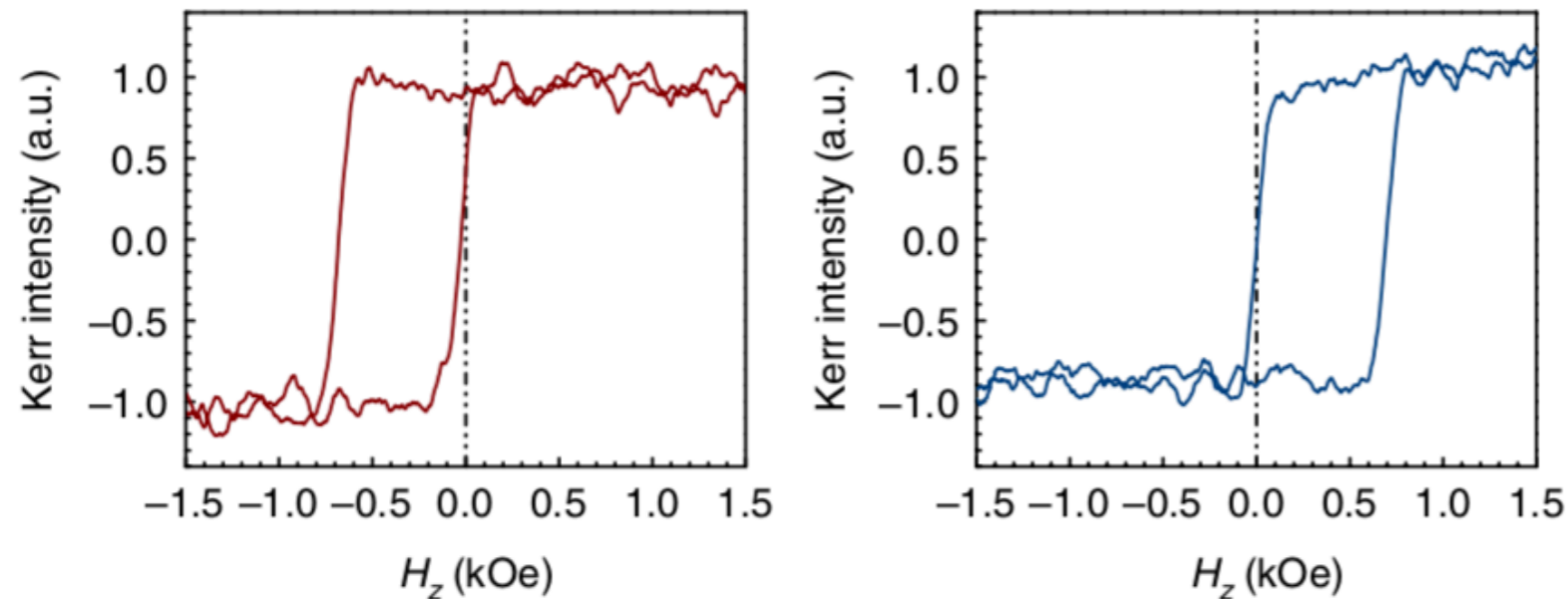
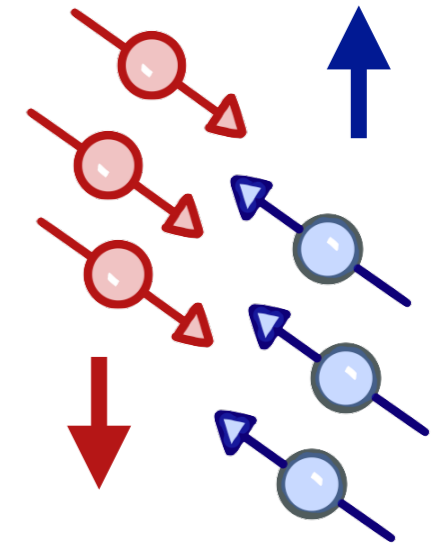
試試自旋流，如何？

Meiklejohn & Bean (美國通用電氣)  
 於1956年發現交換偏移效應

# 電控交換偏移



電流脈衝產生  
自旋流，除了  
翻轉鐵磁層，  
居然……



過往無法有效操控  
的交換偏移，藉由  
自旋流即可翻轉！

# 大發現？或是大錯特錯？

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May 24, 2017

..... Gathering all responses and evidences, I come to the following suspicion: *Is it possible that our findings are so unconventional so that it takes extra efforts to be appreciated?*

*I know this sounds very arrogant, especially after receiving rejection from Nature Communications.*

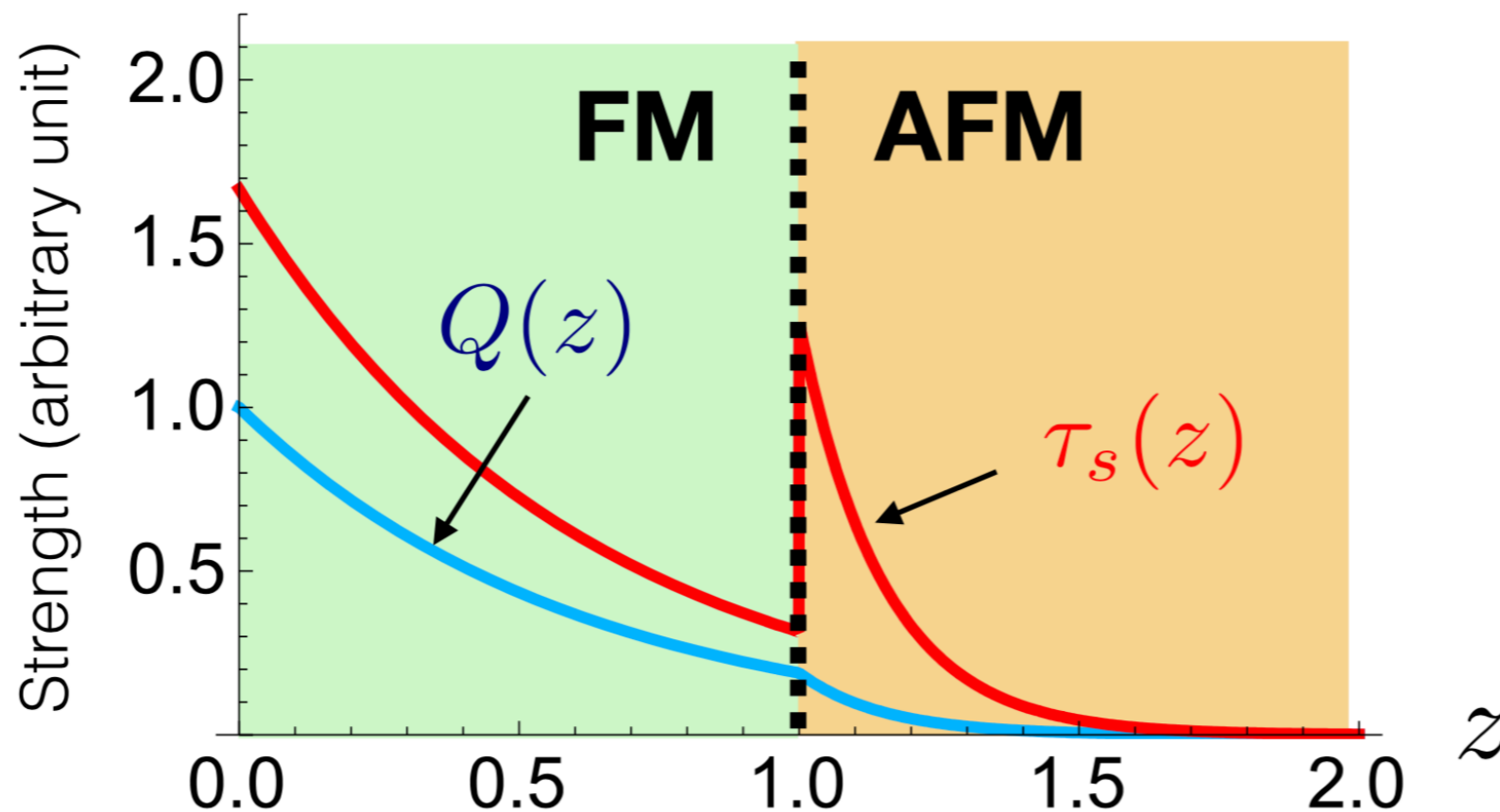
*...I have a different suggestion. What about submitting the manuscript to **Nature Materials**?*

# 介面效應：自旋流 V.S. 力矩

*Nature Materials 18, 335 (2019)*

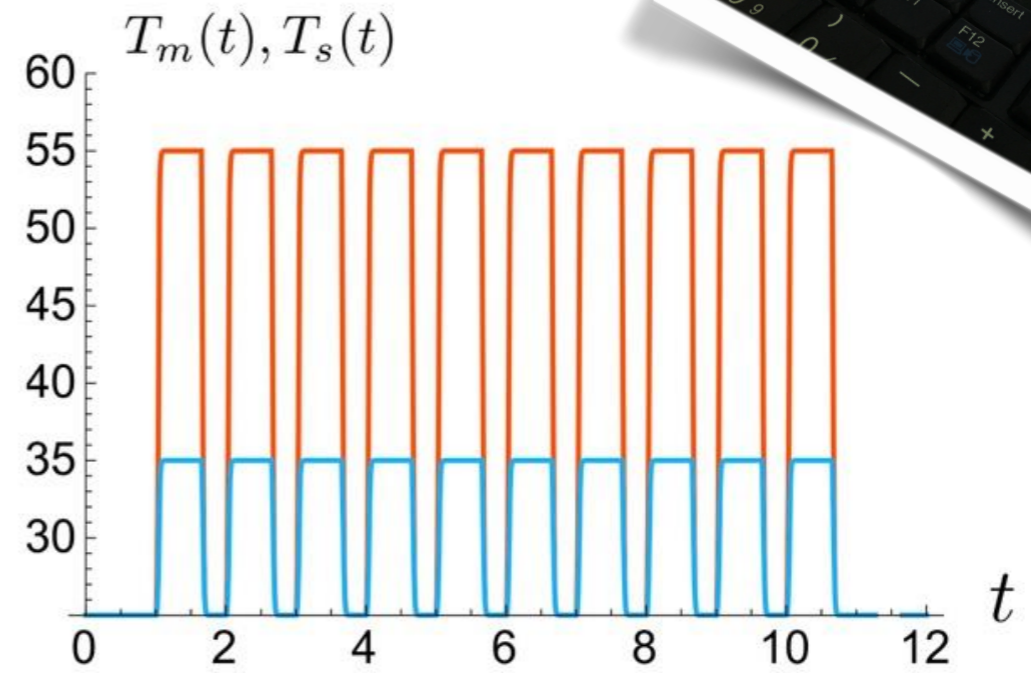
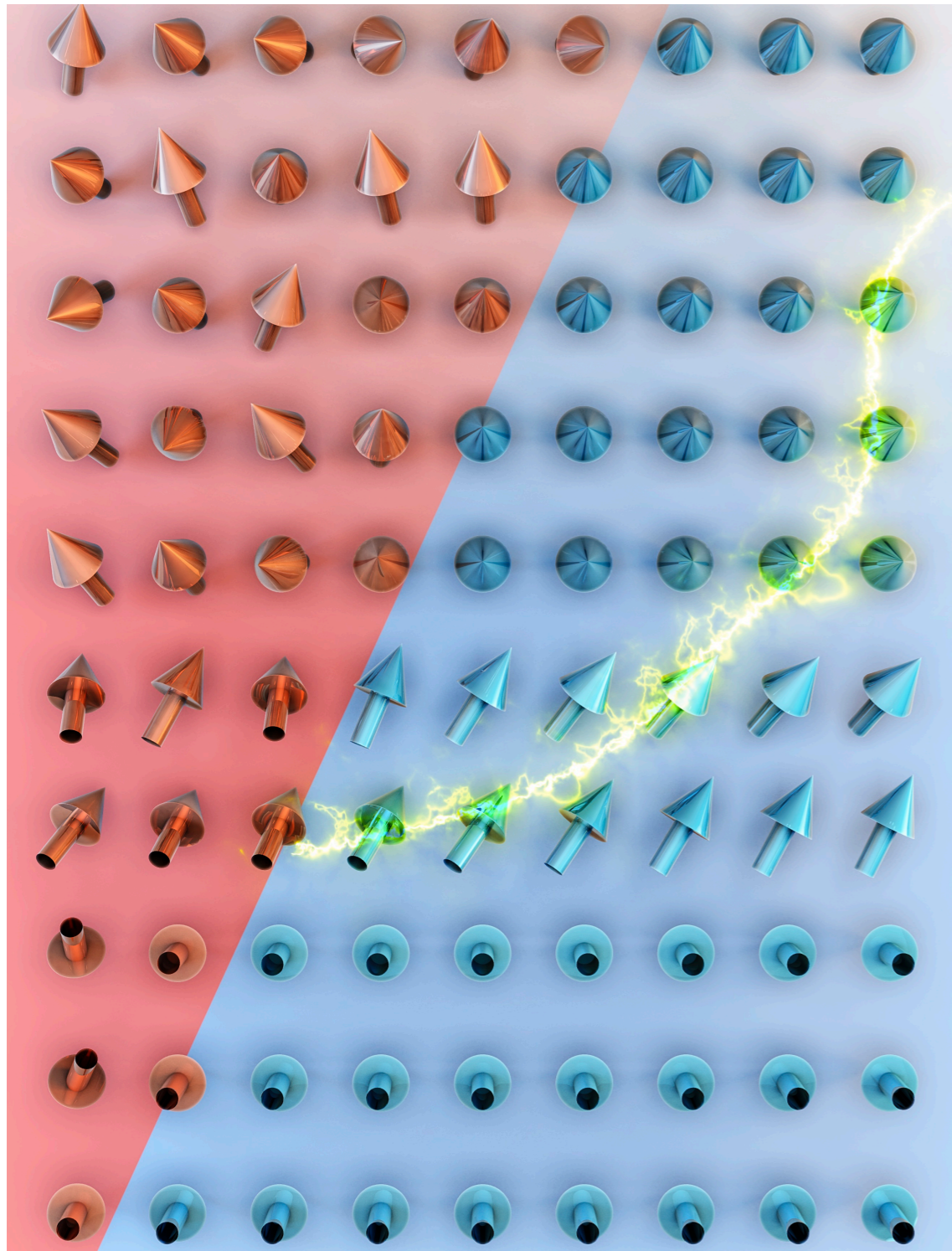
*Landau-Lifshitz-Gilbert equation + corrections*

$$\frac{\partial \mathbf{m}}{\partial t} = -\gamma \mathbf{m} \times \mathbf{H}_{\text{eff}} + \alpha \hat{\mathbf{m}} \times \frac{\partial \mathbf{m}}{\partial t} - \frac{\delta \mathbf{m}}{\tau} - \nabla \cdot \mathbf{Q}$$

