

Digital growth

Nature-inspired procedural generation

Complex patterns emerge from simple rules

Modern understanding of nature (for this presentation) rely on four works:

The Chemical Basis of Morphogenesis, Alan Turing (1952)

Mathematical models for cellular interaction in development, Astrid Lindenmayer (1968)

The Fractal Geometry of Nature, Benoît B. Mandelbrot (1982)

The Algorithmic Beauty of Plants, Przemyslaw Prusinkiewicz and Aristid Lindenmayer (2004)

Goals of this presentation

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What I'll show:

- Brief outlines of each method

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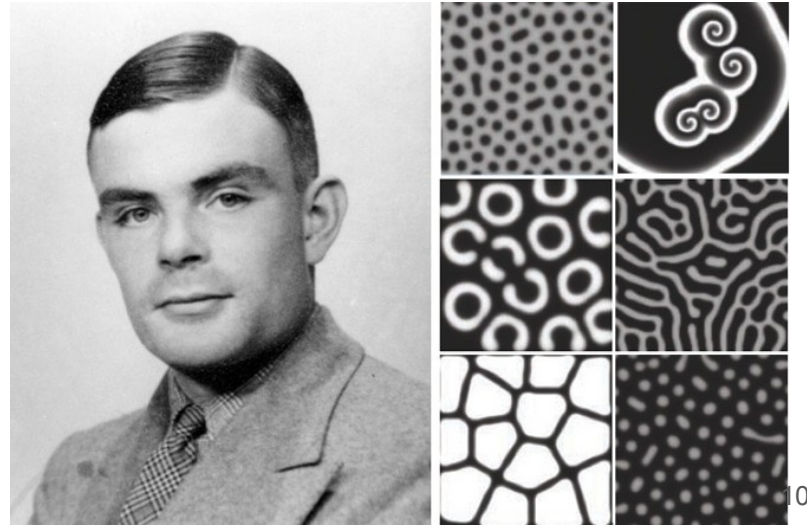
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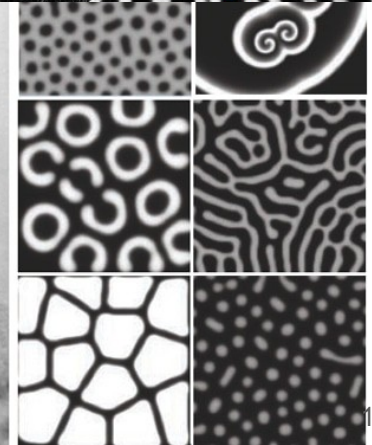
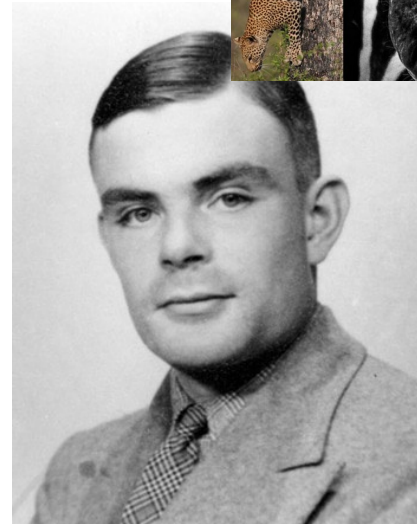
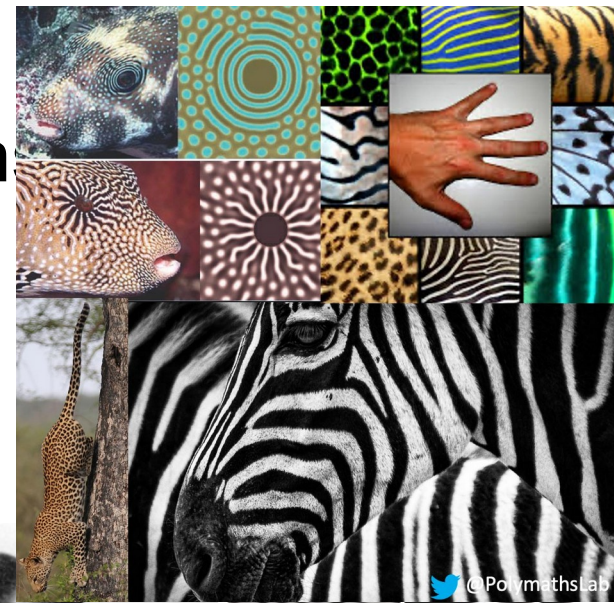
What I'll show:

- Brief outlines of each method
- Implementation ease

Reaction-Diffusion for Turing Patterns

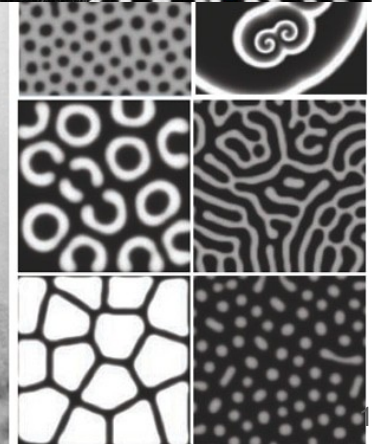
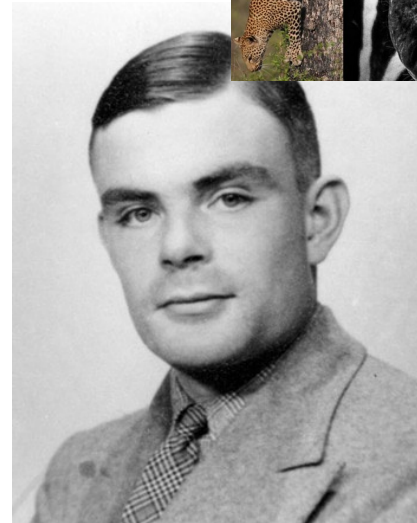
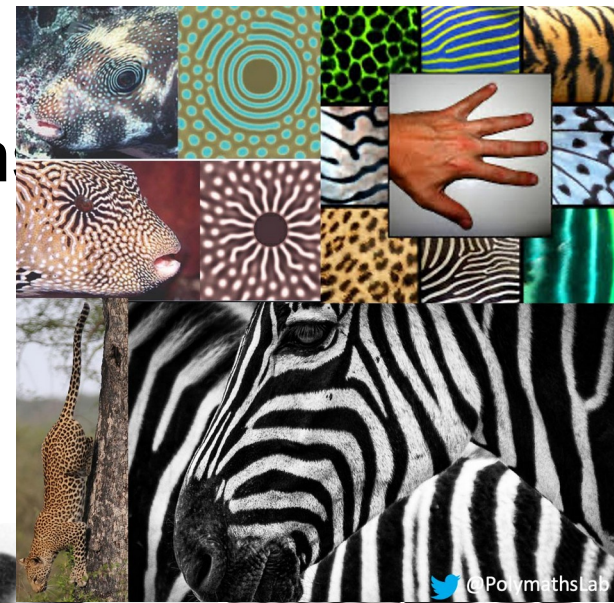


