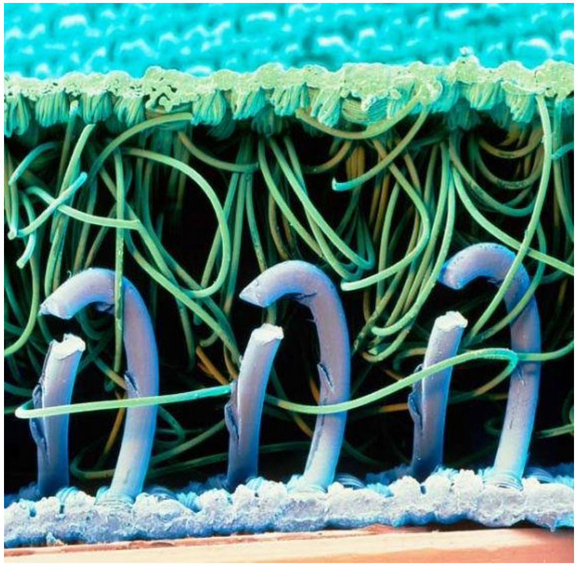
Biomimetics (Biomimicry, Bioinspiration)

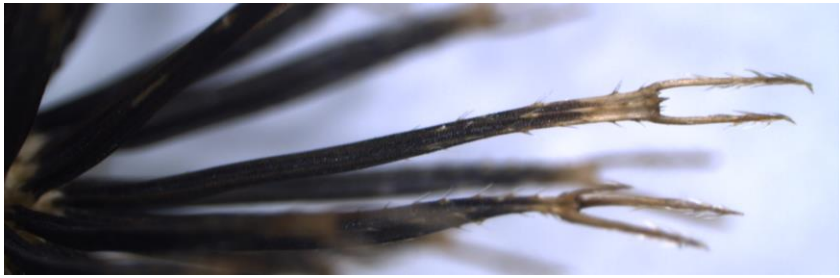
- **Bio**logy + **Mimetic** (imitating_เลียนแบบ)
- Learn from biological structure/function
- Adapt to Manufacturing_การผลิต

Wild Chrysanthemum fruits
Attach to animal hair/human clothes to deliver

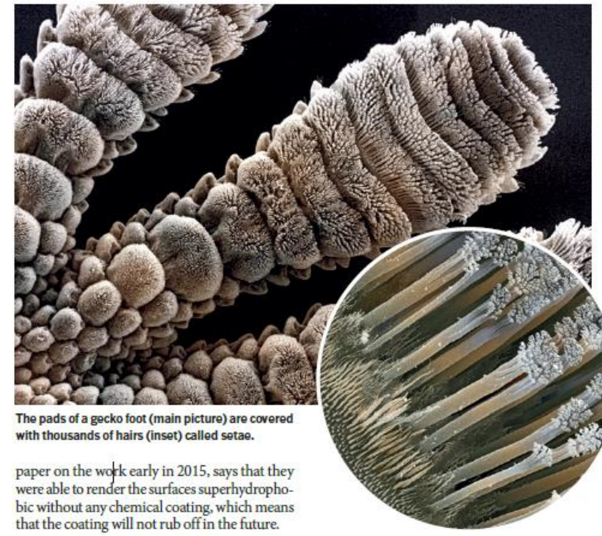
→ Stick and Separate…



http://karapaia.com/archives/51779826.html

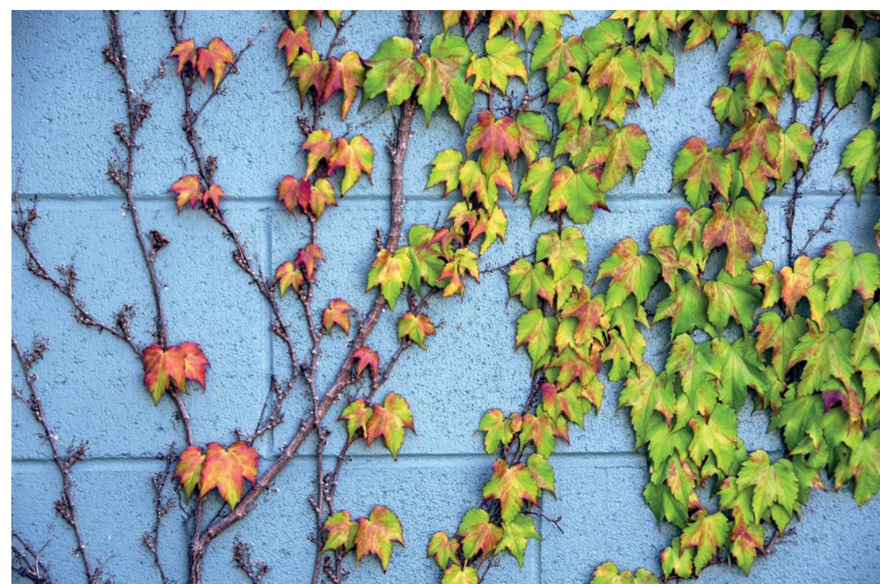


Sticking: Geckos foot and ivy_ ไอวี่, ツタ



Geckos foot

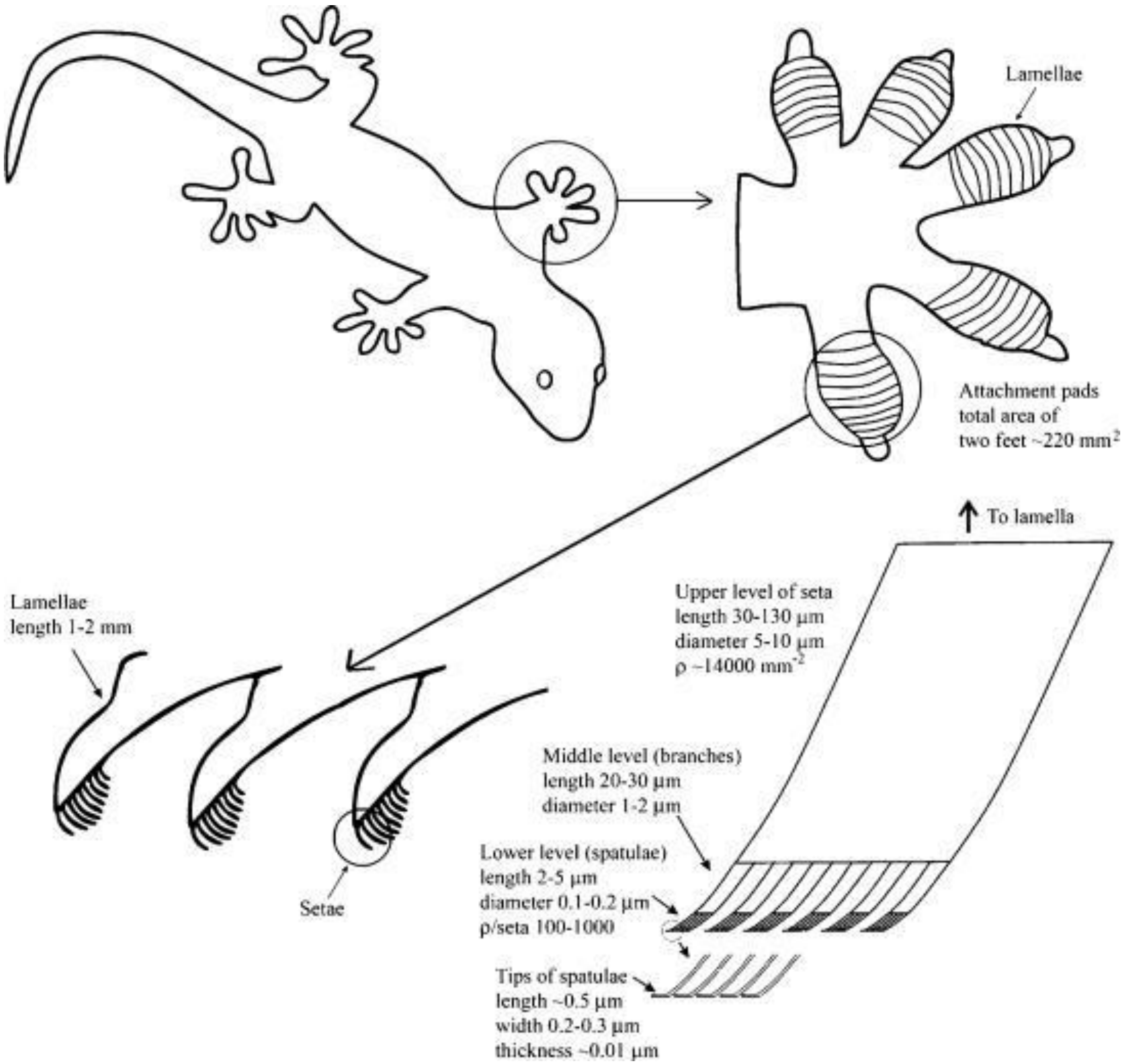
- Very thin structure
- van der Waals force
  (Intermolecular force)

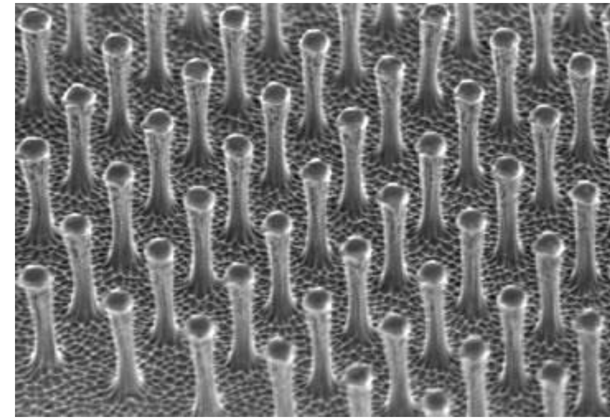


Sticky Ivy

Sucker structure + sticky liquid

Gecko foot


Lamellae
Attachment pads
total area of
two feet ~220 mm^2
To lamella
Upper level of seta
length 30-130 μm
diameter 5-10 μm
ρ ~14000 mm^{-2}
Lamellae
length 1-2 mm
Middle level (branches)
length 20-30 μm
diameter 1-2 μm
Lower level (spatulae)
length 2-5 μm
diameter 0.1-0.2 μm
ρ/seta 100-1000
Setae
Tips of spatulae
length ~0.5 μm
width 0.2-0.3 μm
thickness ~0.01 μm




GECKO
GECKO
GECKO
GECKO
GECKO GRIP
BAR TAPE
ARUNDEL
AVOID A SLIPPERY SITUATION

Nature 519, S3, 2015: Biomaterials

LEARNING FROM NATURE'S BEST

Materials researchers are taking cues from specific plants and animals that make substances that could endow humans with superhero powers. By Julie Gould.

1 SUPER STRONG See page S4

The inspiration

Spiders can make up to seven different types of silk. The strongest is dragline silk, which is used for building webs[1].

Fact Darwin's bark spider (Caerostris darwini) can spin silk threads[2] that can measure up to **25 m.**

The structure

Spider dragline silk is made of fibrils comprising proteins that are made of crystalline structures that provide strength and amorphous, formless, regions that provide flexibility.

The application

Infusing metal into spider silk increases its toughness tenfold[3]. The resulting thread could be used in artificial tendons.

2 SUPER FAST See page S10

The inspiration

Shark skin is made up of tooth-like V-shaped scales called dermal denticles that **align parallel** to the direction of local water flow to reduce drag[4].

The structure

Fact The shortfin mako shark (Isurus oxyrinchus) can reach up to **60 miles per hour** (100 kilometres per hour) in short bursts[5].

The application

A swimsuit made from biomimetic shark skin could increase a human swimmer's speed by almost 7% but the likelihood of it being allowed in competitive sport is slim[4].

References: 1. Römer, L. & Scheibel, T. Prion 2, 154–161 (2008); 2. Gregorič, M. et al. PLoS ONE 6, e26847 (2011); 3. Lee, S.-M. et al. Science 324, 488–492 (2009); 4. Wen, L. et al. J. Exp. Biol. 217, 1656–1666 (2014); 5. Ebert, D.A. et al. Sharks of the World: A Fully Illustrated Guide 230 (Dolby, 2013);

3 SUPER DRY See page S10

The inspiration

The scales of a pine cone are made up of two different layers, each reacting differently to changes in humidity. One layer elongates in damp conditions and the other works to resist this, causing the scales to bend. It is similar to the way a thermostat's bimetallic strip bends in response to changing temperature[6].

The structure

Fact The cones of the knobcone pine (Pinus attenuata) only open their scales to drop seeds in the extreme heat of a **wildfire.**

The application

Researchers have developed smart materials with woollen spikes that are sensitive to relative humidity. The wool spikes open when the wearer sweats and close when the layer dries out.

4 SUPER CLEAN See page S7

The inspiration

The leaves of the lotus plant (Nelumbo spp.) have evolved an intricate structure consisting of papillae covered in a dense coating of wax tubules. Trapped air reduces the liquid-to-surface contact area, so water **rolls off the surface** and collects dust particles on its way[7].

The structure

Fact By 2019, the global nanocoatings market is forecast to reach a value of US$14.2 billion.

The application

Synthetic materials with a hierarchical surface, such as those that mimic the lotus leaf, have **gaps filled with a lubricant** so that the material is stain- as well as water-resistant[8].

5 SUPER STICKY See page S7

The inspiration

Geckos (Hemidactylus spp.) can climb glass walls and hang from ceilings without a visible method of sticking to them. Researchers found that geckos can adhere to gravity-defying surfaces because of the electrostatic interaction between the molecules in their feet and the molecules on a surface[9].

The structure

Fact Geckos' feet are so sticky that, in theory, they could support the weight of a **130 kg** person hanging from the ceiling[10].

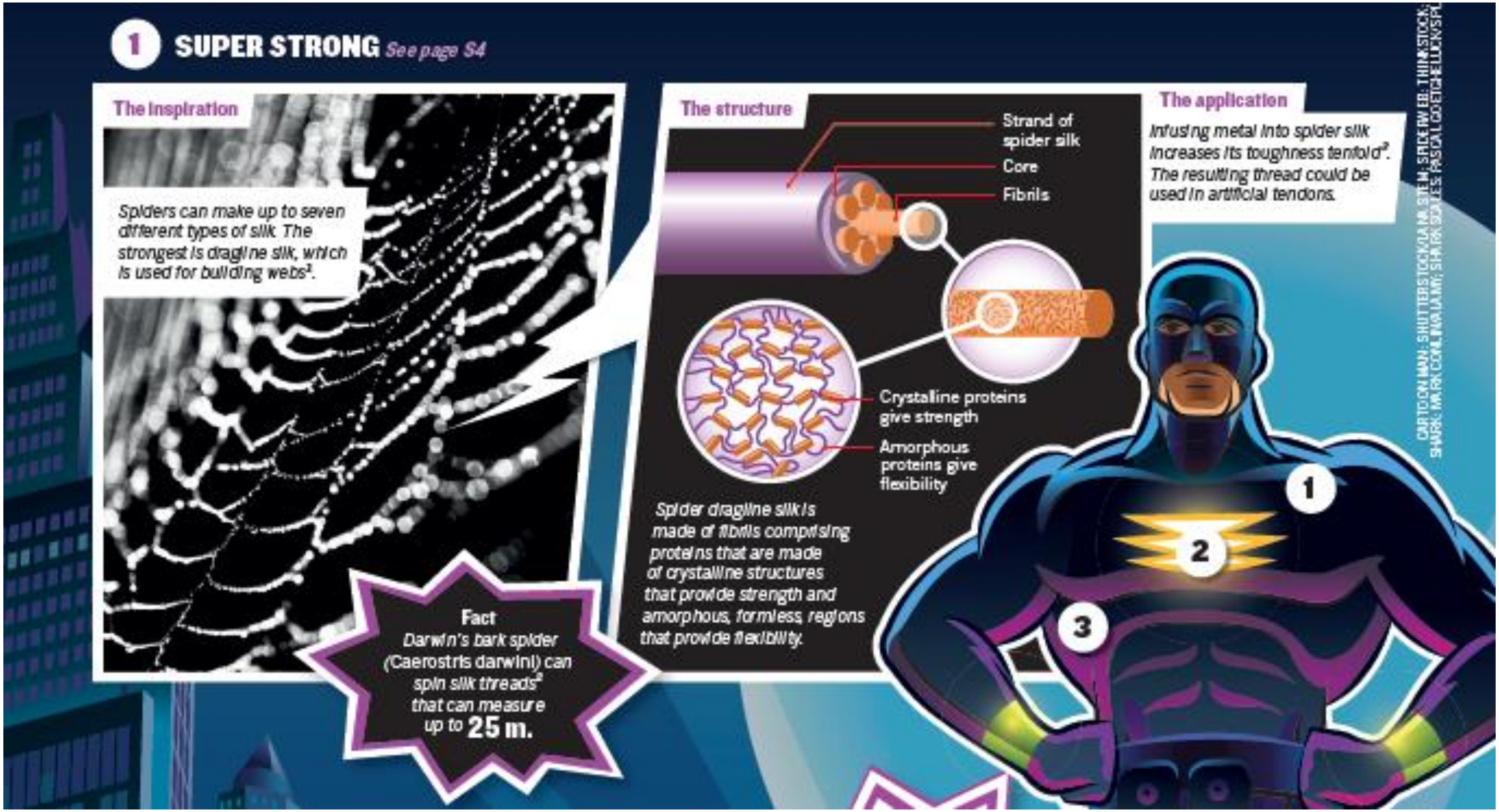
The application

Hand pads, each covered in tiles with tiny silicon rubber hairs that **mimic geckos' feet**, mean humans can scale walls like lizards. The more force applied to the pads, the stickier they become[11].