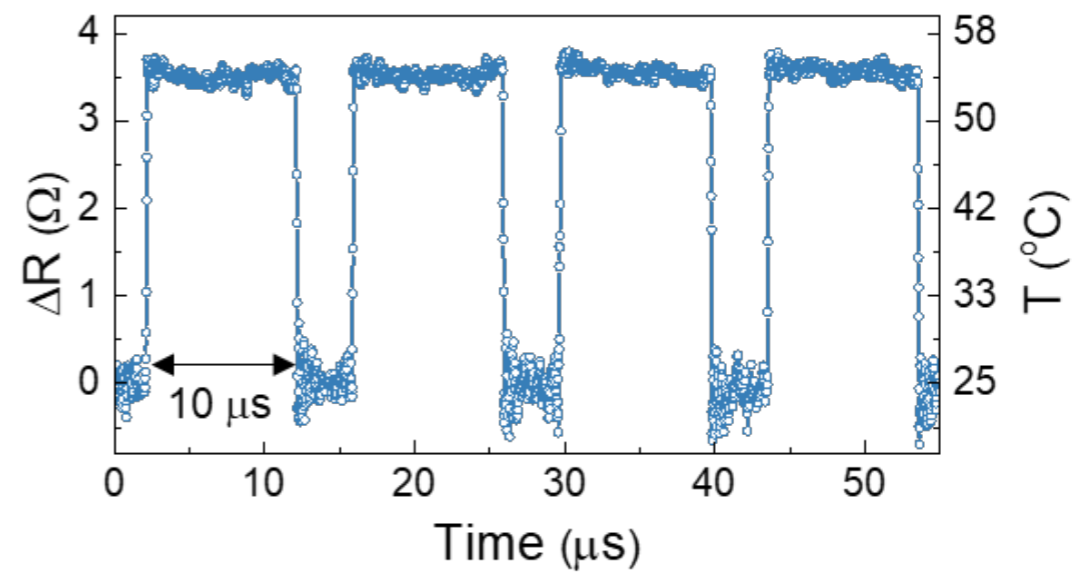


自旋流是二階張量，並非向量，其散度會貢獻到力矩，因此介面效應顯著。

# 理論學家做實驗

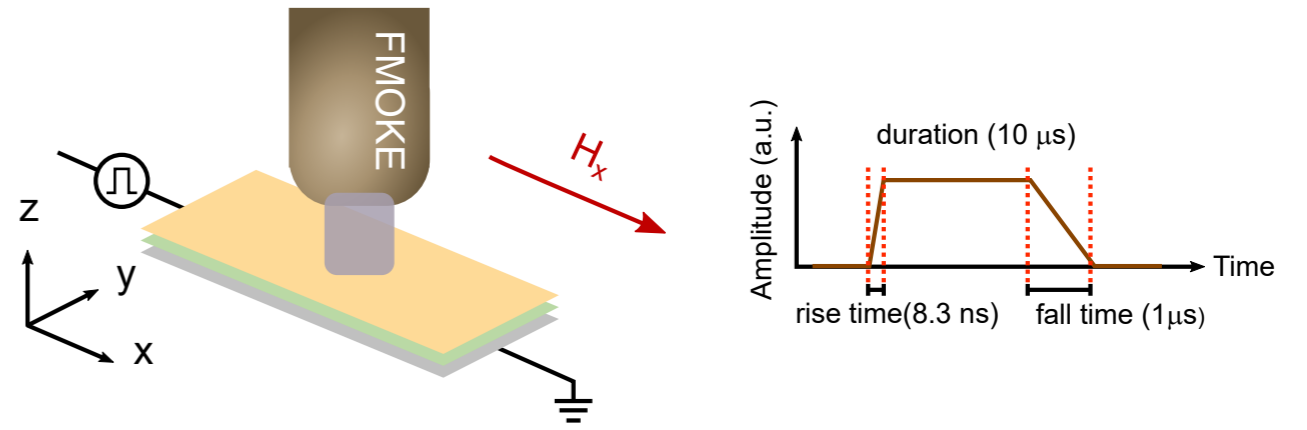


從頭設計奈米/微秒尺度的溫標

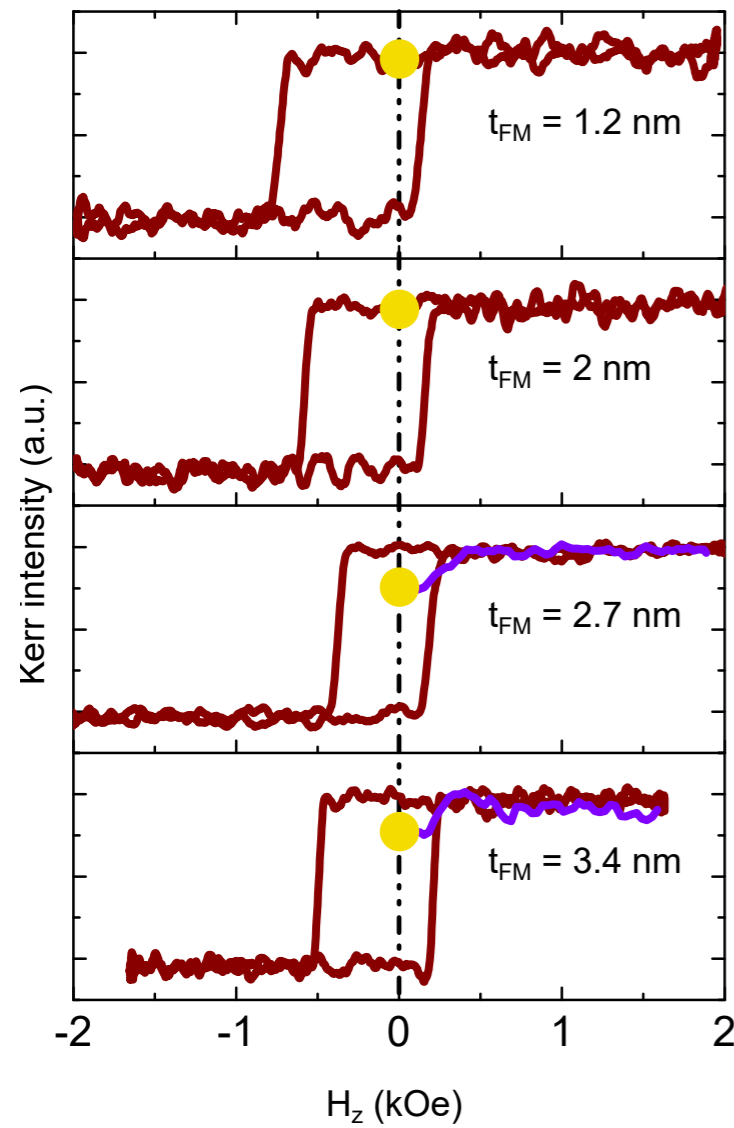


# 電控交換偏移 — 完整版

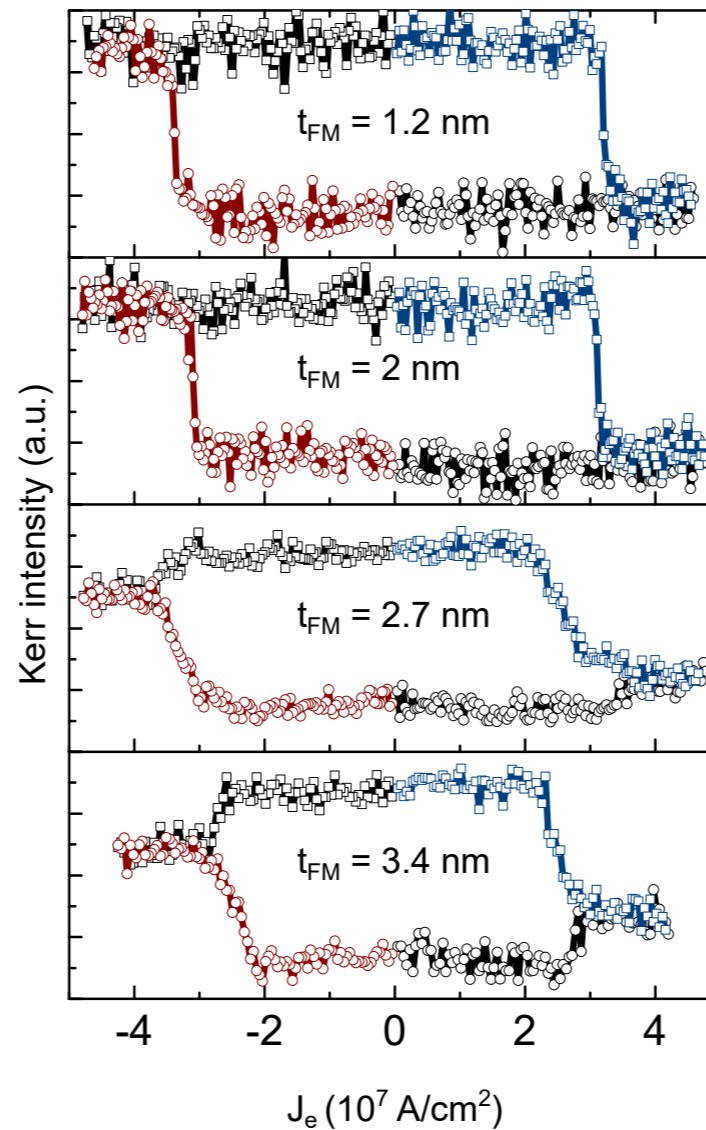
*Nature Materials* 18, 335 (2019)



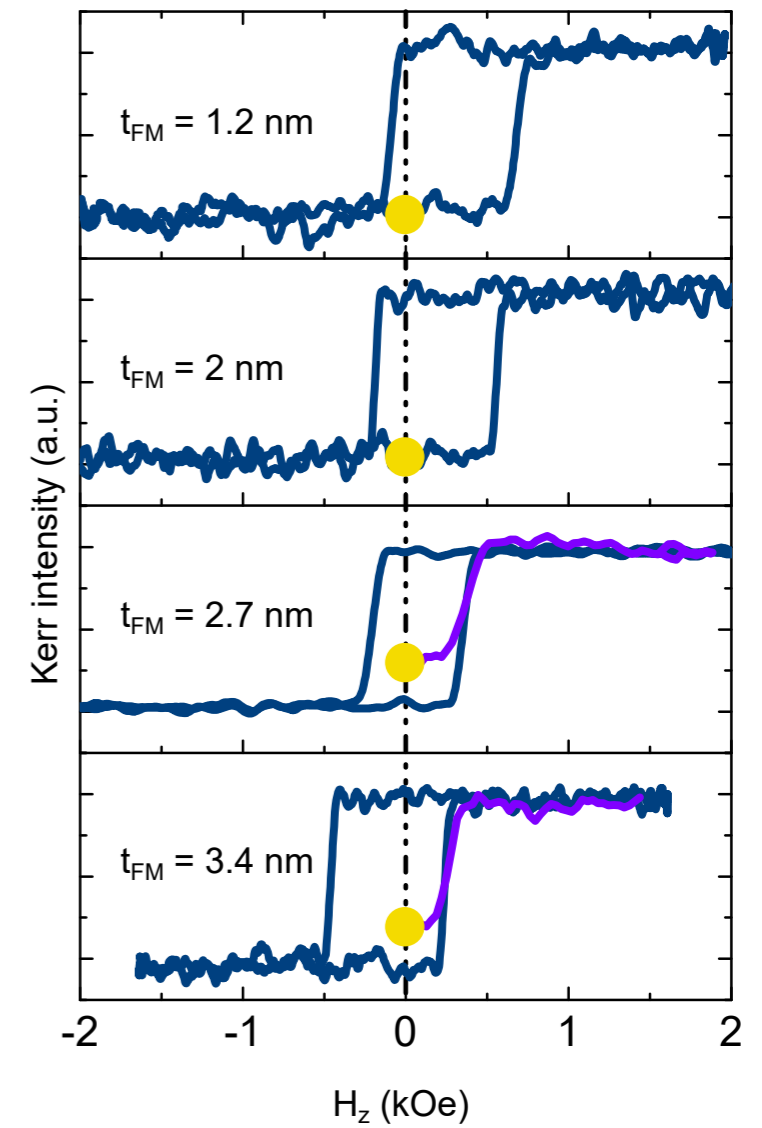
Hysteresis loops:  
After -I SOT switching



SOT switching



Hysteresis loops:  
After +I SOT switching

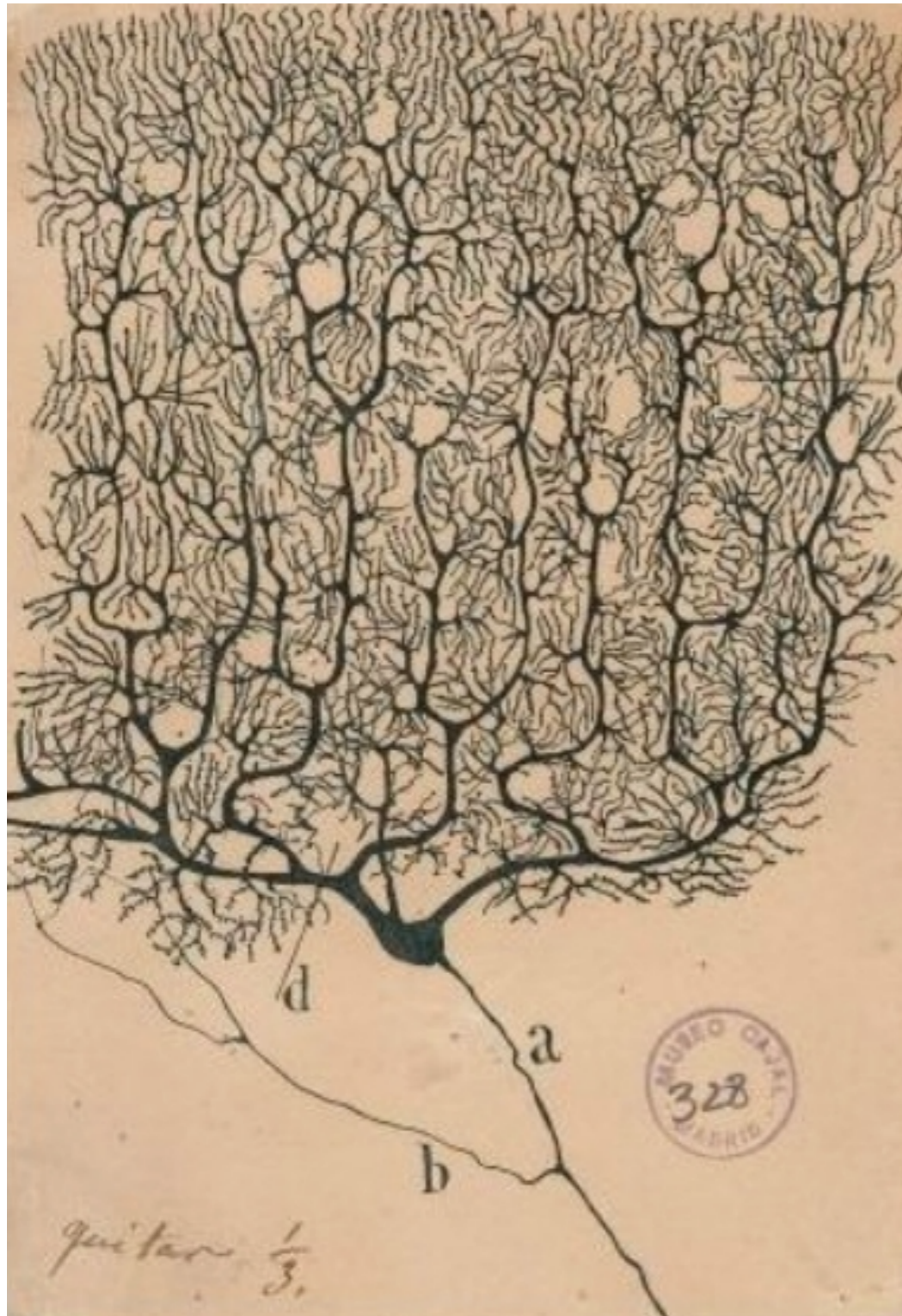


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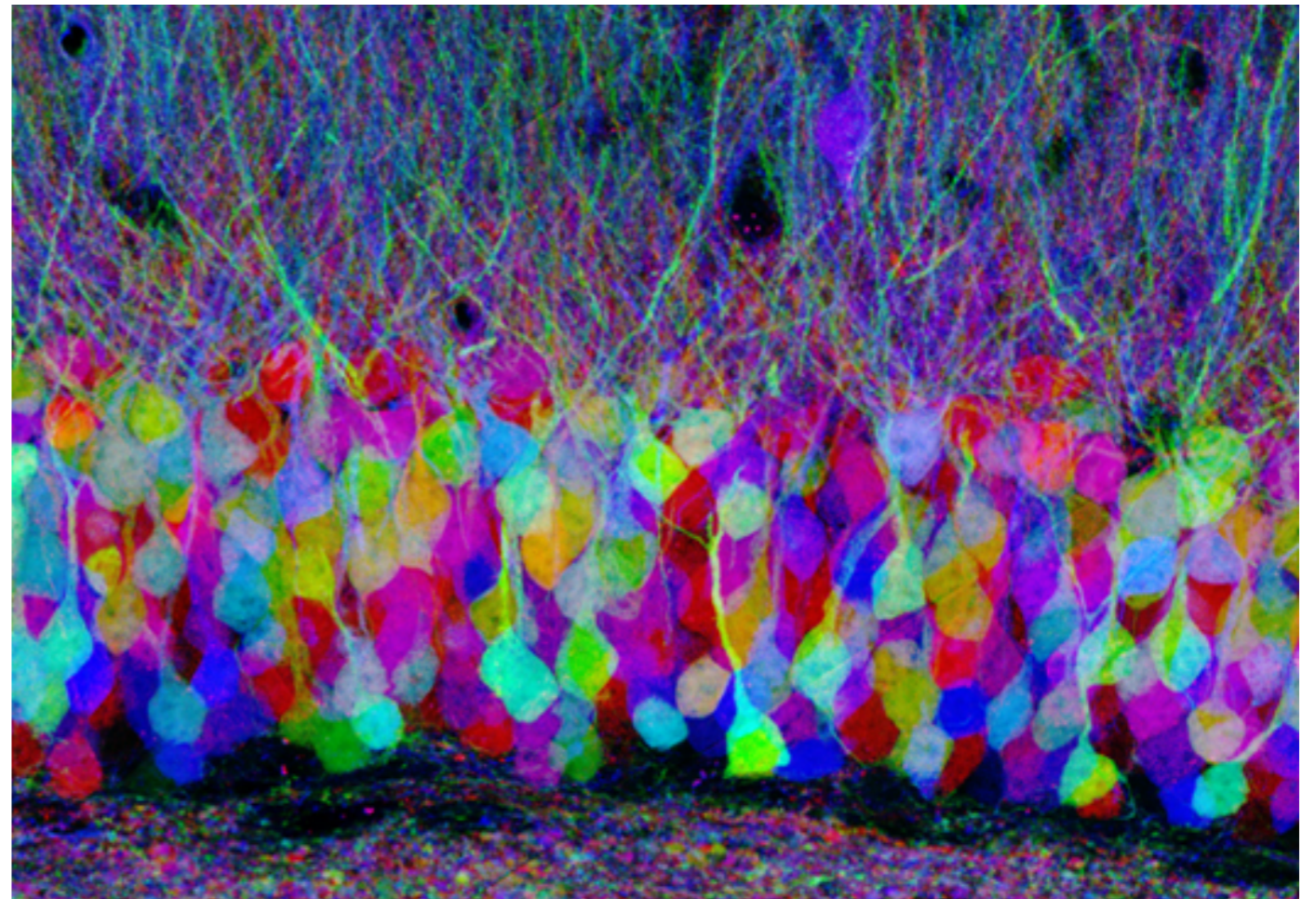
大腦是神經元網絡？

# 腦內的森林

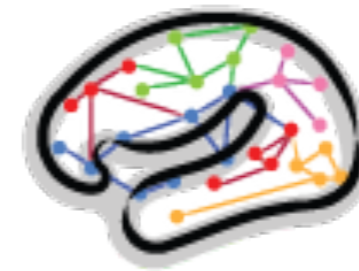
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- 1000億個神經元細胞
- 1000兆的神經連結
- 複雜的神經元網絡

