Visual Models of Morphogenesis

Przemyslaw Prusinkiewicz
Presented by MinHua Huang

Outline

- Introduction
- Features of Models of Morphogenesis
- Space-Oriented Models
- Structure-Oriented Models
- Conclusion

Introduction

- From 1952 to 1994 over 40 decades, scientists have developed several visual models of morphogenesis using database amplification and emergence.
- Database Amplification:

is a process of creating complex images using small data sets

- Emergence:

is a process in which a collection of interacting units acquires qualitatively new properties that can't be reduced to a simple superposition of individual contribution.

- Morphogenesis:

The development of patterns and forms in the domain of living organisms.

Features of Models of Morphogenesis

- The studying of morphogenesis has emphasized on two directions:
  - Substances chemically reacting.
    - (Alan Turing, 1952)

      Space-oriented
  - Rate of growth in various direction.
    - (d'Arcy Thompson, 1952)

      Structure-oriented.

Features of Models of Morphogenesis (Cont.)

- Comparison between these two models:
  - The space-oriented models capture the flow of information in the medium but usually limited the capacity of describing expansion of the medium and of the structure embedded on it: Growth is limited to the boundary.
  - The structure-oriented models can simulate the expansion of whole structure but they do not inherently capture the information flow through the medium.

Space-oriented models

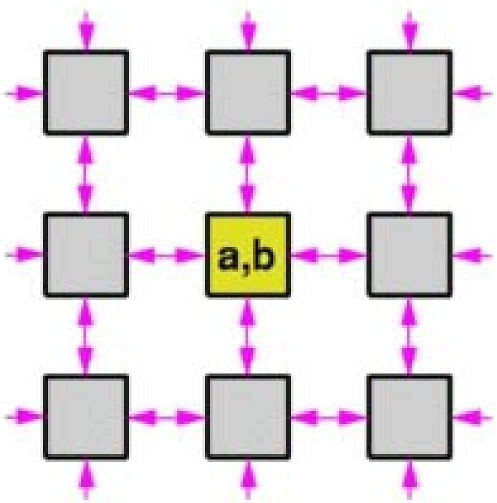
Reaction-Diffusion

- The first model was proposed by
  Alan Turing in 1952, known as reaction-diffusion model.
- Concepts of the reaction-diffusion model:
  Interaction between two or more morphogens that diffuser in a medium and enter into chemical reactions with each other.
- It can be represented by a system of partial differential equation.

Reaction-Diffusion (Cont.)

Laplacian of a (Δa)

Each point can be characterized by two numbers a and b, which represents the concentrations of substances (morphogens)



$$\frac{\delta a}{\delta t} = f(a,b) + D_a\left(\frac{\delta^2 a}{\delta x^2} + \frac{\delta^2 a}{\delta y^2}\right)$$

$$\frac{\delta b}{\delta t} = g(a,b) + D_b\left(\frac{\delta^2 b}{\delta x^2} + \frac{\delta^2 b}{\delta y^2}\right)$$

Reaction–diffusion model (Turing)

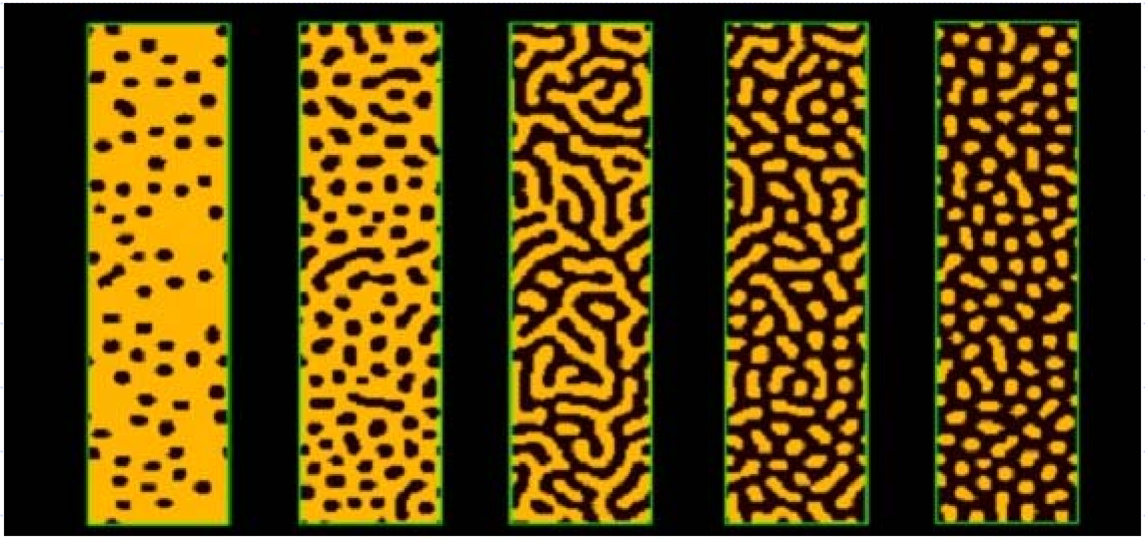
Reaction-Diffusion(Cont.)