6. Dawson, C. et al. Nature 390, 668 (1997); 7. Ensikat, H. J. et al. J. Nanotech. 2, 152–161 (2011); 8. Shillingford, C. et al. Nanotechnology 25, 014019 (2014); 9. Autumn, K. et al. Proc. Natl Acad. Sci. USA 99, 12252–12256 (2002); 10. Autumn, K. & Peattie, A. M. Integr. Comp. Biol. 42, 1081–1090 (2002); 11. Hawkes, E.W. et al. Roy. Soc. Interface http://dx.doi.org/10.1098/rsif.2014.06

DESIGN BY MOHAMED A SHOURY/NATURE

Spider silk



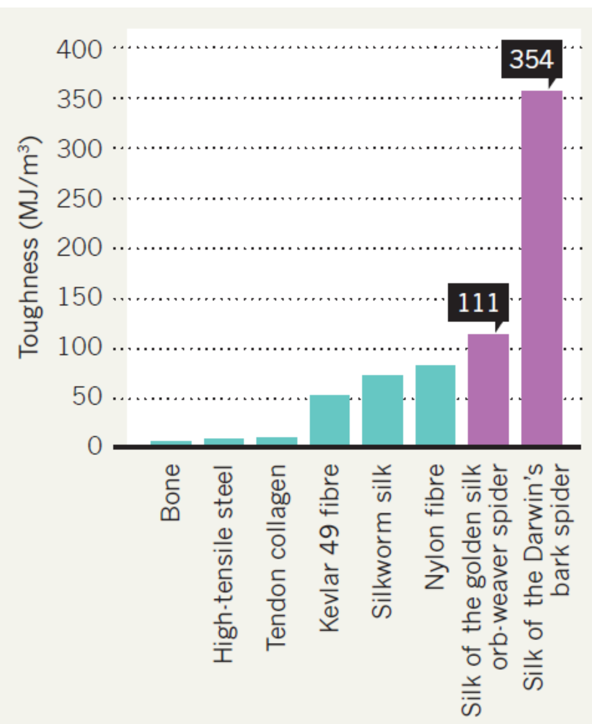
- 7 different types of silk from one spider
- Crystallized protein
- Strong and supple (elastic)

Spider silk

Spiderweb_ใยแมงมุม can be 2m size on the river
7 times stronger than steel, and with elasticity
(Artificial string; still around half strength)

PLoS ONE 2011

Venture from Keio Univ. Japan: **Spiber.Inc (Spider+Fiber)**
- strong fiber, clothes, shock absorption
- strong and <u>light</u> → save energy



クモの糸 柔らか音色

1万本束ね バイオリン弦

2021年11月18日(木)

「夢の繊維」アパレルに新風

クモの遺伝子参考に 脱炭素も追い風

すぐれた伸縮性と強度

世界で開発競争 投資も

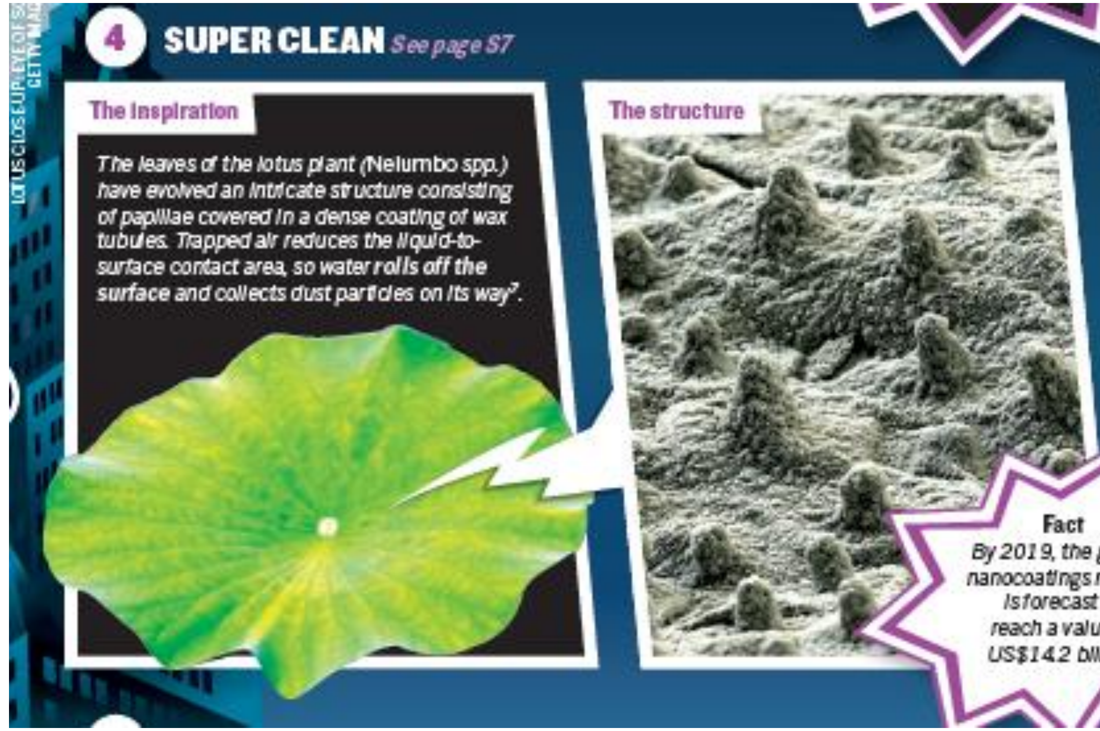
Darwin's bark spider

https://www.youtube.com/watch?v=gSwvH6YhqIM

Superhydrophobic (water-repellent)

- **Lotus leaves (lotus effect)**
- Surface cell structure
- water repelling
- dirt absorption

→ super-clean



Lotus-leaf Sake, Kyoto temple

Small holes on leaf vastulature

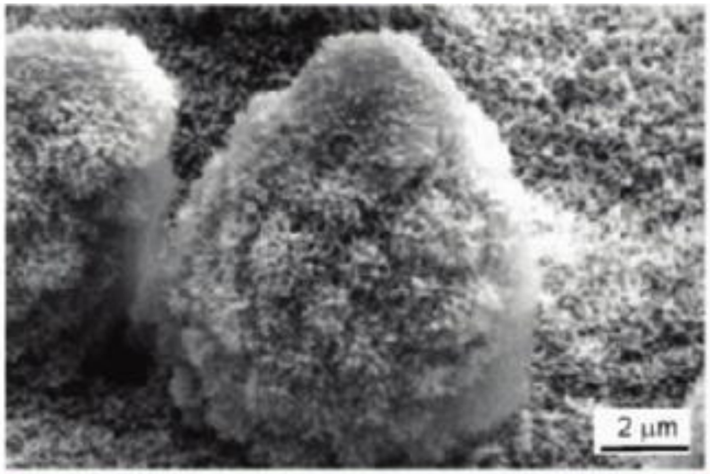
Pour Sake on the leaf and drink

Good for your health and long life

SEM imaging of leaf epidermal cells

Small hairs on surface

Interval of cells, cell structure, and water viscosity_ความหนืด （粘度）



Lotus Effect - superhydrophobic, self-cleaning, low adhesion (Bhushan et al., 2009)

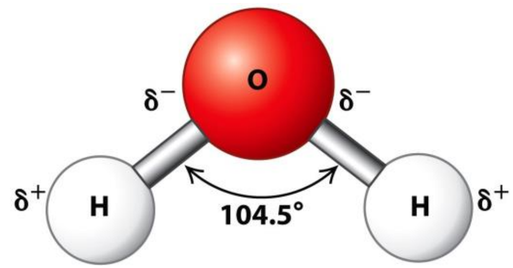
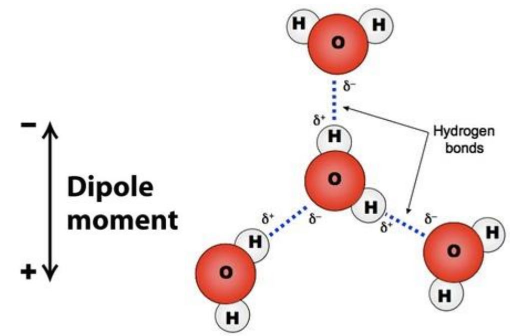
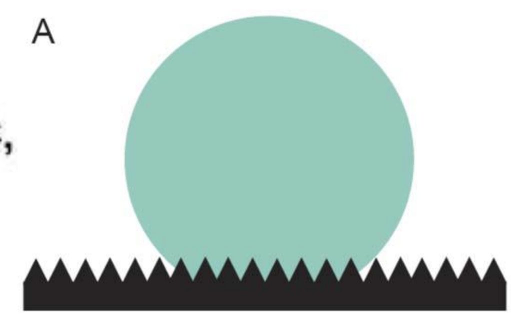


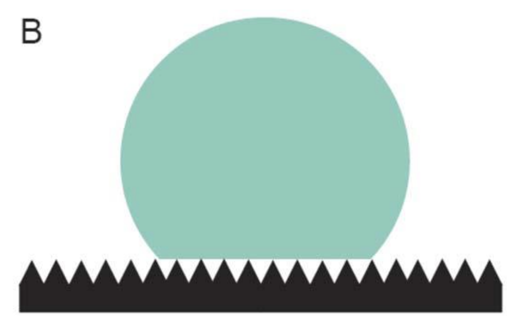
Figure 2-5
Molecular Cell Biology, Sixth Edition
© 2008 W. H. Freeman and Company

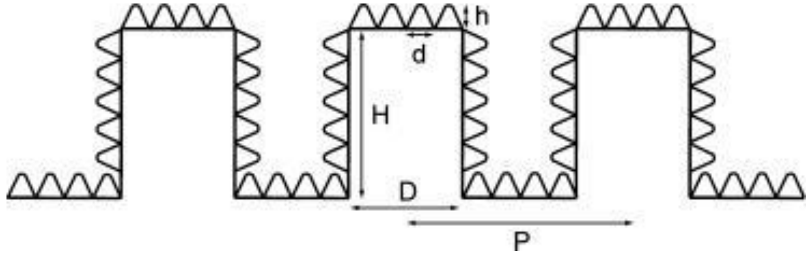


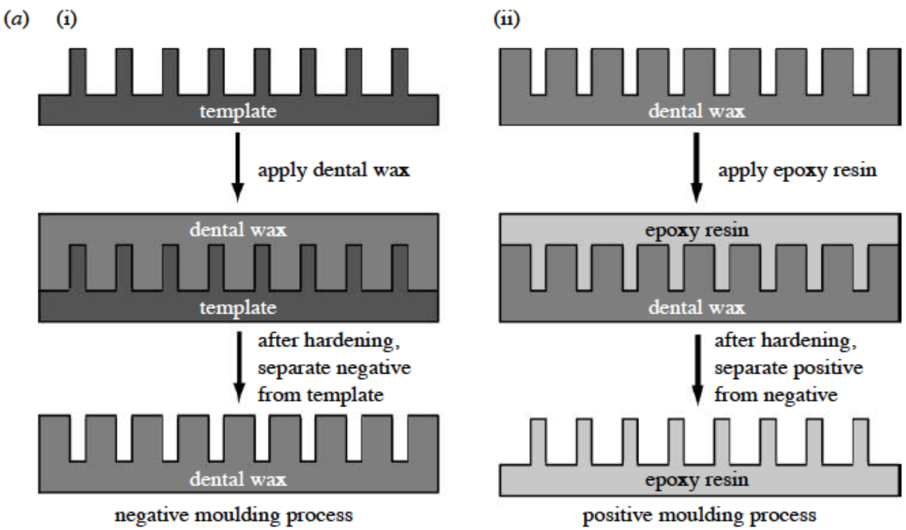
Wenzel wetting



Cassie-Baxter wetting

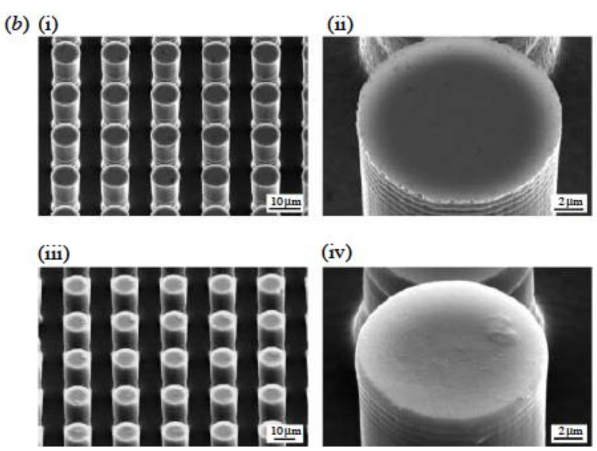






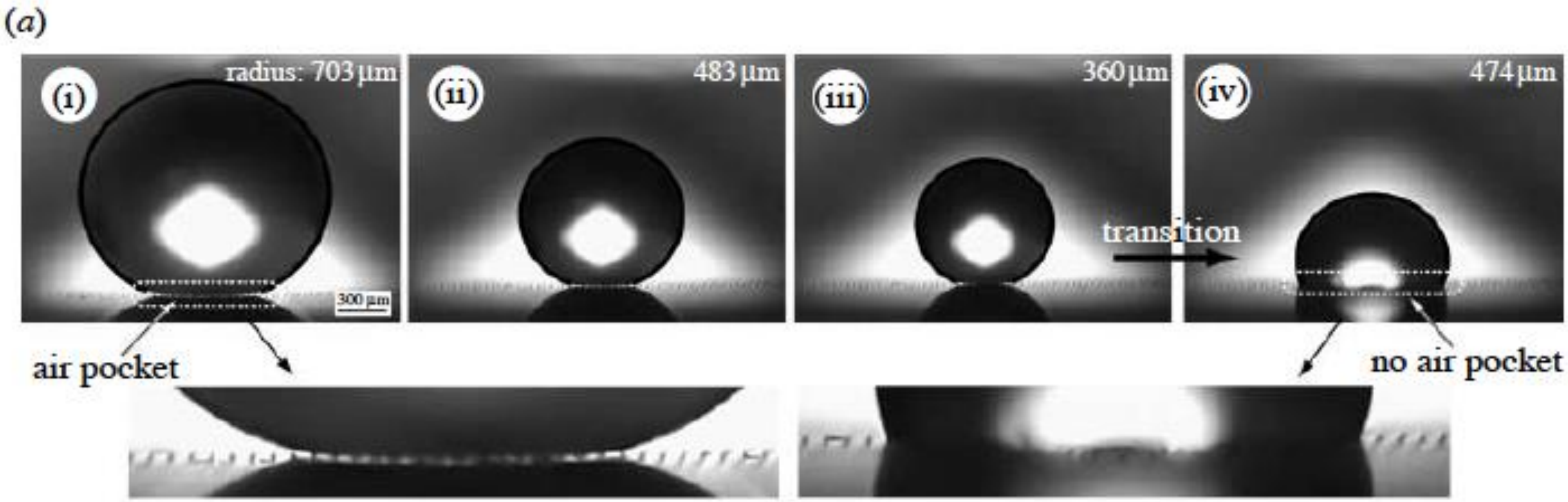
How to make replica

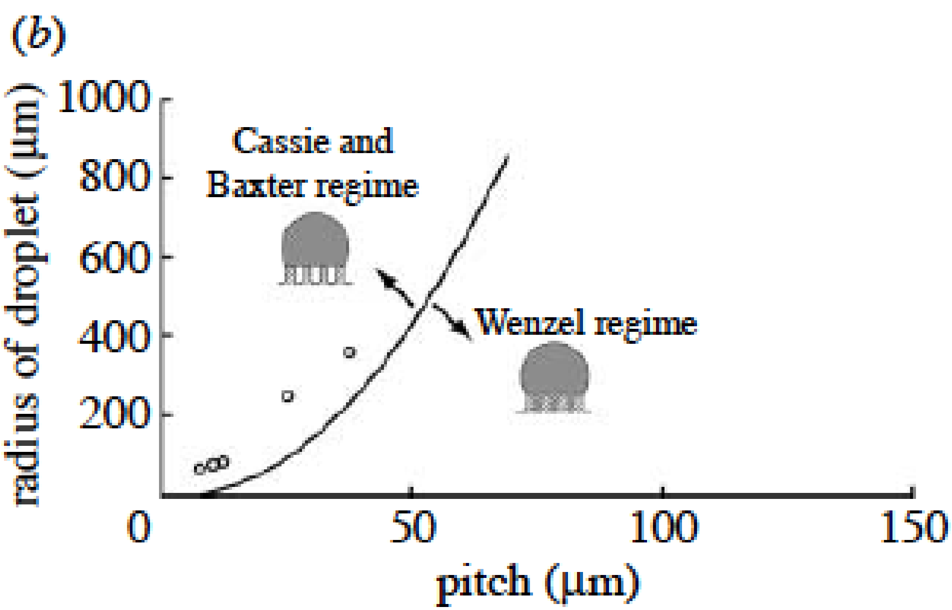
(dental resin)