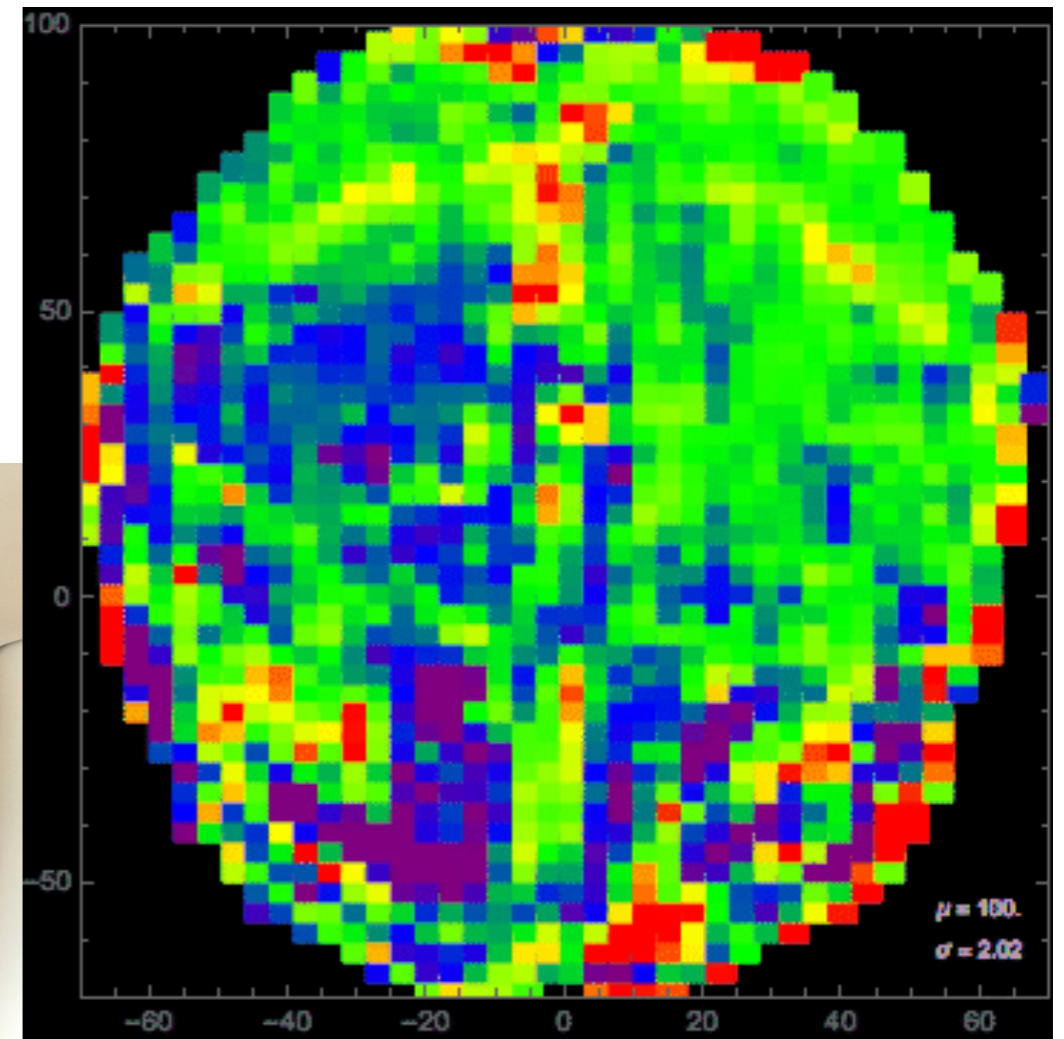


# 人類連結體計畫



HUMAN  
Connectome  
PROJECT

與渥太華的腦科學中心合作，研究大腦的**集體激發**現象，進一步瞭解**認知**與**意識**的動力學。

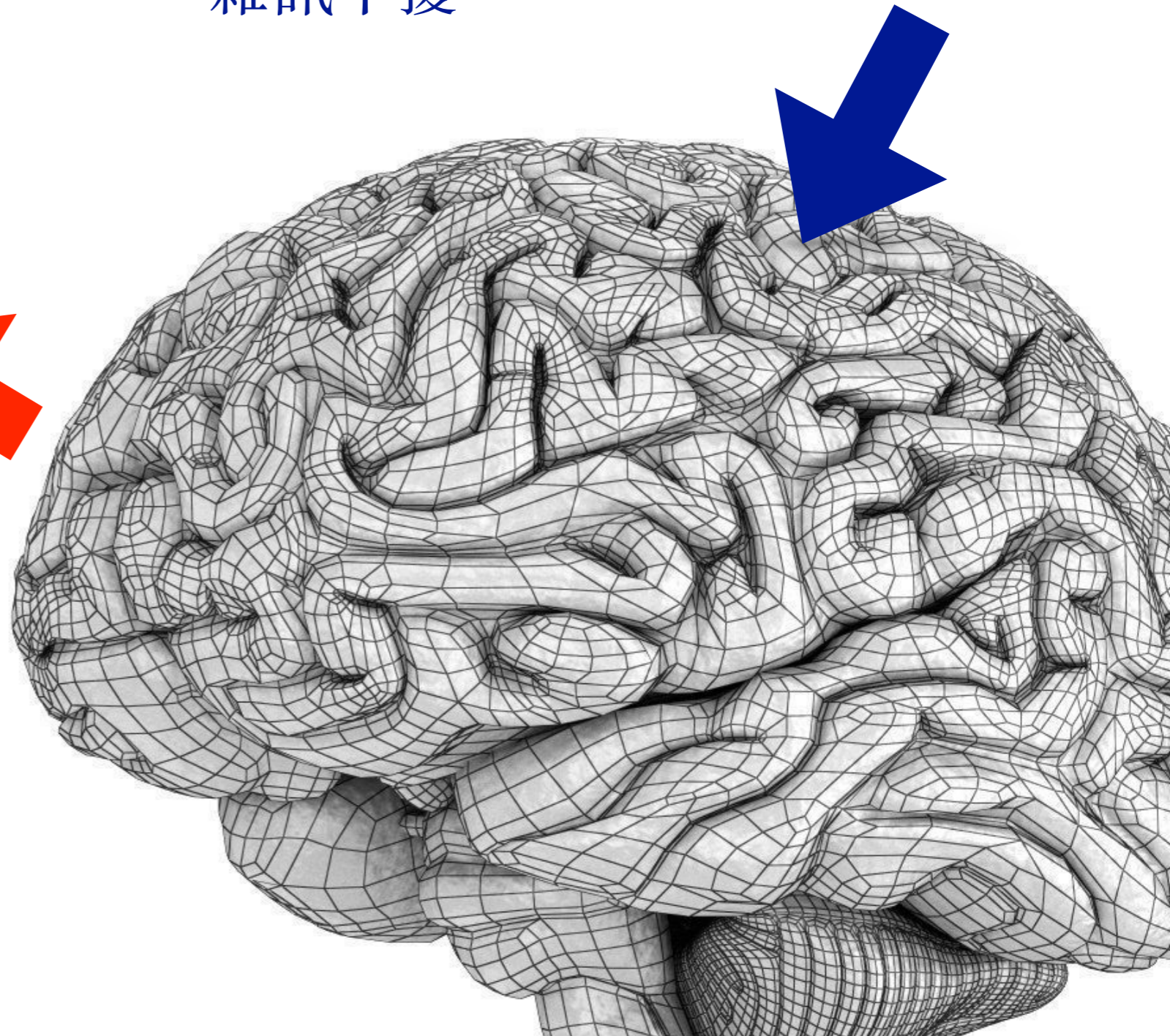
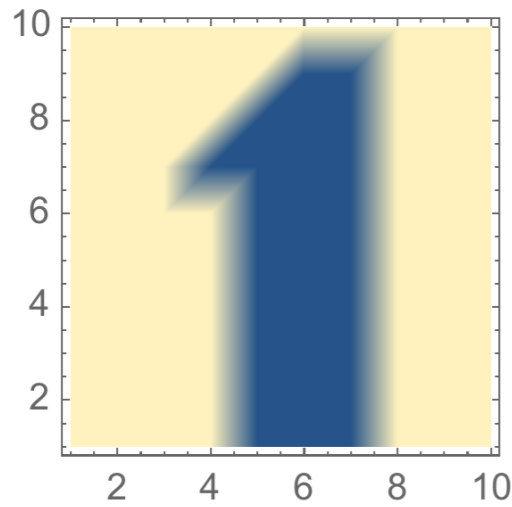
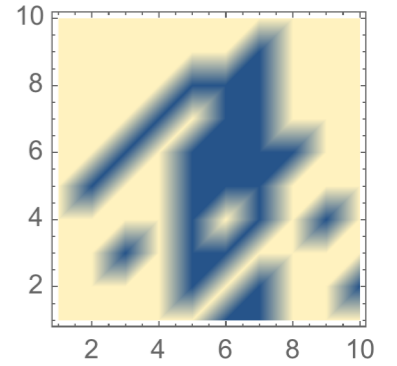


建構神經元間的連結，試著用**全域角度**來瞭解大腦的運作。

# 資訊動態重組！

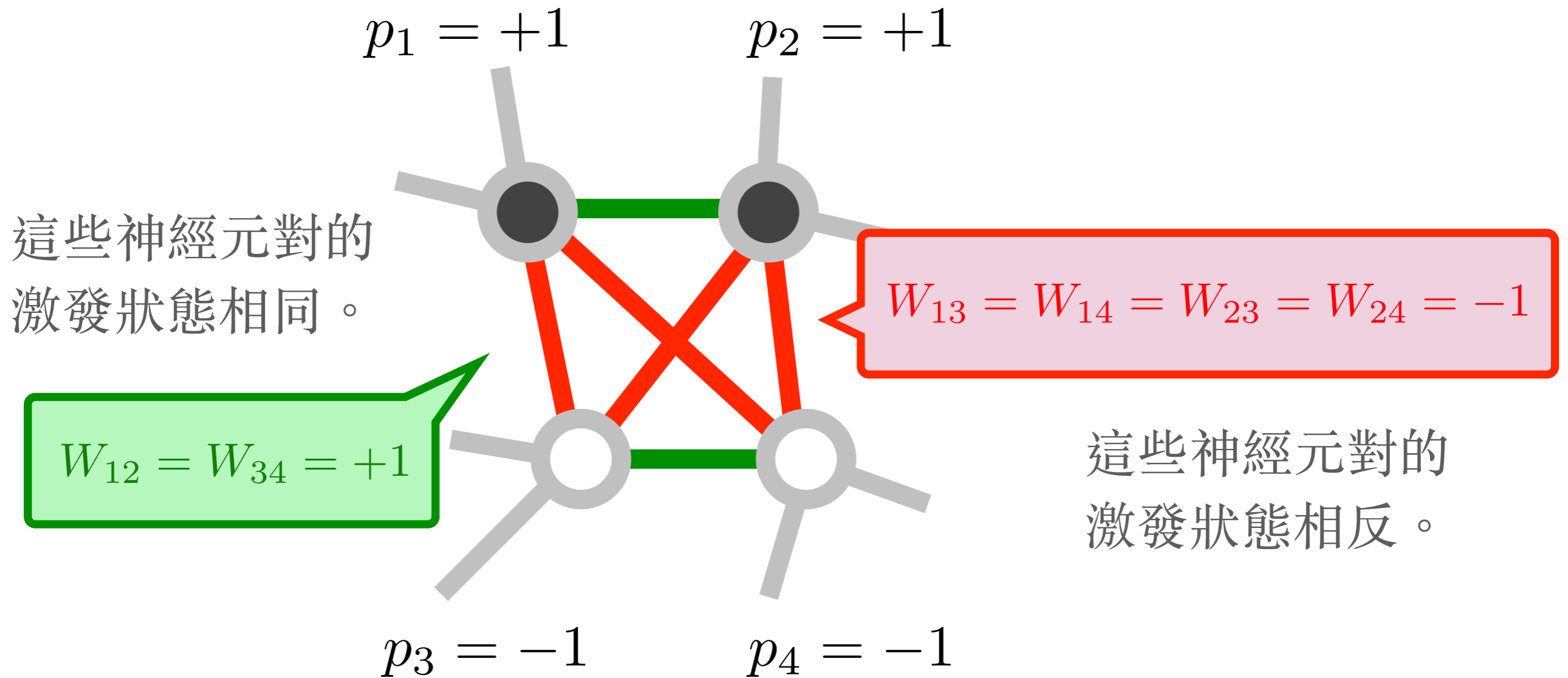
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即便輸入的圖案受到  
雜訊干擾……



大腦還是可以藉由神經元連結，**動態組合**記憶中的資訊，呈現較為完整的圖案。

# HOPFIELD NEURAL NETWORK



定義所有神經元間的連結

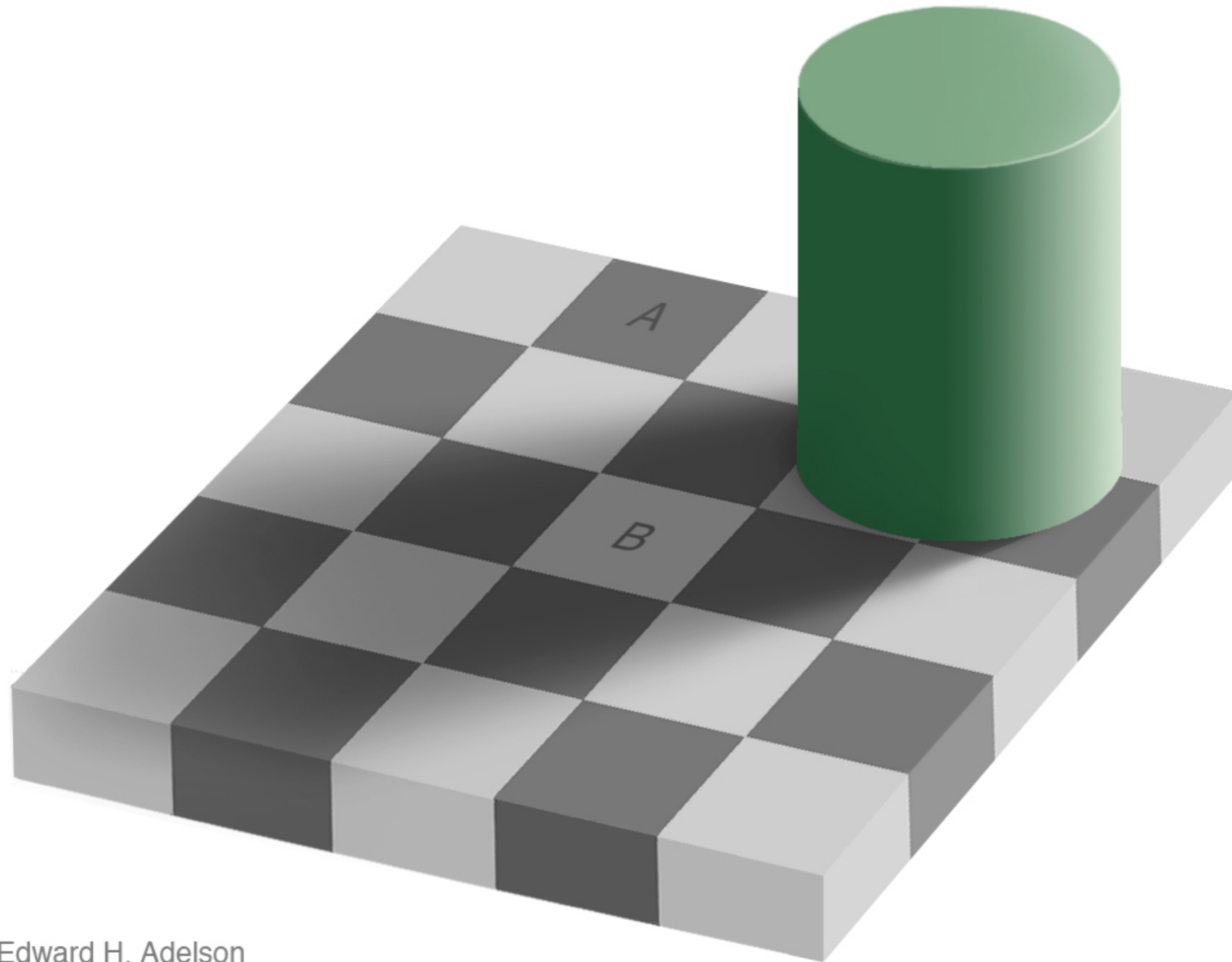
$$W_{ij} = p_i \times p_j$$

“

世故的眼睛

哪個顏色深？哪個顏色淺？

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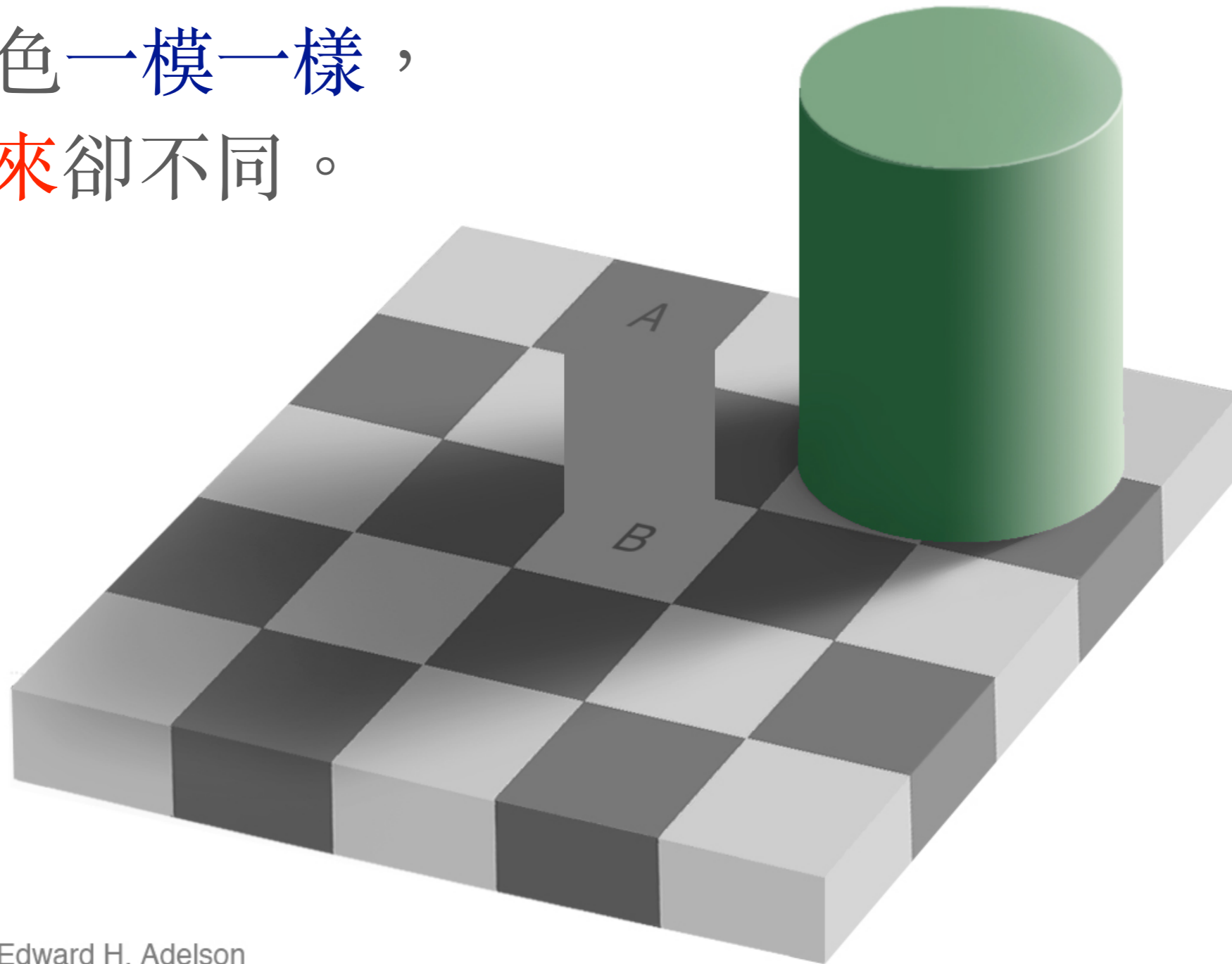