Reaction-Diffusion for Turing Pattern



Reaction-Diffusion for Turing Pattern

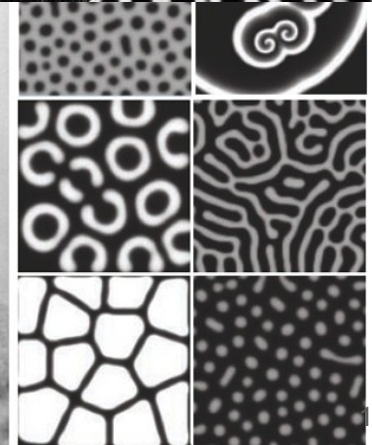
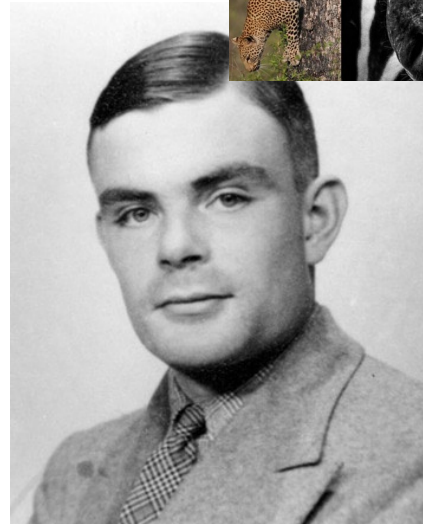
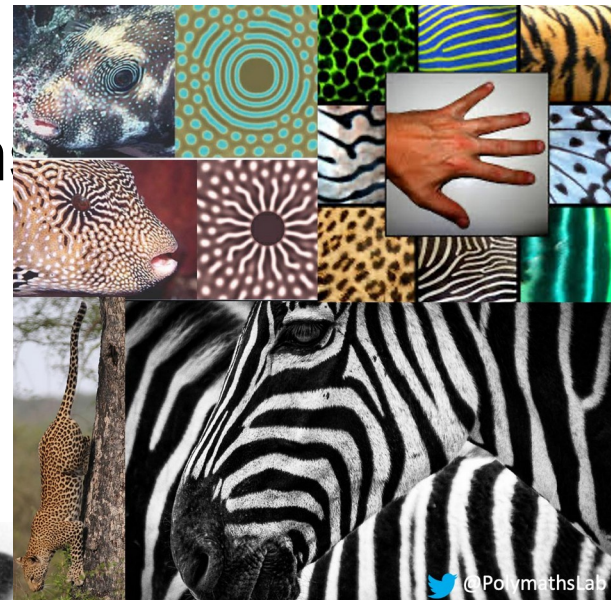
2 components (u and v) are evolving in an environment



Reaction-Diffusion for Turing Pattern

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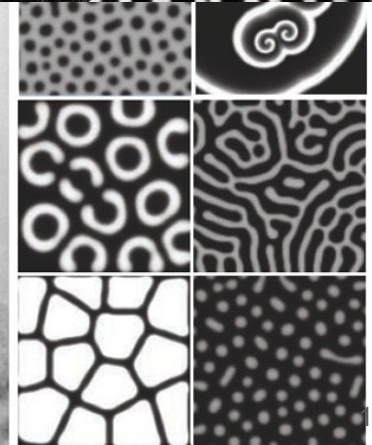
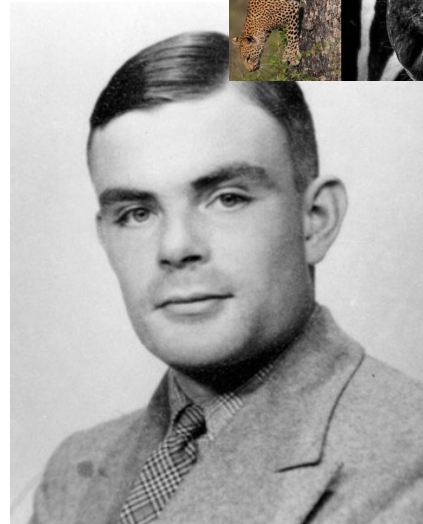
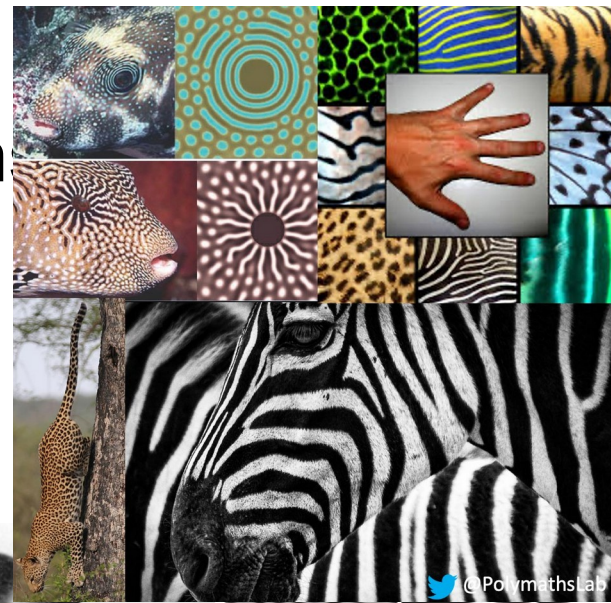
1. They diffuse



Reaction-Diffusion for Turing Pattern

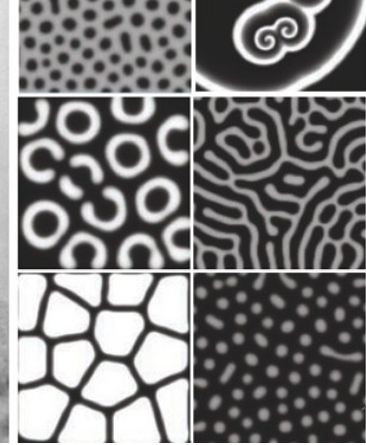
2 components (u and v) are evolving in an environment

1. They diffuse
2. They react to each other



A collage of various patterns and textures. It includes a close-up of a zebra's head, a leopard, a hand, and various geometric and organic patterns. The patterns range from concentric circles and stripes to leopard spots and a handprint. The colors are diverse, including blues, greens, yellows, and blacks. The overall composition is a mix of natural and abstract elements.

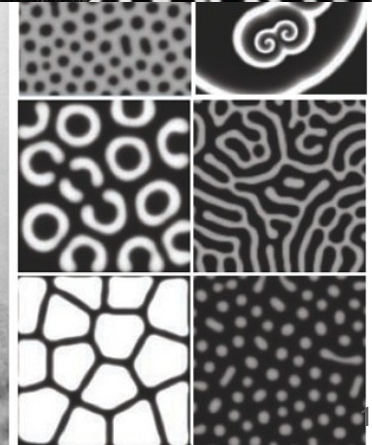
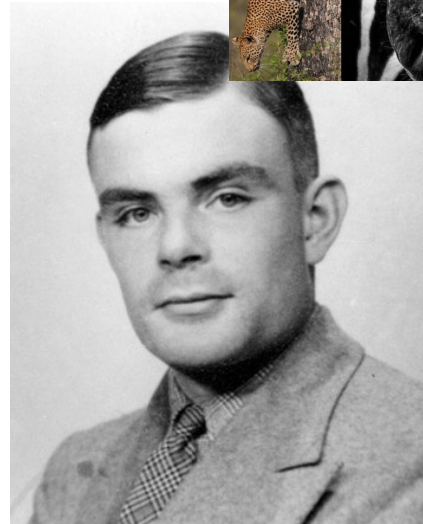
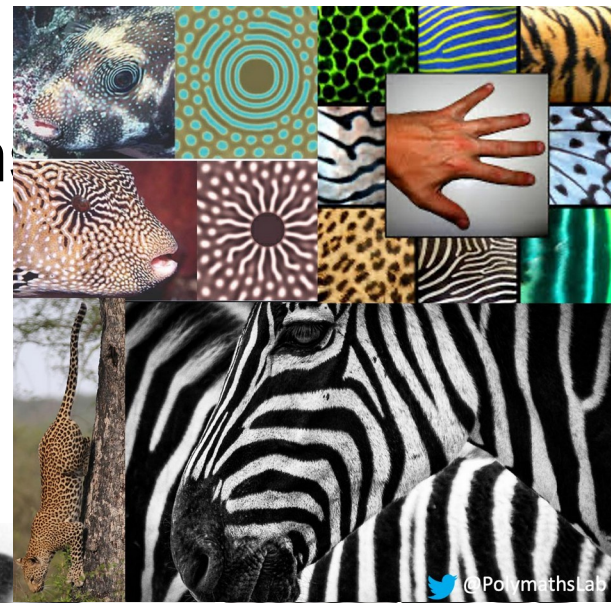
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Reaction-Diffusion for Turing Pattern

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1. They diffuse
2. They react to each other
3. That's all