Si (silicon) surface

14 µm diameter
30 µm height
23 µm pitch





Interval of 凸凹_ความไม่สม่ำเสมอ

Size of droplet

Water repellency

Bhushan et al., Phil. Trans. R. Soc. A 2009, 367, 1631

Lotus effect

・superhydrophobic
・self-cleaning

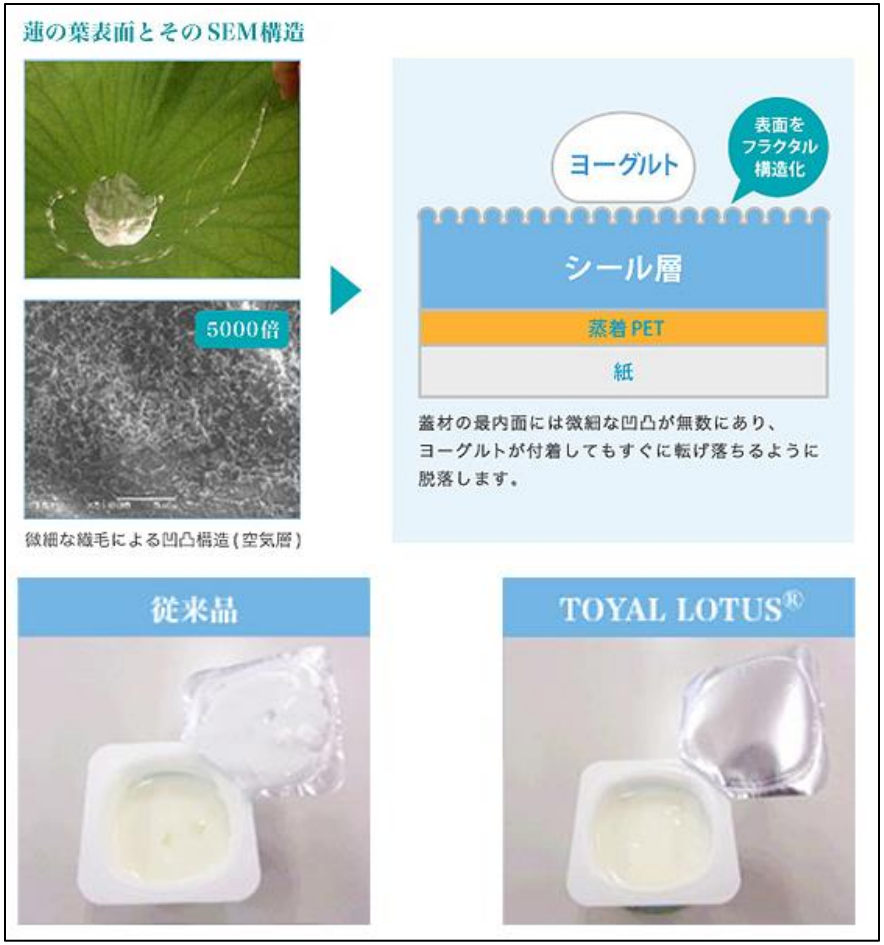
蓮からヒントを得た「濡れない傘」

きっかけはクレームから開発費用は数千万円

　もうひとつのヒット商品は「濡れない傘」だ。傘は通常、生地にフッ素コーティングなどの加工を施して撥水性を出す。当然、時間の経過とともにその機能は衰え、雨のたびに傘が水を含むようになる。福井県の傘メーカー「福井洋傘」の濡れない傘「ヌレンザ」は、ハスの葉の見事なまでの撥水性に着目し、生地そのものの織り方を工夫することで薬剤加工なしに抜群の撥水性を実現した商品だ。当然、月日がどれだけ経とうが機能が衰えることもない。1本3万円を超える高額傘であるにもかかわらず、注

ロータス効果で超撥水レクサスとのコラボも表面が細かな凹凸で構成されているハスの葉の仕組みを、超高密度ポリエステルを用い、縦糸と横糸の織り方を工夫することで再現した傘ヌレンザ（写真提供：福井洋傘）

Water repelling umbrella
JPY 30,000 (THB 8,500)



Other examples

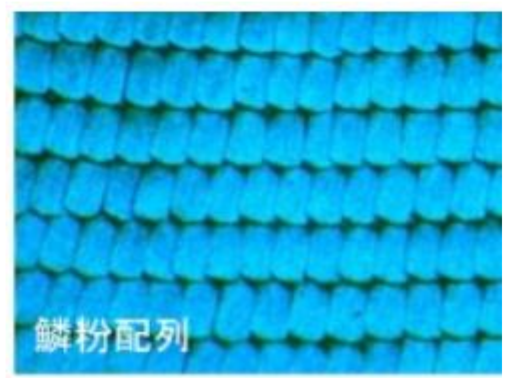
- Birds beak → train head (Super-express)

- Mosquito needle → injection needle

- Snail shell → wall with less dirty

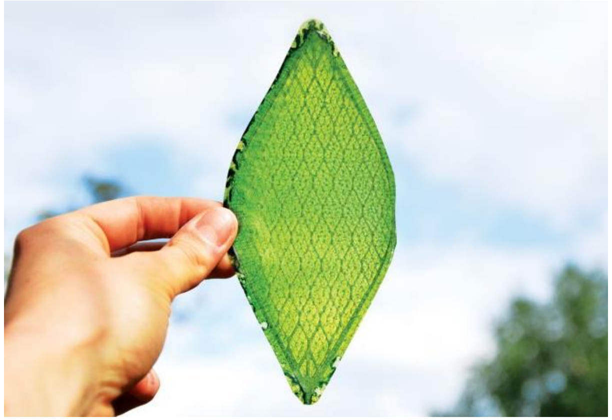
- Moth eye → screen with less reflection

- Morpho butterfly → structural color



https://www.cmicgroup.com/-/C-PRESS/web/00_16.html
http://www.yoshioka-lab.com/kaisetsu/morpho.html

Artificial leaf: silkworm silk + chloroplast



https://createdigital.org.au/artificial-leaves-building-green-infrastructure/

Green island (moth larvae)

https://simonleather.wordpress.com/2019/09/10/green-islands-mining-cytokinins/

Elowan: A plant-robot hybrid (MIT media lab)

cybernetic lifeform

bio-electrochemical signals

Cyborg Botany

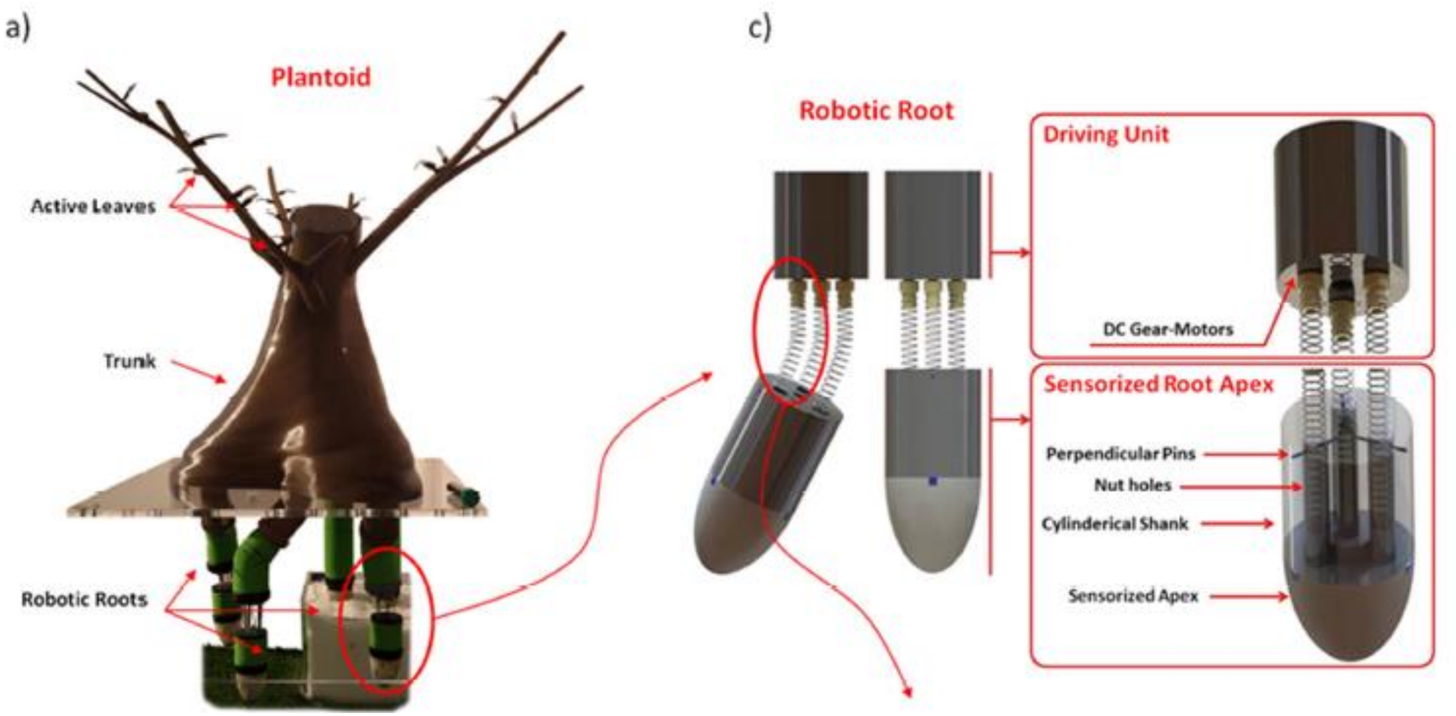
Move by itself towards light
https://www.youtube.com/watch?v=EoXQBQR5OaE

Plantoid (sensorized robotic roots)

Sadeghi et al. 2016
Bioinspiration & Biomimetics

Natural roots (reaction to environmental parameters, i.e. tropisms)
(1) multi-sensing capability
(2) soft bending behavior

Mimicking root system by soft spring-based actuation (SSBA) systems
4 different sensors: touch, humidity, gravity, temperature



Conclusions

- Answers lie in nature

    The answer is blowing in the wind

- Learn biology and adapt to technology

- Depends on your idea!

    (you can be a millionaire)

20 minutes break with watching TED

TED by Heather Barnett
What humans can learn from semi-intelligent slime
「準知的粘菌が人類に教えてくれること」
https://www.ted.com/talks/heather_barnett_what_humans_can_learn_from_semi_intelligent_slime

Finding out **the rule in nature**

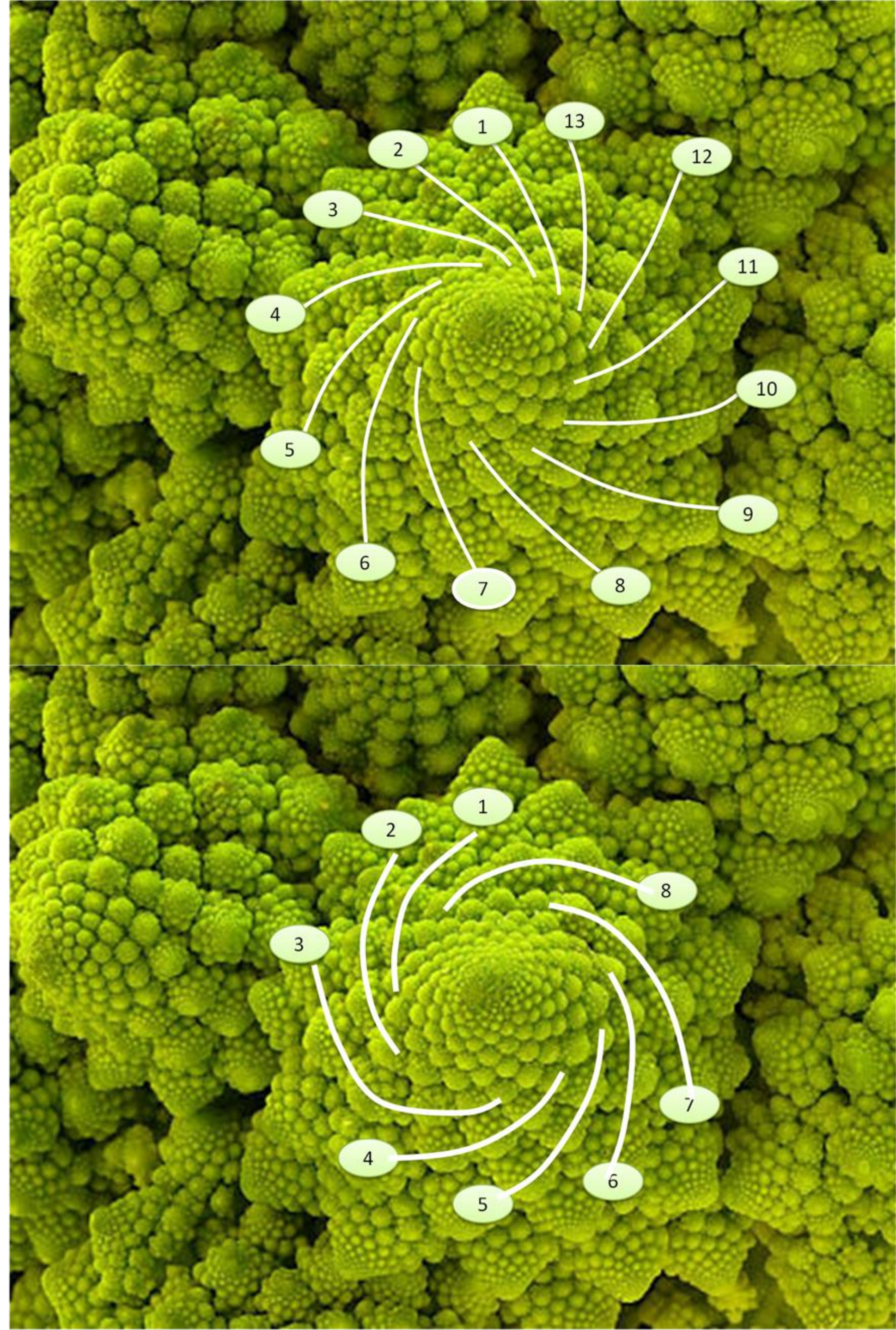
- Phyllotaxis (angle of leaves)

- Fibonacci sequence, golden ratio

Kyoto Botanical Garden

Romanesco (Brassica)

Kondo lab, Oaska Univ



Calculate the spiral pattern?

Golden ratio

Plant spiral pattern: **137.5°**

Leonard Pisano
(Fibonacci)

Fibonacci number/sequence

$$F_{k+1}=F_{k+}F_{k-1}$$

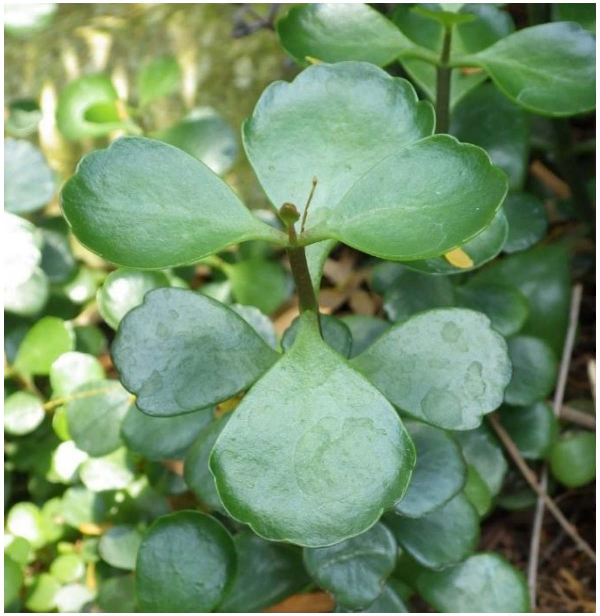
1,1,2,3,5,8,13,21,34,55,89,144,233...

Leaf angle

180°

120°

90°



137.5°

1. เขียนลำดับฟีโบนักชีจาก 1 คำนวณอัตราส่วนของตัวเลขใกล้เคียง 2. คำนวณมุมใบด้วยคำตอบ (หนึ่งวงกลมองศา: 360°)

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, ...

Ratio of neighboring numbers

1/1 = 1
2/1 = 2
3/2 = 1.5
5/3 =
8/5 =
13/8 =
21/13 =
34/21 =
55/34 =
89/144 =
233/144 =

1. Write down the Fibonacci sequence from 1. Calculate the ratio for neighboring numbers.

2. Calculate the leaf angle with the answers.

(One circle degree: 360°)

1. เขียนลำดับฟีโบนักชีจาก 1 คำนวณอัตราส่วนของตัวเลขใกล้เคียง
2. คำนวณมุมใบด้วยคำตอบ (หนึ่งวงกลมองศา: 360°)

Fibonacci sequence

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, ...

Ratio of neighboring numbers

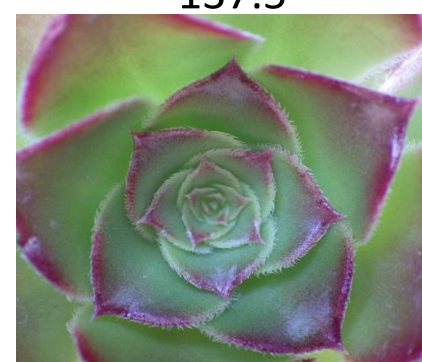
1/1 = 1
2/1 = **2**
3/2 = **1.5**
5/3 = 1.6666666
8/5 = 1.6
13/8 = 1.625
21/13 = 1.615
34/21 = 1.619
55/34 = 1.617
89/55 = **1.618**
144/89 = **1.618**
233/144 = **1.618**

180°

90°

120°

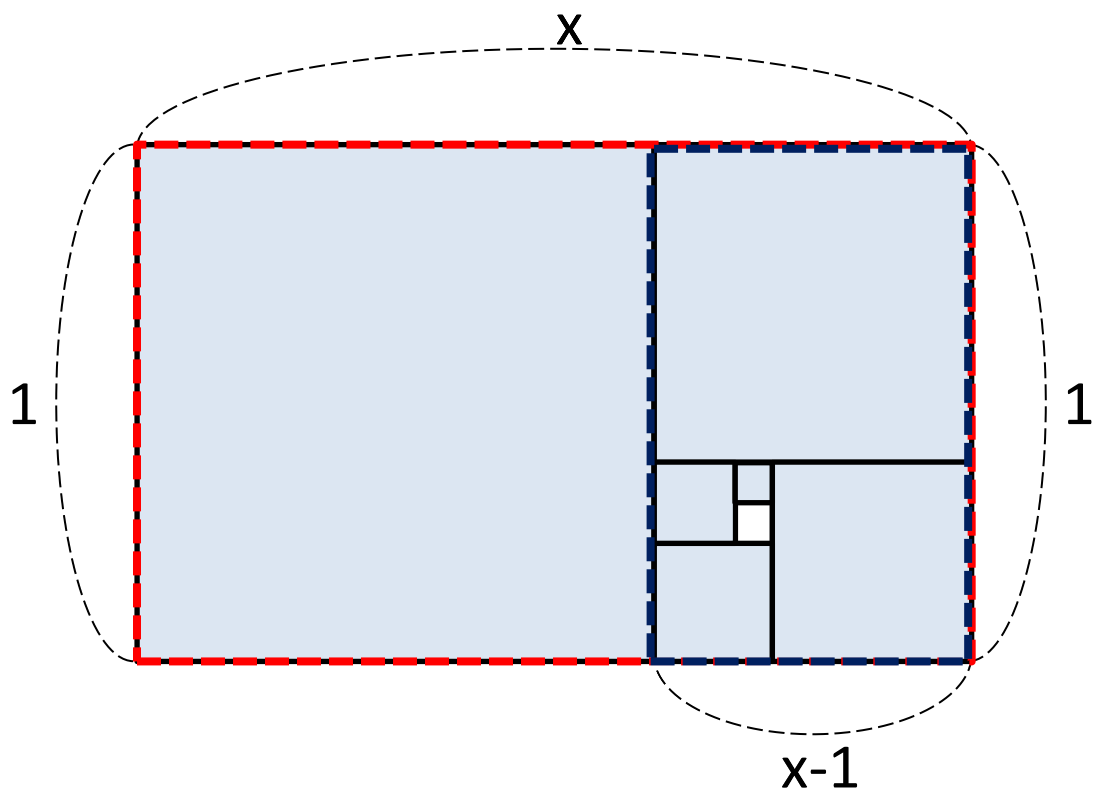
137.5°



1. The golden ratio φ is the answer for x^2-x-1=0.

Solve this quadratic equation_สมการกำลังสอง

2. Derive the phyllotaxis angle 137.5 ° from the obtained x.



Rectangle + square that resembles the original rectangle

side ratio

$x:1=1:(x-1)$

$x(x-1)=1$

$x^2-x-1=0$

*Golden ratio φ (phi: after **Phidias（ペイディアス）**, the greatest sculptor of ancient Greek)
√5 (square root of five)= 2.2360679