Edward H. Adelson

哪個顏色深？哪個顏色淺？

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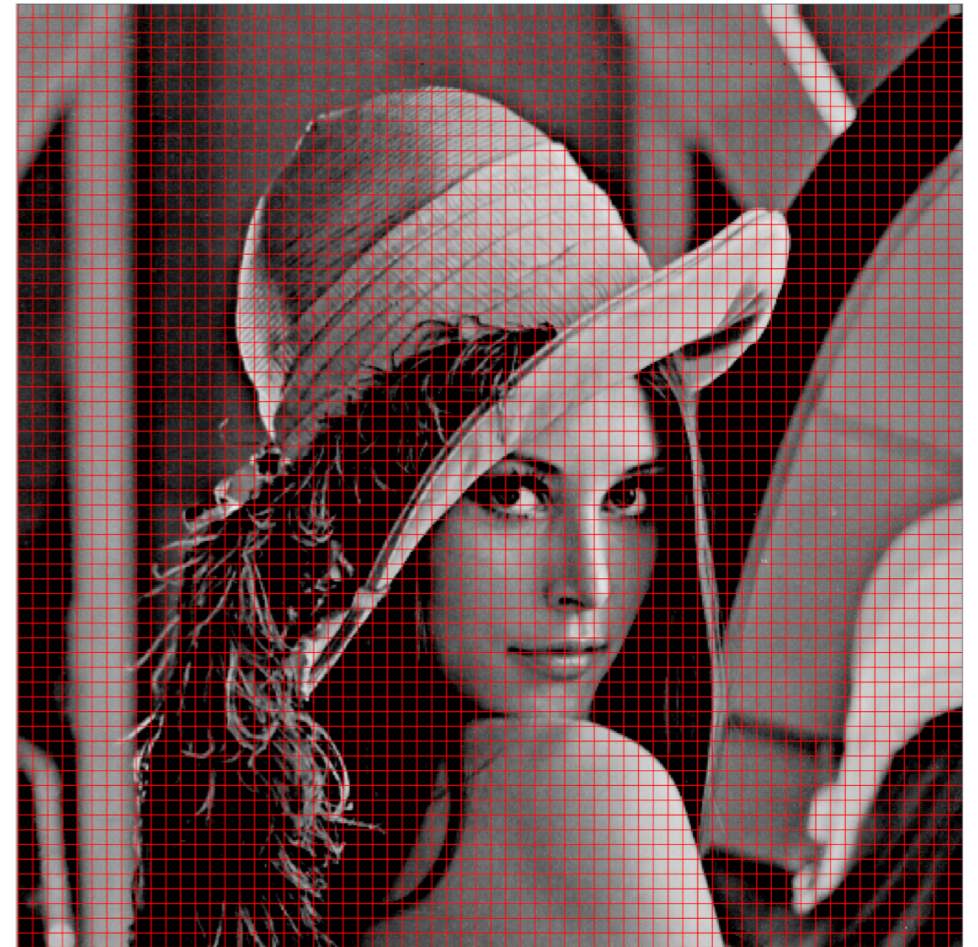
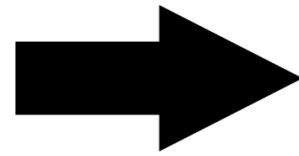
$A, B$  顏色一模一樣，  
但看起來卻不同。



Edward H. Adelson

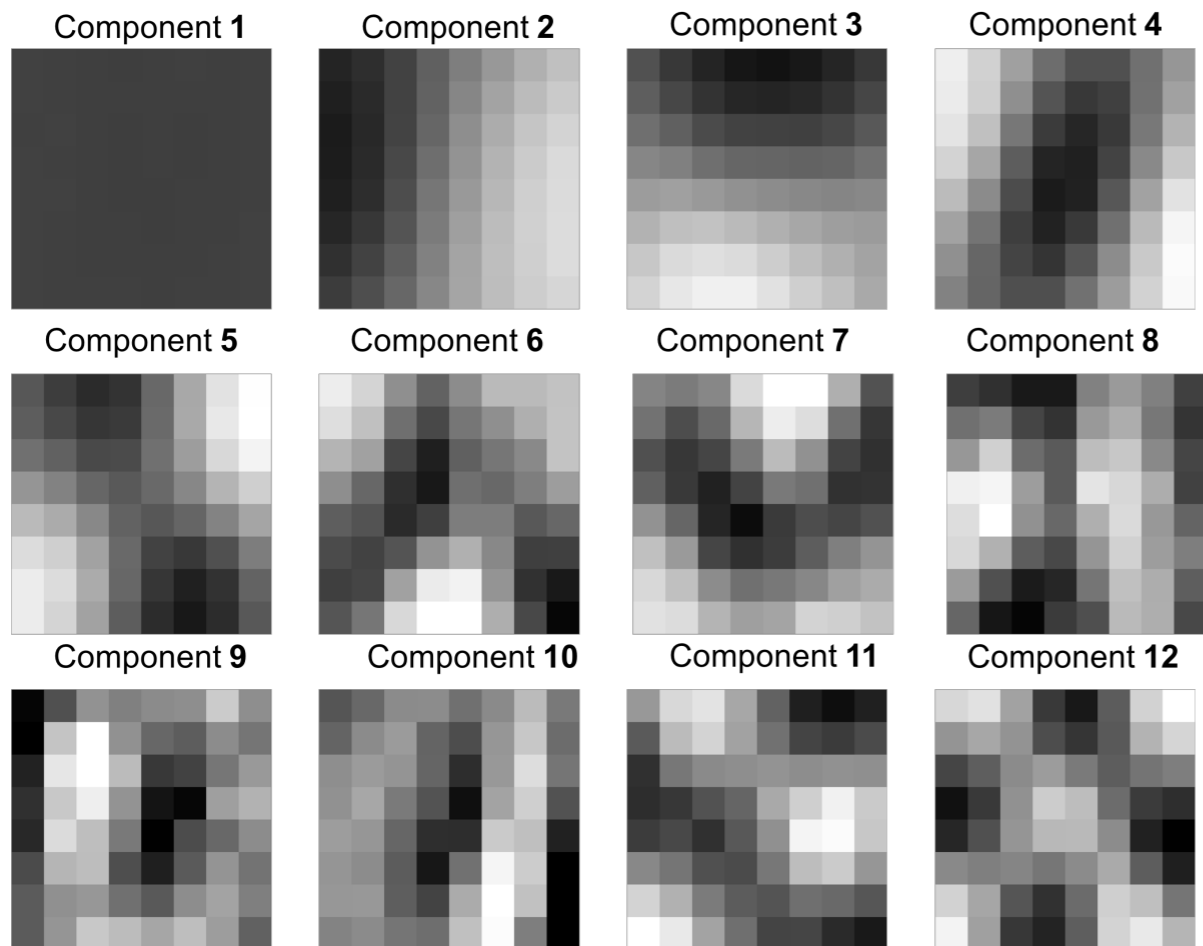
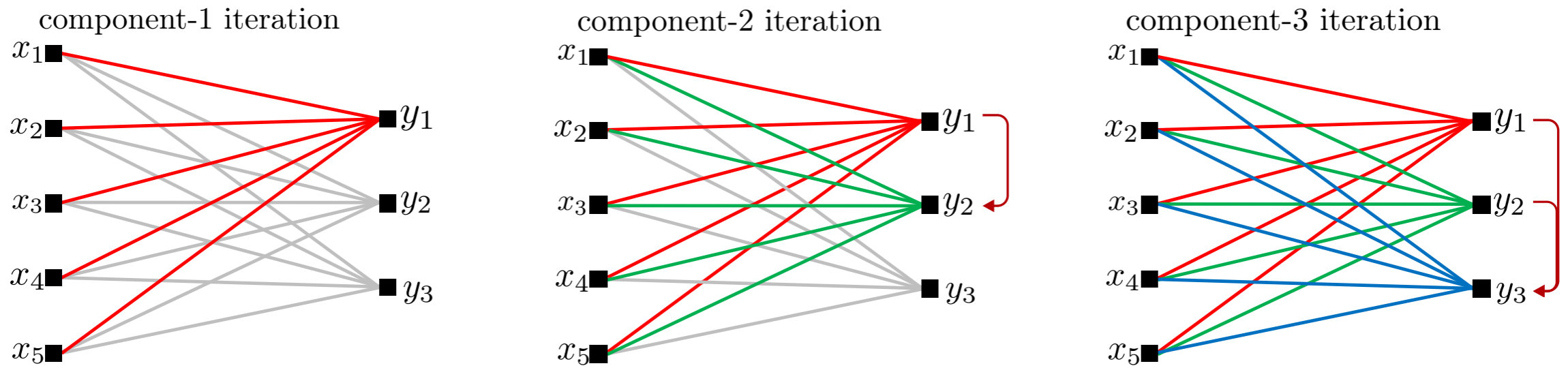
## 圖形辨識

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將圖片剪成 8X8 的小圖片，當成訓練神經網絡的素材，什麼結果會浮現呢？

# 圖形辨識 2



拿成千上萬的小圖形訓練神經網絡，藉由學習改變網絡**權重**，分析圖形隱含的**主要分量**。

# 圖形辨識 3

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20-component



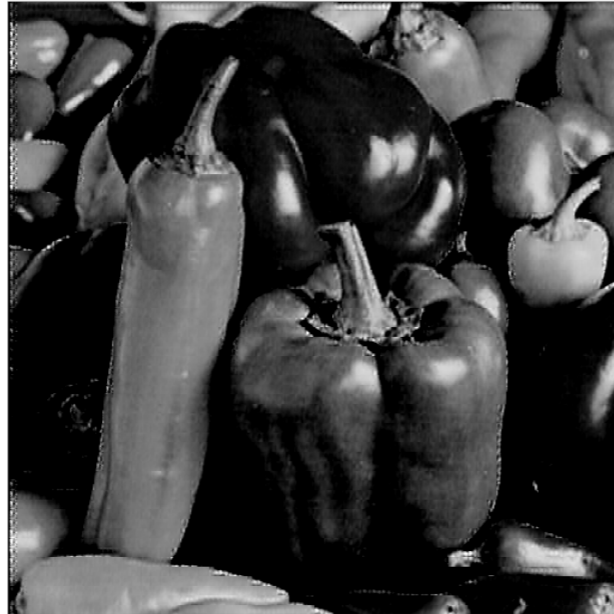
Original image



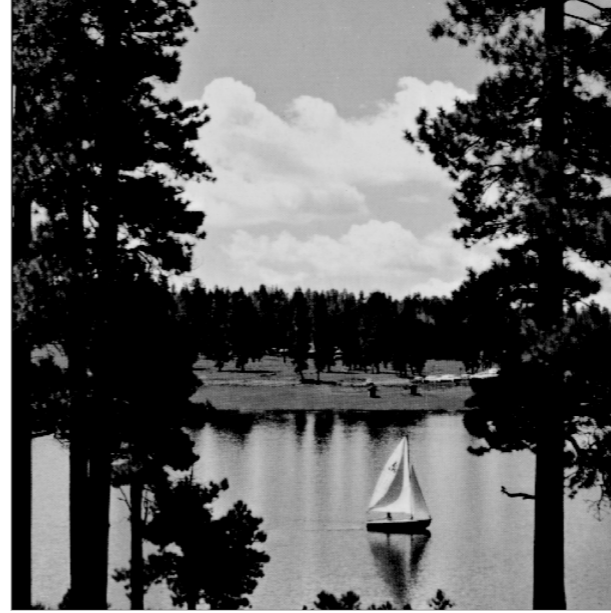
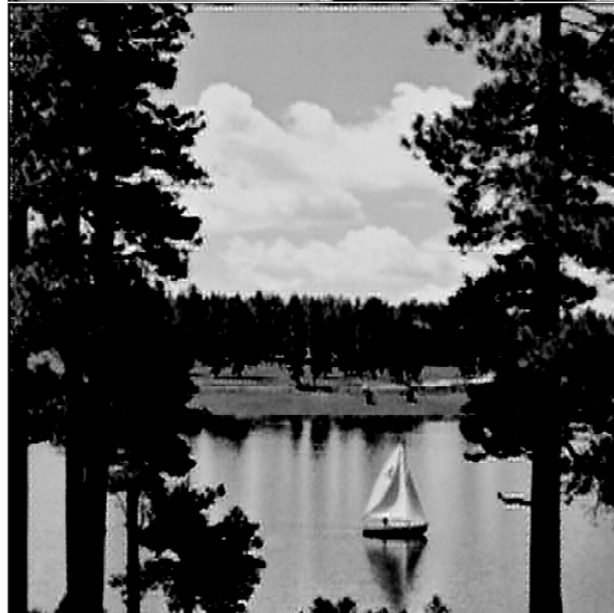
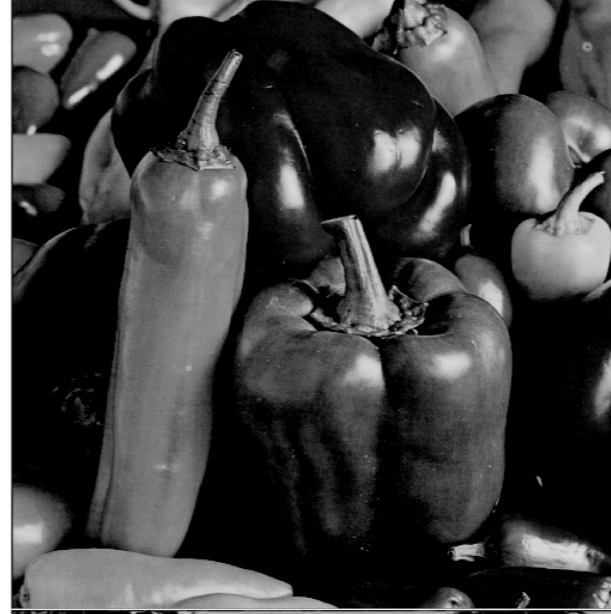
# 圖形辨識 4

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12-component



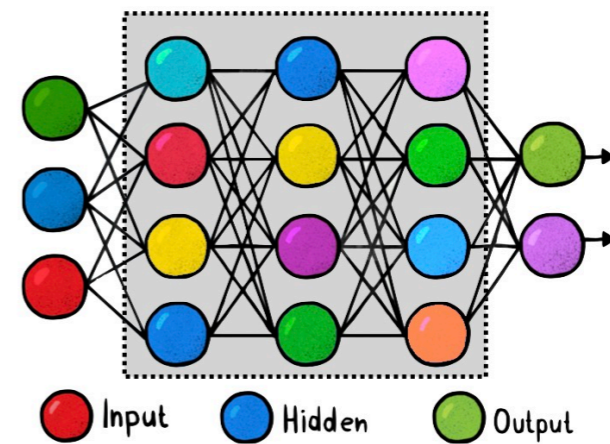
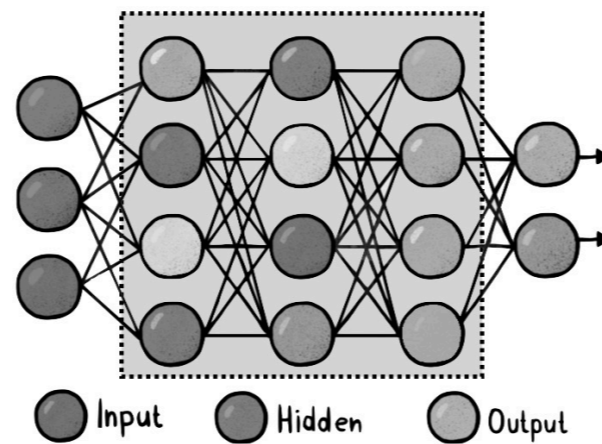
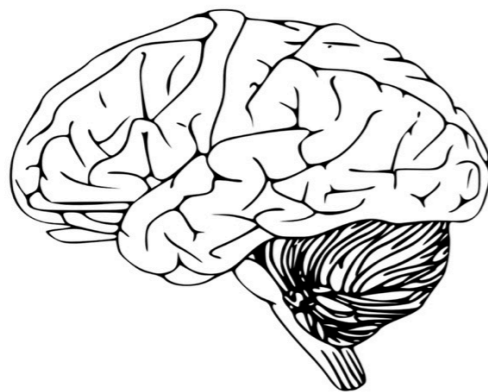
Original image



同樣的主要分量也適用於其他自然的照片……

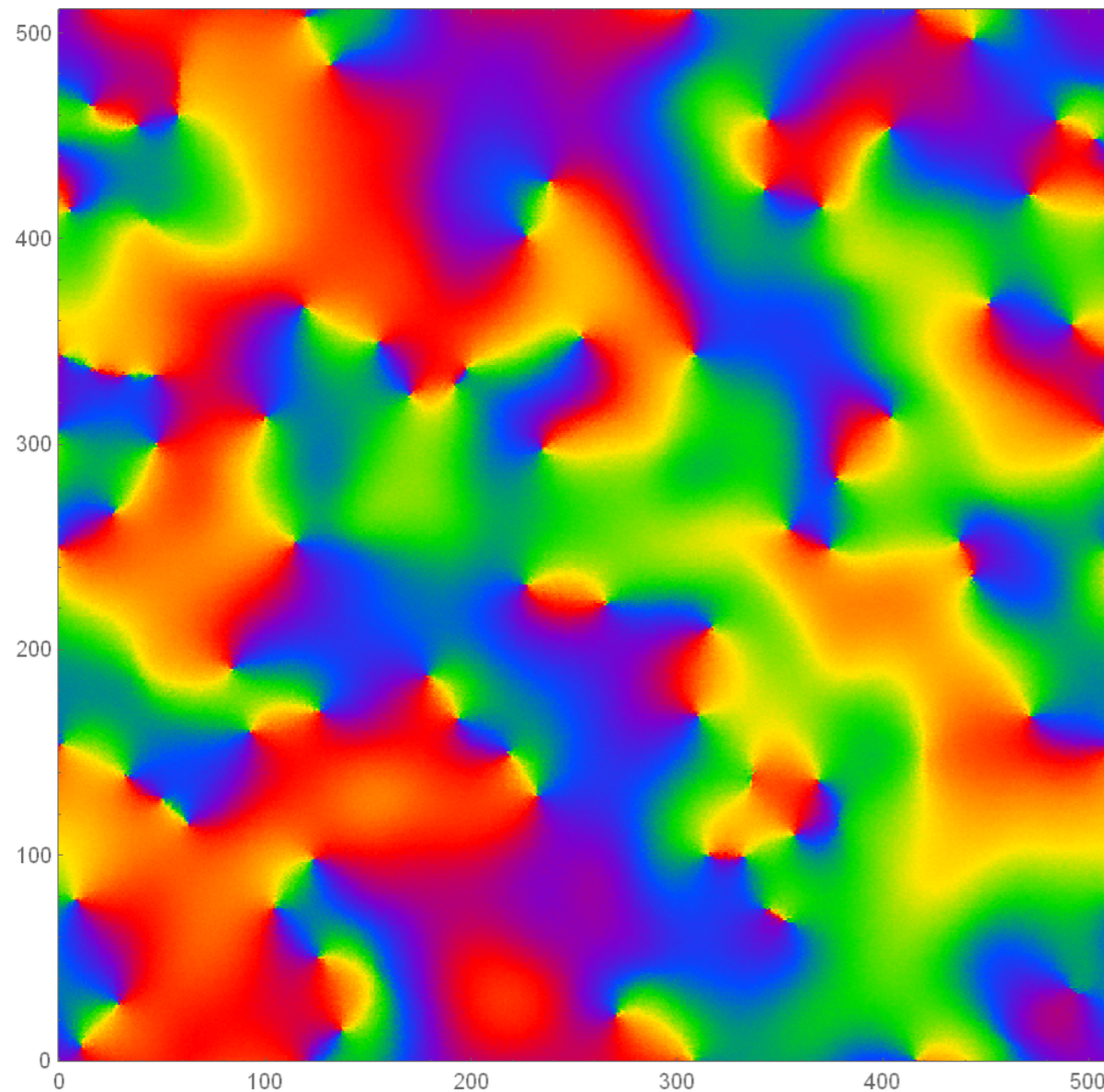
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# U(1) Neuronal Network