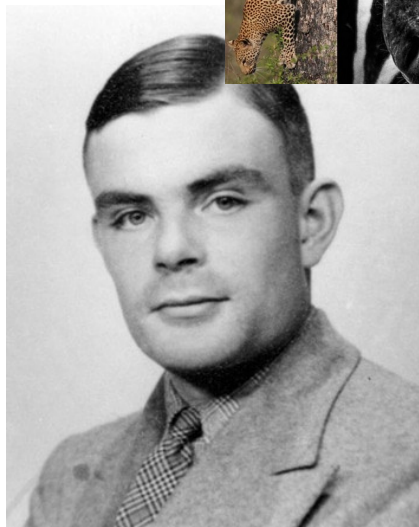
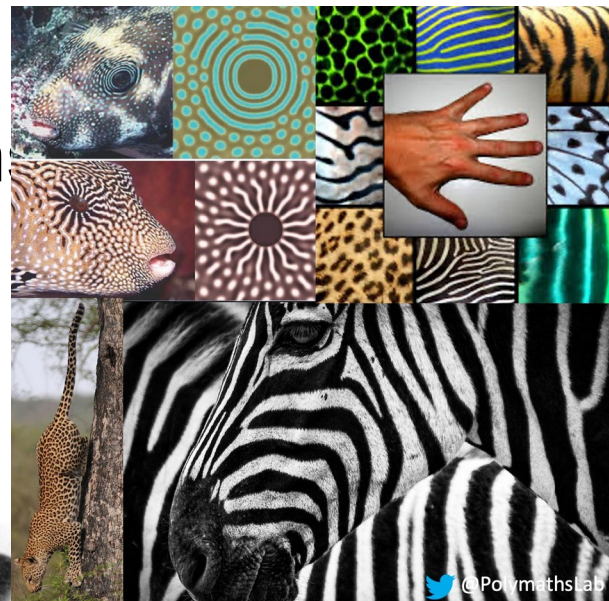


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$$\frac{\partial u}{\partial t} = D_u \nabla^2 u + f(u, v),$$
$$\frac{\partial v}{\partial t} = D_v \nabla^2 v + g(u, v)$$

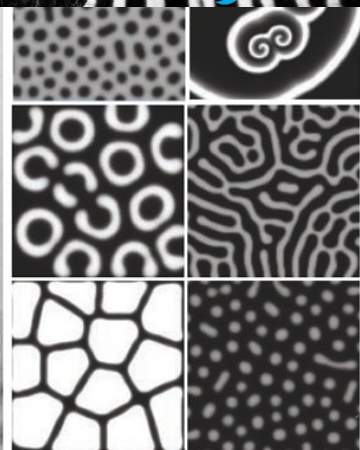
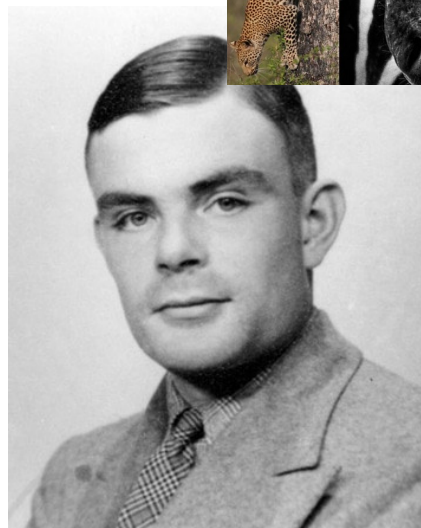
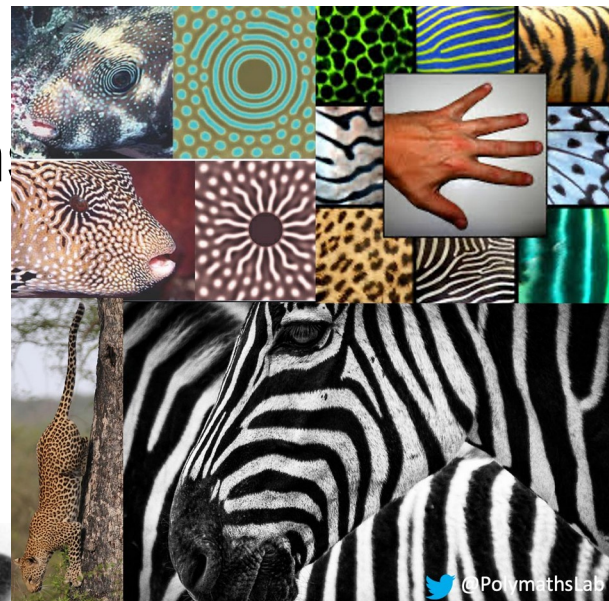


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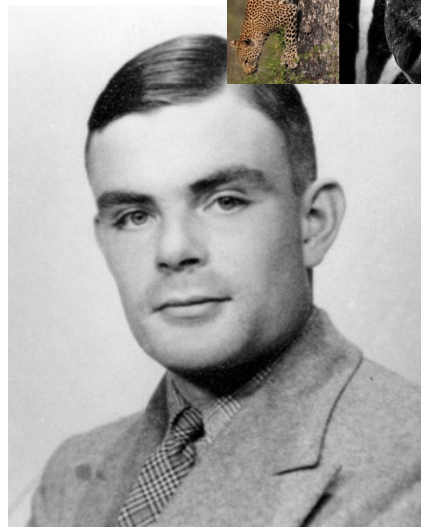
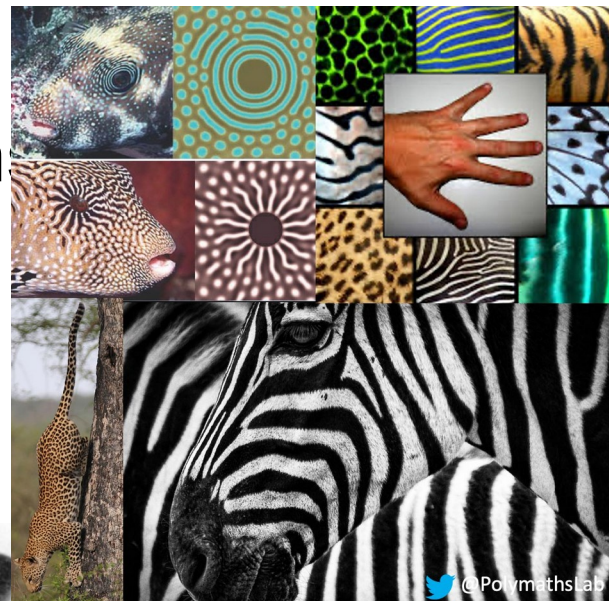


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$$\begin{array}{lcl} & \text{Diffusion} & \text{Reaction} \\ \frac{\partial u}{\partial t} = & \boxed{D_u \nabla^2 u} & + \boxed{f(u, v)}, \\ \frac{\partial v}{\partial t} = & \boxed{D_v \nabla^2 v} & + \boxed{g(u, v)} \end{array}$$



Reaction-Diffusion for Turing Patterns

Gray-Scott model:

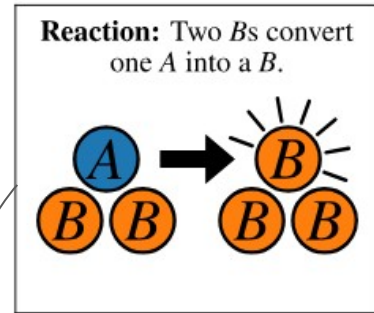
$$\frac{\partial u}{\partial t} = D_u \nabla^2 u - uv^2 + F \cdot (1 - u),$$

$$\frac{\partial v}{\partial t} = D_v \nabla^2 v + uv^2 - (K + F)v$$

Reaction-Diffusion for Turing Patterns

Gray-Scott model:

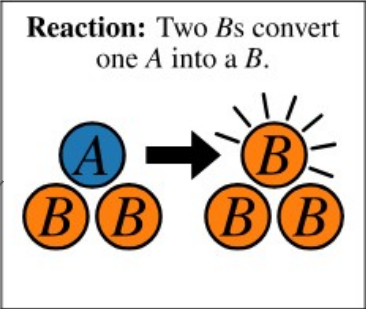
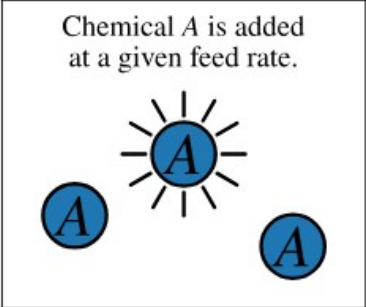
$$\begin{aligned}\frac{\partial u}{\partial t} &= D_u \nabla^2 u \boxed{- uv^2} + F \cdot (1 - u), \\ \frac{\partial v}{\partial t} &= D_v \nabla^2 v \boxed{+ uv^2} - (K + F)v\end{aligned}$$



Reaction-Diffusion for Turing Patterns

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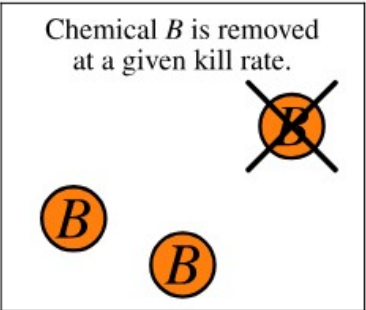
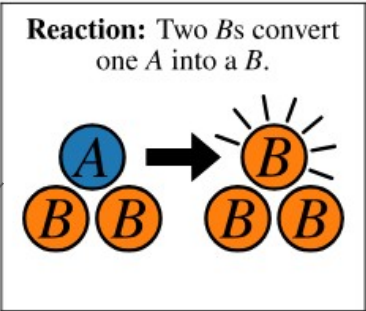
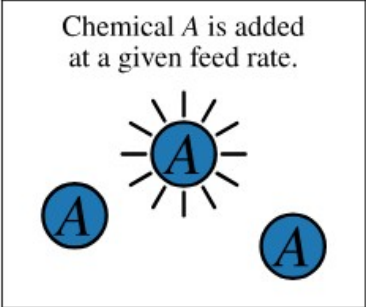
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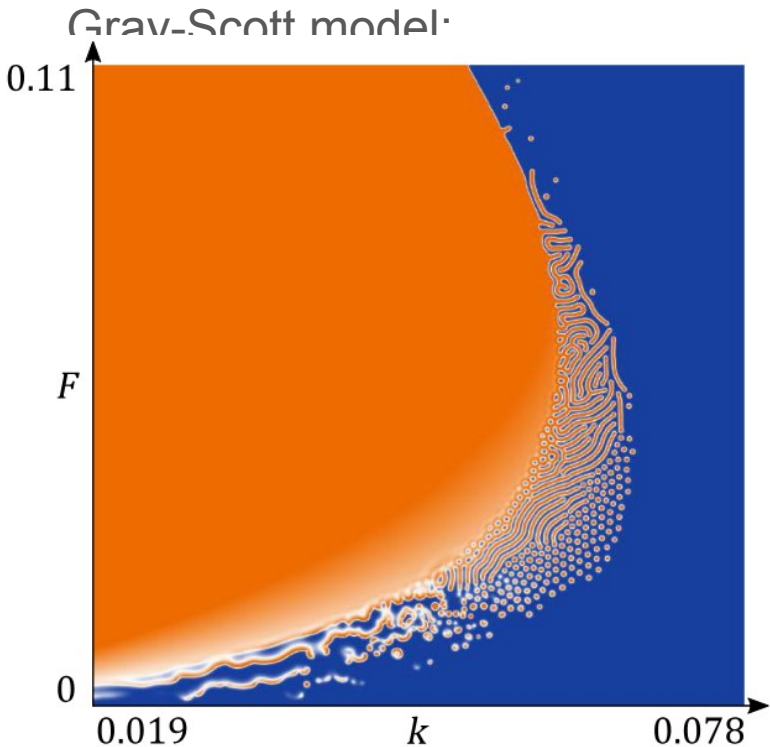
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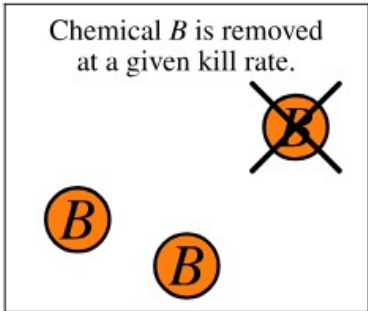
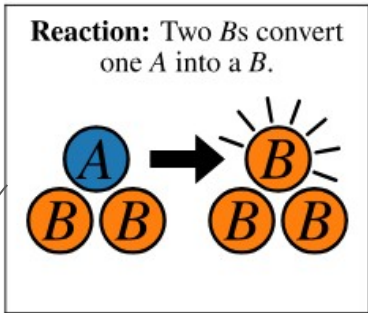
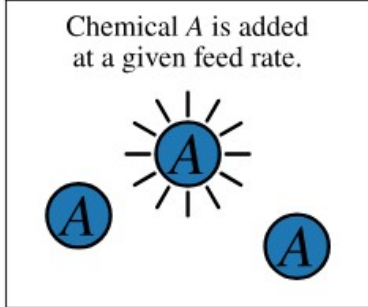
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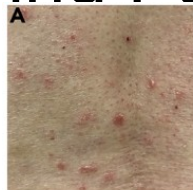
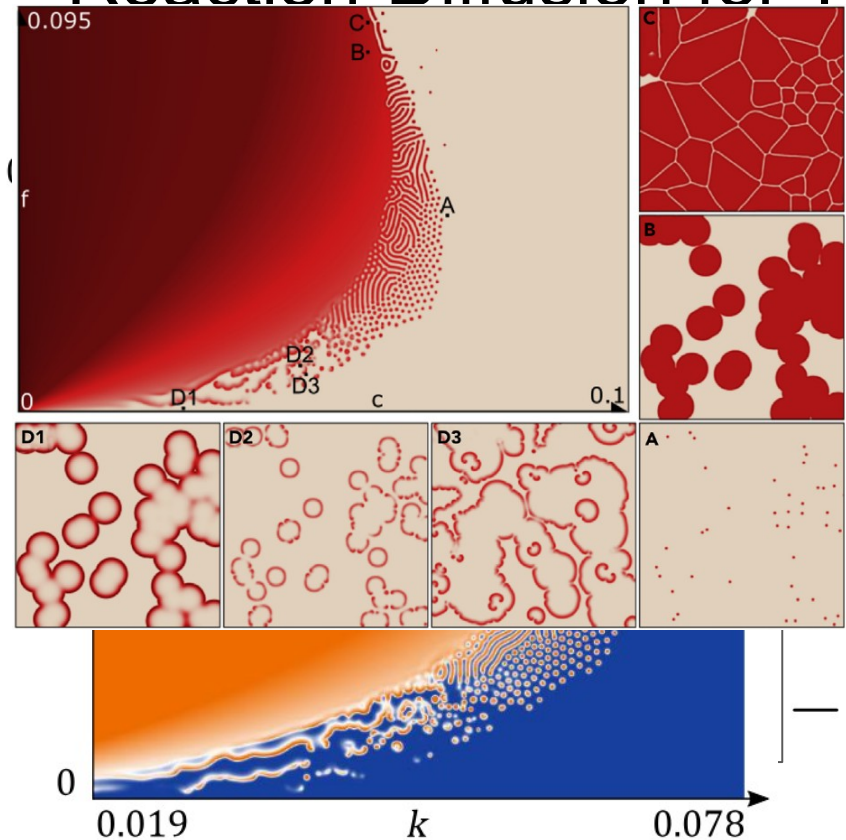
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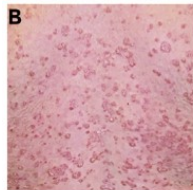
$$+ F \cdot (1 - u),$$
$$- (K + F)v$$



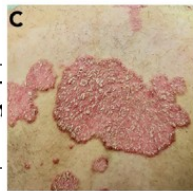
Reaction-Diffusion for Turing Patterns



A. Papular. Small, millimeter-size, scattered, erythematous papules. This pattern also represents the earliest lesion of psoriasis and may evolve into patterns B-D



B. Small plaque/nummular. Round or oval plaques with smooth borders and the diameter less than 30 mm, distributed all over the body. The surface of the lesion does not show appreciable patterning, such as fissuring or faceting. Adjacent, growing nummular lesions merge into polygonal structures.