$x^2 - x - 1 = 0$

$(x - 1/2)^2 - 1/4 - 1 = 0$

$(x - 1/2)^2 = 5/4$

$x - 1/2 = \pm\sqrt{5}/2$

$x = 1/2 \pm \sqrt{5}/2$

$= (1 \pm \sqrt{5})/2$

X is plus: $x = (1+\sqrt{5})/2$

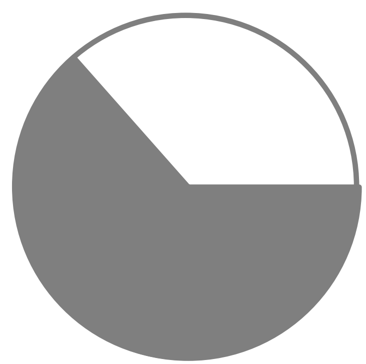
$\rightarrow 3.2360679/2 = 1.61803$

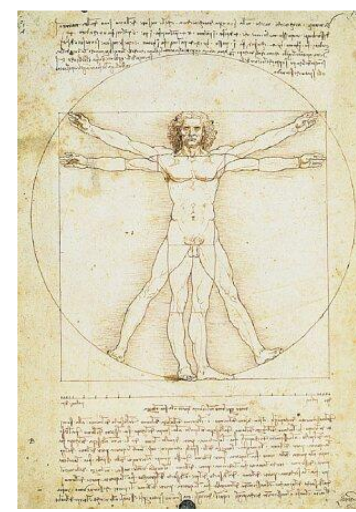
$360/1.61803 = 222.49278$

$360 - 222.49278 = \underline{137.50721}$

1. Make a square with "x^2-x"
2. Subtract the surplus (1/4)
3. Remove the square: ±
4. X is not minus -> plus only
5. Circle angle: 360°

1. สร้างสี่เหลี่ยมด้วย "x2-x"
2. ลบส่วนเกิน (1/4)
3. ลบสี่เหลี่ยม: ±
4. X ไม่ใช่ลบ -> บวกเท่านั้น
5. มุมวงกลม: 360°

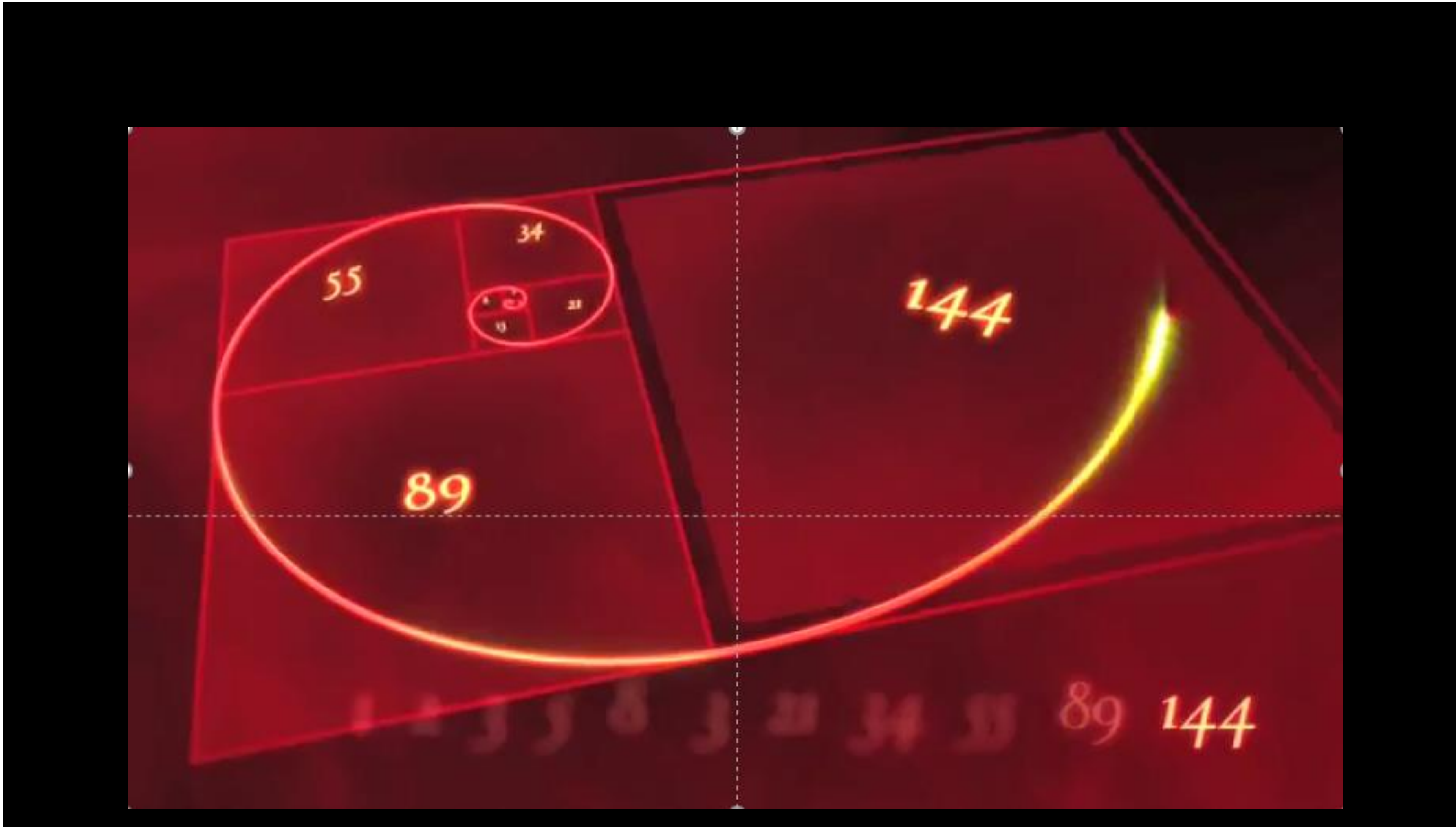




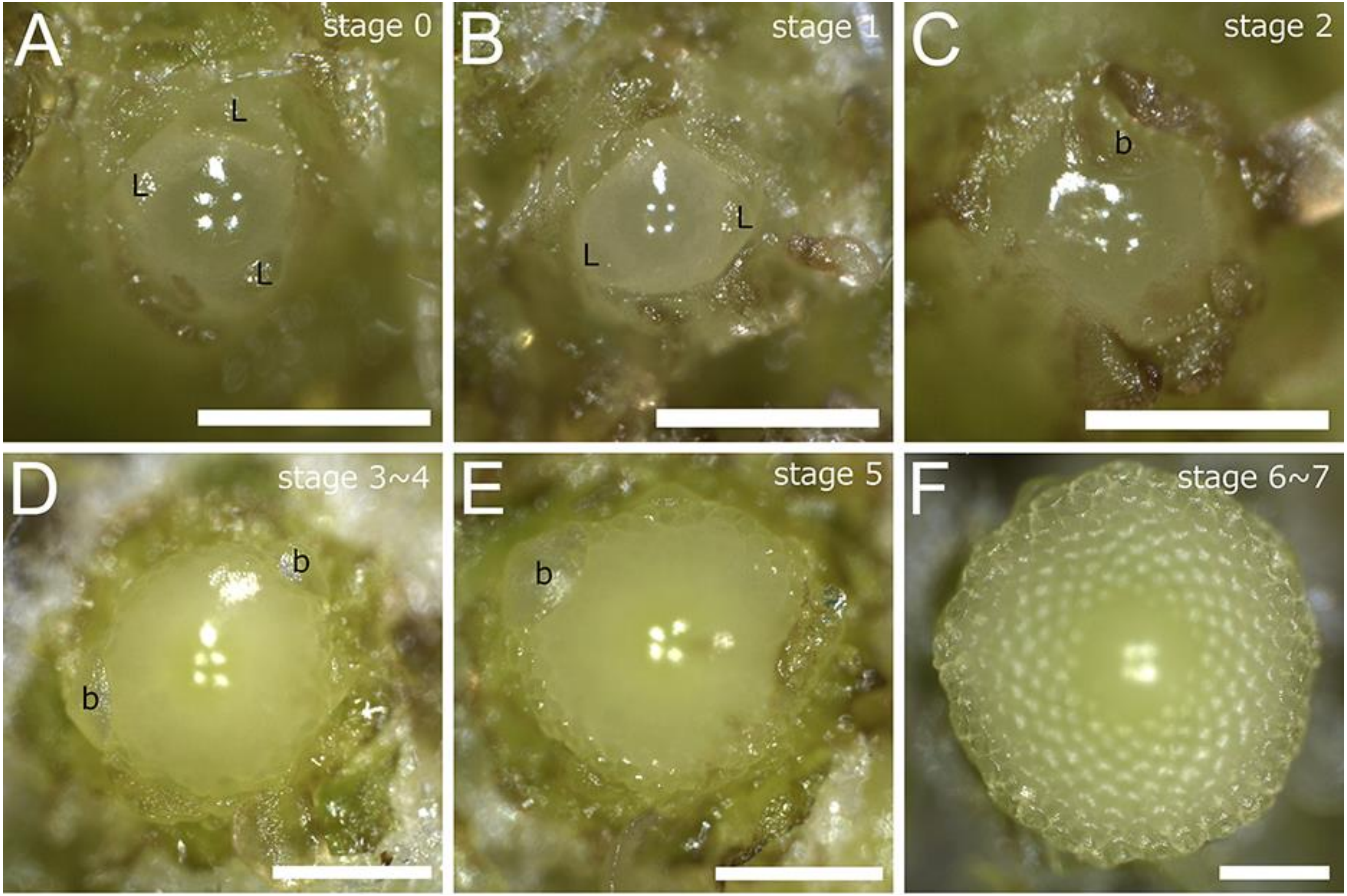
We can show the leaf angle with simple calculation

Fibonacci sequence:
Simple addition of numbers

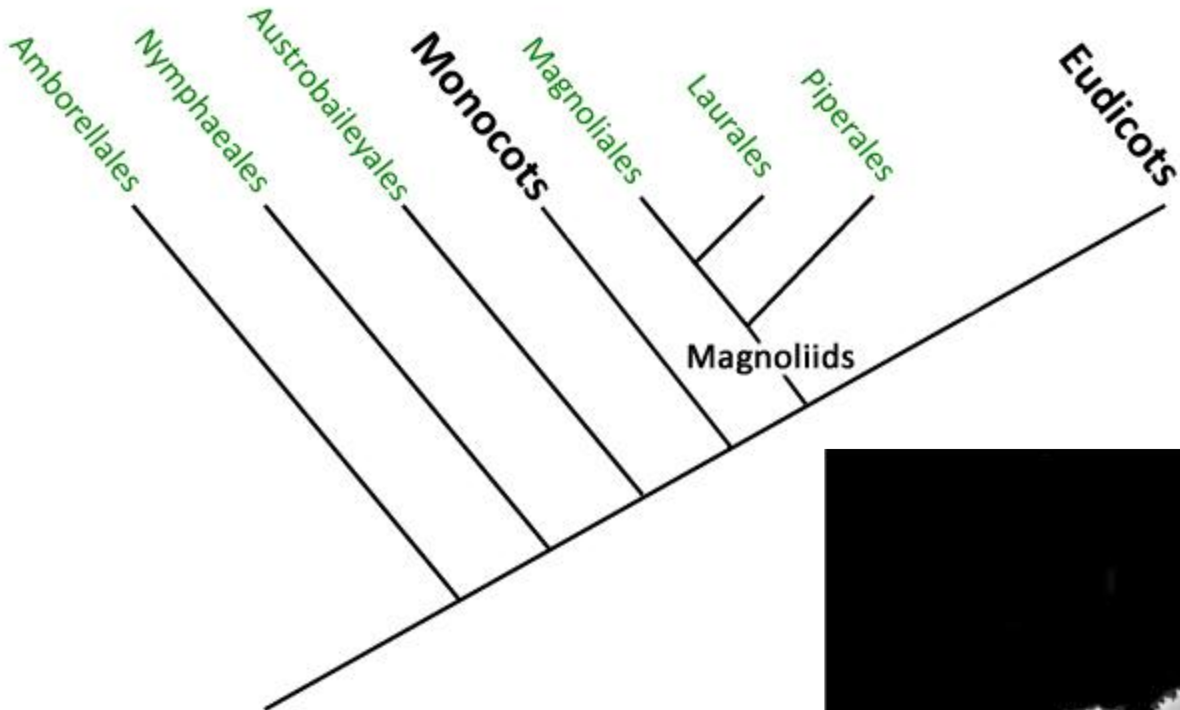
$$F_{k+1}=F_{k+}F_{k-1}$$


34
55
144
89
89
144

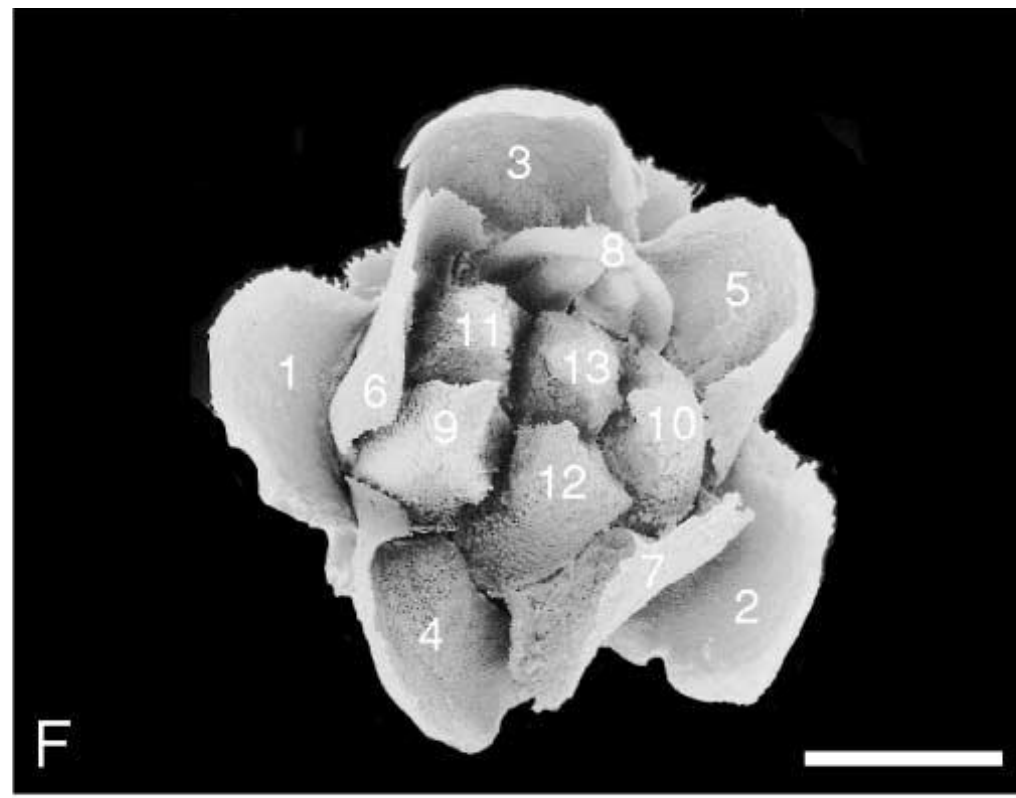
Chrysanthemum shoot apical meristem (SAM): flowers from **outside**