# UNN: U(1) NEURONAL NETWORK

$$\frac{dz_n}{dt} = i[\omega_n + (c_n z_n + \bar{c}_n \bar{z}_n)]z_n - [a_n + b_n |z_n|^2]z_n + \sum_m (iK_{nm} + H_{nm})z_m$$



*firing rate =  $\nu$*



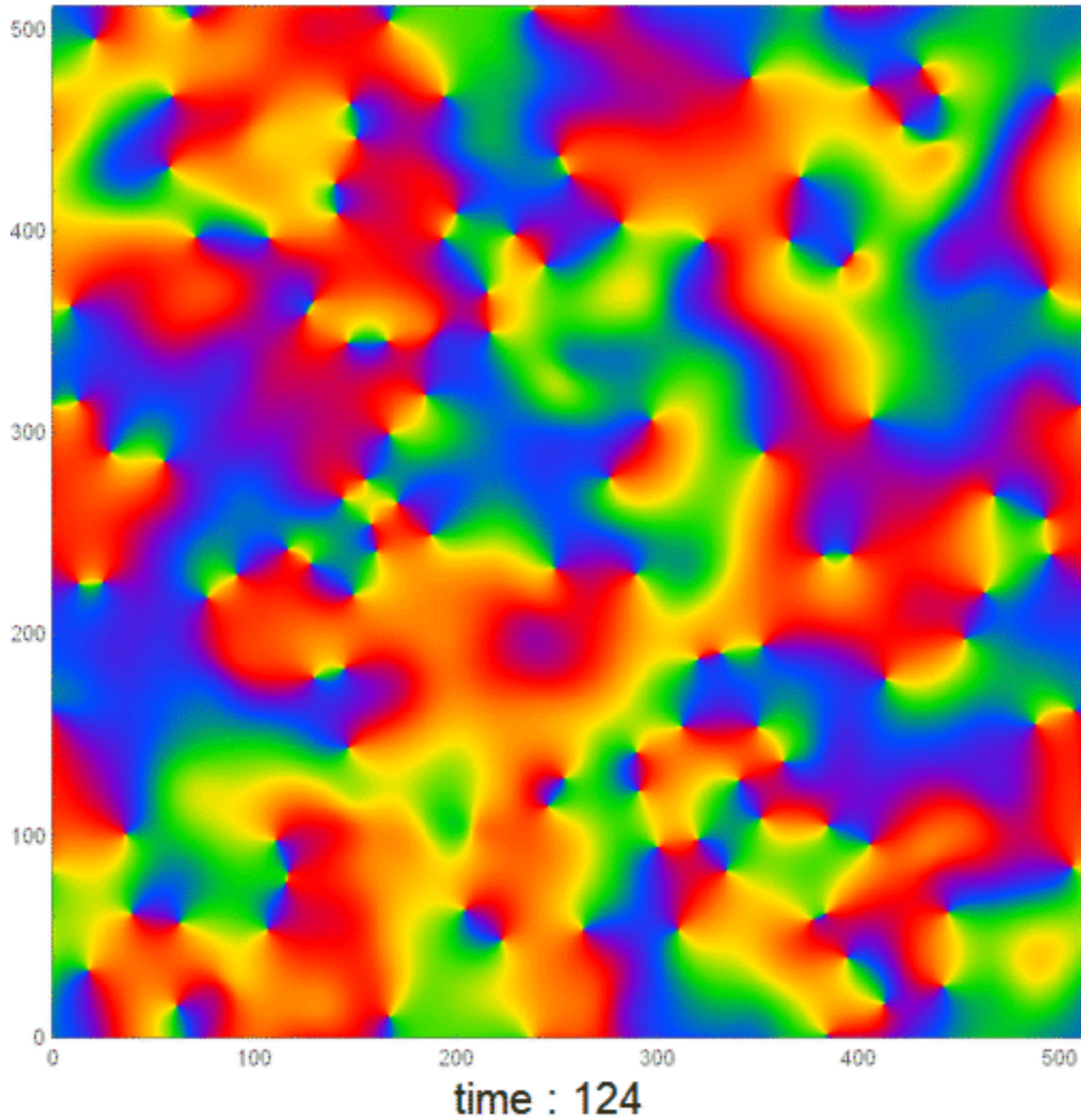
*phase =  $2\pi\nu \cdot \Delta t$*

大腦內的「颱風對」消失，神經元同步現象加劇，大腦資訊處理效率會降低。

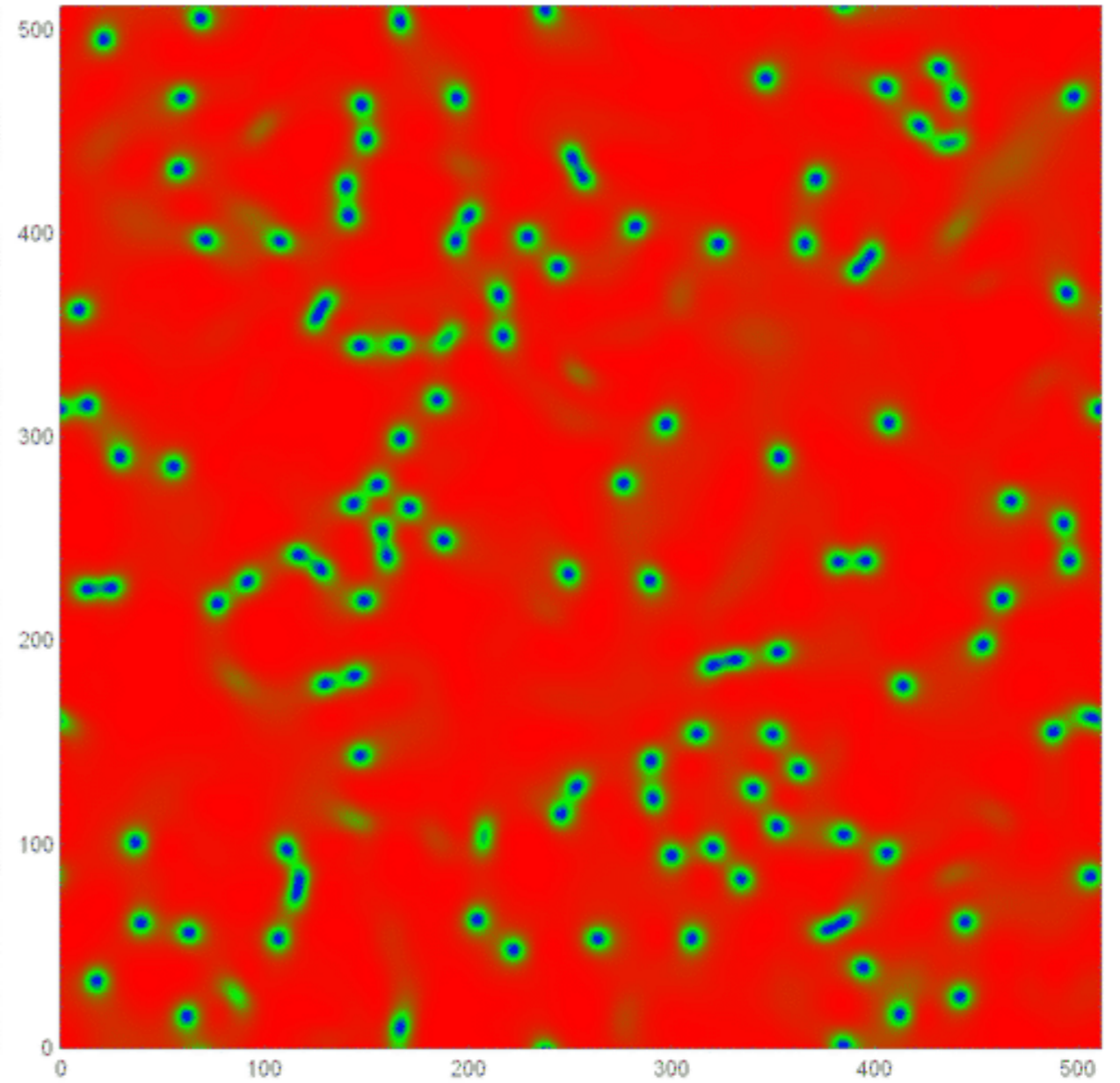
# U(1) NEURONS

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*Phase*



*Amplitude*



# PARKINSON'S DISEASE

Parkinson's disease is the result of lack of dopamine production in the brain.

SYMPTOMS MAY INCLUDE:



Tremors



Balance problems



Stiffness



Changes in speech, voice and swallowing



Slowness of movement



Trouble with handwriting

MOST COMPREHENSIVE CARE AVAILABLE IN THE REGION:

Specially trained clinicians



Nutrition



Exercise



Imaging/Testing



Clinical trials



Education and support



Medications



Over 1,000

electrode implantations performed



## Deep Brain Stimulation

Highly effective in properly selected patients, DBS is a surgery that provides patients with relief from many Parkinson's disease symptoms through electrical stimulation.

[froedtert.com/movement](http://froedtert.com/movement)

50%

average reduction in medications after DBS

Decision making is complicated, not fully understood yet. We focus on **perceptual decision making** here. But even the simpler case can be challenging !

What colors do you see ?

Green and Grey

Red and White



“

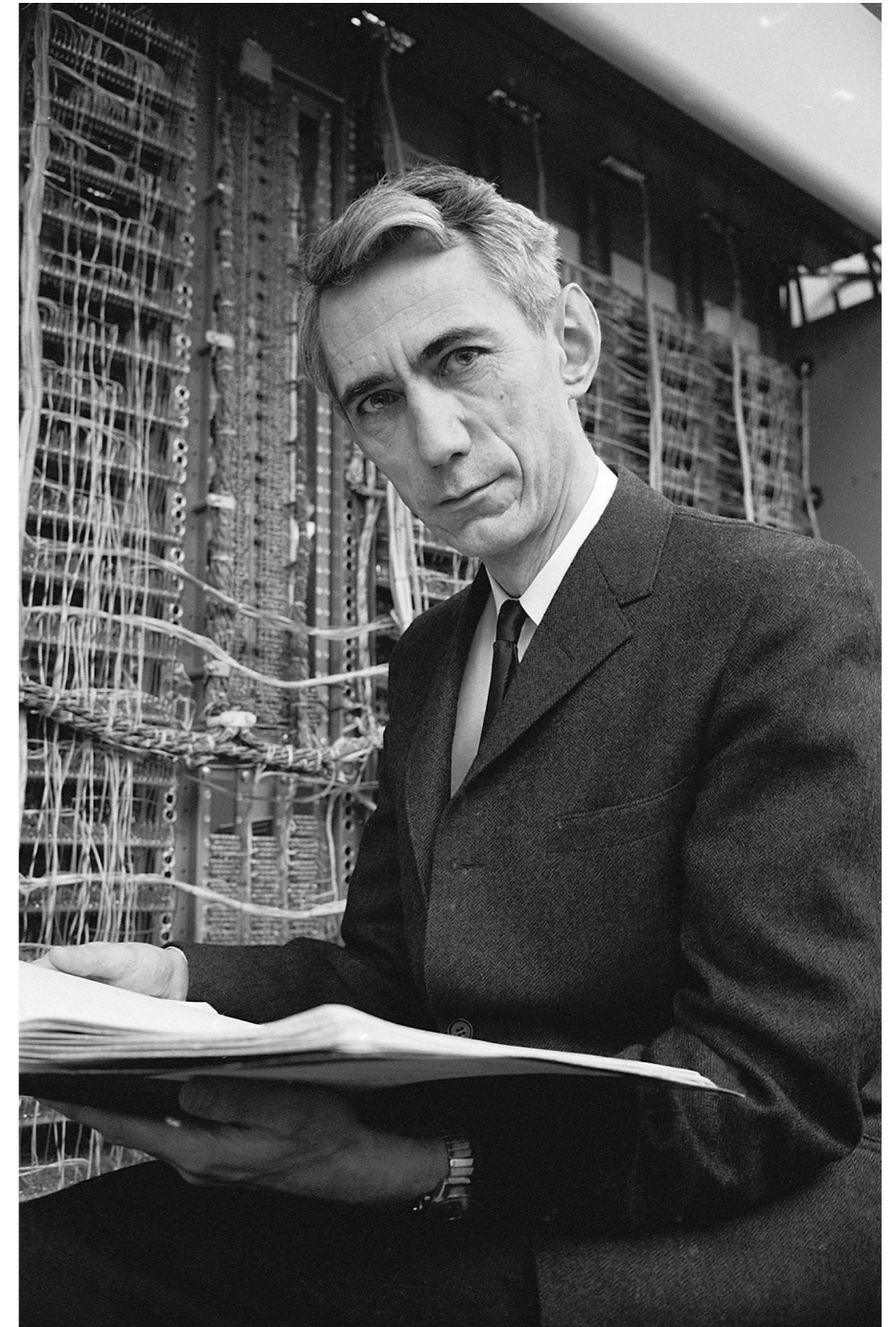
Backup Slides



“*Information is the resolution of uncertainty.*”

向農(Shannon)提出用**機率倒數取對數的期望值**，當成**量化不確定性**的指標，這便是大名鼎鼎的**熵**。

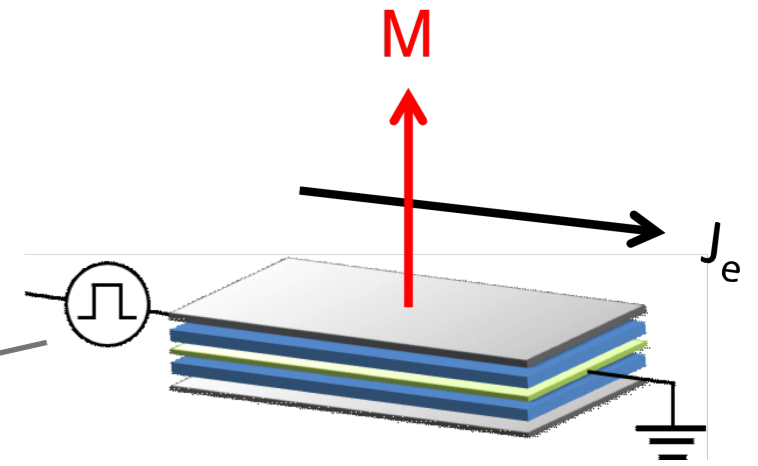
$$H = \sum_n p_n \log_2(1/p_n)$$



Claude Shannon (1916-2001)

# 自旋-軌道力矩

藉由電流脈衝產生自旋-軌道力矩

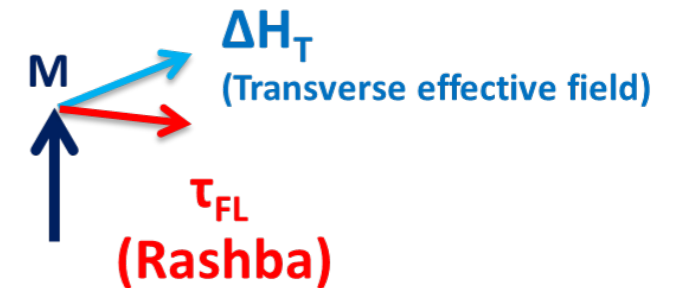
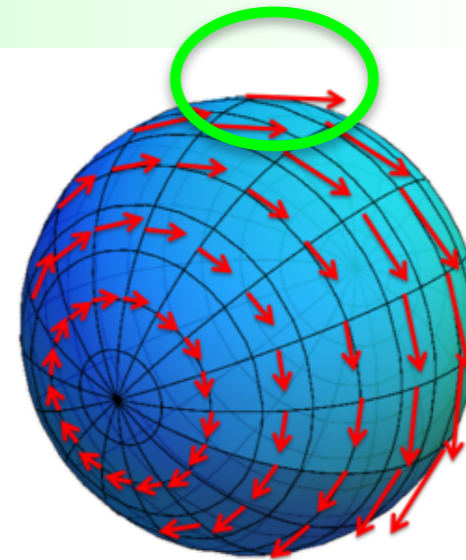


## Rashba interaction

$$\tau_{Rashba} = -\hat{m} \times \vec{H}_R$$

(Field-like torque)

*Nature* 476, 189-193 (2011)

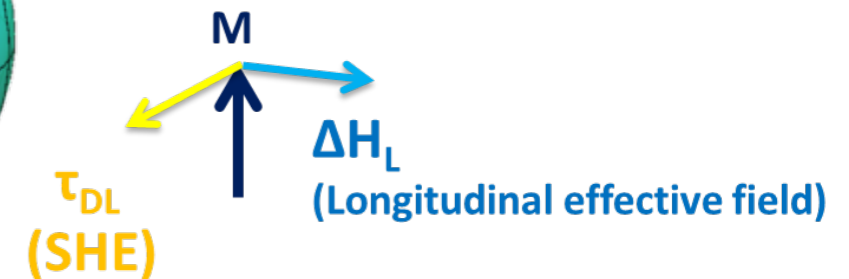
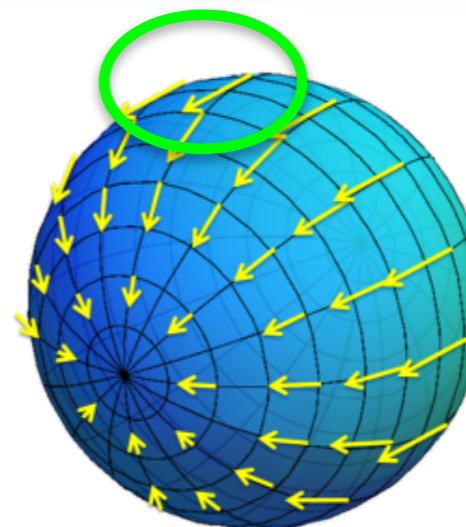


## Spin Hall Effect

$$\tau_{SHE} = \frac{\theta_{SH} \hbar}{2eM_{St}} J_c (\hat{m} \times (\hat{\sigma} \times \hat{m}))$$