C. Large plaque. Scaly, erythematous plaques larger than the nummular plaques of Pattern B. The plaques have irregular, polycyclic contour. Fissuring and faceting of the surface is often present.



D. Circinate.
D1. Annular: Ring-shaped plaques with central clearing. Individual rings do not intersect but merge into a larger annular structure.



D2. Rosettes. Rings with discontinuous boundary.



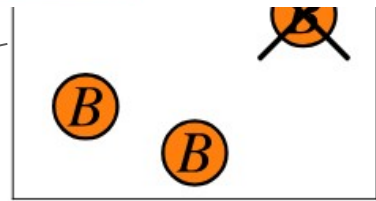
D3. Reniform. kidney form, oval with a notch (arrow).

Chemical A is added at a given feed rate.



F

$$-(K + F)v$$



Reaction-Diffusion for Turing Patterns

Short demo: <https://editor.p5js.org/marchartley/sketches/q-kafkila>

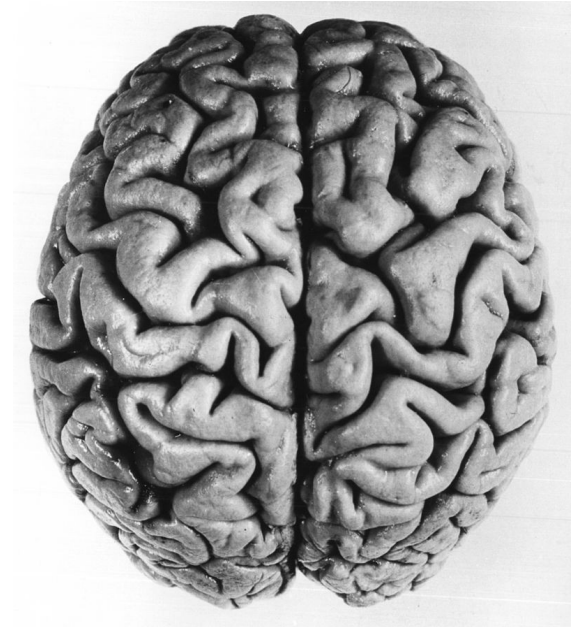
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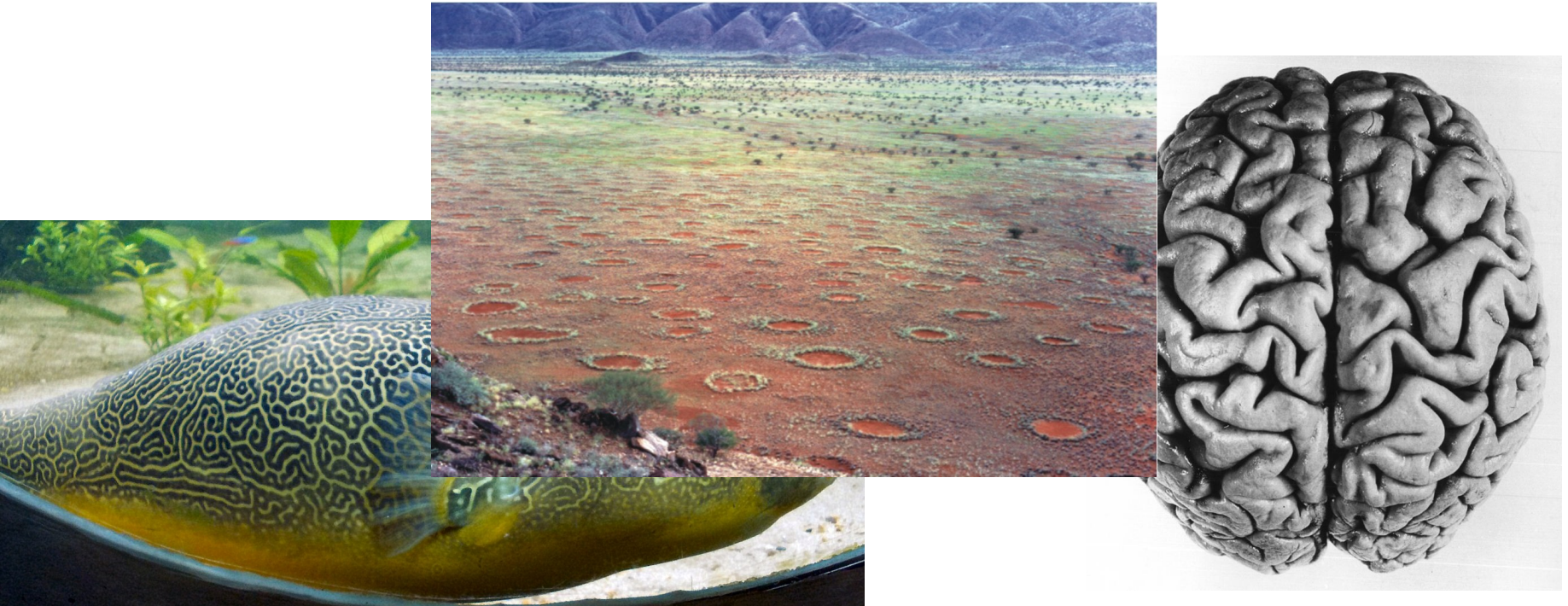
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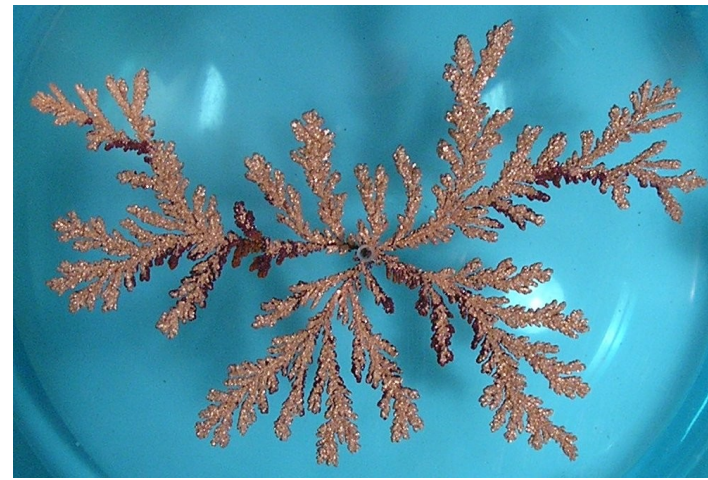
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Diffusion-Limited Aggregation