Takeda et al., Hort J. 2017



Amborella trichopoda

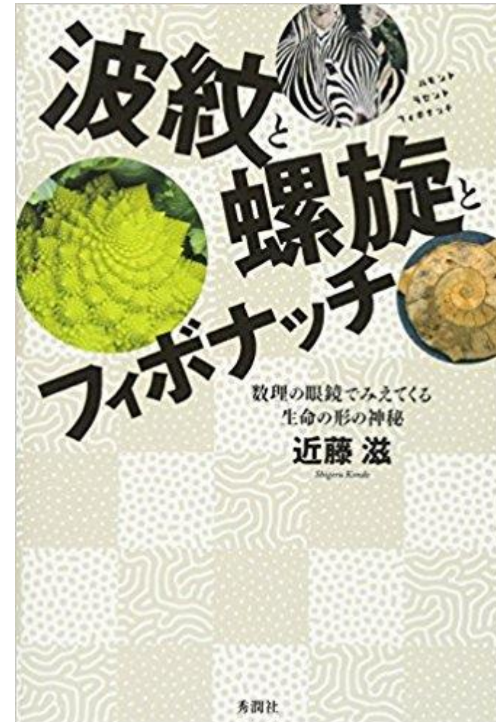


Floral organs arrangement

Co-evolution with pollinators

Int J Plant Sci 2001
http://science.kennesaw.edu/jmcneal7/plantsys/basals.html

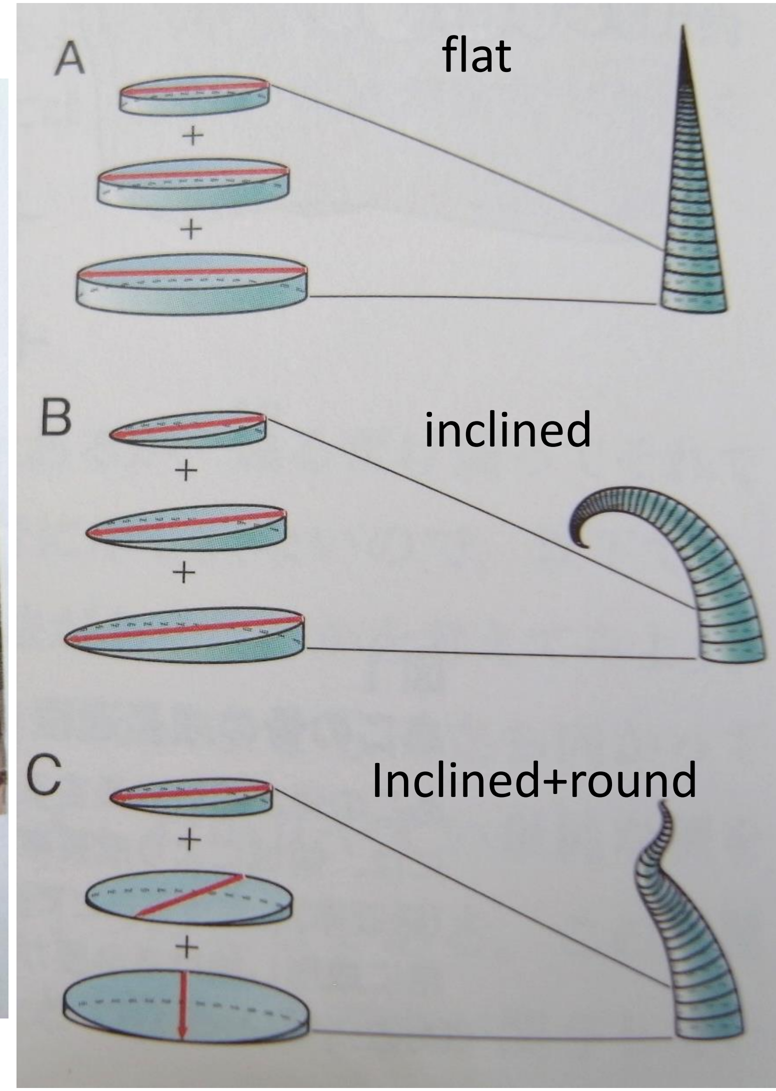
Spiral in animals ①



https://gendai.ismedia.jp/articles/-/55786

Spiral in animals ①

図３　動物の角や牙に見る「付加成長」の例
A：ドーセットホーン、B：ビッグホーン、C：ブラックバックの角、D：マンモスの牙（国立科学博物館所蔵）。



Stacking discs

Spiral in animals ② Ammonite

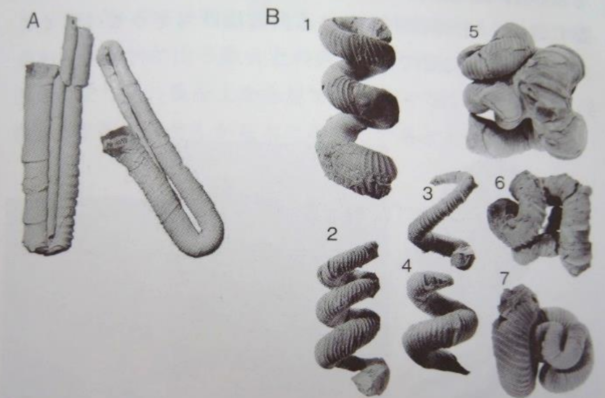


図3　様々な形状のアンモナイト化石

A：ポリプティコセラス。岡本隆・朝見幸司：化石（2002）71: 1-18 より改変。
B：ユーボストリコセラス（1～4）とニッポニテス（5～7）。Okamoto T：Trans. Proc. Palaeont. Soc. Japan, N.S.（1989）154：117-139 より改変。

図4
ニッポニテス・ミラビリス
復元図（左）と化石写真（右）。イラスト：入澤宣幸

朝日 '21 1/4 夕

「異常巻き」新種のアンモナイト

新種の異常巻きアンモナイトの化石3点

アンモナイトは蚊取り線香のような渦巻きが特徴だが、ゼムクリップのような「異常巻き」の新種の化石が北海道北部の中川町で見つかった。既知の化石とは種の一つ上の属レベルで異なっており、新しい属をつくる必要があるという。新属のアンモナイトが日本で見つかるのは37年ぶり。日本古生物学会専門誌に発表された。アンモナイトは、タコやイカ、オウムガイなどの仲間。4億年前ごろに現れて世界中の海で栄え、6500万年前ごろに絶滅した。公益財団法人深田地質研究所（東京都）の村宮悠介研究員は「殻の中にガスをため、その浮力で海底に立っていたのではないか」と話す。

Spiral in animals ② sea shells

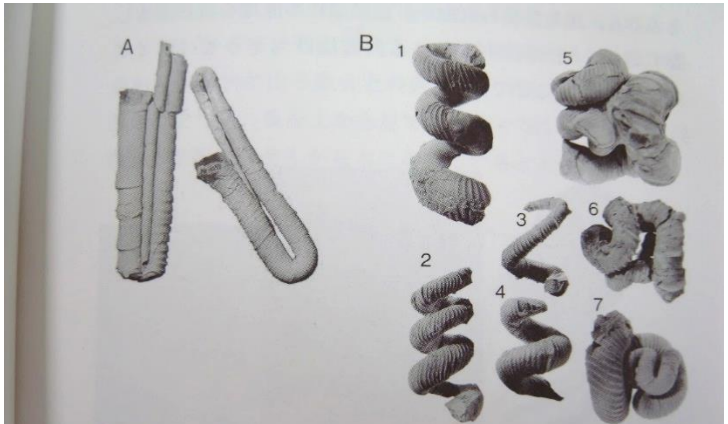


図 3　様々な形状のアンモナイト化石

A：ポリプティコセラス。岡本隆・朝見幸司：化石（2002）71: 1-18 より改変。
B：ユーボストリコセラス（1～4）とニッポニテス（5～7）。Okamoto T：Trans. Proc. Palaeont. Soc. Japan, N.S.（1989）154：117-139 より改変。

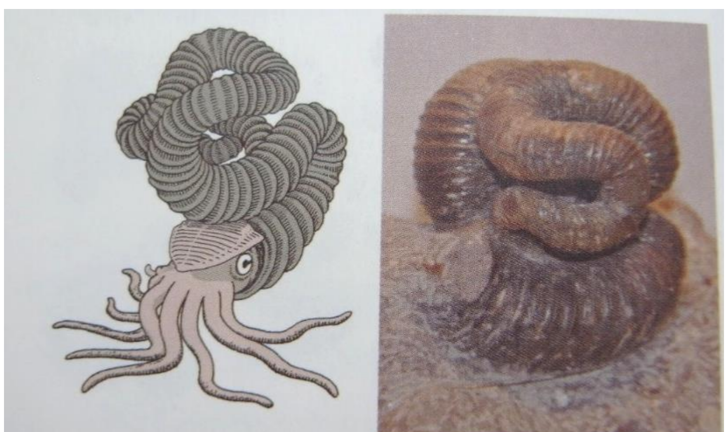
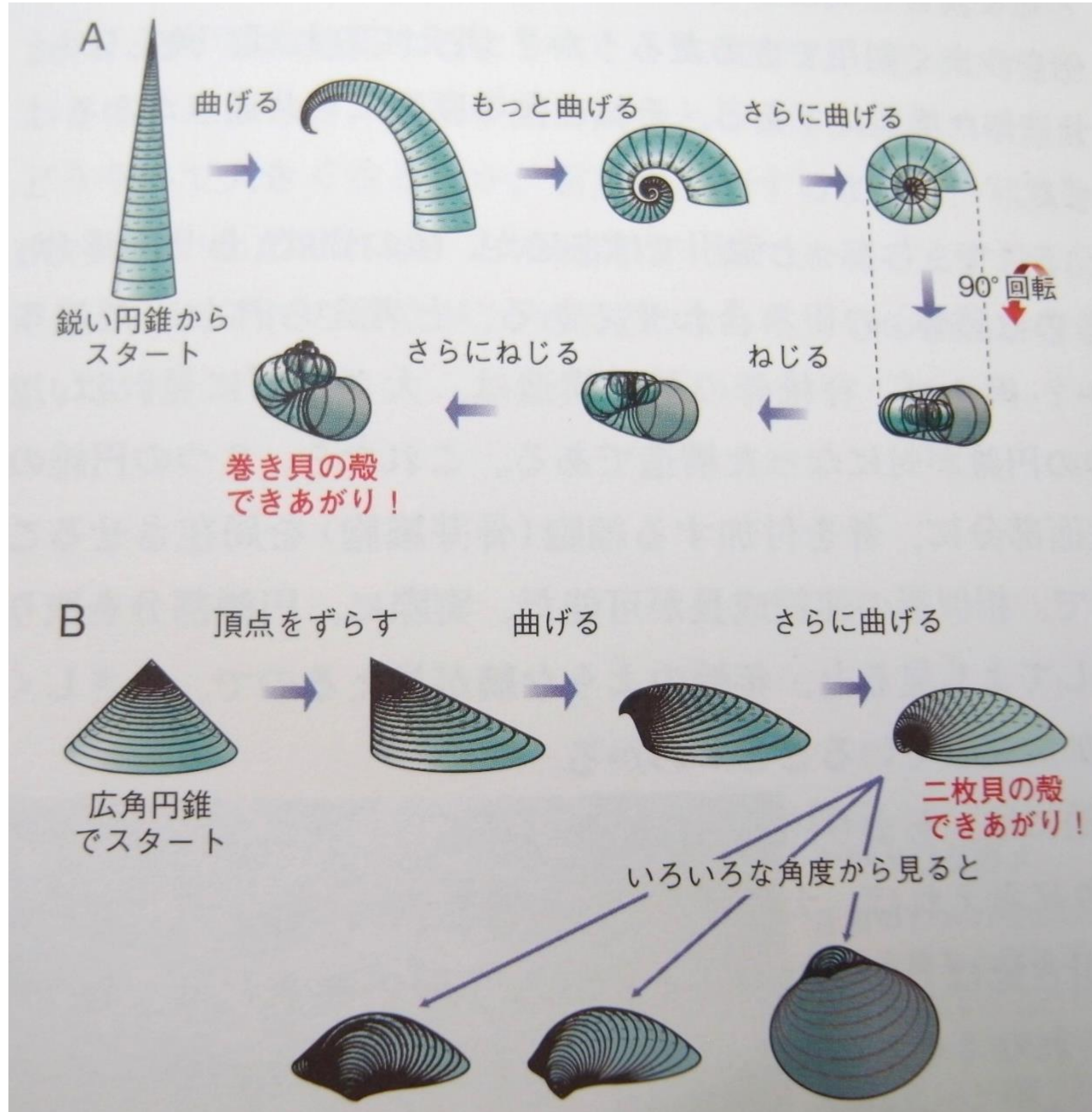


図 4
ニッポニテス・ミラビリス

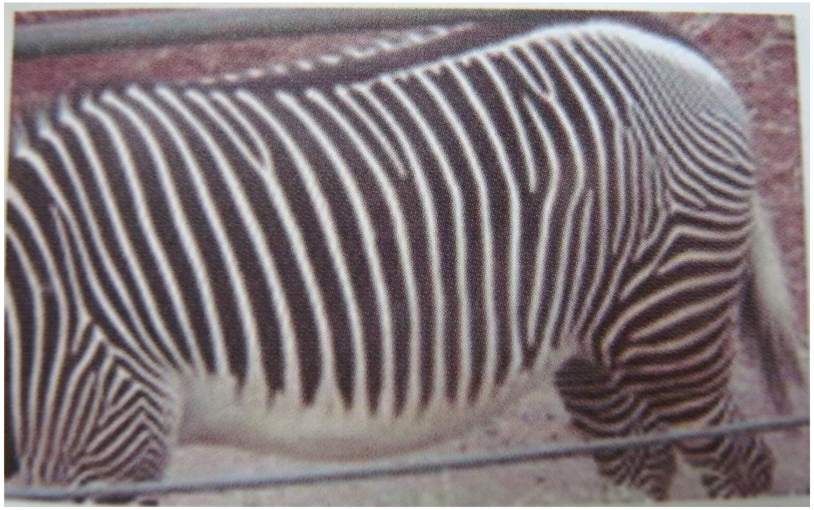
復元図（左）と化石写真（右）。イラスト：入澤宣幸



Spiral in animal③ **turtle shell**

https://gendai.ismedia.jp/articles/-/55786

Striped pattern



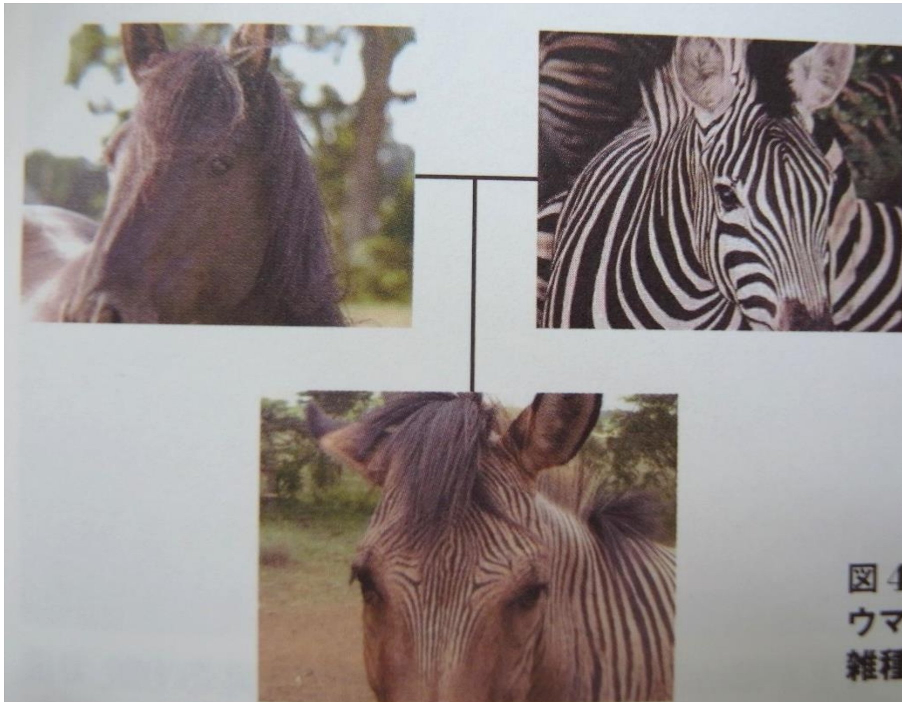


図 4
ウマと
雑種の

図 5　魚の骨格（A）といろいろな模様の魚（B）

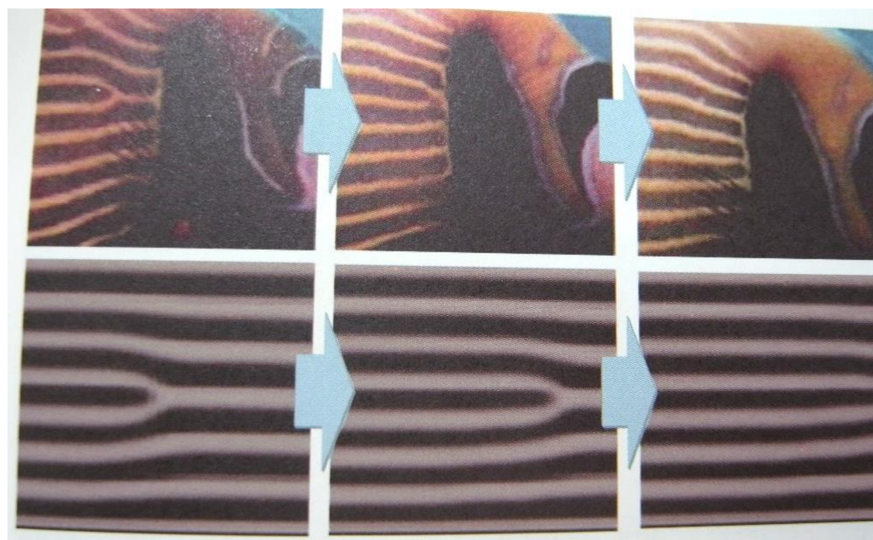
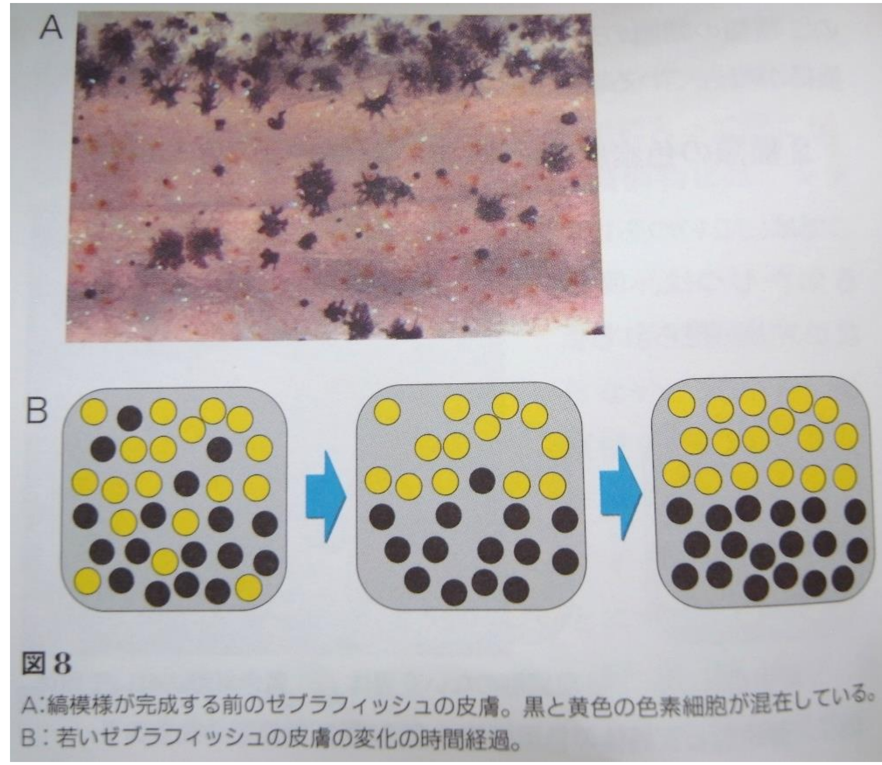
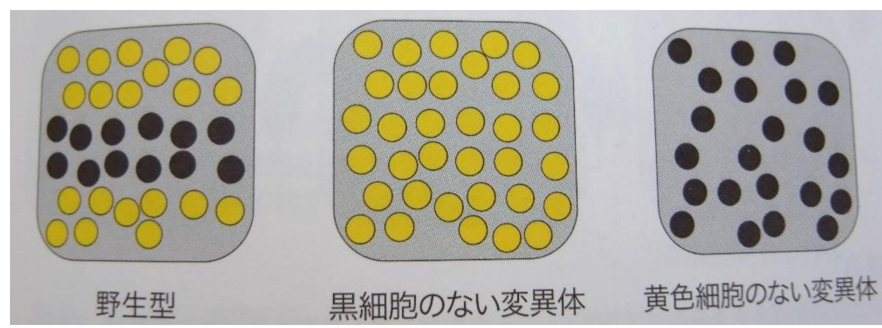