In the equations, f and g are functions, D_a and D_b are coefficients.

the reaction components are capture by function f and g. The diffusion components are represented by the remaining terms.

These substances diffuser and reaction with each other over the time according to the partial differential equations.

Examples:



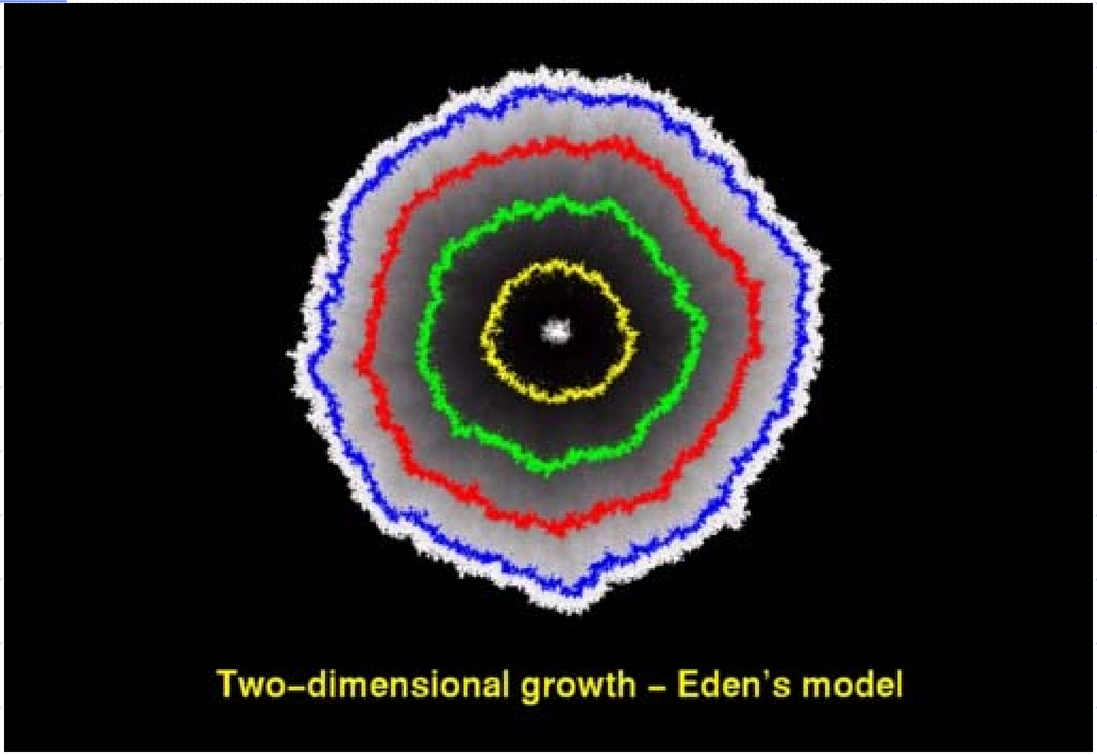
Reaction-diffusion pattern

reaction-diffusion2.mpeg

Space-Oriented Models
Diffusion-Limited Accretive Growth

- It focus on the structure and its gradual expansion along the border.
- Eden's model:
  - proposed by Eden in 1960.
  - Reaction-diffusion takes places in a square grid.
  - A single initial particle is placed in the center of the grid.
  - The subsequent particles are attached one by one to randomly chosen points on the border of the structure formed in the previous steps.

Eden’s model:



The colors indicate the state of the structure at different points in time.

The structure developing according to Eden’s model is roughly circular.

Diffusion-Limited Accretive Growth (Cont.)