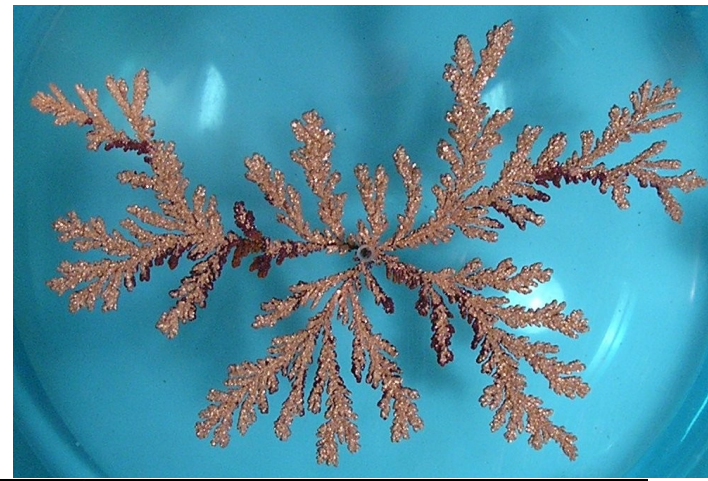
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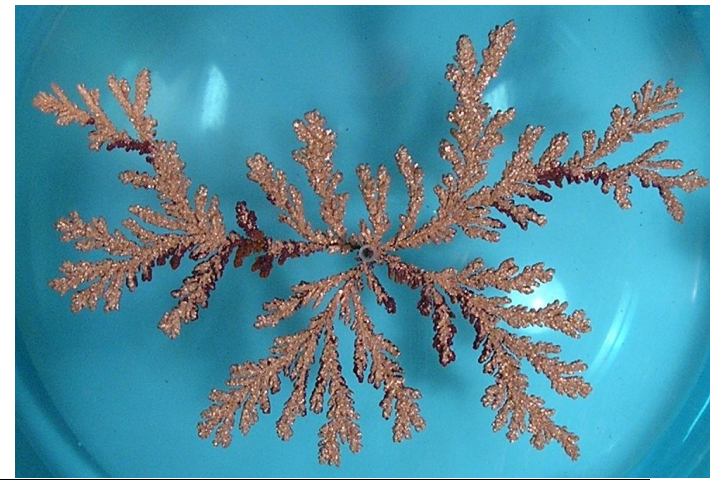


Diffusion-Limited Aggregation



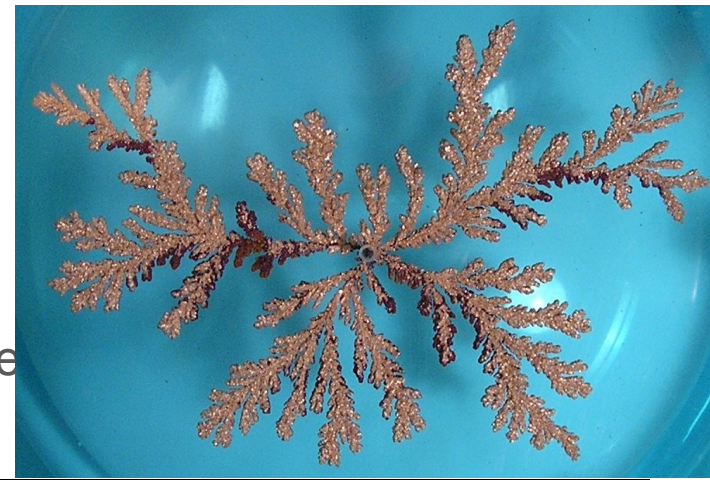
Diffusion-Limited Aggregation

1. Particles move in a brownian motion



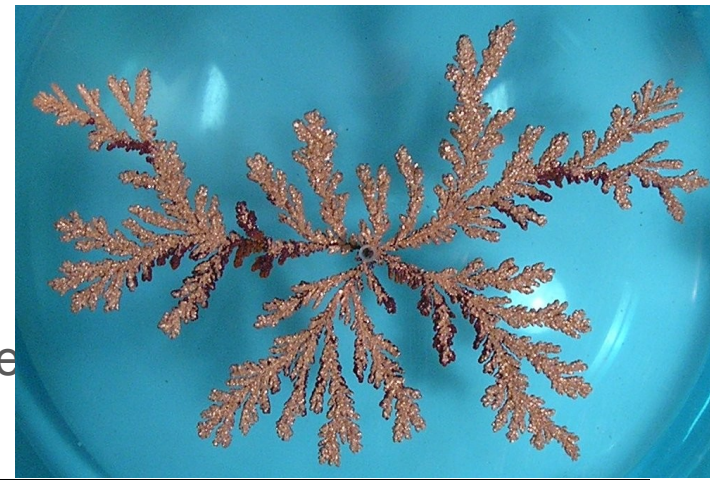
Diffusion-Limited Aggregation

1. Particles move in a brownian motion
2. A particle sticks to a surface imperfection and fre



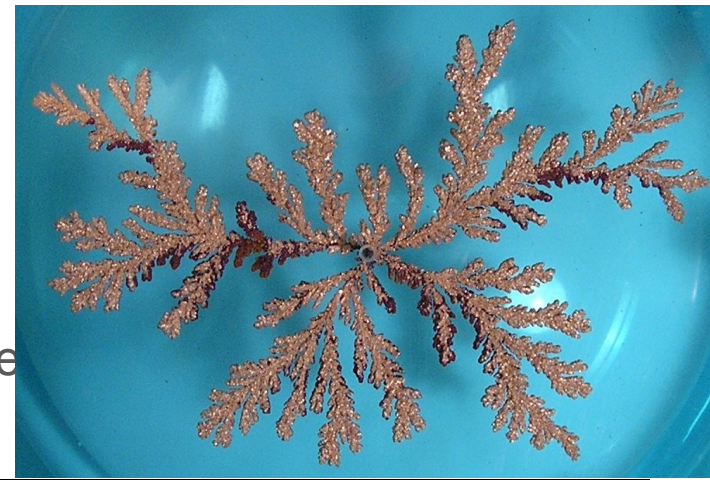
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3. Any other particle touching it also freeze



Diffusion-Limited Aggregation

1. Particles move in a brownian motion
2. A particle sticks to a surface imperfection and freeze
3. Any other particle touching it also freeze
4. And so on



Diffusion-Limited Aggregation

Short demo: <https://editor.p5js.org/marchartley/sketches/ZwPy8xGOp>

Diffusion-Limited Aggregation

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<https://www.flickr.com/photos/marchartley/sketches/ZwPy8xGOp>