図 11　タテジマキンチャクダイ（成魚）の
模様変化（上）とシミュレーション（下）

Striped pattern – zebrafish experiment

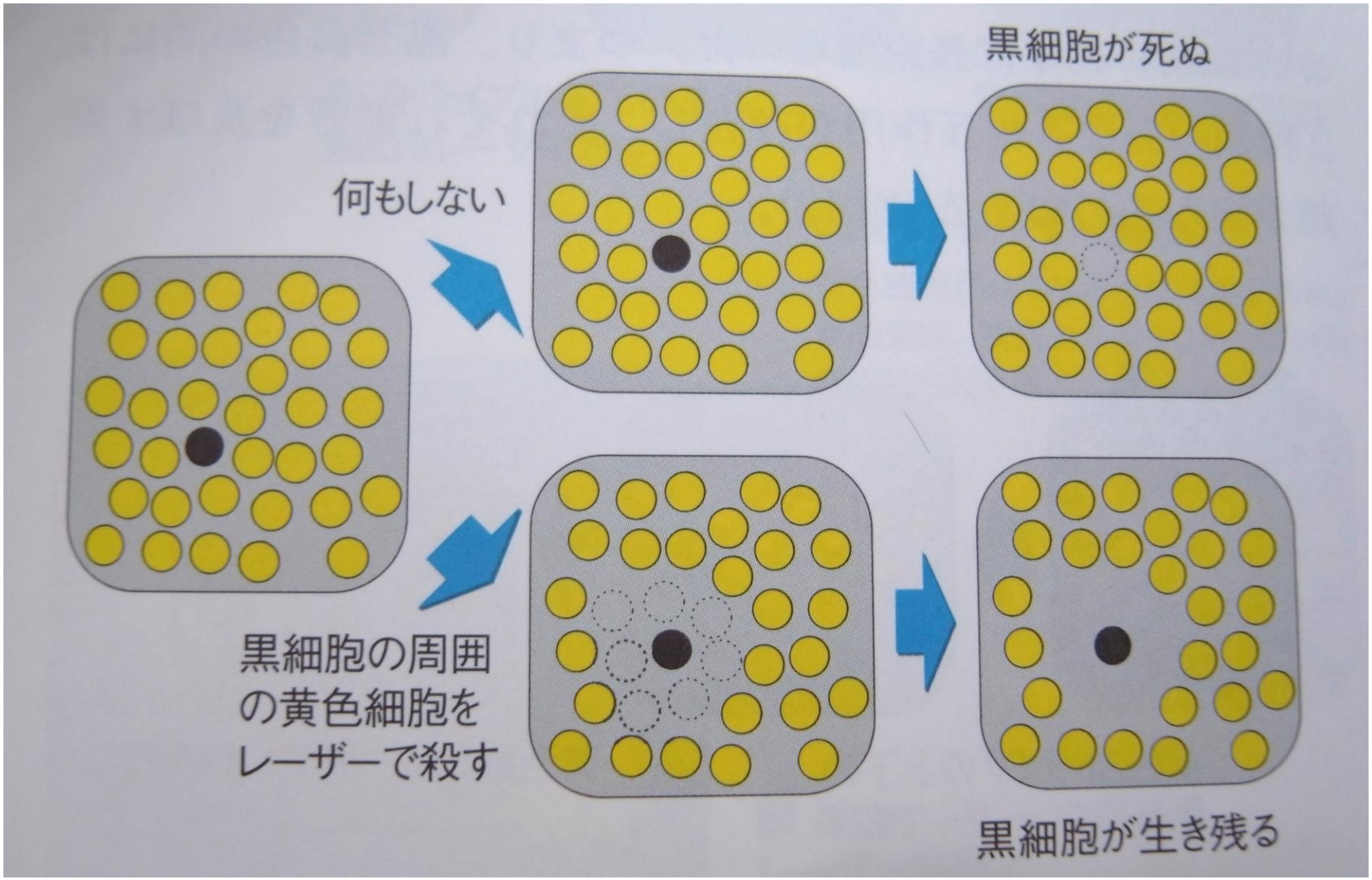


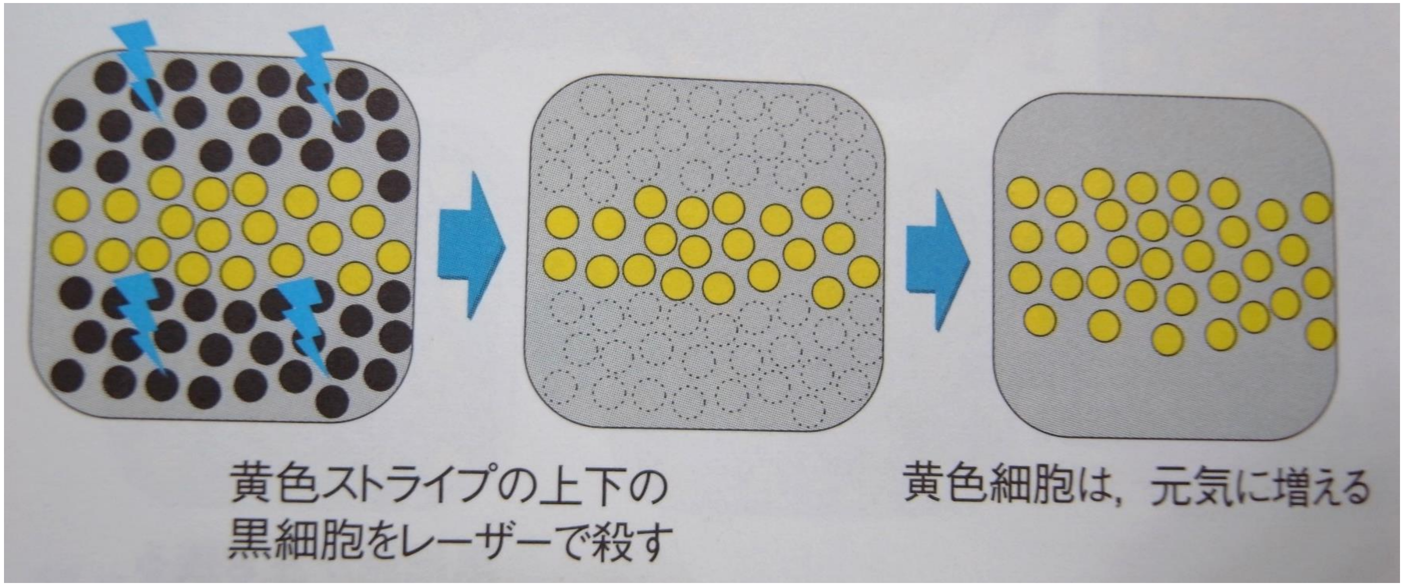


Striped with yellow and black dots

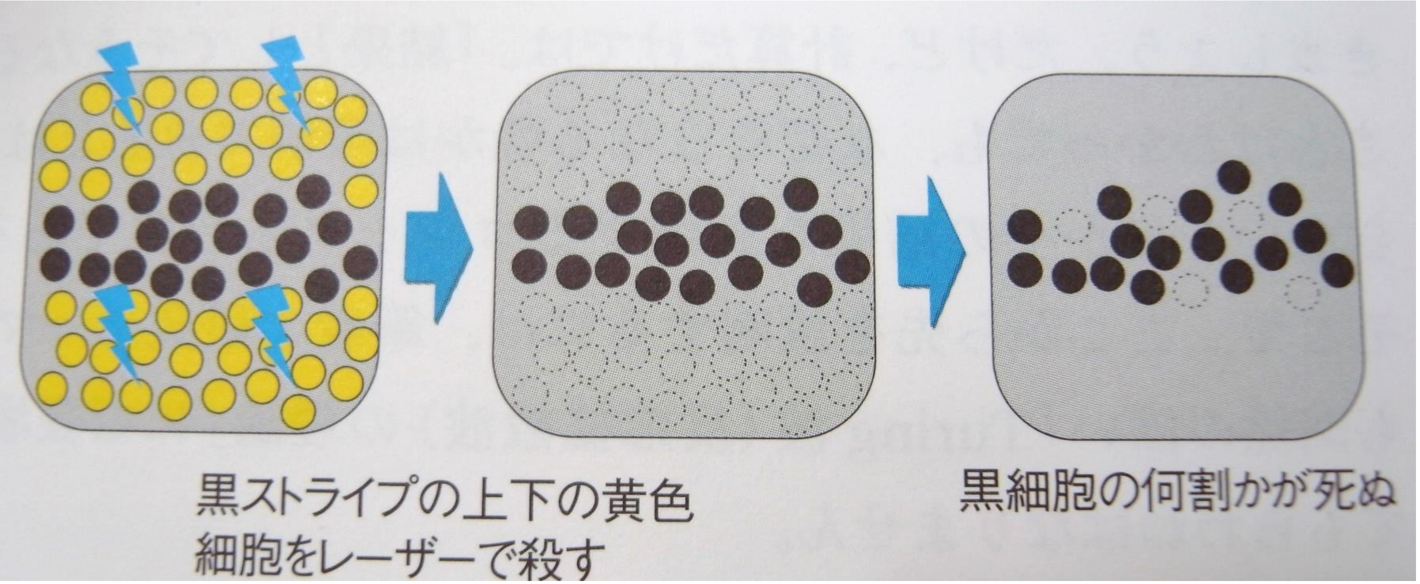
- **Remove yellow or black cells with laser**
- **Same results for yellow and black cells**

→ Inhibit each other





Black inhibit yellow



Yellow required for black

Distance!

Turing’s reaction-diffusion model

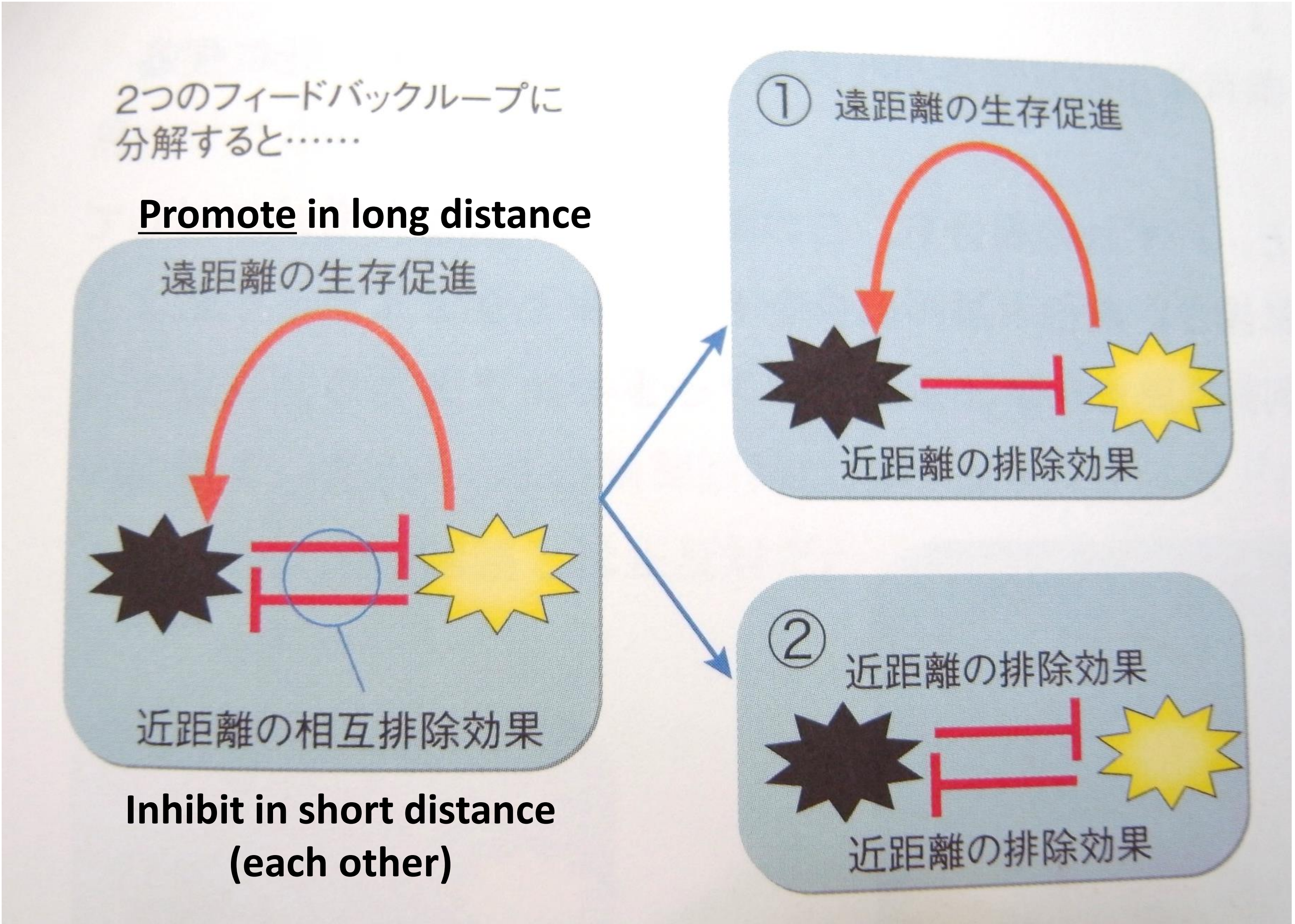
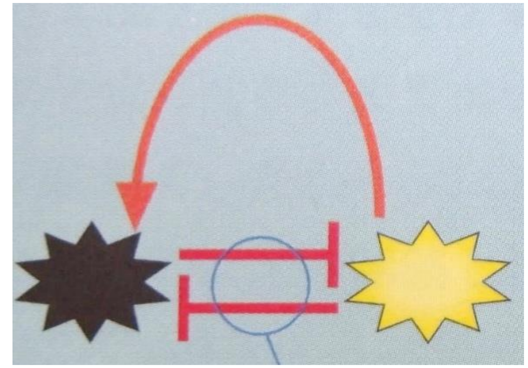


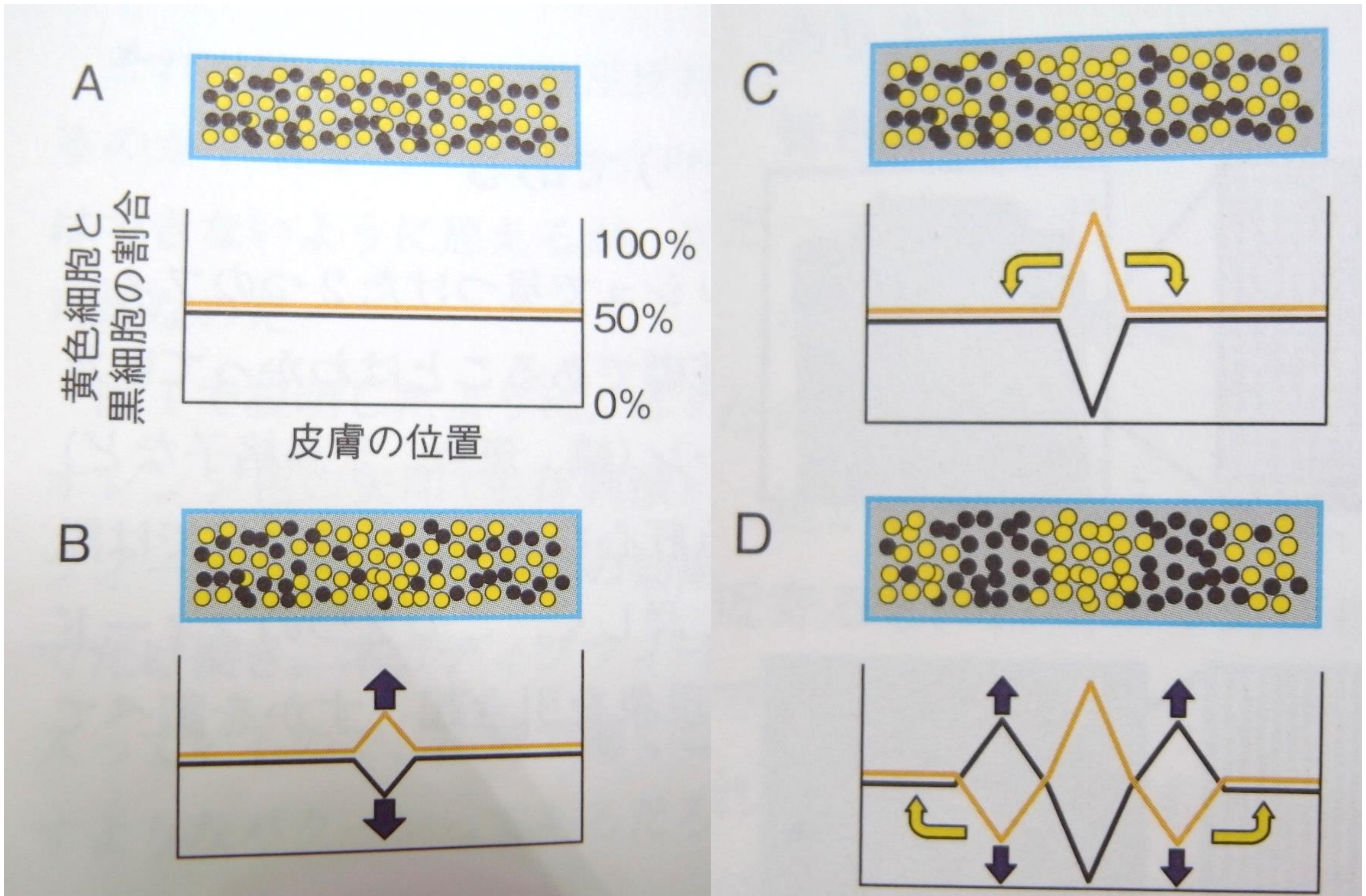
図1　色素細胞間相互作用のネットワークと
それを２つに分解したもの

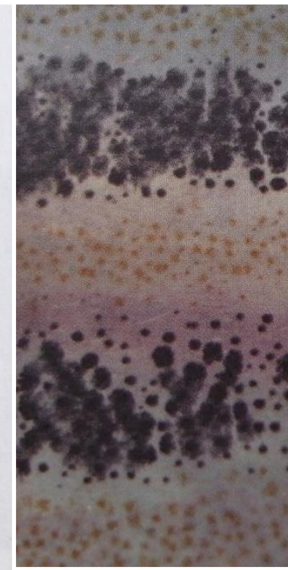
Reaction-diffusion model

- relation of 2 factors
- depends on distance

→ make a 'wave' pattern







Reaction-diffusion model: dot and stripe (leopard, tiger, fish, …)