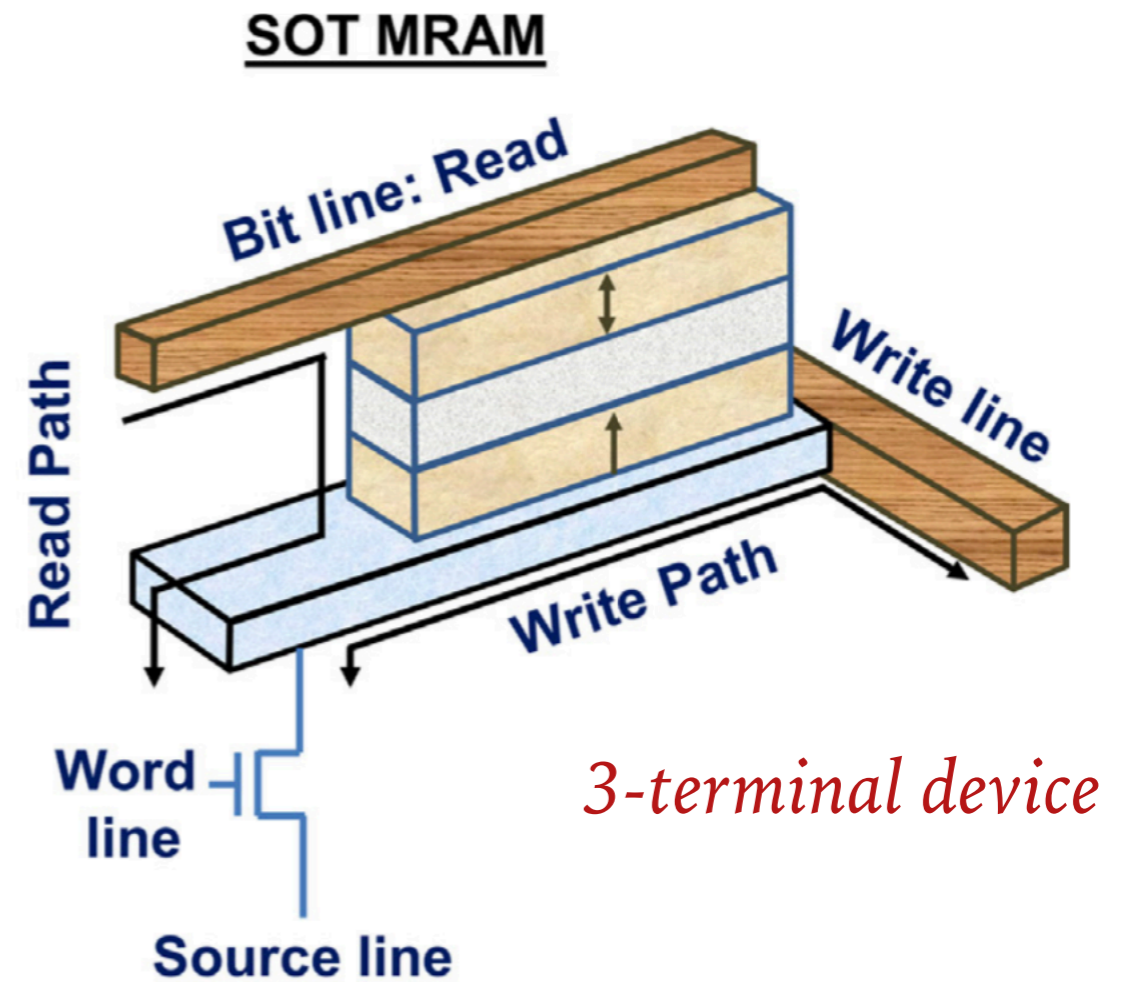
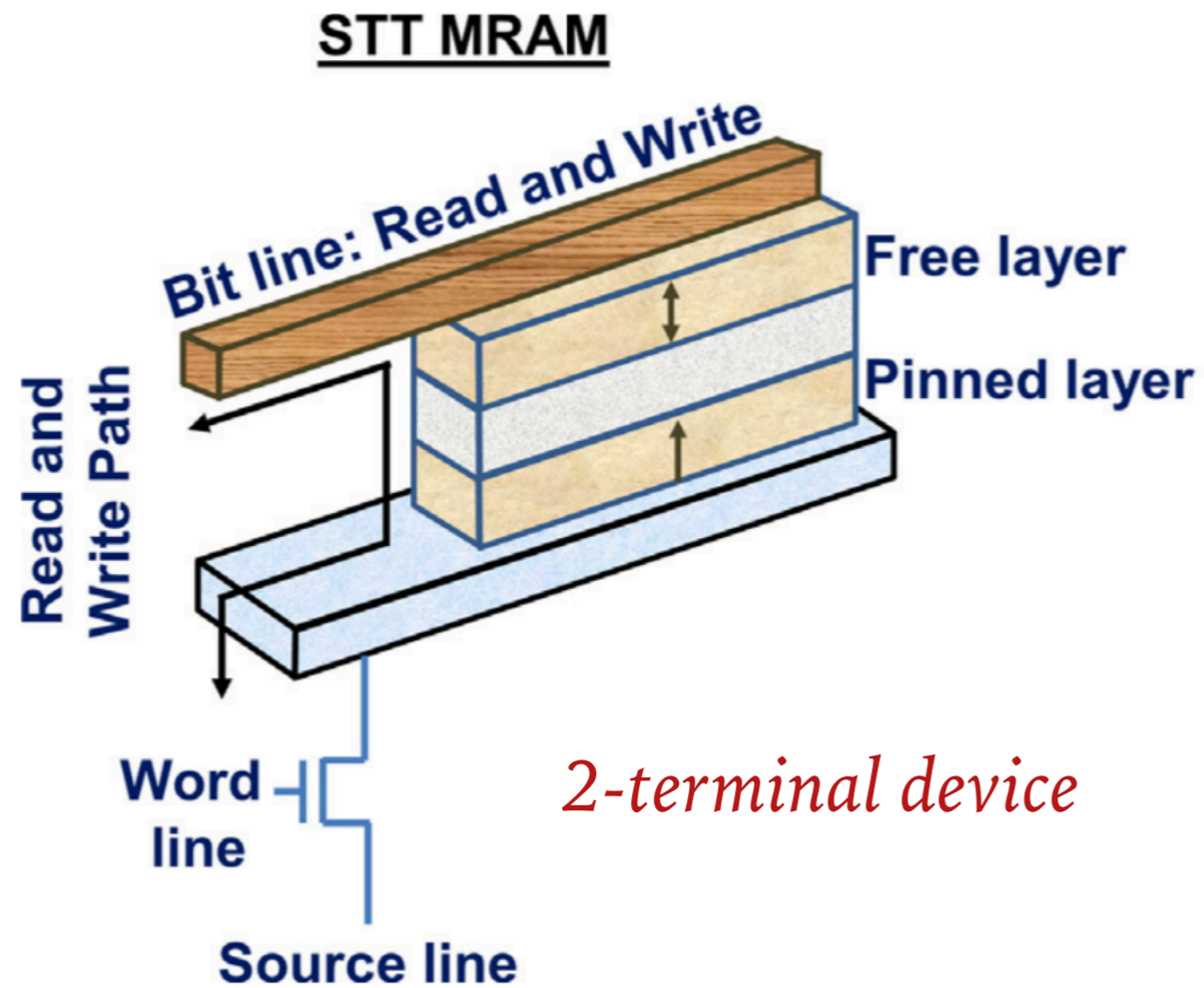
(Damping-like torque)

*Phys Rev Lett* 109, 096602 (2012)



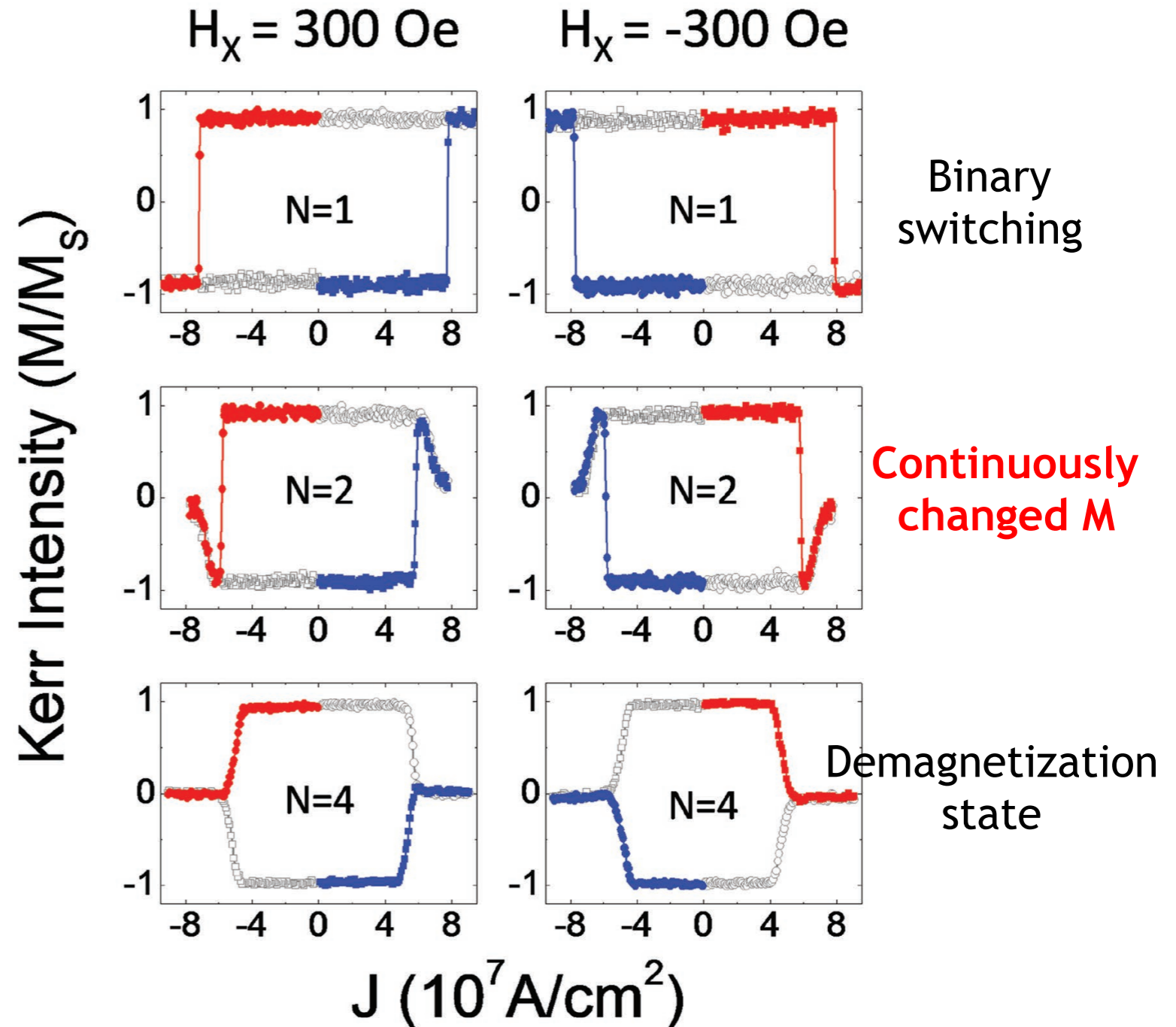
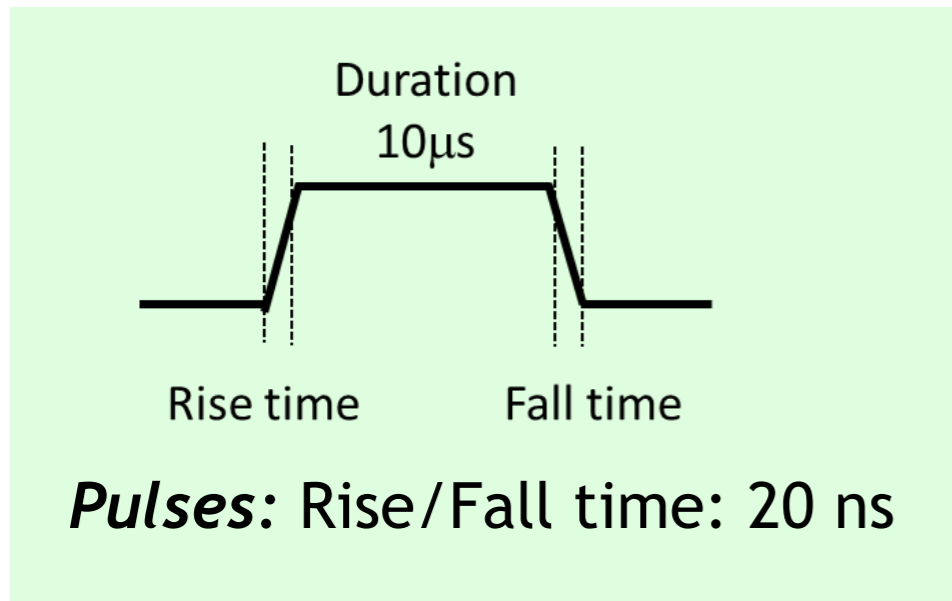
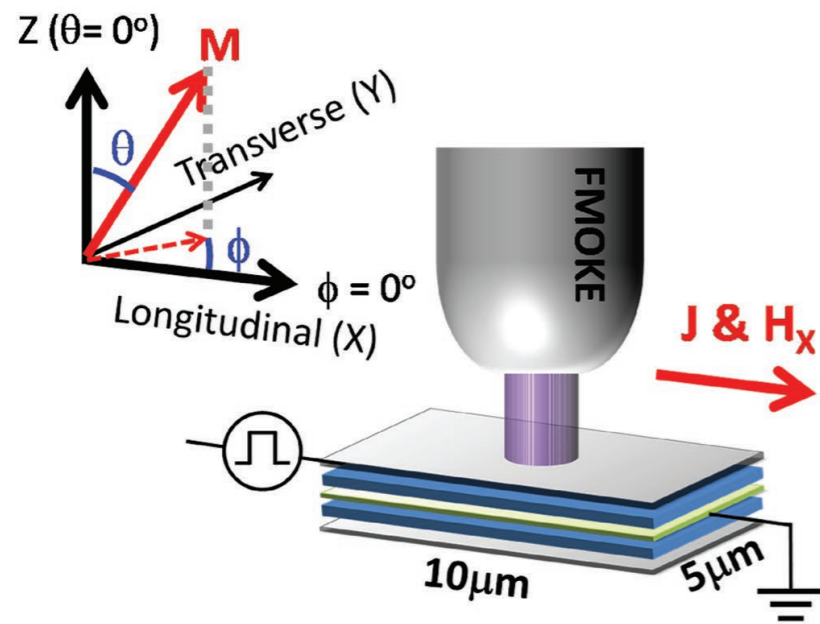
# 現在 (STT MRAM) V.S. 未來 (SOT MRAM)

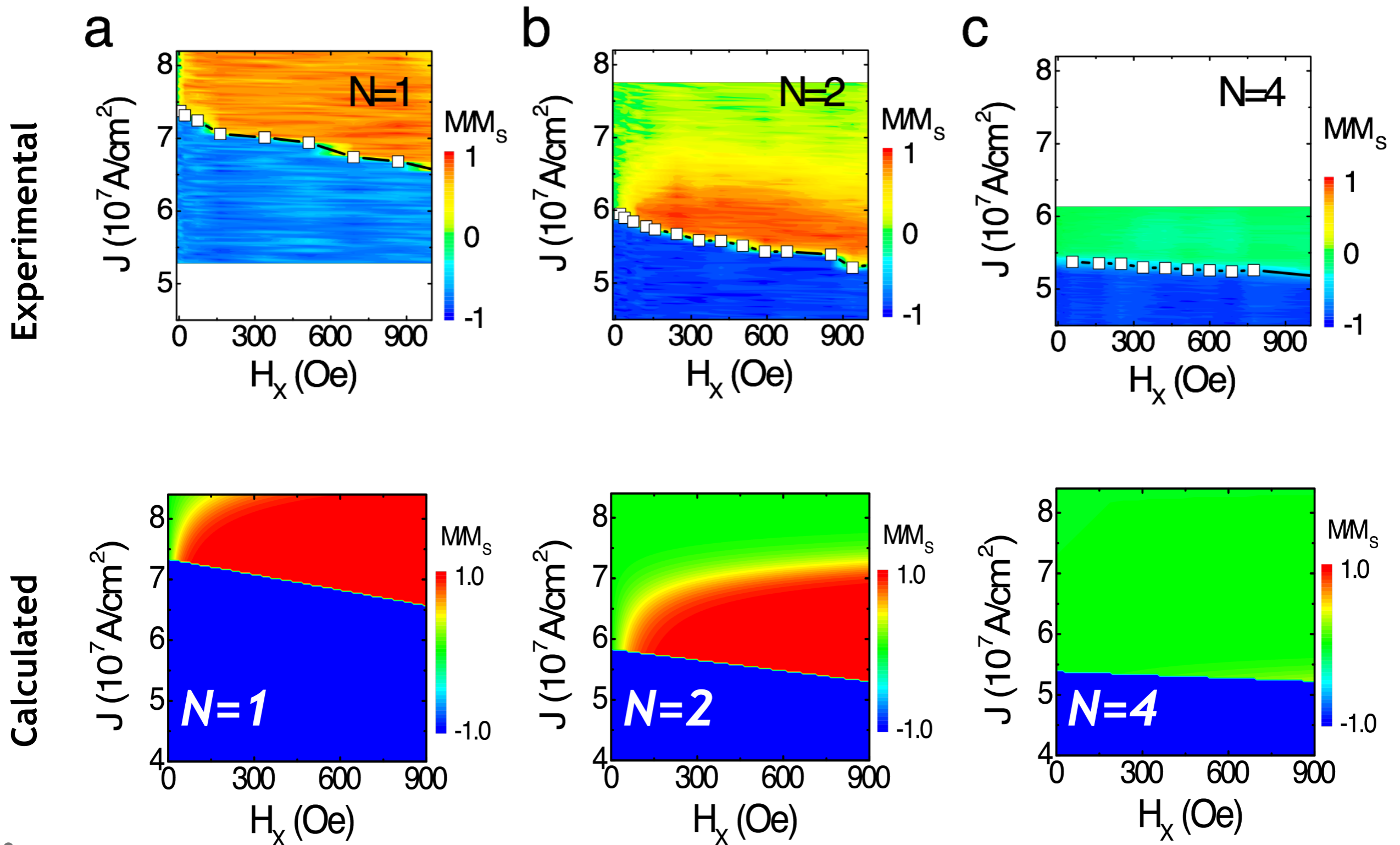
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# 多組態磁性記憶體