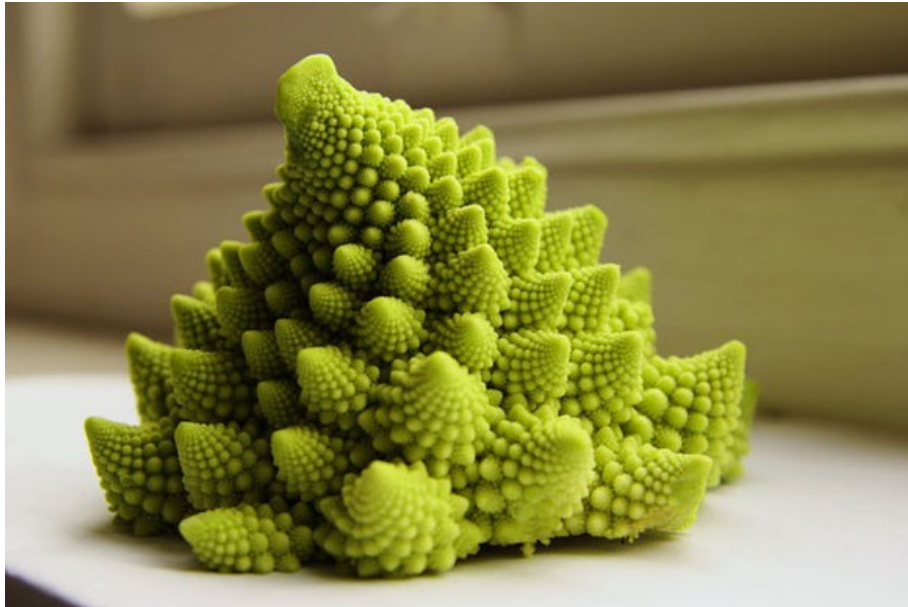


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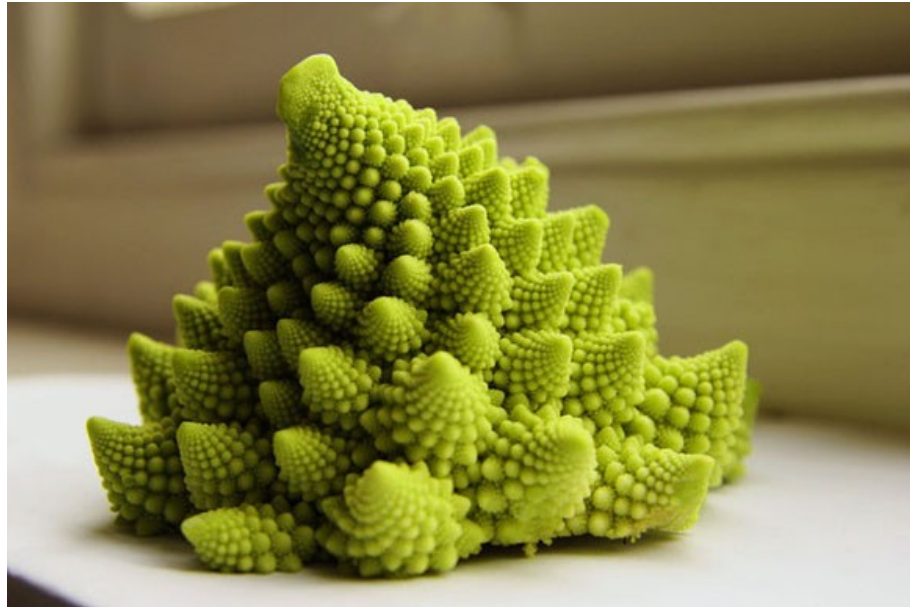
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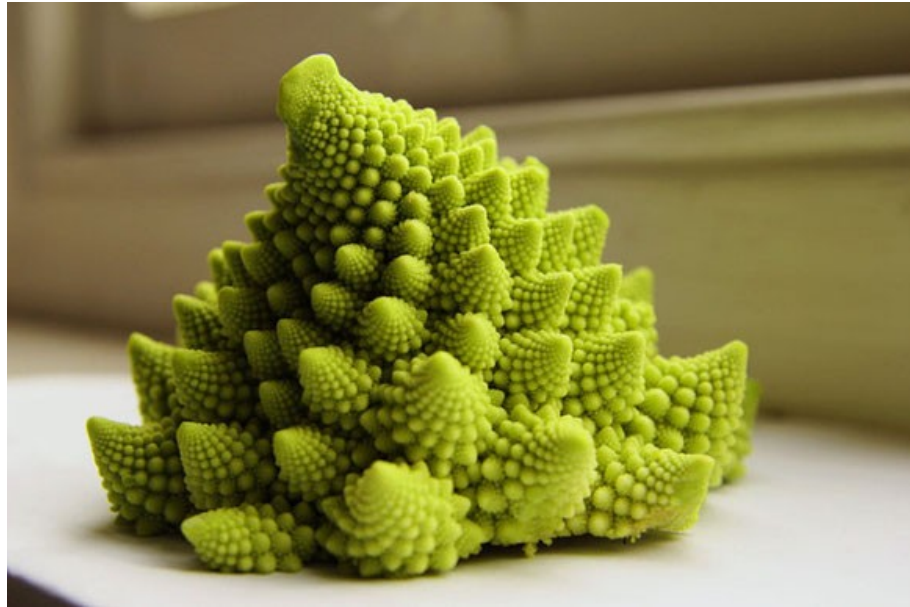
Nature is fractal



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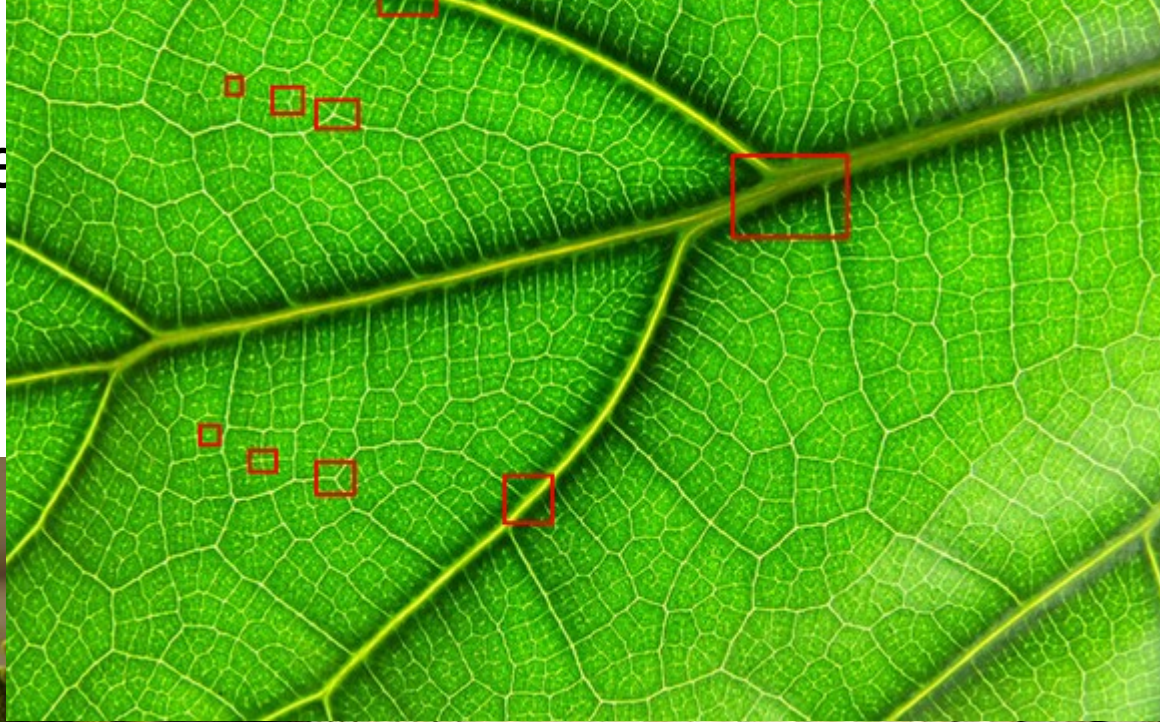
Nature is fractal



Nature is fractal



Nature



L-System, the language of nature

Rewriting system for modeling plant growth with recursivity

Composed of:

- Alphabet (letters to use),
- Axiom (starting point),
- Production rules (how to rewrite each letter)

Usually, the final string is used to command a Turtle genera



L-System, the language of nature

Rewriting system for modeling plant growth

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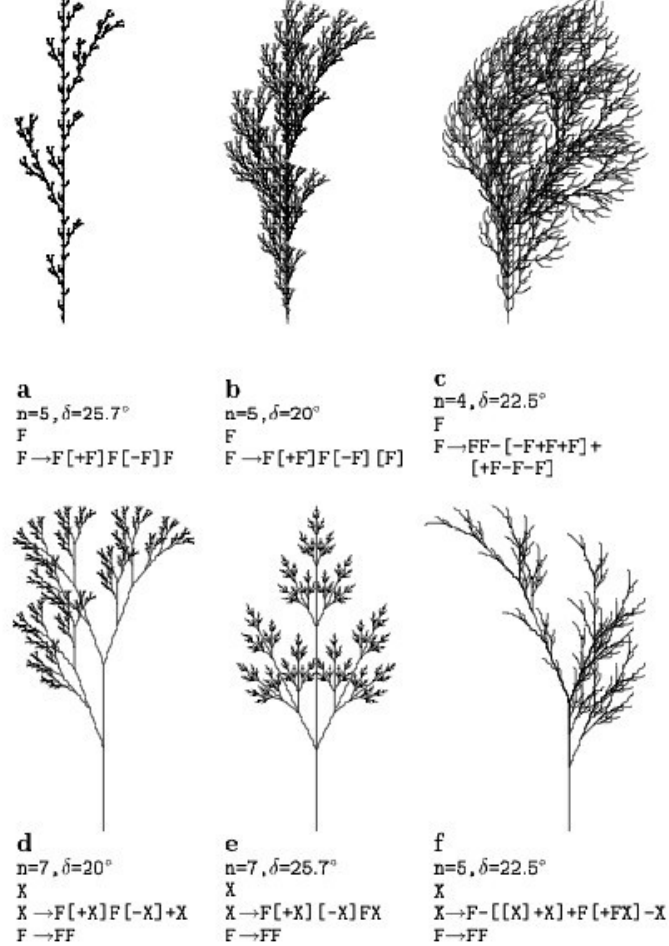


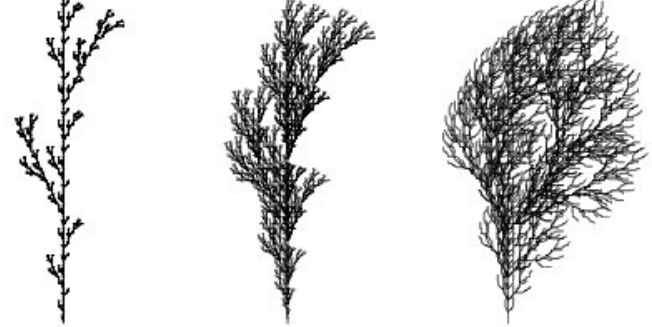
Figure 1.24: Examples of plant-like structures generated by bracketed OL-systems. L-systems (a), (b) and (c) are edge-rewriting, while (d), (e) and (f) are node-rewriting.