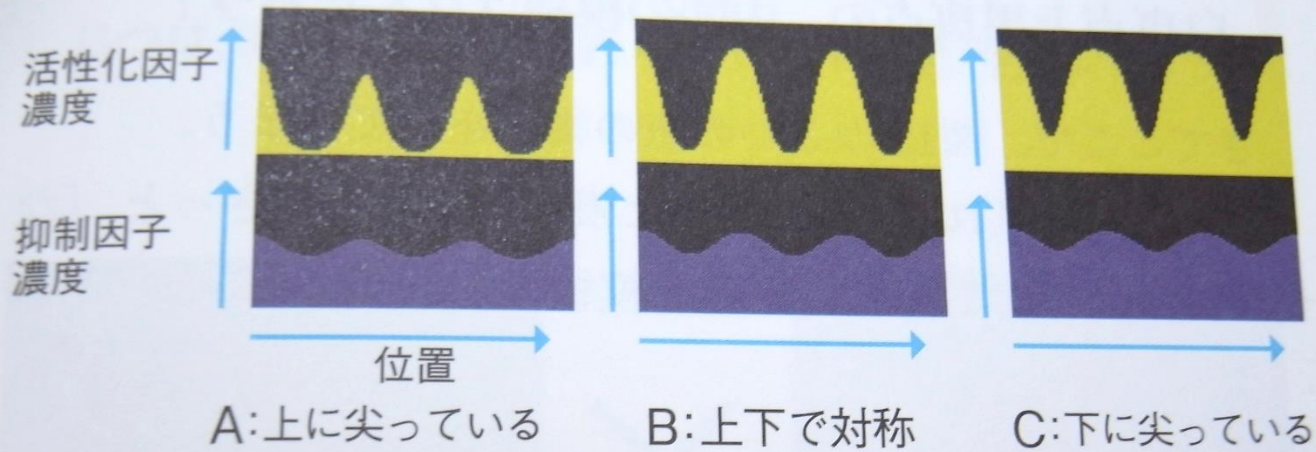


図 13　Turing 波でできる典型的な一次元の波形

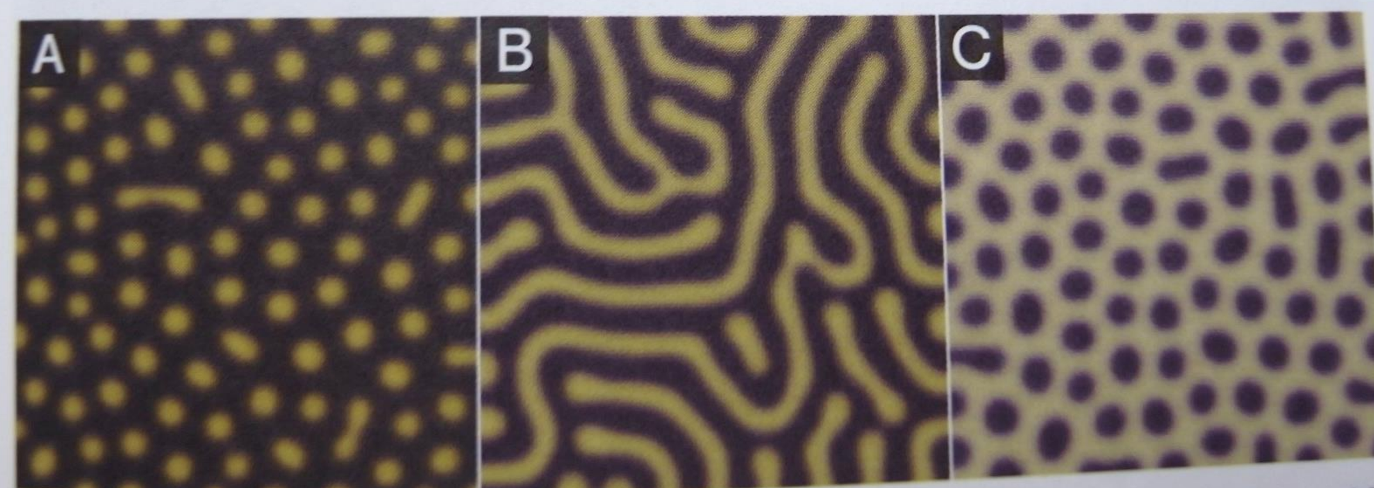
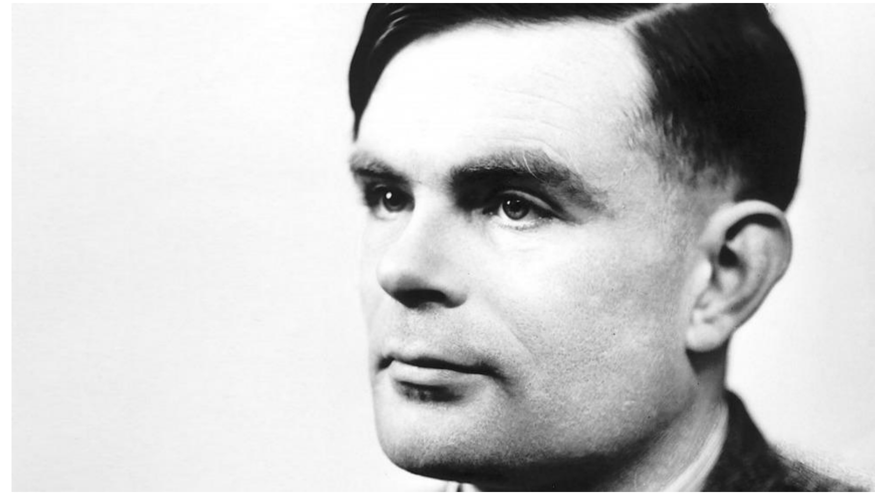
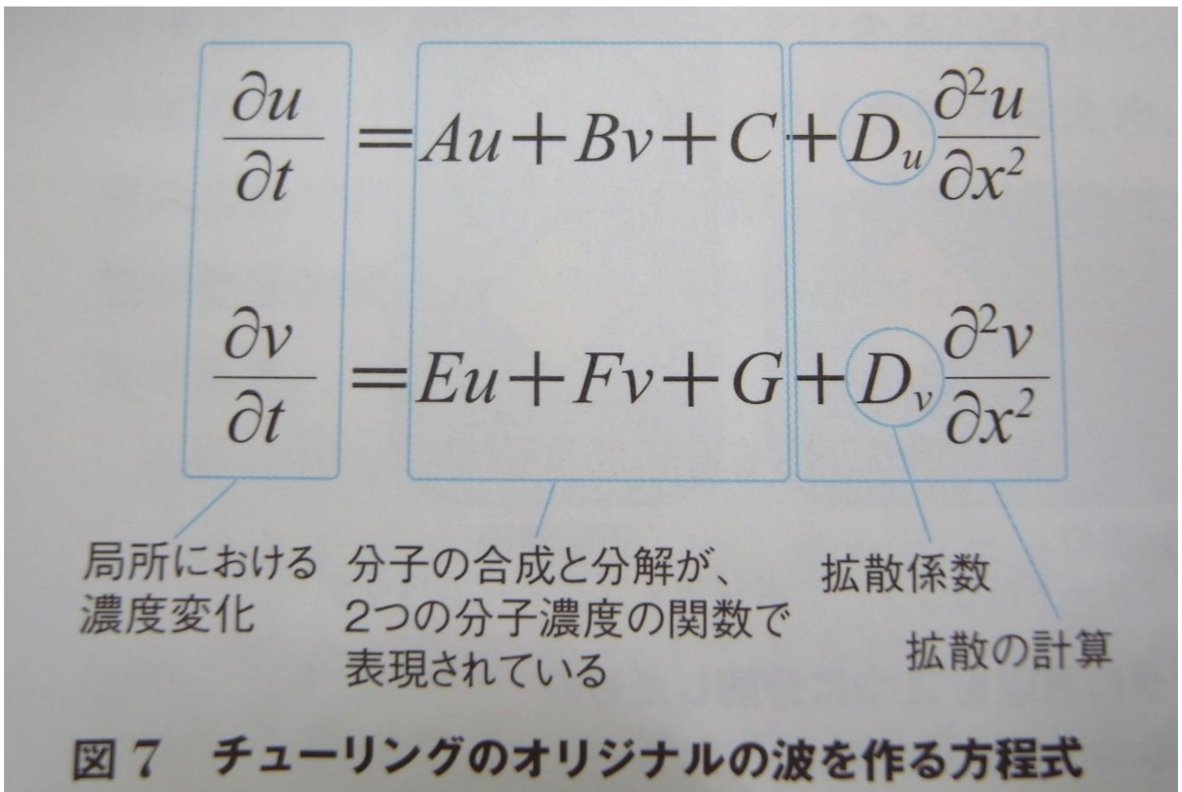


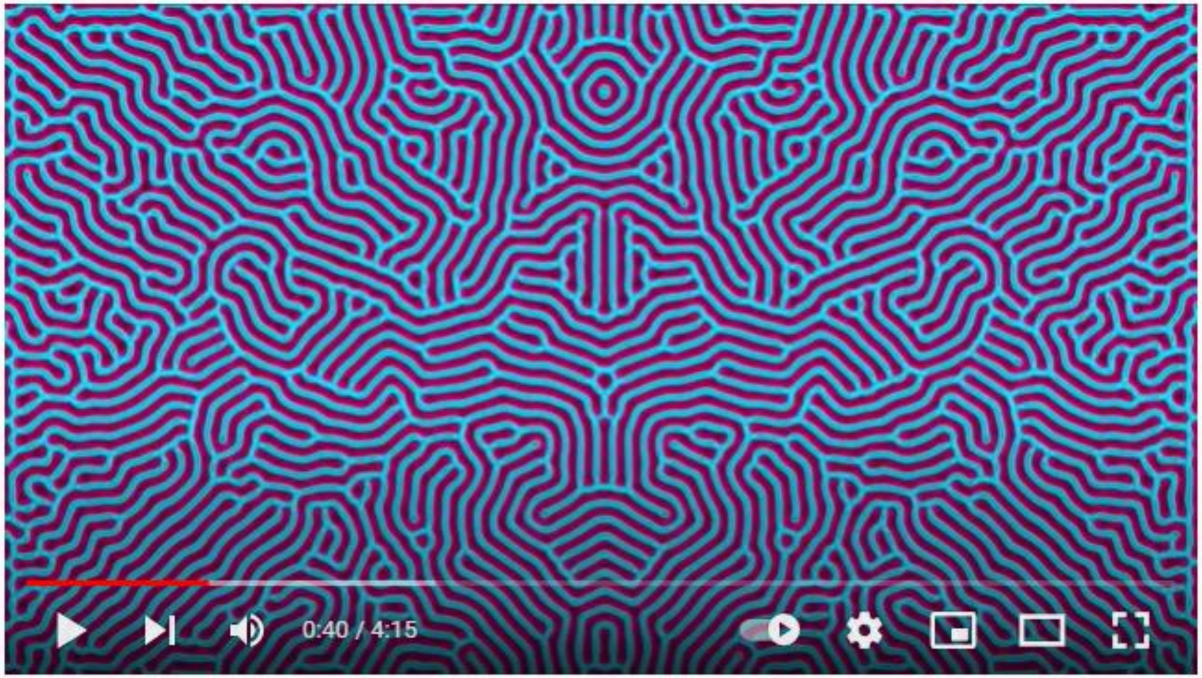
図 14　左から順に、図 13 の A、B、C に対応する二次元の Turing 波
(Turing pattern)

Alan Turing

- UK, 1912-1954年（41 years old）
- Turing machine (computer)
- Decoding the German code (Enigma)







Reaction Diffusion

46,553 回視聴・2014/11/29　883　8　共有　保存

Kerim Dündar
チャンネル登録者数 180人

チャンネル登録

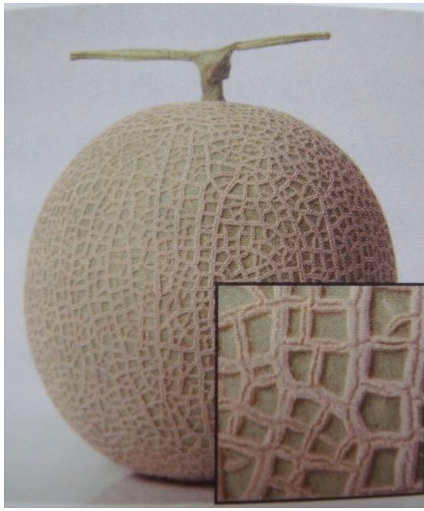
Designers, whom always had the inspiration from nature, were imitating the observed results of nature until recently. From now on, designers can borrow the processes that create those results. Reaction Diffusion is one of the creation processes of nature. In nature, many living beings pattern and form are occurring as a result of this process. The animation you are about to watch in this project, as an example of biomimicry in design, is designed with an algorithm that borrowing the Reaction Diffusion creation process from nature.

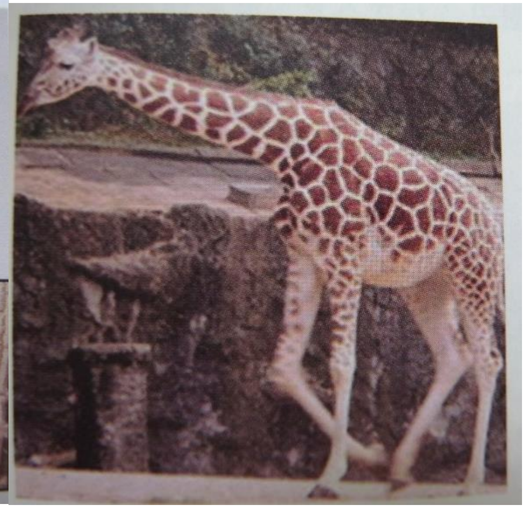
Animation by Kerim Dündar.
Sound by Mehmet Kemaloğlu.

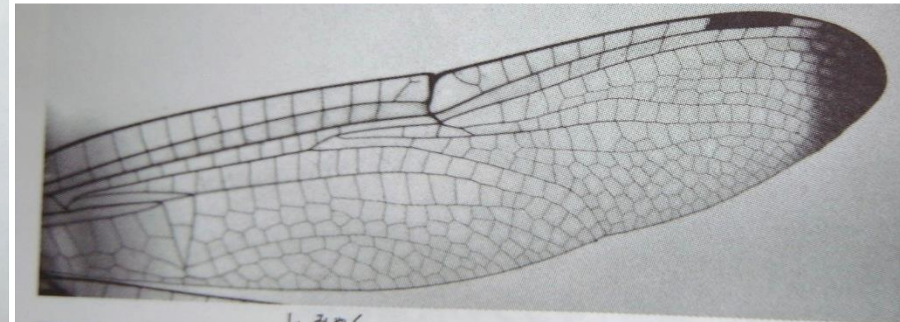
* This animation is in the collection of 2nd Istanbul Design Biennial 2014 Academy Program.