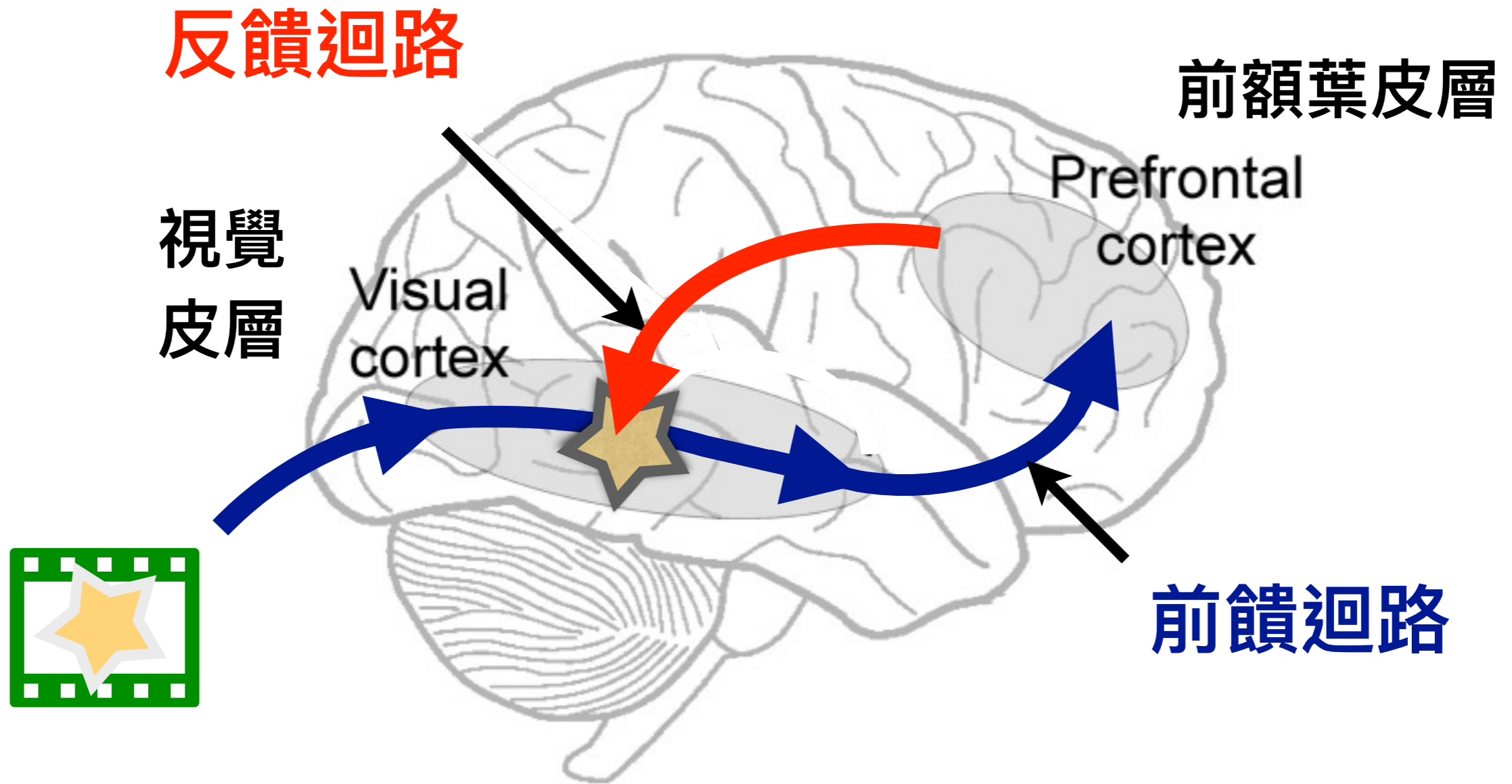
*Advanced Materials* 29, 1601575 (2017)





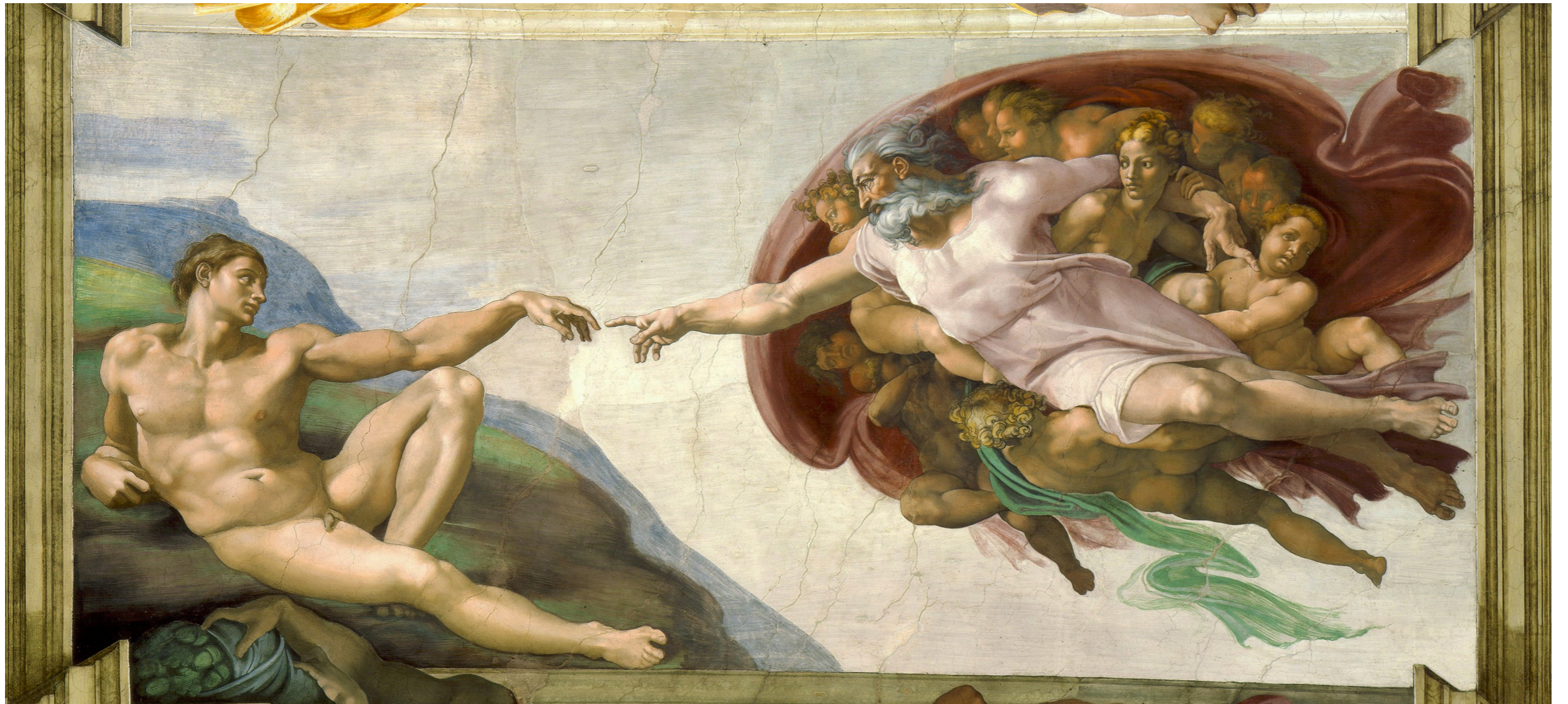
# 前饋與反饋迴路

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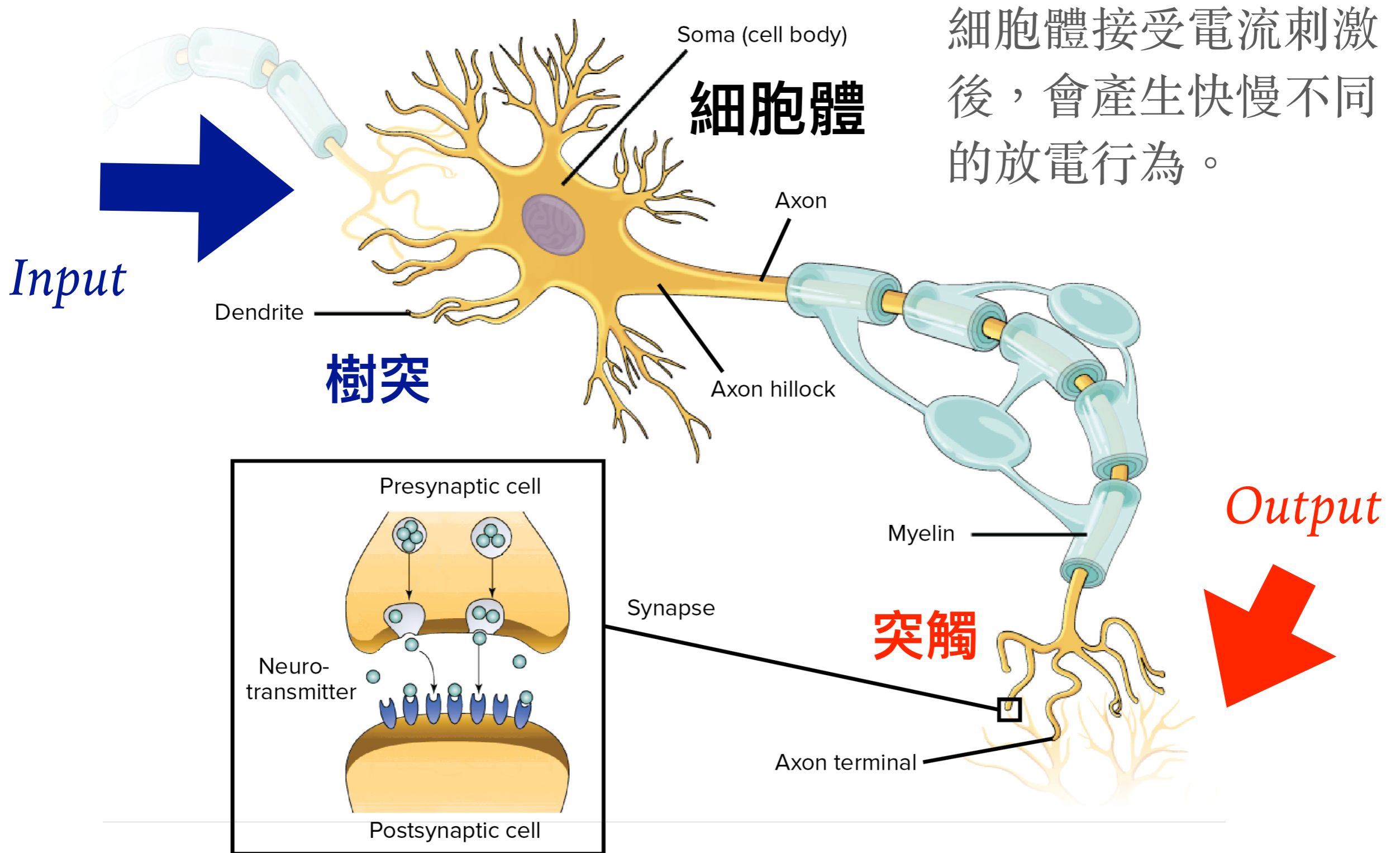
# 理性的源頭

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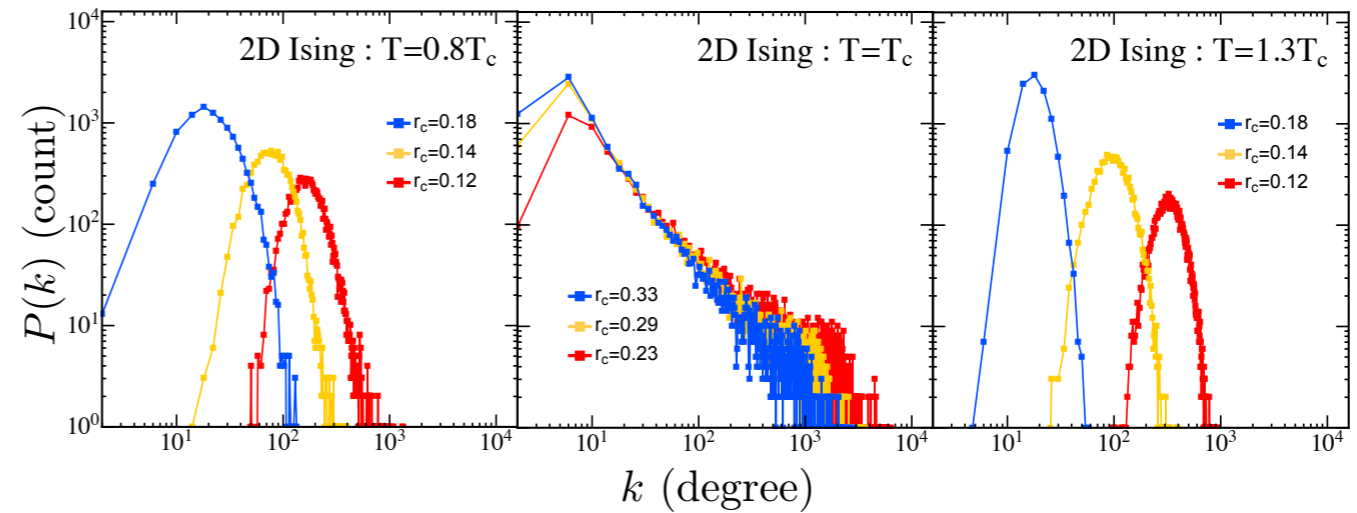
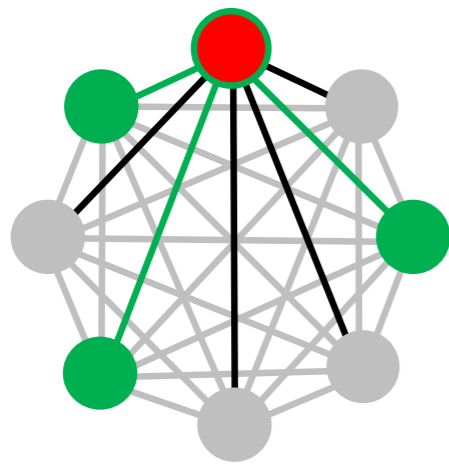


你曾造訪西斯汀大教堂，看看米開朗基羅的畫嗎？

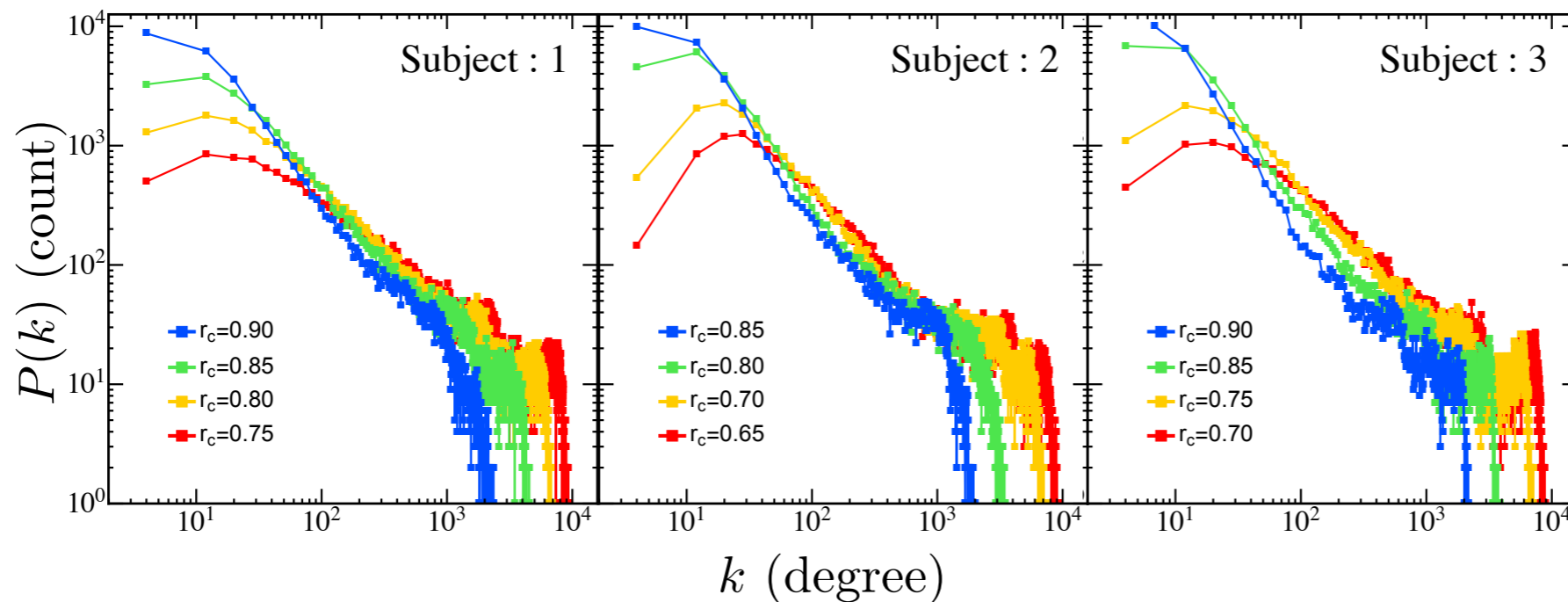
# 神經元細胞



# 我們有個臨界腦？



大腦的動態連結似乎顯示它就在臨界點附近



# 大腦演化快速

## Brain Matters

The brains of Millennials and their Baby Boomer parents already differ as age leads to neurological changes.