- Improvements:
  - The growth rate depends on the local concentration of nutrients that diffuse from a surrounding exterior source and are consumed by the growing structure.
  - Expanding to three dimensions.
- Example of growth of marine sessile organisms (proposed by Kaandorp) in three dimensions.
- sponge.avi

Space-oriented Models
Diffusion-Limited Aggregation

- It was introduced by Witten and Sander in 1983
- It captures diffusion of nutrients by simulating random movement of particles in a grid.
- The growing structure originates in a single fixed cell.
- Free particles move in the grid with the displacement direction chosen at random on each simulation step.
- Once a moving particle touches the structure, it sticks to its rigidly.
- Example: dla.avi

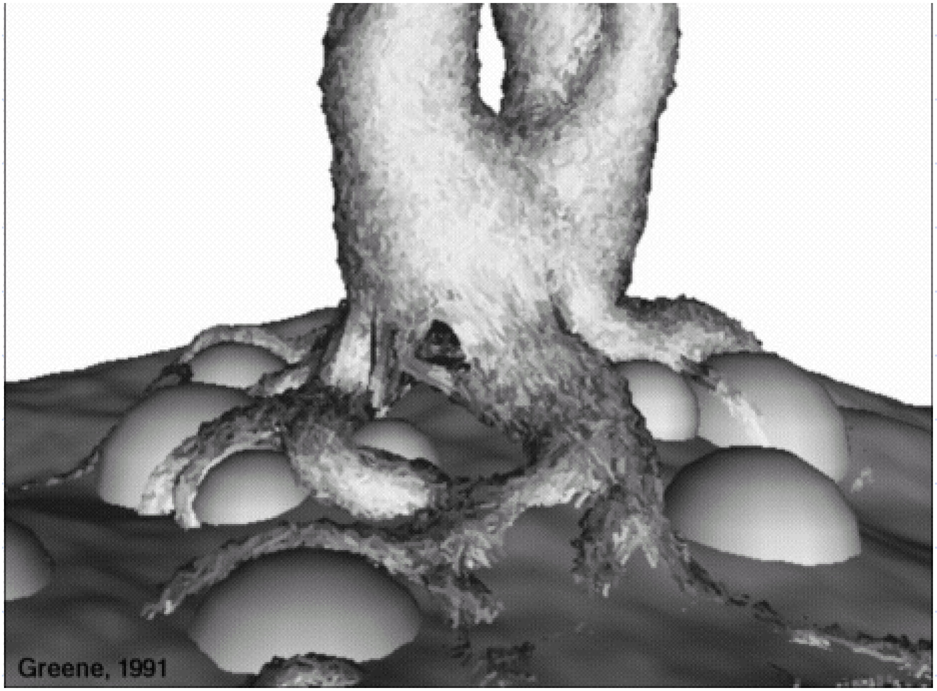
Space-Oriented Models

Cellular Automata

- It was first introduced by Toffoli and Margolus in 1987.
- It can be considered a discrete-space counterpart of reaction-diffusion models.
- The space is presented by a uniform grid with each site or cell characterized by a state chosen form a finite set.
- Time advances in discrete steps.
- All cells change their states according to the same rule.
- The next state is a function of the previous state of a cell and its closed neighbors.
- Example: maltese.avi

Space-Oriented Models
Voxel Automata

- Three-dimensional extensions of cellular automata.
- By Greene 1991
- Example:



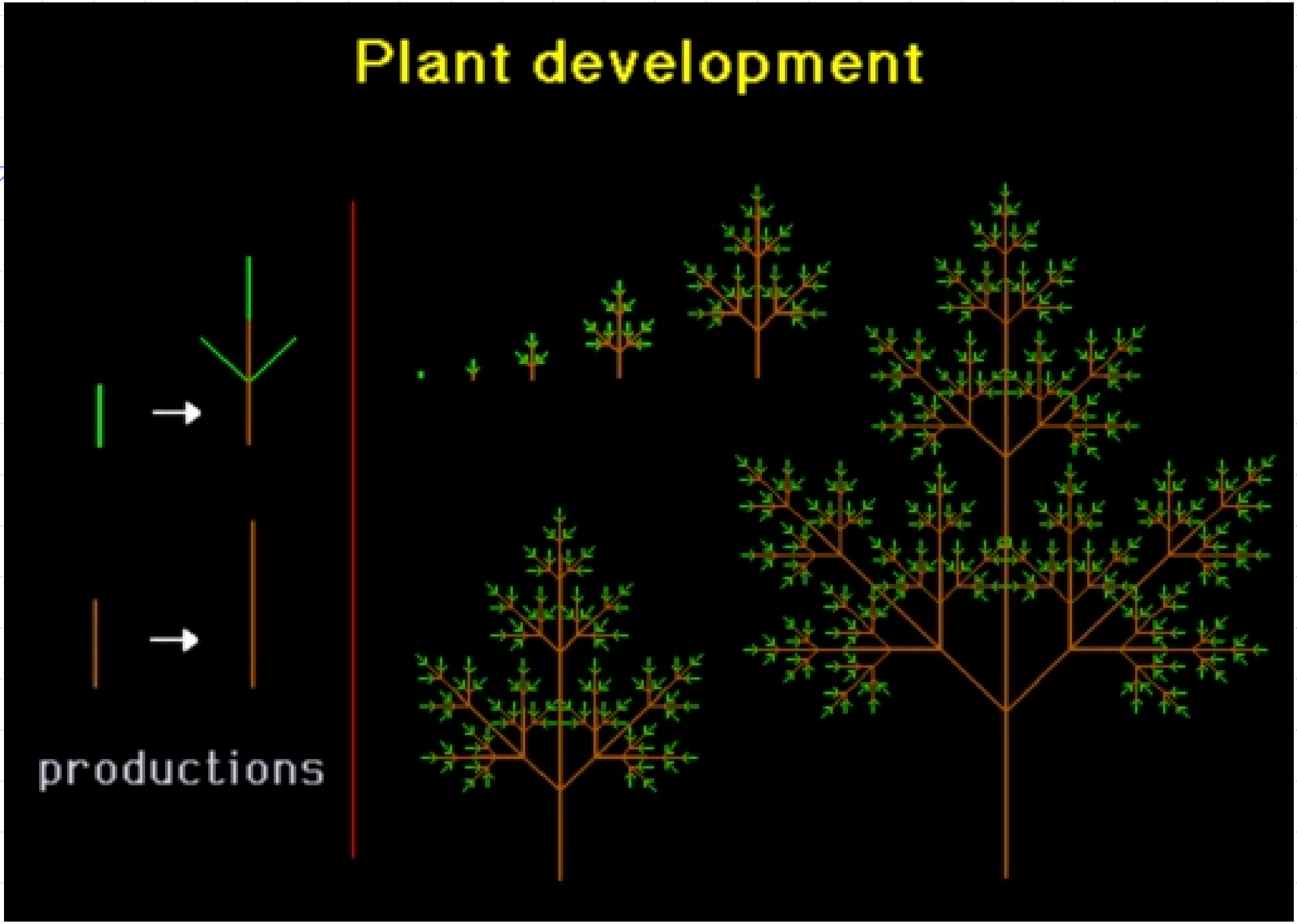
Structure-Oriented Models

L-Systems

- previous models have two limitations:
  - The growth of a structure is controlled by environment. In contrast, it is determined largely by genetic factors
  - All models represent accretive growth. In contrast, the development patterns of higher organisms are often much more complicated.
  - Example:
  - cpoundlf.avi

L-Systems (Cont.)

- L-system was proposed by Lindenmayer in 1968.
- In biological terms, an L-System uses a small set of rules to locally add details to a structure
- In computer science terms, an L-System is a context-free, recursive, text substitution scheme, followed by geometric interpretation.
- A simple L-System starts with a seed, for example, the letter F, and has one rule to replace the existing seed. A simple replacement rule might be: F-F-FF+F-F-F.

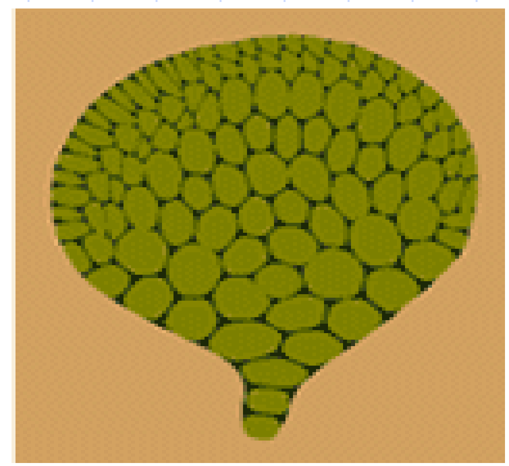

Plant development
productions

Structure-Oriented Models

Map L-Systems

- It is an advanced L-System
- Graphs with cycles.
- Was proposed by Fracchia, Prusinkiewicz, and de Boer in 1990
- Example:

Thalli of microsorium linguaeforme



Structure-Oriented Models
Mobile Cells in a Continuous Medium

- It was proposed by Fleischer and Barr in1993.
- Focus on the generation of connectivity patterns during neural development.
- Discrete cells embedded in a continuous substrate.
- The action of cells are divided into continuous processes and discrete events.

Conclusion

- This paper presented a survey of selected models of morphogenesis that use computer graphics techniques to visualize the results of simulations.
- This models can be used for image synthesis purposes and provide a research tool for studying morphogenesis in nature.
- In the absence of formal measures of what makes tow patterns look alike, visual inspection is a valuable method for comparing the models with reality.

Thanks !