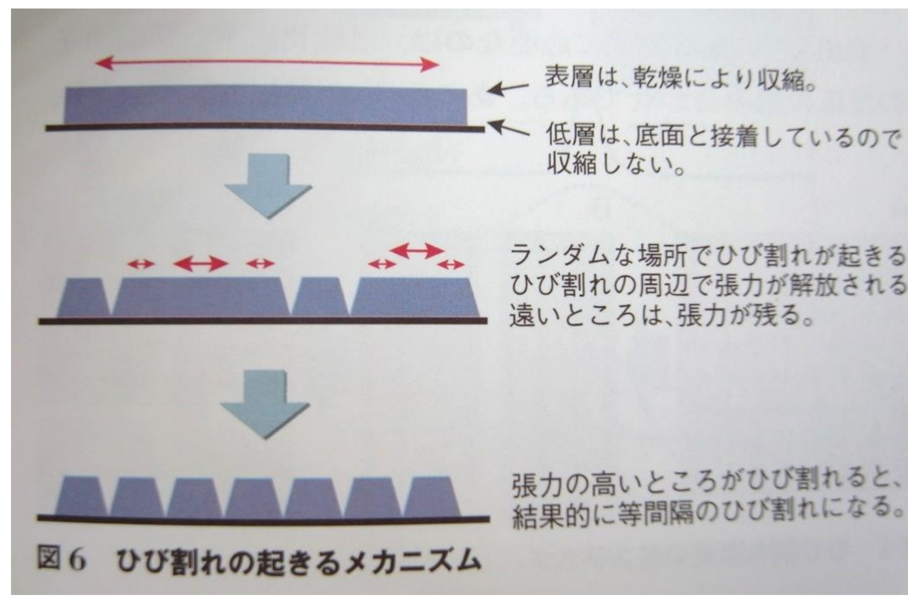
https://www.youtube.com/watch?v=PtPK_xx5Hks

Clack on melon skin, giraffe, soil



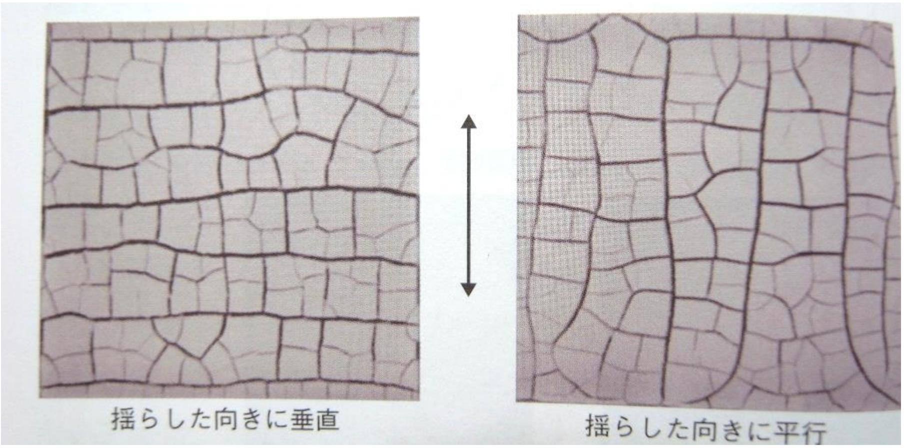




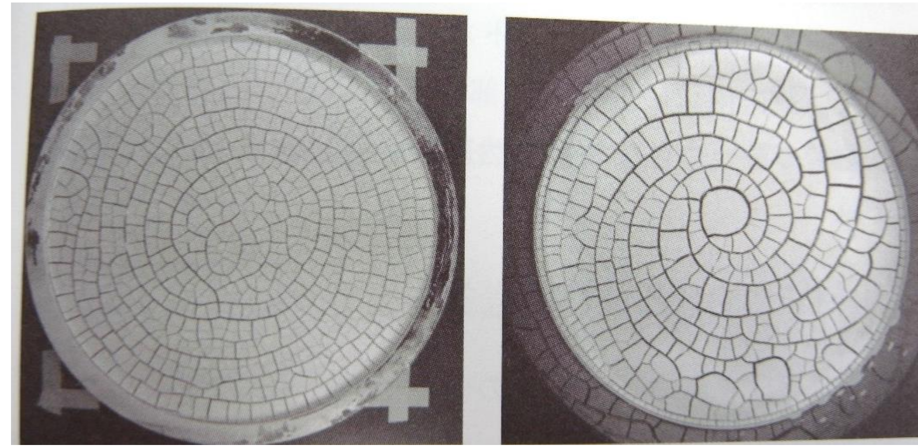


$CaCO_3$ (calcium carbonate) + water → dry

hard **soft**



round



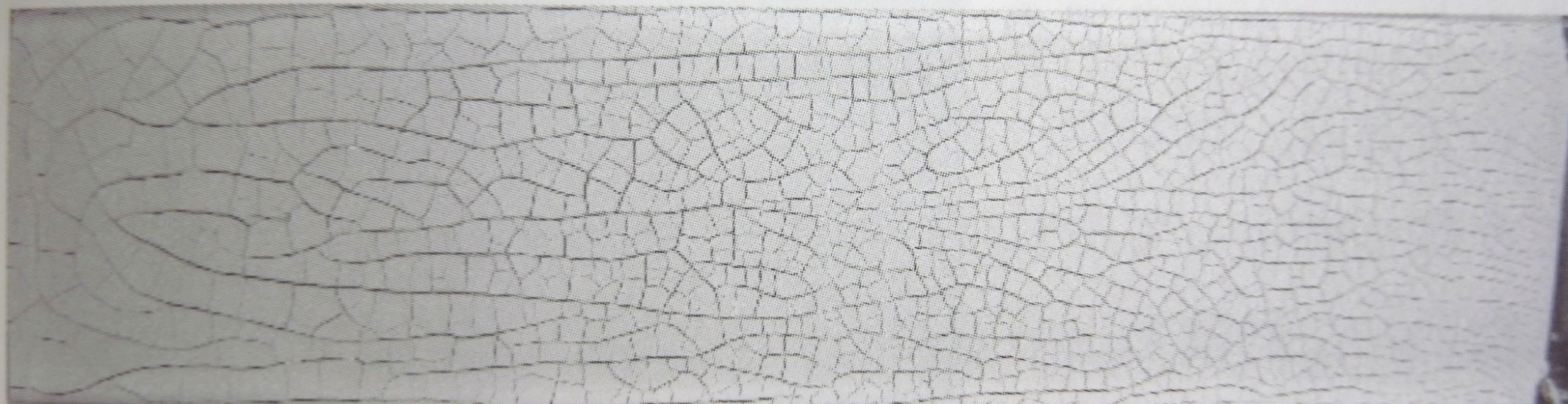
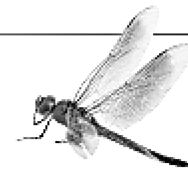


図 13　炭酸カルシウムで作ったトンボの翅脈様のひび割れパターン

Matsuo Y and Nakahara A: J Phys Soc Jpn（2012）81（2）：024801 より転載。

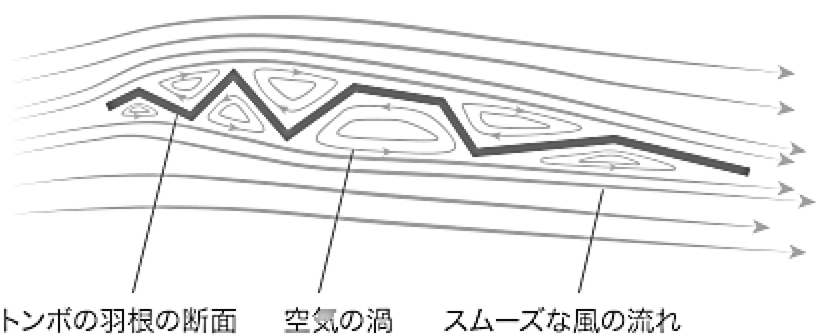
Dragonfly wing structure

トンボの羽根をヒントに、薄型ファンの開発に成功

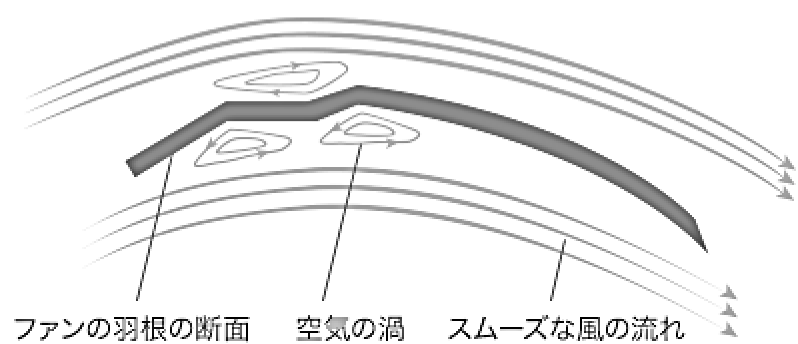


少々の強い風が吹いていても安定して飛ぶことができるトンボ。そのヒミツは羽根の構造にありました。トンボの羽根の断面はギザギザになっていて、飛ぶ時にはその凹部に小さな空気の渦が形成されます。その渦が車輪のような役割を果たし、スムーズに風が流れるので安定して飛べるのです。
このトンボの羽根の構造を空気清浄機のファンに応用し、その効果が最大限に活かせる薄型に進化しました。摩擦抵抗が小さいので効率よく風を送ることができ、薄型でも安定した風量を確保。音も静かです。

■トンボの羽根の断面と、その周りの流れ



■ファンの羽根の断面と、その周りの流れ

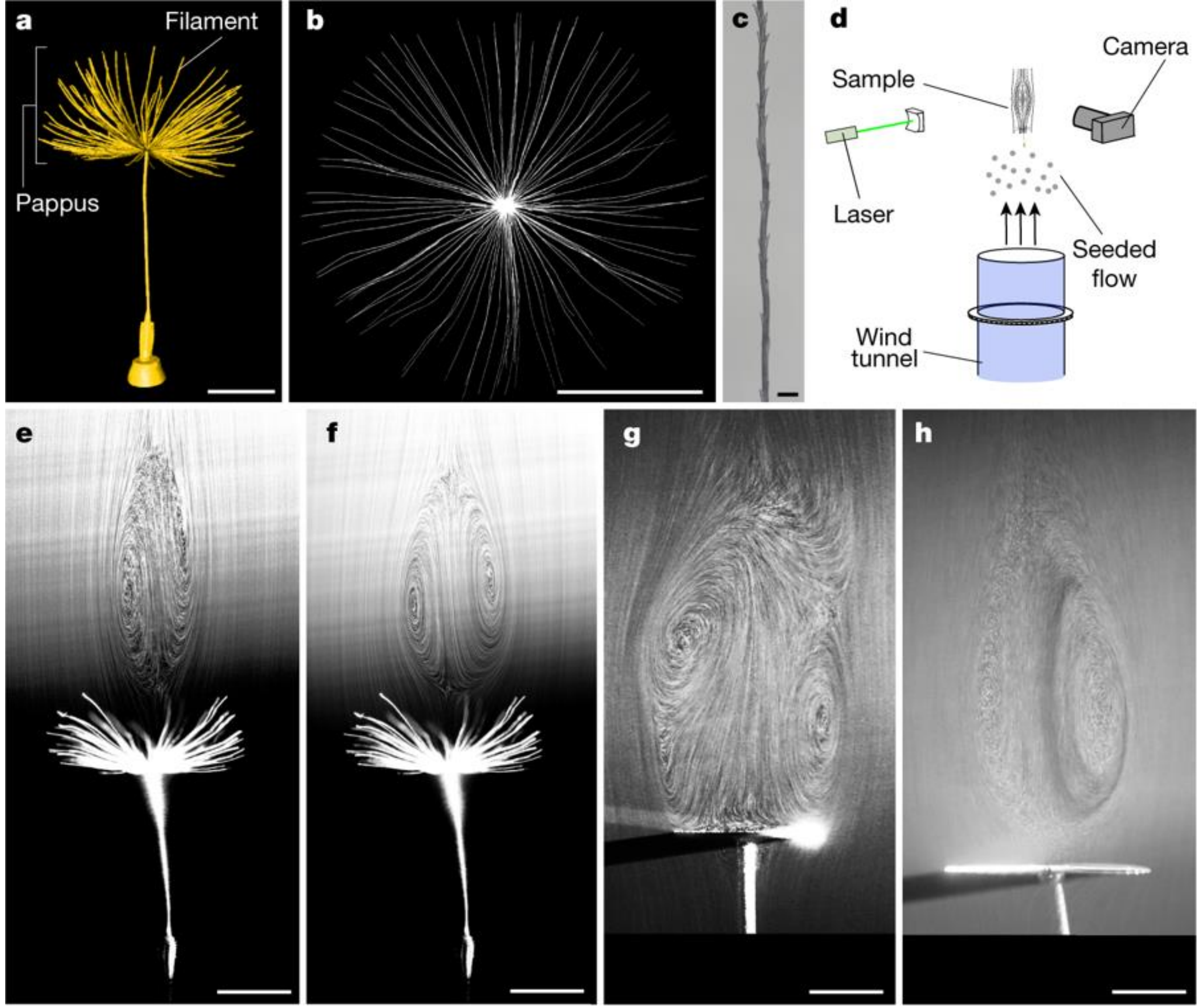


Dandelion fluff

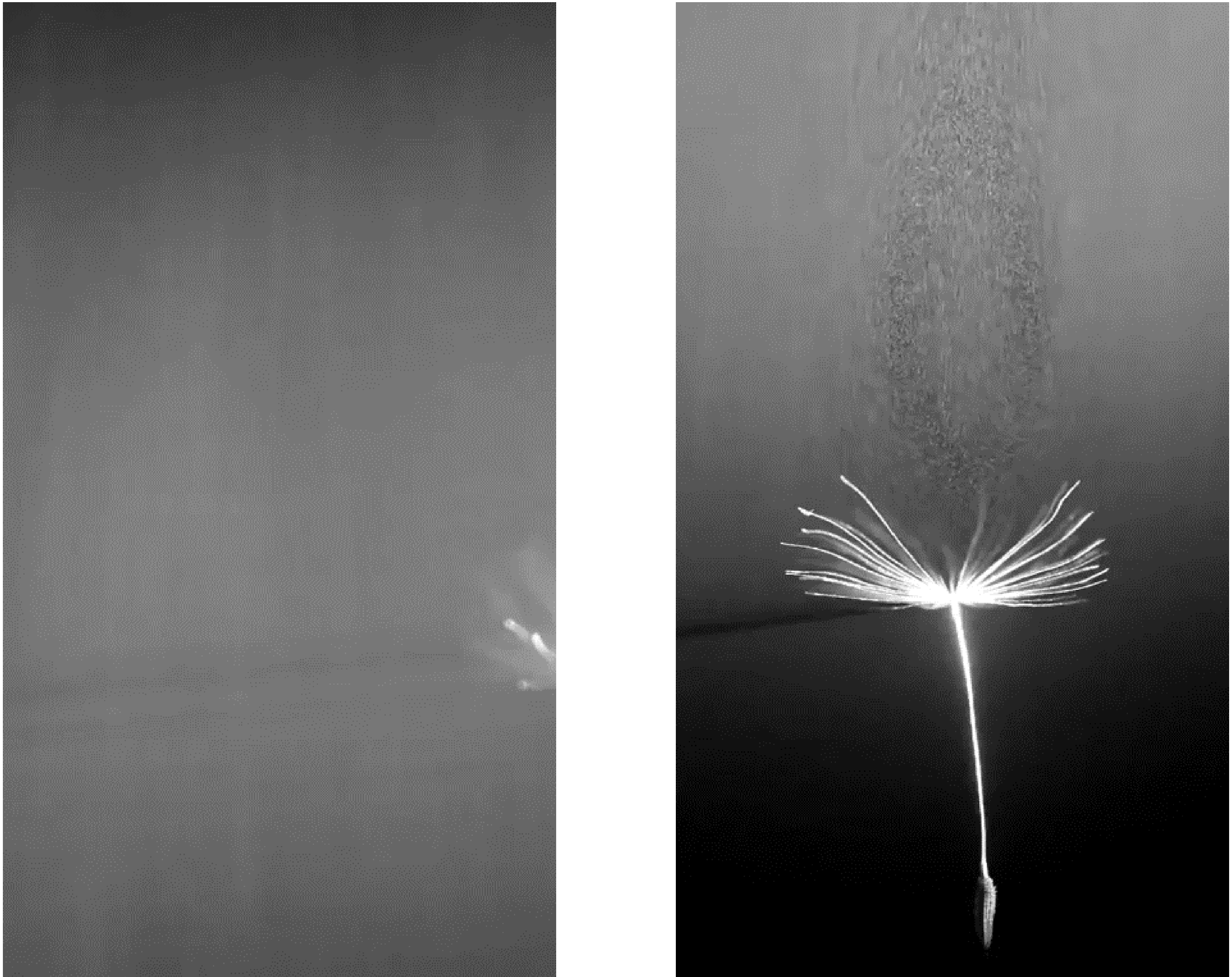
30km ~ 150km trip

Air vortex_กระแสน้ำวน

Nature 2018



a–**c**, Structural features of the drag-generating pappus at multiple scales: the μCT scan of a dandelion seed (**a**), the top-down view of the pappus (**b**) and the light microscopy image of a section of a filament (**c**). **d**, **e**, A vertical wind tunnel (**d**) was used to visualize the steady vortex downstream of a dandelion seed (**e**) at the terminal velocity of a seed. **f**, At 60% of the terminal velocity, the vortex is slightly larger and more symmetric, showing the structure of the separated vortex ring more clearly. **g**, **h**, In the same flow conditions as **e** and **f**, solid and porous disks generate vortex shedding (**g**) and a separated vortex ring (**h**), respectively. Scale bars, 50 μm (**c**) or 5 mm (all other panels).

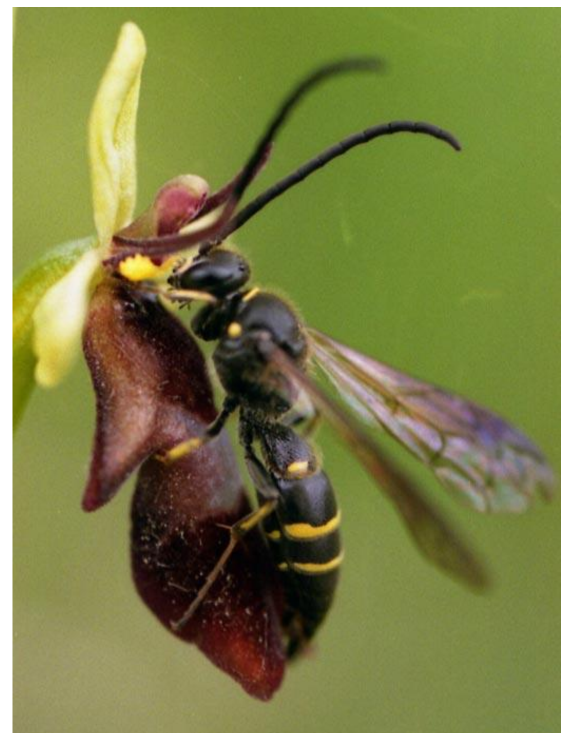


Biological function

Leaf-like moth

Flower-like mantis

Bee-like orchid flower



Conclusions

1. Fibonacci sequence and leaf pattern

2. Fibonacci sequence in nature

3. Spiral in animals: stacking discs

4. Reaction-diffusion model by Alan Turing

We have a lot to learn from nature