### Baby Boomers

Aging brains:

Like repetition and interpret familiar information as truth

Have a harder time suppressing distractions

Are open to more information and have longer attention spans

Source: Nielsen NeuroFocus research; brain icon by Anisha Varghese from the Noun Project



### Millennials

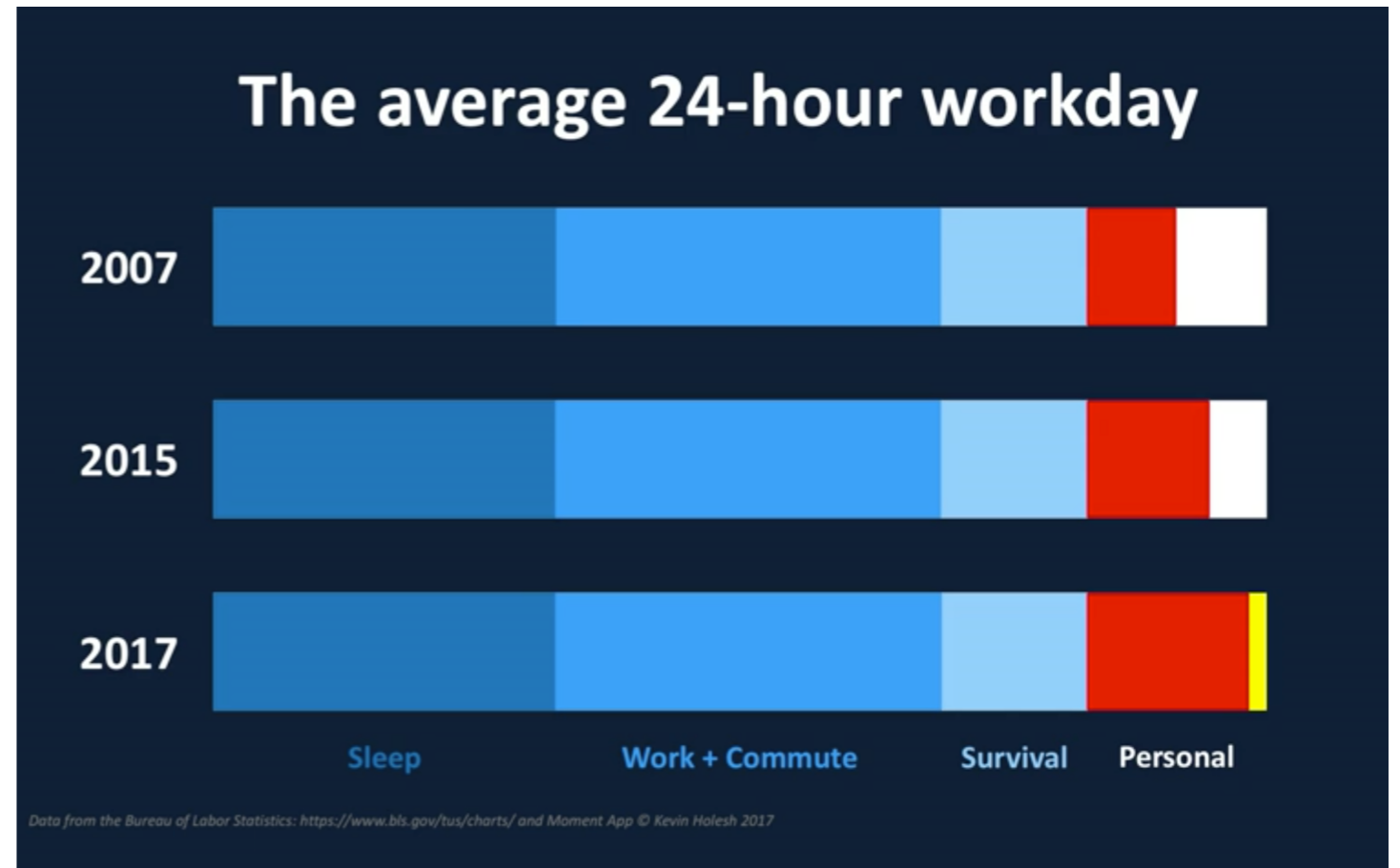
Younger brains:

Engage and remember information presented with rich media or lighting

Have an easier time with multifaceted communication, like banner ads integrated with online stories

Seek multi-sensory communications such as interactive sites

Graphic by Alexandra Kanik / PublicSource

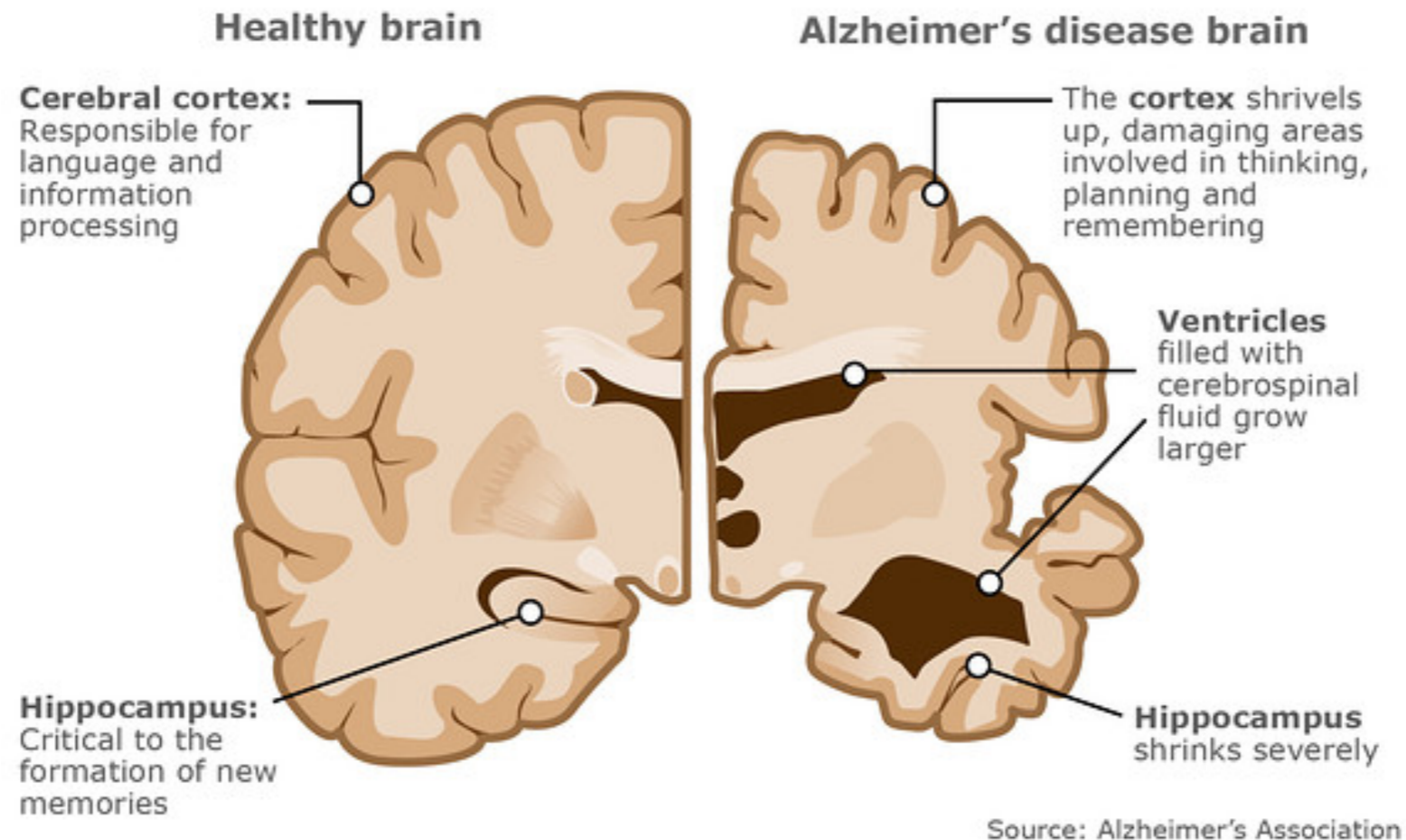


現代科技改變年輕人生活型態，  
也加速大腦神經網絡演化：  
**多感官**、**多工**、**高互動**、**短專注**

# 阿茲海默症

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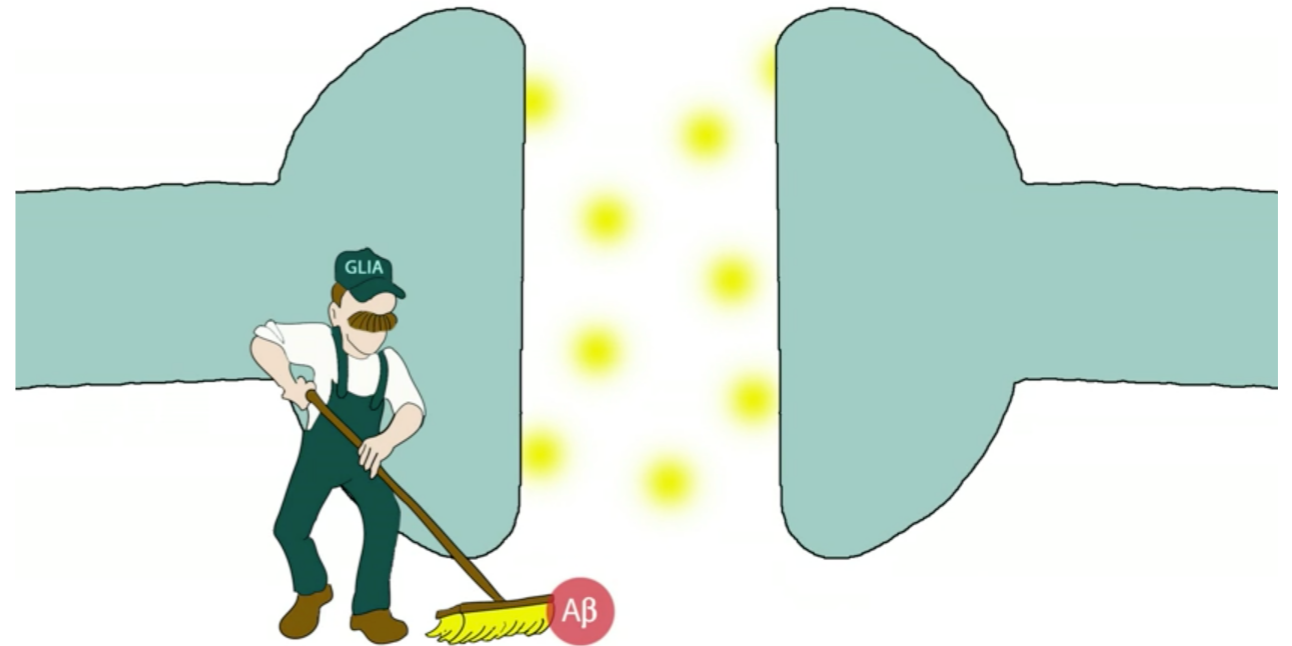
## Alzheimer's disease



左邊是**正常大腦**，右邊是**阿茲海默症患者**大腦，  
出現不正常的**萎縮**症狀

# 神經細胞傳導不良

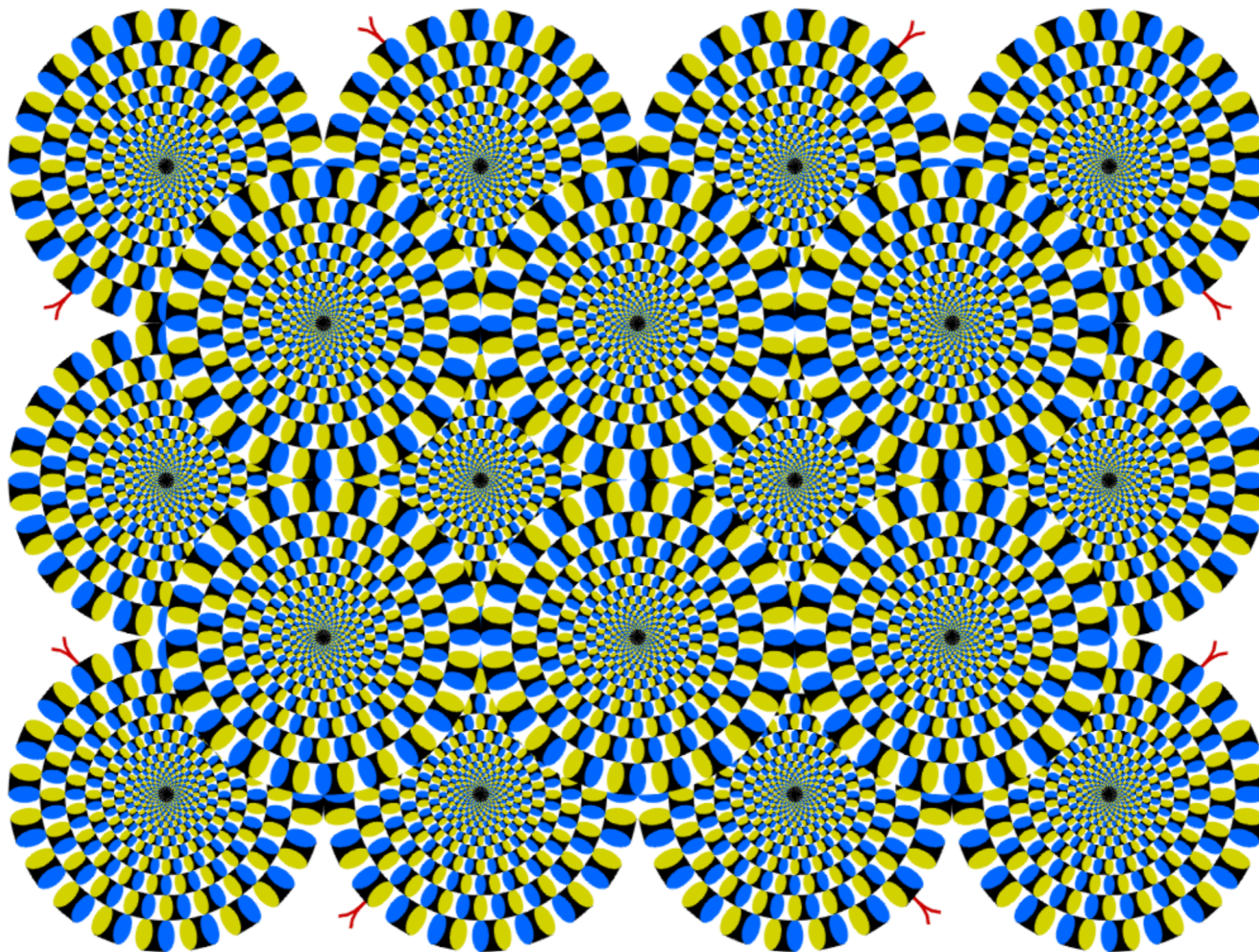
突觸是神經傳導必經之處，累積的化學雜質腦內會自發清理。



*Lisa Genova (TED 2017)*

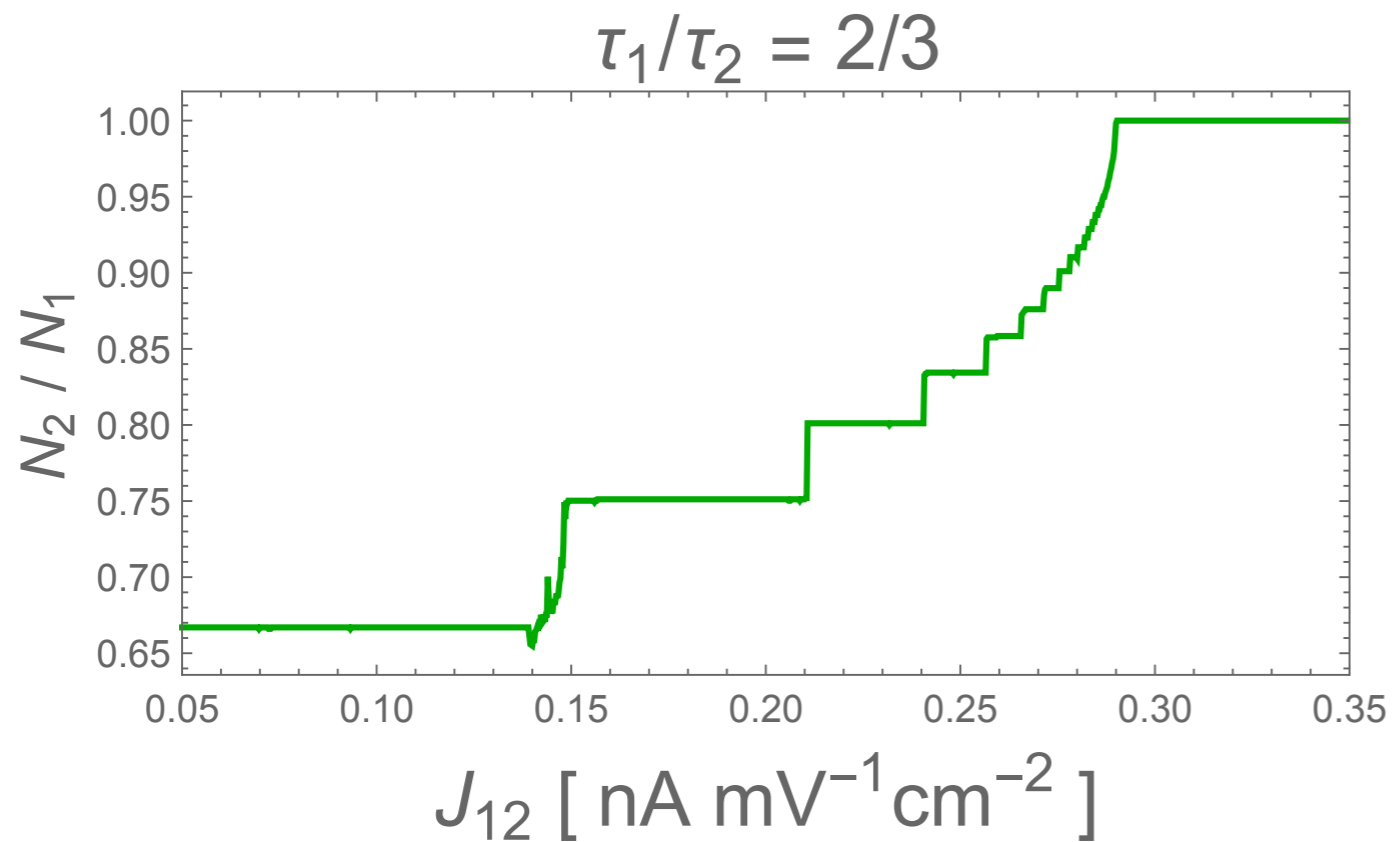
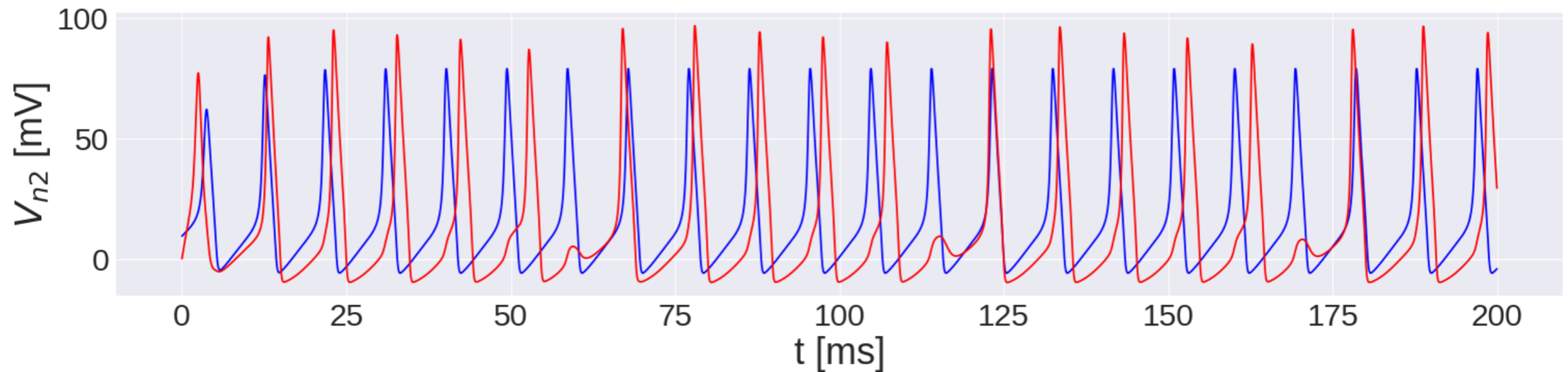


若是化學雜質**累積結塊**，就會**阻擾神經傳導**，則突觸就喪失功能。



蛇在扭？還是大腦在扭？

# 分數鎖模現象



分數鎖模現象可以做為  
邏輯閘的設計基礎