L-System, the language of nature

Rewriting system for modeling plant growth

Composed of:

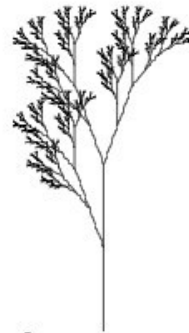
- Alphabet (letters to use),
- Axiom (starting point),



a
 $n=5, \delta=25.7^\circ$
 F
 $F \rightarrow F[+F]F[-F]F$

b
 $n=5, \delta=20^\circ$
 F
 $F \rightarrow F[+F]F[-F][F]$

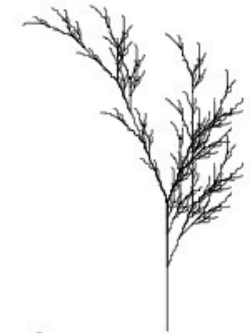
c
 $n=4, \delta=22.5^\circ$
 F
 $F \rightarrow FF[-F+F+F][+F-F-F]$



d
 $n=7, \delta=20^\circ$
 X
 $X \rightarrow F[+X]F[-X]+X$
 $F \rightarrow FF$



e
 $n=7, \delta=25.7^\circ$
 X
 $X \rightarrow F[+X][-X]FX$
 $F \rightarrow FF$



f
 $n=5, \delta=22.5^\circ$
 X
 $X \rightarrow F-[[X]+X]+F[+FX]-X$
 $F \rightarrow FF$

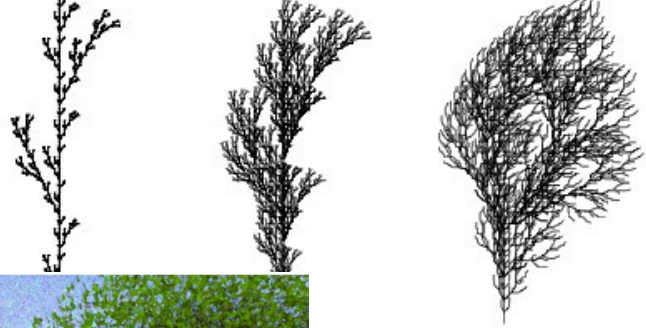
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L-System, the language of nature

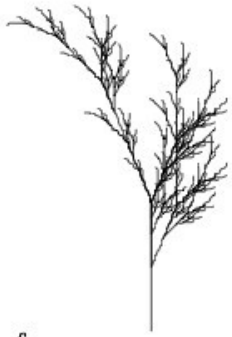
Rewriting system for modeling plants

Composed of:

- Alphabet (letters to use),
- Axiom (starting point),



c
 $n=4, \delta=22.5^\circ$
 F
 $F \rightarrow FF - [-F + F + F] +$
 $[+F - F - F]$



f
 $n=5, \delta=22.5^\circ$
 X
 $X \rightarrow F - [[X] + X] + F [+FX] - X$
 $F \rightarrow FF$

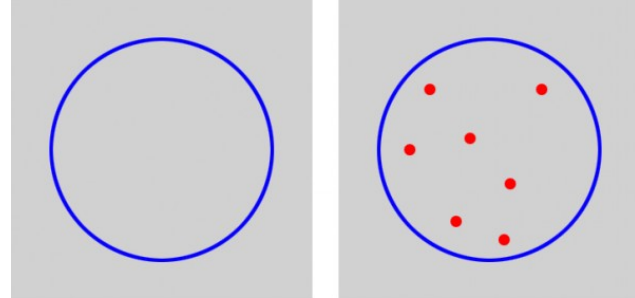
structures generated by bracketed OL-
 systems are edge-rewriting, while (d), (e) and

L-System, the language of nature

Short demo: <https://editor.p5js.org/marchartley/sketches/UkGvoRwob>

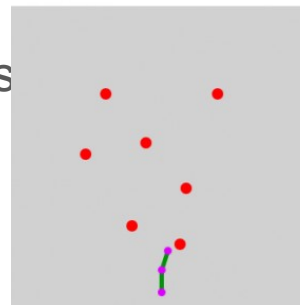
Space Colonization

1. Define a space that will contain the tree
2. Randomly add leaves in it
3. Grow branches (or trunk) in direction of the leaves (with a radius of influence)
4. Remove very close leaves
5. Voilà

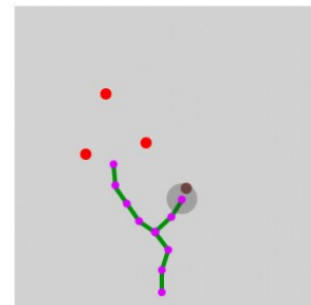


(1)

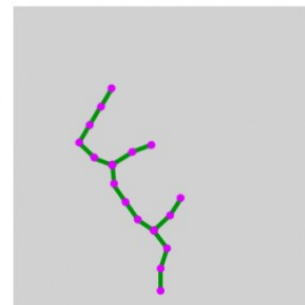
(2)



(3)



(4)



(5)

Space Colonization

Short demo: https://editor.p5js.org/marchartley/sketches/_g3xOJuUy

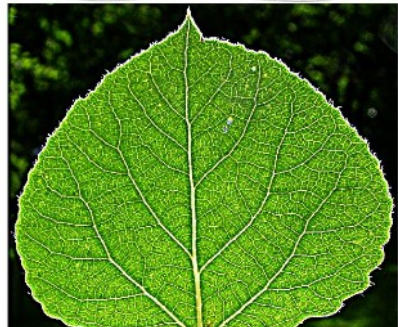
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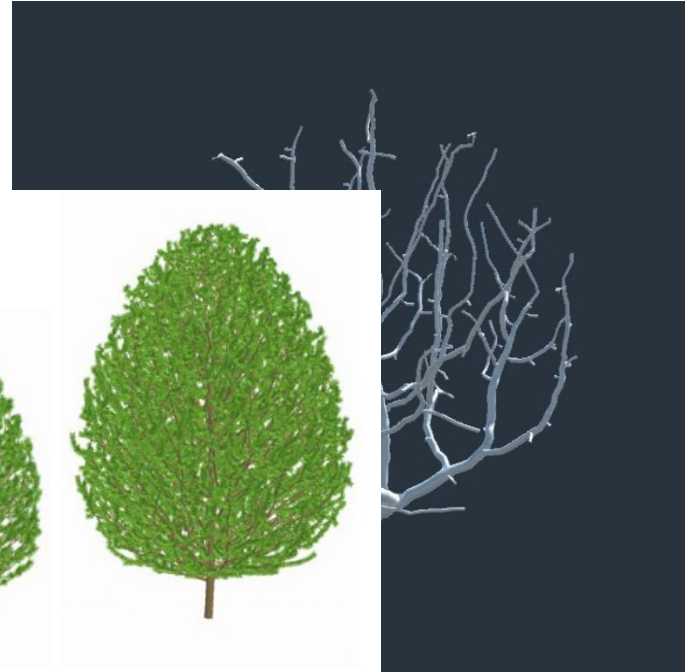


Figure 3.25: Four trees representing nine trees of different ages

Conclusion

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